# Rehabilitation of Degraded Tropical Forest Ecosystems

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# Foreword

The Center for International Forestry Research (CIFOR) was established in 1993, at a time when there was a resurgence of interest in the sustainable management of the world's tropical rainforests. It was felt that to establish such an international center would have a number of major advantages, such as (a) being able to fully harness the knowledge and experience of advanced specialists, (b) delivering information in a politically neutral manner, and (c) fully utilizing the global knowledge base. Since CIFOR's establishment Japan has been its main donor contributor. That generous support from Japan has helped CIFOR to maintain its' global presence, and made a substantial qualitative and quantitative contribution to all of CIFOR's work in developing regions and, in particular, to building close links with partner institutions.

The project "Rehabilitation of Degraded Tropical Forest Ecosystem" aims to develop techniques to reduce forest degradation and to rehabilitate degraded forest ecosystems. The project was launched in response to rapid loss of tropical forests. At present, such forests are decreasing at the rate of some 17 million hectares per year, due mainly to clearing for agriculture. Tropical forests are also being degraded at an alarming rate. Timber harvesting alone accounts for more than 5 million hectares of tropical forests being converted into poorly managed secondary forests every year. The loss and degradation of tropical forests reduce future timber production potential and threaten the global environment. Some natural disasters such as flooding, erosion, landslides and desertification have been attributed in part to degradation and loss of tropical forests. Loss of forests also releases greenhouse carbon gases and reduces the forests available to capture more carbon.

The Japanese Government and CIFOR have implemented the project jointly. Japan has supported the project by out-posting Japanese researchers to CIFOR to work on a problem that is important in many developing countries. The research has been conducted in collaboration with scientists in selected Asian and South American developing countries.

It is great pleasure for me to contribute the foreword for this book, which contains information on the rehabilitation of tropical degraded forest ecosystems based on the activities of partner institutions that CIFOR has facilitated. The data and information presented here provide an invaluable source of reference material, especially for university graduate and post-graduate researchers, and scientists in national and international organizations interested in forest rehabilitation in the tropics. It will particularly benefit those planning rehabilitation of degraded forest ecosystems in the tropics. The book should also be useful to forest managers in both public and private sectors who must make decisions based on the data they have available and who have neither the time nor the resources to delve into the highly dispersed literature on forest rehabilitation in the tropics. Since forest rehabilitation is a long process, this book does not represent the final product of our rehabilitation research, but only an initial milestone along the way. We need to continue our efforts to solve the problem and to develop a sound system of sustainable forest management.

CIFOR is very grateful to many people for their assistance with this book. We would particularly like to thank the Government of Japan for its' continuous support, as well as the contributing authors and their institutions for their commitment and their patience in dealing with the demands the editors have made on them. We also will to thank the reviews and editors who provided critical appraisals of the papers and made valuable inputs. Warm regards go also Shigeo Kobayashi for his leadership on the project, Christian Cossalter for his supervision to the project, John and Jennifer Turnbull who brought contributing together and completed endless checking and crosschecking of the information, Rosita Go for secretarial assistance, Gideon Suharyanto for layout, and all the others who contributed in so many ways.

Dr. David Kaimowitz,
Director General of CIFOR

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# Rehabilitation of Degraded Tropical Forest Ecosystems Project

S. Kobayashi[1], J.W. Turnbull[2] and C. Cossalter[3]

***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).

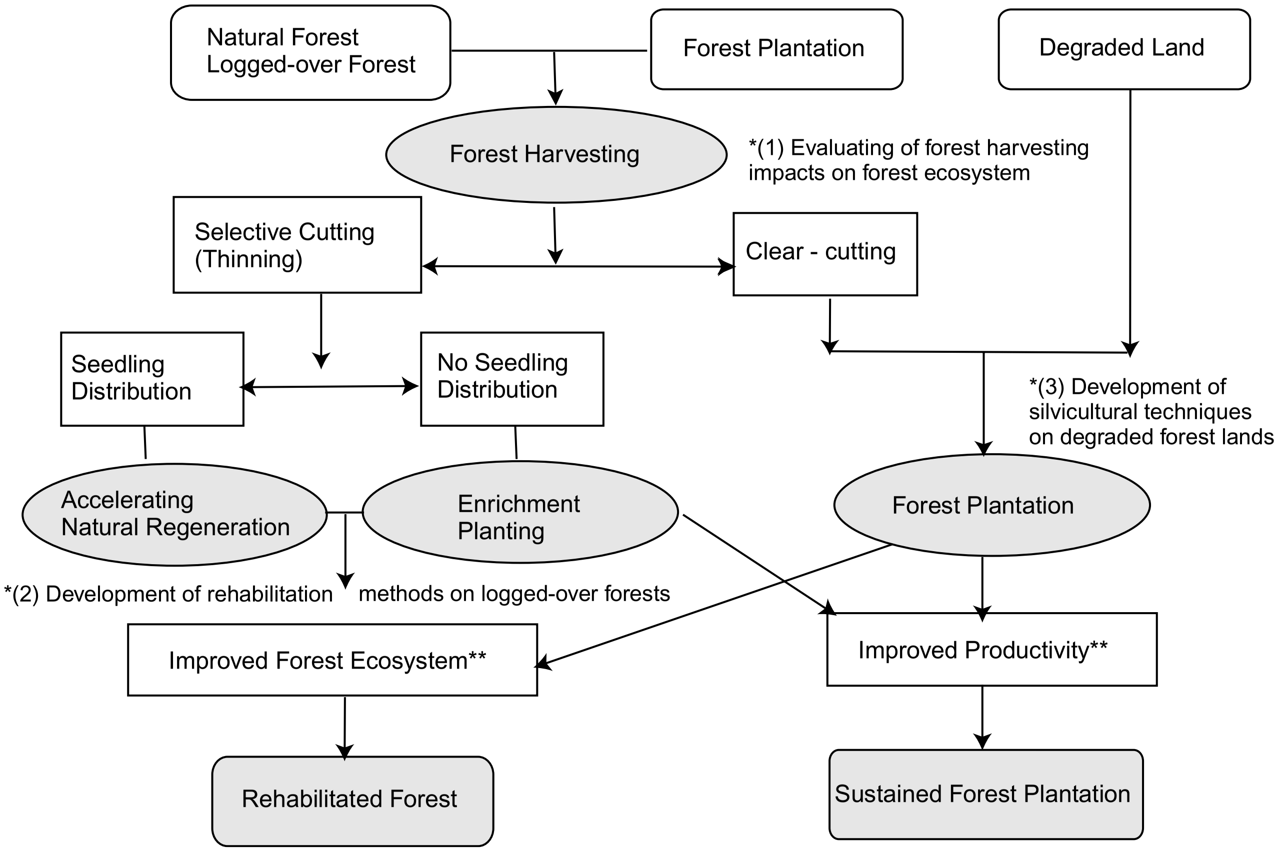
The harvesting of timber affects forest ecosystems in various ways which include site degradation, reduced forest water supply, soil loss and greenhouse gas emission. Selective and clear cutting, fire and burning are major causes of land degradation, and forest harvesting becomes a trigger for other 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

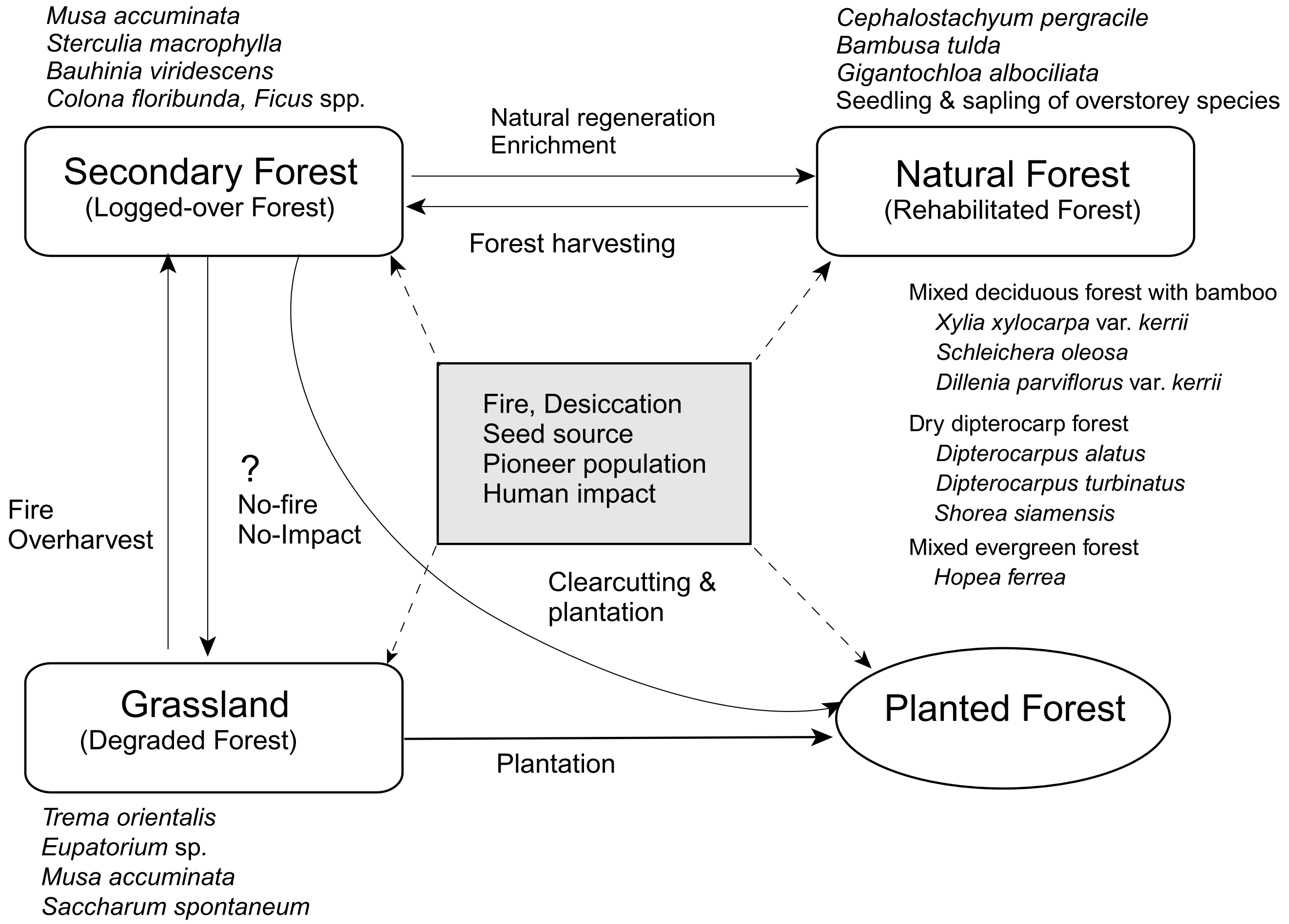


**Figure 3**. Rehabilitation of degraded burnt forest

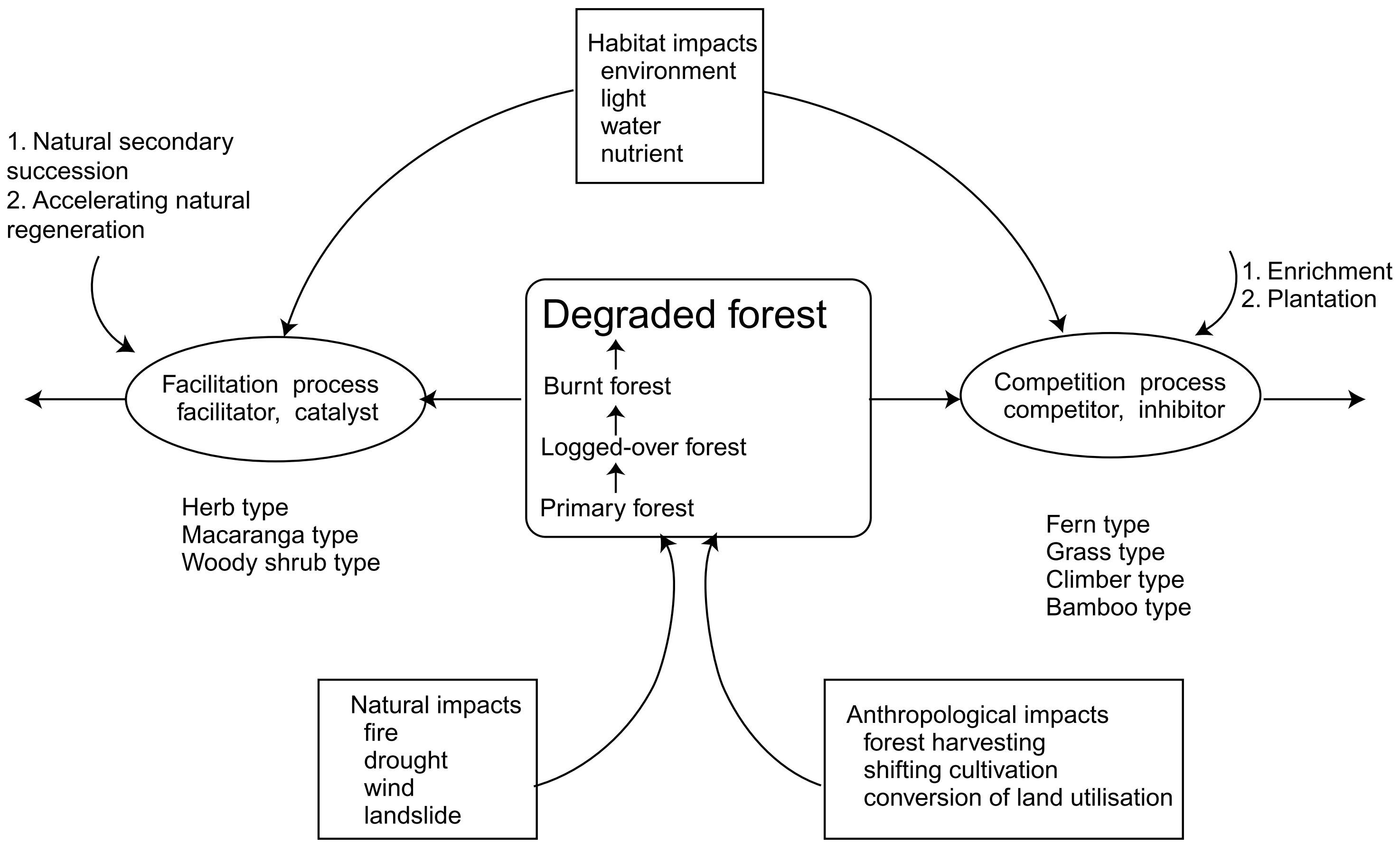
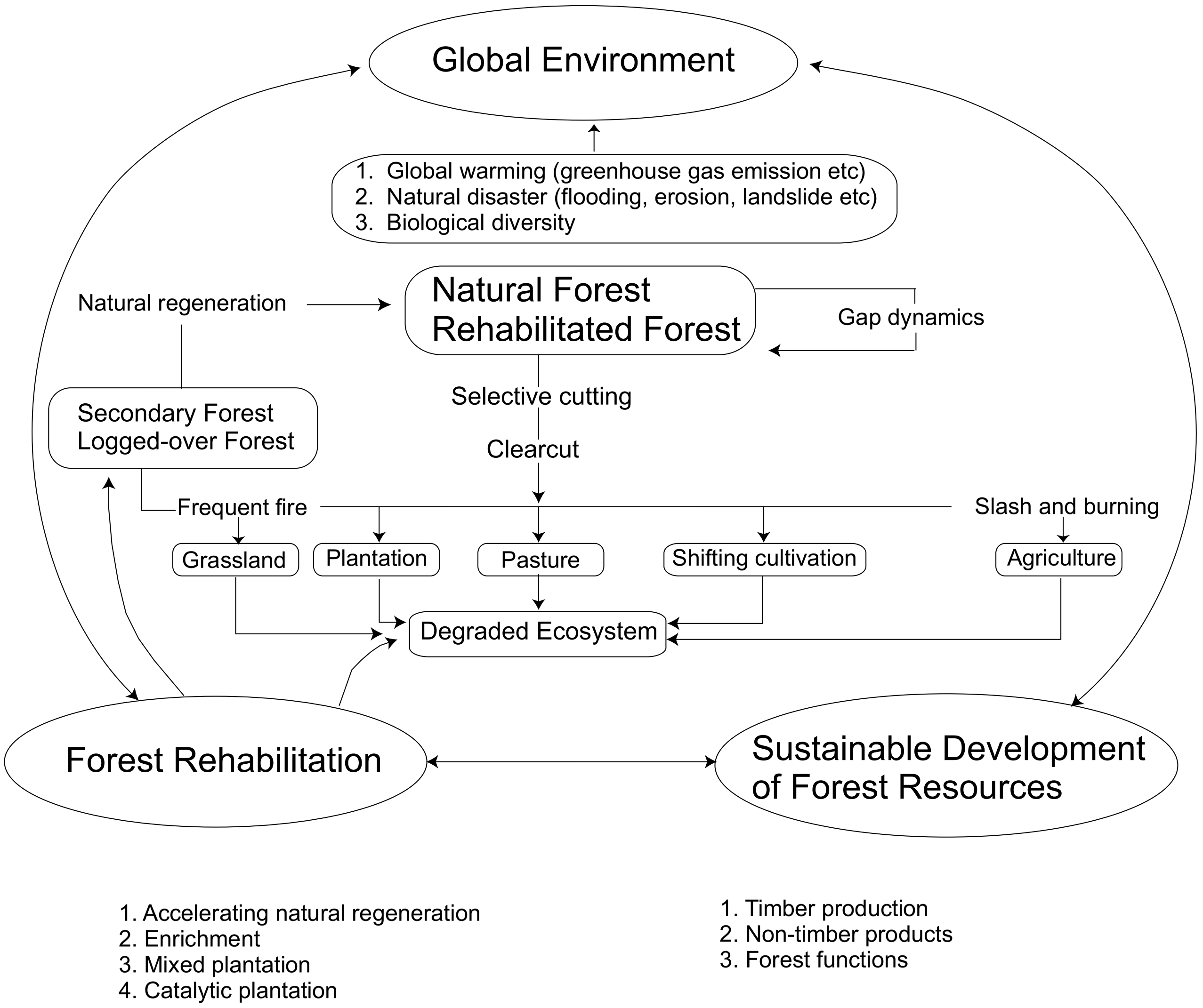


**Figure 4.** Rehabilitation of Degraded Forest Ecosystem (Forest Resources Chain)



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.

## REFERENCES

Evans, J. 1992. Plantation forestry in the tropics. 2nd ed. Clarendon Press, Oxford. 403p.

Forestry Agency and ITTO**.** 1991. Beyond the guidelines - An action program for sustainable management of tropical forests, ITTO Technical Series No.7. ITTO, Yokahama, Japan.

Jordan,C.F. 1985. Nutrient cycling in tropical forest ecosystems. Wiley, New York. 190p.

Kira,T**.** 1991. A new beginning in monitoring tropical forests, Global Environmental Forum, The United Nations University, p. 47-51.

Kitamura, R.C., Dias Filho, M.B. and Serrao, E.A.S. 1982. Analise economica de algumas alternativas de manejo de pastageus cultivadas em Paragominas, Para. Boletim de Pesquisa, 41. EMBRAPA-CPATU.4OP/EMBRAPA-CPATU, Belem, Brazil.

Kobayashi, S. 1988. The maintenance and effective use of forest resources in Negara Brunei Darussalam. Forest Research Note No.11, Brunei Darussalam. 175p.

Kobayashi, S. 1994. Effects of harvesting impacts and rehabilitation of tropical rain forest. Journal of Plant Research. 107: 99-106.

Lamb, D. 1990. Exploiting the tropical rain forest, Man and The Biosphere Series, UNESCO, 259.

Serrao, E.A.S. and Homma, A.K.O. 1982. Recuperacao e melhoramento de pastageus, cultivades em areas de floresta Amazonica. Documentos, 17. EMBRAPA-CPATU. EMBRAPA CPATU, Belem, Brazil. 22p.

Serrao, E.A.S. 1990. Pecuaria na Amazonia: A evolucao da sustentabilidade das pastageus substituindo floresta. Paper to seminar “O Futuro Economico de Agrucultura na

Amazonia", Senado Federal, Brasilia, 23-24 April 1990.

Thang, H.C. 1987. Forest management system of tropical high forests, with special reference to Peninsular Malaysia. Forest Ecology and Management 21: 3-20.

Tiarks, A., Nambiar, E.K.S. and Cossalter, C. 1998. Site management and productivity in tropical plantations. Occasional paper No. 16. Center for International Forestry Research, Bogor, Indonesia.

Uchijima, Z. 1991. Monitoring tropical forests, Global Environmental Forum, The United Nations University, p.52-56.

Weidelt, H.J. and Banaag, V.S. 1982. Aspects of management and silviculture of Philippine dipterocarp forests. GTZ Publication, No.132. Eschborn, West Germany.

Whitmore, T.C. 1975. Tropical rain forests of the Far East. Clarendon Press, Oxford. 352p.

## 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).

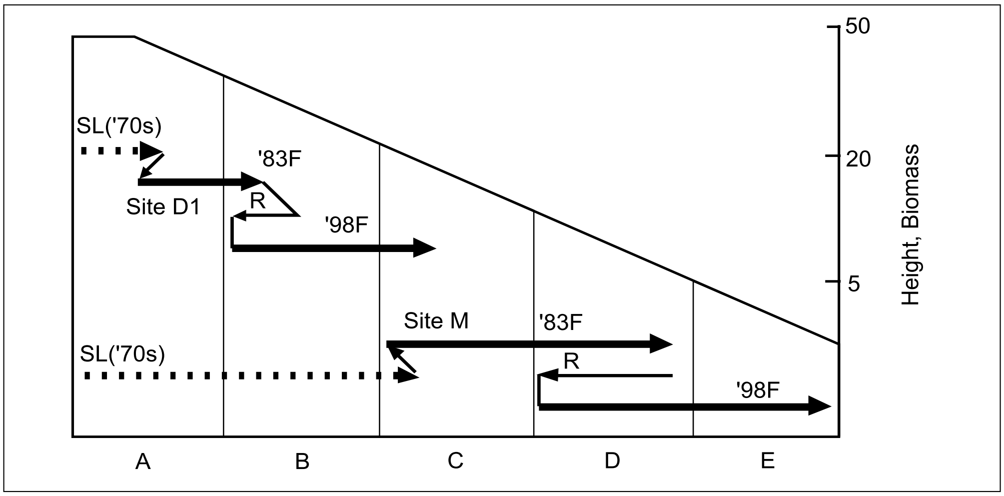
Compared with these primary forests, many forests currently in Bukit Soeharto Forest Reserve area are degraded to various extent. Table 1 shows three typical forests as examples: lightly degraded (D1), moderately degraded (D2) dipterocarp forests, and heavily degraded forest dominated by early pioneer 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.

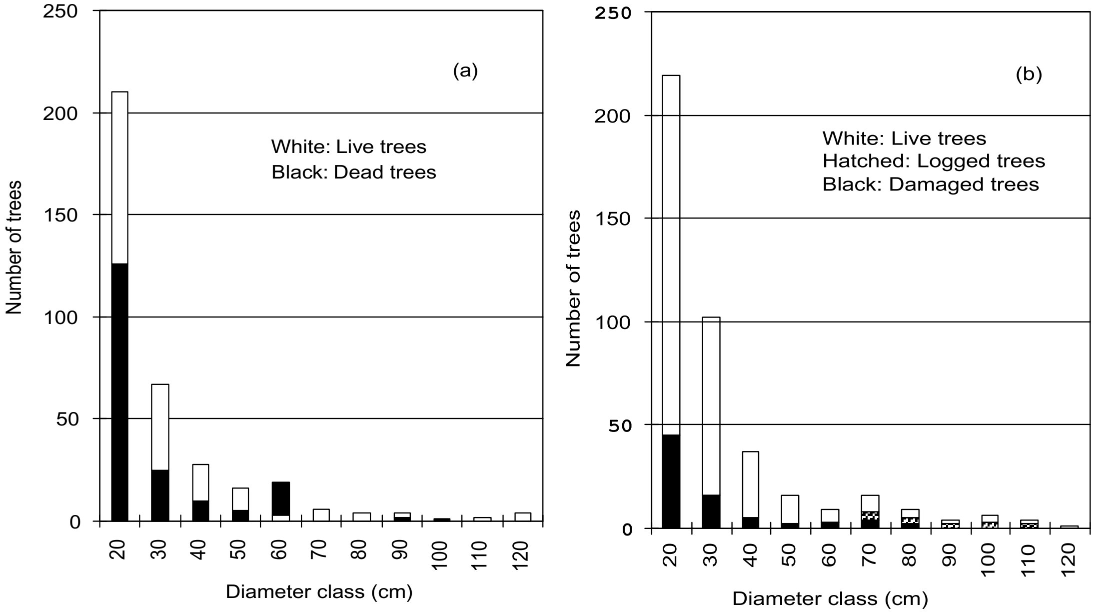
Commercial selective logging and surface fires affect diameter distribution differently (Fig. 2). Selective logging generally harvests trees more than 50 cm dbh. Felling and skidding damages a high percentage of small diameter trees (Ruslim *et al.* 2000, Okimori and Matius 2000a). On the other hand, 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.

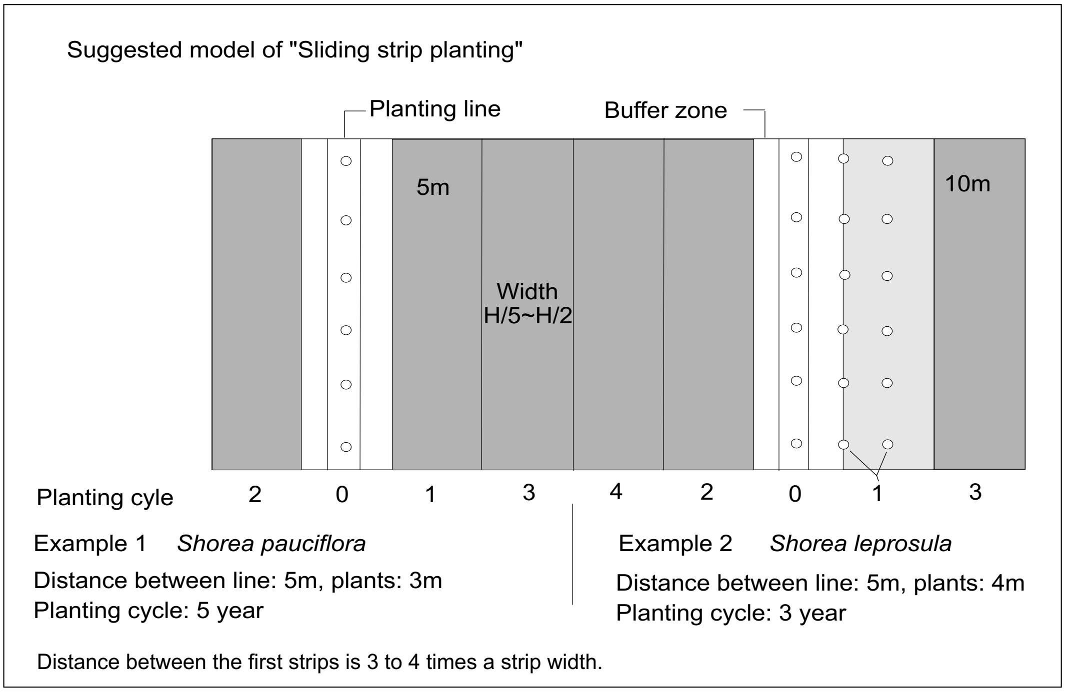
For this type of forest, a sliding strip planting (modified line planting) is proposed. The width of cutting strip is half to one fifth of the surrounding tree height. The strip width changes depending on the light requirements of the species planted. Distance between strips is average tree height of 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


Suggested model of "Sliding strip planting"

Example 1 *Shorea pauciflora*
Distance between line: 5m, plants: 3m
Planting cycle: 5 year

Example 2 *Shorea leprosula*
Distance between line: 5m, plants: 4m
Planting cycle: 3 year

Distance between the first strips is 3 to 4 times a strip width.

**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 $\mu$mole m$^{-2}$s$^{-1}$ | Mass basis $\mu$mole 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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## REFERENCES

Appanah, S. and Turnbull, J.M. (eds.) 1998. A review of dipterocarps; taxonomy, ecology and silviculture. CIFOR, Bogor, Indonesia. 220p.

Appanah, S. and Weinland, G. 1996. Experience with planting dipterocarps in Peninsular Malaysia. *In*: Schulte, A. and Schöne, D. (eds.)

Dipterocarp forest ecosystems. World Scientific, Singapore.

Ashton, M.S. 1998. Seedling ecology of mixed-dipterocarp forest. *In*: Appanah, S. and Turnbull, J. M. (eds.) A review of dipterocarps; taxonomy, ecology and silviculture. 89-98. CIFOR, Bogor, Indonesia.

Hastaniah and Kiyono, Y. 2000. Growth of ulin (*Eusideroxylon zwageri*) seedlings in relation to environmental factors in the forest understory. *In*: Guhrdja, E. Fatawi, M., Sutisna, M., Mori, T. and Ohta, S. (eds.) Rainforest ecosystems of East Kalimantan: el niño, drought, fire and human impacts, 281-288. Springer, Tokyo.

Ishida, A., Toma, T. and Marjenah. 2000. *In situ* study of the effects of elevated temperature on photoinhibition in eight tropical pioneer and three dipterocarp species. *In*: Guhrdja, E. Fatawi, M., Sutisna, M., Mori, T. and Ohta, S. (eds.) Rainforest ecosystems of East Kalimantan: el niño, drought, fire and human impacts. 269-280. Springer, Tokyo.

Ito, S., Nishiyama, Y. and Kustiawan W. 2000. Responses of dipterocarp seedlings to drought stress. *In*: Guhrdja, E. Fatawi, M., Sutisna, M., Mori, T. and Ohta, S. (eds.) Rainforest ecosystems of East Kalimantan: el niño, drought, fire and human impacts. 143-152. Springer, Tokyo.

Jacobs, M. 1981. Dipterocarpaceae: the taxonomic and distributional framework. Malaysian Forester 44: 168-189.

JICA 1994. Multi-storied forest management project in Peninsular Malaysia – interim report. Japanese International Cooperation Agency (JICA), Ipho, Malaysia.

Kartawinata, K., Adisoemarto, S., Riswan, S. and Vayda, A. 1981a. The impact of man on a tropical forest in Indonesia. Ambio 10: 115-119.

Kartawinata, K., Abdulhadi, R. and Partomihardjo, T. 1981b. Composition and structure of a lowland dipterocarp forest at Wanariset, East Kalimantan. Malaysian Forester 44: 397-406.

Kiyono, Y. and Hastaniah. 1997. Slash and burn agriculture and succeeding vegetation in East Kalimantan. PUSREHUT Special Publication No. 6. PUSREHUT-Mulawarman University, Samarinda, Indonesia.

Kiyono, Y. and Hastaniah. 2000. Flowering and fruiting phenologies of dipterocarps in a rainforest in Bukit Soeharto, East Kalimantan. *In*: Guhrdja, E. Fatawi, M., Sutisna, M., Mori, T. and Ohta, S. (eds.) Rainforest ecosystems of East Kalimantan: el niño, drought, fire and human impacts. 121-128. Springer, Tokyo.

Mardji, D. 2000. Disease of dipterocarp saplings planted in Bukit Soeharto Education Forest, East Kalimantan. *In*: Guhrdja, E. Fatawi, M., Sutisna, M., Mori, T. and Ohta, S. (eds.) Rainforest ecosystems of East Kalimantan: el niño, drought, fire and human impacts. 289-298. Springer, Tokyo.

Mori, T. 1980. Physiological studies on some dipterocarp species of Peninsular Malaysia as a basis for artificial regeneration. Research Pamphlet No.78. Malaysia Forestry Department.

Mori, T. 2000. Effects of droughts and forest fires on dipterocarp forests in East Kalimantan. *In*: Guhrdja, E. Fatawi, M., Sutisna, M., Mori, T. and Ohta, S. (eds.) Rainforest Ecosystems of East Kalimantan: El niño, drought, fire and human impacts, 29-48. Springer, Tokyo.

Mori, T., Nakashizuka, T., Sumizono, T. and Yap, S.K. 1990. Growth and photosynthetic responses to temperature in several Malaysian tree species. Journal of Tropical Forest Science 3: 44-57.

Mori, T., Ohta, S., Ishida, A., Toma, T. and Oka, T. 2000. Overview of changing rainforest ecosystems in East Kalimantan. *In*: Guhrdja, E. Fatawi, M., Sutisna, M., Mori, T. and Ohta, S. (eds.) Rainforest ecosystems of East Kalimantan: el niño, drought, fire and human impacts, 309-317. Springer, Tokyo.

Okimori, Y. and Matius, P. 2000a. Impacts of different intensities of selective logging on the low-hill dipterocarp forest in Pasir, East Kalimantan. *In*: Guhrdja, E. Fatawi, M., Sutisna, M., Mori, T. and Ohta, S. (eds.) Rainforest ecosystems of East Kalimantan:

el niño, drought, fire and human impacts, 209-218. Springer, Tokyo.

Okimori, Y. and Matius, P. 2000b. Tropical secondary forest and its succession following traditional slash-and-burn agriculture in Muncimai, Baron Tongkok. *In*: Guhrdja, E. Fatawi, M., Sutisna, M., Mori, T. and Ohta, S. (eds.) Rainforest ecosystems of East Kalimantan: el niño, drought, fire and human impacts. 185-198. Springer, Tokyo.

Otsamo, R., Otsamo, A. and Ådjers, G. 1996. Reforestation experiences with dipterocarp species on grassland. *In*: Schulte, A. and Schöne, D. (eds.) Dipterocarp forest ecosystems: towards sustainable management, 464-477. World Scientific Publishing, Singapore.

Proctor, J., Anderson, J.M., Chai, P., Vallack, H.W. 1983. Ecological studies in four contrasting lowland rain forests in Gunung Mula National Park, Sarawak. I: Forest environment, structure, and floristic. Journal of Ecology 71: 237-260

Ruslim, Y., Matius, P. and Sutisna, M. 2000. A case study of second felling in a logged-over dipterocarp forest. *In*: Guhrdja, E. Fatawi, M., Sutisna, M., Mori, T. and Ohta, S. (eds.) Rainforest ecosystems of East Kalimantan: el niño, drought, fire and human impacts, 219-227. Springer, Tokyo.

Schulte, A. and Schöne, D. (eds.) 1996. Dipterocarp forest ecosystems: towards sustainable management. World Scientific Publishing, Singapore

Sist, P. and Saridan, A. 1998. Description of the primary lowland forest of Berau. *In*: Bertault, J-G. and Kadir, K. (eds.) Silvicultural research in a lowland mixed dipterocarp forest of East Kalimantan, 51-73. CIRAD-forest, FORDA, INHUTANI-I, Indonesia.

Soda, R., Nakamura, K., Nakama, E., Kobayashi, N., Sumarsono, S.B. and Leppe D. 1999. Growth of dipterocarp species in early stage of artificial plantation. *In*: Suhartoyo, H. and Toma, T. (eds.) Proceedings of 3rd International Symposium of Asian Tropical Forest Management, 536-543. PUSREHUT, Mulawarman University, Samarinda, Indonesia.

Sukardjo, S., Hagihara, A., Yamakura, T. and Ogawa, H. 1990. Floristic composition of a tropical rain forest in Indonesian Borneo. Bulletin of Nagoya University Forest 10: 1-43.

Toma, T., Matius, P., Hastaniah, Kiyono, Y., Watanabe. R. and Okimori, Y. 1997 Floristic composition and stand dynamics in logged-over and burnt lowland dipterocarp forests in Bukit Soeharto, East Kalimantan. *In*: Suhartoyo, H., Fatawi, M. (eds.) Proceedings of 2nd International Symposium of Asian Tropical Forest Management, 198-207. PUSREHUT-Mulawarman University, Samarinda, Indonesia.

Toma, T., Matius, P., Hastaniah, Kiyono, Y., Watanabe, R. and Okimori Y. 2000. Dynamics of burned lowland dipterocarp forest stands in Bukit Soeharto, East Kalimantan. *In*: Guhrdja, E. Fatawi, M., Sutisna, M., Mori, T. and Ohta, S. (eds.) Rainforest ecosystems of East Kalimantan: el niño, drought, fire and human impacts, 107-120. Springer, Tokyo.

Weidelt, H-J. 1996. Sustainable management of dipterocarp forests – opportunities and constraints. *In*: Schulte, A. and Schöne, D. (eds.) Dipterocarp forest ecosystems: towards sustainable management, 249-273. World Scientific Publishing, Singapore.

Yamakura, T., Hagihara, A., Sukardjo, S. and Ogawa, H. 1986. Aboveground biomass of tropical rain forest stands in Indonesian Borneo. Vegetatio 68: 71-82.

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) | Tree condition | | | |
|---|---|---|---|---|
| | 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 | Bark thickness classes (mm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (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.

## REFERENCES

Anonymous, 1987. Design Engineering Taman Hutan Raya Bukit Soeharto.Departemen Kehutanan, Direktorat Jenderal Perlindungan Hutan dan Pelestarian Alam, Jakarta.

Beekman, 1949. Houtlett in Indonesia H Veenman And Zonen Waginegen.Terjemahan Wiratmoko Soekotjo. Fakultas Kehutanan Institut Pertanian, Bogor.

Bratawinata, A. A. 1995. Keberhasilan pertumbuhan Ulin (*Eusideroxylon zwageri* T et B) di Bukit Soeharto, Fakultas Kehutanan, Unmul, Samarinda, East Kalimantan.

Delmy, A. 1996. Populasi biji jenis pioneer pada lantai hutan sekunder berbeda umur di Hutan Pendidikan Bukit Soeharto, Samarinda, East Kalimantan.

Okimori,Y. and Matius, P. 1991. Change of vegetation and structure of lowland dipterocarp forest after forest fire, Bukit Soeharto, East Kalimantan. The Tropical Rain Forest Research Project ( JICA).

Richards, P.W. 1964. The tropical rain forest: an ecological study, Cambridge University Press, Cambridge, Great Britain.

Schmidt, F.H. and Ferguson, J.H. 1951. Rainfall types based on wet and dry periods for Indonesia with western New Guinea. Kementrian Perhubungan Djawatan Meteorologi dan Geofisika Verhandelingen No 42. Djakarta.

Tagawa, H. 1988. Change of vegetation in Kutai National Park, East Kalimantan. Kagosima University Research Centre For the South Pacific.

Whitmore, T.C. 1975. Tropical rain forests of the Far East. Clarendon Press, Oxford. 352p.

4

# 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 115º 0'34"-116º 0'054"E and 0º 0'50"-1º 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

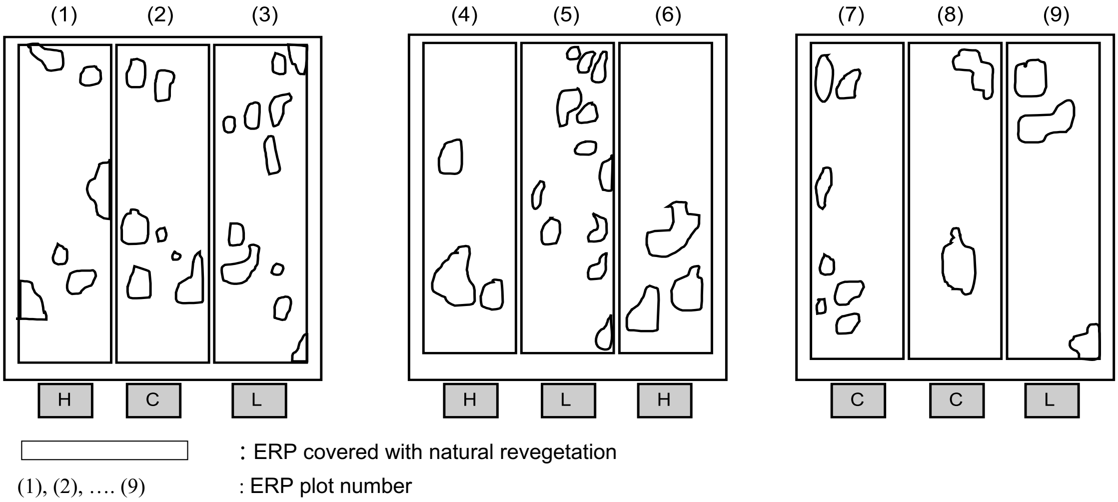
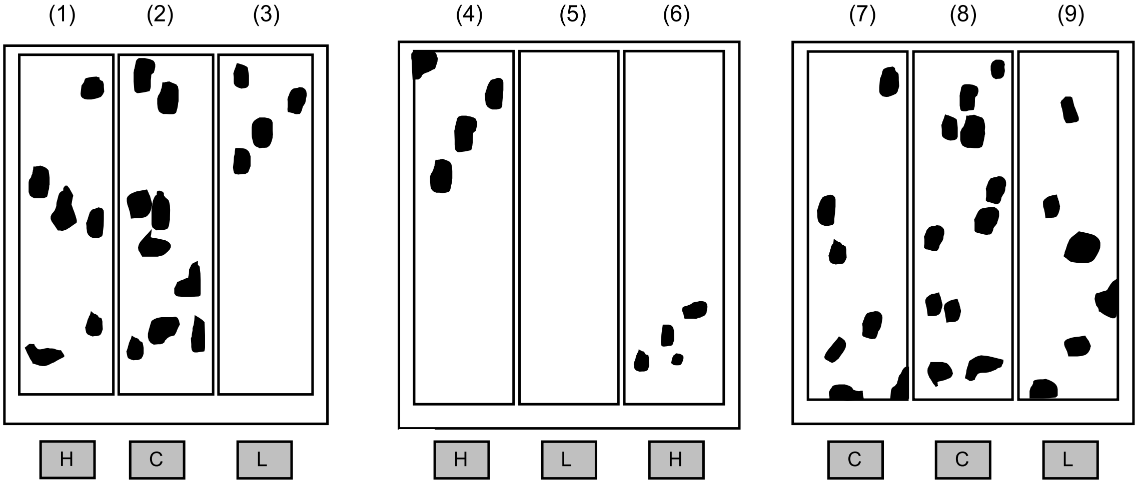


**Figure 2**. Projection of litter Cover at each Erosion Research Plot



▬ : ERP covered with litre/debris

(1), (2), …. (9) : ERP plot number

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 |

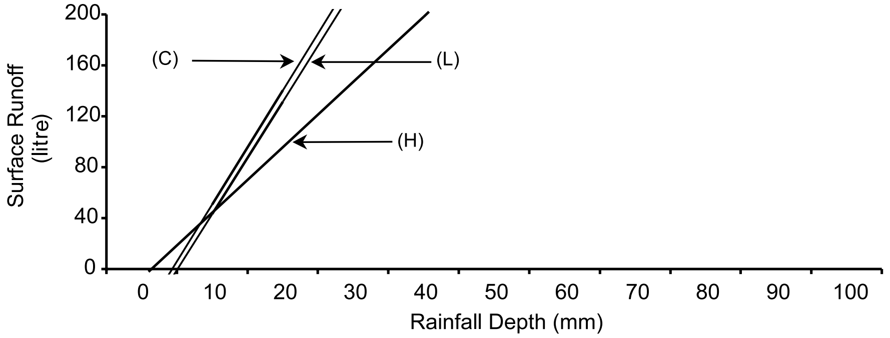
(H). Heavy logging or cutting intensity, (L). Light intensity, (C). Control.

**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) | $Y = 5.1296 X - 6.9673$ | 0.78 |
| | (L) | $Y = 8.7972 X - 44.6030$ | 0.85 |
| | (C) | $Y = 8.9477 X - 38.7440$ | 0.72 |
| Rainfall and eroded soil cover | (H) | $Y = 0.1992 X + 2.5978$ | 0.26 |
| | (L) | $Y = 0.0518 X + 2.8893$ | 0.04 |
| | (C) | $Y = 0.1086 X + 3.1405$ | 0.14 |
| Surface runoff and eroded soil cover | (H) | $Y = 0.0415 X + 2.6477$ | 0.38 |
| | (L) | $Y = 0.0062 X + 3.1122$ | 0.05 |
| | (C) | $Y = 0.0113 X + 3.7136$ | 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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## REFERENCES

Anonymous. 1986. Pedoman penyusunan pola rehabilitasi lahan dan konservasi tanah. Direktorat Jendral Reboisasi dan Rehabilitasi Lahan. Departemen Kehutanan, Jakarta.

Anonymous. 1994. Pedoman penyusunan rencana teknik lapangan rehabilitasi lahan dan konservasi tanah daerah aliran sungai. Dijen RRL-DEPHUT, Jakarta.

Arsyad, S. 1989. Konservasi tanah dan air. Institut Pertanian Bogor, Bogor, Indonesia.

Effendi, S. 1999. Perubahan sifat fisik dan kimia tanah akibat tebang pilih dan kebakaran hutan. Universitas Mulawarman, Samarinda.

Fauzi, A. 1996. Pengukuran erosi dan aliran permukaan pada lahan persiapan HTI di PT. Kiani Lestari Batu Ampar.

Fuliana, D. 1996. Pendugaan erosi dan limpasan permukaan pada lahan alang-alang yang ditanami sengon dengan teknik pengolahan tanah minimum. Fahutan-UNMUL, Samarinda.

Gunawan, M. 1996. Pengukuran limpasan permukaan dan erosi tanah pada areal bekas Kebakaran di hutan pendidikan UNMUL, Bukit Soeharto. Fahutan-UNMUL.

Janawi 1996. Studi tentang teknik pengendalian limpasan permukaan dan erosi tanah secara vegetatif di HP-UNMUL, Lempake. Fahutan-UNMUL.

Pritchett, W.L. 1979. Properties and management of forest soils. Wiley, New York.

Ruslim, Y., Matius, P. and Sutisna, M. 2000. A case study of second felling in a logged-over dipterocarp forest. *In*: Guhrdja, E. Fatawi, M., Sutisna, M., Mori, T. and Ohta, S. (eds.) Rainforest ecosystems of East Kalimantan: el niño, drought, fire and human impacts, 219-227. Springer, Tokyo.

Schmidt, F. H. and Ferguson, J. H. A. 1951. Rainfall types based on wet and dry periods for Indonesia and western New Guinea. Kementrian Perhubungan Djawatan Meteorologi dan Geofisika Verhandelingen No. 42, Jakarta.

Soedardjo. 1982. Erosi dan sedimentasi. Yayasan Pembina Fakultas Kehutanan Universitas Gadjah Mada. Yogyakarta.

Soeratmo, F. G. 1979. Ilmu perlindungan hutan, Pusat Pendidikan Kehutanan Cepu.

Sudarmadji, T. 1995. Studi tentang upaya rehabilitasi lereng lahan rusak secara vegetatif untuk pencegahan dan pengendalian erosi. Laporan Penelitian. PPHT-UNMUL.

Sudarmadji, T. 1997. Identifikasi dampak intensitas pengusahaan hutan terhadap laju erosi di kawasan hutan tropis basah Kalimantan Timur. Pusat Studi Reboasasi dan Rehabilitasi Hutan Tropis. Universitas Mulawarman. Samarinda.

Tangketasik, J. 1987. Perubahan sifat fisik dan kimia tanah akibat Kebakaran Hutan di Kawasan HPH PT. INHUTANI I, Long Nah. Wanatrop Vol.2 No.2.

Toma, T., Marjenah, and Hastaniah. 2000. Climate in Bukit Soeharto, East Kalimantan. *In*: Guhrdja, E. Fatawi, M., Sutisna, M., Mori, T. and Ohta, S. (eds.) Rainforest ecosystems of East Kalimantan: el niño, drought, fire and human impacts, 13-27. Springer, Tokyo.

Utomo, W. H. 1989. Konservasi tanah di Indonesia. Suatu Rekaman dan Analisa. Rajawali Press, Jakarta.

## 5

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

D. Mardji[1]

***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 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Total | Low | Medium | Severe | Highly severe | Dead | (%) | | damage |
| 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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## REFERENCES

Arsensi, I. 1998. Inventarisasi penyakit pada jenis-jenis permudaan dari suku Dipterocarpaceae di hutan Bukit Soeharto, Kabupaten Kutai. Tesis Magister Fakultas Kehutanan Unmul, Samarinda. 102p.

Boyce, J.S. 1961. Forest pathology. 3rd ed. McGraw-Hill Book Company, Inc., New York. 572p.

Butin, H. 1989. Krankheiten der Wald- und Parkbaeume. Georg Thieme Verlag, Stuttgart. 215p.

de Guzman, E.D. 1985. Field diagnosis, assessment and monitoring tree diseases. Institute of Forest Conservation, University of the Philippines Los Banos, College, Laguna. 16p.

Elouard, C. 1998. Pests and diseases of Dipterocarpaceae. *In*: Appanah, S. and Turnbull, J.M. (eds.). A review of dipterocarps: taxonomy, ecology and silviculture, 115-131. Center for International Forestry Research, Bogor, Indonesia.

Eusebio, M.A., Quimio, M.J. Jr. and Ilagan, F.P. 1979. Canker of Moluccan sau (*Albizia falcataria* (L.) back in Bislig, Surigao del Sur. Sylvatrop Philippines Forest Research Journal. 5: 99-122.

Gäumann, E. 1951. Pflanzliche Infektionslehre. 2.Auflage. Verlag Birkhäuser, Basel. 681p.

Gibson, I.A.S. 1975. Diseases of forest trees widely planted as exotics in the tropics and southern hemisphere. Part I. Important members of the Myrtaceae, Leguminosae, Verbenaceae and Meliaceae. Commonwealth Mycological Institute, Kew, Surrey, England. 51p.

Goldammer, J.G., Seibert, B. and Schindele, W. 1996. Fire in dipterocarp forets. *In*: Schulte, A and Schone F.P. (eds.) Dipterocarp forest ecosystems: towards sustainable management, 155-185. World Scientific Publishing, Singapore.

James, W.C. 1974. Assessment of plant diseases and losses. Annual Review of Phytopathology 12: 27-48.

Kobayashi, T. and de Guzman, E.D. 1988. Monograph of tree diseases in the Philippines with taxonomic notes on their associated microorganisms. Bulletin Forestry and Forest Products Research Institute 351: 99-200.

Lee, S.S. and Ahmad, A.M. 1982. *Cylindrocladium scoparium* Morgan - a new pathogen of some forest trees species in Peninsular Malaysia. Pertanika 5: 72-75.

Mardji, D. 1995. Perlindungan hutan di daerah tropis. Bahan kuliah. Fakultas Kehutanan Universitas Mulawarman, Samarinda. 109p.

Mardji, D. 1996. Hama dan penyakit tanaman jenis Dipterocarpaceae di Bukit Soeharto. Laporan Penelitian. Lembaga Penelitian Unmul, Samarinda. 94p.

Mori, T. 2000. Effects of droughts and forest fires on dipterocarp forests in East Kalimantan. *In*: Guhrdja, E. Fatawi, M., Sutisna, M., Mori, T. and Ohta, S. (eds.) Rainforest ecosystems of East Kalimantan: el niño, drought, fire and human impacts. 29-48. Springer Verlag, Tokyo.

Nuhamara, S.T. 1991. Berbagai penyakit pada Hutan Tanaman Industri (HTI) di Indonesia. Makalah Seminar Nasional "Peningkatan Produktivitas Hutan Tanaman Industri (HTI) Melalui Upaya Pengendalian Hama dan Penyakit Secara Terpadu". Kerjasama Fak. Kehutanana IPB dengan Dep. Kehutanan R.I. 24p.

Quiniones, S.S. 1980. Notes on the diseases of forest trees in the Philippines. Sylvatrop Philippines Forest Research Journal 5: 263-271.

Sharma, J.K., Mohanan, C. and Florence, E.J.M. 1984. Outbreak of pink disease caused by *Corticium salmonicolor* in *Eucalyptus grandis* in Kerala, India. Tropical Pest Management 30: 253-255.

Sharma, J.K., Mohanan, C. and Florence, E.J.M. 1985. Disease survey in nurseries and plantations of forest tree species grown in Kerala. Kerala Forest Research Institute, Research Report 36. 268p.

Sharma, J.K.; Florence, E.J.M., Sankaran, K.V. and Mohanan, C. 1986. Toxin bioassay for assessing relative susceptibility of Eucalypts to pink disease. Proceedings of National Seminar on "Eucalypts in India, Past, Present and Future", 400-403. Kerala Forest Research Institute, India.

Singh, U.P. and Mishra, G.D. 1992. Effect of powdery mildew (*Erysiphe pisi*) on nodulation and nitrogenase activity in Pea (*Pisum sativum*). Plant Pathology 41: 262-264.

Singh, S. and Chaturvedi, A.N. 1993. Stagnating disease of eucalypts. Journal of Tropical Forestry 9: 364-367.

Smits, W.T.M., Yasman, I., Leppe, D. and Noor, M. 1991. Some observations on diseases of Dipterocarpaceae. Biotrop Special Publication 41: 147-163.

Soeyamto, Ch. and Mardji, D. 1995. Inventarisasi hama dan penyakit pada hutan tanaman industri (*Eucalyptus deglupta* dan *Paraserianthes falcataria*) PT. Kiani Hutani Lestari Batu Ampar. Laporan. Fakultas Kehutanan Unmul, Samarinda. 53p.

Stevens, F.L. 1966. The fungi which cause plant disease. Johnson Reprint Corporation, New York. 754p.

Toma, T., Marjenah and Hastaniah. 2000. Climate in Bukit Soeharto, East Kalimantan. *In*: Guhardja, E. Fatawi, M., Sutisna, M., Mori, T. and Ohta, S. (eds.) Rainforest ecosystems of East Kalimantan: El Niño, drought, fire and human impacts. 13-27. Springer Verlag, Tokyo.

# 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 3.** Sprouting after fire injury

**Photo 4**. The fire resistant *Shorea ovalis*

**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)<br>*Shorea* spp)<br>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)<br>(*Shorea* spp)<br>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)<br>(*Shorea laevis*)<br>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)<br>(*Shorea laevis*)<br>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<br>*(Anthocephalus cadamba*)<br>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<br>(*Dillenia exelsa*)<br>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 (S*horea johorensis*) (Photo 10).

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

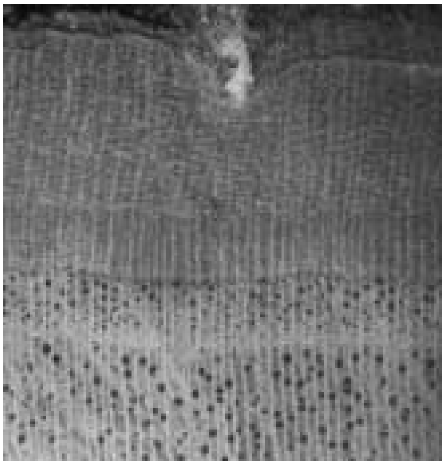
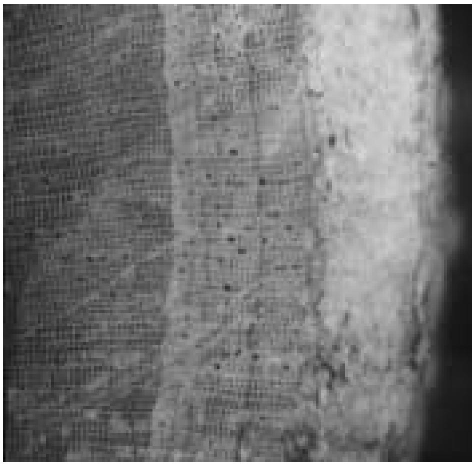


**Photo 6**. Dimension and intensity change of axial parenchyma in bongin (*Irvingia* sp.)



## *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*)

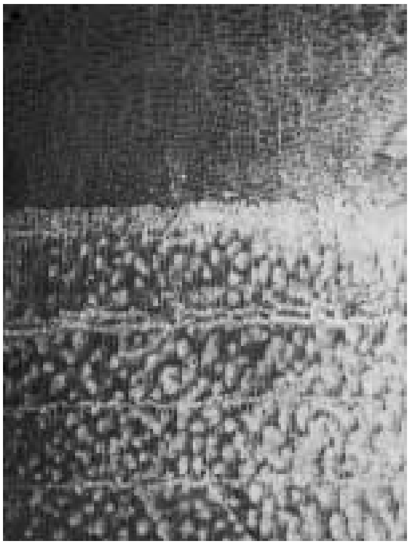


**Photo 8**. Decayed spots in the wood tissue in bangkirai (*Shorea laevis*)

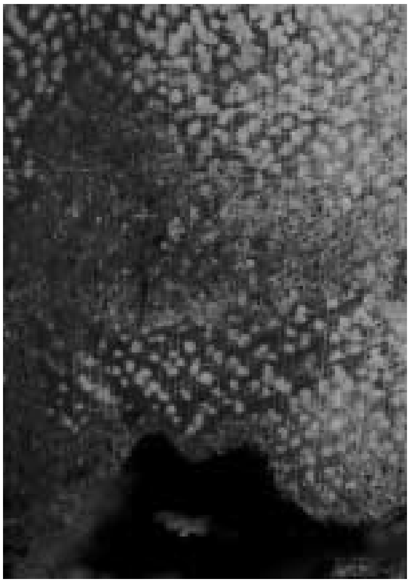


**Photo 9.** Concentrated fibres in a concentric pattern in *Dillenia exelsa*

**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)

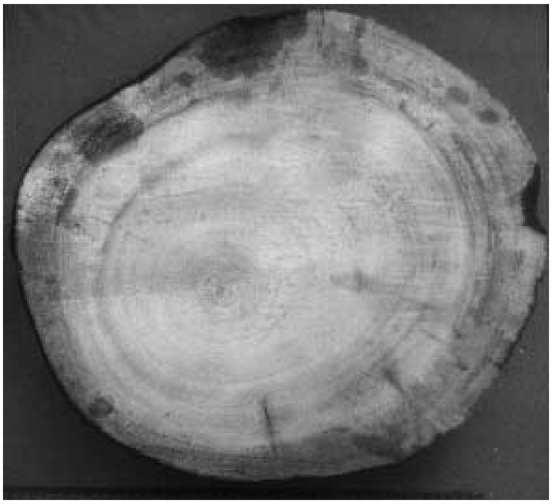
This type has medium and high wood density. The bark is thick and contains much fibre and sclerenchyma. The fire usually only burnt the outer bark, but when exposed to high thermal radiation for a long period the cambium activity stopped for some time. Wood with an abnormal structure is produced. The 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

## ACKNOWLEDGEMENTS

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## REFERENCES

Carlquist, S. 1987. Diagonal and tangential vessel aggregations in wood: function and relationship to vasicentric tracheids. ALISO 11: (4).

Guenter, V. and Hartmut, A. 1983. Atlas zur biologie: tafeln und texte. Germany.

Kobayashi, S., Sutisna, M., Delmy, A. and Toma, T. 1999. Initial phase of secondary succession at the burnt logged-over forest in Bukit Soeharto, East Kalimantan, Indonesia. Which vegetation types are facilitation or competition process? *In*: Suhartoyo H.and Toma T. (eds.) Proceedings 3rd International Symposium on Asian Tropical Forest Management. PUSREHUT Special-Publication No.8. 324-336.

Shigo, A.L. 1989. A new tree biology. Shigo and Tree Associates, New Hampshire, United States.

Wheeler, E.A., Bass. P. and Gasson, P.E. (eds.) 1989. List of microscopic features for hardwood identification International Association of Wood Anatomists. Rijksherbarium, Leiden, The Netherlands.

# 7

# 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<br>6 | All[1]<br>Soils, traffic | IHM-1, IHM-2<br>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%).

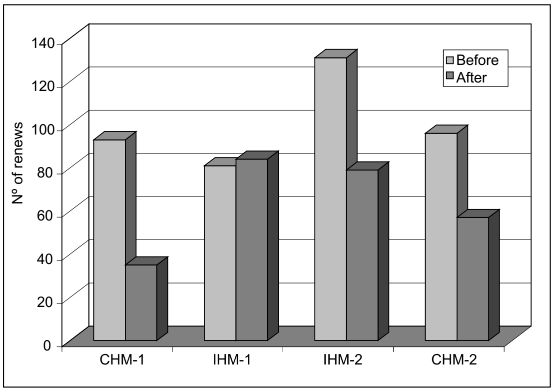
The densities of seedlings and saplings found in the four plots before timber harvesting were between 8333 and 13 366 plants $ha^{-1}$. These figures reached 64% of the regeneration (including the palms) found by Wagner (1997) in a humid premontane forest in Costa Rica.

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.

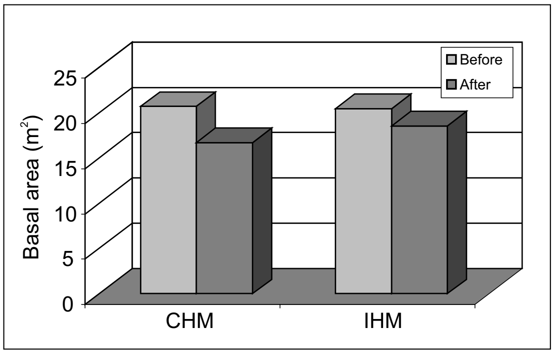
**Table 4.** Total values ($m^2 ha^{-1}$) of structural parameters in each harvesting treatment

| | 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 |

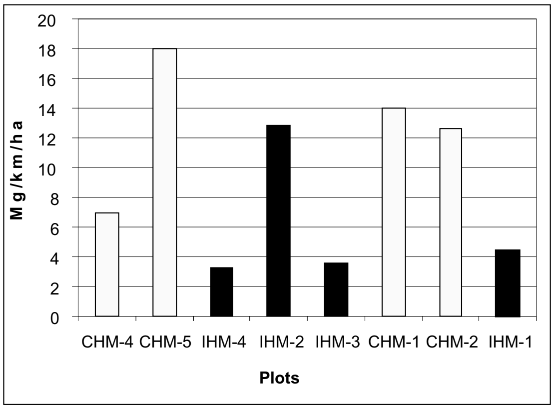
**Table 7.** Relation between damaged trees and harvested trees

| 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.

## REFERENCES

Arango, I. 1998. Impacto de la explotaciòn maderera en los bosques de *Capnosperma panamensis,* Colombia. *In*: Crònica Forestal y Medio Ambiente 13: 41-54.

ASAE 1994. ASAE standard S. 313.4.

Bertault, J.G. and Sist, P. 1997. An experimental comparison of different harvesting intensities with reduced-impact and conventional logging in East Kalimantan, Indonesia. Forest Ecology and Management 94: 209-218.

Contente De Barros, P. 1996. Estudo fitosociológico de una floresta tropical úmida no Planalto de Curuá-una, Amazónia Brasileira. Curitiba. Brasil.

Delgado, R.L. 1995. Efectos en la riqueza, composición y diversidad florística producidos por el manejo silvícola de un bosque húmedo tropical de tierras bajas en Costa Rica. Centro Agronómico Tropical de Investigación y Enseñanza, Turrialba, Costa Rica.

Delgado, D. Finegan, B. Zamora, N. and Meir, P. 1997. Efectos del aprovechamiento forestal y el tratamiento silvicultural en un bosque húmedo del noreste de Costa Rica. Serie Técnica . Centro Agronómico Tropical de Investigación y Enseñanza, Costa Rica.

Dykstra, D.P. and Heinrich, R. 1992. Sustaining tropical forest through environmentally sound harvesting practices. Unasylva 43 (169): 9-15.

Finegan, B. 1995. La composición florística de bosques naturales primarios no perturbados. Centro Agronómico Tropical de Investigación y Enseñanza. (CATIE), Turrialba, Costa Rica.

Gracen, E L and Sands, R. 1980. Compaction of forest soils : a review. Australian Journal of Soil Research 18: 163-189.

Guariguata, M. R. 1998. Consideraciones ecológicas sobre la regeneración natural aplicada al manejo forestal. Nº 14. Serie Técnica Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Costa Rica.

Hutchinson, I. 1993. Silvicultura y manejo en un bosque secundario tropical. *In*: Revista Forestal Centroamericana. 13-18. CATIE, Costa Rica.

Kammesheidt, L. and Torres Lezama, A. 1997. Estructura del rodal y distribución espacial de especies arbóreas comerciales después de la explotación selectiva de un bosque húmedo deciduo en Venezuela. *In*: Memoria del Simposio Internacional sobre posibilidades de Manejo Sostenible en América Tropical. 34-49. BOLFOR, IUFRO, CIFOR. Bolivia.

Kammesheidt, L. Torres Lezama, A., and Franco W. 1997. Efecto de la explotaciòn selectiva sobre la estructura y sostenibilidad del bosque tropical: un caso de los llanos occidentales venezolanos. Revista Forestal Venezolana, 39:19-24

Kobayashi, S. 1994. Effects of harvesting impacts and rehabilitation of tropical rainforest. Journal of Plant Research 107: 99-106.

Lamprecht, J. 1990. Silvicultura en los trópicos. GTZ. 335p.

López Cristóbal, L., Grance, L., Maiocco, D. and Eibl, B. 1996. Estructura y composición florística del bosque nativo en el predio de Guaraní. Yvyraretá 7: 30-37.

McNabb, K.L., Miller, M.S., Lockaby, B.G., Stokes, B.J., Clawson, R.G., Stanturf, J.A. and Silva, J.N.M. 1997. Selection harvest in Amazonian rainforest: long-term impacts on soil properties. Forest Ecology and Management 93: 153-160.

Montagnini, F., Eibl, B., Szczipanski, L. and Rios, R. 1998. Tree regeneration following conventional and uniform spacing methods of selective cutting in a subtropical humid forest reserve. Biotropica 30: 349-361.

Quiros, D. and Finegan, B. 1998. Manejo de un bosque muy húmedo premontano Area de Demostración e Investigación La Tirimbina. *In*: Silvicultura y manejo de bosques naturales tropicales, Vol. 2. Curso Intensivo Internacional, Serie Nº 34. Centro Agronómico Tropical de Investigación y Enseñanza. Costa Rica. 13-24.

Raper, R.L., Johnson, C.E. and Bailey, A.C. 1994. Coupling normal and shearing stresses to use in finite element analysis of soil compaction. Transactions of the ASAE 37: 1417-1422.

Saenz, G. 1996. Manejo de un bosque muy húmedo de altura, Area Piloto Villa Mills-Siberia. *In*: Silvicultura y manejo de bosques naturales tropicales, Vol. 2. Curso Intensivo Internacional, Serie Nº 34. Centro Agronómico Tropical de Investigación y Enseñanza. Costa Rica. 25-38.

Schafer, R L., Bailey, A.C., Johnson, C.E. and Raper, R.L. 1989. A rationale for modeling soil compaction behavior: an engineering mechanics approach. ASAE Paper No. 89: 1097.

Smith, D.L.O. and Dickson, J.W. 1990. The contribution of vehicle weight and ground pressure to soil compaction. Journal of Agricultural Engineering Research 46: 13-29.

Wagner, U. 1997. Efectos del manejo maderero sobre la biodiversidad florística y la estructura de bosques húmedos de Costa Rica. *In*: Memoria del Simposio Internacional sobre posibilidades de Manejo Sostenible en América Tropical. BOLFOR, IUFRO, CIFOR. Bolivia. 50-58.

Wasterlund, I. 1992. Extent and causes of site damge due to forestry traffic. Scandinavian Journal of Forestry Research 7: 135-142.

# 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 |

## REFERENCES

Ashton, P. S. 1964. Ecological studies in the mixed dipterocarp forests of the Brunei state. Oxford Forestry Memoirs 25. Commonwealth Forestry Institute, Oxford.

Brown, S. 1997. Estimating biomass and biomass change of tropical forests. FAO Forestry Paper 134. Food and Agriculture Organization, Rome.

Food and Agriculture Organization. 1973. The timber species of the mixed dipterocarp of Sarawak and their distribution. FO: DP/MAL/ 72/009. Working Paper 21, Kuala Lumpur.

Kamaruzaman, O., Hamid, W.A.S.W.A.R and Azizan, H. 1982. Biomass studies of woody plants in a naturally regenerated secondary forest after shifting cultivation. Diploma Project Report, UPM. 59p.

Kartawinata, K., Rochadi Abdulhadi and Tukirin Partomihardjo. 1981. Composition and structure of a lowland dipterocarp forest at Wanariset, East Kalimantan. Malaysian Forester 44: 397-406.

Kato, R., Tadaki, Y. and Ogawa, H. 1978. Plant biomass and growth increment studies in Pasoh Forest. Malayan Nature Journal 30: 211-224.

Kawahara, T., Kanazawa, Y. and Sakurai, S. 1981. Biomass and nett production of man-made forests in the Philippines. Journal of Japanese Forestry Society 63: 320-327.

Kochummen, K.M., Lafrankie, J.V. and Manokaran, N. 1990. Floristic composition of Pasoh Forest Reserve, a lowland rain forest in Peninsular Malaysia. Journal Tropical Forest Science 3: 1-13.

Lim, M.T. and Basri, M.H. 1985. Biomass accumulation in a naturally regenerating lowland secondary forest and an *Acacia mangium* stand in Sarawak. Pertanika 8: 237-242.

Proctor, J., Anderson, J., Chai, P. and Vallack, H. 1983. Ecological studies in four contrasting lowland rain forests in Gunung Mulu National Park, Sarawak. Journal of Ecology 71: 237-260.

Roland, K.J.H. and Lim, M.T. 1999. An estimate of forest biomass in Air Hitam Forest Reserve, Selangor. Paper presented at Seminar Pengurusan dan Ekologi Hutan Simpan Ayer Hitam, Selangor. UPM, Serdang, 12-13 October 1999.

Wyatt-Smith, J. 1949. A note on tropical lowland evergreen rain forest in Malaya. Malayan Forester 12: 58-64.

Wyatt-Smith, J. 1963. Manual of Malayan silviculture of inland forest. Malayan Forest Record No.23. 146p.

# 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.

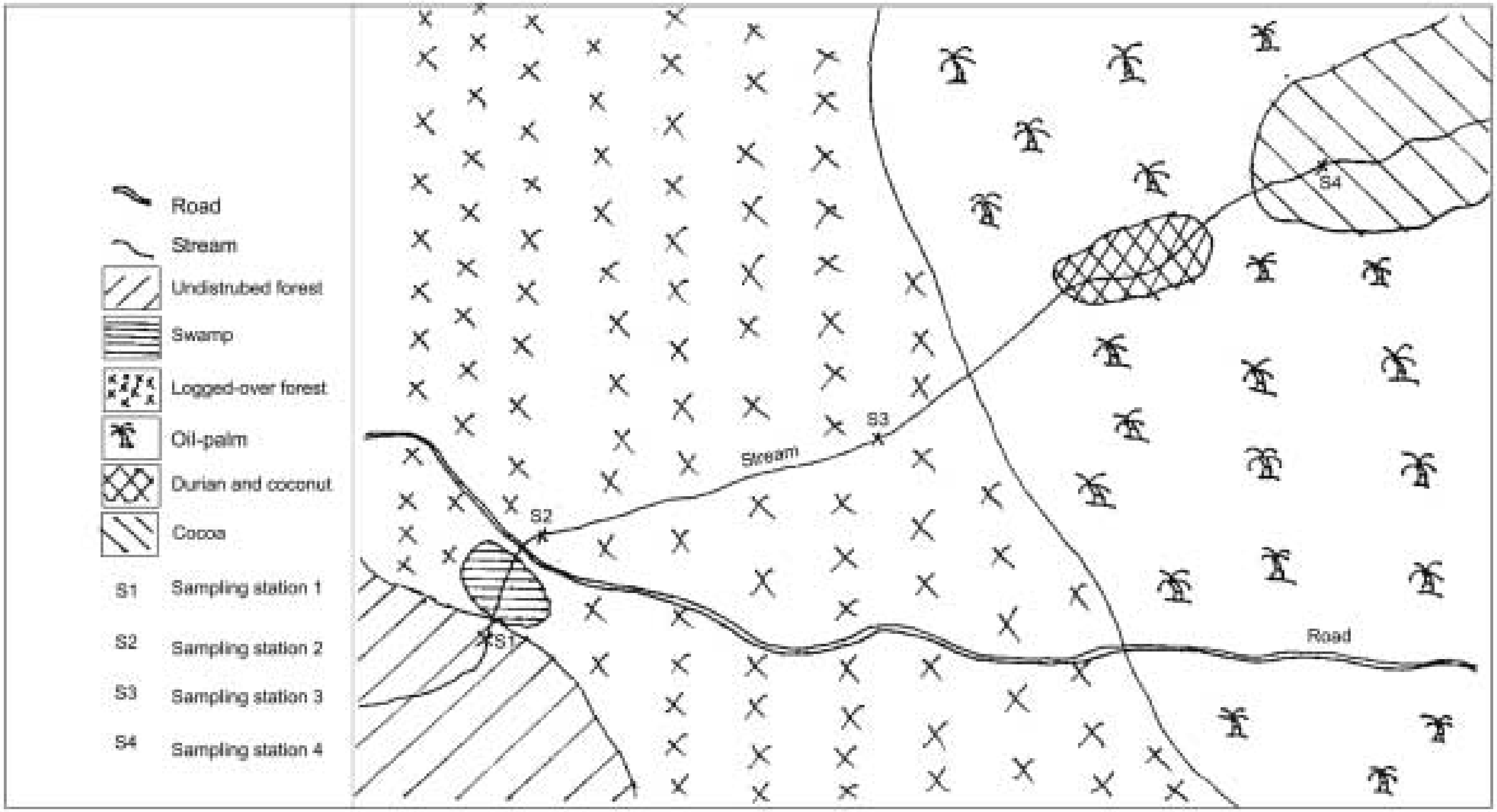
### Sampling Design, Field Work and Sample Preservation

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 $i^{th}$ 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 $j^{th}$ 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 $i^{th}$ parameter;
$R_j(I)$ = rank of the $j^{th}$ observation for the $i^{th}$ 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($\mu$mhos 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 |

## REFERENCES

APHA. 1995. Standard methods for the examination of water and waste water. American Public Health Association, American Water Works Association and Water Pollution Control Federation, Washington.

Azizi M., Ramdzani A., Wan N. A., Mohd Kamil Yusoff and Anton, A. 1997. Land use of a river basin: a case study of Terengganu River classification. Journal of Ensearch 10: 141-149.

Barrows, H.L. and Kilmer, V.J. 1963. Plant nutrient losses from soils by water erosion. Advances in Agronomy 15: 303-316.

Connelk, D.W. 1981. Water pollution: causes and effects in Australia and New Zealand, University of Queensland Press, St Lucia, Queensland.

DOE. 1994. Final report on development of water quality and standards for Malaysia (Phase IV – river classification ), Classification of Malaysian Rivers, Vol. 8b, Juru River.

Feller, M.C. and Kimmins, J.P. 1979. Chemical characteristics of small streams near Haney. *In*: Southwestern British Columbia. Water Resource Research, 15(2), American Geophysical Union.

Frimmel, F.H. 1990. Characterization of organic acids in freshwater: a current status and limitations. *In*: E.M. Perdue and E.T. Gjessing (eds.). Organic acids in aquatic ecosystems. 5-23. Wiley-Interscience, Berlin.

Harkin, R.D. 1974. An objective of water quality index. Water Pollution Control Federation (WPCF) 46: 588-591.

Hedges, J.I. 1990. Compositional indicators of organic acid sources and reactions in natural environments. *In*: E.M. Perdue and E.T. Gjessing (eds.). Organic acids in aquatic ecosystems. Wiley-Interscience, Berlin.

Hewlett, J.D. 1982. Principles of forest hydrology. University of Georgia Press, Athens, Georgia.

Holt, R.F., Dowdy, R.H. and Timmons, D.R. 1970. Chemistry of sediment in water. *In*: T. L. Willrich and G.E.Smith (eds.). Agricultural practices and water quality. Iowa State University Press, Iowa.

Johnson, H.P. and Moldenhauer, W.C. 1970. Pollution by sediment: sources and the detachment and transport processes. *In*: T. L. Willrich and G.E.Smith (eds.). Agricultural practices and water quality. Iowa State University Press, Iowa.

Martin, W.P., Fenster, W.E., and Hanson, L.D. 1970. Fertilizer management for pollution control. *In*: T. L. Willrich and G.E.Smith (eds.). Agricultural practices and water quality. Iowa State University Press, Iowa.

Mohd Kamil Yusoff, Wan N.A.S., Azizi M., Ramdzani A. and Anton, A. 1997. Water quality profile of Sungai Terengganu and Sarawak using DOE-WQI. Journal of Ensearch 10: 47-53.

Norhayati M. 1981. Indices for water quality assessment in a river. Master’s Thesis. Environmental Engineering Department, Asian Institute of Technology, Bangkok.

Rohani H. and Tan M. L. 1997. Water quality management in Malaysia: current status and trends. Journal of Ensearch 10: 5-13.

## 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 14ϒ30′-14ϒ45′N and longitude 98ϒ45′-99ϒ0′E. The climate is monsoonal, the mean annual temperature is about 27.5ϒC with the maximum of 39ϒC in April and the minimum of 14ϒC 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*<br>(25.05)<br>*Berrya ammonilla*<br>(16.08)<br>*Dillenia parviflora*<br>(11.66)<br>Bombax anceps<br>(11.50)<br>*Xylia xylocarpa*<br>(11.03)<br>*Sterculia macrophylla*<br>(8.24) | *Sterculia macrophylla*<br>(45.18)<br>*Lagerstroemia tomentosa*<br>(19.40)<br>*Colona floribunda*<br>(15.17)<br>*Dillenia obovata*<br>(14.23)<br>*Ficus hispida*<br>(13.61)<br>*Xylia xylocarpa*<br>(11.64) | *Trema orientalis*<br>(163.61)<br>*Xylia xylocarpa*<br>(17.25)<br>*Dipterocarpus turbinatus*<br>(15.45)<br>*Garuga pinnata*<br>(14.82)<br>*Ficus hispida*<br>(12.84)<br>*Gmelina arborea*<br>(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

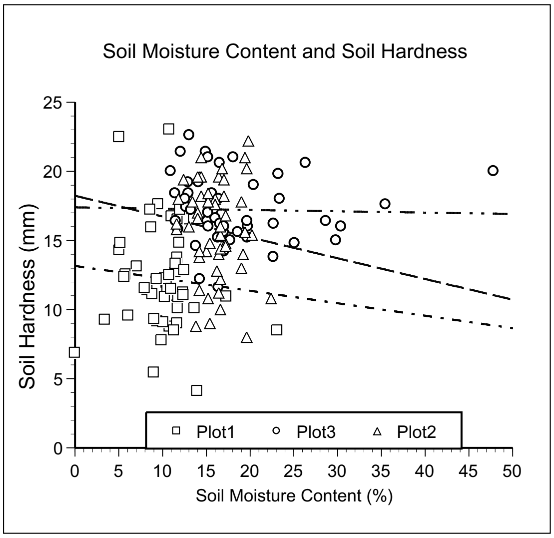
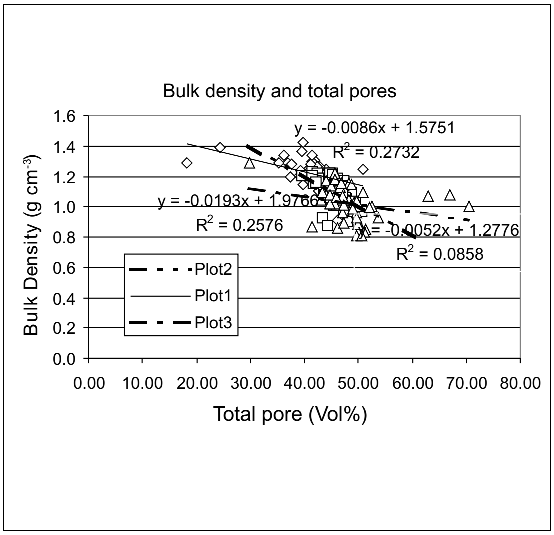


**Figure 2**. Relationship between soil bulk density and total pore volumetric percentage



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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## REFERENCES

Suksawang, S. 1995. Site overview: Thong Pha Phume study site. Proceedings of the International Workshop on the Changes of Tropical Forest Ecosystems by El Nino and Others, Kanchanaburi, Thailand. 33-36. National Research Council of Thailand and the Science and Technology Agency of Japan

Takahashi, M., Kutintara, U., Eiadthong, W. and Kobayashi, S. 1995. Changes of the vegetation pattern in different successional stages. Proceedings of the International Workshop on The Changes of Tropical Forest Ecosystems by El Nino and Others, Kanchanaburi, Thailand. 116-124. National Research Council of Thailand and the Science and Technology Agency of Japan.

Yarwudhi, C., Kobayashi, S., Nakashizuka, T. and Takahashi, M. 1995. Tree population dynamics in a tropical seasonal forest. Proceedings of the International Workshop on the Changes of Tropical Forest Ecosystems by El Nino and Others, Kanchanaburi, Thailand. 97-105. National Research Council of Thailand and the Science and Technology Agency of Japan.

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# Forest Rehabilitation Requires Fire Prevention and Community Involvement

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***Abstract***

In East Kalimantan, drought is frequently followed by fire. The eastern part of Kutai Regency is susceptible to large-scale wildfires during severe droughts related to strong El Niño Southern Oscillation (ENSO) events as shown by the 1982-83 and 1997-98 fires. Since the 1982-83 forest fire, many trials have been conducted to rehabilitate the burned forests. However, the 1998 fires burned both natural and rehabilitated forests in East Kalimantan. It is to be expected that severe droughts related to strong ENSO events and subsequent wildfires will occur again in the near future. At the time of the next severe ENSO event, we should remember that extremely severe drought is likely to recur early in the following year. Without effective fire prevention, the rehabilitated areas will be burned again and the rehabilitation process will not have enough time to reach completion. To rehabilitate burned forests and grasslands as well as to conserve the remaining natural forests, it is important that community-based initiatives are undertaken to reduce potential fire sources and to enhance fire management activities. Clear benefits to the local community should be introduced and announced to the local people before and during forest rehabilitation.

## INTRODUCTION

Two of the world's largest forest fires on record occurred in East Kalimantan within a 15-year period. The first fire was related to an unusually prolonged and severe drought, linked to a strong El Niño Southern Oscillation (ENSO) event in 1982-83 (Goldammer *et al*. 1996). The drought lasted from July 1982 until April 1983, consisting of two rainless phases, one from July to October 1982, and the other from January to April 1983. A later ENSO event from 1997 to 1998 caused another severe drought that also consisted of two rainless phases, from July to October 1997, and from January to April 1998 (Toma *et al*. 2000a). Consequently, huge areas of rain forest in East Kalimantan that had been burned in the 1982-83 fires were again damaged by drought and drought-related fires during the rainless phases in 1997-98 (Toma 1999, Mori 2000).

Fires during severe droughts are an overwhelming problem for workers attempting to rehabilitate forests in East Kalimantan. Up to 1997 (before the 1997-98 fires), semi-natural dipterocarp forests that had been disturbed by selective logging in the 1970s and the 1982-83 fires were on the way to recovery (Toma *et al*. 2000b). Various rehabilitation trials had also been initiated in burned and degraded forests after the large fires in 1982-83. Furthermore, fallow

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grasslands had been rehabilitated as industrial plantations of fast growing species, and enrichment planting by commercial dipterocarp species had been conducted in secondary forests dominated by pioneer species (Sutisna and Fatawi 1994, Fatawi and Mori 2000). Since few dipterocarp trees regenerate naturally in severely burned forests, rehabilitation plantings are an effective means of reducing the time needed for forest recovery. The initial stage of these rehabilitation activities had proceeded successfully (Sutisna 1996, Mubarizi and Nakagoshi 1999, Soda *et al.* 1999). However, the 1997-98 fires burned both the recovering and rehabilitated forests. Indeed, the semi-natural forests were damaged more severely by the 1997-98 fires than they had been by the 1982-83 fires, since they had not recovered their previous health in the intervening period (Goldammer 1999, Mori 2000, Toma *et al.* 2000b). In the rehabilitated forests, the planted trees had not grown enough to survive the fire, so they too were heavily damaged. Clearly, fires degrade forests very quickly but the recovery of forests takes a long time, even with rehabilitation measures. In this context, all silvicultural techniques are useless for forest rehabilitation, unless they include fire prevention. The prevention and management of fires are vital to allow forest recovery and rehabilitation to proceed.

This paper reports on the 1997-98 fires in East Kalimantan and addresses the important questions of what fire prevention measures should be implemented, and what measures should be taken if fires do occur. Secondly, we discuss steps that should be taken to eliminate the problems caused by forest fires in the long-term.

## FIRES IN 1997-98

Maps of the hot spots during the rainless period of 1998 in East Kalimantan show that the areas affected by fires overlapped considerably with those affected by the great forest fires of 1982-83 (Fig. 1). The parts affected by the fires both in 1982-83 and 1997-98 were concentrated in low hills in the eastern part of Kutai Regency. The repeated large-scale fires show that this area is prone to catch fire during severe droughts. The remaining forests in the eastern part of Kutai Regency are surrounded by degraded vegetation, mainly alang-alang (*Imperata cylindrica*) grassland. Grassland fires spread rapidly, with large and vigorous flames. Such intense grassland fire easily escapes control and attacks the forested land from all directions. Fires successfully invading the forest burn mainly the litter layers on the forest floor and progress slowly along the surface of the ground. This type of fire is known as "surface fire" and most forest fires in 1997-98 in East Kalimantan were of this type. Usually, spreading surface fire can be checked simply by clearing the litter layers from a strip beyond the fire, as little as 1 m wide, or less. However, the 1997-98 fires in the forests in East Kalimantan were difficult to control in this fashion, because a lot of fires reached the forested areas simultaneously.

In East Kalimantan, there are two rainless periods during strong ENSO events, and droughts and fires are generally more intense in the second rainless period compared to the first. An ENSO event tends to commence in March to May and to last for a year, or sometimes longer (Walsh 1996). Droughts normally occur over the whole of Indonesia during the first year of an ENSO event. A pronounced ENSO event would also cause a drought in the eastern part of Borneo Island early in its second year (Walsh 1996). In the case of the 1997-98 ENSO events, unusually high air temperatures and low humidity were recorded during the drought in the second year (Fig. 2) (Toma *et al.* 2000a). These weather patterns may have been caused by interaction between the foehn phenomenon and a high pressure air mass generated by the high temperatures associated with the ENSO event (Mori *et al.* 1999, Mori 2000). As a result, the 1998 forest fires in East Kalimantan were more intense than those of 1997. According to a report by the Ministry of Forestry and Estate Crops, the area of burned forest in East Kalimantan was 26 000 ha in 1997 and 533 000 ha in 1998 (Mori 2000). These figures reflected the fact that the fires in 1997 did not invade the well-developed forests, unlike the fires in 1998.

Recent studies using coupled ocean-atmosphere models have shown that increased

**Figure 1**. Fire-affected areas in East Kalimantan, Indonesia

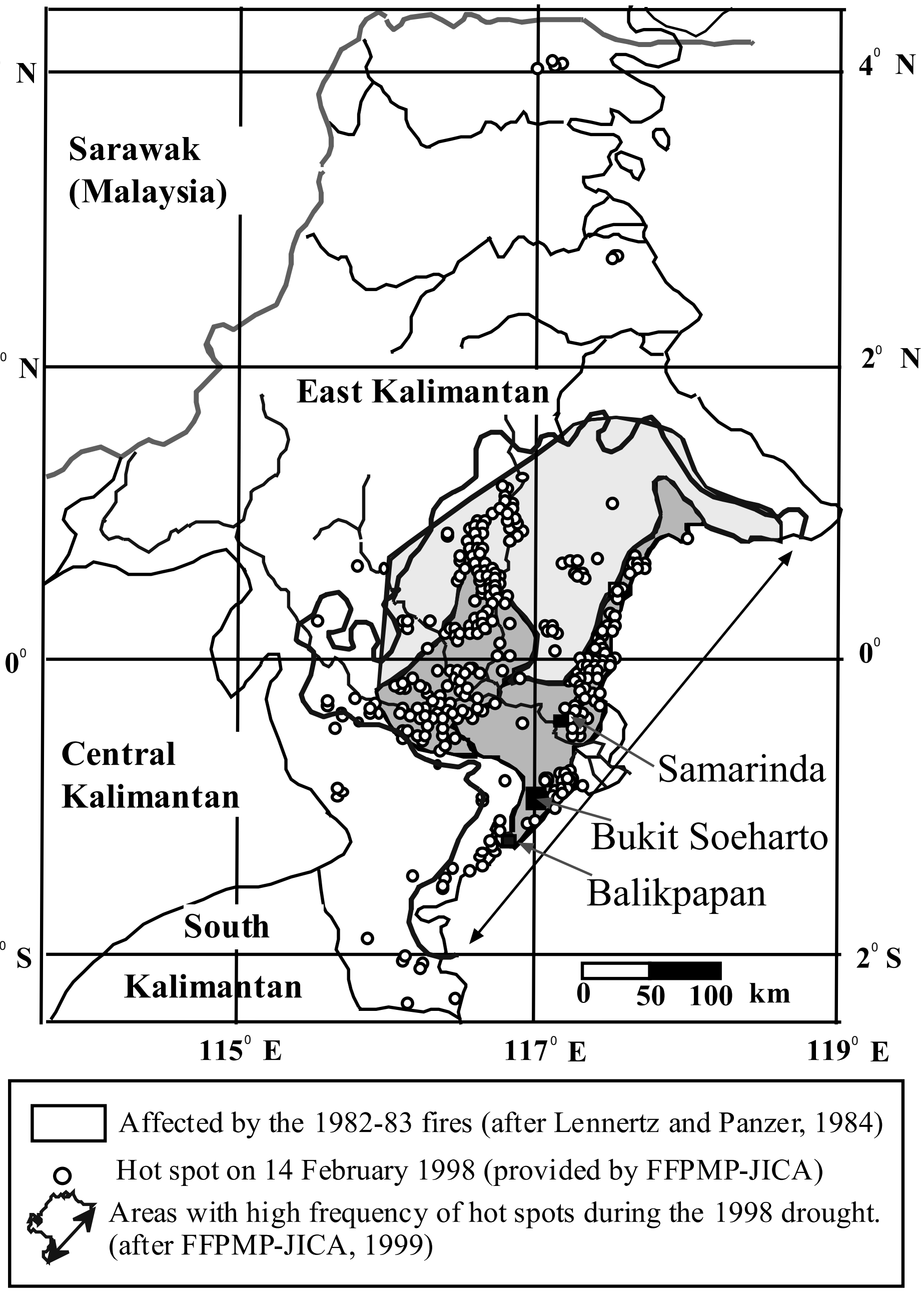
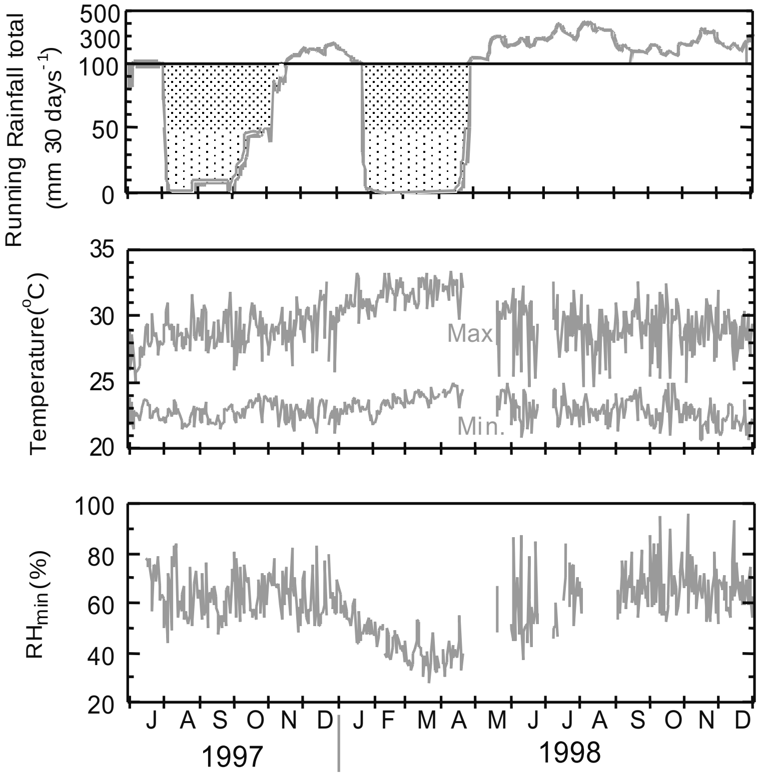


**Figure 2.** Climatic conditions at Bukit Soeharto Education Forest, East Kalimantan, from July 1997 to December 1998. Upper: Running 30-day rainfall totals. The running 30-day rainfall, on a day is the sum of precipitation of the preceding 30 days. Middle: Daily maximum and minimum air temperature at the top of a 60 m tower in a near primary dipterocarp forest. Lower: Daily minimum relative humidity (RHmin) at the top of a 60 m tower in a near primary dipterocarp forest



atmospheric carbon dioxide concentrations lead to El Niño-like global climate changes (Tett 1995, Meehl and Washington 1996). Furthermore, the severity and frequency of extreme ENSO events are expected to occur in Oceania (Timmermann *et al.* 1999). If more extreme ENSO events do occur, they will inevitably cause severe droughts and wildfires (Goldammer *et al.* 1999). In the first year, we could see drought and subsequent large-scale wildfires throughout the whole of Indonesia. The drought and fires might terminate once rainfall recommences at the end of the year. However, we should remember at that point that more severe drought is likely to return to East Kalimantan, early in the following year.

## FIRE PREVENTION MEASURES

During severe drought, fires ignited by human activity easily spread out to become wildfires. Wildfires usually start from fires used for slash-and-burn land preparation, by large companies as well as smallholders. In addition to the fires started to clear land, some fires are started intentionally as a weapon in social conflict (Tomich *et al.* 1998, Gouyon 1999). It has been said that people in East Kalimantan, like people everywhere, typically act in the belief that what they are doing satisfies their best interests, and much of their forest-destroying or land-degrading behaviour is profitable to them (Kartawinata *et al.* 1981). However, it can also be argued that the fires were started in the hope of short-term profits, and the instigators had only a very vague idea of what lay ahead. Such shortsightedness, with respect to fire, has to be improved.

Slash-and-burn clearance for agriculture has been widely applied in Indonesia for centuries. Although it is prohibited officially by the Presidential Declaration of 1st June 1995, the rule is not widely respected, since the people see fire as a cheap and effective tool for land preparation (Saharjo 1999). Given normal levels of rainfall, fires ignited by humans do not spread very widely from the targeted area. During exceptional droughts, however, the fires easily become out of control and rapidly spread to the surrounding area. Therefore, practical regulations for limiting the times that fire can be used for slash-and-burn practices need to be established.

Developing and applying alternative measures to slash-and-burn agriculture would also help prevent forest fires. Santoso *et al.* (1997) suggested that reclamation of degraded land for permanent agricultural use may be an alternative to on-going slash-and-burn agriculture. Agroforestry or social forestry can also be effective means of inducing the local community to help prevent wildfires. Intercropping with annuals in early years, just after planting trees in agroforestry systems, for instance, not only helps prevent *Imperata* grassland from expanding, but also helps smallholders fulfill their needs for food, or to earn additional money (Garrity 1997). Since there is an expensive and unproductive phase when no income is generated from the harvested materials, especially at the beginning of land improvement and agroforestry schemes, appropriate funds or other assistance, with a guarantee of stable land tenure, need to be provided (Santoso *et al.* 1997).

Because wild fires spread out through grasslands and reach forests, converting the grasslands in the remaining forest margins into productive land for the local communities would be another effective way to reduce forest fires. However, security of tenure is essential for this form of community-based fire control (Garrity 1997). It should be noted that fallow grassland has been occupied, in many cases, by local farmers who thought that they had the right to use the land. If the claim is opposed, fires may be deliberately started. For example, in South Sumatra, during conflicts over land tenure, fires are commonly used to drive rivals away, or as acts of revenge (Gouyon 1999). In areas where grassland is converted to productive forest, the farmers responsible for the work should receive priority rights over all the products, including the timber (Garrity 1997). The most effective forest rehabilitation schemes for the degraded land will be those that increase the welfare of the local people by involving them in the rehabilitation activities, by giving job opportunities, and by providing land which can be utilised to satisfy their needs (Wibowo *et al.* 1997). Thus the first step that we have to take is to develop a consensus to promote forest rehabilitation, with the participation of local people.

## CONCLUSION

Most wildfires in East Kalimantan are caused by human activities. The climatic conditions in East Kalimantan will not allow rehabilitated forests to develop well, unless effective measures to prevent fire are applied. To rehabilitate the forests that have burned, and conserve the remaining natural forests in East Kalimantan, the number and size of fires started by human activity must be reduced. Community based initiatives will be essential to decrease this source of fire and to enhance fire management activities. Rehabilitation activities should bring benefits to local communities. Building a consensus is a complex and time-consuming process, compared to merely planting trees. However, if we do not bolster and explain the local benefits, uncontrolled fires will burn the planted trees, and there will never be enough time for the planted areas to become forests.

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## REFERENCES

Fatawi, M. and Mori T. 2000. Description of forest and forestry in East Kalimantan. *In*: Guhardja, E., Fatawi, M., Sutisna, M., Mori, T., and Ohta, S. (eds.) Rainforest ecosystems of East Kalimantan: El Niño, drought, fire and human impacts, 3-12. Ecological Studies, 140. Springer.

FFPMP-JICA. 1999. Annual report of the Forest Fire Prevention and Management Project. Bogor, Indonesia. (unpublished report)

Garrity, D.P. 1997. Agroforestry innovations for *Imperata* grassland rehabilitation: workshop recommendations. Agroforestry Systems 36: 181-202.

Goldammer, J.G. 1999. Forests on fire. Science 284: 1782-1783.

Goldammer, J.G., Hoffmann, A.A., and Abberger, H. 1999. Impacts of fire on dipterocarp forest ecosystems in Southeast Asia. *In*: Suhartoyo, H. and Toma, T. (eds.) Impacts of fire and human activities on forest ecosystems in the tropics (Proceedings of 3rd International Symposium on Asian Tropical Forest Management), 15-39. PUSREHUT, Mulawarman University, Samarinda, Indonesia.

Goldammer, J.G., Seibert, B. and Schindele, W. 1996. Fire in dipterocarp forests. *In*: Schulte, A. and Schöne, D. (eds.) Dipterocarp forest ecosystems: towards sustainable management, 155-185. World Scientific Publishing, Singapore.

Gouyon, A. 1999. Fire in the rubber jungle: fire prevention and sustainable tree crop development in South Sumatra. *In*: Suhartoyo, H. and Toma, T. (eds.) Impacts of fire and human activities on forest ecosystems in the tropics (Proceedings of 3rd International Symposium on Asian Tropical Forest Management), 81-94. PUSREHUT, Mulawarman University, Samarinda, Indonesia.

Kartawinata, K., Adisoemarto, S., Riswan, S. and Vayda, A. P. 1981. The impact of man on a tropical forest in Indonesia. Ambio 10: 115-119.

Lennertz, R. and Panzer, K.F. 1984. Preliminary assessment of drought and forest fire damage in Kalimantan Timur, Indonesia. Report by DFS German Forest Inventory Service Ltd for German Agency for Technical Cooperation (GTZ), Hamburg, Germany.

Meehl, G.A. and Washington, W.M. 1996. El Niño-like climate change in a model with increased atmospheric $CO_2$ concentrations. Nature 382: 56-60.

Mori, T. 2000. Effects of droughts and forest fires on dipterocarp forest in East Kalimantan. *In:* Guhardja, E., Fatawi, M., Sutisna, M., Mori, T., and Ohta, S. (eds.) Rainforest ecosystems of East Kalimantan: El Niño, drought, fire and human impacts. 29-45. Ecological Studies, 140. Springer.

Mori, T., Toma, T., Hastaniah and Ghozali, D.I. 1999. Forest fire and meteorological conditions in Bukit Soeharto Education Forest, East Kalimantan in 1998: Comparative study on the cases in 1997 and 1998. *In*: Suhartoyo, H. and Toma, T. (eds.) Impacts of fire and human activities on forest ecosystems in the tropics (Proceedings of 3rd International Symposium on Asian Tropical Forest Management), 72-80. PUSREHUT, Mulawarman University, Samarinda, Indonesia.

Mubarizi, A. and Nakagoshi, N. 1999. Establishment of mixed dipterocarp species within a lowland tropical rain forest in Lempake educational forest, Samarinda.

*In*: Sabarnudin H.M.S., Suhardi, Okimori, Y. (eds.) Proceedings of the seminar on ecological approach for productivity and sustainability of dipterocarp forests, 70-73. Faculty of Forestry, Gajah Mada University, Yogyakarta, Indonesia.

Saharjo, B. H. 1999. The role of human activities in Indonesian forest fire problems. *In*: Suhartoyo, H. and Toma, T. (eds.) Impacts of fire and human activities on forest ecosystems in the tropics (Proceedings of 3rd International Symposium on Asian Tropical Forest Management), 141-149. PUSREHUT, Mulawarman University, Samarinda, Indonesia.

Santoso S., Adiningsih H., Mutert E., Fairhurst T. and van Noordwijk, M. 1997. Soil fertility management for reclamation of *Imperata* grasslands by small holder agroforestry. Agroforestry Systems 36: 181-202.

Soda, R., Nakamura, K., Nakama, E., Kobayashi, N., Sumarsono, S.B. and Leppe, D. 1999. Growth of dipterocarp species in early stage of artificial plantation. *In*: Suhartoyo, H. and Toma, T. (eds.) Impacts of fire and human activities on forest ecosystems in the tropics (Proceedings of 3rd International Symposium on Asian Tropical Forest Management), 536-552. PUSREHUT, Mulawarman University, Samarinda, Indonesia.

Sutisna, M. 1996. Growth of mixed and cluster planted dipterocarps in East Kalimantan. *In*: Suhardi (ed.) Proceedings of the seminar on ecology and reforestation of dipterocarp forest, 118-124. Gadjah Mada University, Yogyakarta, Indonesia.

Sutisna, M. and Fatawi. M. 1994. Silvicultural aspects of plantation forestry in East Kalimantan. *In:* Suzuki, K., Sakurai, S. and Ishii, K. (eds.) Proceedings of International Workshop BIO-REFOR, 60-63. Yogyakarta, 1993. BIO-REFOR, Tokyo.

Tett, S. 1995. Simulation of El Niño-Southern Oscillation-like variability in a global AOGCM and its response to $CO_2$ increase. Journal of Climate 8: 1473-1502.

Timmermann, A., Oberhuber, J., Bacher, A., Esch, M., Latif, M. and Roeckner, E. 1999. Increased El Niño frequency in a climate model forced by future greenhouse warming. Nature 398: 694-696.

Toma, T. 1999. Exceptional droughts and forest fires in eastern part of Borneo Island. Tropics 9: 55-72. (In Japanese with English abstract).

Toma, T., Marjenah and Hastaniah. 2000a. Climate in Bukit Soeharto, East Kalimantan. *In*: Guhardja, E., Fatawi, M., Sutisna, M., Mori, T., and Ohta, S. (eds.) Rainforest ecosystems of East Kalimantan:El Niño, drought, fire and human impacts, 13-27. Ecological Studies, 140. Springer.

Toma T., Matius P., Hastaniah, Kiyono Y., Watanabe R., Okimori Y. 2000b. Dynamics of burned dipterocarp forest stands in Bukit Soeharto, East Kalimantan. *In*: Guhardja, E., Fatawi, M., Sutisna, M., Mori, T., and Ohta, S. (eds.) Rainforest ecosystems of East Kalimantan:El Niño, drought, fire and human impacts, 107-119. Ecological Studies, 140. Springer.

Tomich T.P., Fagi A.M., Feresta de H., Michon G., Murdiyarso D., Stolle F., and van Noordwijk M. 1998. Indonesia's fires: smoke as a problem, smoke as a symptom. Agroforestry Today 10: 4-7.

Walsh, R.P.D. 1996. Climate. *In:* Richards, P.W. with Walsh, R.P.D. and Baillie, I.C. The tropical rain forest (2nd ed.), 159-205. Cambridge University Press, Cambridge

Wibowo, A., Suharti, M., Sagala, A.P.S., Hibani, H., and van Noordwijk, M. 1997. Fire management on *Imperata* grasslands as part of agroforestry development in Indonesia. Agroforestry Systems 36: 203-217.

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# Taungya Experiment for Rehabilitation of Burnt-over Forest in East Kalimantan

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***Abstract***

The objective of the forest rehabilitation study with taungya system was to find out optimum method, cash crop species, constraints, and how much this system benefits forest rehabilitation. It was carried out using red meranti (*Shorea smithiana*) and rubber (*Hevea brasiliensis*) as plantation trees, and rice (*Oryza sativa*), maize (*Zea mays*), soya bean (*Glycine max*) and cassava (*Manihot esculenta*) for intercropping. The research has shown that there are a number of constraints to the use of taungya in East Kalimantan for the rehabilitation of burnt, logged-over forest. The problems are a mix of technical, economic and social. It was found that the costs of establishing the taungya is comparable with that for establishment of industrial forest plantations but technical problems such as the lack of soil preparation, poor quality seed and inadequate fertiliser application techniques resulted in very low yields of the intercrops. This was exacerbated by protection problems and significant damage by birds and browsing animals further reduced yields. Some of these problems may be overcome by guarding the taungya fields and planting crops such as fibre producers which need less protection. However, unless the taungya system can be made economic and attractive to villagers it will be difficult to implement, especially in an area where there is no shortage of land close to the villages.

## INTRODUCTION

Some of the natural forests in East Kalimantan, including the educational forest of the Mulawarman University in Bukit Soeharto, were burnt by wild fire in 1983, 1991 and 1998. Very few living trees remained and the fire can be classified as heavy intensity. These forests need to be rehabilitated to recover their economical and ecological functions.

In order to encourage local people participation in forestry, the Forest Service allowed timber companies to plant estate crops in the forest to benefit local people. These crop species are cocoa, fruit trees, latex-producing trees, rattan, kayu manis (*Cinnamomum*), candlenut, coffee, etc. With this permission, intercropping between the forest trees and agricultural crops in the forest land (taungya system) is legal. If the cash crops are successful their yield can cover the reforestation cost.

Ecologically, the taungya system reduces fire hazards because the intensive weeding for the cash crop plantation results in less fuel in the field. Moreover, a cash crop plantation will be able to clean the land of weeds economically, but forest plantation cannot be weeded at the same intensity because of limited income. On the other hand, reforestation with taungya system in sparsely populated Kalimantan is not yet practised because local people have enough of their own land near their village and there is no necessity to join a reforestation programme which is often located far away.

As the taungya system can benefit forest rehabilitation, it is necessary to investigate it in Kalimantan. Hypotheses for the experiment are: (1) forest rehabilitation with taungya system in Kalimantan is useful, (2) revenue from cash crops can cover establishment cost of tree planting. The objective of the forest rehabilitation study with

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taungya system is to find out optimum method, cash crop species, constraints, and how much this system benefits forest rehabilitation.

# MATERIALS AND METHOD

## Materials

Plant materials for experiment were seedlings of one tree species (red meranti) and seeds of five cash crops to cultivate 2 ha plots as follows:

- Meranti *(Shorea smithiana)* 225 seedlings + 29 seedlings for replanting.
- Rubber *(Hevea brasiliensis)* 375 seedlings 57 seedlings for replanting.
- Rice *(Oryza sativa*) 15 kg + 5 kg for replanting.
- Maize *(Zea mays*) 10 kg + 7 kg for replanting.
- Soya bean *(Glycine max*) 11 kg + 8 kg for replanting.
- Cassava *(Manihot esculenta*) 4800 cuttings.

To prevent nutrient deficiencies several fertilisers were applied:

- Urea (N fertiliser) 200 kg ha$^{-1}$
- Triple super phosphate (P fertiliser) 100 kg ha$^{-1}$
- Potassium chloride (K fertiliser) 100 kg ha$^{-1}$.

Description plant materials used:

- Maize: variety Hybrida C-3 (Cargill derivate)
- Rice seed: variety Cirata.
- Cassava cuttings: varietas ‘pacar’ from Tanah Merah, Samarinda.
- Soya bean seed: commercial seedlot.

## Location, soil and climate of the experimental area

The experimental area is situated in the Bukit Soeharto Education Forest in the lowland area, between Samarinda and Balikpapan, East Kalimantan, Indonesia. It is between 115?0’54" to 116?0’54" E and 0?0’50" to 1?0’04" S, with an elevation of about 50 m. Relief of the area is low hilly with a slope between 8 to 40% (Effendi 1999). According to Ohta *et al.* (1992), the geology of the area is characterised by Neogene sedimentary rocks of alternate layers of sandstone, claystone and mudstone. Soil of the research plot is Typic Paleudults characterised by low organic matter content, low N and P concentration, medium to high K concentration, very acid to acid pH, low cation exchange capacity, and low base saturation. The texture of topsoil is sandy loam to loam with clay-loam in subsoil (Ruhiyat 1999). The climate is described by Toma *et al.* (2000) as characteristic of a tropical rain forest region: hot and wet throughout the year. From 1988 to 1998, the average annual rainfall was 2002 mm. The monthly distribution of rainfall was bimodial, with peaks of over 200 mm per month occurring both in May and December. The minimum and maximum average monthly rainfalls were 85 mm (September) and 248 mm (December), respectively. Average annual total evaporation measured by an evaporation pan (20 cm in diameter) from 1988 to 1991 was 1273 mm. The yearly mean temperatures were 29.9 ?C for daily maxima and 21.4 ?C for daily minima, and the mean air temperature differed little between months. The yearly mean relative air humidity was 93.2% for daily maxima and 58.5% for daily minima. The average daily range of relative humidity was larger than those between months.

## Procedure and time schedule of experiment

Two plots of one ha each were established in the heavily burned forest. The experimental plot has been established with a procedure and time schedule as shown in Table 1. The dead trees were felled and stacked to make burning easy and secure. Each plot is divided into subplots of 20 x 20 m to facilitate planting and measuring. Data collected from the plots are growth of meranti and rubber tree, weed development, and yield of soya bean and rice. Data were processed with the Statistical Programme for Social Sciences (SPSS).

**Table 1**. Procedure and time schedule of rehabilitation plot establishment

| Activity | Time schedule | Remarks |
|---|---|---|
| Plot establishment | Aug. 31 - Sep. 2, 98 | - |
| Felling of dead trees | Aug. 18 - 22, 98 | By chainsaw |
| Debris piling | Aug. 7 -20, 98 | Manual |
| Debris burning | Sep. 6 - 12, 98 | - |
| Weed spraying | first Oct. 17 - 18, second Oct. 6 -7, 98 | Roundup herbicide (1% in water) |
| Planting | Oct. 15, 98 | Meranti and rubber trees |
| | Oct. 16 - 17, 98 | Cassava |
| | Oct. 20 - 21, 98 | Maize |
| | Oct. 21 - 23, 98 | Soya bean |
| | Oct. 24 - 27, 98 | Rice |
| Weeding | Dec. 15 -30, 98 | Manually |
| Fertilisation | Dec. 26, 98 - Jan. 3, 99 | N, P, K. except on maize |
| Harvest soya beans | Feb. 9 to 14, 99 | Cut and dry |
| Harvest rice | Mar. 15 to 20, 99 | Cut and dry |

**Table 2**. Forest structure after fire and before site preparation for the experiment

| Plot (1 ha) | No. ha$^{-1}$ | Living trees | Dead trees | Mean diameter (cm) | Basal area (m$^2$ ha$^{-1}$) |
|---|---|---|---|---|---|
| A | 319 | 44 | 275 | 20.0 | 11.52 |
| B | 260 | 39 | 221 | 20.9 | 11.28 |
| Mean | 290 | 41.5 | 248 | 20.4 | 11.40 |
| Percent | - | 16.7% | 83.3% | - | |

## RESULTS AND DISCUSSION

### Origin of the plots

The origin of the experimental plots was burnt-over forest on 28 February 1998. Original forest structure before it was burnt is presented in Table 2. Density of original forest shows a typical logged-over forest with 200 to 300 trees ha$^{-1}$. On the other hand a basal area of 11 m$^2$ ha$^{-1}$ is half that of the common logged-over forest in Kalimantan. This forest was already burnt at least twice, i.e. in 1983 and 1998, and probably also in 1991. Many trees were pioneer tree species such as *Macaranga* spp., *Mallotus* spp., and *Trema* spp. The original forest was very heavily burnt with 17% living trees remaining and composition (dbh ? 10 cm) as in Table 3. According to the tree number of each hectare plot, i.e. 34 to 51 trees.ha$^{-1}$ (equal to 1.8-2.6 m$^2$ ha$^{-1}$ in basal area), it was considered that this tree density would not suppress growth of the crops in the plots.

### Growth of meranti and rubber trees

Growth of the main crop meranti *(Shorea smithiana)* and rubber *(Hevea brasiliensis)* is presented in Table 4. In the first year, percentage survival trees of red meranti (86%) was higher than rubber (80%). The red meranti had higher height growth (66 cm yr$^{-1}$) than rubber (30 cm yr$^{-1}$). Because of high mortality, rubber trees needed more replanting. Red meranti in the natural forest is known to grow better in canopy gaps (Sutisna 1996, 1998), but in this intercropping experiment it was planted an open area. Die back of red meranti plantation is found not only in this experiment in the open area but also under the forest canopy. The average initial annual height growth of *Shorea smithiana* in the open area is larger than that found in an enrichment planting under burnt forest canopy in the same area (Sutisna 1994) as shown in Table 5. Through this comparison, it is clear that rehabilitation of cleared burnt-over forest with dipterocarp species is possible.

**Table 3.** Density and basal area of surviving and retained trees in the plots A and B (October 1998)

| Plot | Local name | Species | No ha$^{-1}$ | Basal area (m² ha$^{-1}$) |
|---|---|---|---|---|
| A | Lain-lain | Others | 34 | 1.1886 |
| | Bendang | *Borassodendron borneensis* | 4 | 0.2290 |
| | Keruing | *Dipterocarpus humeratus* | 4 | 0.0239 |
| | Kayuarang | *Dyospyros borneensis* | 2 | 0.0574 |
| | Simpur | *Dillenia eximia* | 2 | 0.0136 |
| | Terap | *Artocarpus elasticus* | 2 | 0.0175 |
| | Keledang | *Artocarpus lanceifolius* | 1 | 0.1698 |
| | Meranti | *Shorea smithiana* | 1 | 0.0031 |
| | Ulin | *Eusideroxylon zwageri* | 1 | 0.1332 |
| Total A | | | 51 | 1.8364 |
| B | Lain-lain | Others | 27 | 1.7633 |
| | Bendang | *Borassodendron borneensis* | 3 | 0.5480 |
| | Keledang | *Artocarpus lanceifolius* | 2 | 0.2188 |
| | Keruing | *Dipterocarpus humeratus* | 1 | 0.0114 |
| | Ulin | *Eusideroxylon zwageri* | 1 | 0.1539 |
| Total B | | | 34 | 2.6957 |

**Table 4.** Growth of meranti and rubber trees after one year

| Plot | Plant condition | Number ha$^{-1}$ | Height growth (cm) | Percent |
|---|---|---|---|---|
| A | Dead | 73 | -94.7 | 19.5 |
| Rubber | Healthy | 209 | 49.0 | 55.7 |
| | Die back | 93 | -14.1 | 24.8 |
| | Living | 302 | 29.6 | 80.5 |
| | Total | 375 | 5.4 | 100 |
| B | Dead | 32 | -35.1 | 14.2 |
| Red meranti | Healthy | 179 | 69.6 | 79.6 |
| | Die back | 14 | 26.4 | 6.2 |
| | Living | 193 | 66.4 | 85.8 |
| | Total | 225 | 52.0 | 100 |

**Table 5**. Height growth of natural and planted dipterocarp seedlings under burnt-over forest canopy

| Tree species | Origin | Number | | Height growth (cm yr$^{-1}$) | |
|---|---|---|---|---|---|
| | | shaded | gap | shaded | gap |
| *Dryobalanops beccarii* | planted | 128 | 179 | 12.9 | 19.9 |
| *Shorea parvifolia* | planted | 194 | 202 | 29.8 | 30.1 |
| *Cotylelobium burckii* | natural | 2 | 2 | 20.0 | 12.0 |
| *Dipterocarpus confertus* | natural | 3 | 6 | -21.7 | 3.8 |
| *Dipterocarpus cornutus* | natural | 3 | 2 | 5.7 | -66.0 |
| *Hopea rudiformis* | natural | 3 | 1 | 32.0 | -49.0 |
| *Shorea leprosula* | natural | 4 | 3 | 6.7 | 12.0 |
| *Shorea seminis* | natural | 1 | 2 | -1.0 | 2.0 |

## Cost of establishment of rehabilitation plot with taungya system

The steps and costs of rehabilitation of burnt-over forest with taungya system are shown in Table 6. The total cost of rehabilitation for 2 ha burnt-over forest was just over Rp 10 million. This establishment cost is not representative for rehabilitation cost per ha, because the cost should be calculated up to secure stage of the main crops, i.e. meranti and rubber tree. The main crop is secure when it does not need weeding any more. The cost for building fences, site preparation, plant materials, and hut dominates among cost components (72.8%), but is not expensive for several reasons:

- the fence can be used for 3 years of intercropping;
- intensive site preparation can be used for 3 years intercropping and to avoid potential fire;
- expensive plant materials (only cassava) will be paid by intercropping yields; and
- the hut can be used for at least 10 years for tending the larger rehabilitation area.

Compared to the government's cost standard of around Rp 5 million ha$^{-1}$, for establishment of industrial forest plantation this taungya cost is within the range of the cost standard.

## Taungya yield

In the first 3 months, the taungya crops of cassava and corn had no yield at all because of pig browsing, even though a 1.5 m high wood fence protected the crops. Soya bean and upland rice produced yields in February and March 1999 as shown in Tables 7 and 8. The total yield of soya beans (87.9 kg ha$^{-1}$) was comparatively very low as productivity of soya beans in Indonesia during 1970-1981 reached 0.7-0.8 t ha$^{-1}$ (Suprapto 1994). There are several reasons, why this yield is very low:

- the cleared forest land is not flat and smooth as agricultural land and some place are not plantable because of creeks, steep slopes, stumps and stems;
- there was no soil preparation in the forest land;
- low quality of seed material; and
- poor fertilisation technique.

**Table 6**. Activities and costs of 2 ha burnt-over forest rehabilitation with taungya system during the first 3 months

| Activity | Wages (Rp) | Materials (Rp) | Cost (Rp) | Cost (%) |
|---|---|---|---|---|
| Lay out for plot | 40 000 | | 40 000 | 0.4 |
| Bordering 2 ha plot | 195 000 | 4 500 | 199 500 | 2.0 |
| Sub blocking | | 27 500 | 27 500 | 0.3 |
| Vegetation inventory | 40 000 | | 40 000 | 0.4 |
| Site preparation | 1 280 000 | 667 450 | 1 947 450 | 19.3 |
| Collect plant materials | | 1 676 600 | 1 676 600 | 16.7 |
| Planting | 900 000 | | 900 000 | 8.9 |
| Weeding | 630 000 | | 630 000 | 6.3 |
| Fertilising | 190 000 | 632 425 | 822 425 | 8.2 |
| Build wood fence | 1 685 000 | 754 600 | 2 439 600 | 24.2 |
| Border cleaning | 70 000 | | 70 000 | 0.7 |
| Build hut | 600 000 | 671 500 | 1 271 500 | 12.6 |
| Total | 5 630 000 | 4 434 575 | 10 064 575 | 100.0 |

**Table 7.** Density of 3-month-old soya beans

| Subplot | Density 400 $m^{-2}$ | | Density $ha^{-1}$ | |
|---|---|---|---|---|
| | clumps | stems | clumps | stems |
| B21 (valley) | 1183 | 2154 | 29 575 | 53 850 |
| B13 (slope) | 1121 | 2110 | 28 025 | 52 750 |
| B25 (ridge) | 1786 | 4383 | 44 625 | 109 575 |
| Mean fertilised | 1363 | 3882 | 34 075 | 97 050 |
| B33 (unfertilised) | 1706 | 3654 | 42 650 | 91 350 |

**Table 8**. Yield of soya bean in 0.48 ha, and rice in 0.52 ha

| Soya bean yield | | | Rice yield | |
|---|---|---|---|---|
| Sub plot 400 $m^2$ | good quality beans (kg) | low quality beans (kg) | Sub plot 400 m | Yield (kg) |
| B1.1. | 0.99 | 1.13 | B3.1 | 3.06 |
| B1.2. | 0.33 | 0.00 | B3.3 | 0.91 |
| B1.3. | 1.66 | 0.00 | B3.5 | 0.63 |
| B1.4. | 3.72 | 2.37 | B4.1 | 7.95 |
| B1.5. | 1.67 | 1.21 | B4.2 | 1.43 |
| B2.1. | 2.25 | 2.94 | B4.3 | 0.24 |
| B2.2. | 0.69 | 0.65 | B4.4 | 1.26 |
| B2.3. | 3.15 | 1.20 | B4.5 | 0.79 |
| B2.4. | 2.86 | 2.45 | B5.1 | 1.92 |
| B2.5. | 4.24 | 1.80 | B5.2 | 1.60 |
| B3.2. | 2.55 | 1.93 | B5.3 | 1.38 |
| B3.4. | 1.10 | 1.35 | B5.4 | 0.34 |
| - | - | - | B5.5 | 0.48 |
| 0.48 ha | 25.16 | 17.03 | 0.52 ha | 16.49 |
| Total 1 ha | 52.42 | 35.48 | Total 1 ha | 31.71 |

The total yield of rice in this experiment was only 32 kg $ha^{-1}$ compared with the yield of rice produced by the farmers that reaches 1600-2900 kg $ha^{-1}$ (Noor 1996). The reasons for the failure are:

- rice grains in the field were partly browsed by birds; and
- a bad season that caused empty grains.

Diseases in the plots were monitored and are described by Mardji in a separate paper in these proceedings.

## CONCLUSIONS

The research has shown that there are a number of constraints to the use of taungya in East Kalimantan for the rehabilitation of burnt, logged-over forest. The problems are a mix of technical, economic and social. It was found that the costs of establishing the taungya is comparable with that for establishment of industrial forest plantations and the satisfactory initial growth and survival of the meranti showed that rehabilitation of cleared burnt-over forest with dipterocarp species is possible. However, technical problems such as the lack of soil preparation, poor quality seed and inadequate fertiliser application techniques resulted in very low yields of the intercrops. This was exacerbated by protection problems and significant damage by birds and browsing animals further reduced yields. Some of these problems may be overcome by guarding the taungya fields with men and dogs; and planting non-edible crops such as fibre producers. However, unless the taungya system can be made economic and attractive to villagers it will be difficult to implement, especially in an area where there is no shortage of land close to the villages.

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## REFERENCES

Effendi, S. 1999. Forest fire and selective logging impact to soil chemical characteristics. Research report to Mulawarman University, CIFOR, and JICA 1998-1999. 38p.

Ohta, S., Effendi, S., Tanaka, N. and Miura, S. 1992. Characteristics of major soils under lowland dipterocarp forest in East Kalimantan, Indonesia. Tropical Rain Forest Research project JTA-9(a)-137, JICA. Pusrehut Special Publication No. 2. Samarinda, Indonesia.

Noor, M. 1996. Padi lahan marjinal (Rice in the marginal lands). Penebar Swadaya, Jakarta.

Ruhiyat, D. 1999. Nutrient cycling in the rehabilitated degraded forest with taungya system. Research report to Mulawarman University, CIFOR, and JICA 1998-1999

Suprapto, H. 1994. Bertanam kedelai (Planting of soya bean). Penebar Swadaya. Jakarta.74p.

Sutisna, M. 1994. Percobaan pengayaan hutan alam bekas kebakaran di Bukit Soeharto, Kalimantan Timur (Enrichment planting result in the burnt-over natural forest in Bukit Soeharto, East Kalimantan). Research report to the Directorate of Research and Extension, Directorate General of Higher Education, Ministry of Education and Culture, Jakarta.

Sutisna, M. 1996. Ujicoba peningkatan riap hutan alam di PT. Sumalindo Lestari Jaya Unit I, Site Batu Putih, Kecamatan Talisayan, Kabupaten Berau, Propinsi Kalimantan Timur (Growth improvement of natural forest in PT Sumalindo Lestari Jaya I site Batuputih, County of Talisayan, Berau Regency, East Kalimantan). Research report submitted to the timber company.

Sutisna, M. 1998. Ujicoba sistem silvikultur binapilih sebagai modifikasi sistem TPTI di PT. Mangole Timber Producer Unit I dan Unit III Kabupaten Maluku Utara (Result of selective tending method as modification of the Indonesian selective logging with planting system in PT Mangole Timber Producers Unit I and III, North Moluccas). Resewarch report submitted to the timber company and Ministry of Forestry.

Toma, T., Marjenah and Hastaniah. 2000. Climate in Bukit Soeharto, East Kalimantan. *In*: Guhardja, E., Fatawi, M., Sutisna, M., Mori, T., and Ohta, S. (eds.) Rainforest ecosystems of East Kalimantan:El Niño, drought, fire and human impacts, 13-27. Ecological Studies, 140. Springer.

# 13

# Adaptability of Six Native Forest Tree Species to Degraded Lands in Pucallpa, Peruvian Amazon

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### *Abstract*

Preliminary results of a field study to determine the establishment of six native forest tree species of economic value on degraded areas abandoned after intensive past agricultural use are reported. Study sites were on slash-and-burn farms partially covered with abandoned agricultural areas on Ultisols dominated by invading vegetation mainly composed of *Imperata brasiliensis*, *Rottboellia cochinchinensis* and *Baccharis floribunda*. Tree species used in the trials were: *Schizolobium amazonicum*, *Tabebuia serratifolia*, *Calycophyllum spruceanum*, *Terminalia oblonga*, *Amburana cearensis* and *Cedrelinga catenaeformis*. These six species were planted in three degraded habitats characterised by the presence of one of the above weed species. After 13 months, *Schizolobium amazonicum* was the best adapted in the three experimental treatments, followed by *Tabebuia serratifolia* and *Calycophyllum spruceanum*. Habitats dominated by *Baccharis floribunda* offered comparatively better conditions for tree establishment and initial growth.

## INTRODUCTION

The deforestation rate in the Peruvian Amazon, about 320 000 ha year$^{-1}$, is alarming (Reátegui 1996) and is mainly attributed to land use change for agriculture and pasture activities, very often in areas best suited to forestry (Arca *et al*. 1996). As a result of the poor sustainability of the agricultural production and weed invasion, extensive degraded areas have appeared. Such areas are generally located near populations, have roads and therefore good access possibilities to markets. Rehabilitation of these degraded areas for production and environmental conservation is currently one, of the main concerns for local governments development programmes and research institutions.

An alternative to rehabilitate degraded areas is the (re-) incorporation of forests to the system. So far, research efforts have mainly focused on techniques and amendments, such as fertilisation, to improve the growth of trees, generally with commercial value. Few studies have addressed the question of which species show the best natural potential for adaptability? This is the case of many native forest species that have developed mechanisms to efficiently exploit the environmental conditions found in tropical humid degraded areas, particularly the low fertility of most soils.

The zone about Pucallpa, in the Ucayali Region, is an example of continued deforestation and land degradation in the lowlands of the Peruvian Amazon. Over 50 years of deforestation and a steadily growing population have led to a range of land uses and landscape conditions. Since 1992, several national and international research institutions have dedicated efforts to develop

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alternatives to rehabilitate degraded areas in this setting. In 1997, the National Agricultural Research Institute (INIA) and the Center for International Forestry Research (CIFOR) set up a collaborative research project on rehabilitation methods for degraded lands in the Ucayali Region. The initial phase of this project aimed to determine the initial adaptability of six native tree forest species of economic value in degraded areas abandoned after intensive agricultural use, and to assess the biophysical changes and dynamic processes of the vegetation and soil on the sites under treatment. This paper presents the first, preliminary results of these studies.

## BACKGROUND

Decreasing economic returns for agricultural products and land degradation is one of the main causes for farm emigration in Pucallpa (Labarta 1998). Soils near Pucallpa are mainly acidic, easily compacted, with aluminium saturation and low phosphorus content (Arca *et al.* 1996). Likewise, invasion by weeds is also causing negative effects on farmers' economy. An example of the high disturbance of these habitats is the dominance of invading herbaceous and shrub plants, such as *Imperata brasiliensis* or *Baccharis floribunda* (Fujisaka *et al.* 1997, INIA/CIFOR 1998), which cause a deviation of the natural plant succession. A survey of farmers in the old agricultural frontier near Pucallpa (over 35-40 years settlement) indicated that in average 28% of the farm is covered with secondary vegetation dominated by invading herbs, compared to 15% on areas recently opened (Smith *et al.* 1999).

Since 1992 a number of species trials have been established on intensively used, highly compacted and eroded soils, mainly covered with low-productivity native pastures (ICRAF/INIA 1996). Forest species used were selected because of their capacity to improve, conserve and restore acidic soils, their fast growth rate and ability to compete with weeds. These research efforts have generated information on survival and growth for eight tree species tested in some representative degraded areas of the Pucallpa zone (INIA/ICRAF 1996, IIAP 1994, UNU 1995).

INIA/ICRAF (1996) determined up to the first year that the native species *Guazuma crinita* and *Swietenia macrophylla* established and grew better on compacted soil (apparent density 1.8 g $cm^{-3}$ up to 10 cm depth) when hole diameter was 40 cm, independent of hole depth. *Calycophyllum spruceanum,* however, established and grew well in any combination of hole diameter and depth.

An experiment on an overgrazed Ultisol (apparent density 1.53 g $cm^{-3}$ up to 20 cm depth) measured the effect of different supplies of an organic fertiliser (worm humus) and a chemical fertiliser on height growth of *Guazuma crinita* and *Calycophyllum spruceanum*. For both species the control (without humus) had higher values than the treatment with 2 kg of humus per hole. The experiment also determined positive growing responses with the application of higher nutrient supply to soil (N: 225, P: 75, K: 75) for *G. crinita, C. spruceanum* and *Aspidosperma macrocarpum* (IIAP 1994).

The above results were supported by a fertilisation study to establish *Guazuma crinita* on similar soil conditions. Plants reached 128 cm height with a supply of N: 150, P: 50 and K: 50. No differences in height growth were detected by applying worm humus (UNU 1995).

On pasture land dominated by *Brachiaria humidicola,* late transplants (plants with 2.5 to 3 m initial height) of *Calycophyllum spruceanum* showed 67% survival after one year, compared with 40% each for *Swietenia macrophylla* and *Guazuma crinita* (INIA 1994).

## STUDY SITE AND METHODS

The study was carried out along the Campo Verde–Nueva Requena road (opened up in 1965), 34 km west of Pucallpa. The longitude is 74° 48'-74°50´W and latitude 8°18'- 8°25´S, with an average elevation of 150 m a.s.l. The climate is tropical humid, with a mean annual temperature of 25°C and about 1800 mm of annual rainfall, showing a bi-modal pattern with wet months in February-May and September-November, and dry months in June-August and December-January.

Thirty three slash-and-burn farmers were surveyed to determine the extent of land abandoned after agricultural use in their farms and the occurrence of invading vegetation. Three main 'weed' species were identified: *Imperata brasiliensis, Rottboellia cochinchinensis* and *Baccharis floribunda*. The high dominance of the above species in the degraded areas visited was taken as a criterion for defining distinctive vegetation types (experimental treatments). In order to have three replications per treatment, nine sites (farms) were selected for the trials. Each site was then characterised in terms of vegetation, land surface and soil. A plot of 40 x 40 m was installed at each site following a stratified randomised design with three replications. On each plot 120 trees of six forest tree species were planted (20 individuals per species) at 3 x 3 m spacing. The species used were: *Amburana cearensis* ('ishpingo'), *Calycophyllum spruceanum* ('capirona negra'), *Cedrelinga catenaeformis* ('tornillo'), *Schizolobium amazonicum* ('pashaco blanco'), *Tabebuia serratifolia* ('tahuarí') and *Terminalia oblonga* ('yacushapana'). At each site the vegetation was sampled according to the dominant life form (herbs and shrubs). Six plots dominated by herbaceous vegetation were inventoried following the 'botanal' method which estimates the occupation in percentage of each plant species in a 1 m$^2$ sampling surface. The sampling intensity was 1%, with samples distributed systematically. The remaining three plots were evaluated using the 'transect' method by a 100% inventory of the shrub vegetation (including resprouts and seedlings). Sampling intensity was 1.25% or 5 samples of 4 m$^2$ each one, systematically distributed. Each plot was subdivided into 25 8 x 8 m squares and soil samples taken from each square with a soil borer at 0–15 cm and 15–30 cm depth. The dominant vegetation at each sampling point was also registered. A textural analysis of the soil samples was used for stratification within each experimental plot in order to relate the resulting textural classes with the existing vegetation cover and to assess the likely effect of these classes in the initial behaviour of the tree species planted.

Site preparation for planting consisted of manually cutting the vegetation cover. No burning or addition of organic or chemical fertilisers took place. During planting approximately four fifths of the planting hole was filled with the upper, organic soil layer. Seedlings which died in the first 45 days after planting were replaced. The plantation area was weeded every two months along lines of 1 m width. The evaluations took place in the same periods by registering for each planted tree the total height, diameter at 10 cm from the base, plant vigour (1 = vigorous, 2 = normal, 3 = inferior) and relevant observations. The analysis of survival and growth was conducted 13 months after trial installation based on seven evaluations. The results obtained from this data set are therefore preliminary, but showing useful trends.

## RESULTS

### General characteristics of the study area

All 33 farms surveyed had abandoned land with past agricultural use ranging from one to 14 years since last cropping. Eighty per cent of the vegetation cover in the study sites was herbaceous and the remaining 20% mainly dominated by shrubs. In most cases (70%) the vegetation height was below 2 m (Table 1). The intensity of past land use in our study area could be considered high when compared with the characteristics reported by Uhl *et al*. (1988) on 8-year-old secondary forests in Pará, Eastern Brazilian Amazon.

The most frequent invading plant species ("weeds") observed were (in decreasing order of importance): *Rottboellia cochinchinensis* ('arrocillo'), *Baccharis floribunda* ('sachahuaca'), *Imperata brasiliensis* ('cashupsha'), *Pueraria phaseoloides* ('kudzu'), *Brachiaria decumbens* ('braquiaria'), *Hyparrhenia rufa* ('yaragua'), *Paspalum virgatum* ('torourco'), *Urena lobata* ('yute'), *Andropogon bicomis* ('cola de caballo'), *Pteridium aquilinum* ('shapumba'), *Pennisetum purpureum* ('carricillo') and *Scleria pterota* ('cortadera'). Surveyed farmers reported that forest

**Table 1.** Main biophysical characteristics of the study areas

| Characteristics | Experimental sites on degraded habitats (R = replications) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | R1 | R2 | R3 | R1 | R2 | R3 | R1 | R2 | R3 |
| Dominant weed species* species* | *Impe.* | *Impe.* | *Impe.* | *Rott.* | *Rott.* | *Rott.* | *Bacc.* | *Bacc.* | *Bacc.* |
| Farm location (km)** | 5.9 | 18 | 17 | 11 | 12.5 | 17.5 | 6 | 14 | 12.2 |
| Past agricultural crop | rice | maize | cassava | cassava | maize | cassava | cassava | cassava | maize |
| Years since abandonment | 14 | 2.5 | 5 | 1 | 7 | 1 | 3 | 1 | 2 |
| Average stand height (m) | 1.2 | 1 | 1 | 1.1 | 1.5 | 1.8 | 3.5 | 1.5 | 3 |
| Fire frequency | annual | annual | annual | annual | annual | annual | irreg. | No | No |
| Slope (%) | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 3 |
| Organic soil layer (cm) | 2 | 3 | 3 | 2.5 | 2.5 | 3 | 2 | 2 | 2 |
| Soil type | Ultisol | Ultisol | Ultisol | Ultisol | Ultisol | Ultisol | Ultisol | Ultisol | Ultisol |
| Textural class | loam | loam | loam | loam | sandy loam | sandy loam | sandy loam | sandy loam | sandy loam |
| Drainage | moderate | poor | good | good | moderate | good | very good | good | good |
| Soil acidity (pH) | 5.0 | 4.5 | 6.7 | 5.1 | 4.9 | 5.6 | 4.5 | 5.6 | 4.3 |
| Biomass (t ha$^{-1}$) | 6.4 | 6.7 | 6.4 | 3.9 | 6.3 | 6 | 6.1 | 4.8 | 15.2 |
| Weed density (number m$^{-2}$) | 287 | 285 | 314 | 237 | 68 | 101 | 28 | 26 | 33 |

* *Impe = Imperata brasiliensis; Rott = Rottboellia cochinchinensis; Bacc = Baccharis floribunda.*

** Location of the farm along the Campo Verde - Nueva Requena road.

tree species in the genera *Tabebuia*, *Aspidosperma* and *Amburana* were growing well in conditions found on degraded environments and have the ability to resprout if affected by fire.

## Study Sites

In the total treatment area of 1.44 ha the most important plant families were: Asteraceae (16% of the total sample), Poaceae (14%), Solanaceae (8%), Rubiaceae (6%), Papilionaceae (6%) and Euphorbiaceae (6%). Likewise the most abundant species found were (in decreasing order of importance): *Imperata brasiliensis, Rottboellia cochinchinensis, Baccharis floribunda, Pueraria phaseoloides, Hyparrhenia rufa, Pseudoelephantopus* sp. and *Brachiaria decumbens.* These results are consistent with those reported by Fujisaka *et al.* (1997) who found that *Imperata brasiliensis* was present in 51% of the surveyed farms, followed by *Homolepsis* sp. ('tororco', present in 48% of the farms), *Rottboellia cochinchinensis* (45%) and *Baccharis floribunda* (39%). The native grass 'torourco' is commonly invades abandoned pasture land in the Pucallpa zone (e.g. Clavo 1993)

## Species' adaptability

Height and diameter growth, survival rate and susceptibility to pests and diseases are key variables to assess species adaptation on altered habitats (Sandoval and Cálix 1999). Table 2 presents a synthesis of the silvicultural behaviour of the six species tested.

Height growth within species was very variable (variation coefficient 15-74%), particularly in *Schizolobium amazonicum.* This species grew best at the three sites after 13 months. *Tabebuia serratifolia* performed equally well at the three sites, while *Calycophyllum spruceanum* was slightly better on Site 1.

Highest mortality was in the 3rd month (9.5%), decreasing to 1.9% in the 5th month and to 0.5% in the 11th month. *Tabebuia serratifolia* and *C. spruceanum* had the lower mortality rates at the three sites, while *Cedrelinga catenaeformis* the highest rate. This species was seriously affected during the first few months after establishment, possibly due the sudden exposure of its seedlings to full sunlight. It was also damaged by termites (80% of the dead plants

**Table 2.** Diameter (D) and height (H) growth and survival rate (S) of six forest tree species 13 months after establishment on three degraded sites

| Species | Site 1 | | | Site 2 | | | Site 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Imperata brasiliensis* (sandy loam–loam) | | | *Rottboellia cochinchinensis* (sandy loam–loam) | | | *Baccharis floribunda* (sandy–sandy loam) | | |
| | D | H | S | D | H | S | D | H | S |
| | (cm) | (cm) | (%) | (cm) | (cm) | (%) | (cm) | (cm) | (%) |
| *Terminalia oblonga* | 1.3 | 107 | 95 | 1.3 | 73 | 92 | 1.4 | 66 | 99 |
| *Schizolobium amazonicum* | 2.3 | 127 | 74 | 3.0 | 167 | 75 | 3.1 | 170 | 82 |
| *Tabebuia serratifolia* | 1.5 | 111 | 95 | 1.4 | 105 | 97 | 1.5 | 109 | 97 |
| *Cedrelinga catenaeformis* | 0.6 | 32 | 5 | 0.8 | 41 | 3 | 0.7 | 37 | 17 |
| *Amburana cearensis* | 1.2 | 97 | 67 | 1.3 | 94 | 93 | 1.1 | 109 | 81 |
| *Calycophyllum spruceanum* | 1.5 | 106 | 97 | 1.4 | 91 | 97 | 1.0 | 65 | 95 |

were infested by Termitidae present in the earthpan).

## Biomass changes

Thirteen months after plantation establishment the habitat dominated by *Baccharis floribunda* (Site 3) offered comparatively better growth conditions for the tree species tested, progressively reducing the living biomass from 15.2 to 4.3 t ha$^{-1}$ (at a rate of 0.8 t month$^{-1}$), or 72% reduction (Fig. 1). This finding is comparable with experiences in La Selva, Costa Rica, where the shade produced by a plantation of *Vochysia guatemalensis* contributed to the early supression of pastures (Powers *et al.* 1997). In the habitat dominated by *Rottboellia cochinchinensis* (Site 2) there are two fluctuations in the curve with the second maximum biomass value occurring after 10 months which corresponds to the vegetative time-span for this weed species. The effect of the trees planted is expressed in a biomass reduction of only 27%. In the case of *Imperata brasiliensis* (Site 1), there is no change in total biomass after 13 months; the initial biomass reduction by 20% was coincident with the dry season and the higher mortality of the herbaceous vegetation during that period (Fig. 1).

## CONCLUSIONS

Land abandoned after agricultural use in Nueva Requena, Pucallpa, has a vegetation cover dominated by three main "weedy" species: *Imperata brasiliensis, Rottboellia cochinchinensis* and *Baccharis floribunda*. Of the six tree forest species planted in three degraded habitats (sites)

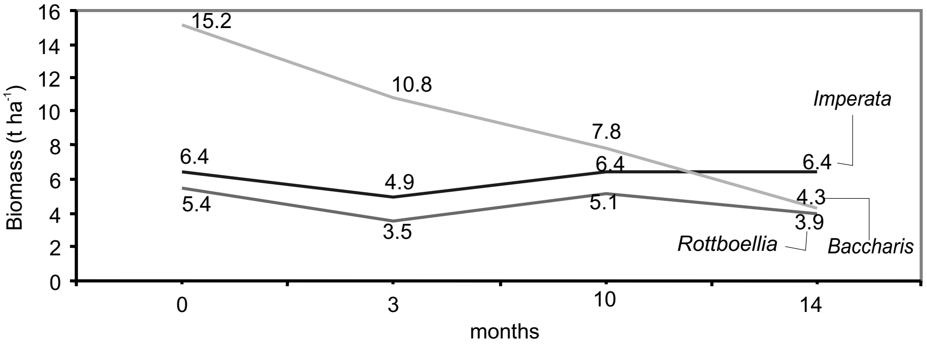
**Figure 1.** Effect of six tree species on the biomass of invasive vegetation

dominated by one of these species, *Schizolobium amazonicum* showed the best adaptation 13 months after establishment, followed by *Tabebuia serratifolia*, *Calycophyllum spruceanum* and *Terminalia oblonga*. The habitat dominated by *Baccharis floribunda* was the most favourable for tree establishment and initial growth.

## REFERENCES

Arca, M., Ydrogo, H. and Ricse, A. 1996. Informe técnico del estudio de zonificación agroecológica y caracterización de suelos en la región Ucayali. Memoria explicativa del mapa fisiográfico. Instituto Nacional de Investigación Agraria. Programa Nacional de Agroforestería y Cultivos Tropicales. Pucallpa, Perú. 52p.

Clavo, M. 1993. Plantas invasoras más frecuentes en las pasturas de la zona de Pucallpa. UNMSM-Instituto de Investigación Veterinaria Tropical y de Altura (IVITA) – CIID. Pucallpa, Perú.

Fujisaka, S., Escobar, G. and Veneklaas, E. 1997. Weedy forests and fields: interaction of colonists land use and plant community and diversity in the Peruvian Amazon. CIAT, Colombia. 6p.

ICRAF/INIA. 1996. Investigación agroforestal para desarrollar sistemas ecologicamente sostenibles en la amazonia occidental. Informe final (1994-1995). Yurimaguas, Perú. 108p.

IIAP. 1994. Informe del ensayo sobre fertilización y aplicación de humus durante el establecimiento de árboles sobre pasturas degradadas. *En*: Investigación Agroforestal para desarrollar sistemas ecológicamente sostenibles en la Amazonía Peruana. Informe Final 95, Convenio BID-ICRAF. Yurimaguas, Perú. 1996.

INIA. 1994. Primer informe sobre el establecimiento de especies forestales en pasturas mediante el transplante tardío y el manejo de la profundización del cuello de la raíz. DGIA. Programa Nacional de Agroforestería y Cultivos Tropicales. E.E.P. Pucallpa, Perú. 4p.

INIA/ICRAF. 1996. Ensayo sobre diámetro y profundidad del movimiento del suelo en el establecimiento de árboles sobre pasturas degradadas. Informe Final. Instituto Nacional de Investigación Agraria. DGIA. Programa Nacional de Agroforestería y Cultivos Tropicales. E.E.P. Pucallpa, Perú.

INIA/CIFOR. 1998. Annual report of the project rehabilitation methods in second-growth forests and degraded lands in the Ucayali Region, Peruvian Amazon. National Institute for Agricultural Research. Pucallpa, Perú.

Labarta, R. 1998. Los productores de la cuenca Amazónica de Perú y la dinámica de uso de la tierra: resultados de la caracterización de Pucallpa y Yurimaguas. Centro para la Investigación de la Agroforestería (ICRAF). Reporte de investigación. Pucallpa, Perú.

Powers, J., Hagger, P. and Fisher, R. 1997. The effect of understory composition on understory woody regeneration and species richness in 7 years old plantations in Costa Rica. Forest Ecology and Management 99: 43-54.

Reátegui, F. 1996. Monitoreo contínuo de los procesos de deforestación en la Amazonía Peruana. Tesis Ing. Forestal UNALM, Facultad de Ciencias Forestales. Lima, Perú. 84p.

Sandoval, C. and Cálix, J. 1999. Especies maderables nativas del bosque húmedo de Honduras. PROECEN. Lancetilla, Atlántida, Honduras. Actualidad Forestal Tropical. OIMT. 7 (2): 14-15.

Smith, J., Van de Kop, P., Reátegui, K., Lombardi, L., Sabogal, C. and Díaz, A. 1999. Dynamics of secondary forests in slash-and-burn farming: interactions among land use types in the Peruvian Amazon. Agriculture. Ecosystems and Environment 76: 85-98.

UNU. 1995. Fertilización química y orgánica al establecimiento de Bolaina blanca (*Guazuma crinita*) en pasturas degradadas. Informe preliminar. En: Investigación Agroforestal para desarrollar sistemas ecológicamente sostenibles en la Amazonía Peruana. Informe Final 95, Convenio BID-ICRAF. Yurimaguas, Perú. 1996.

Uhl, C., Buschbacher, R. and Serrao, A. 1988. Abandoned pastures in Eastern Amazonia. I Patterns of plant succession. Journal of Ecology 76: 663-681.

# 14

# Soil Factors Affecting Growth of Seedlings in Logged-over Tropical Lowland Forest in Pasoh, Negeri Sembilan, Malaysia

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***Abstract***

Effects of soil properties on growth of young tree seedlings of *Hopea odorata* and *Azadirachta excelsa* in line and gap enrichment planting in logged-over tropical lowland forest were evaluated. At 13 months, the trees were grouped into "good" and "poor" growth based on their height increment in the previous 6 months. Organic matter content, penetration resistance, soil texture, thickness of A-horizon, Ca and Mg contents differed significantly between soils with "good" and "poor" growth. Organic matter, thickness of A-horizon, Ca and Mg contents were found to be significantly higher in "good" growth soils than "poor" ones, but penetration resistance was the reverse. Surface soils under "good" growth had lower clay content and higher sand content compared to that under "poor" growth. Favourable soil conditions for good growth were also manifested in biomass and litter accumulation. The mean dry biomass in the "good" and "poor" growth was 174 and 72 g $m^{-2}$ respectively, and for dry litter 300 and 154 g $m^{-2}$ respectively. Properties most limiting seedling growth performance were bulk density (mechanical resistance), depth of A-horizon and amount of clay in the surface soil. Correction of these factors is therefore important in ensuring the success of rehabilitation and reforestation of logged-over degraded forest.

## INTRODUCTION

It is estimated that tropical forest is decreasing at the rate of 16.9 million ha $year^{-1}$ and about 5.1 million ha are annually degraded to logged-over forests. This affects timber production and causes numerous socio-economic and ecological problems such as intensified seasonal flooding with loss of lives and property, water shortages, accelerated erosion of agriculture land, siltation of rivers and coastal waters, greenhouse gas emissions, watershed stability and the loss of some species of plants and animals (Kobayashi *et al*. 1996, FAO 1998). It is therefore an urgent matter to rehabilitate these degraded forests. One promising method is "enrichment planting", e.g. by "line planting" and "gap planting".

Growth of seedlings in a forest ecosystem is influenced by soil and climatic factors. Important soil properties for the seedling growth are texture, bulk density, compaction, moisture, penetration, thickness of A-horizon, organic matter and nutrients content (Kramer and Kozlowski 1979). Plant growth is determined by an interaction of several factors because changes in one factor may bring about changes in other factors, e.g. soil compaction increases bulk density or strength of the soil, commonly referred to as its mechanical impedance, and reduces its conductivity, permeability and diffusivity to water and air (Greenland 1977). In addition, compaction reduces infiltration rate and consequently encourages soil

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and nutrient losses. Hence, it is necessary to identify factors that are more dominant so that corrective measures can be taken during rehabilitation to ensure efficient establishment of seedlings, minimise planting failure risk and reduce costs.

The objectives of the study were to: (1) compare properties of soils from seedlings with "good" growth from that with "poor" growth and (2) identify the most important soil factors influencing the growth. Two forest species, *Hopea odorata* and *Azadirachta excelsa*, commonly used in rehabilitation of lowland logged-over forest ecosystem in Malaysia were used.

## MATERIALS AND METHODS

The experiment was carried out at Pasoh Forest Reserve, Jempol, latitude 3ϒ03′N and longitude 102ϒ21′E and approximately 80 km southeast of Seremban, Negeri Sembilan, Peninsular Malaysia. The area is logged-over forest which was clear cut using a crawler tractor and has remained untouched since 1984. The rehabilitation treatments were line planting with line width of 3m, 5m and 10m, and gap planting: 10 m x10 m x 5 $ha^{-1}$ gaps, 20 m x 20 m x 5 $ha^{-1}$ gaps and 10 m x10 m x 9 $ha^{-1}$ gaps. *Hopea odorata*, *Azadirachta excelsa* and *Vitex pinnata* were planted in July. The first two species were selected because of their fast growth. At 13 months (August 1999), the trees were grouped into "good" and "poor' growth based on their height increment. Each tree was considered as one replicate. Mean height increment was measured between February–August, 1999 and the data are presented in Table 1. The difference in mean height increment between the "good" and "poor" growth for both *Hopea odorata* and *Azadirachta excelsa* was significant at 1% level according to two-paired t-test.

Surface soil samples were taken near each tree, air-dried and analysed for the physico-chemical properties. Determinations were made of texture, by pipette method (Day 1965) using calgon as a dispersing agent, bulk density by core ring method and organic matter by the wet digestion method of Walkley and Black (Allison 1965), cation exchange capacity by ammonium acetate method at pH 7, exchangeable K by autoanalyser and Ca, Mg and Na by atomic absorption spectrophotometer. *In situ* measurements of penetration using a pocket penetrometer and thickness of A- and B-horizons were made. The data from the "good" and the "poor" growth were compared statistically using analysis of variance. The above ground biomass was measured in a one metre-square plot with the planted tree in the middle.

**Table 1.** Mean height increment (cm) of *Hopea odorata* and *Azadirachta excelsa* for 6-month period. Data are mean of 3 trees (replicates)

| | *Hopea odorata* | | *Azadirachta excelsa* | |
|---|---|---|---|---|
| Treatments | Good | Poor | Good | Poor |
| Line planting, 3 m | 55 | 19 | 49 | 3 |
| Line planting, 5 m | 47 | 6 | 29 | 6 |
| Line planting, 10 m | 51 | 18 | 70 | 2 |
| Gap planting, 10x10 m | 35 | 18 | 78 | 0 |
| Gap planting, 20x20 m | 35 | 5 | 63 | 9 |
| Average | 45 | 13 | 58 | 4 |

## RESULTS

The soil conditions under "good" and "poor" growth for *Hopea odorata* and *Azadirachta excelsa* are given in Table 2. Most of the soil properties from the "good" and "poor" growth are significantly different for both *Hopea odorata* and *Azadirachta excelsa*. Organic matter, thickness of A-horizon, available water, K, Ca and Mg contents are higher in the "good" growth soils. On the other hand, penetration value and clay content were lower in the "good" growth soils. Bulk density, although not significantly different, tends to be lower in the "good" growth soils. Dry biomass and litter are significantly higher in the "good" growth soils compared to the "poor" soils. From field observation it is noted that not only the biomass is higher in the former soils but the species composition is more diverse.

**Table 2.** Soil conditions under the different growth groups for *Hopea odorata* and *Azadirachta excelsa*

| Soil properties | *Hopea odorata* | | *Azadirachta excelsa* | |
|---|---|---|---|---|
| | Good | Poor | Good | Poor |
| Bulk density (g $cm^{-3}$) | 1.32a | 1.37a | 1.32a | 1.37a |
| Organic matter (%) | 4.60a | 3.53b | 4.22a | 3.04b |
| Penetration (Mpa) | 0.35a | 0.76b | 0.30a | 0.81b |
| Clay (%) | 20.7a | 23.9a | 17.6a | 26.2b |
| Silt (%) | 13.5a | 11.7a | 13.1a | 12.6b |
| Sand (%) | 65.7a | 63.8a | 69.2a | 61.1b |
| Thickness of A-horizon (cm) | 6.0a | 3.5b | 5.9a | 3.0b |
| Available water (%) | 7.2a | 6.0b | 6.9a | 5.4b |
| CEC (cmol(+) $kg^{-1}$) | 4.99a | 4.79a | 4.38a | 4.5b |
| K (m g $g^{-1}$) | 104a | 90a | 101a | 95a |
| Ca (m g $g^{-1}$) | 248a | 155b | 192a | 106b |
| Mg (m g $g^{-1}$) | 43a | 21b | 27a | 15b |
| Na (m g $g^{-1}$) | 4a | 4a | 4a | 4a |
| Dry biomass (g $m^{-2}$) | 172a | 72b | 175a | 72b |
| Dry litter (g $m^{-2}$) | 332a | 153b | 130a | 55b |

Note: within species, means with the same letter are not significantly different at $P<0.05$

The relationship between various soil properties (bulk density, organic matter, penetration, clay, silt, sand, thickness of A-horizon, available water, CEC, K, Ca, Mg and Na) and tree height increment of *Hopea odorata* and *Azadirachta excelsa* was established using multiple regression analysis (stepwise selection method). A summary of this stepwise procedure analysis is in Table 3.

Table 3 shows that percentage clay, bulk density, thickness of A-horizon and Na content were predominant factors affecting height increment of *Hopea odorata* and *Azadirachta excelsa.* This relationship is represented by the following equation.

$$Y1 = -107.5 - 0.65\ X1 + 69.75\ X2 + 11.82\ X3 + 0.86\ X4 \ldots\ldots.(1)$$

Where Y1 is height increment, X1 is % clay, X2 is bulk density, X3 is thickness of A-horizon and X4 is Na content. This relationship is significant at 1% level with correlation coefficiency of 0.7552.

**Table 3**. Summary of stepwise procedure for relationship between soil properties and tree height increment

| Variable | Parameter estimate | Standard error | Probability>F |
|---|---|---|---|
| Intercept | -107.5 | 37.08 | 0.0055 |
| Clay | -0.65 | 0.34 | 0.0647 |
| Bulk density | 69.75 | 23.38 | 0.0043 |
| A-horizon | 11.82 | 1.60 | 0.0001 |
| Na | 0.86 | 0.55 | 0.0003 |

Note: All variables left in the model are significant at the 0.15 level. No other variable met the 0.15 significance level for entry into the model

Similarly, relationships between various soil properties (bulk density, organic matter, penetration, clay, silt, sand, thickness of A-horizon, available water, CEC, K, Ca, Mg and Na) and the dry biomass were established (Table 4).

Table 4 shows that bulk density and thickness of A-horizon were predominant factors affecting biomass accumulation. This relationship is represented by the following equation.

$$Y2 = -348.71 + 255.12X5 + 28.41X6 \ldots\ldots\ldots(2)$$

Where Y2 is dry biomass, X5 is bulk density and X6 is thickness of A-horizon. This relationship is significant at 1% level with correlation coefficient of 0.5513.

**Table 4**. Summary of stepwise procedure for relationship between soil properties and dry biomass

| Variable | Parameter estimate | Standard error | Probability>F |
|---|---|---|---|
| Intercept | -348.71 | 138.41 | 0.0147 |
| Bulk density | 255.12 | 93.14 | 0.0083 |
| A-horizon | 28.41 | 5.88 | 0.0001 |

Note: All variables left in the model are significant at the 0.15 level. No other variable met the 0.15 significance level for entry into the model

## DISCUSSION

Table 1 shows that there is a distinct difference between properties of soils of the "good" growth and that of the "poor" growth plots. Among the physical properties, organic matter, mechanical resistance, thickness of A-horizon, available water and clay content were found to be significantly different between the "good" and "poor" growth soils. Bulk density, although not significantly different, tends to be lower in the "good" growth soils. This insignificance may be due to higher coefficients of variation found for the bulk density. A similar result was reported by Alegre *et al.* (1986) and Craul (1994). Organic matter is well known to affect the fertility of soils through its influence on many other properties such as water holding capacity, soil structure and nutrient availability. Many previous studies have shown that poor establishment of seedlings during rehabilitation of logged-over forest was attributed to decrease in organic matter due to forest harvesting (Barber and Romero 1994; Kobayashi *et al.* 1996). Mechanical resistance may affect growth through its effect on root expansion and elongation. Raghavan *et al.* (1990) have shown root density decreases with increase in penetration resistance. A-horizon provides the seat for development of root systems and furthermore many plants tend to develop surface root system during initial phase of root development. Thus the thicker and the richer the A-horizon the more extensive is the root system and consequently the better the growth of the plants. A well-developed root system in the A-horizon also influences rate of water permeability into deeper soils and therefore affects water availability in the root zone.

Amongst the chemical properties studied, only Ca and Mg contents were found to be significantly higher in the "good" growth soils. The role of Ca in cell wall development and Mg in the formation leaf chlorophyll have frequently been reported. Thus their presence in available form in the soils is important for the initial growth of the seedlings.

It is envisaged that growth of trees does not depend on a single soil property but interaction of several soil properties. In this study a stepwise multiple regression analysis was carried out between the growth and the soil parameters. The equation established between height increment and soil properties suggests that tree growth was strongly and positively influenced by bulk density and thickness of A-horizon and less strongly and negatively by clay content (Equation 1). A similar result was also found for the growth of biomass where quantity of above ground biomass was strongly and positively related to bulk density and thickness of A-horizon (Equation 2). The results indicate that the two most limiting factors in affecting growth of young seedlings were bulk density and thickness of A-horizon and, to a much lesser extent, clay content. This result contradicts the earlier result that there is no significant difference in bulk density between the "good" and "poor" sites. However, although not significantly different, the bulk density tended to be lower in the "good" growth soils. Further it has been argued that the insignificance may be due to higher coefficients of variation found for the bulk density.

In general the above results imply that in evaluating the impact of forest harvesting on subsequent forest regeneration, consideration should be given to bulk density and thickness of A-horizon because both were drastically impaired due to harvesting operation (Kobayashi *et al.* 1996). So to improve growth and seedling establishment in rehabilitation of degraded logged-over forest, it is necessary to adopt silvicultural practices which can enhance soil properties. For example, the size of planting holes can be enlarged (e.g. 60 cm x 60 cm x 50 cm) and a mixture of topsoil, organic compost and fertiliser used to refill the holes after planting.

## CONCLUSION

The predominant factors limiting growth performance of seedlings in the study area are high bulk density or high mechanical resistance, shallow depth of A-horizon, high amount of clay fraction in surface soil and content of Ca and Mg. High bulk density and thinness or absence of the A-horizon are most important. Correction on these factors is therefore essential for successful rehabilitation and reforestation of degraded forest ecosystems. This can be achieved through silvicultural practices which improve soil properties that are important in a sustainable forest production system. Using a modified planting technique, e.g. constructing a large planting hole and using a mixture of topsoil, organic compost and fertiliser to refill the hole after planting.

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## REFERENCES

Alegre, J.C., Cassell, D.K. and Bandy, D.E. 1986. Effects of land clearing and subsequent management on soil physical properties. Journal of the Soil Science Society of America 50: 1379-1384.

Allison, L.E. 1965. Organic carbon. *In*: C.A. Black *et al.* (eds.). Methods of soil analysis. Part 2. Agronomy 9: 1367-1378. ASA Madison, Wisconsin, USA.

Barber, R.G and Romero, D. 1994. Effects of bulldozer and chain clearing on soil properties and crop yields. Journal of the Soil Science Society of America 58: 1768-1775.

Craul, P.J. 1994. Soil compaction on heavily used sites. Journal of Arboriculture 20: 69-73.

Day, P.R. 1965. Particle fraction and particle size analysis. *In*: C.A. Black *et al.* (eds.) Environmental science and technology methods of soil analysis, Part 2, Agronomy. ASA Madison, Wisconsin, USA.

FAO. 1998. Guidelines for the management of tropical forest. FAO Forestry Paper 135. Food and Agriculture Organization of the United Nations, Rome.

Greenland, D.J. 1977. Soil structure and erosion hazard. *In*: Greenland, D.J. and Lal, R. (eds.) Soil conservation and management in the humid tropics. 17-23. Wiley, Chichester.

Kobayashi, S., Yarwudhi, C. and Suksawang, S. 1996. Changes of soil and understory biomass before and after the harvesting of *Eucalyptus camaldulensis* plantation in Thong Pha Phum, Kanchanaburi, Thailand. Proceeding of the Fortrop'1996: Tropical Forestry in the 21st Century, 25-28 November 1996, Kasetsart University, Bangkok.

Kramer, P.J. and Kozlowski, T.T. 1979. Physiology of woody plants. Academic Press, New York. 483p.

Raghavan, G.S.V., Alvo, O. and McKyes, E. 1990. Soil compaction in agriculture: a view toward managing the problem. *In*: Lal, R. and Stewart, B.A. (eds.) Soil degradation. 1-32. Springer-Verlag, New York.

# 15

# Evaluation of Methods for Rehabilitation of Logged-over Lowland Forest in Pasoh, Negeri Sembilan, Malaysia

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***Abstract***

Four rehabilitation methods were tested in logged-over lowland tropical forest in Pasoh Forest Reserve, Negeri Sembilan, Peninsular Malaysia. The treatments were: line planting (T1), gap planting 10m x 10m x 5 $ha^{-1}$ (T2), gap planting 20 m x 20 m x 5 $ha^{-1}$ (T3) and gap planting 10 m x 10 m x 9 $ha^{-1}$ (T4). *Hopea odorata, Azadirachta excelsa* and *Vitex pubescens* were planted in the lines and gaps. One year after planting, percentage survival of seedlings were: 97%, 96%, 93% and 93% respectively for T1, T4, T2 and T3 for *Hopea odorata*; 96%, 90%, 88% and 85% respectively for T4, T1, T3 and T2 for *Azadirachta excelsa*; and 97%, 94%, 87% and 76% respectively for T4, T1, T3 and T2 for *Vitex pubescens*. The costs for each treatment per hectare were RM 2862; RM 1520; RM 684 and RM 380 for T1, T3, T4 and T2 respectively. In general soil properties (bulk density, organic matter, soil moisture and pH) before and after rehabilitation treatments were not significantly different suggesting all the rehabilitation methods can prevent soil degradation. Technically, line planting and gap planting methods were suitable for rehabilitation of this area but in terms of economic cost and effective area planted, gap planting was more efficient and effective than line planting. *Hopea odorata, Azadirachta excelsa* and *Vitex pubescens* are suitable for rehabilitation of this forest.

## INTRODUCTION

Tropical forest is one of the complex, self-supporting and stable ecosystems but removal of the protective forest vegetation exposes structurally unstable soil to the destructive force of raindrops resulting in drastic ecosystem changes (Meka 1994). The most notable, regional and local effects of exploitation or forest harvesting include changes in hydrologic cycle, micro climate, energy balance, nutrient recycling, and biotic environment including soil micro-floral and faunal activities (Lal 1985). To reduce logging impacts, rapid forest function recovery is essential and planting of tree species is the easiest and most reliable method to achieve this (Sakurai *et al.* 1994). The rehabilitation technique and choice of tree species are crucial factors for successful rehabilitation of degraded logged-over forest.

The objectives of this study were firstly to identify a cost-effective method of rehabilitation of logged-over forest and secondly to determine if *Hopea odorata, Azadirachta excelsa* and *Vitex pubescens* are suitable for rehabilitation of this forest.

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# MATERIAL AND METHODS

## Site description

The study was conducted at Compartment 121, Pasoh Forest Reserve, Jempol, latitude 3°03'N and longitude 102°21'E and approximately 80 km southeast of Seremban, Negeri Sembilan, Peninsular Malaysia. The soil, derived from acidic granites, shales and interbedded shales and sandstones, is classified as a Kaolinitic Isohypertermic Typic Palaeudult (Allbrook 1973). The area is undulating with slopes ranging from gentle to steep. The forest was selectively logged manually by chainsaw and has remained untouched since 1984. Annual rainfall ranges from 1728–3112 mm with a mean of 2054 mm, wet months with rainfall 250–350 mm month$^{-1}$ were April–May and November–December, driest months with rainfall 30-100 mm month$^{-1}$ were February-March and July-August. Air temperature fluctuated from 19.6 to 35.9°C, with a monthly mean of 24.8°C (Soepadmo and Kira 1977).

## Experimental design

The rehabilitation methods tested were:

- *Line planting* (T1): Seedlings were planted east-west in two rows within each line, distance between lines was 10m. There were three different widths of line in each plot namely 3 m, 5 m and 10 m, each containing double rows of seedlings with row distance of 2 m, 3 m and 6 m respectively and seedling spacing within rows of 2 m. There were 102 trees per line planting or 612 trees ha$^{-1}$ and total area planted was 3600 m$^2$ ha$^{-1}$.
- *Gap planting* (T2): Tree seedlings were grown in a gap 10 m x 10 m and each treatment plot had 5 gaps. In each gap, the seedlings were spaced 2 m x 2 m giving 16 trees per gap and 80 trees ha$^{-1}$.
- *Gap planting* (T3): Tree seedlings were grown in a gap 20 m x 20 m and each treatment plot had 5 gaps. In each gap, the seedlings were spaced 2 m x 2 m giving 64 trees per gap and 320 trees ha$^{-1}$.
- *Gap planting* (T4): Tree seedlings were grown in a gap 10 m x 10 m and each treatment plot had 9 gaps. In each gap, the seedlings were spaced 2 m x 2 m giving 16 trees per gap and 144 trees ha$^{-1}$.

The four methods were replicated three times in a Randomized Complete Block Design and each treatment plot was 100 m x 100 m. *Hopea odorata*, *Azadirachta excelsa* and *Vitex pubescens* were planted. Lines and gaps were cleared by sickle and chainsaw before planting and the planting pits, 15 cm diameter and 30 cm deep, were made at the time of planting. Christmas Island rock phosphate (CIRP) fertiliser at rate 30 g per seedling was applied at planting in July-August 1998.

## Data collection and analysis

Survival rate of seedlings was recorded based on a census of all planted seedlings. Soil properties: bulk density, soil moisture characteristic, organic matter and pH were measured. Bulk density was measured using undisturbed core samples (4 cm long and 7.5 cm diameter). Total organic matter was determined by Walkey and Black's titration method (Piper 1950). Soil moisture characteristics at 0, 1, 10, 33 and 1500 kPa were determined by the pressure plate method (Richards 1947). Soil pH in water with 1:2.5 ratio of soil to solution was measured with a pH meter. All undergrowth (plants of less than 2m in height) in a 1 m x 1 m quadrat was collected to determine dry matter weight. A planting cost per hectare was estimated for each treatment.

# RESULTS AND DISCUSSION

In this study we observed several variables, such as survival rate of seedlings, cost estimate, changes of soil properties and development of undergrowth, as indicators of successful rehabilitation treatment. Seedling growth and soil data are most of the important indices required for planning operations.

## Survival of seedlings

Seedling survival of each species was measured a year after planting in July 1999 and the results are shown in Table 1.

**Table 1**. Survival rate of seedlings after one year

| Treatment | *Hopea odorata* | *Azadirachta excelsa* | *Vitex pubescens* |
|---|---|---|---|
| | | % | |
| T1 | 97a | 90a | 94a |
| T2 | 93a | 85a | 76b |
| T3 | 93a | 88a | 87a |
| T4 | 96a | 96a | 97a |

Within columns, numbers followed with the same letter are not significantly different at 5% level (Duncan's Multiple Range Test)

A year after planting, the seedling survival rate *Hopea odorata, Azadiracta excelsa* and *Vitex pubescens* was high (>85%), Among treatments, there were no significant differences except for *Vitex pubescens,* whose percentage survival seedling was lower in gap planting T2 compared to other treatments. Although survival rate was high, growth performances from visual observation in the field were not homogenous in each treatment (plot). This indicates the reaction of seedlings to environmental conditions is very specific. For example, near the river seedlings grew fast but on compacted soil areas seedlings grew slowly. Evans (1992) reported that many factors affect initial survival rate, including (i) planting skill, (ii) immediate post-planting weather, (iii) condition of seedlings, (iv) poor soil condition, (v) insects, such as termites, (vi) weed competition and (vii) animal damage. It follows that the most important step in the rehabilitation of logged-over forest is to identify and minimise those factors that limit seedling growth and contribute to mortalities.

## Cost estimate of rehabilitation technique

A planting cost per hectare was calculated for each treatment. For this study, a compounded rehabilitation cost was calculated from preparation of the area until the seedlings were planted using a hypothetical labour cost of Ringgit Malaysia (RM) 7.50 hour$^{-1}$ and a seedling cost of RM 1.00. Labour cost for site preparation was RM 0.20 m$^{-2}$ and planting seedlings RM 1.00 per seedling. The results are shown in Table 2.

Gap planting was less expensive than line planting (Table 2). Total planting area and number of seedlings per hectare were the main variable costs in the rehabilitation of logged-over forest.

## Soil properties

Soil properties were measured before and a year after treatments (Table 3). The soils from all treatment plots before rehabilitation had a high bulk density, low to medium organic matter and were acidic. These conditions indicated the soils were degraded. Sanchez *et al.* (1994) reported physical and chemical degradation of forest land involves soil compaction, sheet and gully erosion, significantly increased soil acidity and decreased available nutrients.

Data in Table 3 shows that there was generally no significant changes of soil properties one year after the rehabilitation treatments. This may be due to tree felling by sickle and chainsaw during manually clearing the plot. However, significant changes in bulk density were shown in the line planting method as it decreased from 1.48 g cm$^{-3}$ to 1.30 g cm$^{-3}$.

**Table 2.** Cost estimates (Ringgit Malaysia) of different rehabilitation techniques

| Treatments | Cost | | | |
|---|---|---|---|---|
| | Preparation planting area | Seedlings | Planting | Total |
| T1 | 720 | 1,530 | 612 | 2862 |
| T2 | 100 | 200 | 80 | 380 |
| T3 | 400 | 800 | 320 | 1520 |
| T4 | 180 | 360 | 144 | 684 |

Note: RM 1.00 = US $ 0.262

**Table 3**. Soil properties before and after rehabilitation treatments

| Soil Properties | T1 | | T2 | | T3 | | T4 | |
|---|---|---|---|---|---|---|---|---|
| | Before | After | Before | After | Before | After | Before | After |
| Bulk density (g cm$^{-3}$) | 1.48* | 1.30* | 1.25$^{ns}$ | 1.28$^{ns}$ | 1.38$^{ns}$ | 1.27$^{ns}$ | 1.42$^{ns}$ | 1.27$^{ns}$ |
| Organic matter (%) | 2.86$^{ns}$ | 3.10$^{ns}$ | 3.84$^{ns}$ | 3.92$^{ns}$ | 3.48$^{ns}$ | 3.06$^{ns}$ | 4.04$^{ns}$ | 4.02$^{ns}$ |
| pF 0 (% v/v) | 49$^{ns}$ | 50$^{ns}$ | 53$^{ns}$ | 40$^{ns}$ | 46$^{ns}$ | 48$^{ns}$ | 44$^{ns}$ | 40$^{ns}$ |
| pF 1 (% v/v) | 41$^{ns}$ | 43$^{ns}$ | 38* | 34* | 40$^{ns}$ | 35$^{ns}$ | 38$^{ns}$ | 34$^{ns}$ |
| pF 2 (% v/v) | 31$^{ns}$ | 32$^{ns}$ | 27$^{ns}$ | 27$^{ns}$ | 32$^{ns}$ | 30$^{ns}$ | 31$^{ns}$ | 28$^{ns}$ |
| pF 2.54 (% v/v) | 25$^{ns}$ | 29$^{ns}$ | 21$^{ns}$ | 24$^{ns}$ | 25$^{ns}$ | 26$^{ns}$ | 25$^{ns}$ | 24$^{ns}$ |
| pF 4.19 (%v/v) | 22$^{ns}$ | 22$^{ns}$ | 17$^{ns}$ | 19$^{ns}$ | 21$^{ns}$ | 21$^{ns}$ | 20$^{ns}$ | 20$^{ns}$ |
| Available water (%v/v) | 3$^{ns}$ | 7$^{ns}$ | 4$^{ns}$ | 5$^{ns}$ | 4$^{ns}$ | 5$^{ns}$ | 5$^{ns}$ | 4$^{ns}$ |
| pH H$_2$0 1: 2.5 | 4.75$^{ns}$ | 4.73$^{ns}$ | 4.79$^{ns}$ | 4.90$^{ns}$ | 4.72$^{ns}$ | 4.37$^{ns}$ | 4.66$^{ns}$ | 4.15$^{ns}$ |

ns = non significant at 5% level * = significant at 5% level

**Table 4**. Changes of dry undergrowth at 6 months in the rehabilitation area

| Treatment | Undergrowth (t ha$^{-1}$) | | |
|---|---|---|---|
| | September 1998 | February 1999 | Growth rate (times) |
| T1 | 1.20 | 6.77 | 5.6 |
| T2 | 1.05 | 4.12 | 3.9 |
| T3 | 0.92 | 3.54 | 3.9 |
| T4 | 1.13 | 2.99 | 2.7 |

## Undergrowth

The undergrowth productivity measured on an oven-dry weight basis showed that after a period of 6 months the undergrowth increased from 1.20 to 6.77 t ha$^{-1}$ in line planting, from 1.05 to 4.12 t ha$^{-1}$ in gap planting 10m x 10m x 5 ha$^{-1}$, from 0.92 to 3.53 t ha$^{-1}$ in gap planting 20m x 20 x 5 ha$^{-1}$and from 1.13 to 2.99 t ha$^{-1}$ in gap planting 10m x 10m x 9 ha$^{-1}$ (Table 4). It was clear that the undergrowth in line planting developed more quickly than in gap planting. This may be because the large area opened in line planting allows increased growth of undergrowth by increasing the amount of sunlight. Ochiai *et al*. (1994) also found that the undergrowth in gap planting is less than in line planting. Sometimes the undergrowth interfered with the growth of young seedlings, e.g., *Bauhinia* spp. climbing on young seedlings. To prevent competition between undergrowth and young seedlings, selective weeding around planted seedlings must be practised during the rehabilitation process.

## CONCLUSION

These results suggest that technically, line planting and gap planting methods were suitable for rehabilitation of this area but in terms of economic cost and effective area planted, gap planting was more efficient and effective than line planting. *Hopea odorata, Azadirachta excelsa* and *Vitex pubescens* are suitable for rehabilitation of this forest.

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## REFERENCES

Allbrook, R.F. 1973. The soils of Pasoh Forest Reserve, Negeri Sembilan, Malaysian Forester 36: 22-33.

Evans, J. 1992. Plantation forestry in the tropics. (2nd ed.). Clarendon Press, Oxford.

Lal, R. 1985. Need for, approaches to, and consequences of land clearing and development in the tropics. 15–27. Tropical Land Clearing Sustainable Agriculture. Proceedings of an IBSRAM Inaugural Workshop.

Meka, E.Z. 1994. IITO and the rehabilitation of degraded forest land in tropics. JIRCAS International Symposium. Series 1: 10–19.

Ochiai, Y., M. Alimanar and Yusop, A.R. 1994. Natural distribution and suitable method for plantation of two *Dryobalanops* species in Negara Brunai Darussalam. Bulletin of the Forestry and Forest Products Research Institute No. 366. Ibaraki, Japan. 31 – 56.

Piper, C.S. 1950. Soil and plant analysis. University of Adelaide, Adelaide.

Richards, L.A., 1947. Pressure-membrane apparatus: construction and use. Agricultural Engineering 28: 451-454.

Sakurai, S., Ragil, R.S.B. and de la Cruz, L.U. 1994. The growth and productivity degraded forest land. JIRCAS International Symposium Series 1. Tsukuba, Ibaraki, Japan. 64–71.

Sanchez, A., Woomer, P. L. and Palm, C. A. 1994. Agroforestry approaches or rehabilitating degraded lands after tropical deforestation. JIRCAS International Symposium. Series 1: 108–119.

Soepadmo, E. and Kira, T. 1977. Contribution on the IBP-PT research project to the understanding of Malaysian forest ecology. *In*: A new era in Malaysian forestry. 63-90. Universiti Pertanian Malaysia. Serdang Selangor.

## 16

# Rehabilitation of Tropical Rainforests Based on Indigenous Species for Degraded Areas in Sarawak, Malaysia

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***Abstract***

A study was conducted on forest rehabilitation based on indigenous species at the Universiti Putra Malaysia, Bintulu, Sarawak. Areas of open abandoned shifting cultivation, man-made mounds, *Macaranga* secondary forest and shrubby undergrowth were used for trial planting with different types of planting techniques. The research showed that selected species from the natural vegetation community easily adapt to the site conditions similar to their native habitat. The planted seedlings were classified as light demanding, shade tolerant and late growth species on the basis of their height growth performance in the trials. The indigenous tree species recommended for checkerboard plantations are: *Shorea ovata, S. mecistopteryx, S. macrophylla, Dryobalanops aromatica, Parashorea parvifolia, Hopea beccariana, Durio carinatus* and *Eusideroxylon zwageri.*

## INTRODUCTION

The concern over depletion of the tropical rainforests has resulted in an increasing emphasis on forest rehabilitation to maintain the ecological balance within the ecosystem. Forest clearfelling in Sarawak is mainly by shifting cultivation practices. The figures based on the satellite imageries of 1990 to 1991, show the total area of land affected by shifting cultivation is about 3 million hectares. Of this, 116 121 hectares are located within the permanent forest estate while 11 404 hectares are in totally protected areas. In view of the loss, an extensive reforestation program is necessary both to sustain the forest resources and to rehabilitate the deteriorating ecosystem. Malaysian research in this area has included planting of native species on barren land and in secondary vegetation and much experience is available from research dating back to the 1920s.

Rehabilitation of forest involves re-establishment of a more intact canopy that is found in undisturbed forests (Lim 1992). It is also important to define the objective of rehabilitation so the efforts can be evaluated subsequently. This can be the restoration of the degraded forests to its original pristine stage with the use of indigenous tree species. The case for using indigenous species has often been overlooked, possibly because of a lack of information but perhaps more likely so through the biased view that exotics are better. There are problems associated with the use of indigenous species, such as the lack of ecological understanding of the requirements for growth, the inadequate collection of seeds, the relatively slow growth and the purported uneconomic proposition of using indigenous species. These problems can be overcome through research. On the other hand, there are numerous other advantages of using indigenous species. They are already adapted to the local conditions, the genetic base is easily

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accessible, and the supply of seeds may not be as difficult as anticipated previously. There is a wealth of information available locally that can be usefully exploited.

Even though the potential of using indigenous tree species for forest plantation in Malaysia has been known since 1921 (Appanah and Weinland 1993), the species were never planted on a large scale. They were planted as part of experimental research or reforestation projects. Species, such as *Shorea macrophylla, S. pinanga, S. splendica, S. palembanica* and *S. streoptera,* were planted in Sarawak mainly due to their fast growth and illipe nuts (Joseph 1992). Many rehabilitation efforts using different techniques have been carried out in Malaysia with varying degrees of success. One technique that has been successful in the warm temperate zone is dense planting (e.g. Miyawaki 1993). This technique was used in Bintulu, Sarawak to rehabilitate the degraded shifting cultivation area with indigenous tree species.

The study reported here had two objectives:

- to understand the nature of tree-environment relationships of the native species and,
- to recommend the most suitable species and the best planting techniques for different sites conditions for rehabilitation of tropical rainforest.

## MATERIALS AND METHODS

The study was conducted on a 47.5 ha area within the former campus of Universiti Putra Malaysia, Bintulu, Sarawak the campus premise. It is located about 600 km northeast of Kuching, latitude $3^0$ 12' N, longitude $113^0$ 05' E and 50 m a.s.l. Mean annual rainfall is 2993 mm and the rainy season is November-January during the northeast monsoon. The mean daily temperature recorded is $26.7^0$ C and relatively consistent throughout the year. Mean monthly relative humidity is usually above 80% but slightly lower during the rainy season. The soil belongs to Nyalau and Bekenu series and is well-drained. The Nyalau series is characterised by coarse loam, light yellowish brown topsoil 9 cm deep with brownish yellow subsoil. The Bekenu series is a fine loam, light yellowish brown top soil 4-15 cm deep and brownish yellow subsoil (Peli *et al*. 1984).

The planting methods and site preparation employed depended on the condition of the sites:

- Site A: severely eroded and compacted areas,
- Site B: man-made mounds,
- Site C: under *Macaranga* secondary forest,
- Site D: in grasses and undergrowth.

At Site A and Site B, the planting of three seedlings per metre square with a mixed and random distance was applied. For under *Macaranga* secondary forest (Site C), the seedlings were planted at 3 metres between them and oriented in line. But for Site D, the planting distance just 1 metre and the clearance of the line for planting area was 1 metre width. The distance between line were located at 3 metres each. The dense planting technique (three seedlings per metre square) shortens the time for the canopy closer and controls the weed growth.

Data on growth performance (basal diameter and total height) and survival rate of planted seedlings were recorded for 72 months (Site A and Site C) and 60 months for Site B and 66 months for Site D.

## RESULTS AND DISCUSSION

*Survival*. In general, survival rate decreased rapidly soon after planting, especially for the shade demanding species. The strong and direct sunlight burned the leaves of newly planted seedlings. After one year, the light-demanding species had no further mortalities. The slow height growth of some species reduced survival rate, as the seedlings did not have enough sunlight for the photosynthesis process, and competition for sunlight also affected the survival rate of *Parashorea parvifolia*. The size of the newly-planted seedlings (less than 50 cm tall) also contributed to the low survival rate. Seedlings less than 50 cm in height cannot compete with the growth of weeds for nutrients, sunlight and growing space (Mohamad Azani *et al*. 1995).

**Table 1.** Survival rate (%) of planted species at four different planting sites

| Species | | Site | | | |
|---|---|---|---|---|---|
| | | A | B | C | D |
| | | Survival (%) | | | |
| 1 | *Calophyllum ferrugenium* | 24 | 25 | - | - |
| 2 | *Cotylelobium burckii* | 33 | - | - | 0 |
| 3 | *Dryobalanops aromatica* | 51 | 45 | - | 50 |
| 4 | *Durio carinatus* | 45 | 45 | - | 73 |
| 5 | *Eugenia* sp. | 25 | 18 | - | 56 |
| 6 | *Eusideroxylon zwageri* | - | - | 96 | - |
| 7 | *Hopea beccariana* | 14 | 14 | - | - |
| 8 | *Hopea kerangasensis* | 15 | 25 | - | 0 |
| 9 | *Parashorea parvifolia* | 10 | - | - | - |
| 10 | *Pentaspodon motleyi* | - | 80 | 69 | - |
| 11 | *Shorea gibbosa* | 23 | 20 | - | - |
| 12 | *Shorea leprosula* | 35 | 20 | - | 34 |
| 13 | *Shorea macrophylla* | - | 80 | 85 | 62 |
| 14 | *Shorea materialis* | 16 | 10 | - | - |
| 15 | *Shorea mecistopteryx* | 40 | 67 | 73 | 59 |
| 16 | *Shorea ovata* | 41 | 43 | - | 56 |
| 17 | *Vatica nitens* | - | 10 | - | - |
| 18 | *Whiteodendron moultianum* | 56 | 55 | - | - |

Survival rate at Site B was higher than at Site A (Table 1). The highest survival rate was 80% for *Shorea macrophylla* and *Pentaspodon motleyi,* while *Shorea mecistopteryx* and *Whiteodendron moultianum*. were above 50%. The lowest survival rate was 10% for *Vatica* sp. Better site conditions at Site B were probably responsible for the higher survival rate. These were: (a) good aeration, through using topsoil as a main material for the man-made mound, and less compaction, (b) more nutrients in the top soil, (c) good drainage and less weed competition.

The survival rates for seedlings under shade (Sites C and D) were higher than for direct sunlight (Table 1). The mortality of *Hopea kerangasensis* and *Eugenia* sp. at Site D was caused by the small seedlings which could not compete with the weed growth. The shade provided a better planting condition in terms of humidity and amount of sunlight. The sunburned effect was not found on any newly-planted seedlings under shade. The survival rate of planted seedlings at Site D was 40-80%, while for Site C it was over 60%.

Rahim (1992) reported survival rate of 44% for *E. zwageri* at the Segaliud Lokan enrichment planting by line planting under natural forest shade. The 100% mortality of *Hopea kerangasensis* and *Cotylelobium burckii* at Site D was due to the small size of the seedlings at the time of planting. *Durio carinatus* had the highest survival with 73% after 5 years. Dipterocarpaceae species (*Dryobalanops aromatica, Shorea macrophylla, S. mecistopteryx, S. ovata* and *S. leprosula*) had 34-62% survival. Anuar and Abtah (1990) reported a survival rate for *Dryobalanops lanceolata* (84%)*, Shorea beccariana* (64%)*, S. mecistopteryx* (72%) and *S. superba* (76%) in the enrichment planting by line planting. The survival rates suggest that planted seedlings can easily adapt to the site condition at Site D with reduced sunlight and small temperature changes.

The site conditions under *Macaranga* secondary forest (Site C), which is mesic, had low sunlight penetration (around 50% at the time of planting) and less weeds, were very suitable for *Eusideroxylon zwageri*, *Pentaspodon motleyi*, *Shorea macrophylla* and *S. mecistopteryx* to grow.

The inability of some seedlings to adapt to the site's microclimate may have attributed towards some seedling mortality especially during the first six months after planting (Mohd Zaki *et al*. 1993). Taller seedlings competed better for sunlight, water, nutrient or space and survived better than smaller trees.

*Growth.* In general, the species planted in severely eroded and compacted areas (Site A) had moderate growth in basal diameter and height, except *Dryobalanops aromatica* and *Whiteodendron moultianum* which showed good growth (Tables 2 and 3). On mounds (Site B), *Pentaspodon motleyi* had the highest basal diameter MAI (2.88 cm), followed by *Whiteodendron moultianum* (1.99 cm). *Calophyllum ferrugenium* had the lowest MAI ( 0.46 cm) at Site B but moderate (0.64 cm) at Site A. The four species planted at Site C had low MAI basal diameters (0.31-0.93 cm). Of the *Shorea* species tested, *S. leprosula* and *S. ovata* had higher MAI in height at Sites B and D. The slowest species in the trials was *S. gibbosa* (17.00 cm MAI height) at Site A (Table 3).

In direct sunlight, *Dryobalanops aromatica, Shorea ovata, S. leprosula, Whiteodendron moultianum, Pentaspodon motleyi* and *Durio carinatus* had the highest mean height growth. At Site A *Dryobalanops aromatica,* reached a height of 598 cm, followed closely by *Whiteodendron moultianum* (594 cm) and *Shorea ovata* (588 cm). *Whiteodendron moultianum* had highest diameter (9.5 cm), while *D. aromatica* was (9.2 cm). *Shorea leprosula* had only moderate growth in total height and volume and other species on this site showed less growth.

On the man-made mounds (Site B), *Pentaspodon motleyi* had the biggest height and basal diameter growth, while at Site D, in grasses and undergrowth, *Shorea leprosula* had the best growth (both height and basal diameter). At Site B, *P. motleyi, S. leprosula, S. ovata* and *W. moultianum* had good growth in total height, but only P. *motleyi* showed good growth in basal diameter. *Pentaspodon motleyii* appears to have a weak apical dominance and so needs strong lateral competition to stay erect. Its self-pruning capacity is good but not its self-thinning ability. The crowns are feathery and much light penetrates to the ground floor.

**Table 2.** Mean annual increment (MAI) of basal diameter of planted species at four different planting sites

| Species | | Sites | | | |
|---|---|---|---|---|---|
| | | A | B | C | D |
| | | Basal diameter MAI (cm year$^{-1}$) | | | |
| 1 | *Calophyllum ferrugenium* | 0.64 | 0.46 | | |
| 2 | *Cotylelobium burckii* | 0.75 | | | Dead |
| 3 | *Dryobalanops aromatica* | 1.53 | 1.01 | | 1.09 |
| 4 | *Durio carinatus* | 0.49 | 0.78 | | 0.49 |
| 5 | *Eugenia* sp. | 0.42 | 0.51 | | 0.42 |
| 6 | *Eusideroxylon zwageri* | | | 0.31 | |
| 7 | *Hopea beccariana* | 0.68 | 0.83 | | |
| 8 | *Hopea kerangasensis* | 0.55 | 0.49 | | Dead |
| 9 | *Parashorea parvifolia* | 0.78 | | | |
| 10 | *Pentaspodon motleyi* | | 2.88 | 0.93 | |
| 11 | *Shorea gibbosa* | 0.90 | 1.17 | | |
| 12 | *Shorea leprosula* | 1.32 | 1.45 | | 1.48 |
| 13 | *Shorea macrophylla* | | 0.86 | 0.44 | 0.70 |
| 14 | *Shorea materialis* | 0.97 | 0.63 | | |
| 15 | *Shorea mecistopteryx* | 0.85 | 1.18 | 0.63 | 0.98 |
| 16 | *Shorea ovata* | 0.93 | 1.79 | | 0.95 |
| 17 | *Vatica nitens* | | 1.59 | | |
| 18 | *Whiteodendron moultianum* | 1.58 | 1.99 | | |

**Table 3.** Mean annual increment (MAI) of height of planted species at four different planting sites

| Species | | Sites | | | |
|---|---|---|---|---|---|
| | | A | B | C | D |
| | | Height MAI (cm year$^{-1}$) | | | |
| 1 | *Calophyllum ferrugenium* | 43.0 | 24.0 | | |
| 2 | *Cotylelobium burckii* | 47.3 | | | Dead |
| 3 | *Dryobalanops aromatica* | 99.7 | 68.0 | | 83.2 |
| 4 | *Durio carinatus* | 41.8 | 41.6 | | 60.9 |
| 5 | *Eugenia* sp. | 18.3 | 37.4 | | 30.8 |
| 6 | *Eusideroxylon zwageri* | | | 31.4 | |
| 7 | *Hopea beccariana* | 50.3 | 37.0 | | |
| 8 | *Hopea kerangasensis* | 18.3 | 32.0 | | Dead |
| 9 | *Parashorea parvifolia* | 59.3 | | | |
| 10 | *Pentaspodon motleyi* | | 64.0 | 113.3 | |
| 11 | *Shorea gibbosa* | 17.0 | 64.0 | | |
| 12 | *Shorea leprosula* | 77.5 | 131.3 | | 103.0 |
| 13 | *Shorea macrophylla* | | 70.8 | 46.4 | 62.8 |
| 14 | *Shorea materialis* | 65.7 | 65.4 | | |
| 15 | *Shorea mecistopteryx* | 64.0 | 65.6 | 117.5 | 69.0 |
| 16 | *Shorea ovata* | 98.0 | 131.1 | | 91.2 |
| 17 | *Vatica nitens* | | 37.4 | | |
| 18 | *Whiteodendron moultianum* | 99.0 | 110.7 | | |

The results confirm the observation of Appanah and Weinland (1993) that *Shorea parvifolia* is shade demanding and slow growing when young but later requires full sunlight to grow well. *Shorea leprosula*, when young, is less shade tolerant than *S. parvifolia*, and will die. Its self-pruning capacity was superior to *S. parvifolia*. *Shorea leprosula* is suited for planting in less competitive conditions but needs strong competition to prevent formation of wolf trees, and if early growth rates are too high, brittle heart may develop (Appanah and Weinland 1993). As a mature tree, *Shorea leprosula* forms a distinctly open and wide spreading crown, and light penetrates easily to the ground. It is therefore preferable to mix it with species having a dense crown. *Shorea leprosula* reached 73 cm in height after 1 year and 3 m after 4 years on man-made mounds (Ismail Adnan Malek and Othman 1992, Mohamad Azani 1995).

*Shorea macrophylla* had exceptionally fast growth and a wide spreading crown with big limbs, as shown at Site A. It needs medium shade at the early stage of planting, and under shade it grows with excellent form (Appanah and Weinland 1993). It makes an excellent species for line planting into secondary growth and on cleared sites it needs a nurse crop. *Shorea macrophylla* has a very fast diameter growth but after initial fast height growth this levels off (Azman *et al.* 1990). *Shorea ovata* performed well in the open and confirmed its classification as a light demander by Wood and Meijer (1964).

From the results, *Dryobalanops aromatica* was distinctly shade tolerant at the young stage and had excellent growth in basal diameter and height. Appanah and Weinland (1993) recommended it must be raised under strong competitive conditions to prevent formation of brittle heart. It was selected as a potential species for mixed plantations with *Shorea leprosula, Shorea ovata, Hopea odorata, Endospermum malaccense, Dyera costulata* and *Khaya ivorensis* (Appanah and Weinland 1993). Numerous other researchers have noted its good survival under shade, e.g. Barnard (1949), Mohd Zaki *et al.*

(1993). It has good potential for rapid height growth, e.g. Watson (1935) found it reached an average of 6 m height and 11.3 cm diameter in six years and Edwards and Mead (1930) estimated that it takes only 43 years to reach 50 cm diameter and 66 years to reach 70 cm diameter. At Kepong, Malaysia, plantations aged 46 years had trees over 50 cm diameter and with a mean annual increment of 8 $m^3$ $ha^{-1}$

Based on the mean total height growth of planted species under the four different conditions, three categories of species can be recognised:

- **Light demander species:** *Shorea ovata, S. mecistopteryx, Dryobalanops aromatica, Pentaspodon motleyi* and *Whiteodendron moultianum.*
- **Shade tolerant species:** *Shorea macrophylla, S. gibbosa, S. materialis, Parashorea parvifolia, Hopea beccariana, Cotylelobium burckii, Calophyllum ferrugenium, Durio carinatus* and *Eusideroxylon zwageri.*
- **Late growth species**: *Hopea kerangasensis, Eugenia* sp., and *Vatica* sp.

It is recommended that mixed and dense planting can give fast restoration results, but when the planting area is large, a checkerboard plantation design can be applied as an alternative rehabilitation technique. The cost of rehabilitation in wide areas can be reduced by using this method because less seedlings are used. The indigenous tree species recommended for checkerboard plantation were *Shorea ovata, S. mecistopteryx, S. macrophylla, Dryobalanops aromatica, Parashorea parvifolia, Hopea beccariana, Durio carinatus* and *Eusideroxylon zwageri.*

## REFERENCES

Anuar, M. and Abtah, D. 1990. A preliminary progress report of forest plantation programme R&D project, Segaliud Lokan. *In*: Forest Department Annual Report 1990: 57–65.

Appanah, S. and Weinland, G. 1993. Planting quality timber trees in Peninsular Malaysia - a review. Malayan Forest Record No. 38. FRIM Kepong, Kuala Lumpur. 221p.

Azman, H., Razali, W.M., Shahrulzaman, I. and Rahman, A.K. 1990. Growth performance of indigenous species under enrichment planting in logged-over forests. *In*: Appanah, S., Ng, F.S.P. and Roslan, M. (eds.) Malaysian Forestry and Forest Products Research Proceeding, 30-40, Forest Research Institute Malaysia, Kepong, Kuala Lumpur.

Barnard, R.C. 1949. Planting after clear felling and burning. Malayan Forester 12: 142-143.

Edwards, J.P. and Mead, J.P. 1930. Growth of Malayan forest trees, as shown by sample plot records, 1915-1928. Federated Malay States, Singapore. 151p.

Ismail Adnan Abdul Malek and Othman B. 1992. Application of Miyawaki's forest rehabilitation technique towards a uniquely Malaysian landscape. International symposium on rehabilitation of tropical rainforest ecosystems: research and development priorities. Nik Muhamad Majid, Ismail Adnan Abdul Malek, Mohd Zaki Hamzah and Kamarazuman Jusoff (eds.) Faculty of Forestry, Universiti Pertanian Malaysia, Malaysia.

Joseph J. K. 1992. Forester's perception on indigenous species for forest plantations in Sarawak. *In*: Ahmad Said, S., Razali, A.K., Mohd Shahwahid, H.O., Aminuddin, M., Faridah Hanum, I. and Mohd Hamami, S. (eds.) National seminar on indigenous species for forest plantations : proceedings of a national seminar, 14 - 21. Universiti Pertanian Malaysia, Serdang.

Lim, M.T. 1992. Some ecological considerations in rehabilitating tropical forest ecosystems. International symposium on rehabilitation of tropical rainforest ecosystems: research and development priorities, Nik Muhamad Majid, Ismail Adnan Abdul Malek, Mohd Zaki Hamzah and Kamarazuman Jusoff (eds.) Faculty of Forestry, Universiti Pertanian Malaysia, Malaysia.

Miyawaki, A. 1993. Restoration of native forests from Japan to Malaysia. *In*: Leith, H. and Lohmann, M. (eds.) Restoration of tropical forest ecosystems, 5-24. Kluwer Academic Publishers, Netherlands.

Mohamad Azani, A. 1995. Rehabilitation of tropical rain forest with indigenous tree species in Bintulu, Sarawak, Malaysia. Unpublished Masters thesis.

Mohamad Azani, A., Fujiwara, K. and Miyawaki, A. 1995. The rehabilitation of the tropical rainforest ecosystems in Sarawak, Malaysia– four year results of a scientific study by Universiti Pertanian Malaysia and Yokohama National University Japan. Bulletin of the Institute of Environmental Science and Technology, Yokohama National University. 21, No. 1.

Mohd Zaki H., Ismail Adnan A.M. and Othman B. 1993. Growth performance of indigenous tree species planted with different rehabilitation techniques. Paper presented at the International Symposium of Tropical Phytogeography, 5-8 July, 1993, Paris, France. 10p.

Peli, M., Husni, A. and Ibrahim, M.Y. 1984. Report and map of the detailed soil survey of UPM Farm, Bintulu Campus, Sarawak. UPM Sarawak Campus Technical Paper no. 1. 73p.

Rahim, S. 1992. Site suitability assessment index for forest plantation species.11th Malaysian Forestry Conference. Working paper no. 1123-3. 19p.

Watson, J.G. 1935. Plantation experiments at Kepong. Malayan Forester 4: 110-119.

Wood, G.H.S. and Meijer, W. 1964. Dipterocarps of Sabah (North Borneo). Sabah Forest Record No. 5, Forest Department, Sabah.

## Short Communication

# Preliminary Results of the Effects of Different Gap Sizes on the Growth and Survival of Six Forest Tree Species in Papua New Guinea

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Forest degradation due to logging is becoming an acute problem in Papua New Guinea. Research started at two sites in 1998-1999 to develop the most effective methods to rehabilitate logged-over forest sites by applying different treatments, observing changes in the forest ecosystem and determining whether these methods are more effective than allowing natural regeneration to rehabilitate the forest. It aimed to test different size gaps (10 m x 10 m x 9, 10 m x 10 m x 5, 20 m x 20 m x 5) for planting in logged-over forest and to measure the growth and survival of three species with potential for use in rehabilitation at each site.

Gumi (site 1) is montane forest about 33 km west of Bulolo at an altitude of 2300 m. The forest is dominated by species of Fagaceae, especially *Castanopsis acuminatissima*. The species planted at Gumi are *Castanopsis acuminatissima, Phyllocladus hypophyllus* and *Euodia melicope.* Yalu (site 2) is typical lowland rainforest, about 15 km from Lae at about 100 m asl. *Pterocarpus indicus, Instia bijuga,* and *Pometia pinnata* were planted at this site. There is an 8 ha plot at each site with three gap treatments and a control in four 1 ha plots with two replications. The treated plots were planted in different gap size clearings of 10 m x 10 m x 9; 10 m x 10 m x 5 and 20 m x 20 m x 5. At 2 m x 2 m spacing, all planted trees were tagged and numbered including those residual trees within the plot with diameter breast height greater than 10 cm. Parameters were recorded on monthly basis and commercial trees regenerating naturally within the cleared gaps were recorded. Seedlings were nursery stock or directly from the forest as wildings. The parameters measured are: seedling height, branch internodes, number of branches and leaves. Mortality is also recorded and refilling carried out where necessary. Light intensity is measured within the treated plots between gaps, control and surrounding natural forest.

A preliminary analysis was made 9 months after planting at site 1 and after 3 months at site 2. It was found that at the high altitude site seedlings grew better growth in gap size 10 m x 10 m x 9 while at the low altitude best growth was in 20 m x 20 m x 5. There was high seedling mortality (35%) in the smaller (10 m x 10 m) gaps at low altitude. *Castanopsis acuminatissima* had 95% survival rate in 10 m x 10 m x 9 gap size at this stage shows the most promise for planting in the montane forest followed by *Euodia melicope*. At the low altitude site *Pterocarpus indicus* followed by *Instia bijuga* shows most potential. The trial plots will be monitored to confirm these initial observations.

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# Coppicing Ability of Teak (*Tectona grandis*) after Thinning

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***Abstract***

The research was carried out at the Forest Industry Organization's Thongphaphum Plantation in Kanchanaburi province, Thailand. The main objective was to determine the effects of different thinning methods on coppicing ability of 17-year-old teak leading to two canopy levels. Teak stumps were planted in 1980 at a spacing of 4 x 4 m and average survival rate was 72%. In 1997 the thinning experiment was set up in a randomised block design with 3 replications and 4 treatments : low thinning, 1:1 mechanical thinning, 2:2 mechanical thinning, and clearcutting. Average stand density after thinning was 40 trees plot$^{-1}$, equivalent to 250 trees ha$^{-1}$. The thinned teak had average diameter breast height (dbh) of 18.5 cm and a commercial volume of 0.2411 m$^3$ tree$^{-1}$. Thinning methods did not affect shoot density, but affected shoot growth. Three months after thinning, there were 11.6 shoots stump$^{-1}$. This dropped to 7.9 shoots stump$^{-1}$ at 1-year-old, due to competition. Average dbh and total height of 1-year-old shoots varied with available space after thinning having maximum figures for clearcutting (dbh 3.2 cm, height 2.91 m), followed by 2:2 thinning (dbh 2.6 cm, height 2.29 m), 1:1 thinning (dbh 2.5 cm, height 2.20 m), and low thinning (dbh 2.1 cm, height 1.75). The findings indicate that shoot growth is promoted by wider gaps after thinning due to the light-demanding characteristics of teak.

## INTRODUCTION

Teak is indigenous to the Indian peninsula and continental Southeast Asia in a discontinuous or patchy distribution pattern in India, Myanmar, Thailand and Lao PDR at latitudes between 9°-25°30'N and longitudes between 73°-104°30'E. Teak in Indonesia is considered to be naturalised (Kadambi 1972, Siswamartana 1999). An introduction of teak from India to Nigeria in 1902 was the first transfer out of Asia (Ball *et al.*1999). Now it is one of the most widely cultivated hardwood timber species in the world having a total plantation area of 2.25 million ha (Ball *et al.* 1999), although according to Kaosa-ard (1996), India and Indonesia alone had 2.6 million ha.

In Thailand, the first teak plantation was established in 1906 by the Royal Forest Department (RFD) in Phrae province. Dibbling or direct seeding methods applied initially have been replaced by stump planting since 1935. In 1968 the state enterprises, Forest Industry Organization (FIO) and Thai Plywood Company (TPC), started growing teak and extensive commercial planting by the private sector started in 1992 with financial support from the RFD's Reforestation Fund during the first five years. Total area of teak plantation in Thailand in 1998 was about 300 000 ha; 69% owned by RFD, 27% by FIO, and 4% by the private sector (Thaiutsa 1999). Teak is planted in the North (79%), Central Plains (12%), Northeast (9%) and South (0.1%). Spacings of 3 x 3 m and 4 x 4 m intercropped with upland crops such as

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upland rice and pineapple are the most common practice leading to a rotation of 30-40 years with 3-4 thinnings.

A major problem of teak plantations in Thailand is appropriate site selection. Growth and yields are site-dependent. Based on site quality analysis of Chanpaisaeng (1977), a 30-year-old rotation of teak in northern Thailand can produce as high as 184 $m^3 ha^{-1}$ from superior planting site (6.13 $m^3 ha^{-1} yr^{-1}$) with a mean of 140 $m^3 ha^{-1}$ (4.67 $m^3 ha^{-1} yr^{-1}$). Table 1 shows site quality index of plantation teak in the North of Thailand.

Productivity of teak in northern Thailand was found to be the lowest in a comparison of mean annual increment at 50 years rotation age on different sites in various countries (Table 2). For example, such figure was 4.70 $m^3 ha^{-1} yr^{-1}$ for the best site in Thailand (Chanpaisaeng 1977), but they were 10.0 $m^3 ha^{-1} yr^{-1}$ in India, 17.3 $m^3 ha^{-1} yr^{-1}$ in Myanmar, and 21.0 $m^3 ha^{-1} yr^{-1}$ in Indonesia (Ball *et al.*1999).

The degree of plantation manipulation is a factor affecting growth and yields of most planted trees including teak. Thinning is defined as removals made in an immature stand to stimulate the growth of trees that remain leading to increase total yield of useful material from the stand (Smith 1962). There are several methods of thinning. Mechanical thinning seems to be very common for the first thinning, while selection thinning may generate some income from the thinned wood due to cutting of the commercially dominant trees. The appropriate method of thinning, age of stand to be thinned, and thinning frequency vary with tree species, original spacing, planting site and preference of owners. In Myanmar, tree height determines the timing of the first two thinnings which are mechanical or modified mechanical method. Teak plantations with an initial spacing of 1.8 x 1.8 m are generally considered for the first mechanical thinning when the stems reach an average height of 7.6-9.1 m. The second thinning in good quality plantations is when stem height reaches 12.2-13.7 m (Myanmar Department of Forestry 1999). The intervals of thinning cycles at 10, 15, and 20 years of age are practised by the Thailand's FIO plantations for good sites, while such intervals would be 15, 22, and 30 years of age for poor site with the rotation length of 30 and 40 years, respectively.

**Table 1**. Commercial volume of plantation teak in northern Thailand

| Age (yr) | Site quality (30 yr) | | |
|---|---|---|---|
| | Poor | Medium | Good |
| | | $m^3 ha^{-1}$ | |
| 10 | 23 | 52 | 81 |
| 20 | 67 | 103 | 144 |
| 30 | 96 | 140 | 184 |
| 40 | 122 | 166 | 213 |
| 50 | 142 | 190 | 235 |
| 60 | 162 | 212 | 259 |

*Source*: Chanpaisaeng, 1977.

**Table 2.** Mean annual increment (MAI) at 50 years rotation on poor, average and best site classes

| Country | Site Classes | | |
|---|---|---|---|
| | Poor | Average | Good |
| | | MAI ($m^3 ha^{-1} yr^{-1}$) | |
| India | 2.0 | 5.8 | 10.0 |
| Myanmar | 4.3 | 8.7 | 12.0 |
| Indonesia | 9.6 | 13.8 | 17.6 |
| Thailand | 2.8[*/] | 3.8[*/] | 4.7[*/] |

*Source*: Ball *et al.*1999; [*/] Chanpaisaeng 1977.

As a result of thinning, new shoots may sprout from the stumps to form new stands in the following rotations. A stand originating vegetatively from stump sprouts is referred to as "coppice", which normally grows faster than seedlings and enables a much shorter rotation. Another advantage of a coppiced stand is the low cost of establishment because little or no site preparation is required for regeneration from stump sprouts. Coppicing ability varies with tree species and cutting conditions. Teak coppices well after clearcutting, however, its coppicing ability after thinning requires investigation.

The main objective of this research is to determine the effect of thinning methods on the ability of young teak to coppice which may result in a two-storey management system for teak plantations in future.

## MATERIALS AND METHODS

### Study Site

The study site was located at Thongphaphum Plantation belonging to the Forest Industry Organization (FIO) in Thongphaphum district, Kanchanaburi province, western Thailand at the latitude of 14°8'-14°46'N and the longitude of 98°37'-98°46'E. It is considered a relatively superior site for teak plantation because its elevation of about 400 m is about 300 m below the upper limit for growing teak in Thailand. Another advantage of Thongphaphum Plantation is its landform surrounded by limestone mountains resulting in Pakchong Soil Series of Reddish Brown Lateritic Soils and Oxic Palcustults. Top soil is as sandy clay loam about 30 cm deep. Some soil physical and chemical properties reported by Teejuntuk (1997) are summarised in Table 3.

**Table.3.** Physical and chemical properties of soil at Thongphaphum Plantation, Kanchanaburi

| Soil Property | Value |
|---|---|
| Sand % | 47.4 |
| Silt % | 24.3 |
| Clay % | 28.3 |
| Moisture % | 30.4 |
| Bulk density g cc$^{-1}$ | 0.93 |
| pH | 5.35 |
| Organic matter % | 8.06 |
| Total N % | 0.40 |
| Available P ppm | 7.78 |
| Exchangeable K ppm | 267 |
| Exchangeable Ca ppm | 1269 |
| Exchangeable Mg ppm | 391 |
| CEC meq 100 g$^{-1}$ soil | 24.1 |

*Source*: Teejuntuk 1997.

The climate of Thongphaphum Plantation is generally affected by monsoons and can be divided into hot, rainy and cold seasons. April is the hottest month with the average temperature of 36.7°C, while January is the coldest month with average temperature of 15.8°C . However, critical minimum and maximum temperature might range between 6-42°C. Rainy season starts from early May to late October with the average rainfall of 1765 mm yr$^{-1}$ and 156 rainy days yr$^{-1}$. Dry periods cover about 6 months, from early November to late April having only 187 mm of rainfall equivalent to 10.6% of the annual rainfall during such period.

The investigation was started in April 1997 at the 17-year-old teak plantation planted in 1980 with the original spacing of 4 x 4 m. One-year-old stumps were used as planting material. Survival rate prior to thinning experiment was 71.5% and the stand density was 447 trees ha$^{-1}$.

### Experimental Design

A completely randomised block design with 4 treatments and 3 replications was used. Methods of thinning were considered as treatments as follows:

A : Low thinning
B : 1:1 mechanical thinning
C : 2:2 mechanical thinning
D : Clearcutting

A plot of 40 x 40 m (0.16 ha) consisted of 81 planted teak. Two outer rows of each plot were treated as guard rows. Diameter breast height of all trees, including in buffer zones, was recorded prior to thinning, while total height was recorded from the thinned trees to estimate stem volume.

Aboveground biomass of stems and branches were measured by weighing. Numbers of sprouts as well as their heights and diameters were measured at 3 months and 1 year of age for statistical analysis. Parameters such as aboveground biomass of undergrowth, percentage ground cover, soil properties and light intensity were also recorded but they are not reported in this paper.

## RESULTS AND DISCUSSION

Three methods of thinning together with clearcutting resulted in differences in gap size and light intensity. Low thinning provided the smallest gap, followed by 1:1 mechanical thinning and 2:2 mechanical thinning, while clearcutting left no trees at all, i.e., the largest gap and full sunlight. Growth parameters of the thinned teak are in Table 4. Low thinning had the lowest dbh because of the small-tree cutting leading to minimum commercial volume per hectare.

Growth parameters of the trees from the clearcutting plot can be considered as the representative figures of this plantation. That is, the 17-year-old teak plantation has an average dbh of 21.1 cm, 109.38 t ha$^{-1}$ total biomass, commercial volume of 0.3433 m$^3$ tree$^{-1}$ and 171.87 m$^3$ ha$^{-1}$. The MAI of 10.11 m$^3$ ha$^{-1}$ yr$^{-1}$ showed that site quality of this plantation is superior to teak plantations in northern Thailand reported by Chanpaisaeng (1977), because of better soil factors, higher annual rainfall and many rainy days. Moreover, this MAI value is higher than the values of average site classes in India and Myanmar reported by Ball *et al.* (1999).

Table 5 presents the numbers of shoots per stump for 3 months and 1-year-old. However, they were not statistically significant between treatments. Reduction of the number of sprouts is a result of competition for light which is similar to the report of Sukwong *et al.* (1976) who studied the coppicing ability of teak in natural stands in the North and found that teak with dbh of 30 cm might have as many as 19 sprouts per stump after havesting. If intercropping is introduced to the coppiced stand, this competition would also reduce the yield of intercrops (Verinumbe and Okali 1985). Further decrease in the numbers of sprouts per stump will occur as they become older due to natural thinning. To manage the coppiced stands for commercial purpose, the sprouts should be thinned to leave only one sprout per stump.

Height and dbh growth of the 1-year-old shoots after thinning given in Table 6 showed that both height and diameter increased with increasing gap sizes. Shoots of low thinning had the smallest dbh (2.1 cm), followed by those of 1:1 mechanical thinning (2.5 cm), 2:2 mechanical thinning (2.6 cm), and clearcutting (3.1 cm). Total height also

**Table 5.** Numbers of sprouts per stump after thinning the 17-year-old teak

| Thinning | Number of shoots per stump | |
|---|---|---|
| | 3 months | 1 year |
| Low | 10.9 | 7.3 |
| 1:1 mechanical | 11.9 | 8.7 |
| 2:2 mechanical | 12.2 | 8.6 |
| Clearcutting | 11.5 | 7.1 |
| Mean | 11.6 | 7.9 |

**Table 4.** Growth parameters of the thinned teak from the 17-year-old plantation

| Thinning regime | Dbh | Commercial volume | | Biomass (t ha$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | (cm) | (m$^3$ tree$^{-1}$) | (m$^3$ ha$^{-1}$) | Stem | Branch | Total |
| Low | 14.8 | 0.1117 | 30.52 | 21.18 | 4.36 | 25.54 |
| 1:1 mechanical | 19.7 | 0.2866 | 74.37 | 37.44 | 8.34 | 45.78 |
| 2:2 mechanical | 18.3 | 0.2229 | 57.83 | 31.93 | 6.98 | 38.91 |
| Clearcutting | 21.1 | 0.3433 | 171.87 | 88.96 | 20.42 | 109.4 |

showed the same trend with the average of 2.6 cm for dbh and 2.3 m for height. Based on statistical analysis, both dbh and height were found to be significantly different at 95% confidence level. The figures also indicated that coppice sprouts grew faster than seedlings. Sukwong *et al.* (1976) suggested that coppiced teak should have dbh not larger than 30 cm in order to have maximum numbers of shoots per stump and total height of shoots. However, increased sprout number is of little importance if they are reduced to a single sprout per stump for commercial purposes.

**Table 6.** Diameter and total height of the 1-year-old shoots after thinning the 17-year-old teak

| Thinning | Diameter bh (cm) | Height (m) |
|---|---|---|
| Low | 2.1a | 1.75a |
| 1 : 1 mechanical | 2.5b | 2.20b |
| 2 : 2 mechanical | 2.6b | 2.29b |
| Clearcutting | 3.1c | 2.91c |
| Mean | 2.6 | 2.29 |

Numbers with a different letter are significantly different at the 5% level.

## CONCLUSION

Methods of thinning did not affect shoot density, but affected dbh and total height of shoots. Both height and diameter growth of new shoots varied with space available due to thinning, maximum for clearcutting, followed by 2:2 mechanical thinning, 1:1 mechanical thinning, and low thinning. The findings suggest that modified mechanical thinning, such as 2:2 mechanical thinning, would be the thinning method recommended for faster growth of new shoots, if the clearcutting is not able to be applied.

## REFERENCES

Ball, J.B., Pandey, D. and Hirai, S. 1999. Global overview of teak plantations. Paper to regional seminar on site, technology and productivity of teak plantations, Chiangmai, Thailand. 17p.

Chanpaisaeng, S. 1977. Productivity of teak plantation. M.S. Thesis, Kasetsart University, Bangkok. 57p.

Kadambi, K. 1972. Silviculture and management of teak. Stephen F. Austin State University, School of Forestry, Bulletin 24. 37p.

Kaosa-ard, A. 1996. Domestication and breeding of teak (*Tectona grandis* Linn.f.). RAS/91/004 Technical Paper No. 4. FAO, Bangkok. 53p.

Myanmar Department of Forestry. 1999. Teak plantation in Myanmar. In : Regional seminar on site, technology and productivity of teak plantations, Chiangmai, Thailand. 19p.

Siswamartana, S. 1999. Teak plantation productivity in Indonesia. Paper to Regional seminar on site, technology and productivity of teak plantation, Chiangmai, Thailand. 9p.

Smith, D.M. 1962. The practice of silviculture. Wiley, New York. 578p.

Sukwong, S.C., Charoenpaiboon, B., Thaiutsa, T., Kaewla-iad, and Suwannapinunt, W. 1976. Natural regeneration in dry teak forest after clearcutting. Kasetsart Journal. 9:55-67.

Teejuntuk, S. 1997. Surface soil properties and tree growth of mixed culture in Thongphaphum Plantation, Kanchanaburi. M.S. Thesis, Kasetsart University, Bangkok. 136p.

Thaiutsa, B. 1999. Current state of teak plantation technology in Thailand. Paper to Regional seminar on site, technology and productivity of teak plantation, Chiangmai, Thailand. 1p.

Verinumbe, I. and Okali, D.U.U. 1985. The influence of coppiced teak (*Tectona grandis* L.F.) regrowth and roots on intercropped maize (*Zea mays* L.). Agroforestry Systems 3: 381-386.

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# Site Characterisation and the Effects of Harvesting on Soil Tillage on the Productivity of *Eucalyptus grandis* Plantations in Brazil

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***Abstract***

Two commercial eucalypt sites were selected in São Paulo State, Brazil, to evaluate productivity and soil chemical and physical properties before clearcutting, and the effect of harvesting and soil tillage system on productivity of second rotation. At site 1, the *Eucalyptus grandis* plantation was 7 years old, on its first rotation, and reached 21 m mean height, 13.6 cm diameter breast height (dbh), an estimated commercial volume of 479 $m^3$ $ha^{-1}$ and a mean annual increment of 68 $m^3$ $ha^{-1}$ $year^{-1}$. At site 2, *E. grandis*, also on its first rotation, but 12-years-old, had 25 m mean height, dbh 16 cm, an estimated volume of 662 $m^3$ $ha^{-1}$ and a mean annual increment of 55 $m^3$ $ha^{-1}$ $year^{-1}$. Litter collected at site 2 before harvesting totalled 19.8 t $ha^{-1}$, and after harvesting and new planting, litter left on surface totalled 2.64 t $ha^{-1}$. At site 1, 31.3 t $ha^{-1}$ of litter accumulated before harvesting and 7.6 t $ha^{-1}$ after new planting. Soils of both sites are classified as Dark Red Latosol (Oxisol), having loam texture at site 2 and clay texture at site 1. Clay content difference between sites was around 10 %, available soil water content between sites varied less than 0.02 $cm^3$ $cm^{-3}$. Penetrometer soil resistance measured before harvesting and after new planting was less than 21 kg $cm^{-2}$, at 50 cm besides tree row, on both sites. Greater soil resistance measured at tree row was found at 15-cm depth, in both sites. Soil of site 1 has greater CEC, base saturation and organic matter content compared to site 2. One year after planting eucalypts growing on soil tilled with subsoiler with one shrank were smaller at site 2.

## INTRODUCTION

The harvesting of timber affects ecosystems in various ways, including degradation of site, reduced forest water supply and soil loss. 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, and leaching. However, plantation forestry not only offers opportunities for meeting wood demands and reducing deforestation by decreasing pressures on natural forests, but can restore degraded soils and enhance biodiversity (Parrotta 1992).

There is increasing information on nutrient cycling in tropical plantations which suggests long-term sustainable production will rely on management practices which maintain soil organic matter, conserve nutrient stores and minimise direct nutrient losses. The risk that plantation forestry will not be sustainable depends on the alignment of interdependent variables that include ecological capabilities of the site, intensity of management, impact on soil, water and other environmental values (Nambiar and Brown 1997).

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The greatest impacts from management inputs occur due to operations associated with harvesting, site preparation, planting and early silviculture, including fertilisation and weed control. Soil degradation on *Eucalyptus* sp. commercial plantations, due to heavy and intense harvesting machine traffic and soil tillage operations for regrowth or new plantings, influences soil structure, causing compaction, and plant growth, reducing its development (Greacen and Sands 1980). Soil deformation, caused by changes in soil physical and chemical properties, occurs mainly by: increasing soil resistance to root penetration, reducing aeration, changing soil water and heat flux and soil water and nutrient availability (Lacey *et al*. 1994, Rab 1994, Shetron *et al*. 1988). This can cause plant development restrictions, depending on soil type, climatic conditions, type and stage of plant development.

Maintenance of productivity on forest areas has been always a problem, considering the size of plantation areas and, by being private property, they would be used to produce the same species for many years. Among natural factors that affect plant productivity, soil is the most easily modified by management. Restoring soil physical conditions, that can reduce plant development, can be reached by soil tillage. Completely reclaiming soil conditions is difficult and this implies greater costs, lowering profits and reducing sustainability of these areas.

The main objectives of this study were as follows:

- to evaluate the impact in the long-term of different harvesting and soil tillage methods on compaction and site productivity of eucalypt plantations;
- to develop soil tillage systems to alleviate soil compaction effects and to reclaim eucalypt plantation sites; and

**Table 1**. Soil chemical properties from the two *E. grandis* sites

| Site | Soil depth | pH | CEC | Base saturation | Al saturation | Organic matter |
|---|---|---|---|---|---|---|
| | cm | $CaCl_2$ | $c.mol_c dm^{-3}$ | % | % | $g dm^{-3}$ |
| Mogi-Guaçú (site 2) | 0-10 | 3.78 | 8.53 | 11.8 | 62 | 20.2 |
| | 10-20 | 3.99 | 7.16 | 12.8 | 59 | 12.0 |
| | 20-30 | 4.03 | 6.21 | 14.6 | 51 | 8.1 |
| | 30-50 | 4.10 | 5.82 | 14.1 | 48 | 7.0 |
| São Miguel (site 1) | 0-10 | 3.83 | 10.83 | 14.4 | 61 | 37.6 |
| | 10-20 | 3.90 | 10.00 | 18.4 | 53 | 29.4 |
| | 20-30 | 3.92 | 9.45 | 16.9 | 55 | 25.7 |
| | 30-50 | 3.90 | 7.97 | 19.5 | 50 | 15.2 |

**Table 2**. Soil particle distribution analyses from the two *E. grandis* sites

| Site | Soil depth | Sand | | | Silt | Clay |
|---|---|---|---|---|---|---|
| | | total | coarse | fine | | |
| | cm | $g 100 g^{-1}$ | | | | |
| Mogi-Guaçú | 0-10 | 69 | 48 | 21 | 11 | 20 |
| | 10-20 | 68 | 45 | 23 | 10 | 23 |
| | 20-30 | 69 | 45 | 24 | 9 | 23 |
| | 30-50 | 67 | 43 | 24 | 8 | 25 |
| São Miguel | 0-10 | 51 | 26 | 25 | 19 | 31 |
| | 10-20 | 49 | 22 | 26 | 19 | 33 |
| | 20-30 | 50 | 21 | 29 | 16 | 34 |
| | 30-50 | 49 | 20 | 29 | 16 | 36 |

- to test different residue management in eucalypt site exploration and its effects on site sustainability.

## SITE DESCRIPTION

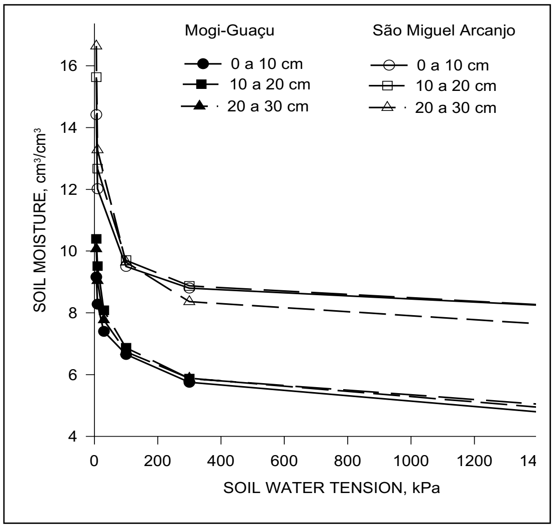
Site 1. – Suzano Paper and Cellulose Co., São Miguel Arcanjo- São Paulo State (SP) (23°51’S, 47°46’W and 715 m asl), a dark red clayey latosol, in a commercial *E. grandis* plantation aged 7 years. Site 2 – Champion Co., in Mogi-Guaçu-SP (22º07’S, 47°03’W and 680 m asl), a dark red sandy latosol, in a commercial *E. grandis* plantation aged 12 years.

Chemical data and particle distribution data from soils of both sites are given in Tables 1 and 2. In Fig. 1, curves of soil water retention are presented for soils from both sites and at three different soil depths. Soil chemical and physical analyses were made before harvesting.

### Methods

At site 1, São Miguel Arcanjo, seven treatments (T1 to T7) were tested including different levels of fertilisers, two types of subsoiling and residue management, distributed in randomised blocks, four replications and 100 trees per plot.

**Figure 1.** Soil water retention curves from two sites growing *E. grandis*, at three soil depths, before harvesting



T1. All above ground organic residue removed from the area, including crop tree residue and accumulated litter. Soil surface organic matter was not disturbed. Soil tillage for next plantation was performed with one unit subsoiling and fertiliser dose will be 80 g tree$^{-1}$ of the formula 8-32-16. For eucalypt harvesting a feller was used;

T2. All trees were harvested. Residue from crop trees, as branches and bark, was left on site. Soil tillage and fertilisation was as in T1;

T3. Same procedures for harvesting and fertilisation as in T2, soil tillage for next plantation was performed with a two unit subsoiling;

T4. Same as T3, but soil tillage with a three unit subsoiling;

T5. Same procedures for harvesting and soil tillage as in T2, but an increase the fertilisation level compared to the preceding treatments;

T6. Harvesting and soil tillage system as in T3 and fertilisation as in T5.

T7. Harvesting and soil tillage system as in T4 and fertilisation as in T5.

At site 2, Mogi-Guaçu eight treatments (T1 to T8) were tested including different levels of industry residue, two soil tillage systems and tree residue management, minimised in randomised blocks, five replication and 60 trees per plot, with the following treatments:

T1. All above ground organic residue including crop trees and litter was removed from the plots. The soil organic matter on the surface was not disturbed. Soil for next plantation was tilled with a three unit shrank subsoiler and fertilisation was 80 g tree$^{-1}$ with NPK 8:32:16.

T2. All commercial stems were harvested and removed from the site, including tree bark. Others crop residues were left on site surface well-distributed. Soil tillage and fertilisation were the same as T1;

T3. Harvesting methods were those commonly used by the owner, soil tillage and fertilisation were the same as in T1;

T4. Harvesting and soil tillage were the same as in T3, and fertilisation was with 7.5 t ha$^{-1}$ of cellulose residues and 2 t ha$^{-1}$ of lime;
T5. Harvesting and fertilisation were the same as in T4, and soil tillage was performed with an one-unit subsoiler;
T6. Harvesting and soil tillage were the same as in T4, and fertilisation was completed with 15 t ha$^{-1}$ of cellulose residues and 4 t ha$^{-1}$ of lime;
T7. Harvesting and soil tillage were the same as in T5, and fertilisation was the same as in T6;
T8. Harvesting and soil tillage were the same as in T4, and fertilisation was the same as in T6.

## Data Collection

### *Preharvest stand*

Twenty eucalypt trees from 20 planting lines (400 trees) had their height and dbh measured before harvesting to estimate wood volume and biomass produced. Litter production was also estimated before harvesting and samples taken for chemical analysis.

### *Tree growth*

The height and diameter of 12 eucalypts in three planting lines on each treatment plot were measured at 1 year after planting.

### *Soils*

Bulk density, soil resistance to penetration and hydrological properties were measured in each treatment before harvesting, and at 1 year after new planting. At the same time, samples were collected from the soil profile for chemical analysis.

# RESULTS AND DISCUSSION

All measurements taken from 12-year-old eucalypt trees were greater than those from 7-year-old trees (Table 3). However, mean annual increment was greater for the 7-year-old tree site. This is probably due to competition and the row and tree intervals being used, at both sites 3 x 2 m. Soil at site 1 has better chemical properties, especially CEC, base saturation and organic matter content (Table 1). Soil at site 1, has larger percentage of clay (Table 2) which is an advantage in terms of plant nutrient and water retention. Fig. 2 shows that soil water available content is very low (less than 10%) for both sites, considering the amount of water between 6 and 1500 kPa soil water tension. About 2% more soil water is available in soil from site 1 than from site 2.

**Figure 2.** Available soil water content at the two *E. grandis* sites before harvesting

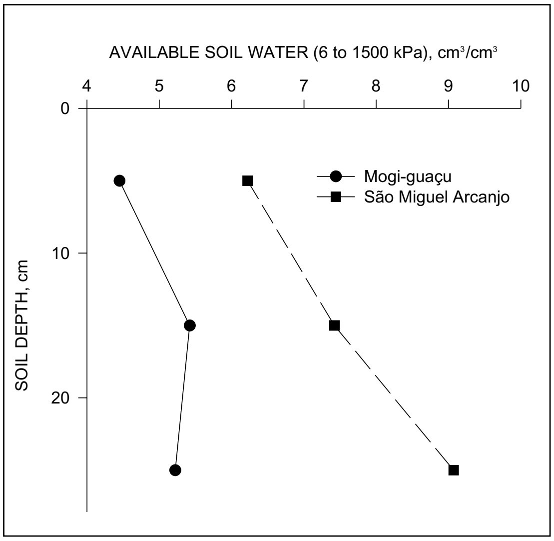


**Table 3.** *Eucalyptus grandis* productivity at Mogi-Guaçu and São Miguel Arcanjo

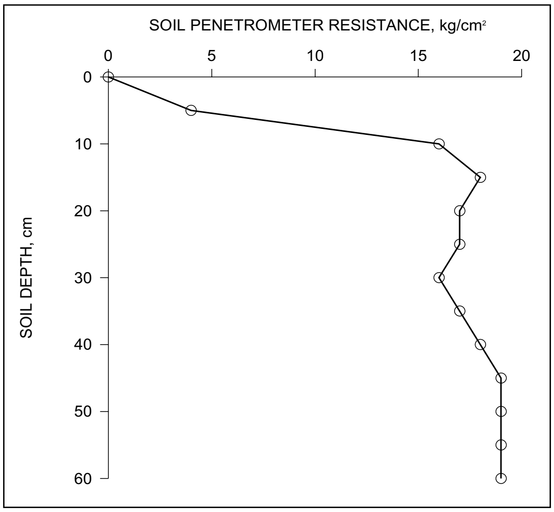
| Site | Age<br>yr | Height<br>m | dbh<br>cm | Volume<br>$m^3$ | Survival<br>% | Volume<br>$m^3$ $ha^{-1}$ | MAI<br>$m^3$ $ha^{-1}yr^{-1}$ |
|---|---|---|---|---|---|---|---|
| Mogi-Guaçú | 12 | 25.4 | 15.8 | 0.554 | 80 | 663 | 55.2 |
| São Miguel | 7 | 21.0 | 13.6 | 0.394 | 81 | 479 | 68.4 |

Litter collected at site 2 before harvesting, totalled 19.8 t ha$^{-1}$ and after harvesting and new planting, litter left on surface of plots without residue totalled 2.64 t ha$^{-1}$. At site 1, there was 31.3 t ha$^{-1}$ of litter before harvesting. After harvesting and new planting the amount of litter on plots with no residue left was 7.6 t ha$^{-1}$. These two sites had a very different harvesting procedures. At site 1, only commercial stems were taken from the plantation area, while in site 2, almost the entire tree was taken from the site. At site 2, the entire tree was skidded to the border area, where debarking and other procedures were performed.

There was little difference in nutrient content in litter obtained from both sites before harvesting. Among the macronutrients, content of P and Ca differed in litter from the two sites, and Fe content, among the micronutrients. The differences in P and Ca content in litter could be a matter of fertiliser quantities used. The larger amount of Fe presented in litter from site 1 could be a matter of soil type, especially due to its greater clay content.

Soil penetrometer resistance at site 1 was performed before harvesting and after new planting. Figure 3, based on the means of 22 points, shows data for soil resistance only before harvesting. Measurements were made 50 cm apart from the planting row. Considering a limiting value 20 kg cm$^{-2}$, no sample reached this limit.

**Figure 3.** Soil penetrometer resistance in a dark red clayey latosol under a commercial *E. grandis* plantation at São Miguel, Brazil



At site 2, all seven treatments were measured one year after planting *E. grandis* (Fig. 4). The tree heights in treatments that received cellulose residues as additional fertilisation did not differ statistically. Tree heights differed statistically in those treatments that received only chemical fertilisers at planting time. It is important to point out that the only two treatments prepared with a one-unit-shrank subsoiler were the tallest. Soil water availability must be playing an important role in tree growth. The treatment that had all harvesting residues removed from the soil surface had the lowest tree height, and when all residues were kept on soil surface there was better growth than the normal harvesting treatment. Treatment 6 that received the highest level of fertilisation had the greatest standard deviation (20%). and was ranked second for height growth.

Soil resistance data obtained with a penetrometer before harvesting, immediately after new planting and one year after planting are summarised in Fig. 5, for site 2 only. Measurements of soil penetrometer resistance were made counting the number of impacts to go through a 10 cm of soil layer and the data transformed by an equation presented by Stolf (1991). They represent an average (20 points) of the measurements of soil resistance before harvesting. and after soil tillage and new planting. Measurements were taken in two different plots:

**Figure 4.** Height growth of one-year-old *E. grandis* under different systems of soil tillage, fertilisation and harvesting, Mogi-Guaçu, Brazil

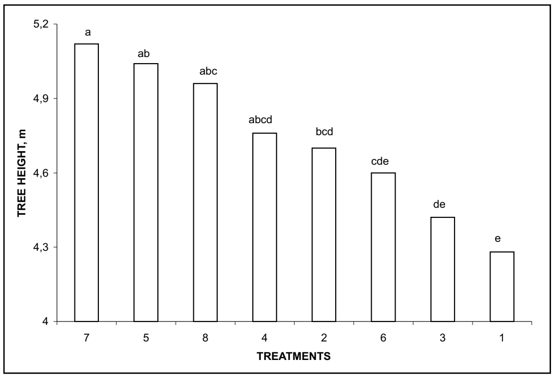
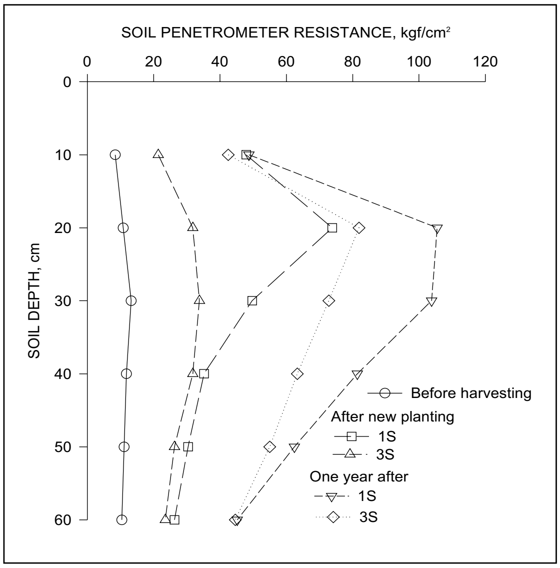


**Figure 5.** Soil penetrometer resistance using different tillage systems, in a *E. grandis* plantation, Mogi-Guaçú, Brazil



1. 3S–soil tilled with a three-shrank subsoiler; and
2. 1S–soil tilled with a one shrank subsoiler.

Differences in soil moisture at measuring times were less than 3% and it can be seen that harvesting operations can increase soil resistance very much (Fig. 5). Measurements were made 50 cm from the planting line, and it can be observed that tilling with a one-shrank subsoiler did not overcome most of the soil compaction, or at least not as well as a three-shrank subsoiler. One year after new planting, soil resistance has increased where soil was tilled with a three-shrank-unit subsoiler and did show much variation from the one-unit-shrank subsoiler tillage system. Even at greater soil resistance, *E. grandis* growing in soil tilled with one-unit-shrank subsoiler had greater height growth. Perhaps, for this kind of soil, with a high sand content and very high water permeability due to the dominance of macropores, a little compaction may increase soil water retention and less soil movement could reduce deep-water drainage.

## CONCLUSIONS

Based on data collected before harvesting it was concluded:

- *E. grandis* volume production was greater at site 2 with 12-year-old trees;
- soil fertility at site 1 was greater than at site 2, based on CEC, base saturation and organic matter content;
- soil from site 1 had higher clay content and more soil water available for plants.

From data collected one year after new planting at site 2 (Mogi-Guaçu), it was concluded:

- trees had greater height growth in treatments where soil was tilled with a one-shrank-unit subsoiler;
- soil penetrometer resistance was higher in those treatments with taller trees; and
- retention of all tree residues on the soil surface increased tree height growth compared to normal harvesting when the same soil tillage system and fertilisation level were applied.

**Table 4.** Nutrient content of the litter before clearcutting of *E. grandis* at two sites at different tree ages

| Sites | N | P | K | Ca | Mg | Cu | Fe | Mn | Zn |
|---|---|---|---|---|---|---|---|---|---|
| | | | $g\ kg^{-1}$ | | | | $mg\ kg^{-1}$ | | |
| Mogi-Guaçú | 6.89 | 0.23 | 0.56 | 8.61 | 0.77 | 10 | 1341 | 232 | 13 |
| São Miguel | 7.01 | 0.44 | 0.54 | 5.57 | 0.90 | 8.9 | 4013 | 346 | 24 |

## REFERENCES

Greacen, E.L. and Sands, R. 1980. Compaction of forest soils: a review. Australian Journal of Soil Research 18: 163-189.

Lacey, S.T., Ryan, P.J., Huang, J. and Weiss, D.J. 1994. Soil physical property change from forest harvesting in New South Wales. Research Paper. 25. State Forests of NSW. West Pennant Hills, Australia. 81p.

Nambiar, E.K.S. and Brown, A.G. 1997. Towards sustained productivity of tropical plantations: science and practice. *In*: Nambiar, E.K.S. and Brown, A.G. (eds.). Management of soil. nutrients and water in tropical plantation forests. 527-557. ACIAR Monograph no. 43. Australian Centre for International Agricultural Research, Canberra.

Parrotta, J. 1992. The role of plantation forests in rehabilitating degraded tropical ecosystems. Agriculture Ecosystems and Environment 41: 115-133.

Rab, M.A. 1994. Changes in physical properties of a soil associated with logging of *E. regnans* forest in southern Australia. Forest Ecology and Management 70: 215-229.

Shetron, S.G., Sturos, J.A., Padley, E. and Tretin, C. 1988. Forest soil compaction: effect of multiple passes and loadings on wheel track surface soil bulk density. Northern Journal of Applied Forestry 5: 120-123.

Stolf, R. 1991. Teoria e teste experimental de fórmulas de transformação dos dados de pentrômetro de impacto em resistência do solo. Revista Brasileira de Ciência do Solo, Campinas-SP. 15: 229-235.

# 20

# Quantification of the Biomass and Nutrients in the Trunk of *Eucalyptus grandis* at Different Ages

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***Abstract***

The accumulation and cycling of nutrients in planted forest is essential to the establishment of management practices that can lead to the sustainable production of the forest site. The uptake, accumulation and release of nutrients depend on tree age and stage of development. The knowledge of accumulation and cycling of nutrients allows the estimation of output and replacement of nutrients to the forest site. This makes it possible to correct nutritional disorders caused by the use of inadequate management techniques. The usual method of sampling biomass and nutrients is always destructive making it impossible to establish permanent plots for nutritional monitoring. This study aimed at selecting models to estimate the biomass (volume and weight) and the nutrient contents in different parts of the trunk of *Eucalyptus grandis*, and reducing costs of sampling and analysis. Forty-five trees were selected from the dominant class (15 trees), co-dominant (15 trees) and suppressed (15 trees) in commercial plantations of *E.grandis* at ages 3, 5 and 7 years, in the municipality of Itatinga, SP, Brazil. Samples were taken of bark, sapwood and heartwood separately. Models to estimate volume and weight in the different components of the trunk were generated from the diameter at breast height (dbh) using regression analysis. Models to estimate content of N, P, K, Ca and Mg in the bark, sapwood and heartwood from the nutrient contents in a section of the trunk were also defined, so enabling a recommendation for non-destructive sampling.

## INTRODUCTION

Soil analysis is not an efficient tool for monitoring nutritional status of trees. The presence of nutrients in the soil does not mean that the tree is satisfactorily nourished. The availability of nutrients to the trees is conditioned by the content of water in the soil, soil aeration, soil temperature, soil microorganisms and the efficiency of the root system to absorb nutrients (Raij 1981). Samples of tree tissues are valuable tools to establish the relationship between growth and nutritional status of the trees. However some factors can modify the nutrient contents of the tree tissues. Among them are the sampling criteria of Lavender and Carmichael (1966), the position of the sample in the tree, the season of the year and the age of the sampled material (Evans 1979, Silva 1983, Bellote 1990). Leaves are not the only part of the tree able to represent the nutritional status of the trees, however they have been recommended for monitoring most of the nutrients (Smith 1962). Nutrient content of other parts of the trees are considered for estimating export and efficiency of utilisation of nutrients (Silva 1983). Variations of nutrient contents in the same component has been detected for instance from the base to the top of the trees (Attiwill 1979) and in the radial direction from the heartwood to the sapwood (Ferreira *et al.* 1993). These variations enhanced the importance of

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quantifying the proportion of heartwood and sapwood to infer the processes of mobilisation and translocation of nutrients in the stem.

Research on distribution and accumulation of nutrients in the stem and other compartments of *Eucalyptus* trees in plantations, has intensified since the early 1980s. These studies are very important for estimation of nutrient removals from the site, identification of more efficient trees and species, and nutritional implications of whole tree harvesting (Bellote 1979, Silva 1983, Pereira *et al*. 1984). Furthermore, the knowledge of nutrient quantities in different parts of *Eucalyptus* trees is useful for the estimation of the nutritional rotation age, and replacement of nutrients to the soil.The precision of the estimates of quantities of nutrients removed depends on a better knowledge of the sampling and its precision. So, the main objectives of this paper are:

- To improve the precision of the estimates of nutrients in different compartments of the tree, by improving sampling procedures;
- To reduce costs of sampling and analyses of samples;
- To select mathematical models that enable estimation of accumulation and export of nutrients, volume and biomass by non-destructive methods.

## MATERIALS AND METHODS

Trees of *E. grandis* were sampled from plantations 3, 5 and 7 years old, planted at 3 x 2 m spacing in the municipality of Itatinga. All areas belong to Companhia Suzano de Papel e Celulose S.A, a pulp and paper forest enterprise. A total of 45 trees per age group, from three different canopy classes, (dominant, co-dominant and suppressed trees), were sampled according to the method of Zöttl and Tschinkel (1971). Wood discs were collected from the base to the top at 1 m intervals, including the diameter breast height (dbh), to a minimum diameter 4 cm. Diameters with and without bark were measured and also the extent of heartwood and sapwood, when heartwood was present. The specific gravity of each sample was estimated according to the M14/70n ABCP (Brazilian Association of Pulp and Paper) rule. Also, samples were collected from each disc for nutrient content determination. The total volume including bark, sapwood and heartwood was estimated using the regressions of Silva (1996). The total content of nutrients in the bark, sapwood and heartwood was obtained by adding the contents of each segment. Mathematical models were developed through regression analysis. They were intended to evaluate contents of nutrients in the different compartments by means of non-destructive methods and ease access sampling points.

## RESULTS AND DISCUSSION

Removal of stems with bark is the component that most contributes to the export of nutrients from the site. Table 1 gives the quantities of nutrients in a *Eucalyptus grandis* trunk at ages 3, 5, and 7 years. Nutrient accumulation was greater between the third and the fifth years (223%) than between the fifth and seventh years (20%). Competition among the trees is probably the reason for the decrease observed. The quantities of Ca, K and P increased from the third to the seventh year, while N leveled off after the third year and Mg decreased. The reason for the decrease of Mg content is the internal cycling of the nutrient for new tissues and a possible lower demand as age increased.

The mathematical models for estimation of nutrient contents in the bark of *E. grandis* at 3, 5, and 7 years old are presented in Table 2. Segments of the bark from different positions in the stem were selected as independent variables. To estimate the contents of the nutrients it is emphasised that all samples for all nutrients studied can be taken from 1-2 m stem height. At age 3 years the squared correlation coefficients ($r^2$) were all above 0.96 and the highest standard deviation obtained was 18.5%. The precision shown by these values is more than sufficient for the objectives of this paper. Almost the same results can be reported for the ages 5 and 7 years, and for different nutrients in the bark. The squared correlation coefficients were no lower than 0.943 and the maximum standard

**Table 1.** Nutrient accumulation and biomass of the trunk of *Eucalyptus grandis* at ages 3, 5 and 7 years

| Age (yr) | Nutrient accumulation (g) | | | | | Biomass (kg) |
|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | |
| 3 | 44.5 | 5.5 | 43.9 | 44.9 | 11.7 | 38.8 |
| 5 | 78.5 | 10.6 | 56.0 | 87.0 | 28.5 | 88.8 |
| 7 | 78.1 | 18.4 | 67.1 | 107.9 | 23.2 | 106.8 |

**Table 2.** Equations for indirect estimation of nutrient accumulation in the bark of Eucalyptus grandis at ages 3, 5 and 7 years

| | Nutrient/Equation | $r^2$(1) | $S_{XY}$%(2) |
|---|---|---|---|
| 3 years | | | |
| | $N = 10,2536^* N_{1m}$ (3) | 0.98 | 12.81 |
| | $P = 8.7925^* P_{1m} + 10.1343^*{}_{1.3m}$ | 0.97 | 18.51 |
| | $K = 41.7454^* K_{1.3m}$ | 0.99 | 8.89 |
| | $Ca = 24.3941^* Ca_{1.3m}$ | 0.99 | 12.39 |
| | $Mg = 8.8574^* Mg_{1m}$ | 0.99 | 1.98 |
| 5 years | | | |
| | $N = 85.8013^* N_{1.3m}$ | 0.95 | 23.30 |
| | $P = 9.9600^* N_{1.3m}$ | 0.99 | 17.08 |
| | $K = 52.4622^* K_{1.3m}$ | 0.90 | 14.80 |
| | $Ca = 4.7158^* Ca_{base}$ | 0.96 | 22.33 |
| | $Mg = 11.2591^* Mg_{1m}$ | 0.95 | 23.42 |
| 7 years | | | |
| | $N = 50.9402^* N_{1.3m}$ | 0.98 | 12.92 |
| | $P = 2.7638^* N_{1.3m} + 13.3973^* N_{1m}$ | 0.98 | 14.25 |
| | $K = 6.4473^* N_{1.3m} + 31.2538^* N_{1m}$ | 0.96 | 21.16 |
| | $Ca = 4.9205^* Ca_{1m} + 18.0455^* Ca_{1.3m}$ | 0.98 | 13.52 |
| | $Mg = 48.0414^* Mg_{1.3m}$ | 0.97 | 18.16 |

Note: (1) squared correlation coefficient; (2) standard deviation % (3) 1 and 1.3. indicate samples at 1.0 m and 1.3 m height

deviations no higher than 23.4%. All samples needed for the estimates can be taken from the base, 1.0 and 1.3 m height in the trunk, as detailed in Table 2.

The rate of biomass accumulation of bark was lower than the whole trunk biomass (Table 1) for all ages. There is a tendency of levelling the relative amount with age. The bark represents 10.4%, 8.0% and 7.5% of the biomass of the trunk for ages 3, 5 and 7 years, respectively. Also, *E. grandis* accumulates relatively small quantities of nutrients in the bark (10% of N, 20% of P and 25% of K) as compared to the total nutrients in the leaves. However, depending on species, the bark can accumulate 39-48% of the total Ca present in the crown. Despite accumulating less quantities of mobile nutrients in the bark, they are in an available form and play an important role in the growth of new branches (Bowen and Nambiar 1984). The bark also accumulates larger quantities of Ca and Mg than the sapwood and heartwood. The rate of Ca accumulation in the bark is higher from the third to the fifth year and lower from the fifth to seventh year (Table 3). This trend was also observed for K and P, but in a lesser rate. A similar behaviour to K and P were observed for Mg and N with higher accumulation being from the third to the fifth year. This behaviour can be associated with the mobility of these elements in the tissues and also with an increase of the amount of dead tissues in the bark. The quantity of P in the bark increased with the age.

The coefficients of the mathematical models for the quantification of nutrient contents in the sapwood of *E. grandis* are presented in Table 3 and the quantities of nutrients accumulated with age in Table 4. The estimates were obtained from small segments of sapwood collected at the base of the trees, and from 1.0 m and 1.3 m up the trunk.

Models for estimating contents of nutrients in the sapwood had satisfactory precision as shown by the squared coefficient of correlation values, low standard deviations and acceptable distribution of residuals obtained (Table 4). The precision of the equation coefficients for Ca, K, N and Mg was higher from the third to the fifth year. This can be explained by the maximum accumulation of nutrients occurring when trees are 7 years old. Also the distribution of the standard deviations improved as the nutrient quantities mounts in the trunk reached the maximum accumulated at age seven years.

The quantities of Ca and Mg in the bark of *E. grandis* is higher than in sapwood at 3, 5 and 7 years old. On the other hand, N, P and K were higher in the sapwood than in the bark. (Table 5). The Mg and N had similar trends of accumulation as in the bark but even more intensive at age 5 years. A comparison between the biomass of the trunk and the biomass of sapwood shows that sapwood represents 88.5, 58.2 and 56.4% of

**Table 3.** Nutrient accumulation and biomass of the bark of *Eucalyptus grandis* at 3, 5 and 7 years of age

| Age (yr) | Nutrient accumulation (g) | | | | | Biomass (kg) |
|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | |
| 3 | 14.15 | 2.26 | 11.81 | 33.07 | 6.27 | 4.2 |
| 5 | 23.42 | 4.10 | 17.18 | 64.15 | 13.77 | 7.1 |
| 7 | 21.22 | 8.61 | 20.48 | 77.14 | 12.08 | 8.0 |

**Table 4.** Equations for the estimation of nutrient quantities in the sapwood of *Eucalyptus grandis* at age 3, 5 and 7 years

| | | Nutrient/Equation | $r^2$(1) | $S_{XY}$%(2) |
|---|---|---|---|---|
| 3 years | | | | |
| N | = | $35.7751^* N_{1m}$ (3) | 0.98 | 13.33 |
| P | = | $39.0684^* P_{1.3m}$ | 0.98 | 14.83 |
| K | = | $38.1580^* K_{1.3m}$ | 0.98 | 14.08 |
| Ca | = | $6.6860^* Ca_{base}$ | 0.98 | 17.88 |
| Mg | = | $35.6887^* Mg_{1.3m}$ | 0.97 | 17.71 |
| 5 years | | | | |
| N | = | $14.3834^* N_{1m}$ | 0.98 | 14.55 |
| P | = | $68.1484^* P_{1.3m}$ | 0.98 | 16.70 |
| K | = | $12.1259^* K_{1m}$ | 0.98 | 14.63 |
| Ca | = | $8.8852^* Ca_{base}$ | 0.95 | 23.89 |
| Mg | = | $52.9199^* Mg_{1.3m}$ | 0.98 | 12.92 |
| 7 years | | | | |
| N | = | $6.8581^* N_{1.3m} + 33.2438^* N_{1m}$ | 0.99 | 8.48 |
| P | = | $27.2632^* P_{base} + 30.9341^* P_{1.3m}$ | 0.87 | 21.71 |
| K | = | $13.5624^* K_{1m}$ | 0.99 | 9.36 |
| Ca | = | $15.3568^* Ca_{1m}$ | 0.98 | 14.18 |
| Mg | = | $54.2122^* Mg_{1.3m}$ | 0.99 | 11.97 |

Note: (1) squared correlation coefficient; (2) standard deviation % (3) at base and 1.0 m and 1.3 m height.

the total biomass for ages 3, 5 and 7 years respectively. So the proportion of trunk biomass increased relatively more than the sapwood biomass. This can be explained by the increase in the heartwood biomass after the third year.

Nitrogen, P, Ca and K were higher in the sapwood than in the bark. The same nutrients also show a trend of continuous accumulation in the sapwood through the rotation. The coefficients obtained for the models developed in order to estimate nutrient quantities in the heartwood of *E. grandis* are presented in the Table 6. In general the squared coefficients of correlation were high. The lower values were obtained for Ca at 3 years and K at 5 years. The distribution of the standard deviations was not satisfactory, mainly at younger ages, due possibly to the differentiation of the sapwood into heartwood and a heterogeneous migration of the mobile nutrients generated very different concentrations of nutrients in the heartwood for the different trees at the same age.

An approximate estimate shows that sapwood accumulates 2.5 to 3.0 times more nutrients than heartwood (Tables 5 and 7). This strongly suggests that the nutrients migrate to the sapwood and other parts of the trees in a process similar to the migration of nutrients from old and senescent leaves to new tissues (Marschner 1995). The larger differences between sapwood and heartwood relate to K. Although heartwood is 63.9% of the sapwood

**Table 5.** Nutrient accumulation and biomass of the sapwood of *Eucalyptus grandis* at ages 3, 5 and 7 years

| Age (yr) | Nutrient accumulation (g) | | | | | Biomass (kg) |
|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | |
| 3 | 30.3 | 3.2 | 32.0 | 11.8 | 5.4 | 35.9 |
| 5 | 38.4 | 6.0 | 36.0 | 11.7 | 10.8 | 51.7 |
| 7 | 41.3 | 9.2 | 43.4 | 14.4 | 7.8 | 60.3 |

**Table 6.** Equations for the determination of nutrient quantities in *Eucalyptus grandis* heartwood at ages 3, 5 and 7 years

| Nutrient/Equation | | | $r^2$(1) | $S_{XY}$%(2) |
|---|---|---|---|---|
| 3 years | | | | |
| N | = | $4.6722 * N_{1m}$ (3) | 0.97 | 17.03 |
| P | = | $4.7796 * P_{1.3m}$ | 0.98 | 14.49 |
| K | = | $7.5584 * K_{base} + 3.1887 * K_{1.3m}$ | 0.98 | 10.56 |
| Ca | = | $4.4865 * Ca_{1m}$ | 0.96 | 18.00 |
| Mg | = | $0.1705 * Mg_{base} + 1.5451 * Mg_{1m}$ | 0.98 | 2.10 |
| 5 years | | | | |
| N | = | $33.2659 * N_{1.3m}$ | 0.99 | 9.27 |
| P | = | $33.4577 * P_{1.3m}$ | 0.99 | 8.91 |
| K | = | $7.3175 * K_{base}$ | 0.98 | 15.35 |
| Ca | = | $34.5843 * Ca_{1.3m}$ | 0.99 | 7.40 |
| Mg | = | $9.9419 * Mg_{1m}$ | 0.99 | 8.20 |
| 7 years | | | | |
| N | = | $35.5906 * N_{1.3m}$ | 0.99 | 9.11 |
| P | = | $35.1882 * P_{1.3m}$ | 0.99 | 9.81 |
| K | = | $-2.7928 * K_{base} + 48.7976 * K_{1m}$ | 0.99 | 5.53 |
| Ca | = | $36.0385 * Ca_{1.3m}$ | 0.99 | 9.16 |
| Mg | = | $35.7885 * Mg_{1.3m}$ | 0.99 | 7.82 |

Note: (1) squared correlation coefficient; (2) standard deviation % (3) at base and 1.0 m and 1.3 m height

**Table 7.** Nutrient accumulation and biomass of *Eucalyptus grandis* heartwood at ages 3, 5 and 7 years.

| Age (yr) | Nutrient accumulation (g) | | | | | Biomass (kg) |
|---|---|---|---|---|---|---|
| | N | P | K | Ca | Mg | |
| 3 | 0.04 | 0.0007 | 0.018 | 0.02 | 0.007 | 51.22 |
| 5 | 16.65 | 0.58 | 2.8 | 11.17 | 3.91 | 29953.99 |
| 7 | 15.61 | 0.59 | 3.22 | 13.34 | 3.29 | 38559.01 |

volume, at age 7 years, the amount of K is some fifteen times less, which implies a smaller removal of the nutrient relative to the wood volume exploited.

Heartwood biomass is quite undeveloped until the third year, mainly for trees with dbh smaller than 13 cm (Bellote *et al.* 1993). For instance, heartwood is 0.14, 57.9 and 63.9% of the total biomass of the trunk at ages 3, 5 and 7 years respectively. As shown in Tables 5 and 7, there is a high migration of nutrients when heartwood is being formed, and this is a process extremely important to the economy of nutrients. The mobilisation does not occur for all nutrients. For instance, Ca is a quite immobile nutrient and is a component of the tree tissues being present in the cellular membrane. The fact that sapwood and heartwood have almost the same quantities of Ca, despite the heartwood biomass being much smaller, is clearly due to a higher concentration of Ca.

The bark, which represents 7.5% of the trunk at age 7 years old, accumulates more N, P, K, Ca, and Mg than branches and heartwood. It is emphasised that the bark is a component that accumulates larger quantities of Ca than the sapwood (Silva 1983).

In the bark and sapwood, N and Mg quantities increased between the third and the fifth year. However, after that age, N and Mg quantities levelled off although bark and heartwood biomass increased. This suggests an intensive migration of mobile nutrients as sapwood is transformed into heartwood. As an important mechanism for the economy of nutrients and the sustainability of forest ecosystems, the timing of heartwood formation should be considered when exploitation plans are developed.

## CONCLUSION

The sampling methodology proposed in this paper shows acceptable results for estimating volume, biomass weight and nutrients content in different components of *E. grandis* trees. The methodology proposed allows the determination of nutrient contents by means of non-destructive sampling and the use of mathematical equations to estimate the accumulation of nutrients. Samples can be taken up to a maximum trunk height of 2 m without felling the trees. The precision of the equations is acceptable to estimate accumulation and removal of nutrients through harvesting.

## REFERENCES

Attiwill, P.M. 1979. Nutrient cycling in *Eucalyptus obliqua* (L'Herit.) forest. III Growth, biomass and net primary production. Australian Journal of Botany 27: 439-458.

Bellote, A.F.J., Ferreira, C.A., Andrade, G. de C., Silva, H.D. Da, Moro, L., Diniz, S.and Zen, S. 1993. Implicações ecológicas e silviculturais do uso de cinzas de *Eucalyptus grandis*. Colombo: EMBRAPA-CNPF. 45p. (unpublished).

Bellote, A.F.J. 1979. Concentração, acumulação e exportação de Nutrients pelo *Eucalyptus grandis* (Hill, ex-Maiden) em função da idade. Piracicaba, Tese (Mestrado) - ESALQ, Universidade de São Paulo.

Bellote, A.F.J. 1990. Nährelementversorgung und wuchsleistung von gedüngten *Eucalyptus grandis* - plantagen in Cerrado son São Paulo (Brasilien). Freiburg, 160p. Tese (Doutorado) - Albert-Ludwigs-Universität.

Evans, J. 1979. The effects of leaf position and leaf age in foliar analysis of *Gmelina arborea*. Plant and Soil 52: 547-552.

Ferreira, C.A., Bellote, A.F.J. and Silva, H.D. da. 1993. Concentração de nutrientes minerais no lenho de *Eucalyptus saligna* e sua relação com a aplicação de fertilizantes. *In*: Congresso Florestal Brasiliero 7, Curitiba. Anais. São Paulo: SBS/SBEF,1: 227-230.

Lavender, D.P. and Carmichael, R.L. 1966. Effect of three variables on mineral concentrations in Douglas-fir needles. Forest Science 12: 441-446.

Marschner, H. 1995. Mineral nutrition of higher plants. 2nd.ed. Academic Press, London. 889p.

Pereira, A.R., Andrade, D.C. de, Leal, P.G.L. and Teixeira, N.C. dos S. 1984. Produção de biomassa e remoção de nutrientes em povoamentos de *Eucalyptus citriodora* e *Eucalyptus saligna* cultivados na região de cerrado de Minas Gerais. Floresta, 15:(1/2) 8-16.

Raij, B. 1981. Avaliação da fertilidade do solo. Instituto da Potassa and Fosfato, Piracicaba. 142p.

Silva, H. D. 1983. Biomass e aspectos nutricionais de cinco espécies do genero *Eucalyptus*, plantados em solo de baixa fertilidade. Tese (Mestrado). ESALQ, Universidade de São Paulo, Piracicaba.

Silva, H. D. 1996. Modelos matematicos para a quantificação de biomass e nutrients em *Eucalyptus grandis* Hill ex Maiden. Tese (Doutorado), Curitiba.

Smith, P. F. 1962. Mineral analysis of plant tissue. Annual Review of Plant Physiology 13: 108.

Zöttl, H.W. and Tschinkel, H. 1971. Nutricion y fertilizacion forestal: una guia pratica. Dep. Recursos Forestales, Universidad Nacional de Colombia, Medellin.

## 21

# Nutrient Export by Clear Cutting *Eucalyptus grandis* of Different Ages on Two Sites in Brazil

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### *Abstract*

At two sites, where *Eucalyptus grandis* plantations were 7 and 12 years old, twelve dominant trees were cut and measured. The 12-year-old-trees were 29.4 m mean height, 19.9 cm diameter over bark and estimated volume 0.40 $m^3$ $tree^{-1}$. The 7 year-old trees were 30.7 m mean height, 20.6 cm diameter and estimated volume 0.49 $m^3$ $tree^{-1}$. Of total biomass, 92% was trunk (sapwood, heartwood and bark). Based on a population of 1500 trees $ha^{-1}$, there is an export of biomass of 296 t $ha^{-1}$ from 302 t $ha^{-1}$ being produced, when the entire trunk is removed. When only commercial stems are removed, there is an export of 277 t $ha^{-1}$. Within a whole tree, N is the nutrient present in greatest amount, followed by K, Ca, Mg and P. When parts of the tree are analysed, calcium is the nutrient present in greatest amount in bark. Phosphorus was not detected by the chemical analysis in heartwood in trees of 12 years of age, but it was present in trees aged 7 years. The amount of N and K extracted from soil by the trees is greater than the amount of these nutrients supplied by fertiliser, usually around 20 g $plant^{-1}$ of N and 15 g $plant^{-1}$of $K_2O$. More than 50% of N, Ca and Mg are in the heartwood, sapwood and bark. Even if only commercial stems are taken from the plantation area, most of the nutrients will be exported.

## INTRODUCTION

From the environmental point of view, *Eucalyptus* plantations help reduce pressure on native forests. Nevertheless, fast-growing species in Brazil impose high demands on soil resources, especially water and nutrients. This has raised the question of sustainability of these systems under intensive cultivation. The sustainability of site productivity is a challenge for forest management. Of all practices used, the forest clear cutting is the most aggressive operation in terms of site damage including export of nutrients and soil compaction. Further the use of mechanical operations, especially in harvesting, also affects soil permeability, water infiltration, erosion, and nutrient cycling.

Harvesting only the trunk, and keeping leaves, branches and bark on site to protect the soil and to maintain the nutrients in the system is often recommended. The amount of mineral nutrients present in the aerial parts of a tree is represented by the sum of nutrients contained in the different parts. Each part has a certain amount of nutrients, according to its physiological function. The nutrient content in leaves, branches and bark of eucalypts is very impressive. These residues when kept on site reduce the impact of nutrient export. Poggiani *et al.* (1983) estimated nutrient export and biomass per area. They observed that leaves represent 9% of the biomass, branches 7%, and trunk 83%. However, 37% of the nutrients are in leaves, 10% in branches and 53% in the trunk. The nutrient export problem is made even worse by short rotations and

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exploitation of young trees (around 7 years old) which increase losses of nutrients from a site, and this can have a pronounced effect on sustainability (Pereira *et al*. 1984, Poggiani *et al*. 1983, Poggiani 1985, Pereira 1990). This situation can remove more nutrients than harvesting trees of more advanced ages (Lima 1993). In addition, soil preparation for the next rotation, sometimes includes burning of residues left on the soil surface after harvesting (Costa 1995).

This study reports the effects on nutrient export of clear cutting *Eucalyptus grandis* of different ages on two sites in São Paulo State, Brazil.

## MATERIALS AND METHODS

This work was developed in two plots of *Eucalyptus grandis* at 7 and 12 years after planting. The 7-year-old eucalypt site is in the municipality of São Miguel Arcanjo (latitude $23^0$51'S and longitude $47^0$46'W, 715 m above sea level) and the 12-year-old trees were in the municipality of Mogi Guaçu ($22^0$07'S, $47^0$03'W and 680 m asl), areas belonging to the Companhia Suzano de Papel e Celulose and Champion Papel e Celulose, respectively. Both places are representative of *Eucalyptus* plantations in the State of São Paulo, Brazil. The trees were spaced 3 m x 2 m with a stocking of 1500 trees $ha^{-1}$. The soil in São Miguel Arcanjo is a dark red clayey latosol, and in Mogi Guaçu is a dark red sandy latosol.

After an initial survey of tree height and diameter breast height (dbh), 12 dominant trees were selected at each site representing the average growth (height and diameter) of the stand. These trees were felled and dbh, total height, commercial height measured. They were divided into leaves, branches and trunk (sapwood, heartwood and bark). All leaves were separated, weighed and a representative sample of them was taken, to determine its dry weight and its mineral nutrient content. Based on nutrient concentration, determined by chemical analysis, and on total dry weight, the amount of N, P, K, Ca and Mg (g) in leaves was determined.

Discs were collected at 1 m intervals upwards from the base of the trunk, including at dbh and commercial height (diameter >4 cm) and their diameters with and without bark measured. Sapwood, heartwood and bark were removed from each disc, their basic densities determined and they were analysed for N, P, K, Ca and Mg content. Procedures for sampling, volume calculations and dry matter weight for each part were performed according to methodology proposed by Silva (1996). Branch sampling also followed methodology proposed by Silva (1996). Branches were classified and separated according to their diameters: thin branches (less than 3 cm), medium branches (from 3 to 8 cm) and thick branches (above 8 cm). Each class was weighed in the field and a sample taken to determine its dry matter weight and mineral nutrient content. Based on this information, total dry biomass and nutrient content (N, P, K, Ca and Mg) were calculated for each tree.

## RESULTS AND DISCUSSION

Eucalypts are grown in Brazil in a great variety of climate and soil conditions, with a significant variability in available soil water and mineral nutrient content for the tree growth. Mineral fertilisation is widely practised. In the State of São Paulo, tree volume productivity varies from about 20 to 100 $m^3$ $ha^{-1}$ $year^{-1}$. Table 1 shows tree growth in height and diameter and the total volume of trees of 7 and 12 years of age, grown at the two sites.

Among several factors that contribute to the production variability, climate (Barros and Novais 1990), and physical (Melo 1994), chemical (Santana 1994) and biological (Facelli and Pickett 1991) properties of soil stand out. The area of lower productivity (12-year-old trees) is located on savanna-type natural vegetation and where the moisture regime includes a well-defined period of drought, lasting around 6 months. This does not occur in the area of high productivity (7-year-old trees). The savanna's soil has a lower level of natural fertility, less clay and organic matter content compared to soil in the 7-year-old plantation. These differences contribute

**Table 1.** Means of dominant height, diameter breast height and volume for trees and for the *E. grandis* stands

| Age (yr) | Height (m) | dbh (cm) | Stem (volume with bark) | |
|---|---|---|---|---|
| | | | Tree ($m^3$) | Stand ($m^3$ $ha^{-1}$) |
| 7 | 30.7 ± 0.5 | 20.6 ± 0.8 | 0.49 ± 0.04 | 735 ± 63 |
| 12 | 29.4 ± 1.1 | 18.9 ± 1.0 | 0.40 ± 0.05 | 600 ± 84 |
| F test | * | ** | ** | ** |

[1] based on 1500 trees per hectare

F test - * and ** significant at the 5 and 1% level, respectively

significantly to differences in productivity, among the studied areas. The larger stem wood production of the 7-year-old eucalypts is related to differences in tree height and diameter. Although a variation in wood volume was observed, the same was not true of biomass production and total dry matter production per hectare for the two sites is statistically the same.

Among different tree components, the largest accumulation of biomass is in the trunk. Trees of 7 years of age had more sapwood than heartwood. In the 12-year-old trees, heartwood and sapwood were the same. At both sites, heartwood and sapwood comprise about 86% of the total biomass produced. At harvesting, generally, the trunk with all its components (heartwood, sapwood and bark) is removed from the site. For the two sites this would mean an export of 92% of total biomass and contribute to a large removal of mineral nutrients, as the bark containing the functional phloem, stores a significant amount of nutrients, (Table 3). Bark has the smallest biomass weight, among the components of the trunk but it has a larger amount of Mg than in heartwood and sapwood, also larger amounts of P and K than in heartwood. The amount of Ca in the bark is larger than in any other parts of the tree. This was also found by Bellote (1979), Bellote *et al*. (1980), Poggiani *et al*. (1983), Pereira *et al*. (1984) and Poggiani (1985). The bark is usually used for energy production but its retention as a residue on site has great importance in the sustainability of production. Export of bark through successive rotations contributes to a decrease of the forest productivity as fertilisation with NPK, a common practice in eucalypt plantations, is insufficient to restore nutrients removed in the bark.

Among all nutrients present in the biomass, the bark had 46% of the Ca, 11% of the N and 16-20% of the K. The amount of P in the bark varied as a function of the age of the tree, being larger in older trees. The amount of Mg in the bark was negatively correlated with the tree age, being larger in the youngest trees. The crown, composed of leaves, branches and toplog (trunk with diameter <4 cm), is usually left on the site, as a residue. It represents only 8% of the total biomass produced by the tree butt is an important source of organic matter and mineral nutrients. The trees aged 12 years had larger amounts of Ca and K in the crown, than the trees of 7 years of age. These results show that it is important that the determination of age at which plantations are harvested should not only be based on economic factors.

Phosphorus, K and Mg are the most limiting elements for eucalypt growth in the State of São Paulo (Bellote and Ferreira 1993). The results showed that appreciable amounts of K and Mg are kept on site if the crown and bark are retained as residues. Twelve-year-old trees had about 73% of the tree's total K and Mg in the crown and bark.

The trunk, composed of heartwood and sapwood, is the part of a tree removed from the site. The amount of all mineral nutrients in the heartwood, in both ages studied is less than in the sapwood. These data indicate that with the increase of the tree age the amount of heartwood increases. The same does not happen with the sapwood so the relative amount of nutrient removed from the site is reduced. Phosphorus was not recorded in the heartwood of the trees at 12 years of age and the quantity of all the other nutrients, except N, in the heartwood decreases with the age of the trees. In this case, it is supposed that the nutrients are

**Table 2.** Means and confidence interval for dry total biomass produced by *E. grandis* at 7 and 12 years of age

| Age | Trunk | | | Crown | | | Total |
|---|---|---|---|---|---|---|---|
| | Sapwood | Heartwood | Bark | Leaves | Branches | Toplog | Tree |
| yr | | | | $t\ ha^{-1}$ | | | |
| 7 | 145.4 ± 12 | 129.2 ± 17 | 20.2 ± 2 | 9.8 ± 2 | 14.6 ± 4 | 1.5 ± 0.3 | 321 ± 35 |
| 12 | 139.4 ± 16 | 141.7 ± 25 | 16.4 ± 3 | 7.1 ± 1 | 15.8 ± 3 | 3.9 ±0.4 | 324 ± 43 |
| F test | ns | ns | * | ** | ns | ** | ns |

F test – (ns = not significant); * and ** significant at the 5 and 1% level, respectively

**Table 3.** Mineral nutrients accumulated in the different parts of the trees (based on 1500 trees $ha^{-1}$)

| | Trees | Tree components ($kg\ ha^{-1}$) | | | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Age (yr) | Sapwood | | Heartwood | | Bark | | Crown | | | |
| N | 7 | 126.8 | ns | 78.0 | ns | 59.3 | ns | 253.5 | ns | 517.6 | ns |
| | 12 | 116.9 | | 81.7 | | 53.3 | | 211.3 | | 463.2 | |
| P | 7 | 8.6 | ** | 0.4 | ** | 3.8 | ** | 13.2 | ns | 26.0 | ** |
| | 12 | 16.6 | | - | | 14.0 | | 15.8 | | 45.9 | |
| K | 7 | 123.4 | ** | 17.5 | ** | 55.2 | * | 77.5 | ** | 274.2 | ns |
| | 12 | 64.0 | | 5.4 | | 37.8 | | 126.4 | | 233.6 | |
| Ca | 7 | 37.0 | ** | 22.9 | ** | 97.6 | ns | 53.8 | ** | 211.3 | ns |
| | 12 | 23.0 | | 14.1 | | 98.0 | | 79.0 | | 214.1 | |
| Mg | 7 | 21.7 | ** | 8.8 | ** | 39.2 | ** | 36.0 | ** | 105.9 | ** |
| | 12 | 12.3 | | 3.7 | | 14.3 | | 23.6 | | 53.9 | |

F test – (ns = not significant); * and ** significant at the 5 and 1% level, respectively

moved from the heartwood to another part of the tree, through the well-known process of biochemical cycling.

## CONCLUSIONS

- Clear cutting trees of 12 years of age exports less mineral nutrients than trees at 7 years of age.
- In the two studied ages, the amount of mineral nutrients present in the residues left on site, as bark, leaves, branches and toplog represents more than half of all nutrients in the total biomass of the trees.
- The export of nutrients from a site can be minimised by removing only the trunk (heartwood and sapwood).

## REFERENCES

Barros, N.F. and Novais, R.F. 1990. Relação solo-eucalipto. Universidade Federal de Viçosa, Viçosa. 330p.

Bellote, A.F.J. 1979. Concentração, acúmulo e exportação de nutrientes pelo *Eucalyptus grandis* (Hill ex-Maiden) em função da idade. Dissertação (Mestrado em Solos e Nutrição de Plantas) - Universidade de São Paulo, Piracicaba. 129p.

Bellote, A.F.J., Sarruge, J.R., Haag, H.P. and Oliveira, G.D. 1980. Extração e exportação de nutrientes pelo *Eucalyptus grandis*, em função da idade. I – macronutrientes. Revista do IPEF, Piracicaba 20(6): 1-23.

Bellote, A.F.J. and Ferreira, C.A. 1993. Nutrientes minerais e crescimento de árvores adubadas de

*Eucalyptus grandis*, na regiâo do cerrado, no Estado de São Paulo. Boletim Pesquisa Florestal., Colombo, no. 26/27, 17-28.

Costa, M.D. 1995. Biomassa microbiana e atividade biológica do solo decorresntes da decomposição de resíduos de eucalipto. *In:* Congresso Brasileiro de Ciência do Solo – O solo nos grandes domínios morfoclimáticos do Brasil e desenvolvimento sustentado (25: 1995 : Viçosa). Resumos expandidos. Viçosa: SBCS, Vol. 1: 474-475.

Facelli, J.M. and Pickett, S.T.A. 1991. Plant litter: its dynamics and effects on plant community structure. Botanical. Review 57: 1-32.

Lima, W. P. 1993. Impacto ambiental do eucalipto. Ed. da Universidade de São Paulo (2a ed). São Paulo. 301p.

Melo, V.F. 1994. Relação entre a reserva mineral dos solos e a produção de nutrientes em povoamentos puros de *Eucalyptus saligna* Smith no Rio Grande do Sul. 145 f. Dissertação (Mestrado) - Universidade Federal de Viçosa, Viçosa.

Pereira, A. R., Barros, N. F., Andrade, D.C. and Campos, P.T.A. 1984. Concentração e distribuição de nutrientes em *Eucalyptus grandis* em função da idade cultivado na região do cerrado. Brasil Florestal 14 (59): 27-37.

Pereira, J.S.M. 1990. Algumas notas sobre o impacto ambiental do eucalipto. *In:* Colóquio Eucalipto, Economia e Território. Oeiras: Sociedade Portuguesa de Estudos Rurais. 6p.

Poggiani, F. 1985. Ciclagem de nutrientes em ecossistemas de plantações florestais de *Eucalyptus* e *Pinus*. Implicações silviculturais. Tese de livre-docência, ESALQ-USP. 221p.

Poggiani, F., Couto, H.T.Z. and Suiter Filho, W. 1983. Biomass and nutrient estimates in short rotation intensively cultured plantation of *Eucalyptus grandis*. IPEF, Piracicaba, 23: 37-42.

Santana, R.C. 1994. Crescimento e eficiência nutricional de procedências de *E. grandis* e *E. saligna* em sítios do estado de São Paulo. 73 f. Dissertação (Mestrado em Agronomia) - Universidade Federal de Viçosa, Viçosa.

Silva, H.D. 1996. Modelos matemáticos para a estimativa da biomassa e do conteúdo de nutrientes em plantações de *Eucalyptus grandis*, em diferentes áreas. 101 f. Tese (Doutorado em Ciências Florestais) – Universidade Federal do Paraná, Curitiba.

# 22

# Changes in Biological Factors of Fertility in Managed *Eucalyptus* Plantations on a Savanna Soil in Congo

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I.M.C. Mboukou-Kimbatsa[3] and G. Reversat[1]

### *Abstract*

Biological factors of fertility were assessed through the study of litter quantity and quality, soil organic matter quantity and quality, soil microfauna, soil macrofauna, organic matter dynamic, particularly decomposition and non-symbiotic nitrogen fixation in an age series of *Eucalyptus* PF1 and one stand of *E.* urograndis (*E. urophylla* x *E. grandis*). The litter system underwent drastic changes with plot age: litterfall was higher in the older plots than in the younger ones. Soluble carbon and lignin content decreased significantly with plot age and decomposition rate increased. Change in soil organic matter amount occurred in the top layer of soil only and increased with plot age. This enhanced cation exchange capacity. Increase in soil organic matter content was due to the light organic fraction (>0.05 mm), and the amount of C did not change in the organo-mineral fraction. Soil organic matter quality changed also, and the C/N ratio increased with plot age. Evidence for N fixation was not observed. A drastic decrease in free living nematode density from savanna to young plantations was observed after which it increased slowly with plot age although in the 19-year-plots it was still about ten times lower than in savanna. The importance of *Xiphinema parasetariae,* a parasite of eucalypts, was confirmed. Its density increased markedly with plot age and the size of the patches where it occurred increased. All soil macrofauna, earthworms, termites and litter inhabiting groups, except the ant group, increased in density with plot age. Termite density decreased in logged stands but no other measured parameters showed any significant difference between plantations and clear felled areas. The long-term effect of harvesting was observed mainly in the litter systems which appeared to be strongly disturbed by previous logging. Previous logging did not affect soil organic matter and nematode populations, either free living or plant parasitic. Soil macrofauna groups slightly increased after harvesting. Total phenolic compounds and fibre content were very different in leaf litter among clones and hybrids.

## INTRODUCTION

Pulp production is the aim of the 40 000 ha of fast-growing tree plantations in Congo and foresters address the problem of getting maximum production in a sustainable system which preserves soil potentialities. Biological factors of soil fertility have a tremendous importance as they determine organic matter quality and turn-over, exchange capacity and nutrient cycling, and tree health.

Previous studies carried out in “Catalytic effect of plantations” (World Bank Project, 1995-1996) emphasised the evolution of the poor native savanna environment towards a more fertile forest environment which is characterised by a set of factors including understorey vegetation, fauna, soil characteristics, and

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reduced light. The Congolese *Eucalyptus* plantations are a simple model of changing environment from savanna to forest, and give the opportunity to study the processes involved. Logging is one of the main factors which may counter environmental evolution. Eucalypts are clear-cut when 7 years old, with changes in microclimate and in organic matter input to the soil. Then the trees coppice from the stumps for another 7-year-rotation, and new trees are planted after three rotations. Because litterfall and organic matter accumulation are assumed to be the driving factor of biological fertility change, it is questioned whether successive rotations allow environmental changes to occur in the same way as in unlogged plantations.

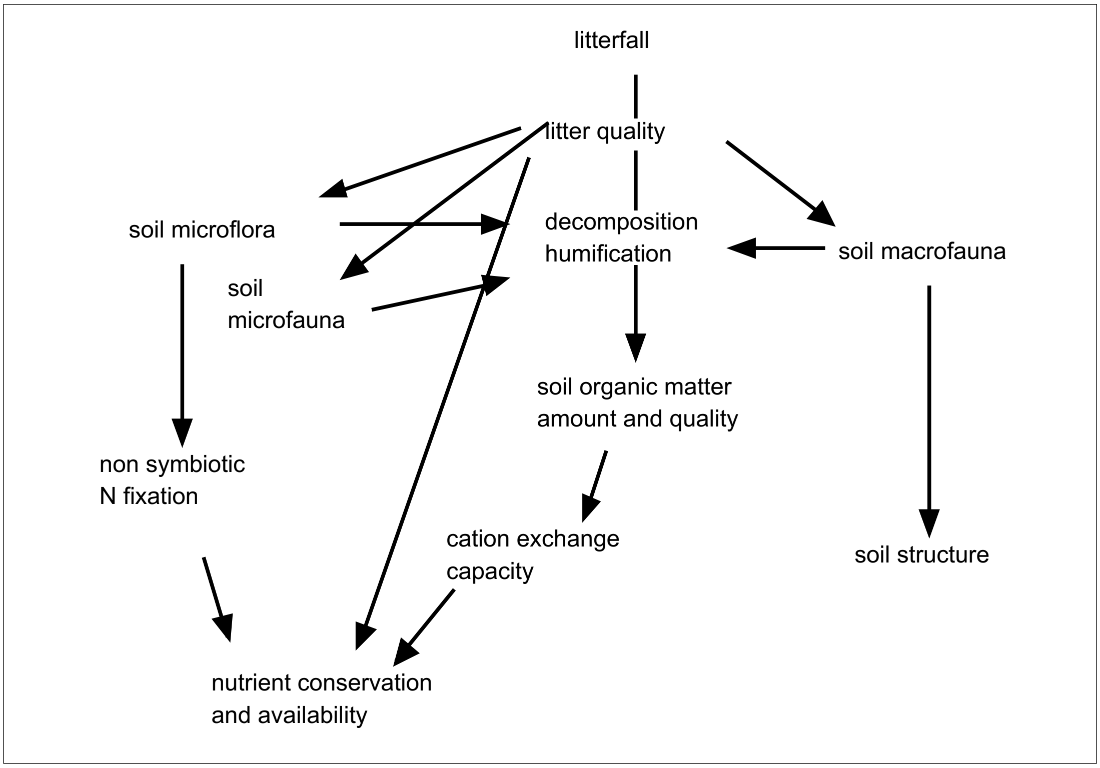
In this paper biological fertility factors are assessed through the study of litter quantity and quality, soil organic matter quantity and quality, soil microfauna, soil macrofauna, organic matter dynamic, particularly decomposition and non-symbiotic nitrogen fixation. (Fig.1).

## SITES AND METHODS

The sites were chosen in the commercial eucalypt plantations near Pointe-Noire, Congo, which are grown on savanna. In this area, forest vegetation is restricted to patches mainly situated in the valleys. In the coastal area (Pointe-Noire), these forested valleys are very imbricated with the plateau savannas, but are not planted with eucalypt. Two *Eucalyptus* hybrids were considered: *E.* PF1 and *E.* urograndis (*E. urophylla* x *E. grandis*). The chosen series (Table 1) was dependent on the available situations inside the planted area, and some drawbacks were unavoidable

Litter quality was studied on freshly fallen leaf litter collected on the ground. The determinations were (Bernhard-Reversat 1999): soluble carbon by the chemical oxygen demand (DCO) with HACH reagents (Anonymous 1994), phenolic compounds by the Folin Ciocalteu method with HACH reagents on water or methanol extracts, nitrogen by acid digestion and Nessler

**Figure 1.** Relationships between biological factors and fertility studied in eucalypt plantations



reagent, fibres by the Van Soest (1963) method. In the age series plots litterfall was collected every one or two weeks in ten 25 dm quadrats or in fifteen 56 $dm^2$ quadrats. Litter decomposition was measured in 1-2 mm mesh litterbags with 12 replication after a 4-week or 12-week *in situ* incubation.

Soil organic C and N were analysed on 6 replicates of soil samples from 0-10 cm and 10-20 cm depth. The particle size fractionation of soil organic matter was performed on three replicates of soil samples 0-5 cm depth. Nematodes were sampled in 424 ml soil cores taken on contiguous tree lines on one from two trees, at 0-15 cm depth. Nematodes extraction from soil was made with the two-flask technique (Seinhorst 1955). Macrofauna was sampled according to the TSBF (Tropical Soil Biology and Fertility Program) method (Anderson and Ingram 1993.): 10 samples were taken in each plot, 5 m apart along a randomly chosen transect. Each sample was a block of soil, 30 cm deep on area of 25 x 25 cm. The macrofauna was sorted out by hand. Assymbiotic nitrogen fixation was measured in the laboratory as ARA (acetylene reduction activity) on core samples taking together the litter and the 0-5 cm layer of soil. Three replications were made in each plot (Le Mer and Roger 1999).

## RESULTS AND DISCUSSION

### Changes in biological factors with plantation age

The litter system was shown to undergo drastic changes with plot age: litterfall, litter quality, and litter decomposition were affected. Litterfall was higher in older plots than in younger ones (Table 2). Litter quality was less affected but soluble carbon and lignin content decreased significantly with plot age (Fig. 2), and the responsible factor is not known; lignin content is known not to be related to soil nutrient content (Tissaux 1996). Decreasing

**Table 1**. Characteristics of the studied plots

| plot | hybrid | clone | plot age | tree age | forest | present exploitation | previous exploitation |
|---|---|---|---|---|---|---|---|
| T 92-82E | PF1 | 1-41 | 6 | 6 | high forest | no | 0 |
| T 92-82 | PF1 | 1-41 | 6 | 0 | high forest | clear felled | 0 |
| L 85-10 | PF1 | 1-41 | 13 | 6 | coppice | no | 1 |
| L 84-06 | PF1 | 1-41 | 14 | 0 | coppice | clear felled | 1 |
| K 79-37 T | PF1 | 1-41 | 19 | 7 | coppice | no | 2 |
| K 79-37 F | PF1 | 1-41 | 19 | 19 | high forest | no | 0 |
| R 90-07 | PF1 & urogr. | sub plots var. clones | 8 | 8 | high forest | no | 0 |
| R 92-04 | PF1 | sub plots var. clones | 6 | 6 | high forest | no | 0 |

**Table 2.** Litterfall in g $m^{-2}$ $year^{-1}$ (and standard error in brackets) in the studied eucalypt plots

| plot | | hybrid | age | Leaves | twigs & barks | fruits | total |
|---|---|---|---|---|---|---|---|
| T 92-81e | H | PF1 | 6 | 431 (75) | 256 (80) | 0 | 688 (107) |
| L 85-10 | C | PF1 | 13 | 831 (27) | 256 (48) | 0 | 1087 (54) |
| K 79-37 T | C | PF1 | 19 | 664 (28) | 271 (37) | 0 | 938 (46) |
| K 79 37 F | H | PF1 | 19 | 888 (44) | 378 (57) | 25 (3) | 1290 (76) |
| R 90-07 | H | urograndis | 8 | 684 (27) | 320 (72) | 0 | 1004 (77) |

Because of the calculation method, the standard error refers to the seasonal as well as to the spatial variability, except for the T 92-81e plot, for which the standard error refers only to the seasonal variability. H: high forest plot; C: coppice plot

**Figure 2.** Change of soluble organic matter and lignin content in eucalypt litter with plot age

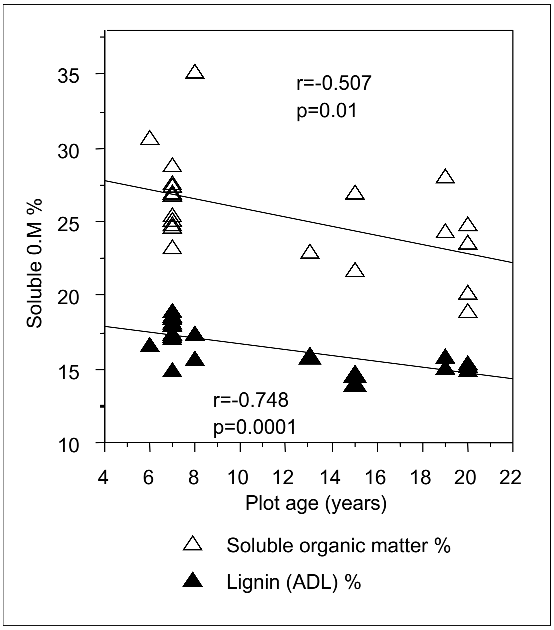
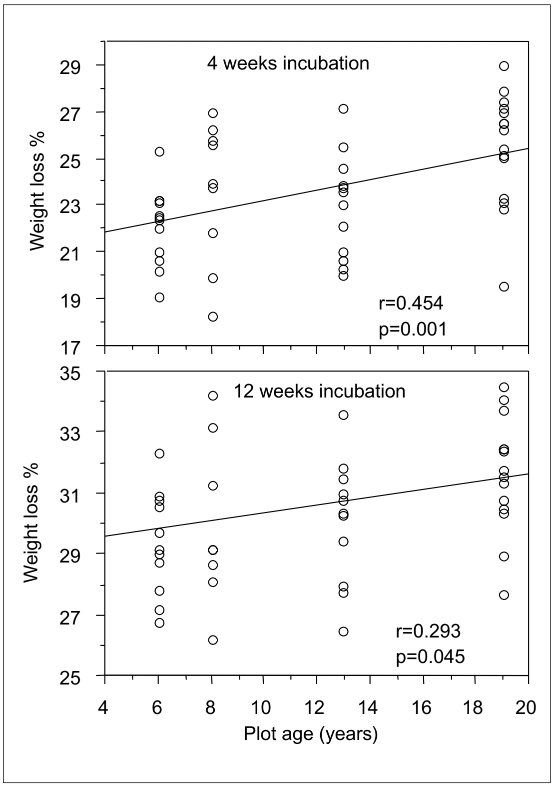


**Figure 3.** Increase of *in situ* decomposition rate with plot age



lignin content might be one of the causes of the small but significant increase in decomposition rate with plot age (Fig. 3). The decomposition rate of eucalypt litter is slower in plantations than in native Australian eucalypt forest (Spain and Le Feuvre 1987, Bernhard-Reversat 1993) and limits nutrient cycling. Increased decomposition rate together with increased litterfall in ageing plantations is assumed to enhance nutrient cycling and particularly direct cycling from litter to roots, which occurs in tropical forests on poor soils (Jordan 1982). Bargali *et al.* (1993) observed a decrease in decomposition rate with age in *E. tereticornis* plantations from 1 to 8 years old, related to the decrease in litter and top soil content in N, P, and K. In the older plantations of the present study, leaf litter nutrient content did not change with plot age. Although soil nutrient content was not measured, the decrease of pH with age observed by Bandzouzi (1993) was an indication of decreasing nutrients, and direct cycling could help alleviating soil nutrient deficiency.

Change in soil organic matter amount with age was also significant although it occurred in the top layer of soil only (Fig. 4). The increase in soil organic matter enhanced cation exchange capacity (Fig. 5) and was assumed to improve the retention of nutrients from rainfall, throughfall and litter. The increase in soil organic matter content with plot age was due to the light organic fraction (>0.05 mm), and the amount of C did not change in the organo-mineral fraction, (Fig. 6) as observed in other sandy soils (Feller *et al* 1991). Soil organic matter quality changed also, and the C/N ratio increased with plot age due to the fine particle size fractions (<0.2 mm). The savanna organic matter was replaced by N-poor eucalypt organic matter. This could result in N shortage in the long term. Evidence for N fixation was not observed either in litter or in soil; only potential fixation activity was observed in litter when glucose was added, mainly in the older coppice (Le Mer and Roger 1999), unlike the situation in Australian natural eucalypt forests (O'Connell and Grove 1987).

Free living nematodes are the most abundant microfauna group in soil and contribute

**Figure 4.** Change of soil C content with plot age in eucalypt plantations

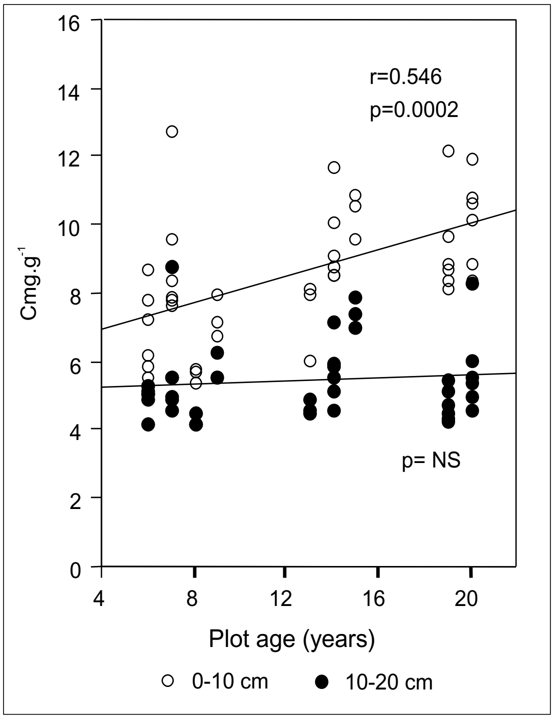


**Figure 5.** Change of cation exchange capacity (CEC) with plot age in eucalypt plantations before and after organic matter oxydation by oxygen peroxide, showing the part of CEC due to organic matter

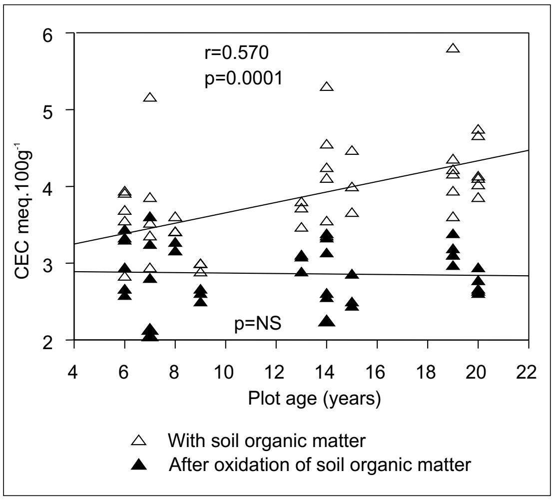
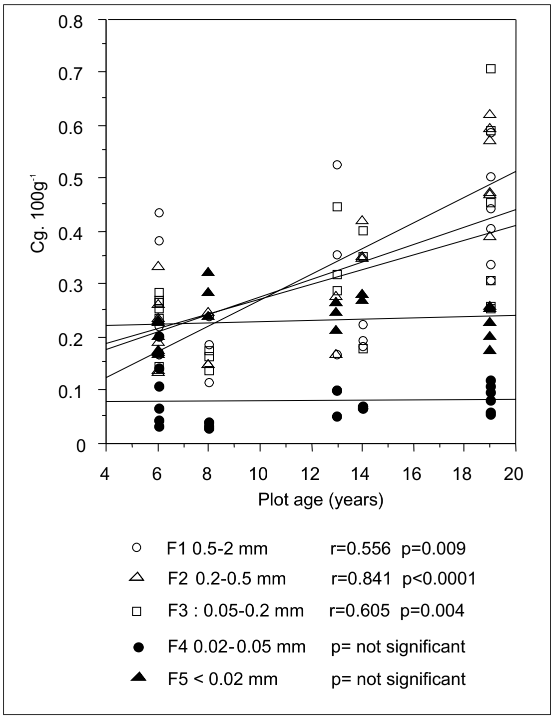
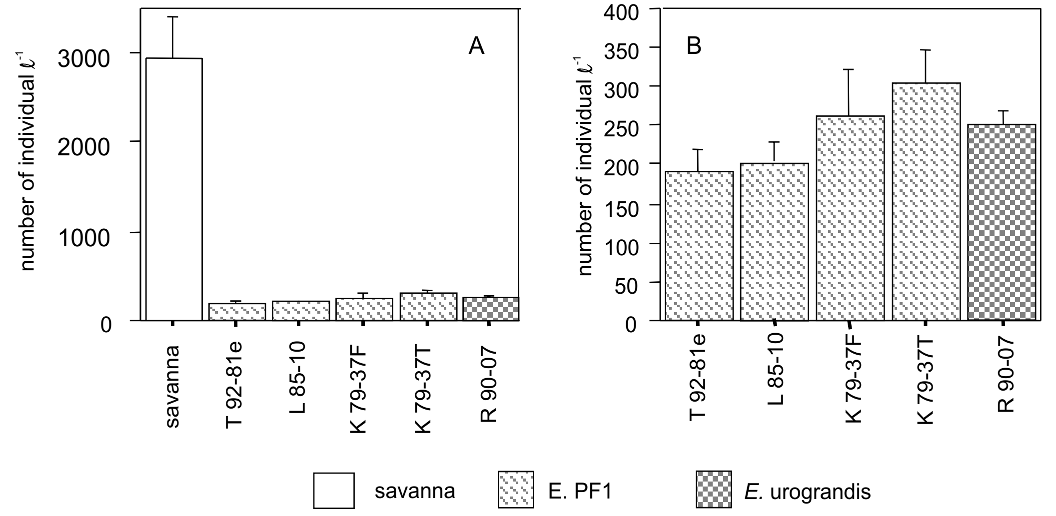


**Figure 6**. Carbon in particle size fractions in eucalypt plots of increasing age. Open and solid symbols show show light and organo-mineral fractims, respectively



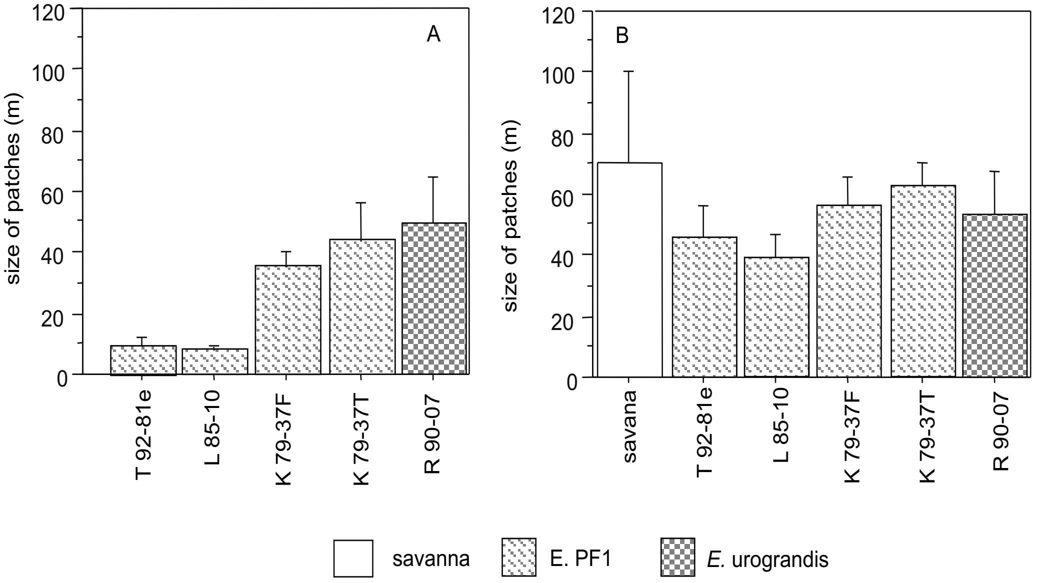
to the organic matter and N turn-over and control the micro-food web (Lavelle *et al.* 1993). A drastic decrease in free-living nematode density from savanna to young plantations was observed (Fig. 7). Then free-living nematode density increased slowly with plot age although in the 19-year-plots it was still about 10 times lower than in savanna. Among the plant parasitic nematodes, the importance of *Xiphinema parasetariae,* a parasite of eucalypts, was confirmed. This nematode was present in the savanna as parasites of some leguminous herbs and very scarce in young eucalypt plots. Its density increased very significantly with plot age. This nematode was distributed in patches, and the size of the patches increased from an average of 8 m in the 6-year-old plot to an average of 50 m in the 19-year-old plot, whereas the size of the patches free from nematodes decreased with plot age (Fig. 8). These results suggested that continuous eucalypt cultivation will result in an entirely infested area.

**Figure 7.** Free living nematode density in eucalypt plots of increasing age



A: In savanna and eucalypt plantation,
B: In eucalypt plantations

**Figure 8.** Average length of patches of nematodes in eucalypt plantations



A: Patches of samples with *Xiphinema parasetariae*,
B: Sum of the lengths of patches of samples with nematodes and patches without nematodes

The effect of this parasite on eucalypt growth is not well known although the genus *Xiphinema* was found on eucalypt plantations in South Africa (Marais and Buckley 1993, Spaull 1998). The most probable injurious effect will be on young cuttings replanted on old eucalypt plots, because they are more susceptible than adult trees.

Changes in macrofauna distribution were observed in the industrial plantations, as well as previously in experimental plantations (Mboukou-Kimbatsa *et al.* 1998). Earthworms, termites and the litter inhabiting group increased in density with plot age (Fig. 9). Only the ant group did not increase. Improved soil functioning is expected from the increase in density of earthworms, termites and litter fauna, related mainly to a faster organic matter turn-over and an improved soil structure (Lavelle *et al.*1997).

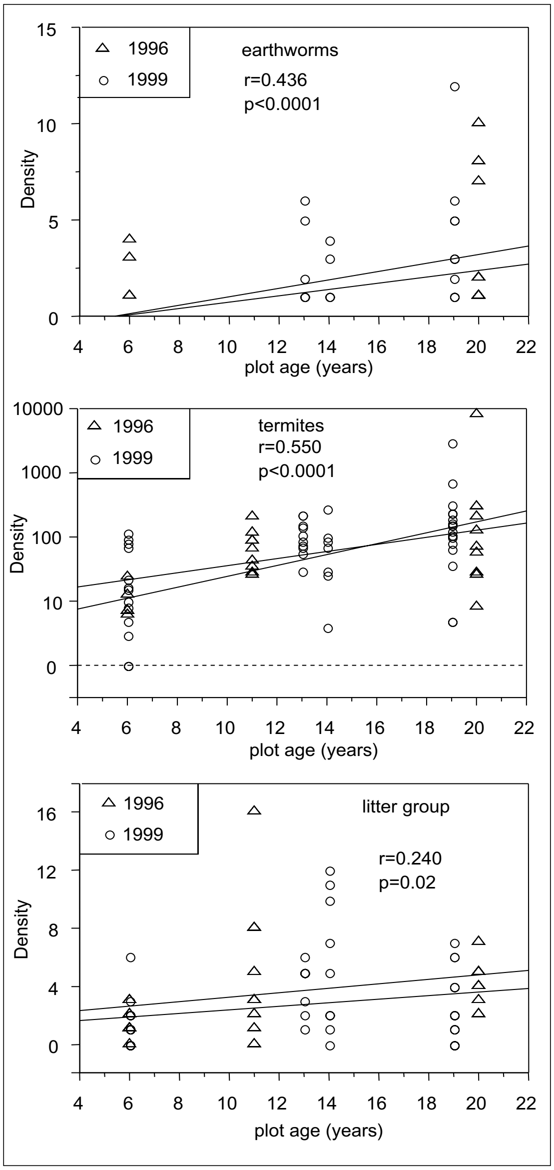
## Effect of the present exploitation practices on biological fertility

Eucalypts are logged every 6-8 years and logs above 7 cm in diameter are removed. Part of the remaining woody material is collected to make charcoal. Leaves and twigs are laid on the soil, either in swathes or spread on the whole surface. The main immediate changes when trees are clear-felled concern microclimate and litter input.

The two 6-8-year-old plots and the two 13-14-year-old plots allowed the study of biological factors before and after clear-felling. None of the measured parameters on litter and soil organic matter showed significant differences. Among the macrofauna, the termite group alone showed a slight significant difference, with a decreased density after clear felling perhaps because of changing micro-climatic conditions. On the whole, clear-felling did not bring about major perturbations among the measured parameters.

The long-term effect of harvesting was studied in the 19-year-old coppice and high forest plots, and in the 14-year-old coppice. In the 19-year-old plots, litterfall was significantly higher in the high forest plot than in the coppice and resulted in a greater amount of nutrient cycling through litter. The similarity of the litter nutrient contents in the two 19-year-old plots was noticeable. The comparison of the two coppices (13-year-old and 19-year-old) suggested that litterfall could decrease with successive logging, possibly because of the physiological or pathological ageing of the rooting system, or nutrient shortage. Litter decomposition rate was 1-5% lower in the coppice than in the high forest of the same age, according to the season. Litter accumulation in the high forest plot was more than twice that in the coppice. The litter systems

**Figure 9.** Change in soil macrofauna population densities (number per TSBF samples) in eucalypt plantations with plot age



appeared to be strongly disturbed by previous logging. However the soil organic matter was apparently not affected by previous exploitation. It has been estimated that about 22 t ha$^{-1}$ of biomass remains on the ground after clear-felling in a 7-year-old plot (Laclau 1997), which is the equivalent of 3 t year$^{-1}$. This amount was approximately the annual difference in litterfall input between the coppice and the high forest and could make up for it. The branch wood is easily humified because its lignin is less polymerised than that of the stem wood, and it has a higher nutrient content (Lemieux 1996).

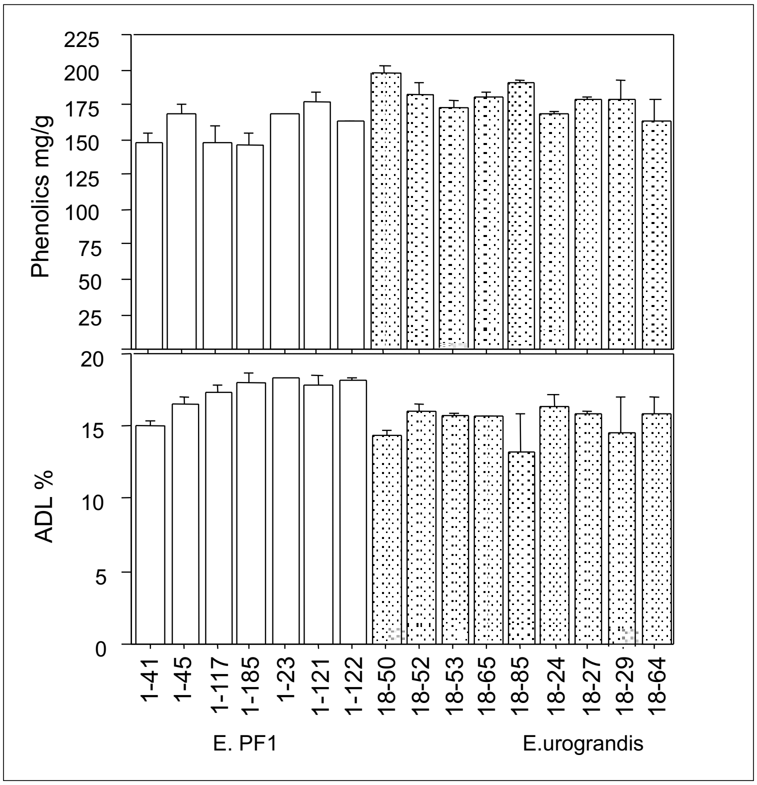
Nematode populations, either free-living or plant parasitic, were not affected by previous logging. Free-living nematodes need soil organic matter and microflora to feed on and these resources did not change with logging. With ageing of plantations, the increase in size of soil patches infested with parasitic nematodes occurred in coppice areas as well as in the high forest plots because the tree root systems were not destroyed by the logging. Soil macrofauna groups were slightly increased by the harvesting.

Few data are available on the effect of eucalypt harvesting, and the conservation of litter on the soil was recommended to prevent nutrient export (O'Connell and Sankaran 1997); the conservation of litter also contributes to the maintenance of soil organic matter content and soil fauna density.

## Biodiversity due to hybrids and clones

The planting of different clones aims to introduce biodiversity in the plantations. Litter quality alone was compared between clones. Few of the studied litter characteristics were significantly different among clones, but they are important as total phenolic compounds content and fibre content (NDF, ADF and ADL of the Van Soest method) (Fig.10) were highly significantly different among

**Figure 10.** Methanol soluble phenolics and ADL content of clones and hybrids of eucalypt



clones. This was expected to result in different decomposition rates which will influence organic matter and nutrient dynamics. Differences in phenolics and fibres could also result in different resistance to diseases and herbivory (Landsberg and Cork 1997).

The hybrids are chosen according to their growth rate. When the chemical composition of the litter was compared between hybrids, *E.* urograndis litter was significantly poorer in N and fibres and had a higher content in phenolics than *E.* PF1. The *in situ* measurements in the studied plots (6-year-old *E.* PF1 and 8-year-old *E.* urograndis) showed that soil organic matter accumulation in top soil was greater in *E.* PF1, although litterfall was smaller, and soil organic matter from *E.* PF1 litter was consequently assumed to be less degradable than that of *E.* urograndis, at least in the fine light organic fraction (0.05 to 0.2 mm) that was mainly responsible for the difference. Litter decomposition rate was higher in *E.* urograndis during the dry season; it was attributed to soil invertebrate activity because microbial mineralisation did not occur when litter was dry; however, higher faunal activity in *E.* urograndis than in *E.* PF1 did not fit the observations on phenolic compound content, and only the lower lignin content was in agreement with greater faunal activity. It would be interesting to analyse terpene compounds in hybrids and clones because they are known, like phenolics, to be related to herbivory and disease resistance.

Mineral cycling by litter was higher in *E.* urograndis*,* mainly because of its higher litterfall, and because of the higher P and K content in its litter. Fauna comparison between hybrids was made more difficult by the variability of the results in two *E.* urograndis plots and further studies are required.

## CONCLUSIONS

Eucalypts are generally suspected to alter soil quality and prevent plant growth. Starting from a poor savanna soil, the main tendency in this study was the opposite as organic matter, undergrowth vegetation and soil fauna density increased (Loumeto and Huttel 1997, Mboukou-Kimbatsa *et al.* 1998). However the particular features of eucalypt litter had many implications for soil biology. Phenolic compounds in litter were shown to be strongly negatively related to termite density, and could also control, together with soil C, free-living nematode density and earthworm density (p for multiple regression significance was 0.11 and 0.06 respectively). The noticeable lack of N fixation activity in soil and litter seemed also to be due to litter quality, and most of the few samples where N fixation activity was found with glucose added were taken in the plot where the litter had the lowest content of phenolics (Le Mer and Roger 1999). Indications for other disturbed microbial processes were given by the lack of nitrification (Bernhard-Reveresat 1996) and of white rot fungi for lignin degradation (Bernhard-Reversat and Schwartz 1998), and microbial processes in eucalypt plantations deserve further studies.

## REFERENCES

Anderson, J.M. and Ingram, J.S.I. 1993. Tropical soil biology and fertility. A handbook of methods. C.A.B/International, Oxford. 221p.

Anonymous 1994. Model DR/700 Portable colorimeter instrument manual. 69.7-69.12. Hach Company, Loveland.

Bandzouzi, J. 1993. Variabilité spatiale de quelques caractéristiques édaphiques (pH, carbone, granulométrie) des sols sableux sous *Eucalyptus* du littoral congolais. Mémoire IDR, Université de Brazzaville, ORSTOM Pointe Noire. 58p. + annexes.

Bargali, S.S., Singh, S.P. and Singh, R.P., 1993. Pattern of weight loss and nutrient release from decomposing leaf litter in an age series of eucalypt plantation. Soil Biology and. Biochemistry 25: 1731-1738

Bernhard-Reversat, F. 1993. Dynamics of litter and organic matter at the soil-litter interface in fast-growing tree plantations on sandy ferralitic soils (Congo). Acta Oecologia 14: 179-195.

Bernhard-Reversat, F. 1996. Nitrogen cycling in tree plantations grown on poor savanna soil in Congo. Applied Soil Ecology 4: 161-172.

Bernhard-Reversat, F. 1999. Change in $CO_2$ release relationships with initial litter quality during early laboratory decomposition of tropical leaf litters. European Journal of Soil Biology 34: 117-122.

Bernhard-Reversat, F. and Schwartz D. 1997. Change in lignin content during litter decomposition in tropical forests soils (Congo): comparison of exotic plantations and native stands ComptesRendus de l' Académie des Sciences, Paris., Sciences de la Terre et des Planètes 325: 427-432.

Feller, C., Fritsch, E., Poss, R. and Valentin, C. 1991. Effet de la texture sur le stockage et la dynamique des matières organiques dans quelques sols ferrugineux et ferralitiques (Afrique de l'Ouest en particulier). Cahiers ORSTOM, serie Pedologie 26: 25-36.

Feller, C. and Ganry, F. 1982. Decomposition et humification des résidus végétaux dans un agro-système tropical. III. Effet du compostage et de l'enfouissement de divers résidus de récolte sur la repartition de la matière organique dans différents compartiments d'un sol sableux. Agronomie Tropicale 37(3): 262-269.

Jordan, C.F. 1982. Amazon rain forests. American Scientist 70: 394-401.

Laclau, J.P. 1997. Dynamique de l'incorporation des éléments minéraux majeurs (N, P, K, Ca, Mg) dans une futaie d'*Eucalyptus* au Congo. Cirad Forêt, DEA INA P-G. 48p.

Landsberg, J.J. and Cork S.J. 1997. Herbivory: interaction between eucalypts and the vertebrates and invertebrates that feed on them; *In*: Williams, J. and Woinarski, J. (eds.) Eucalypt ecology, 342-372. Cambridge University. Press, Cambridge.

Lavelle, P., Blanchart, E., Martin, A. and Martin, S. 1993. hierarchical model for decomposition in terrestrial ecosystems:application to soils of the humid tropics. Biotropica 25: 130-150.

Lavelle, P., Bignell, D., Lepage, M., Wolters V., Roger, P., Heal, O.W. and Dhillon S. 1997. Soil function in a changing world: the role of invertebrate ecosystem engineers. European Journal of Soil Biology 33: 159-193.

Le Mer, J. and Roger, P. 1999. $N_2$ fixation assessment in soil and litter samples from Congolese savanna and eucalypt plantations under various managements. *In*: IRD (ORSTOM)/UR2PI/CIFOR Agreement Report Change towards forest environment when *Eucalyptus* are planted on savanna soils : biological factors of fertility as affected by plantation management. A7.1-A7.5. IRD, Bondy, France.

Lemieux, G. 1996. Cet univers caché qui nous nourrit: le sol vivant. Université de Laval, Faculté de Foresterie et de Géomatique, Groupe de Coordination sur les Bois Raméaux publication no. 59. Http://forestgeomat.for.ulaval.ca/brf

Loumeto, J.J. and Huttel, C. 1997. Understorey vegetation in fast-growing tree plantations on savanna soils in Congo. Forest Ecology and Management 99: 65-81.

Marais, M. and Buckley, N.H. 1993. Plant parasitic nematodes in forest soils in the Transvaal and Natal, South Africa. South African Forestry Journal 166: 9-16.

Mboukou-Kimbatsa, I.M.C., Bernhard-Reversat, F. and Loumeto J.J. 1998. Change in soil macrofauna and vegetation when fast growing trees are planted on savanna soils. Forest Ecology and Management 110: 1-12.

O'Connell, A.M. and Grove, T.S. 1987 Seasonal variation in $C_2H_2$ reduction ($N_2$-fixation) in the litter layer of eucalypt forests of south-western Australia. Soil Biology and Biochemistry 19: 135-142.

O'Connell, A.M. and Sankaran, K.V. 1997. Organic matter accretion, decomposition and mineralisation. *In*: Nambiar, E.K.S. and Brown, A.G. (eds.) Management of soil, nutrients and water in tropical plantation forests 443-479. ACIAR/CSIRO/CIFOR, Canberra.

Seinhorst, J.W. 1955. Een eenvoudige methode voor het afschieden van aaltjes uit grond. Tijdschrift over Plantenziekten 61: 188-190.

Spain, A.V. and Le Feuvre, R.P. 1987. Breakdown of four litters of contrasting quality in a tropical

Australian rainforest. Journal of Applied Ecology 24: 279-288.

Spaull, V.W. 1998. A note on the effect of using a nematicide on sugar cane planted in a sandy soil previously cropped to *Eucalyptus* trees. Proceedings of the Annual Congress of the South African Sugar Technology Association. 72: 94-97.

Tissaux, J.C. 1996. Une revue bibliographique des principaux mécanismes pédogénétiques pour caractériser le rôle du bois raméal fragmenté (BRF) dans le processus d'humification» mémoire de fin d'étude Université de Laval, Faculté de Foresterie et de Géomatique, Groupe de Coordination sur les Bois Raméaux, publication no. 60.

Van Soest, P. J. 1963. Use of detergents in the analysis of fibrous feeds. II. A rapid method for the determination of fiber and lignin. Journal of the Assistant Officers in Agricultural Chemistry 46: 829-835.

# 23

# Rehabilitation of Degraded Forest with *Shorea leprosula* and *S. selanica* Cuttings

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### *Abstract*

Komatsu Ltd. and the Forest and Nature Conservation Research and Development Center (FNCRDC) of the Ministry of Forestry, Indonesia have developed a cutting propagation technique for dipterocarp species. This technique uses a fog-cooling system to lower the temperature inside cutting boxes in a greenhouse. This method is suitable for mass production of vegetative propagules of some dipterocarps species. Rooting percentage of S. *leprosula* and *S. selanica* (meranti) cuttings was 95% and 92% respectively during the experimental stage, and 67% at mass production stage. The planting stock production of the dipterocarp cuttings in 1997 and 1998 were 42 000 and 53 000 respectively. Reforestation of degraded forest by using these dipterocarp cuttings was studied on 70 ha trial plot in West Java. Planting stock from cuttings and seedlings of *S. leprosula* and *S. selanica* were planted at various spacings. Preliminary results indicated that at this site *S. selanica* grows better than *S. leprosula*, planting stock from cuttings of both species performed better than planting stock from seedlings, and closer spacing resulted in better growth and survival. These findings suggest that planting stock from cuttings can be used to reforest degraded forest.

## INTRODUCTION

The dipterocarp family (Dipterocarpaceae) which makes up most of the tropical forests of Southeast Asia is important ecologically and also useful economically for plywood, building material, and furniture, etc. The diperocarps have been commercially logged for many years. Moreover, their disappearance is also due to improper slash and burn farming, agricultural land conversion, etc. However, technical problems remain in reforestation techniques so planting with dipterocarps is not advanced.

Reproductive characteristics influence reforestation by the dipterocarps as their flowering pattern is irregular (Ashton *et al.* 1988) and seed storage period is short (Sasaki 1980), so making continuous seedling production on a large-scale difficult. Hence, the establishment of a planting-stock production method is important for reforestation. The use of vegetative propagules offers a feasible solution to this problem. There are reports of vegetative propagation methods for the dipterocarps (Aminah 1991, Smits 1983). However, there are no reports of large-scale experiments or successful mass production.

A unique propagation method called “fog-cooling system” has been developed by the Forest and Nature Conservation Research and Development Center and Komatsu (Sakai *et al.* 1994). Basically the system controls humidity, temperature and light intensity at a suitable level for transpiration and photosynthesis. Since it was developed, the system has been used to produce more than one hundred thousand vegetative propagules of *Shorea* species including *S. leprosula, S. selanica, S. javanica, S. pinanga, S. seminis,* and *S. stenopthera*. However only *S. leprosula, S. selanica,* and *S. javanica* at this stage can be produced on a large scale using this method.

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The project is now focused on *S. leprosula* and *S. selanica*, as they are fast growing dipterocarps (Masano *et al*. 1987) and have potential for reforestation of degraded forest. So far no data on vegetative propagule performance in the field is available, and this has to be tested before they are recommended for large-scale plantation establishment.

This paper reports a study on controlling environmental conditions suitable for root formation of the stem cuttings including media, light intensity, temperature and humidity, and also growth performance of vegetative propagules on degraded secondary forest at Leuwiliang, West Java, Indonesia.

## MATERIALS AND METHODS

Autotrophic shoots of the dipterocarps taken from wildlings were used as cutting material. The autotropic shoot was prepared to a length of 8 cm with two leaves. The stem cuttings were planted in a tray of 5 x 9 pots. The pot tray was placed inside a propagation box, which was covered by a clear plastic cover. Crushed coconut fibre with rice husk mixed was used as the medium. Two levels of humidity (80% and above 95%) and two levels light intensity (*ca*.1100 and 4600 lux) were used to test their influence on rooting percentage of the cuttings. A shading net regulated light intensity. The fog-cooling system was operated to lower the temperature inside the propagation box daily from 10 am until 4 pm with a timer and a thermostat controller. One nozzle was installed for each 2.5 $m^2$ area, which sprayed 70 ml $minute^{-1}$ of water as fog. The number of rooted cuttings was evaluated after two months. Rooted cuttings were transplanted to plastic bags and raised in the nursery. Planting stock from cuttings and seedlings of *S. leprosula* and *S. selanica* was used to test their field performance. Four different spacing regimes i.e. 2 x 2 m, 3 x 3 m, 4 x 4 m, and 5 x 5 m were applied. The planting site was degraded secondary forest with hilly-terrain and prone to soil erosion. The trees of each treatment were planted in a square plot 100 m x 100 m.

## RESULTS AND DISCUSSION

### Fog Cooling System

The fog-cooling system was used to control the environment of the greenhouse (Fig. 1). The environmental conditions suitable for root formation of the cutting can easily be controlled using an air conditioner, a fluorescent lamp and a humidifier, but the cost of producing vegetative propagules is very expensive, especially for large-scale production. The fog-cooling system was designed to produce planting stock on a large scale at low cost. Cooling of this system is by spraying very fine water particles (fog) into the air. Evaporating fog takes heat from the surroundings to lower the temperature inside the greenhouse below 30$^o$C (Fig. 2). In addition, a shading net and misting unit were provided to control light intensity, and clear plastic covered propagation box was used to keep humidity above 95%.

### Effect of Humidity

Cuttings are susceptible to dehydration due to poor absorption of water. Hence, intensive transpiration from leaves due to unfavourable environmental conditions must be avoided. To suppress transpiration, humidity must be kept high (above 95%). Ninety cuttings of *S. leprosula* and *S. selanica* were tested. There was a significant effect of humidity on root formation. Lower humidity (80%) resulted in no root formation of the cuttings, whereas higher humidity (about 95%) resulted in 95% and 92% rooted cuttings for *S. leprosula* and *S. selanica* respectively.

### Effect of Light Intensity

Adequate light energy is required by cuttings to perform photosynthesis for root formation. The test comprised 117 cuttings of *S. selanaca* at a low light intensity (1139 lux) and 90 cuttings of *S. selanica* at a high light intensity (4637 lux). Higher light intensity resulted in better rooting percentage (91%) as compared to lower light intensity (33%) after 2 months. On the other hand, increased light radiation increases the temperature inside the greenhouse and subsequently increases

**Figure 1.** The design of the greenhouse with the fog cooling system

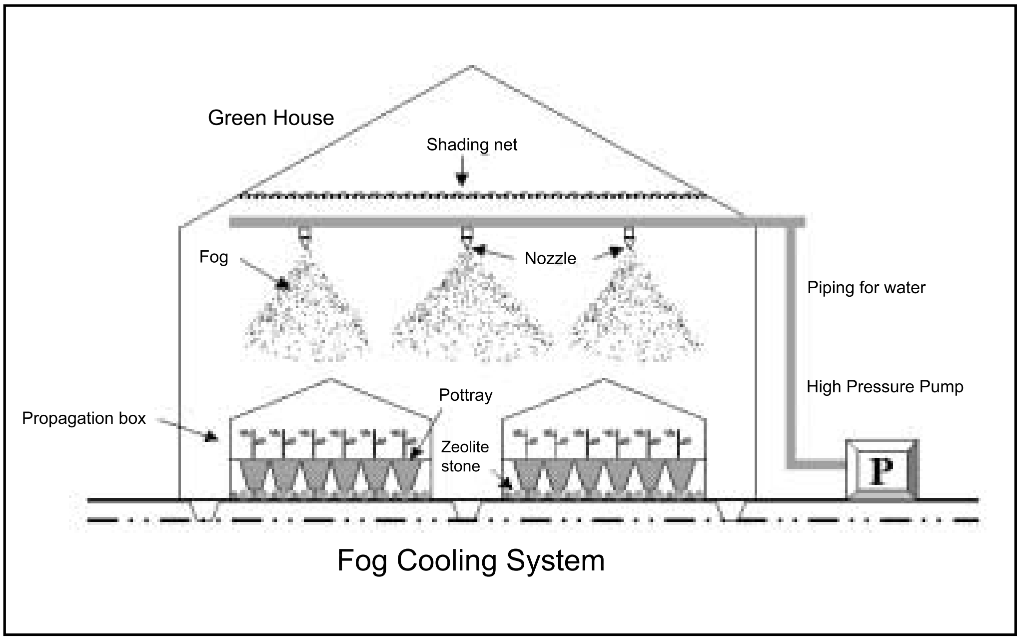
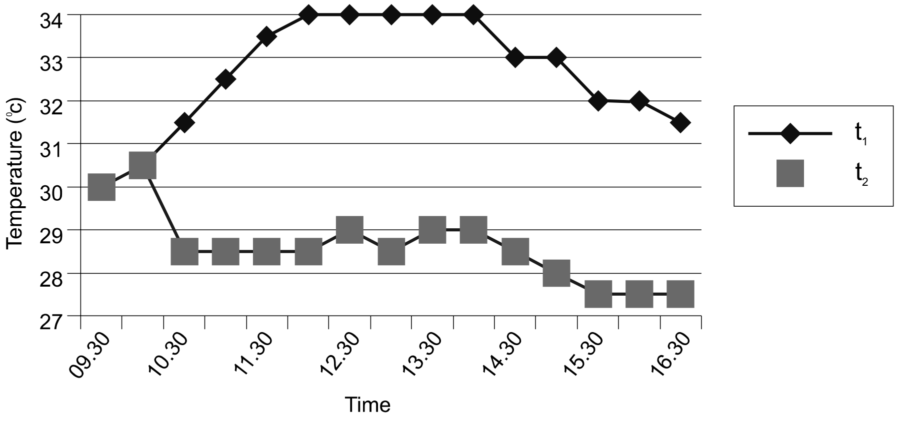


**Figure 2**. Temperature control by fog cooling system



$t_1$ = temperature inside the propagation box without fog cooling system

$t_2$ = temperature inside the propagation box under fog cooling system transpiration of the cutting leading to cutting dehydration. Successful vegetative propagation of the dipterocarps appears to require a condition in which the cuttings receive enough light but the temperature must be kept below 30°C.

## Mass Production

The fog cooling system has been used to produce large-scale vegetative propagules of dipterocarps. In 1997 and 1998 the collaborative project produced about 42 000 and 55 000 cutting propagules respectively. During mass production of cuttings, rooting percentage dropped to about 50%. This decline was due to human error during maintenance of vegetative propagules, such as not closing the plastic cover tightly after watering the cuttings resulting in lower humidity in the propagation box. Another source of decline was the algae growing on the plastic cover, which reduced light intensity inside the propagation box. In 1999 the propagation box was improved to minimise these problems, and rooting percentage improved to about 72%.

## Field Performance of the Cuttings

Vegetative propagules of *S. leprosula* and *S. selanica* in this planting site showed a steady height increment up to 18 months after planting. Survival and growth rate of both species planted in higher density plots were higher than those in lower density plots (Table 1). Planting stock from cutting of both species planted at 4 x 4 m spacing performed better than those from seedling at the same spacing (Table 1). At this particular site, the performance of *S. selanica* was similar to *S. leprosula*. These findings suggest that planting stock from cuttings of *S. leprosula* and *S. selanica* can be used to reforest this degraded forest.

## CONCLUSION

Humidity, temperature and light intensity are the critical environmental conditions for the vegetative propagation of dipterocarps, and their mass production requires a method to control environmental conditions. The method must be economical so the price of vegetative propagules is not too expensive for practical application. The fog cooling system is a suitable technique for mass propagation of *S. selanica* and *S. leprosula*. Planting stock from cuttings of *S. leprosula* and *S. selanica* are recommended for rehabilitation at this degraded site in West Java. Planting at closer spacing gave better survival and growth than at wider spacing and the performance of cuttings was better than seedlings.

## REFERENCES

Aminah, H. 1991. Rooting ability of stem cuttings of eleven dipterocarp species. Journal of Malaysian Applied Biology 20: 155-159.

Ashton, P.S., Givnish, T.J. and Appanah, S. 1988. Staggered flowering in Dipterocarpaceae: new insights into floral induction and the evolution of mast flowering in the seasonal tropics. American Naturalist 132: 44–66.

**Table 1.** Growth and survival of *S. leprosula* and *S. selanica* of different origin at different spacings at age 15 months from planting at Leuwiliang

| Treatment | *S. leprosula* | | *S. selanica* | |
|---|---|---|---|---|
| | Height (cm) | Survival (%) | Height (cm) | Survival (%) |
| Cuttings 2 x 2 m | 128.9 | 76 | 131.5 | 83 |
| Cuttings 3 x 3 m | 100.4 | 59 | 129.1 | 75 |
| Cuttings 4 x 4 m | 100.1 | 72 | 94.2 | 78 |
| Cuttings 5 x 5 m | 109.2 | 45 | 97.9 | 53 |
| Seed 4 x 4 m | 68.7 | 56 | 85.2 | 65 |

Masano, Alrasjid, H. and Hamzah, Z. 1987. Planting trials of dipterocarps species outside their natural distributional range in the Haurbentes experimental forest, West Java. *In*: Kosterman, A.J.G.H (ed.). Proceedings of the Third Round Table Conference on Dipterocarps. 19–37.

Sakai C., Yamamoto Y., Subiakto A., Hendromono and Prameswari D. 1994. Vegetative propagation of Dipterocarpaceae. *In*: Ratnam, W., Yahya, A.Z., Sharif, A.H.M., Ahmad, D.H., Khoo. K.C., Suzuki, K., Sakurai, S. and Ishii, K. (eds.). Biorefor Proceedings Kangar Workshop. 147-149.

Sasaki, S. 1980. Storage and germination of dipterocarp seeds. The Malaysian Forester 43: 290–308.

Smits, W.T.M. 1983. Vegetative propagation of *Shorea* cf. *obtusa* and *Agathis dammara* by means of leaf-cuttings and stem-cuttings. The Malaysian Forester 46: 175-185.

# 24

# An Overview of Development Processes and Farmers' Interactions in a Participatory Forest Fire Prevention Programme in Jambi Province, Indonesia

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***Abstract***

The participatory forest fire prevention programme of Forest Fire Prevention Management Project (FFPMP) aims at intensive fuel management and fire control with the integrated green belt on community land on the boundary of Berbak National Park, Jambi Province, Sumatra. It aims to motivate farmers to cultivate their land continuously, reducing fire hazards and risks through formation of fuel breaks around the forest. Participating farmers face technical limitations in seedling production, land preparation without burning, and crop planting and protection. They cannot easily perceive benefits of the green belt with line planting of the small number of trees. Land-oriented farmers experienced in growing crops and constructing facilities are more advantaged than local farmers dependent on forest resources. Current socio-economic conditions have accelerated diverse programme evolution with farmers' different responses. FFPMP has funded materials and facilities to substitute for farmers' lack of technical and economic capabilities. It may also modify the programme to optimise farmer participation and facilitate effective fuel break formation, including flexible design of planting sites along the green belt with various crops, new land preparation technologies, establishment of pilot small-scale nurseries, and strengthening of community organisations for less advanced farmers. This paper addresses the socio-economic sustainability of the participatory green belt programme.

## INTRODUCTION

The Forest Fire Prevention and Management Project (FFPMP) has implemented a participatory forest fire prevention programme at its site around Berbak National Park, Jambi Province, Sumatra, since 1997. The programme stresses park-border communities' active participation in long-term prevention of wild fires on their land through establishment of integrated green belts (IGB) with fire-resistant tree rows along the park boundary, associated with intensification of farmers' land uses. Through IGB trials FFPMP has determined crucial socio-economic factors for successful programme development at the community level.

This paper aims to analyse current progress and constraints on IGB trials of FFPMP at the Jambi site and to recommend viable programme modifications.

### Site Description

The programme is implemented at Rantau Rasau and Sungai Rambut villages, Rantau Rasau Sub-District, Tanjung Jabung District, Jambi Province (Fig. 1). Both villages are situated along the boundary of Berbak National Park that protects indigenous lowland swamp forests. Inhabitants

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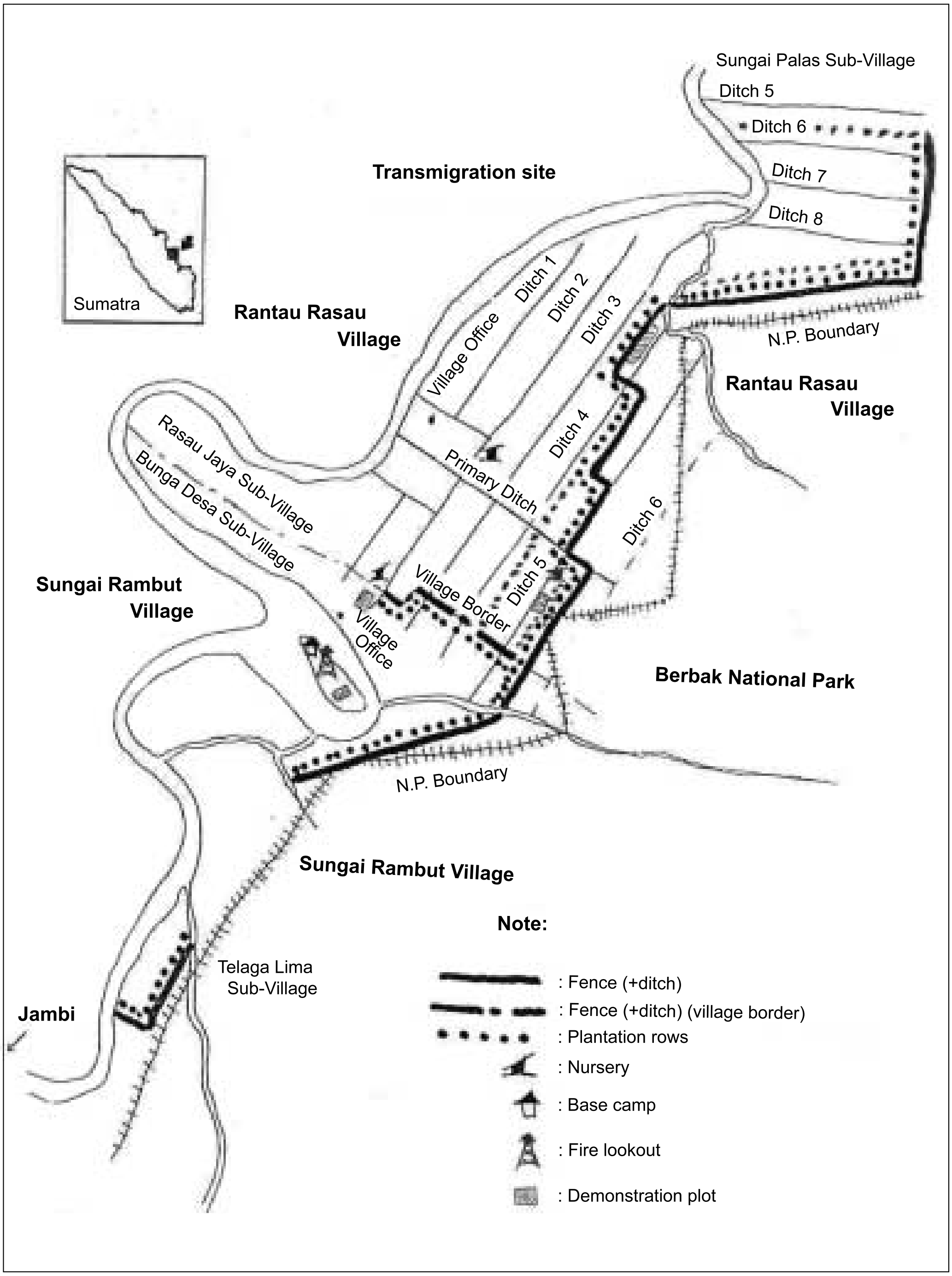
**Figure 1.** Project site



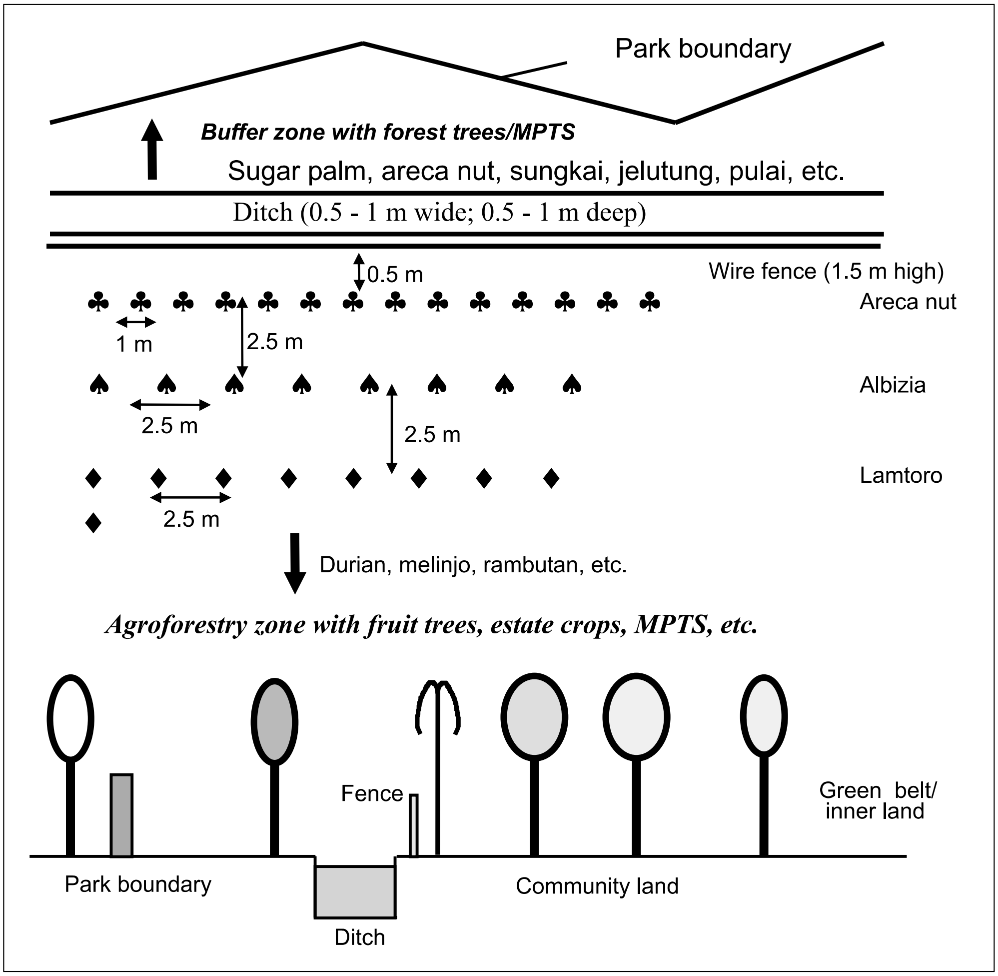
consist of local in-migrants (Malay), Javanese transmigrants, and spontaneous in-migrants from South Sulawesi (Buginese). Most of the Malay live along the riverside for riverine fisheries and rice farming, while other ethnic groups live in inland areas and grow various crops. Communities' settlements are well-organised along primary and secondary ditches, divided into small administrative units called neighbourhood associations (RT).

## CONCEPT OF PARTICIPATORY INTEGRATED GREEN BELTS

Integrated green belts (IGB) aim to safeguard the park forests against wild fires and community land against wild boars through promotion of farmers' land use intensification. IGB is established along the border of the existing cultivation land close to the park boundary with the expectation of farmers' active participation. IGB consists of a wire fence, a ditch, and tree rows (Fig. 2). The wire fence is effective to block wild boars, while the ditch cuts off surface and ground fires and stores water for initial suppression. The tree rows are expected to control both surface fires and wild boars, and then stimulate farmers' intensive cropping on their land.

Suitable tree species had to be selected for effective fire prevention (fuel control and fire resistance) and for economic benefits to farmers preferably with non-timber products. The selected trees have to be adapted to grow well on the wet and peaty soils of the site. Three species were

**Figure 2.** Model of Integrated Green Belt



selected from farmers' preferences and the project needs for the first stage. They were areca nut (*Areca catechu*), albizia (*Paraserianthes falcataria*), and lamtoro (*Leucaena leucocephala*). Areca nut is planted along the wire fence to prop it up when existing wooden props decay. Albizia is one of the more valuable timber species, yielding profitable timber in a short period while forming tree stands quickly. Some farmers prefer lamtoro for its multipurpose functions, including soil improvement and fodder production. In the initial green belt design FFPMP restricted the number of tree species, based on fire prevention and ease of cultivation. At the second stage other promising species were introduced to study their fire prevention effectiveness. Fruit trees and multipurpose trees (MPTS), such as durian (*Durio zibethinus*), rambutan (*Nephelium lappaceum*), and melinjo (*Gnetum gnemon*), were planted inside the fence. Demonstration plots were established to test these new tree crops on the inner community land. The green belt is being expanded both toward the inner community land (inside the fence) and the park boundary (outside the fence) with the selected tree species. Nurseries were established in the two site villages to produce seedlings and improve farmers' abilities to grow seedlings.

These tree crops are expected to be fire-resistant to some degree, although this needs to be examined during the trials. Farmers have observed that trunks of areca nut are fireproof due to their thick bark. Long branches of albizia can effectively control undergrowth and weeds on the ground, outweighing the vulnerability of its trunk to fire. Lamtoro is similar to albizia, but its trunk is more resistant to fires. Durian, rambutan, and melinjo are generally resistant to fire due to their long branches and high moisture of their trunk. The immediate benefit of IGB is to effectively control wild fires from community land or forests. However, it is also expected that IGB will facilitate reduction of inflammable undergrowth and farmers' land burning by ensuring reliable growth of annual and perennial crops on their land. Target group farmers are expected to participate actively in green belt activities with material assistance from FFPMP.

## SUMMARY OUTCOMES OF PARTICIPATORY IGB PROGRAMME

Up to March 1999, over 12 km of the fence has been constructed at two villages. The length of the ditch reached 10 km. The row of areca nut extends the full 12 km along the fence. However, the albizia and lamtoro are less successful on account of unfavourable site conditions. In addition to these three species, various other species were introduced to the green belts and three demonstration plots, including durian, rambutan, melinjo, coconut (*Cocos nucifera*), sugar palm (*Arenga pinnata*), breadfruit (*Artocarpus communis*), sungkai (*Peronema canescens*), jelutung (*Dyera lowii*) and pulai (*Alstonia scholaris*).

The green belt is being expanded from the initial three rows to about ten rows. Several forest trees such as jelutung, pulai, and sungkai, and MPTS such as areca nut and sugar palm are being tried in the park buffer zone outside the fence, while other new species are being tested on the inner community land free of wild boars. More than 160 000 seedlings were produced, or provided from the outside, for planting the green belts and demonstration plots. The rate of seed germination ranges between 75 and 90%. Three pilot nurseries with 39 seedbeds were built in the villages. Supporting facilities were constructed, including a base camp and a 23 m high fire lookout. Over 310 households in 13 groups have participated in the IGB activities. Self-help groups were organised out of the existing neighbourhood associations and farmer groups.

### Costs and Self-help Abilities of Participating Farmers

IGB requires initial investment to support its various activity components. Table 1 analyses activity costs and farmers' self-help abilities in IGB development. A large amount of funds and labour had to be allocated for wire fence construction, including provision of wire, props, nails, and tools as well as their transportation. A sharp rise of prices of wire and other materials has also influenced the cost of the wire fence construction, particularly since the economic crisis in early 1998. Farmer groups worked very hard on a voluntary basis plaiting wire and setting up fences, reflecting their strong desire to control wild boars on their land. Ditch construction cost much less because the experienced Javanese farmers carried it out efficiently. They were strongly motivated to dig ditches by themselves in order to enhance fire prevention and wild boar control, stimulated by assistance from FFPMP for wire fences.

Nursery management required funds for construction materials, seedlings, fertilisers, and wages. Participating farmers' self-help abilities are still limited on seedling production owing to lack of their experience and skill. Consequently additional seedlings had to be purchased from the outside the site villages.

Planting activities were rather economical in terms of costs and labour inputs, except for weeding and land preparation of the idle land overgrown with thick undergrowth. Farmers often demanded small remuneration for these activities. The figures in Table 1 probably underestimate the costs and labour contributions to plant and protect trees, and may increase as the programme continues. Transportation of seedlings inside the village and fertilisation are somewhat laborious and costly, although farmers show strong interest in various perennial crops, expecting income generation in the future. Nursery establishment and seedling provision could be a big challenge to sustainable planting activities on the community land, especially when farmers are unfamiliar with tree growing technologies.

Initial funds were indispensable to develop IGB, particularly for wire fences, even though the programme is to be carried out with farmers' self-help efforts. Farmers have difficulty in meeting all the costs of the intensive IGB establishment. Another emerging constraint on farmers' activities is protection of crops, fences and other facilities. They cannot afford to maintain all of the activities for a long period without immediate tangible benefits, so protection of the planted trees and the fences is a burden. Costs of fertilisation will increase when farmers introduce fruit trees, such as durian and rambutan, which require large doses of fertilisers.

**Table 1.** Assessment of activity costs and farmers' self-help abilities in IGB development

| Activity | Activity cost | | | Voluntary contributions from farmer groups | | |
|---|---|---|---|---|---|---|
| | Unit cost (Rp.) | Fund allocation (%) | Assistance | Labour input (person days) | Labour input (person days tree$^{-1}$) | Activity |
| Wire fence construction | 5305 m$^{-1}$ | 32.9 | Wire, props (partly), nails, tools, transportation | 10 770 | 0.85 | Plaiting of wire, gathering of props, setting up of fences |
| Ditch construction | 106 m$^{-1}$ | 0.5 | Remuneration/wages, tools (hoes, etc.) | 2400 | 0.23 | Digging of soils |
| Nursery/ seedling production | 315 tree$^{-1}$ | 14.6 | Wooden materials, fertilisers, pesticides, wages, transportation | 2450 | 0.03 | Weeding, watering, guarding |
| Seedling provision | 635 tree$^{-1}$ | 48.2 | Seedlings, seeds, transportation | - | - | |
| Planting on the green belt | 356 tree$^{-1}$ | 3.8 | Fertilisers, transportation, remuneration for weeding/land preparation | 825 | 0.04 | Weeding/land preparation (planting holes), planting, protection |

**Table 2.** Outcomes of the IGB trials at two villages (up to March 1999)

| Outcomes/Village | | Rantau Rasau | Sungai Rambut |
|---|---|---|---|
| Ethnic group of participating farmers | | Javanese, Buginese (in-migrants) | Malay (local)<br>Partly Javanese |
| Participating farmers (households) | | 192 | 118 |
| Wire fence (km, % target length) | | 10.2 km (97%) | 2.4 km (59%) |
| Ditch (km, % target length) | | 9.6 km (90%) | 0 km (0 %) |
| Green belt planted (km, % target length) | | 10.2 km (97%) | 1.9 km (46 %) |
| Seedlings produced (trees) | | 50,710 | 44,355 |
| Trees planted on the green belt | | 18,515 | 3420 |
| Activity cost per unit | Wire fence | Rp. 4778 m$^{-1}$ | Rp. 7565 m$^{-1}$ |
| | Ditch | Rp. 106 m$^{-1}$ | ——- |
| | Nursery | Rp. 184 tree$^{-1}$ | Rp. 465 tree$^{-1}$ |
| | Planting | Rp. 243 tree$^{-1}$ | Rp. 971 tree$^{-1}$ |
| Labour contributions from farmer groups (person x day, person x day per unit (m or tree)) | Wire fence | 8280 (0.81) | 2490 (1.04) |
| | Ditch | 2400 (0.23) | 0 (0.00) |
| | Nursery | 1970 (0.04) | 480 (0.01) |
| | Planting | 530 (0.03) | 295 (0.09) |

## RESPONSES OF FARMER GROUPS TO INTEGRATED GREEN BELTS

This section analyses various responses of farmer groups to the IGB development.

### Acceptability of ethnic groups to IGB

Outcomes of the IGB development are quite different among the participating farmer groups. Table 2 compares farmers' performances in the IGB development between the two villages. These data show that in-migrant farmers (the Javanese and Buginese) at Rantau Rasau performance was better in terms of cost effectiveness and self-help abilities than local inhabitants (the Malay) at Sungai Rambut in all of the activities. Farmers of Rantau Rasau established the green belts more quickly with lower costs than those of Sungai Rambut. They were also active in seedling production.

In contrast, higher activity costs were caused by delayed implementation, price increases for wire and other materials, greater input of materials such as wire and props, and wage labour for weeding and land preparation at Sungai Rambut. Local farmers could not plait wire efficiently, and used more wire to set up fences than farmers at Rantau Rasau. Their self-help capabilities are also seriously limited in land preparation and farming. They cannot initiate ditch construction by lack of experience in digging soils with hoes.

This variation in farmers' performance may derive from their diverse acceptability to the IGB programme, affected by their socio-cultural backgrounds[4]. The Javanese and Buginese farmers as in-migrants are more motivated to take initiatives for new activities to improve their

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[4] The authors presume that the initial IGB development was disadvantageous to the local Malay farmers as compared with the in-migrant Javanese and Buginese farmers based on observation of their activities with field staff. However, it can definitely not be generalised that the Malay groups have the same tendency in all activities everywhere, as the assumption is supported by nothing but a case from the site villages. Nevertheless, the authors recognise the significance to understand farmer groups' diverse responses to the IGB programme at the site for appropriate programme modifications. In the follow-up activities FFPMP will document evolution of both local and in-migrant farmers' interactions and performances in the modified IGB programme to assess its adaptability to the site communities.

livelihoods at new settlements even at the risk of failure. They are very eager to make a success of their new life after leaving their homeland in Java or Sulawesi. These in-migrants have gained wide experience and interest in various activities, and evolved many communication channels though migration, which expedites their active participation in new activities with their own knowledge and skills. The Javanese have a strong tradition of hoeing the land, and very experienced in intensive farming with various annual and perennial crops. The Buginese are also acquainted with intensive farming with coconut and citrus. Both groups still maintain strong social bonds and are good at organising collective actions such as mutual assistance (*gotong royong*) for ditch construction and land cultivation. Conversely, local Malay groups maintain their traditional life usually along the riverside, depending on riverine fisheries, tapping latex of jelutung, and gathering of other forest resources besides rice growing for their livelihood. Part of the Malay inhabitants also migrated into the site out of other villages, but their experience and communication are still limited within the living sphere of the Malay. They are reluctant to run a risk in new activities without substantial experience, and are less positive about participation in the IGB activities before seeing benefits of the programme to other Malay farmers. Even the success of the Javanese and Buginese is not a convincing example for them due to different cultural backgrounds. They are unfamiliar with collective actions in the project, and tend to seek quicker benefits than the Javanese and Buginese on account of their poorer economic situations. They prefer rice and other annual crops to tree growing.

It is concluded that the initial IGB activities are more acceptable to the in-migrant farmers than the local farmers because of higher adaptability of the former groups to land preparation and planting activities.

## Farmers' preferences for tree planting

Although the IGB development aims at intensive tree planting in a row along the border of farmers' cultivation land, they often show more interest in tree planting on their inner cultivation land especially at Sungai Rambut, as suggested in Table 3. In particular they prefer to plant areca nut on their dryland or home gardens to gather seeds more easily. This adversely affects their willingness to maintain the green belt by weeding and fertilisation. It is often observed that they actively weed the inner land rather than the green belt farther from their houses. It might also be because they cannot yet perceive the benefits of the green belt before harvest of products from the planted trees. Line planting of small number of trees and high maintenance costs for a long period may be less satisfactory to them. Out of the three initial species, some albizia and lamtoro seedlings remained unused in the nursery.

Often farmers failed to schedule timely tree planting owing to inundation of the lower land, delayed rice harvest caused by the preceding long drought, and other income supplementing activities. Synchronisation of tree planting with farmers' activities is difficult, aggravated by unforeseeable natural conditions and their unstable economic status.

**Table 3.** Planting areas of three major species up to March 1999

| Village Area/ species | Proportion of planted trees (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rantau Rasau | | | Sungai Rambut | | | Total | | |
| | Areca nut | Albizia | Lamtoro | Areca nut | Albizia | Lamtoro | Areca nut | Albizia | Lamtoro |
| Green belt | 75.4 | 48.4 | 50.3 | 59.1 | 15.1 | 14.3 | 67.3 | 36.0 | 36.1 |
| Inner land | 17.3 | 0.0 | 0.0 | 33.5 | 0.0 | 0.0 | 25.4 | 0.0 | 0.0 |
| Replacement | 6.1 | 15.9 | 19.2 | 1.2 | 4.5 | 5.9 | 3.6 | 11.6 | 14.0 |
| Not yet planted | 1.3 | 35.7 | 30.5 | 6.2 | 80.4 | 79.8 | 3.7 | 52.3 | 49.9 |

### Condition of crops based on farmers' observations

Growing condition of farmers' crops may largely affect their responses to the on-going IGB development. Table 4 compares mortality of six major crops and its causes in the green belt, based on a questionnaire survey with the participating farmers. Areca nut survives quite well, while the mortality rate of albizia, lamtoro, and melinjo is higher. Acid soils and inundation killed areca nut trees, while albizia and lamtoro mortality was mostly due to acid soils. Durian and rambutan survive best so far, though they are newly planted and so their growth needs to be carefully monitored. Melinjo was affected by not only inundation but also other various factors, especially wilt and pests, possibly due to farmers' inadequate treatment. Some melinjo and rambutan seedlings were trampled by passers-by or cattle. It is expected that crops on the inner land will be more susceptible to disturbance by people and livestock, as compared with the initial species along the fence.

These results generally coincide with the plot survey of growth of the initial three species in five plots. The mortality rate is 0% in areca nut, 34% in albizia, and 28% in lamtoro. It is concluded that better growth of areca nut compared to albizia and lamtoro is due to its high adaptability and good planting environment on the embankment along the ditch. Some albizia and lamtoro trees were killed by inundation on the lower land.

The condition of planted tree crops has been influenced by farmers' enthusiasm for crop protection, but simultaneously it may largely affect their concern with the crops. In this respect timber trees have so far few good prospects for development on the wet community land, discouraged by uncertain timber markets, despite initiatives of FFPMP and farmer groups for formation of the green belt with fast-growing timber species.

## IMPEDIMENTS TO SUSTAINABLE IGB DEVELOPMENT

As discussed in the preceding sections, farmers' participation in the IGB development is not yet optimal particularly at Sungai Rambut. The following obstacles confront the participating farmers during implementation of the IGB programme:

### High initial investment costs

Initial investment in material assistance such as wire and seedlings will be a limiting factor for sustainable development of IGB in terms of cost-effectiveness. The wire fence is an effective tool to control wild boars, yet its cost may already be too high to be borne by farmers themselves. Meanwhile, no promising alternative technologies have yet been found for this site. Hedgerow trees might be recommended for formation of live fences by cuttings, such as waru (*Hibiscus* sp.) as observed at part of the site, but their survival rate is uncertain on the wetland.

### Inadequate nursery technologies

Nursery establishment and seedling provision are another difficulty at the site villages. Seedlings of farmers' favourite tree species are quite hard to produce at the village level, above all fruit trees,

**Table 4.** Mortality of crops and its causes by farmers' observation (%)

| Species | Mortality | Causes of crop death | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Inundation | Acid soils | Wilt | Destruction by passers-by | Pests | Fungi | Livestock | Others |
| Areca nut | 17.8 | 57.3 | 33.8 | 1.1 | 0.0 | 0.3 | 0.0 | 0.9 | 6.6 |
| Albizia | 39.6 | 6.5 | 89.9 | 1.5 | 0.0 | 0.3 | 1.0 | 0.1 | 0.8 |
| Lamtoro | 37.2 | 9.8 | 87.2 | 0.0 | 0.0 | 0.7 | 0.0 | 1.4 | 0.9 |
| Melinjo | 37.2 | 48.9 | 10.9 | 20.7 | 0.0 | 4.4 | 4.4 | 4.8 | 6.1 |
| Rambutan | 7.8 | 0.0 | 0.0 | 77.8 | 22.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Durian | 9.2 | 0.0 | 0.0 | 96.0 | 0.0 | 4.8 | 0.0 | 0.0 | 0.0 |

owing to technical limitations. Few farmers can afford to purchase these seedlings.

### Difficulty of land preparation without burning

Farmers encountered serious problems of land preparation through clearance of thick undergrowth and weeds without burning. The current government policy bans farmers from burning their land or spraying herbicides, but they have not yet worked out alternative land preparation technologies that they can apply easily.

### Insufficient green belt protection

Farmers cannot easily protect the green belt due to their lack of capital and motivation. Their land cannot be cleared or cultivated continuously on the green belt and without enough capital or labour is quickly invaded with weeds and undergrowth. Furthermore, tree growth is stagnant without sufficient funds for fertilisation. Several fast-growing timber trees would be easier to grow on the favourable land, but are so far less attractive to farmers on account of uncertain marketing opportunities. Part of the green belts run across critical land, such as peat swamps or flood plains, which incurs high costs of soil amelioration and land improvement.

### Uncertain benefits of line planting

Although line planting of tree crops might be advantageous in maintaining inner agricultural land in accordance with instructions by the local government, it is less favourable to farmers because crop harvests are small. A number of farmers are more concerned with broad-scale tree planting on the inner land.

### Disadvantage of local farmers

Local farmers cannot easily develop their skills for the IGB activities as compared with in-migrant farmers. They lack experience in collective actions and land cultivation, as they still live on natural resource gathering for quick income. They are inclined to expect more short-term in-kind or cash incentives during the development of IGB. Consequently funds had to be provided to encourage their activities.

## MODIFICATIONS OF THE PARTICIPATORY IGB PROGRAMME

Although the IGB model is attractive to accomplish long-term fire prevention with tree planting at the community level, several constraints must be overcome to sustain farmers' active participation for a long period. This section recommends technical and institutional programme modifications.

### Diversification of crop species

In the later period of implementation FFPMP tried to give participating farmers better opportunities to design more suitable planting models through diversification of crop species, with more attention to their skills and interest. Farmers were encouraged to select their favourite crops that they can grow easily within their economic abilities. Table 5 shows the current preferences for perennial crops based on the questionnaire survey of 336 participating farmers. It indicates that a large number of farmers want estate crops such as local coconut, hybrid rubber (*Hevea brasiliensis*), cacao (*Theobroma cacao*), and coffee (*Coffea arabica*). The Javanese and Buginese groups (216 farmers) at Rantau Rasau favoured local coconut and citrus, while the Malay groups (120 farmers) at Sungai Rambut requested hybrid rubber and local coconut. Farmers' preferences are more diverse at Rantau Rasau than at Sungai Rambut, reflecting variation in their cropping experience. Timber trees are less popular on account of few economic benefits, and even fruit trees are not favoured, except citrus and rambutan, because of long growing periods and high costs of management including fertilisation. Farmers' choices of perennial crops are greatly influenced by marketing environment of the products rather than non-commercial factors.

These crops have various characteristics for fire prevention. Cacao is supposed to be resistant to fires, and effective in green belt formation due to its fast growth. Nonetheless, the fire-resistance of cacao must be closely studied at the FFPMP site. Trunks of rubber and coconut may be quite susceptible to fires, but they will effectively control weeds and undergrowth. At first FFPMP did not

**Table 5.** Farmers' proposals for perennial crops

| Total (152 965 trees) | | Rantau Rasau (106 172 trees) | | Sungai Rambut (46 793 trees) | |
|---|---|---|---|---|---|
| Species | % | Species | % | Species | % |
| Local coconut | 29.0 | Local coconut | 32.9 | Hybrid rubber | 34.8 |
| Citrus | 15.7 | Citrus | 20.0 | Local coconut | 20.2 |
| Hybrid rubber | 12.8 | Cacao | 10.1 | Areca nut | 9.5 |
| Areca nut | 8.8 | Areca nut | 8.5 | Local rubber | 7.2 |
| Cacao | 7.1 | Rambutan | 5.2 | Rambutan | 6.0 |
| Rambutan | 5.5 | Coffee | 3.7 | Citrus | 5.9 |
| Others (29 sp.) | 21.1 | Others (28 sp.) | 19.7 | Others (17 sp.) | 16.4 |

approve the estate crops, afraid of exacerbation of farmers' forest encroachment and fire occurrence. However, these crops are not suitable to grow outside the fenced area where there are more critical soils and pests. Farmers are also expected to be more careful with the use of fire after their land is planted with their selected crops. FFPMP will try a variety of perennial crops in and around the green belt to examine their resistance to fires, motivating farmers to plant and protect them.

## Modification of planting sites

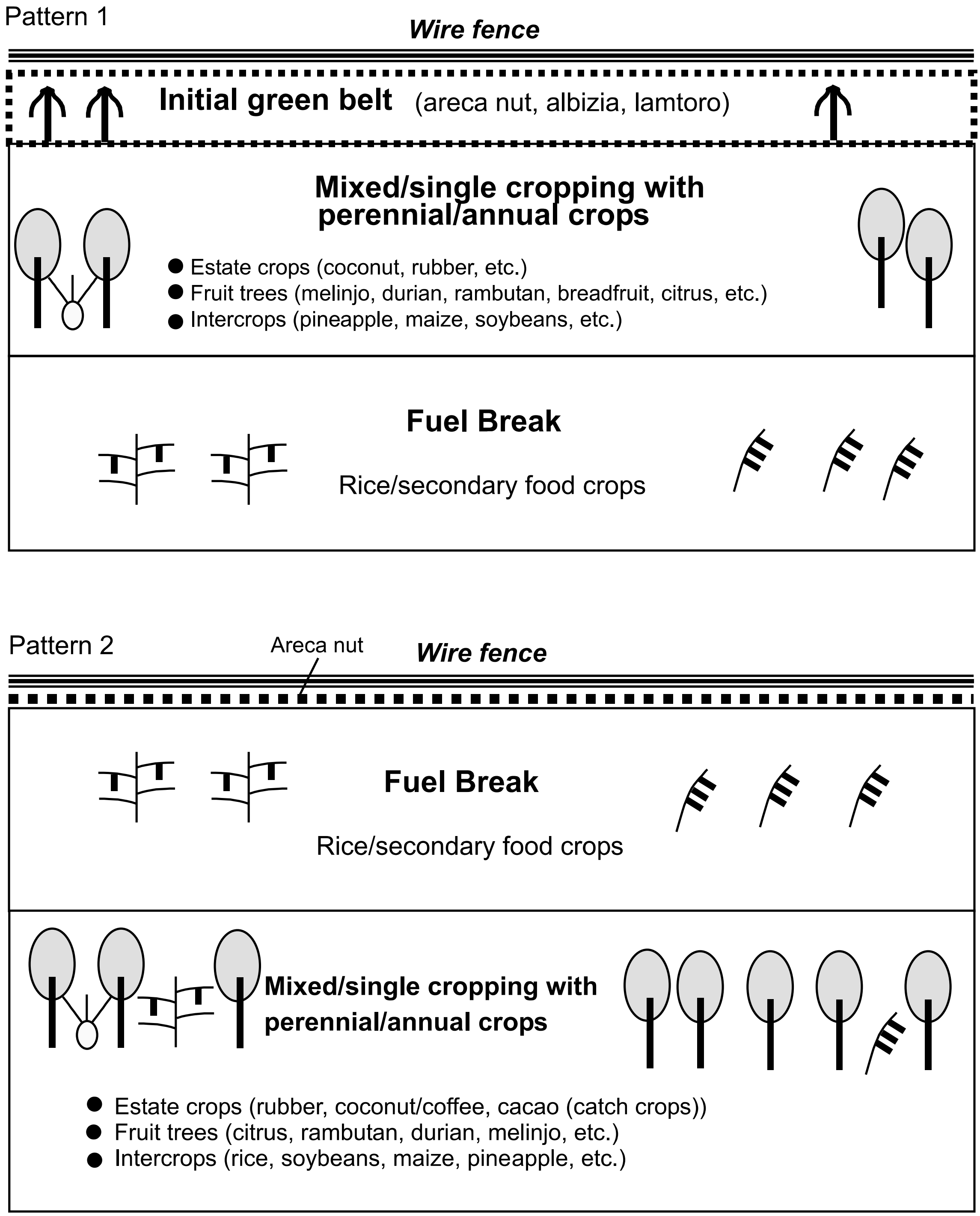
FFPMP will help farmers determine appropriate planting sites more flexibly in and around the green belt to guarantee optimal growth of the selected crops without heavy land improvement work. Figure 3 classifies farmers' ideas which emerged in the questionnaire survey for tree planting in and around the green belt. Pattern 1 aims to expand the existing green belt along the fence with farmers' favourite tree crops together with annual and short-cycle intercrops, which suits the project objective best. On the inner land farmers grow rice and food crops every year, developing fuel breaks. Pattern 2 is to develop the fuel breaks with annual crops along the fence and the row of areca nut on the lower land, accompanied by the tree planting on the higher land. For this pattern, the effects of the fuel breaks to suppress weeds and undergrowth, and cut off surface fires will be examined, while closely monitoring farmers' skills of controlled burning in land preparation. Patterns 3 and 4 are oriented to alley cropping with annual or short-cycle crops on the inner land, parallel or perpendicular to the initial green belt. Trees will be planted on ridges, embankments, or other higher topography, or otherwise indigenous wetland species will be introduced on the lower land. Pattern 2 is to be applied to areas where tree planting is difficult just along the fence due to frequent inundation or flood, but could be converted into Pattern 3 upon farmers' initiatives, if the fuel breaks turn out to be ineffective in control of fuel and wild fires.

Farmers will be encouraged to mix several perennial and annual crops on the green belt and the inner land for economic and ecological stability. In spite of this, they may prefer single cropping of estate crops, above all rubber, to try to maximise cash incomes. Nevertheless, farmers will be advised to space out rubber and other estate crops and to intercrop them with rice or other food crops for several years. It is expected that farmers will be more eager and responsible to prepare their land and then plant and protect their selected tree crops with the modified models, while the functions of the green belt will be strengthened. Coupled more closely with farmers' initiatives, tree growing should be more sustainable in and around the green belt, enhancing formation of fuel breaks and control of burning.

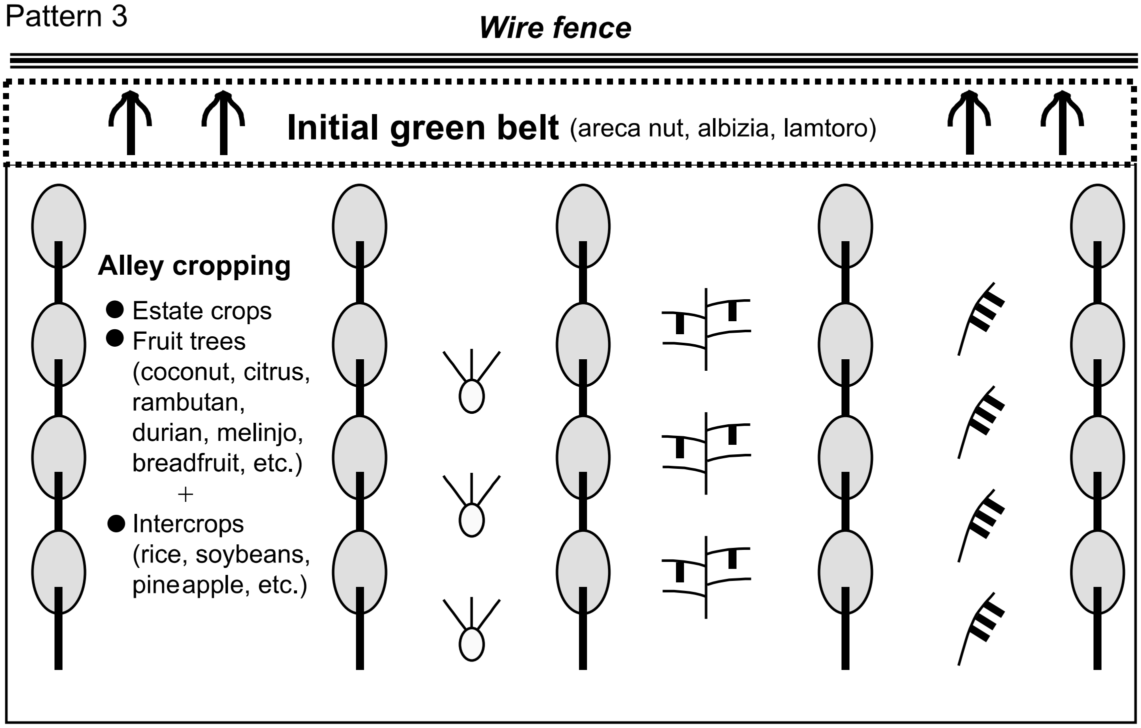
## Improvement of technologies for land preparation and crop protection

Initial land clearance and subsequent weeding are still a problem for farmers without burning or spraying practices. Even though some farming tools might be helpful, farmers still feel it a burden

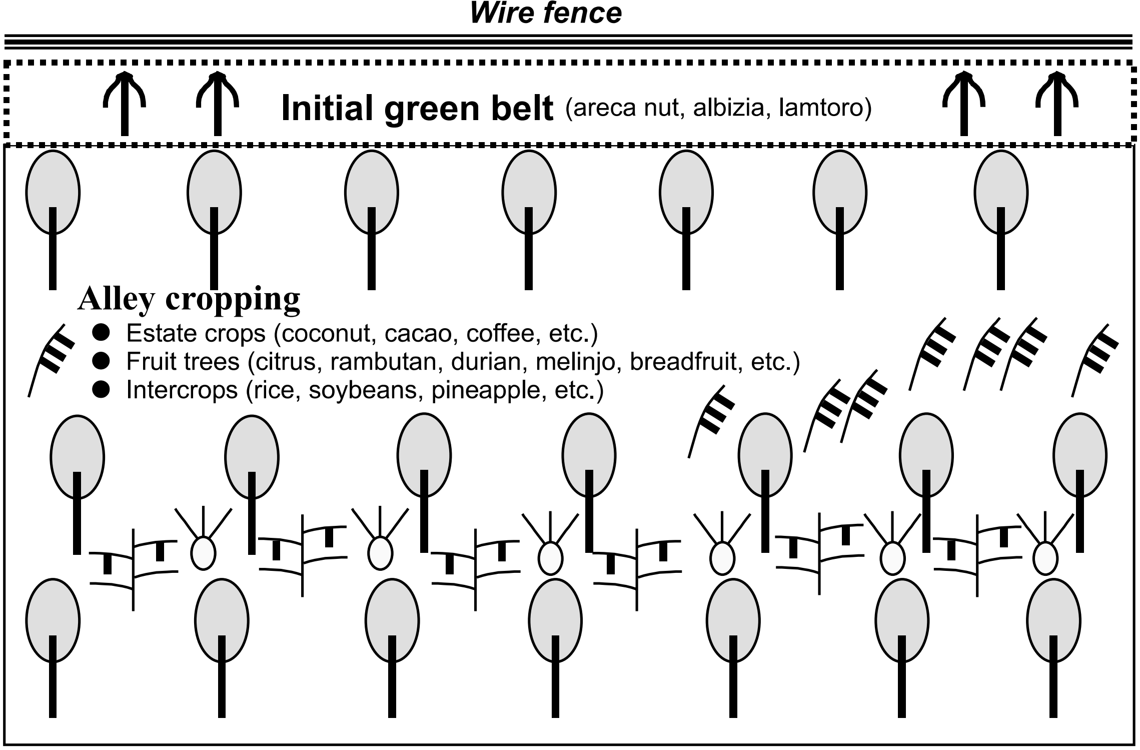
**Figure 3.** Farmers' ideas for land uses



Pattern 3



Pattern 4



to prepare their land by manual weeding. Assistance in food crops might be considered for participating farmers to facilitate weeding of the green belt with quick harvests. Gradual land use intensification with annual and perennial crops will help farmers prepare land more easily with reduction of weeding costs in the near future. Fertilisation problems could be surmounted by selection of crops requiring little fertiliser. FFPMP will also try to provide farmers with technical assistance in production of mulches and composts out of weeds and dung to minimise chemical fertilisation. Generation of the demand for green manure could also stimulate farmers' sound land preparation in the future.

## Development of alternative fencing technologies

More simple and effective fencing technologies must be found as an alternative to expensive wire fences for wide application in other areas. A potential method would be formation of hedgerows by direct sowing of seeds of several leguminous trees such as turi (*Sesbania grandiflora*) or planting of cuttings of local trees such as bungur (*Lagerstroemia speciosa*), although its technical feasibility needs to be tested at the site.

## Facilitation in seedling production and nursery building

Table 6 indicates farmers' willingness to produce seedlings inside the two villages with 27% interested in seedling growing. Farmers of Rantau Rasau (39) are more positive than those of Sungai Rambut (4). In correspondence with their crop preferences, farmers are eager to produce seedlings of coconut, citrus, cacao, rambutan, durian, coffee, rubber etc.

Farmers do not have sufficient experience for seedling production of all selected crops. Coconut seedlings are relatively familiar to farmers and growing of areca nut seedlings has been demonstrated during implementation of the project. Some farmers are experienced in producing albizia seedlings. A few have tried to plant cuttings of rubber on their land. Nonetheless, very few have raised seedlings of other species, above all fruit trees. Citrus and melinjo require special care with fertilisation and pest management to maintain the quality of their fruits. Farmers have not yet acquired grafting skills and other technologies to produce good quality seedlings of durian, rambutan, and duku (*Lansium domesticum*). They can grow jackfruit (*Artocarpus heterophyllus*) fairly well by simply transplanting wildings that germinate around their houses.

**Table 6.** Farmers' interest in seedling growing

| Crop species | Interested farmers (%) | | |
|---|---|---|---|
| | Rantau Rasau | Sungai Rambut | Total |
| Coconut | 18 | 4 | 13 |
| Citrus | 15 | 1 | 10 |
| Cacao | 14 | 0 | 9 |
| Rambutan | 12 | 1 | 8 |
| Durian | 10 | 0 | 7 |
| Others (17 sp.) | 46 | 9 | 33 |

As farmers' technical and economic capacities are still limited for seedling production, small pilot nurseries need to be established and maintained for demonstration of seedling production technologies, with assistance by external agencies, including Ministry of Forestry and Estate Crops and local extension services. It is expected that the pilot seedling production will gradually assist technology transfer from farmer to farmer inside the villages.

## Strengthening of community organisation

Community consultation and organisation processes are imperative to build up farmers' working abilities especially in underdeveloped areas. The organisation work must be adapted to local socio-cultural conditions, and suitable personnel who comprehend them must be appointed to enable good communication with farmer groups. Oral instructions alone will never be enough for local Malay inhabitants. Joint field trials are indispensable together with frequent technical orientation and pilot demonstration. Considerable government support will be essential for community organisation and extension for the whole period of programme implementation.

## CONCLUSIONS

Although the IGB trials are a good example of participatory forest fire prevention along the forest boundary through intensification of farmers' land uses, there are obstacles to their sustainable implementation. Main limitations are high initial investment costs in materials and facilities, above all wire fences, and farmers' limited capacity for land preparation, seedling production, and protection of crops and facilities. Local inhabitants are less capable of the IGB development than in-migrant farmers.

To address these shortcomings, FFPMP will focus on more effective fuel management inside the fenced areas through agroforestry development with various perennial crops proposed by farmers. They have increasingly urged FFPMP to balance fire prevention objectives and their living needs in establishment of the green belt on their land, which results in diversification of tree crops and cropping patterns with adaptation of planting sites. FFPMP will also seek for opportunities to expand the green belt outside the fence along the park boundary with indigenous tree species resistant to pests and fires, with a view to upgrading fire prevention and wild boar control. Incentives may be indispensable for active participation of farmers, but more cost-effective funding techniques need to be explored with simpler technologies for economical fencing, sustainable seedling production, and sound land preparation and crop protection.

Careful modification and adaptation of the programme to the local conditions are crucial through positive integration of initiatives of farmers and the project to optimise outputs and minimise activity costs in the latter period of implementation. Community participation programmes inevitably involve processes of problem analyses, innovations, and programme modifications. Rigid and predetermined approaches result in ineffective programme organisation and intolerably high activity costs. Responding to various farmer groups' performances, programme options and farmer organisation skills need to be diversified as far as possible for more sustainable development of IGB. Reiterative learning processes should be given high priority for disadvantaged farmer groups. The government must support the activities technically and financially.

FFPMP will use an evaluation matrix to assess effects of the on-farm green belt trials with various perennial and annual crops in fuel management, burning control, wild fire prevention, and farmers' self-reliance. The developed expertise on participatory tree planting would be valuable for not only forest fire prevention but also rehabilitation of ex-fire forests around community settlements. It is highly expected that rehabilitation of degraded forests in park buffer zones will be facilitated through collaboration between forestry personnel and local people with evolved participatory techniques.

## ACKNOWLEDGMENTS

This study was carried out under the participatory forest fire prevention programme of Forest Fire Prevention Management Project by Japan International Cooperation Agency and Ministry of Forestry and Estate Crops– Government of Indonesia. The authors express sincere gratitude to Dr. Shigeo Kobayashi and Ms. Rosita Go, CIFOR, for their warm invitation to the workshop and invaluable advice on the paper. The authors also thank Mr. Koes Saparjadi, Director of Forest and Estate Protection, Directorate General of Nature Protection and Conservation (PKA), MOFEC, Mr. Soedarmo, Sub-Director of Forest and Estate Fire Control, Directorate of Forest and Estate Protection, PKA, Mr. Morita Kazuyuki, Team Leader, FFPMP-JICA, Mr. Takai Hideaki, Assistant Team Leader, FFPMP-JICA, Mr. Hachinohe Hideki, Coordinator, FFPMP-JICA, and other experts and counterparts of FFPMP for their cordial assistance in and suggestions on the field activity and the paper. The authors highly appreciated the kind cooperation and assistance of Mr. Atang Setiawan, Head of Forest Protection and Nature Conservation Division (PHKA), Regional MOFEC Office in Jambi Province, Mr. M. Djoko Wibisono, Head of Protected Area

Conservation Section, PHKA/Regional MOFEC Office, Mr. Kuspriyadi S., Head of Berbak National Park Center (UTNB), Mr. Agus Priyambudi, Head of Natural Resource Conservation Unit (UKSDA), Mr. Bambang M., Head of Soil Conservation and Land Rehabilitation Center (BRLKT), Mr. Madari, UKSDA, Mr. P. Harahap, BRLKT, Messrs. Hapiz, Suratman, and Ramsen, both UTNB, other staff, Heads of Rantau Rasau and Sungai Rambut Villages, and all the participating farmers.

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# Information and Dataset System on the Rehabilitation of Degraded Tropical Forest Ecosystems Project for the International Network

M. Anazawa[1], H. Sawada[1] and S. Kobayashi[2]

***Abstract***

This information and dataset system aims to facilitate international exchange and synthesis of the scientific and technical information based on results of the CIFOR/Japan project on the rehabilitation of degraded tropical forest ecosystems. There are two main pathways. One path integrates general information at the study site from annual reports, site map, remote sensing data, aerial chart and vegetation map into plot data of each site. Their outputs are data on site condition, vegetation, soil, climate, etc. which are accessible to the public. Another path is to accumulate experimental raw data into "Download" the use of which is restricted and requires a password. Version 1 of this system is experimentally located on the website at: http://www.ffpri.affrc.go.jp/labs/fmrt/cifor/start.htm

## INTRODUCTION

This information and dataset system aims to facilitate international exchange and synthesis of scientific and technical information based on results of the CIFOR/Japan project on the rehabilitation of degraded tropical forest ecosystems. Collaborators in this project have produced the annual reports, data directory and database which consist of the research results on the changes of forest ecosystems and soils. Final outputs are expected to contribute to the long-term monitoring of degraded forest ecosystems, information networking among collaborators (scientists, forest managers, small forestholders), site evaluation and zoning for rehabilitation, and syntheses of rehabilitation techniques. This information and database integration-reference system has two main path ways. One path integrates general information at the study site from annual reports, site map, remote sensing data, aeronautical chart and vegetation map into plot data for each site. Outputs are data on site condition, vegetation, soil, climate etc., which are accessible to the public. Another path is to accumulate the experimental raw data into "Download" the use of which is restricted and requires a password. This system consists of "Window display and links among "information" and "database retrieval and download". The main structure of this system directory involves "public directory structure", "open data directory structure in public directory", "image directory structure in public directory", "project directory structure and download files"and "project directory structure and image files". This system is necessary to develop "database retrieval system" and to discuss the "access restriction" for download files and easier "data supply format"for data integration

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from collaborators. Version 1 of this system is now experimentally on the website of http://www.ffpri.affrc.go.jp/labs/fmrt/cifor/start.htm The start window of this dataset is shown in Fig.1.

## EXPLANATION OF THIS DATASET CD-ROM

### Contents

There are three types files in this CD-ROM : a HTML file, a GIF file, and an Excel file (xls) as a download file. In the upper part of the left frame, contents contain the introduction of the CIFOR project and annual reports of several countries (Fig. 2-(a)). In the annual reports, the user can select each partner country of this project and can see the report which contains figures and tables. The user can see any table as a gif image, but cannot download the data file directly, if the download button below the tableis clicked the user will return to data download menu in the start window.

### Data Download

DATA DOWNLOAD site is located in the lowest part of the left frame (Fig. 1). Clicking here, the data index and download table menu which lists seven countries will appear (Fig. 2-(b)). An authorised user can download any statistical data and inventory data as an Excel file (xls).

### Data Open to the Public

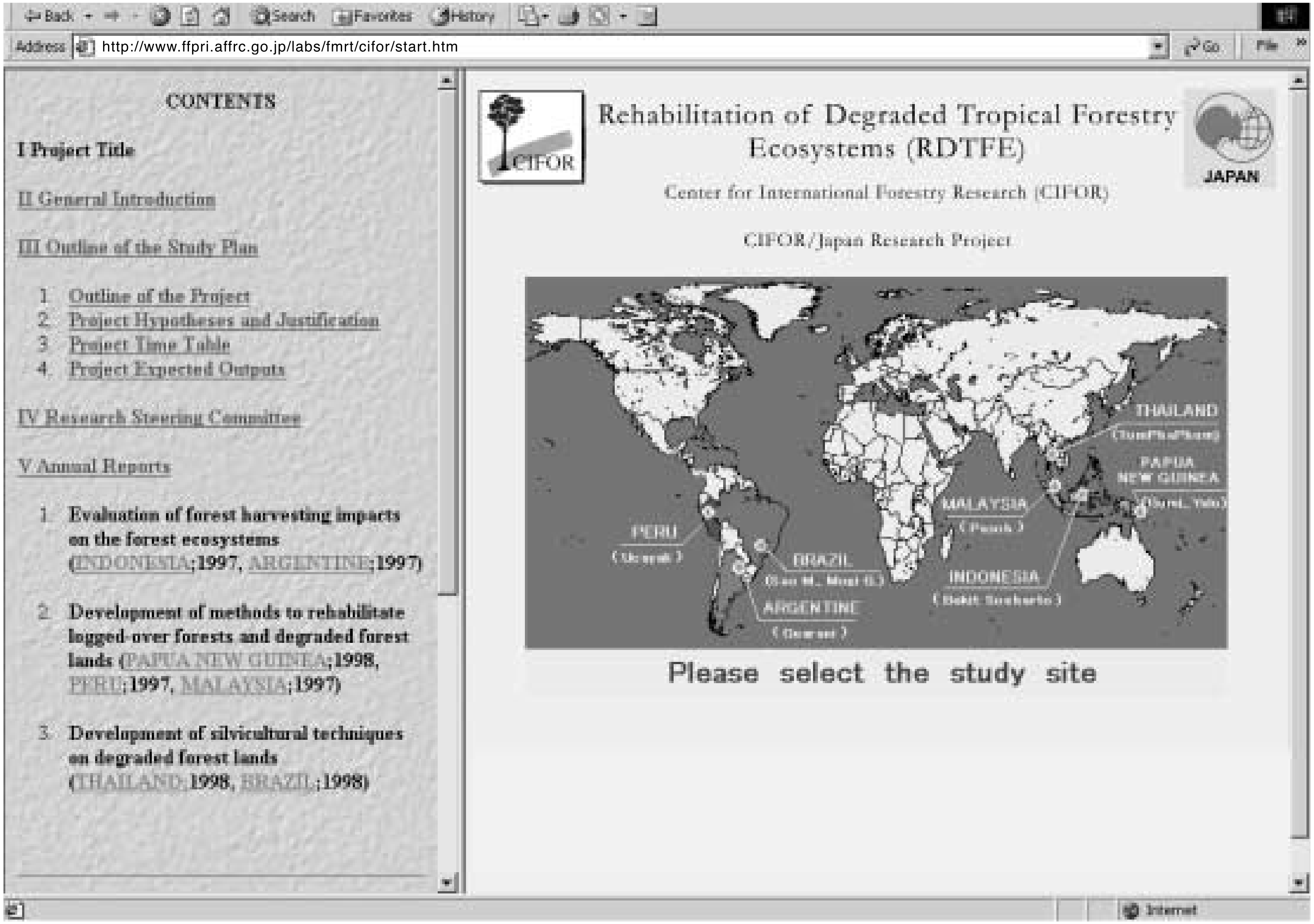
DATA OPEN TO THE PUBLIC site is located in the lower part of the left frame (Fig. 1). From here the user can access the open data from experimental forest plots (Fig.2-(c)). First, the Start Menu shows seven countries with study sites and seven data items i.e., research organisation/project title, general information, preexperimental, postexperimental, control plot, publications and references. Furthermore, each item is divided into subitems, e.g., general information contains site information, and data on vegetation, soils, climate etc. (Fig. 3).

### Clickable World Map

In the right frame (Fig. 1), the user can select the country of the study site. Clicking here, the Main Menu of each country will appear and this is divided into Report/Data and Map /Image (Fig. 2-(d)). This Main Menu has several buttons which links annual report, plot data (open to the public), forest map, aeronautical chart, satellite image, NDVI image with DCW (digital chart of the world) and study site detailed map. Clicking these buttons, the user can open new windows of these images. Also, the user can directly move to Main Menu of the another country by selecting the country button at the bottom (Fig. 4).

The general disposition structure of tropical plot data is divided into vegetation, climate, soil and miscellaneous as essential categories, in some cases site, water, socioeconomics etc.are added to these categories.

**Figure 1.** Start Window of this Dataset (Start window consists of two (left and right) frames



http://www.ffpri.affrc.go.jp/labs/fmrt/cifor/start.htm

CONTENTS

I Project Title

II General Introduction

III Outline of the Study Plan

1. Outline of the Project
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1. Evaluation of forest harvesting impacts on the forest ecosystems (INDONESIA;1997, ARGENTINE;1997)
2. Development of methods to rehabilitate logged-over forests and degraded forest lands (PAPUA NEW GUINEA;1998, PERU;1997, MALAYSIA;1997)
3. Development of silvicultural techniques on degraded forest lands (THAILAND;1998, BRAZIL;1998)

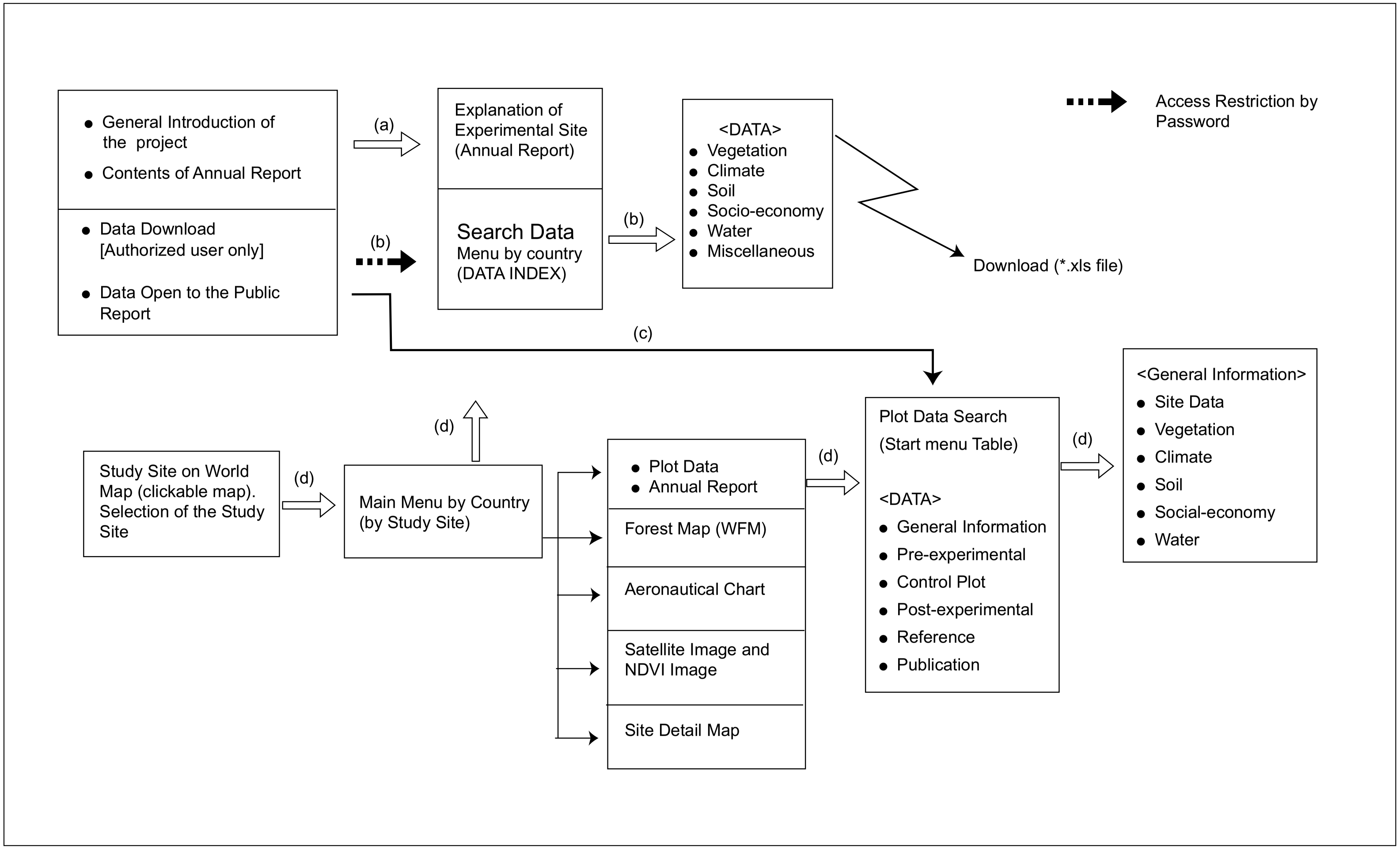
Rehabilitation of Degraded Tropical Forestry Ecosystems (RDTFE)

Center for International Forestry Research (CIFOR)

CIFOR/Japan Research Project

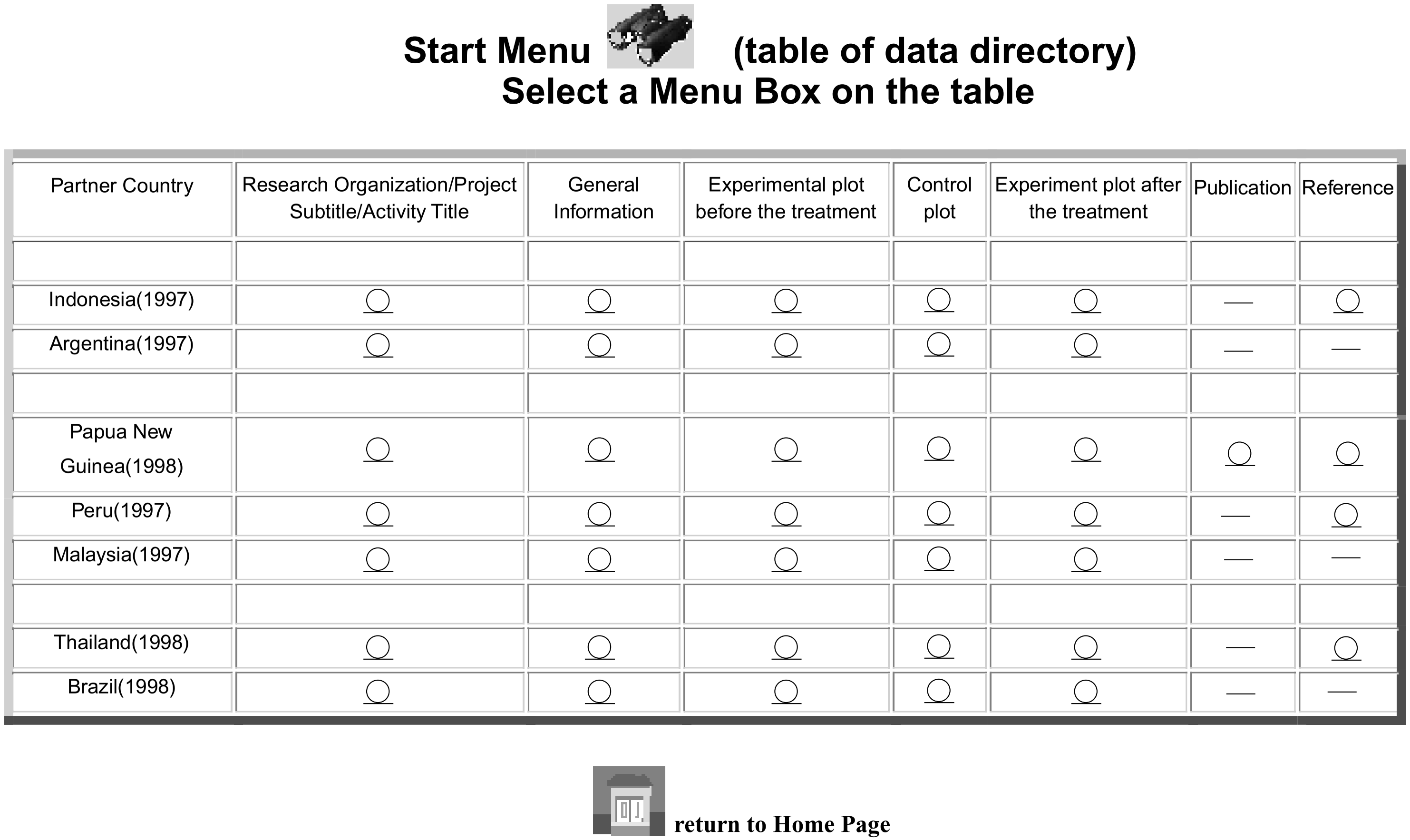
Please select the study site

**Figure 2.** Flow Chart of Information and Dataset System on RDTFE



(a), (b), (c), (d) represents the entrance and its link route, repectively

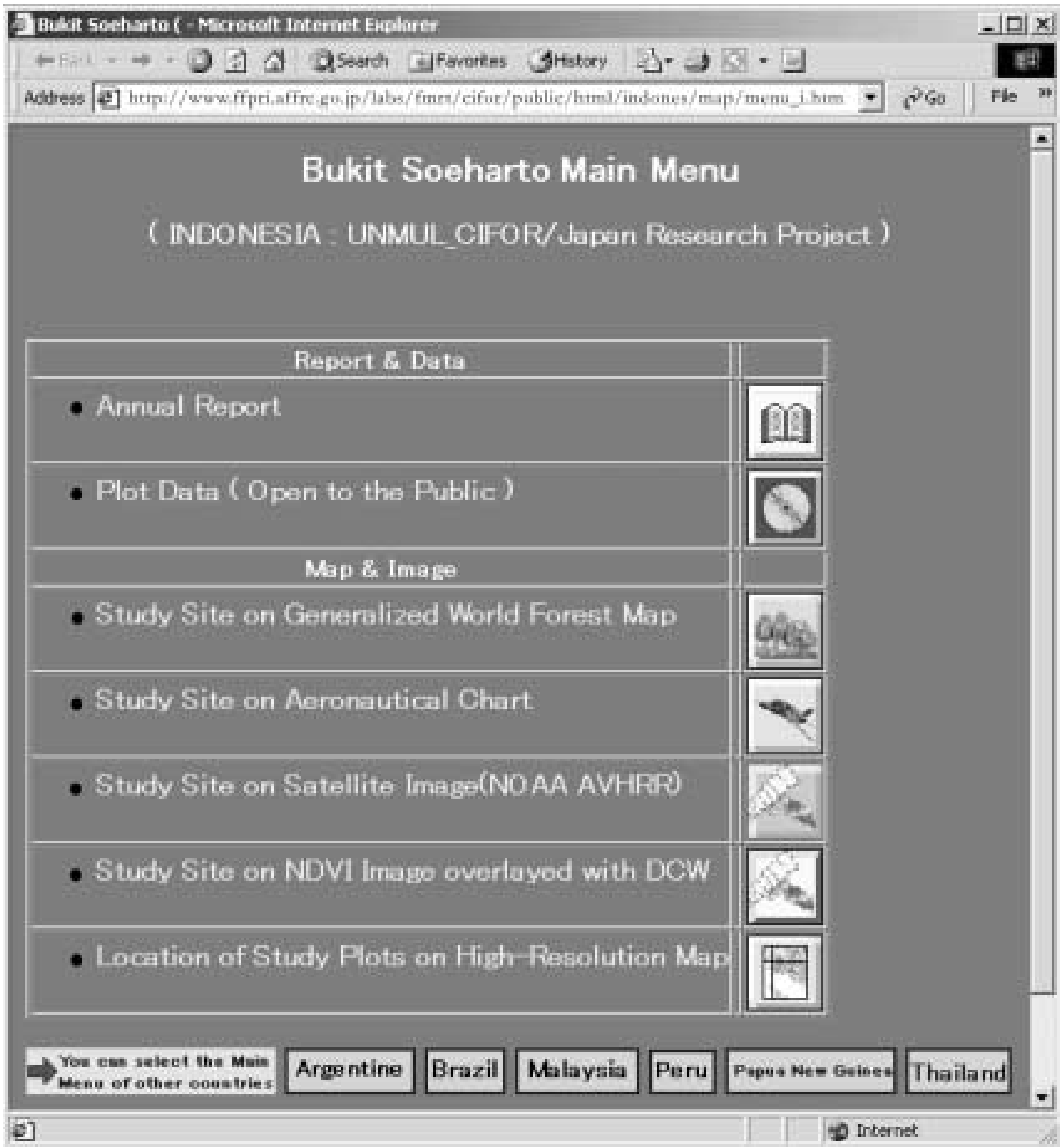
**Figure 3.** Start Menu Table Window



**Start Menu (table of data directory)**
**Select a Menu Box on the table**

| Partner Country | Research Organization/Project Subtitle/Activity Title | General Information | Experimental plot before the treatment | Control plot | Experiment plot after the treatment | Publication | Reference |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| Indonesia(1997) | ○ | ○ | ○ | ○ | ○ | — | ○ |
| Argentina(1997) | ○ | ○ | ○ | ○ | ○ | — | — |
| | | | | | | | |
| Papua New Guinea(1998) | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Peru(1997) | ○ | ○ | ○ | ○ | ○ | — | ○ |
| Malaysia(1997) | ○ | ○ | ○ | ○ | ○ | — | — |
| | | | | | | | |
| Thailand(1998) | ○ | ○ | ○ | ○ | ○ | — | ○ |
| Brazil(1998) | ○ | ○ | ○ | ○ | ○ | — | — |

**Figure 4.** Main Menu Window by Study Site Country



Bukit Soeharto Main Menu

( INDONESIA : UNMUL_CIFOR/Japan Research Project )

Report & Data

- Annual Report
- Plot Data ( Open to the Public )

Map & Image

- Study Site on Generalized World Forest Map
- Study Site on Aeronautical Chart
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- Study Site on NDVI Image overlayed with DCW
- Location of Study Plots on High-Resolution Map

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# FORSPA Initiative for Rehabilitation of Tropical Forests in the Asia-Pacific Region

S. Appanah[1] and C.T.S. Nair[2]

**_Abstract_**

Tropical forests of the Asia-Pacific region are the most heavily threatened from high population density and rapid economic growth. Extensive forest areas have become degraded as a result of over-exploitation and poor management. Unless these degraded forests are rehabilitated, they will come under pressure from other land uses. Recognising this, the Forest Research Support Programme for Asia and the Pacific (FORSPSA) of FAO initiated a Rehabilitation Programme and has started to set up a series of model plots of about 100 ha in each of the eco-climatic regions of Asia and the Pacific. Unproductive second growth forest areas will be rehabilitated using indigenous species of commercial value and techniques that are most familiar locally and well-proven. The plots will be model areas for research and training extend the methods to other parts of the region with similar ecological conditions. These plots, which are accessible to international scientists, will be maintained for long enough to achieve and extend results. To further enhance the rehabilitation work, the group of scientists and forest managers will be soon linked through the Asia Pacific Forest Rehabilitation Network (APFReN). This will link together scientists and managers engaged in rehabilitation work to share experiences and solve problems. The Rehabilitation Programme will include training courses, workshops and publication of literature on forest rehabilitation issues.

## INTRODUCTION

Annual surveys of forest statistics published by FAO indicate a poor situation for the Asia-Pacific Region. The rate of deforestation and degradation far exceeds that in the American and African tropics (Table 1). This is mainly because the Asia-Pacific region has had a longer period of agricultural development and has higher human populations. The extent of degradation varies between countries, but all are anthropogenic in origin. The degradation results from: unsustainable shifting agricultural practices; bad logging practices; mining; and fires escaping from land-clearings to forested areas during prolonged droughts. Other bad practices have also resulted in degraded forests, e.g., planting forests using unsuitable tree species. An example is in Malaysia where native forests were cut down and planted with the exotic *Acacia mangium*. This species has performed poorly and foresters are now looking for ways to rehabilitate such sites.

While forests converted to other forms of uses are lost forever, there are also large tracts of forests that have become degraded. Although still considered forest land in a country's statistics, the quality of the forest is reduced considerably (Table 2). The causes of this degradation are many, and include uncontrolled logging, shifting agriculture, mining and fires. The resulting lands range from those that are completely denuded to those that retain the tree vegetation but with few

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**Table 1.** Status of forest cover and change in tropical countries

| Region | Total area 1990<br>Natural forest (million ha) | Annual change (1980-1990)<br>Natural forest (million ha) | Annual change (1980-1990)<br>Natural forest as a percentage cover of total land |
|---|---|---|---|
| Africa | 528 | -4.1 | -0.7 |
| Asia-Pacific | 315 | -3.9 | -1.2 |
| South America | 918 | -7.4 | -0.8 |
| Total | 1761 | -15.4 | -0.8 |

**Table 2.** Estimated harvesting intensities and areas of broadleaved forest harvested annually in the tropical Asia-Pacific region

| Period | Average harvest intensity | Area of forest harvested annually (000 ha) | |
|---|---|---|---|
| | | Primary forest | Secondary forest |
| 1961-65 | 42 | 510 | 78 |
| 1966-70 | 43 | 750 | 135 |
| 1971-75 | 35 | 1343 | 221 |
| 1976-80 | 33 | 1732 | 319 |
| 1981-85 | 32 | 1718 | 369 |
| 1986-90 | 33 | 1861 | 453 |

commercial timbers in them. While some of the denuded areas may never recover naturally, the less degraded sites may do so in time, perhaps several centuries later. While it is possible to let nature take its course, socio-economic and political conditions may not give these forests such a reprieve. The reasons are several. Populations in the tropics are rising rapidly, increasing the demand on the natural resources, particularly land for agriculture and industrial crops. The chances are there will be strong forces to convert these unproductive lands for such purposes. Forests are the first to go when feeding of the population becomes critical.

Loss of tropical forests, including their degradation, could also mean permanent loss of a considerable number of plants and animals in these biodiversity-rich centres of the globe. Bad logging practices, usually entered into for earning foreign exchange rapidly and for funds to fuel industrial development, often can result in marginalisation of large numbers of rural and forest dwelling populations. Loss or degradation of forests impoverishes the lives of those who have depended on the forest resources for much of their physical needs, including food, shelter, medicines, and some cash income from sale of forest produce. An additional concern is the fact that loss and degradation of tropical forests represents also a loss in an efficient system of carbon sequestration system, which can lead to global warming. One way to ameliorate these effects and regain the forests, both in terms of biodiversity and timber productivity, is to rehabilitate them.

## THE NEED FOR ACTION

Considering the extent of forest devastation in the region, something has to be done to reverse the situation. Researchers have been looking intensively into the causes of degradation and rehabilitation techniques. Identifying the causes will help authorities in preventing or reducing forest degradation, but what can be done with the extensive areas of degraded forests that already exist? Rehabilitation has been suggested as the best option. A quick glance of the literature in the field of rehabilitation suggests that considerable amount of work has already been undertaken. Despite it, there is little rehabilitation work in the region to vindicate the research efforts. Numerous reasons can be identified for the lack of success in rehabilitation work. Some of the constraints include:

## Continuity

The major problem is the lack of continuity either of research or extension pilot trials. Funds often are not allocated for many of such long-term rehabilitation trials, and the essential observations are not made and published. Staff often get moved and field trials may be forgotten. Records are often made on an *ad hoc* basis.

## Research site security

Often the sites where trials have been located may be alienated for other purposes and the trials are lost. Also, if the trials are located in areas with difficult access, temporary roads may deteriorate and the plots become inaccessible. When the trials are not adequately protected from grazing or fire, hard work goes to waste. Likewise, many inaccessible research sites are maintained by locals who have no interest or foreseeable benefits from the work. Such sites are in constant danger from external threats.

## Purposes of rehabilitation

Views on rehabilitation have been evolving. At one time, rehabilitation may be focused on production of timber as the end output while soil protection may be a secondary effect. However, the primary focus on timber production has been set aside where community needs are taken into consideration and the end products may be timber, fuel wood, animal fodder, fruit, medicinal plants, etc. At present, ecosystem rehabilitation is coming into vogue. Planting is considered appropriate if the end result is a heightened biodiversity in the forest. Other cases of rehabilitation are linked with $CO_2$ sequestration. As concepts change, researchers also move with the result that important studies on the silvics of species have been neglected.

## Economic evaluations

Most of the projects concentrated on the rehabilitation in terms of the biological aspects have paid scant attention to the viability of the system in socio-economic or monetary terms. As a consequence, the systems developed have had little or no practical value. This kind of effort disappointed field managers who are looking for practical and implementable systems.

## Design of research

There have been a plethora of research initiatives on rehabilitation but they were not undertaken in a manner which allowed cross-region or cross-country comparisons. This limited the application of the findings to the local conditions. The experience and knowledge gained could not be extended to neighbouring countries which share similar forest and climatic conditions other than in a general sense. The many research efforts can be short-circuited with one exemplary project that can act as a demonstration plot for the whole region. Such research and formulation of field work may require collaboration and networking through international agencies rather than by individual countries. However, there are already many international initiatives operating without the benefits of networking and collaboration.

## Analysis and publication

If research trials are poorly formulated, they are difficult to analyse. Sometimes, the assistance of statisticians is not available and the results are never properly analysed. Many results do not get published and remain in inaccessible departmental records. The lessons learned by one generation may be forgotten, and a whole new crop of people start the same work without the benefit of lessons previously learned.

## FORSPA'S INITIATIVE

The Forestry Research Support Programme for Asia and the Pacific (FORSPA) identified rehabilitation of degraded forests as critical in the coming decades. Some 40-50% of the existing "productive" forests in the region may require rehabilitation. In 1997 FORSPA in a joint collaboration with the Forest Research Institute Malaysia (FRIM) initiated the programme of forest rehabilitation for the Asia-Pacific region. As the programme developed, and interest in rehabilitation began, the two organisations initiated a network to promote forest rehabilitation with collaborating countries in the region.

First, a meeting of experts from the region was held to identify the kinds of research, agencies best suited to undertake such research, best sites for the research, and the kinds of funding needed to start the work. Next, a network of scientists was formed. The Asia Pacific Forest Rehabilitation Network (APFReN) began in 1997, with its Secretariat FRIM. The network aims to provide technical support to countries/institutions to demonstrate how rehabilitation can be undertaken in the field, to support sharing of information and the development of channels for exchange of expertise and technology.

FORSPA also intends to raise funds for research, especially for setting up demonstration trials in specific parts of the region. Such a demonstrations can provide a model or reference point on which to base future work.

## DEMONSTRATION PLOTS

The demonstration plots set up in strategic parts of the region should adhere to certain common guidelines and protocols so as to facilitate comparative studies and to enable extension of findings to other locations. When such norms are adopted in the establishment of plots, their management, recording of measurements, and analyses of data can be enhanced. Expert groups can develop many of the techniques which can then be employed in development of such plots even if expertise is lacking in the country. The plots should also address the location-specific problems.

### Objectives for plot establishment

#### *Proven technology*

The plots will mainly focus on demonstrating well-proven technology applied on an operational basis and shall not be used for initiating new rehabilitation research. Probes to test out finer aspects of some of the technology may be adopted on a small scale. The plots shall serve to assess the value and practicality of the techniques involved. And as a means of technology transfer to managers.

#### *Degraded forests*

The rehabilitation techniques shall be confined to degraded forests, and not address issues related to establishment of regular plantations. They will focus on improving degraded forest areas that represent a working unit, e.g. the size of a compartment.

#### *Existing protocols*

Demonstration areas shall aim at improving and refining existing protocols for large-scale rehabilitation of degraded forests and, wherever possible, incorporate local people's interests.

#### *Indigenous species*

Techniques developed shall involve indigenous species as much as possible, which meets the secondary objective of rehabilitation of the ecosystem and enhancement of the biodiversity.

#### *Monitoring*

The demonstration plots will facilitate long-term monitoring of changes and responses to the treatments. This monitoring should be long enough to ensure the full implication of the techniques, species and financial impacts is captured.

### Criteria for site selection

Due consideration should be given to site selection criteria as they are vital for the permanency or long-term existence of demonstration plots.

Factors that need to be considered include the following:

- Only important commercial indigenous species should be used.
- The proposed technique to be used must be economically viable. An economic/financial analysis should be carried out to evaluate the returns on investment over time.
- The techniques must be practical, feasible and achievable and congruent with the country's economic and social conditions.
- The techniques must serve as a reference for all future effort in rehabilitation of degraded forests in the country.
- Wherever possible, the local communities and their needs should be integrated into the rehabilitation work. In this regard, the social impact of project should also be studied.
- The rehabilitation work should also address issues of environmental amelioration.
- The forest should be representative of the most important natural forest formation in the area, and one that is subjected to heavy disturbances. The disturbances should be those regularly occurring in the forests.
- The site should allow for a range of rehabilitation techniques to be demonstrated.
- The site should be free of all encumbrances in terms of ownership, and where no future conversion plans exist. The duration should cover at least one rotation of the climax phase species used in the rehabilitation work.
- The institutions involved should be committed to maintain the area for a sufficiently long period.
- The site should be easily accessible currently and in the future.

## Size of demonstration site

The size of demonstration site should be sufficient to meet several requirements, which include:

- Demonstration of most of the techniques for rehabilitation of logged over areas.
- Be at least the size of a forest working unit, e.g. a watershed or a compartment.
- Sufficiently large to allow for scaling up of demonstrations to pilot scale trials.
- A size that is easy to manage.
- The scale and nature of operations should reflect the normal conditions under which rehabilitation would be undertaken.

## Treatments

The rehabilitation treatment for the area should be determined clearly. As indicated earlier, we will not be undertaking any original studies or research, and the effort will be directed entirely to demonstrating specific techniques with much potential. The protocol being developed should take into consideration the following:

- The nature of the treatments.
- How the treatments will be laid out?
- What measures have to be taken to ensure that it is possible to scale up from demonstration to large-scale application.

## Data to be gathered

The data and background information need to be fully evaluated before the demonstration work is begins. The bench mark information required includes:

- A full description of the techniques used, the research findings and results.
- A work plan and a breakdown of the estimated cost of project implementation and maintenance.
- Topographic map on a scale of 1:50 000 to indicate the relative position of the demonstration plot and its access route.
- Soil map/soil studies map of scale 1:5000 to indicate the general topography and soil fertility.
- Inventory and regeneration survey map of scale 1:1000 to indicate the status of regeneration in the area with the objective of defining the nature of treatments.

- Working map of scale 1:1000 to mark the boundaries of the different techniques used.
- Description of the species composition, stocking and volume of the stand before the degradation occurred. This may not be always obtainable, and in such a case a general description may have to suffice.
- Past history of the area, inclusive of activities carried out.
- General description of the current status of the area, including stocking, species composition and ground cover. Existing community use and social implications of demonstration plot will require some additional attention.
- Climatic data, if available, especially on rainfall and temperature - 10 years mean monthly and annual rainfall and temperature patterns will be useful.
- Working plan and methodology of the rehabilitation programme.
- Subsequent tending, treatment, monitoring and maintenance of the area.
- What records are to be maintained?

## DEVELOPMENTS

Based on the ideas developed above, national forestry agencies have been approached. The proposals have been received very enthusiastically, and some countries have begun establishing demonstration plots. The following countries have started the activities.

### Laos

The Lao Forest Department has established a 100 ha plot in Pakkading District of Bolikhamsay Province. The site is being developed in collaboration with the District and Provincial Agriculture and Forestry Offices and the National University of Laos. The area is located within a 10 000 ha block of logged forests designated for rehabilitation. The demonstration site is being developed to incorporate research, education, training and extension functions. The first phase survey and demarcation, and preliminary mapping and classification of the area based on forest cover have been completed. An additional facet of work here is the raising of awareness among local communities. This should ensure their participation and the success of the project. A nursery has been established and seeds and wildings of selected tree species are being collected. Planting techniques have been identified.

### Papua New Guinea

The Forest Research Institute of Papua New Guinea has started a preliminary survey of the demonstration site in Medang and approval from the landowner families has been obtained. They will be extensively involved in the setting up and managing of demonstration plot.

### Sri Lanka

The Forest Department has located the site for the demonstration plot in Kalavana range of the Ratnapura district. The initial survey of the residual vegetation has been completed. Based on the survey, the need for the demonstration plot here has been affirmed. The precise location of the plot, the type of planting activities and the suitable species can be determined on the basis of the survey.

### Vietnam

The Forest Science Institute of Vietnam is developing a demonstration site in the Kon Ha Nung area in Gai Lai Province. One hundred hectares have been demarcated for the demonstration plot, and for testing out practical and cost effective technologies for restoring logged-over natural forests. Survey, demarcation, and sample inventory of trees and young regeneration have been completed.

## NETWORKING

FORSPA has identified FRIM as the referral centre for assisting in the development of the rehabilitation demonstration plots throughout the region. FRIM has also signed Memoranda of Understandings with Papua New Guinea Forest Research Institute and the Forest Science Institute

Vietnam to boost the collaboration among the institutes in the region. Activities have included a training workshop for 20 forest managers and researchers from the region. The training included general lectures on natural forest management, silviculture and mensuration. The workshop dealt in greater detail specific issues of management of second growth forests, enrichment planting techniques, inventory and sampling methods, and data analysis using computer software. The participants also conducted field work that included assessing planting trials in two forest reserves in Peninsular Malaysia.

To maintain links and discussions among the participating countries in the region, a newsletter "Asia-Pacific Forest Rehabilitation Network" (APFReN) will be launched. This will be augmented with a web page, now that electronic networking is becoming accessible to more and more people throughout the region. Additional workshops and meetings on rehabilitation issues are being planned. The demonstration plots, which will cover many parts of the region, are expected to act as nodes for further development in the region.

## CONCLUSIONS

Networking is becoming an integral part of international and regional collaboration for scientific development work. The objective of international development work in R&D should aim at strengthening the capacities of individuals and institutes to carry out the necessary work, enable transfer of technology, and bring about scientific exchange and collaboration among the regions' Institutes. However, often international development work puts undue emphasis on basic research rather than solving problems that are facing developing countries. Moreover, the thrust of international assistance programmes too often directs local research and management institutions into academic work, with emphasis on publication credits. With this kind of arrangement, the benefits accrue more to the international scientists than to the collaborating agency. Much energy gets expended and many of the inexperienced scientists are thwarted from pursuing solutions for immediate problems. Unfortunately, even a cursory examination quickly indicates that in many countries, there does exist a lot of research and practical solutions, and considerable local knowledge. Even if it does not exist in the specific country, many of the neighbouring countries have reliable techniques for adaptation.

Hence, international research collaboration should aim to try and solve important problems instead of seeking to do more research of an academic orientation. FORSPA's initiative represents an important model, for the following reasons:

- The issue of rehabilitation is vital, will bring about definite gains for the host country, and the solutions are wide-based in a socio-economic sense.
- The experiences among the member countries in the region are many, and with slight adaptations they can be employed.
- A lot of expertise is available in the region and can be engaged cheaply or *gratis*.
- FORSPA identified an agency (FRIM) to take the lead, and become the referral centre for training and transfer of technology.
- Small grants were adequate to set up the demonstration plots, as most of the work was done by local scientists. FORSPA overall encourages the local institutions to do all the work, and assistance from outside is minimal, mostly in guidance on some techniques.
- These demonstration sites become models for testing out the best techniques already known in the region, and the plots are kept active for adequate length of time for others to gain the knowledge as well.
- Other agencies in the country are encouraged to work together with the lead agency in each country. Likewise, neighbouring countries can also gain experience from these sites.
- The networking can extend the experience and findings throughout the region.
- FORSPA further provides other kinds of training to the local scientists including monitoring of the plots, writing proposals to

apply for grants from international sources, and transfer of the findings to real situations. The networking overall aims to strengthen the local participants to do the work independently.

Overall, the FORSPA model has proven to be quite successful although it is still a very small initiative and the costs are minimal.

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