Management of Secondary and Logged-Over Forests in Indonesia

Selected Proceedings of an International Workshop

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P. Sist, C. Sabogal and Y. Byron

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Executive Summary

As a result of increasing rate of deforestation, secondary and logged-over forests cover more than 600 million ha of the land area in the tropics (Brown and Lugo 1990). As the area of secondary forests increases, generally at the cost of primary forest, interest in research on the management of these forests is now emerging in various tropical countries and international organizations (CIFOR, CATIE, IUFRO, FAO, van der Linden and Sips 1998). Recently, workshops and seminars focusing on the issue of the management and the value of secondary forests were also organized (e.g. The Pucallpa Declaration, World Forestry Congress, Antalya-Turkey, 1997). However, a synthesis of our knowledge of how to manage these forests has still to be completed. In 1997, CIFOR started a literature review on the management of secondary forests in the humid tropics. The main objective was to collect a comprehensive set of references on the management of secondary and logged-over forests emphasizing silvicultural practices. The final objective will be to produce a synthesis in the form of a book. In this process, a number of workshops will be conducted in each of the tropical regions concerned to present and to discuss contributed papers from collaborators. The international workshop on the management of secondary forests held in Bogor (Indonesia) from 17-19 November 1997, was the first workshop conducted in the framework of this research synthesis initiative. This workshop, jointly organized by CIFOR and Cirad-Forêt and sponsored by USAID, aimed to create a forum of discussion on the research priorities for the sustainable management of secondary forests in Indonesia and more generally in South East Asia. Over the three days, more than 80 participants from 10 different countries, attended the workshop (see list of participants). During the first two days, 24 communications were presented and discussed in four plenary sessions. Three main thematic areas were discussed in working groups on the final day: (WG 1- Typology, covering and ecology of secondary forests; WG 2 - Economic and environmental value, silviculture and management; WG 3 - Policy for sustainable forest management) to make conclusions and recommendations on these specific issues.

Initially, the term secondary forests was used in a broad sense to include logged-over forests, pure stands of pioneer vegetation, and regenerating forests after high disturbance (i.e. fire, shifting cultivation). However, a suitable definition for secondary forests was debated at length during the workshop. This reflected the ambiguity also found in the literature (e.g. Brown and Lugo 1990, Corlett 1995). Based on discussions held in working group 1, the workshop participants agreed on the following definition**: "woody vegetation regrowing on land whose previous forest cover was destroyed by at least 90 % by human activities or natural disaster"**. This is not only the broadest definition reported in the literature (Whitmore 1984, Corlett 1995, Richards 1996) but it is also in line with the ecological aspects of forest regeneration involving a succession of different types of pioneer vegetation before late successional forest types (or climax) is restored. However, the participants also recognized the importance of logged-over forests in the discussion and in the issue of sustainable forest management. As a consequence the original workshop title "The management of secondary forests in Indonesia" was changed to "The management of secondary and logged-over forests in

Indonesia". After a long review period, 11 papers of the 16 originally submitted to the editors were accepted for publication in the proceedings. As a result of the discussions held in the workshop on the definition of secondary forests, the 11 papers were divided into two main sections:

- Ecology and management of secondary forests (5 papers)
- Ecology and management of logged-over forests (6 papers)

The first section focuses on the use and manipulation of secondary forests as part of smallholders' resource management strategies. The second section refers to management aspects of logged-over forests for timber production, mainly focusing on the application of silviculture (e.g. conditions for natural regeneration and enrichment techniques). The last section closes with an analysis of the socio-economic consequences of forest changes in relation to the future economic development of two Indonesian provinces (study by Piketty).

Ecology and management of secondary forests

Most primary forest conversion in Indonesia is for agriculture, usually by shifting cultivators. The annual rate of loss of rain forest for 1981-1990 was estimated at 1.3 million ha of which 775,000 - 880,000 ha was logged forest converted to agricultural land by shifting cultivators (Barbier *et al.* 1993).

The first paper in this section, by Nagy and Proctor, deals with early secondary succession after hill rice cultivation in Central Kalimantan. The five fallow sites chosen followed a chronosequence of 0-2 years after harvest at sites of secondary forest origin and 0-1 years on cleared primary forest land. Soil fertility (extractable phosphorus and exchangeable cations) and vegetation were related to fallow age, primary or secondary forest origin and, for sites with secondary forest origin, rotation. The soil data showed no indication of differences among sites. The composition of the vegetation was largely dependent on age and could not be reliably accounted for either by origin or number of past rotations.

Plants for medicinal uses are important components of secondary vegetation associated with human settlements. The study presented by Caniago describes medicinal plant species and their uses in a Dayak village in West Kalimantan. The abundance and distribution of medicinal plants was studied in seven locally recognised forest types, which take into account the successional stages of forest dynamics from the young pioneer vegetation after clearing to the primary forest. The late successional, primary and river bench forests contained the highest diversity of medicinal species and the highest number of species restricted to specific forest types. It was also found that all of forest types sampled contained higher medicinal species diversity levels than logged forests, although logged forests contained greater numbers of certain individual medicinal plants. High medicinal species diversity and numbers in secondary forests could be related to the fact that secondary forests are generally closer to the villages and more often visited than primary forests especially by women, the most frequent users of medicinal plants. Therefore, villagers might have grown or favoured the growth of medicinal plants in these environments.

The use of secondary successions to satisfy human needs is also illustrated by the "jungle rubber" case. This is a complex agroforestry system developed by smallholders in the lowlands of Sumatra and Kalimantan, now covering over 2.5 million ha. According to Penot (see third paper of this volume), complex agroforestry systems, and in particular highly productive rubber gardens, also called Rubber Agroforestry Systems (RAS), represent economically and ecologically sustainable cropping systems for smallholders. RAS have the structural and biodiversity similarities with secondary forest. At the current pace of deforestation in Indonesia, jungle rubber is likely to be the main reservoir of lowland forest biodiversity in the plains of Sumatra and probably West Kalimantan.

Due to economic growth and new crop opportunities, jungle rubber is not currently competitive and its productivity needs to be improved through integration of innovations such as clonal rubber and increases in inputs and labour. Several types of RAS are currently being trialled on a large scale in three provinces. According to Penot, the adoption of improved RAS, with consequent increases in farm incomes, would reduce pressure on remaining forests and promote the shift from *ladang* (shifting agriculture) to permanent tree crop-based agriculture, requiring less land per household for an improved income.

Complementing the above, Werner's paper focuses on the impact of management practices on secondary forest species richness within productive rubber agroforests. In her study, Werner demonstrates that management practices (in the form of selective cleaning) in rubber gardens have an important impact on both plant species and richness, if compared to that of natural secondary forest regrowth. These practices also have an impact on the forest structure. The main conclusion is that management intensity is an important factor in the biodiversity and species composition of complex agroforestry systems.

The paper by Fuhr and Delegue highlights the potential of secondary forest stands for timber production in Africa. They focus on the silviculture of *Aucoumea klaineana* (Okoumé), which grows mainly in Gabon, Equatorial Guinea and the coastal areas of Cameroon and Congo. For these countries, Okoumé represents the largest part of the logged volume exported (80% in Gabon), mainly for plywood. This species is a typical long-life pioneer species dominating the secondary forests and able to colonise at the early stages large open areas. Okoume stands are established within 5-10 years during forest regrowth after shifting cultivation, and can dominate the secondary succession for at least 100 years, forming a monodominant forest. The authors report on a study based on research carried out in the coastal savannas of Gabon, where Okoumé stands originate from natural regeneration after shifting cultivation and are distributed within the mature forest. Because of the high density of this very valuable species, extracted volume may reach 50 m^3/ha, similar to the volume frequently harvested in South East Asian dipterocarp forests.

Ecology and management of logged-over forests

Among the estimated 63.5 M ha of lands under concession in Indonesia, logged-over forests represent 22.5 M ha while remaining primary forests cover about the same area (25.3 M ha, MAPPINDO unpublished data). With the present rate of logging (800,000 ha/year, in Sunderlin and Resosudarmo 1996), logged-over forests will rapidly become the main suppliers of timber for the national plywood industry. Definition of sound silvicultural regimes to meet future industry timber demands whilst achieving long-term forest management is of great importance. The papers of this section provide some examples of silvicultural research aimed at improving our knowledge of the processes of forest regeneration after logging operations.

Regeneration of logged-over forests is one of the main concerns in sustainable forest management for timber production. The density of residual trees, saplings and seedlings of commercial *dipterocarp* species in logged-over forest is often low, especially if the forest has been heavily logged or burnt. Interest in silvicultural treatments, planting and tending techniques appropriate for the rehabilitation of logged-over and degraded forest is increasing as the amount of timber extracted from primary forest falls (Clearwater *et al.,* this volume). There have been few long-term studies of the effects of silvicultural treatments and, under certain conditions, the chosen treatment may not always achieve the intended result. There is thus a need for further applied research and refinement of current methods for the management of secondary forest for timber production.

Clearwater, Nifinluri and van Gardingen (see first paper in this section) examined the growth and photosynthetic characteristics of wild light red meranti seedlings after logging disturbance and related them to the microclimate of logged forest. The paper describes the seedling height growth response to light and determines the physiological basis of the observed response. Changes in patterns of leaf nitrogen partitioning during acclimation suggest that seedling nutrient status is an important component of acclimation to very open sites. A reduced acclimation capacity resulting from poor nutrient status may explain the low or more variable growth rates of seedlings planted or establishing from seed in open areas with high photosynthetic Photon Flux Density (PPFD) and disturbed soil. Treatments with mycorrhizal inocula, addition of forest topsoil or fertilisation may be required before full acclimation can occur. An implication for management is that techniques using canopy opening to increase *dipterocarp* seedling growth rates should aim for moderate daily PPFDs which are sufficient to saturate the *dipterocarp* seedling growth response but which do not result in unnecessary release of pioneer species. Examples include the cutting of lanes for line planting and the creation of artificial canopy gaps.

The management of logged-over forests for timber production usually involves some form of deliberate canopy opening to increase seedling growth rates and promote the recruitment of valuable *dipterocarp* species. The creation of canopy gaps is therefore an important silvicultural technique. For logged-over and secondary forests in Indonesia there is little published information on possible methods for gap creation and their effects on forest regeneration. In their paper, Nifinluri, Clearwater and van Gardingen provide a simple measure of gap size in lowland *dipterocarp* forest that could be related to the light environment prevailing near the gap centre. The study determines the maximum size a logging gap can be before PPFD near the gap centre exceeds that required to saturate *dipterocarp* seedling growth, and provides an estimation on the width lanes and gaps should be cut for enrichment planting treatment of logged-over forest. To quantify the light requirements for each *Shorea* species the authors propose the use of an index of light availability similar to that presented in the paper, but based on lane width and direction.

Supriyatno and Becker report a case study with experimental logging plots in Central Kalimantan. The study is aimed at establishing an optimal harvest regime for natural forest, especially logged-over natural forest through a detailed pre-felling planing and careful logging operation. This includes a pre-harvesting inventory, the determination of a minimum diameter for trees to be felled (60 cm dbh) and a cutting intensity of 20-25% of the harvestable trees. To minimise soil disturbance and damage to the remaining stand, skidding trail networks and landings were carefully planned and felling direction was prescribed prior to felling. Harvesting intensity at the first cutting 11 years ago was on average 6.1 stems/ha with a commercial timber volume of about 38 m^3/ha. The second harvest for commercial species with dbh > 50 cm, took out in average 3.6 stems/ha with commercial timber volume of 28 m^3/ha. *Dipterocarps* represented 90% of the extracted timber. On average, secondary logging damage affected only 8.7% of the original tree population or 6.7% of the original basal area.

An alternative for rehabilitating logged-over forests in Indonesia by using a non-timber forest product such as rattan (*Calamus ornatus*, *C. merrillii*, *C. manan* and *C. subinermis*) is described in Bacilieri, Alloysius, Maginjin, Pajon and Garcia. They report on the experience of Innoprise Corporation Sdn Bhd (ICSB) and CIRAD-Forêt in Sabah (Malaysia) with commercial rattan plantings, established in lines under the logged-over forest. This system was adopted because a number of large trees that could support the rattans without suffering damage were still present in the forest, and no silvicultural treatment that could disturb or be rendered difficult by the thorny rattans was planned for this area. However, the method showed some limitations, resulting in rattan stands with heterogeneous growth. Bacilieri *et al.* designed a study on the correlation between rattan growth and a number of physical environmental variables (such as light, soil and slope) and biotic variables (such as stand density, species composition and competition). The study revealed that the two key factors having a major impact on rattan growth were light and competition from surrounding trees. Furthermore, the study showed that competition from surrounding trees (especially *dipterocarps*) was more important than the effect of light. According to the authors, combining the information on competition and light effects will help optimise rattan planting techniques.

Cost-effective monitoring and management tools for tropical forests are indispensable, and remote sensing could be one of them. In their paper, Beaudoin and Lo Seen refer to new technologies available to overcome some of the problems with the more conventional tools: the Synthetic Aperture Radar (SAR) systems and the multi-temporal use of SAR images. These are recommended to monitor the environmental and man-made changes such as logging of primary forest or burned areas. According to the authors, space-borne SAR imagery should be considered as one element of a forest management system which could also include other higher resolution remote sensing data, together with GIS tools.

Through an historical and economic analysis of the development of two Indonesian provinces taken as case study (Riau and East Kalimantan), Piketty exposes the main features influencing regional development and its impact on forest changes and transformation. Regional development in these two provinces has been based on significant irreversible modifications to forests, which will most likely have consequences for the future development of these regions. The decline in plywood production in both provinces is interpreted as the result of a significant decrease of timber production from natural forests. The capacity of production forests, and particularly of forests logged in the late 60's which will enter their second felling cycle, to supply the plywood industry in the future still remains unknown. The possible socio-economical consequences of the yield decline in production forests yield are also discussed.

Conclusions

Secondary and logged-over forests are complex ecosystems providing a large range of timber and forest products and environmental values. However, during the workshop discussions, all the participants recognized that a clear typology of these very different forests is still to be defined. Research on development of forest typology systems based on an ecological vegetation classification, taking into account the dynamic processes and therefore the degree of disturbance is an urgent need. Without this knowledge, land-use systems cannot be refined because they must be based on the natural resource capacity and potential. New imagery technology such as those described in Beaudoin and Lo Seen paper is a promising tool which should be promoted and developed.

Secondary forests in the sense of the definition given in the workshop, are quite different from logged-over forests in both structure and species composition, at least in the first and middle stage of their dynamic. For this reason, the participants of working group 2 insisted on the need to develop new silviculture concepts taking into account the specificity of secondary forest management. The development of silvicultural interventions favouring non timber forest products (NTFP) based on ecological studies, such as that described in Bacilieri *et al.* (second section) should be promoted.

Indonesian forest policy and regulations and their implications for logged-over forests were extensively debated during the workshop. The socio-economic aspects were also recognized as an important feature, which should retain more attention in forest regulations than in the past. The potential of the Indonesian Selective Logging System (TPTI) in achieving and promoting forest management is now questionable as witnessed by the high logging intensity in primary forest in South-East Asia (more than 8 trees/ha on average) and the short rotation cycle (35 years). The TPTI system is mainly based on diameter limit which results in a very high logging intensity often exceeding the sustained yield capacity of the forest within a 35 year rotation cycle fixed by TPTI (Sist *et al.* 1998). The application of this regulation in logged-over forest where standing volume is lower (Supriyatno and Becker) will undoubtedly lead to depleted and degraded forest which is not consistent with sustainability. Participants of the workshop recognized that new rules based on research results from various research and development projects must be defined within TPTI regulations which, with adequate enforcement, has potential to attain many of the criteria associated with sustainable forest management. Moreover, it was also recognized that introducing greater flexibility into the existing or forthcoming forest regulation systems and the integration of research findings would lead to a more efficient improvement. Logged-over forests (i.e. forest logged in the 70's) will be the main suppliers of the timber industry for the next felling cycle (35 years) because production from timber plantations is clearly not able to support it (Piketty). In this condition achievement of sustainable forest management in the remaining production forests is not only an environmental concern but an important economic issue for the country.

Promoting timber plantations could release part of the pressure on natural forest. However, plantations should not be developed in locations where natural forests (primary, logged or secondary) occur. Conversion of forest lands must not be based solely on standing volumes as is still the case in the regulations. Other services provided by natural forests to the environment and local population are also important to take into account even, though the economic value of those services are still difficult to evaluate. Forest value and environmental services have been so far under-evaluated in forest management systems. Conservation of both soil and biodiversity or carbon sequestration have been recognized as key values, particularly in secondary forests. New regulations acknowledging, promoting and incorporating these values into forest policy and land-use decision making are urgently needed. Research on these issues must be therefore encouraged and developed.

Social issues such as land use rights conflict, or legal recognition of forest communities as managers are demanding significant government attention. Forest communities should be clearly and legally recognized by forest regulation as potential stakeholders.

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1. Early Secondary Forest Growth after Shifting Cultivation

L. Nagy[1] and J. Proctor[1]

Abstract

Early regrowth following hill rice cultivation was studied at five fallow sites in the Ulu Barito area, Central Kalimantan. The sites followed a chronosequence of 0-2 years after harvest at sites of secondary forest origin and 0-1 years on cleared primary forest land. Soil fertility (extractable phosphorus and exchangeable cations) and vegetation were related to fallow age, primary or secondary forest origin and, for sites with secondary forest origin, rotation. The soil data showed no indication of differences among sites. The composition of the vegetation was largely dependent on age and could not be reliably accounted for either by origin or number of past rotations. A spectral analysis and comparison of diversity indices among sites are also discussed.

Introduction

Shifting cultivation has been practised all over the world and two-thirds of the world's secondary forest area in 1980 was shifting cultivation fallow (Lanly 1982). The annual rate of loss of rain forest in Indonesia for 1981-90 was estimated at 1.3 million ha of which 775,000 - 880,000 ha was logged forest converted to agricultural land by shifting cultivators (Barbier *et al*. 1994). In Kalimantan shifting cultivation has been practised for centuries and has affected large riverside tracts of forest. The low population density has allowed the practice to be sustained in upriver and headwater areas, while around the large river deltas and on the more densely populated plains permanent agriculture is the norm.

In Kalimantan shifting cultivation involves clear felling and burning followed by dry rice cultivation for one, or occasionally, two years. Then the field is fallowed to restore the nutrient status of the soil, suppress herbaceous weeds and eliminate pests. The length of the fallow period is from 5 to 40 years depending on the local demand for land and site and crop quality.

Studies of secondary forest regeneration in South-east Asia have been made in Peninsular Malaysia (e.g., Symington 1933; Wyatt-Smith 1955; Kochummen 1966; Kochummen and Ng 1977), Thailand (Kunstadter *et al*. 1978), the Philippines (Kellman 1969) and East Kalimantan (Kartawinata 1977; Kartawinata *et al.* 1980; Sukardjo 1990; Riswan and Kartawinata 1991). Some of these studies dealt with secondary succession after agricultural land use while others used experimental manipulation to compare secondary forest recovery under a range of conditions.

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The present study is the first on early secondary forest growth in Central Kalimantan and complements that of Prajadinata (1996) on later regrowth (3-50 years) in the same area. The main aims of the present paper were to compare vegetation regrowth with fallow age (up to 2 years) and with the number of forest–crop–fallow rotations, and to investigate possible changes in soil chemistry.

Materials and Methods

Description of the study area

The study was carried out in the Ulu Barito area in Central Kalimantan at an estimated altitude of about 150 m a.s.l. The terrain is undulating, often with steep slopes, and there are two major rivers, the Joloi and the Busang. At the base camp of Project Barito Ulu (0^0 04' N; 134^0 24' E), the mean annual rainfall for 1990-1995 was about 3700 mm and was evenly distributed with usually over 100 mm/month. However, there were three severe droughts in 1991, 1994 and 1997. The mean maximum temperature was 33.5 ^{0}C and the mean minimum was 22.7 ^{0}C. The geology of the area is characterised by mudstone and sandstone parent materials on which ultisols and spodosols have developed. The soils under cultivation are ultisols with generally low concentrations of major nutrients and landslides may occur on steep slopes. There are extensive riverside areas with sandy banks which have been cultivated and have a mixture of secondary and remnant primary vegetation.

Site selection

In October 1994, five sites were selected, based on the knowledge of local population, to include fallows of different age (0-2 years) and rotation (0-4). The sites were:

- 0PF: an area previously covered by primary forest, felled and burnt in September 1994;
- 0SF: an area previously covered by secondary vegetation, felled and burnt in September 1994;
- 1PF and 1SF: one-year old fallow derived from fields cultivated from October to March 1994 and originally and covered by primary and secondary forest; and
- 2SF: derived from a secondary forest felled in 1992.

Two-year old fallow resulting from the cultivation of a primary forest area could not be found. One 50 m x 50 m plot was established at each site and five 5 m x 5 m quadrats were selected in a stratified random manner within each plot. The quadrats were used for seed bank sampling and soil chemical composition at all sites in the vegetation survey conducted in May 1995, and in the 0SF and 0PF as permanent sampling units for canopy development.

Soil sampling and analysis

Between 15-20 January 1995, surface samples (0-10 cm) were collected at random within each of the five 5 m x 5 m quadrats of each 50 m x 50 m plot. The samples were air dried and ground and a 150 g sub-sample of each was taken to Stirling for analysis. Organic matter content was estimated by calculating percentage loss-on-ignition (L.O.I.) values after Allen (1989). Soil pH was measured in a 1: 2.5 soil: 0.01 M $CaCl_2$ solution (pH($CaCl_2$)).

Exchangeable cations were extracted by leaching 5 g of soil with 100 ml of 1 M ammonium acetate. Potassium and sodium were determined by flame emission spectrophotometry using an acetylene-air flame and calcium and magnesium by atomic absorption spectrophotometry using an acetylene-nitrous oxide flame. For acidity measurements 5 g sub-samples were leached with 100 ml 1 M KCl. Total acidity was determined by titrating the extracts with 0.025 mM NaOH and, after reacting the titrated samples with 10 ml 1 M NaF, they were back-titrated with 0.01 mM HCl to determine exchangeable (H^+) acidity. Cation exchange capacity (CEC) was calculated as the total of exchangeable bases and exchangeable acidity. For available phosphorus, 5 g soil were extracted by shaking in 0.5 M acetic acid for 30 min. Phosphorus concentrations were determined by photometry on a TECATOR auto-analyser using the stannous chloride-ammonium molybdate method.

Soil seed bank

Four 10 cm x 10 cm x 10 cm samples were collected and bulked from each of five 5 m x 5 m quadrats of the 50 m x 50 m plots from each fallow. In the 0PF and 0SF sites only one sample was taken from each quadrat (to reduce disturbance to growing crops). The cored samples were sieved and the soil put in perforated plastic-lined boxes at the Barito Ulu Base Camp on 15 November 1995. The emerging seedlings were recorded and after assigning them to separate taxa they were removed from the boxes. Daily recording began on 1 December 1994 and after the initial seedling flush the recordings were made every two weeks from 20 January to 15 May 1995.

Vegetation sampling

The cover abundance (Domin values) of each species in the five 5 m x 5 m quadrats used for soil sampling and a further five randomly selected quadrats of the same size were recorded at each site in May 1995. To characterise the structure of the vegetation profiles one 10 m strip was photographed at each of the five sites in September 1995.

The 0PF and 0SF sites were under cultivation at the beginning of the study in October 1994. To follow the development of vegetation cover over time, the five 5 m x 5 m quadrats were permanently marked at both sites and their vegetation recorded on 18 November 1994, 14 January and 17 May 1995. This study had to be abandoned after May 1995 as a number of the quadrats were cleared for growing vegetables.

Results and Discussion

Soil analysis

Analyses of variance on soil chemical and physical attributes showed no significant differences among the sites at $p \leq 0.05$ (Table 1). There was, however a consistent difference between the 2SF and 0PF ($p \leq 0.052 - p \leq 077$) for potassium, sodium, calcium, magnesium and CEC, 0PF having higher values. Loss-on-ignition was low, 2.0-16.1% and was similar to the values obtained for undisturbed lowland evergreen rain forest soil from the Ulu Barito (pers. obs.). Irrespective of site there was a high variation in the values for pH (3.0-6.8) and extractable phosphorus, probably because of the local effects of burning. The CEC of the samples was very low to low (3.4-19.1 $\text{cmol}_c\ \text{kg}^{-1}$) and the values for percentage base saturation (BSP) were medium to high (26.9-100%).

Table 1. Loss-on ignition (L.O.I.); pH measured in $CaCl_2$; extractable phosphorus (P); exchangeable potassium (K), sodium (Na), calcium (Ca), magnesium (Mg), acidity (H) and aluminium (Al); cation exchange capacity (CEC) and Base Saturation Percentage (BSP) of soil samples (n = 5) collected from two fields (0PF and 0SF) under crops and three fallows (1PF, 1SF and 2SF) in the Ulu Barito in January 1995. The values shown are means with ranges in parentheses.

	0PF	0SF	1PF	1SF	2SF
L.O.I. (%)	8.7	8.2	6.6	7.8	5.7
	(8.1-9.9)	(2.0-16.1)	(3.6-11.5)	(5.7-10.5)	(5.1-6.7)
$pH_{(CaCl_2)}$	3.7	5.4	4.5	4.2	3.9
	(3.5-3.9)	(3.6-6.8)	(3.0-5.9)	(3.9-4.7)	(3.5-4.3)
P (μg g^{-1})	0.8	36.4	5.8	5.8	0.3
	(0.3-1.2)	(0.8-138.9)	(0.6-20.5)	(0-2.9)	(0-0.6)
K ($cmol_c$ kg^{-1})	0.24	0.51	0.20	0.18	0.15
	(0.2-0.3)	(0.1-1.2)	(0.1-0.4)	(0.1-0.2)	(0.1-0.2)
Na ($cmol_c$ kg^{-1})	0.04	0.03	0.02	0.01	0.01
	(0.01-0.07)	(0.02-0.08)	(0-0.06)	(0-0.02)	(0-0.02)
Ca ($cmol_c$ kg^{-1})	2.1	5.2	4.3	4.7	1.6
	(1.2-3.0)	(1.4-9.4)	(1.3-9.3)	(3.1-9.2)	(0.6-2.6)
Mg ($cmol_c$ kg^{-1})	1.2	2.9	0.6	0.8	0.5
	(0.9-1.9)	(0.6-8.4)	(0.2-1.5)	(0.6-1.2)	(0.2-0.7)
H ($cmol_c$ kg^{-1})	0.9	0.4	0.2	0.4	0.3
	(0.6-1.2)	(0-0.9)	(0-0.4)	(0-1.0)	(0-1.1)
Al ($cmol_c$ kg^{-1})	1.87	0.51	0.75	0.71	1.29
	(1.29-2.23)	(0-1.88)	(0-1.35)	(0-1.16)	(0-2.58)
CEC ($cmol_c$ kg^{-1})	6.31	9.53	6.09	6.78	3.75
	(6.05-6.88)	(4.79-19.1)	(3.42-11.44)	(5.07-10.47)	(2.93-4.53)
BSP	56.5	83.0	75.1	82.8	57.3
	(46.0-65.3)	(47.3-100)	(51.8-100)	(64.9-98.0)	(26.9-75.3)

In one-factor analysis of variance no significant differences ($P \leq 0.05$) were found for any of the physical or chemical properties among sites.

The changes in soil chemistry that occurred after clear felling and burning (increase in BSP, pH, exchangeable Ca and Mg) were consistent with other reports (Riswan and Kartawinata 1991). No significant differences were found in soil chemistry among the different fallow sites. The near-significant differences between the 0PF and 2SF may indicate a real decrease in soil fertility in the 2SF which was known to have had a history of three or four rotations as opposed to the 0PF which was growing rice for the first time. Another possible explanation is that a temporary depletion of nutrients was occurring in the 2SF whilst the 0PF was still rich in nutrients after the burning about 75 days earlier. The dynamics of nutrients are characterised by a net loss from the soil during the crop phase and a further decrease in the early stages (bush period) of fallow (1-4 years). After the bush period, soil reserves will tend to increase from litterfall until the secondary forest is felled again (Nakano and Syahbuddin 1989). Full recovery of organic carbon and nitrogen, in the absence of further felling, was found after about 40-50 years for soil organic matter and about 15-20 years for nitrogen in Costa Rica (Brown and Lugo 1990). Trenbath (1983) has quoted several references which show an initial decrease in soil fertility (judged by total soil nitrogen concentration) and a recovery by the end of the fallow period.

Soil physical properties are important for maintaining fertility and have been reported to be better preserved under shifting than permanent cultivation in eastern Bolivia (Gerold 1994). This maintenance is largely due to protection by vegetation and litter cover during the fallow phase which reduces soil erosion. As the fields in the Ulu Barito area are often on steep ground it is important that the vegetation-free period is short and adequate lengths of fallow are allowed. Shifting cultivation on soils with high erosion and leaching potential take longer to recover than fallows with low erosion and high nutrient-retaining capacity (Bruijnzeel 1990).

Soil seed bank

The total number of seedlings which emerged dm^{-3} soil over 180 days was significantly lower in the 0PF samples than in the 1SF and the 2SF. The 1PF had significantly lower numbers than the 1SF (Table 2). It is noticeable that the numbers were about 2-5 times lower in the fallows that followed cultivation of a formerly primary forest area than in those derived from secondary forest, and that the seed bank in the 0PF did not differ from that in the 1PF.

Table 2. The mean ± standard deviation number of viable seeds m^{-2}. The values were estimated from the number of seedlings emerged over a six month period from composite samples of four 10 cm x 10 cm x 10 cm monoliths (n=5 per site) from five fallow sites.

Fallow	Mean ± std. number of seeds m^{-2}
0PF	100 ± 28
0SF	460 ± 368
1PF	340 ± 72
1SF	1415 ± 867
2SF	805 ± 563

A one-factor analysis of variance on the log-transformed values showed significant differences between 0PF and 1SF ($p \leq 0.01$), 0PF and 2SF ($p \leq 0.05$) and 1PF and 1SF ($p \leq 0.05$).

The results of the quantitative analysis of the seed bank were confirmed by the composition of the vegetation in the early stages at the 0PF and 0SF sites. The vegetation in the former consisted predominantly of rice while in the 0SF site weed species also contributed. Concern about weeds influences farmers' decisions to clear primary forest which, although it requires more work than clearing secondary forest, often gives a better crop because of the freedom from weeds. Another study in the area estimated the size of the seed bank to be c. 4300 m^{-2} in a 3-year old fallow as opposed to 175 m^{-2} in primary forest (Prajadinata 1996).

Vegetation

There was a rapid development of plant cover in the 0PF and 0SF, at first by herbs and later by tree species, that ranged from 0-5% one month after planting, 15%-80% after three months, and 75%-95% after six months. The values did not differ between the two sites except in January 1995 when the 0SF had higher cover. The main species in October and January was rice (*Oryza sativa*), but other species (*Macaranga hosei*, *M. hypoleuca*, *Scleria purpurescens* and *Trema orientalis*) became dominant by May 1995.

A total of 190 vascular plant taxa (belonging to ferns and 61 Angiosperm families) were recorded from the quadrats at the five sites in May 1995 (Figure 1). The most abundant species for each site are summarised in Table 3. Bare ground was prominent in the 0PF and 0SF but sharply declined in 1PF and 1SF where ferns dominated the understorey (Figure 2). Ferns and the following Angiosperm families, *Cyperaceae, Moraceae, Poaceae, Ulmaceae* ranked among the 10 highest contributors to plant cover at all sites followed by *Euphorbiaceae*, *Rubiaceae* and *Verbenaceae* which were among the 10 highest at four sites (Figure 2). Of the total number of species, secondary-forest trees contributed about 20% in the 0PF and 0SF and the corresponding values for the older fallows were slightly higher at about 25%. The fallows which had only been cultivated once had about two or three times more primary forest tree species than the fallows which followed more rotations (Table 4).

Figure 1. Mean number of species per 5 m x 5 m quadrat (n=10) with + Standard Deviations indicated recorded at five fallow sites in May 1995. The single horizontal lines above each bar indicate the total number of species recorded in the 10 quadrats at each site. Number of species: 0PF: 62; 0SF: 72; 1PF: 79; 1SF: 82; 2SF : 69.

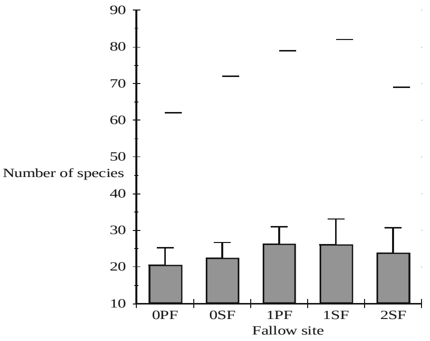
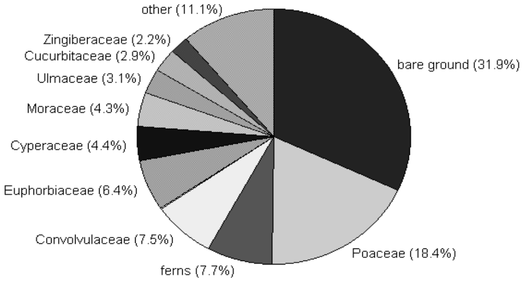


Figure 2. Average percentage contribution of bare ground, ferns and flowering plant families to vegetation cover in 0PF, 0SF, 1PF, 1SF and 2SF. The values shown are means (n = 10) and were calculated by taking the relative percentage values for bare ground, ferns and Angiosperm families after linearising the Domin cover-abundance values after Bannister (1966) for each of the ten 5 m x 5 m quadrats at each site.

Figure 2a. 0PF



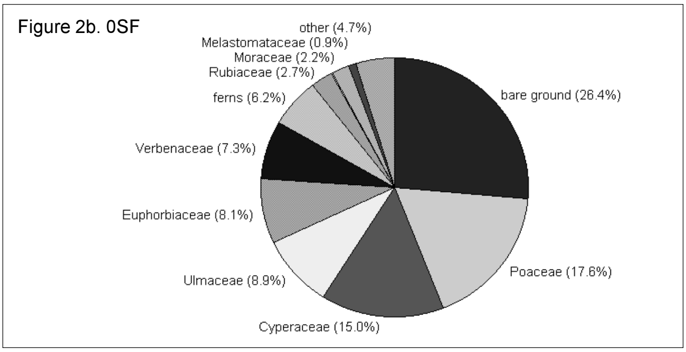


Figure 2b. 0SF

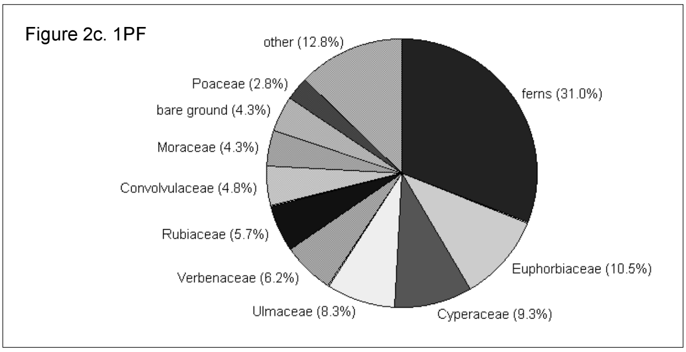


Figure 2c. 1PF

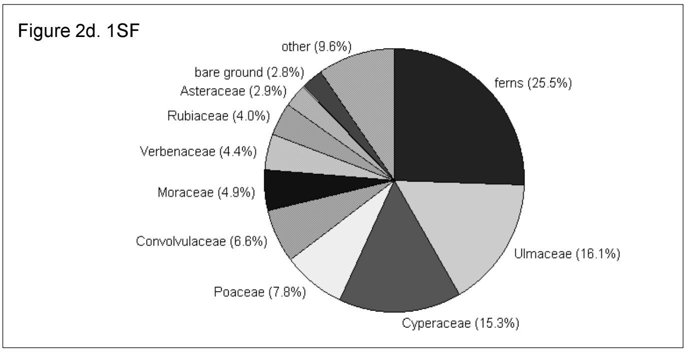


Figure 2d. 1SF

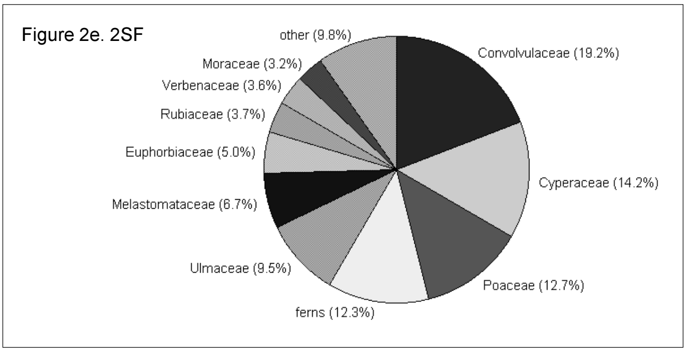


Figure 2e. 2SF

Table 3. The frequency (number of quadrats out of 10), with the range of Domin values in parentheses, of species which have a frequency of at least 6 in one of the sites in the 0PF, 0SF, 1PF, 1SF and 2SF sites in the Ulu Barito area, Central Kalimantan in May 1995.

Species	Family/Phylum	0PF	0SF	1PF	1SF	2SF
Blumea balsamifera	Asteraceae			7 (1-3)	8 (+-4)	
Jacquemontia sp.	Convolvulaceae				9 (+-5)	9 (3-7)
Merremia peltata	Convolvulaceae					9 (1-6)
Cyperus sp.	Cyperaceae	6 (+-2)	6 (+-2)			
Scleria purpuescens	Cyperaceae	6 (+-4)	10 (1-5)	9 (+-6)		10 (2-7)
Glochidion sp.	Euphorbiaceae	7 (+-2)				8 (+-3)
Macaranga hypoleuca	Euphorbiaceae	10 (+-4)	10 (+-3)			9 (+-3)
Macaranga sp.	Euphorbiaceae	10 (1-3)	10 (1-4)	10 (+-3)	8 (+-2)	7 (+-2)
Curculigo cf. *villosa*	Hypoxidaceae				6 (1-3)	6 (+-2)
Leea indica	Leeaceae	6 (+-1)			8 (+-2)	7 (+-5)
Melastoma malabathricum	Melastomataceae		7 (+-2)	9 (+-4)	7 (+-2)	8 (+-6)
Ficus sp1	Moraceae		8 (+-2)			
Ficus sp2	Moraceae		7 (+-2)	9 (+-2)	6 (+-6)	6 (+-2)
Ficus sp3	Moraceae				6 (+-2)	
Ficus sp4	Moraceae			7 (1-3)	6 (1-4)	6 (+-2)
Oryza sativa	Poaceae	10 (+-6)				
Unidentified	Rubiaceae				8 (+-3)	
Uncaria sp1	Rubiaceae			9 (+-5)	8 (+-2)	
Uncaria sp2	Rubiaceae			9 (+-5)		
Rutaceae sp.	Rutaceae			6 (+-4)		
Trema orientalis	Ulmaceae	8 (1-4)	10 (1-5)	7 (1-8)	10 (1-8)	9 (2-4)
Callicarpa cf. *longifolia*	Verbenaceae					7 (1-5)
Geunsia	Verbenaceae	7 (1-3)	10 (1-6)		6 (1-6)	
Costus speciosus	Zingiberaceae					6 (+-2)
Unidentified	Zingiberaceae	9 (+-4)	7 (+-1)			
Blechnum orientale	Pteridophyta		6 (+-2)		8 (+-5)	
Cyclosorus sp.	Pteridophyta		7 (+-3)			
Dicranopteris cf. *pubigera*	Pteridophyta			6 (+-1)		
Lygodium circinnatum	Pteridophyta		7 (+-3)			
Lygodium microphyllum	Pteridophyta					6 (+-4)
Microlepis puberula	Pteridophyta			8 (+-1)		
Nephrolepis biserrata	Pteridophyta			10 (3-6)	9 (+-6)	9 (+-8)
Pityrogramma calomelanos	Pteridophyta		7 (1-2)	8 (2-7)		
Pteris tripartita	Pteridophyta	8 (1-3)				
Stenochleana palustris	Pteridophyta			6 (+-1)	6 (+-5)	

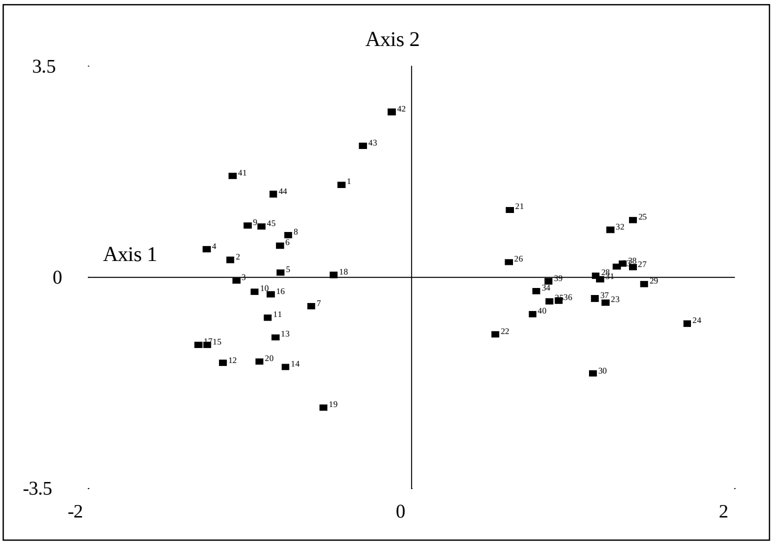
Table 4. The percentage contribution of crop, secondary and primary forest and other species to total species numbers at the five fallow sites in the Ulu Barito, Central Kalimantan in May 1995.

	0PF	0SF	1PF	1SF	2SP
Crop	16	2.8	0	1.2	0
Secondary trees	19.4	20.8	25.3	24.4	24.6
Primary trees	11.3	2.8	12.7	4.9	4.3
Other	53.3	73.6	62	69.5	71.1

There was a noticeable shift from the early dominance of herbaceous species to a mainly tree-dominated phase after about eight months of fallow which was followed by an increase in the cover of climbers, mainly *Convolvulaceae*, over extensive patches. The development of vertical canopy structure in 0PF and 0SF was less distinct than in 1PF and 1SF where an herbaceous undergrowth and a tree canopy could be distinguished. In the 2SF the vegetation was a mosaic of open herbaceous nature and closed tree canopy where the tree canopy was overtopped by climbers, mainly belonging to the *Convolvulaceae* family. This was reflected by a high cover of herbaceous undergrowth in 0PF, 1PF, 0SF and 1SF; in sharp contrast with the 2SF where herbs were only abundant in open areas dominated by ferns and *Imperata cylindrica* (Alang Alang) while in the dense shade cast by the trees and climbers they formed only a sparse undergrowth. The youngest fallows (0PF and 0SF) had the lowest stature vegetation, but there was no canopy height difference among in the 1PF, 1SF and 2SF fallows because in the 2SF the climbers inhibited vertical growth and their weight often caused the trees to snap.

In the Principal Component Analysis, the first two axes accounted for 21.6 % and 6.6% of the variance in the data. There were two main groups along Axis 1: one made up of 0PF and 0SF quadrats (right of Axis 2) and the other by the older fallows (Figure 3). Age was highly correlated with Axis 1 ($r = 0.82$) and the Monte-Carlo test showed that Axis 1 was highly significant ($F = 11.3$, $p = 0.01$), indicating that it was the main factor explaining differences in vegetation. In the present ordination , the differences within dominant species in the largest number of quadrats were analysed (Greig-Smith 1983) and little weighting was given to rare species. Although there was a continuous sequence of 1PF, 1SF and 2SF quadrats with little overlap along Axis 2, the separation could not be attributed to either rotation or origin because Axis 2 only accounted for 6.6% of the total species variance. Overall, there was a large percentage of species variance that was unaccounted for. Wyatt-Smith (1955) differentiated 11 vegetation types in 2-year old regrowth in Perak. Had this applied to the Ulu Barito area it would have resulted in the ordination in a distinct clumping of quadrats belonging to the same vegetation type. This was not the case and quadrats from different sites separated along the ordination axes. This separation was least obvious between the 0PF and 0SP sites, presumably owing to the high similarity of early vegetation. Individual fallows in the study area have been observed to form stands which are dominated by one or a few species and individual sites can bear dissimilar vegetation after 7-10 years of fallow (pers. obs.).

Figure 3. Site scatter diagram for the PCA of 45 quadrats at five sites (0PF, 21-30; 0SF, 31-40; 1PF, 11-20; 1SF, 1-10; 2SF, 41-45) in the Ulu Barito area, May 1995. The data were log-transformed and the data matrix centred by species and standardised by standard deviation of the stand.



Shifting cultivation has been perceived as a sustainable system at human population densities of 7 km^{-2} or less (Whitmore 1984). The soil data showed no significant differences in soil chemistry among sites and further studies are needed to estimate the upper limit at which the system is sustainable. Low population density allows the clearings to be small and spatially not isolated from primary forest with a consequent species-rich regrowth (Kochummen 1966; Ewel *et al.* 1985). If, however, extensive areas are used by shifting cultivators, or the fallow period is shortened, impoverishment in species may occur (Kochummen and Ng 1974; Kartawinata *et al.* 1980). Shifting cultivation at its present intensity in the Ulu Barito region does not appear to threaten biodiversity but creates additional habitats for plant and animal life. However, if it is greatly extended it will reduce the area of primary forest. As biodiversity in the Ulu Barito primary forest is very high the preservation of its flora and fauna is of major importance and the containment of shifting cultivation needs careful consideration.

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2. The Diversity of Medicinal Plants in Secondary Forest Post-Upland Farming in West Kalimantan

I. Caniago[1]

Abstract

This study documents the abundance, distribution and knowledge of medicinal plant species in a Ransa Dayak village and adjoining forest in West Kalimantan, Indonesia. The villagers utilise over 200 medicinal plant species from 165 genera and 75 families. Late successional, primary forest and river bench forest contained the highest diversity of locally used medicinal species and the greatest number of species restricted to a single forest type for which alternative species or remedies were unavailable. Epiphytes and trees restricted to primary forest are particularly important sources of plants used to treat unusual ailments. A 100% survey of village residents, at least 15 years of age, revealed that people older than 25, and older females in particular, possessed greater knowledge of medicinal plants and their uses than younger people and males. All residents, except the male healer, were more knowledgeable about medicinal plants found in early successional forests than those in primary forests. The loss of habitat through deforestation and of traditional knowledge through acculturation pose twin challenges to the persistence of traditional medicinal plant use in this Ransa village and throughout much of Kalimantan.

Introduction and Background

Many rural people throughout the tropics rely on medicinal plants because of their effectiveness, a lack of modern medical alternatives and cultural preference (Plotkin and Famolare 1992; Balick *et al.* 1996). On a global basis, approximately 80% of the world's population is believed to rely, to some extent, on medicinal plants (Farnsworth 1988), yet fewer than 10% of the earth's approximately 250 000 flowering plant species have been studied for pharmaceutical properties (Stix 1993). Moreover, little is known about the abundance and distribution of medicinal plants or the effect of land conversion on medicinal plant populations.

Indigenous forest-dwelling peoples tend to be particularly dependent on medicinal plants and often have exceptional medicinal plant knowledge (Comerford 1996; Johnston and Colquhoun 1996). However, exposure to modern culture, increased trade and access to modern conveniences (including modern medicines) are altering the distribution and extent of this knowledge and use of medicinal plants in these societies (Plotkin 1988; Leach 1994; Rocheleau 1995).

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Following disturbance (whether natural treefall, logging or shifting cultivation), light-demanding secondary species re-establish and close gaps in the forest canopy. Secondary forests differ from late successional and primary forests in that they are generally less diverse and relatively simple in terms of forest structure (Whitmore 1984). Secondary forests that develop following shifting cultivation differ from those succeeding logging in that they are usually more uniform in size and age, are dominated by few species, and contain residual crop and herbaceous weeds (Richards 1952).

Forest clearing may alter the abundance and distribution of medicinal plants. In fact, entire life forms may disappear given severe disturbance. For example, the growth and reproduction of epiphytes (an important group of medicinal plants) can be adversely affected by slight microclimatic changes and the loss of specific bark conditions found only on certain mature canopy trees (Whitmore 1984).

This study describes medicinal plant species and their uses in a Ransa Dayak village, the abundance and distribution of medicinal plants in seven locally recognised forest types, which take into account the succesional stages of forest dynamics from the young pionneer vegetation after clearing to the primary forest. This paper also presents the extent of medicinal plant knowledge and use among local people by age and gender.

Study Site and Methods

The study was conducted in West Kalimantan in a Dayak village and adjoining forests of Nanga Juoi. Nanga Juoi is located near the Bukit Baka-Bukit Raya National Park and a large forest concession operated by PT. Kurnia Kuala Kapuas (PT. KKP). Vegetation ranges from lowland mixed dipterocarp to montane forests and contains a rich assemblage of the region’s flora and fauna (Nooteboom 1987), including an estimated of 2000-4000 vascular plant species (Davis 1995). Nanga Juoi is inhabited by a Dayak sub-group known as the Ransa who report living in the area for generations. Many villagers observe traditional practices, including extensive use of medicinal plants.

A variety of research methods were used in the study, including participant observation, formal and informal surveys of all village residents 15 years and older, and establishment of random sample plots and line transects in seven locally recognised forest types. Initial plant collection and interviews with knowledgeable healers from Nanga Juoi and neighbouring villages were conducted between 1992 and 1995. A regionally recognised healer from the village, Udat Bin Badung (age 65), served as principal informant. A detailed ethnobotanical survey, including collection of voucher specimens of all medicinal plant species utilised by the healer, and extensive plot and transect sampling was completed in 1995. Medicinal plant specimens were identified in the local vernacular by the healer and in scientific nomenclature by taxonomists from Herbarium Bogoriense, Indonesia. Many of the sample specimens were available in sterile condition only and thus could be identified to genera only. Where the healer and botanical identification differed, both were recorded (i.e., in several instances the healer identified distinct species that herbarium botanists considered single species).

The Ransa Dayak of Nanga Juoi have developed a forest classification system which they use to demarcate hunting areas, swidden farms and sites for medicinal plant collecting. The Ransa classification system includes four primary successional stages reflecting the ecological transition from abandonment of recently cultivated swiddens through primary forest (Table 1). The Ransa system is based on progression from a single layer of shade-intolerant pioneer species through development of structurally complex, species-rich Dipterocarp dominated forests.

Table 1. Number of plots in each forest type.

Code	Forest Types (Dynamics succession)		Vernacular Name	Sample
I	Initial Secondary		Tempalai	38 plots (2 m x 2 m)
E-1	Young Secondary	(early)	Bawas baling	23 plots (2 m x 2 m)
E-2		(late)	Bawas beliung	11 plots (10 m x 10 m)
L-1	Old Secondary	(early)	Agung kelengkang	23 plots (100 m x 2 m)
L-2		(late)	Agung tua	30 plots (100 m x 2 m)
PF	Primary Forest		Rimba	7 transects (1000 m x 2 m)
RB	River Bench		Pinggir sungai	134 plots (2 m x 2 m)

The distribution of forest types in Nanga Juoi is complex due to the patchy distribution of agricultural activities. In 1994, fewer swidden fields were opened than in the past. Consequently, the area of young fallow was small relative to old fallow, recently logged forest and primary forest. Furthermore, unlike primary and logged forest, swiddens typically occurred only in clusters near settlements and in areas with favourable soil and slope conditions. For this reason, a variety of methods were used to sample the abundance and distribution of medicinal plants in the different forest types (Table 1). In the earliest successional stage (*tempalai*), where densities of some medicinal species were very high, 38 plots (2 m x 2 m) were established. In young secondary forest (*bawas baling*), that had high densities of medicinal plants but occupied a smaller area, we established 23 plots (2 m x 2 m). In later successional stages (late secondary forests, early and late old secondary forests), plant densities were lower and land areas larger, but sites remained clustered. In these stages, larger sample plots and line transects were used (Table 1). Finally, in river bench forest (*pinggir sungai*) 134 plots (2 m x 2 m) were sampled. In each sample plot or transect, the identity, life form and number of each medicinal plant was noted. If locally important medicinal plants were not recorded in any sample plots, the healer was asked to provide information regarding their relative abundance, distribution and site preferences. These methods follow the guidelines recommended by Hall and Bawa (1993).

To ascertain the extent of medicinal plant knowledge and use among people in Nanga Juoi, all village residents 15 years of age and older were interviewed (n = 32). Formal surveying was completed at the end of the research period after village residents had become comfortable responding to questioning. Informal discussions corroborated the survey data and provided additional information. In the surveys, people were asked if they knew the identity and use of all medicinal plants listed. They were also asked to identify the specific ailments treated with each plant, the plant part used, and how it was used.

Results

Medicinal plants and their uses

The healer of Nanga Juoi identified and uses 237 medicinal species from at least 165 genera and 75 families; 155 of these plants were identified to species level. Trees were the primary source of medicinal plants in terms of number of species used (81), followed by herbs (65) and vines (45). Epiphytes, ferns and aquatic plants comprised a smaller proportion of the medicinal plant flora (Table 2).

Table 2. Medicinal plant species by life form.

Life form	Number of species
Epiphytes	15
Ferns	14
Herbs	65
Shrubs	15
Trees	81
Vines	45
Aquatic plants	2
TOTAL	237

These medicinal plants are used to treat a wide variety of ailments in Nanga Juoi, including those of the skin, eye and ear, headaches, toothache pain, problems associated with the respiratory, circulatory, digestive, nervous and reproductive systems, as well as providing astringents. Some species are used on regular basis to treat common ailments (particularly headaches, fever, skin ailments and digestive problems), while others are only occasionally used to treat specific and unusual ailments (Table 3).

Table 3. Main uses of medicinal plant species.

Purposes	Total # of species	%
Headache and fever	79	33.3
Skin treatments	78	32.9
Digestive system	45	19.0
Kidney system	36	15.2
Respiratory systems	33	13.9
Reproductive systems	33	13.9
Nervous system	33	13.9
Tonic	24	10.1
Toothache	10	4.2
Astringent	10	4.2
Heart disorder	7	3.0
Eye ailment	6	2.5
Blood circulation	5	2.1
Rheumatic	2	0.8
Malaria	2	0.8
Biopest	2	0.8

Abundance and distribution of medicinal plants

Medicinal plants are abundant and widely distributed in the forests around Nanga Juoi (Table 3.) Medicinal plant diversity was highest in old secondary forest (79 species), river bench (61 species), and primary forest sites (42 species). The lowest species richness was recorded in logged forests (18 species) and early successional vegetation (29-37 species). Density was highest in early successional and logged forest where several species were observed in very high densities (Table 4). Thus, medicinal plant populations appear to exhibit the same general diversity and density patterns characteristic of tropical forests; namely high species diversity but low densities in late succession vegetation and primary forest, and low species diversity, but high density of few species in early succession stages.

Table 4. Medicinal plant species abundance in different forest types.

Forest type		Number of species found	Restricted species	Total density (per ha)
Initial secondary		37	1	132 271
Young secondary	(early)	29	1	94 990
	(late)	36	1	24 491
Old secondary	(early)	79	4	9 112
	(late)	28	0	5 806
Primary		42	10	744
River bench		61	3	37 750

Twenty medicinal species were restricted to a specific forest type as determined by sampling (but 40 species according to the healer) (Table 4). Primary forests contained the largest number (10) of restricted species. If vegetation types are grouped into secondary and primary forests, the result is even more pronounced: 94% of medicinal species could be found in secondary forest (237-(10+3)/237). Of these, 64% grew only in secondary forest compared to only 1% restricted to primary forests. All of the medicinal plants restricted to early successional stages are common throughout Indonesia (i.e., *Blumea balsamifera, Mallotus paniculatus, Melastoma affine, Pityrogramma tartarea, Urena lobata* and *Cassia alata*) (Wijayakusuma 1996).

Villagers cultivated seventeen (7%) of the medicinal species collected in this study. They were not only cultivated for medicinal purposes. Six species were used as spice (all gingers), six species for consumption (*Citrus* sp., *Cocos nucifera, Arenga pinnata* and *Areca catechu*) and five species for ornamental use (*Tagetes erecta, Celocia orgentea, Gomphrena globosa, Cosmos caudatus* and *Coleus scutellaroides*).

Traditionally, the residents of Nanga Juoi maintained small areas of primary forest (*gupung*) for religious reasons. These forests cannot be cleared for agriculture and are used for collecting medicinal plants. Some sacred river bench sites have reportedly remained free of disturbance for hundreds of years, not withstanding high agricultural value, and provide unique primary forest micro-environments. In addition to high species diversity, the density of medicinal species is high in river bench forests (13 000/ha).

Medicinal plant knowledge among residents of Nanga Juoi

The level of knowledge about medicinal species and their uses varies widely among residents of Nanga Juoi. In general older people, and older women in particular, are more knowledgeable than young people and men (Table 5). On average, people over the age of 25 could identify and describe the use of 46% of the medicinal plants utilised by the healer whereas younger people (below 25) could only identify 23% (Table 5). Older women were the most knowledgeable among the residents of Nanga Juoi since they could identify and describe the uses of 50% of all species.

Table 5. Medicinal plant knowledge among Nanga Juoi Residents.

Residents Group	Medicinal Plant Knowledge (%)
All men	26
All women	42
People older than 25	46
People younger than 25	23
Men older than 25	41
Men younger than 25	11
Women older than 25	50
Women younger than 25	34

Conclusions and Discussion

Late successional, primary and river bench forests contained the greatest diversity of medicinal species and the highest number of species restricted to specific forest types. All of the forest types sampled contained higher medicinal species diversity levels than logged forests, although logged forests contained greater numbers of certain individual medicinal plants. High medicinal species diversity and abundance in secondary forests (early and late successional stage) could be related to the fact that secondary forests are generally closer to villages and more often visited than primary forests, especially for women, the most frequent users of medicinal plants. Therefore, villagers grow or favour the growth of medicinal plant in these environments.

It is difficult to specify which medicinal plants are most important to the Ransa Dayak. As Grenand (1992) has noted, the term ‘useful species’ does not have the same meaning for all cultures and probably not for all individuals within a society. In fact, the Nanga Juoi healer observed that ‘all plants in the forest are useful’ to the Ransa (Udat Bin Badung, pers. comm.). Similar values are found in other cultures, such as the Mende of West Africa who report that ‘We Mende feel that all plants can be medicines’ (Leach 1994).

Simply totalling the number of useful species in a given forest is not a measure of that forest’s importance (Phillips *et al.* 1994). Since primary and river bench forests contained the largest number of restricted species for which alternative remedies were unavailable, and most remaining primary forests are subject to logging, the conservation of primary and river bench forests will be crucial to the continued availability of traditional medicinal plant species. As is the case in other tropical environments (Leach 1994), the primary forests around Nanga Juoi provide medicines for rare ailments that can not be treated by other means and are an irreplaceable repository for the future. Thus, river bench forests may be a particularly important source of medicinal species in Kalimantan, just as they are in the Peruvian Amazon where flood plain forests were found to be the most ethnobotanically important forest type (Phillips *et al*. 1994).

While the maintenance of small forest reserves may contribute to the conservation of medicinal plants, small reserves cannot ensure their long-term survival. For example, Turner *et al*. (1996) recorded 51% loss of plant species richness over a 10-year period in a 4 ha lowland rainforest fragment in Singapore, with shade tolerant understorey shrubs, climbers and epiphytes showing particularly high extinction rates. Extensive logging and the creation of isolated forest patches will pose similar problems for the conservation of medicinal plant species around Nanga Juoi. Such patterns probably recur throughout Kalimantan due to extensive timber harvesting.

Gender differences with respect to plant knowledge and use is widespread in many rural societies. This reflects the fact that women tend to be more responsible for family and especially child health care, and a division of labour in which women often tend fields and gardens (Leach 1994; Rocheleau 1995). In Nanga Juoi, women work in swiddens that are located near the village and that were cleared from secondary forests. This may explain their greater familiarity with medicinal plants found in early successional environments. In contrast, older men are more knowledgeable about medicinal species found in primary forests (traditional male activities involve hunting and forest product collecting in primary forests). Younger males no longer hunt and collect forest products as did their elders, but instead work as commercial loggers where they learn little about medicinal plants.

All villagers were more familiar with medicinal plants of secondary forests (e.g., ferns and herbs) than those found in primary forests. Voeks (1996) observed similar patterns in coastal Brazil where he found that second-growth forest yielded 2.7 times the number of medicinal species as primary forests and that healers demonstrated a strong preference for disturbed areas. Voeks attributed this to the high relative availability and intrinsic value of disturbance species, as well as the increasing rarity of primary forests and acculturation (i.e., loss of traditional plant knowledge). The Ransa Dayak of Nanga Juoi appear to be in transition along this continuum with the healer still utilising primarily river bench and late fallow forest species, while villagers are more knowledgeable about early successional species and young people have little medicinal plant knowledge at all. The conservation of medicinal plant habitat will require more research on the amount of habitat and area required for sustainable use of medicinal species. However, any efforts would be meaningless without the conservation of the knowledge itself.

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3. Prospects for Conservation of Biodiversity within Productive Rubber Agroforests in Indonesia

Eric Penot[1]

Abstract

During this century, forests have been extensively slashed and burned mainly in the lowlands of Sumatra and Kalimantan, first for shifting cultivation by local smallholders, then for establishment of jungle rubber. In this context, smallholders have developed complex agroforestry systems which now cover more than 2.5 million ha in Indonesia. Over the last two decades, large-scale projects of industrial plantations (oil palm and fast-growing trees) have been also promoted.

The paradox of jungle rubber in Indonesia is that the rubber boom unquestionably triggered conversion of a part of the existing primary forest at the beginning of the century. Two million hectares have been converted in Sumatra which is less than 5% of the whole island area and less than 10% of the natural area of lowland rainforest. As these lowland forests disappear, and because of its nature as a complex agroforestry system which has structural and biodiversity similarities with secondary forest, jungle rubber remains as the major reservoir of biodiversity (lowland forest species) in the plains below 500 m a.s.l. in Sumatra (and probably West Kalimantan) at the end of the same century. Due to economic growth and new crop opportunities, jungle rubber is not currently competitive and its productivity needs to be improved through integration of innovations such as clonal rubber and increases in inputs and labour. Several types of 'RAS' (Rubber Agroforestry Systems) are currently being trialled on a large scale in three provinces of Indonesia and managed by GAPKINDO/CIRAD/ICRAF in an on-farm trials network. The adoption of improved RAS, with consequent increases in farm incomes, would reduce pressure on remaining forests and promote the shift from *ladang* (shifting agriculture) to permanent tree crop-based agriculture, requiring less land per household for an improved income. The role of rubber agroforestry as a trap for biodiversity in systems providing sufficient income to remain attractive will be considered as an interesting alternative to other systems (oil palm or pulp trees) in an effort to decrease pressure on remaining forests. The potential of developing such RAS to rehabilitate *Imperata* grassland with lower risks can also be considered.

Introduction

During the 19th century, agriculture in Sumatra and Borneo was mainly subsistence shifting cultivation supplemented by hunting and forest products collection. Until the end of the last century rubber production in Indonesia and South-east Asia in general,

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was limited to collection of latex of ‘gutta percha’ (*Palaquium* spp., Sapotaceae) in natural forest (Dove 1993b). This situation changed in the early 20th century with the introduction of the rubber tree to Indonesia bringing a rapid transition from an extrativist system to a production system. Nowadays in Sumatra and Kalimantan, rubber cultivation based mainly on rubber agroforestry systems covers more than 2.5 million ha. These production systems provide income for more than one million farmers and are also a cropping opportunity on poor soils (Dove 1993a,b; DGE 1996). In Kalimantan, rubber complex agroforests allowed formerly migrating Dayak groups to establish permanent villages, while in Sumatra they provided a livelihood for spontaneous Javanese migrants and local Malayu farmers.

Commercial logging began in the 1960s and 1970s with parts of the logged forest intentionally clear-cut for land conversion as part of government transmigration programmes. In the 1980s and 1990s, large-scale plantation and estate crop programmes were promoted and developed because of the strong demand for oil palm and pulp. Estates have been increasingly established on village lands and have attracted local smallholders, many of whom were shifting cultivators and rubber planters (Dove 1985, 1986). Forest conversion and agricultural intensification have a critical impact on biodiversity. However, several studies have demonstrated that biodiversity of jungle rubber approaches that of secondary forests for collembole, birds (Thiollay 1995) and vegetation (de Foresta 1992a; De Foresta and Michon 1997; Michon and de Foresta 1997). Rubber Agroforestry Systems or RAS, commonly called jungle rubber, are now likely to replace the role of secondary forests for biodiversity conservation in rural areas.

Indonesian farmers have developed a wide range of agroforests in Sumatra and Kalimantan based on products such as rubber, resin (damar), illipe nut, timber, benzoin and durian (Michon and de Foresta 1999). Among these, rubber agroforests are the most common systems and are tree crop plantation systems as opposed to ‘extractive systems’. Traditional rubber agroforests require limited labour during the immature period and provide income diversification through non-timber forest products collection. These rubber gardens are generally called Complex Agroforests or CAF (Michon and de Foresta 1999). In these systems part of the germplasm (rubber) is planted by farmers for production or selected (fruit and timber trees from regeneration) for further production. The farmer develops a strategy in allocating land, capital and labour to different cropping patterns. The important characteristic of CAF, including RAS, is that they are managed in a planned way.

The development of rubber agroforests and the value of these cropping systems have been extensively reported (Barlow and Muharminto 1982; Gouyon *et al.* 1993; Penot 1995; Levang *et al.* 1997; Michon and de Foresta 1999). These CAF, planted with unselected seedlings, generate up to 80% of the total cash income of rubber smallholders (Gouyon 1995). However, the main constraint on traditional RAS is their low productivity resulting from the use of unselected rubber seedlings. The mean production of dry rubber in RAS is 500 kg/ha/year while that of clonal rubber plantations is 1500-1800 kg/ha/year. Improved productivity of rubber agroforests through planting clonal material could therefore offer more reliable and interesting alternatives to current jungle rubber and rubber monoculture systems. It is therefore important to trial different rubber agroforestry systems leading to an increase of both rubber and other associated products (fruits, timber, intercrops), while conserving the nature and advantages of traditional agroforestry practices. Trials have been carried out by the Smallholders Rubber Agroforestry Project (SRAP) in Sumatra and Kalimantan. This paper aims to present the preliminary results of this project and to discuss the outlook for RAS development in Indonesia.

The Srap Project

This project started in 1994 and is a joint research programme of CIRAD, the National Rubber Association of Indonesia (GAPKINDO) and ICRAF. The main component of the project is the introduction of clonal planting material with high productivity in the rubber agroforests. Three experimental RAS are currently being tested by the project in the provinces of Jambi, West Sumatra and West Kalimantan. SRAP proposes that yield production in RAS systems using clonal material is similar to that of rubber monocultures. A related assumption is that rubber production is not affected by the competition of associated trees (fruit trees, timber and others). The main advantage of RAS is their much higher biodiversity level compared to monoculture stands.

RAS 1: rubber + secondary forest regrowth

The first trial (RAS 1) is similar to the traditional jungle rubber system, in which unselected rubber seedlings are replaced by selected high-yielding clones. The main objectives are to:

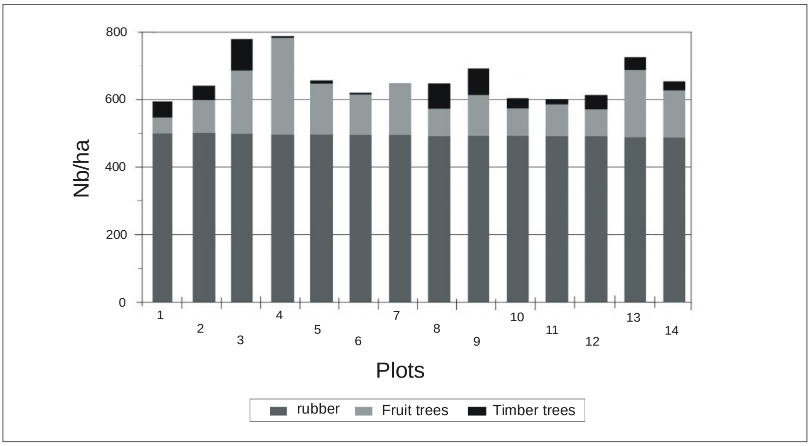
- assess growth and survival patterns of clonal rubber germplasm in a jungle rubber environment;
- double yields;
- assess the required minimum management level; and
- assess the level of biodiversity conservation in the jungle rubber system.

The rubber clones must be able to compete with natural secondary forest growth. Various weeding protocols are currently being tested. Two planting densities are applied (550 and 750 rubber trees/ha) to identify minimum levels of management needed for the system. This is a key factor for farmers whose strategies depend mainly on labour and cash availability. RAS 1 is applied in pioneer vegetation, old jungle rubber or old agroforests. Experience has shown that RAS 1 is not suitable in *Imperata* grasslands (Penot *et al.* in press).

RAS 2: rubber + associated trees + annual intercrops

In RAS 2, rubber trees as well as perennial timber and fruit trees are established after slash and burn, at a density of 550 rubber trees/ha and a range of 90-250 other associated trees/ha. Annual crops are cultivated during the first 3-4 years, emphasising improved upland varieties of rice with various levels of fertiliser application. Intercrops are annual (predominantly upland rice or a rotation of rice or leguminous crops such as groundnut) or perennial (cinnamon) during the first years of establishment. A wide range of trees are grown in association with rubber (Figure 1), e.g., meranti (*Shorea* spp.), nyatoh (*Sapotaceae*) and sungkai (*Peronema canensis*) trees for timber; durian (*Durio zibethinus*), rambutan (*Nephelium lappaceum*), duku (*Lansium domesticum*), cempedak (*Artocarpus integer*), petai (Parkia speciosa) and jengkol (*Archidendron pauciflorum*) for fruits; and tengkawang (*Shorea* spp., illipe nut) and kemiri (*Aleurites moluccana*) for nuts.

Figure 1. Re-introduction of associated trees in former rubber monoculture plots: the case of Sanjan village in West Kalimantan.



In Sanjan, 13 years after introduction of monocultures, 15 of the original 50 farmers (30%) have re-introduced associated trees into their original monoculture clonal rubber plots. The density of associated trees was between 94 and 291 trees/ha (average of 167) for 500 rubber trees/ha with emphasis on the following species in decreasing order of importance: pekawai and Durian (*Durio* spp.), belian (*Euxyderoxylon zwageri*), rambutan (*Nephelium lappaceum*), cacao, assam (*Tamarindus indica*), cempedak (*Artocarpus integer*), petai (*Parkia speciosa*) and Nyatoh (*Palaquium* spp.). Pekawai, durian and rambutan were present in all the plots, revealing farmers' preferences for fruit trees. Sixty-four per cent of the trees were planted, the rest resulted from natural regrowth and selection. In the study area, income diversification and re-introduction of an economically interesting plant diversity in former monocultures are part of Dayak farmers' strategies.

RAS 3: rubber + associated trees + cover crops + pulp trees for *Imperata* grasslands rehabilitation

RAS 3 is similar to RAS 2 (same tree density) but with no intercrops except in the first year, followed by a combination of cover crops, Multi-purpose Trees (MTP) and Fast-growing Trees (FGT). It is established on degraded lands invaded by *Imperata cylindrica*. The grass precludes the growing of annual crops, therefore selected cover crops (*Mucuna*, *Flemingia*, *Crotalaria*, *Setaria*, *Chromolaena*) or MPT (*Calliandra*, *Wingbean*, *Gliricidia*) and FGT (*Gmelina*, *Paraserianthes*, *Acacia*) are established. The objective is to eliminate weeding requirements by providing a favourable environment for rubber and associated trees to grow, as well as supplanting and preventing *Imperata* growth.

Rubber Agroforests and Biodiversity: Background and Hypothesis

The maintenance of biodiversity is not a priority for farmers. It is a by-product resulting from farmers balancing the need to clean gardens for yield optimisation with labour efficiency maximisation. The resulting plant diversity provides a source of additional income through fruits, timber and NTFPs. For Dayak in the Sanggau/Sintang areas, land use at the village/community level is balanced between production-oriented cropping systems (including rubber agroforests and illipe nuts), managed forests and forests protected by customary law to guarantee a permanent supply of forest products. Conservation of biodiversity in CAF as an integral part of such a land use system seems to be a promising method of local resource management (Werner 1993).

The problem facing researchers is how to value and conserve biodiversity, whether through integration, segregation or both (Noordwijk *et al.* 1995). In pioneer zones of Africa and South-east Asia, it has been found that segregating an area of forest by enforced exclusion is not sufficient to ensure maintenance of biodiversity. Ivory Coast is an example where severe deforestation (15 million ha in 1960 were reduced to 0.5 million ha in 1995) is a result of forest conversion to coffee and cocoa plantations and where the only remaining primary forest is the Tai National Park in the south-west. This shows that 'segregation' is necessary to maintain a refugium for biodiversity, but is not sufficient. So 'integration' into cropping systems should be considered, on the condition that productivity is not affected. Rubber is one tree crop that allows such an integration. Although the extension of rubber agroforests has been a driving force in the deforestation process in Sumatra and Kalimantan, they are now the major reservoir of biodiversity where natural forests have almost disappeared (de Jong 1997; Michon and de Foresta 1999).

Deforestation will continue until primary forest has vanished where the following conditions exist: 1) land is available; 2) there is an abundant source of immigrants; 3) easy and low risk cropping patterns allow income generation through agriculture; and 4) markets are able to absorb any increase in production. These are typical conditions of any 'crop boom', where there is little chance for the natural forest to remain protected as long as the market is driving the boom (Ruf 1990). With primary forest shrinking and efficient and productive monocultures such as rubber and oil palm increasing, integration of biodiversity into the agricultural production system has to be considered to provide refugia for forest species. The rubber garden is one of the few systems able to integrate biodiversity into cropping patterns and still ensure a sufficient income for farmers without disturbing production potential.

Dove (1993b), in discussing 'booms', notes that 'whenever a natural resource experienced a commercial boom and attracted the attention of government and industry, steps were taken, ostensibly for the common good but often out of self-interest of the political-economic establishment, to restrict its exploitation by smallholders'. This was the case in the 1930s with the 'Stevenson plan' that restricted the production of estates, but yet triggered the rubber smallholder expansion. This 'political ignorance' policy might be another way of restricting the importance of the sector through the non-recognition of its existence.

Productivity and Incomes in Ras: Some Preliminary Results of the Srap Project

The use of clones under a good management regime during the critical first three years after planting in RAS to ensure a viable plantation is the key to obtaining a yield comparable to that of clonal rubber in monocultures (triple that of jungle rubber). In West Kalimantan (village of Sanjan), preliminary observations suggest that yield in former clonal rubber plantations where 150-300 associated trees/ha have been reintroduced by farmers is not significantly different from that recorded in pure plantations (i.e., without associated trees).

The main constraints to RAS adoption by farmers are by order of importance:

- access to improved clonal planting material;
- access to technical information about clones and rubber cropping systems; and
- availability of capital for plantation investment, at least for the first three years.

In Jambi and West Kalimantan there is a clear preference of local farmers for perennial crops, compared to rice, upland (*ladang*) or irrigated (*sawah*), particularly in terms of labour productivity (Figure 2). There is also a significant difference in terms of yields and incomes for rubber systems between these two provinces (Figure 3). In West Kalimantan, jungle rubber trees are quite old and produce less than those in Jambi. For the first smallholder plots planted with clones through the SRAP projects, the selected clone was GT1 that suffered from a leaf disease (*Colletotricum*) that reduces the average production level from 1600 kg/ha to 1000-1300 kg/ha. The project plantations established after 1990, were planted with an adapted clone (PB 260) that should perform far better.

Figure 2. Comparison of labour productivity in Jambi and West Kalimantan, 7/97.

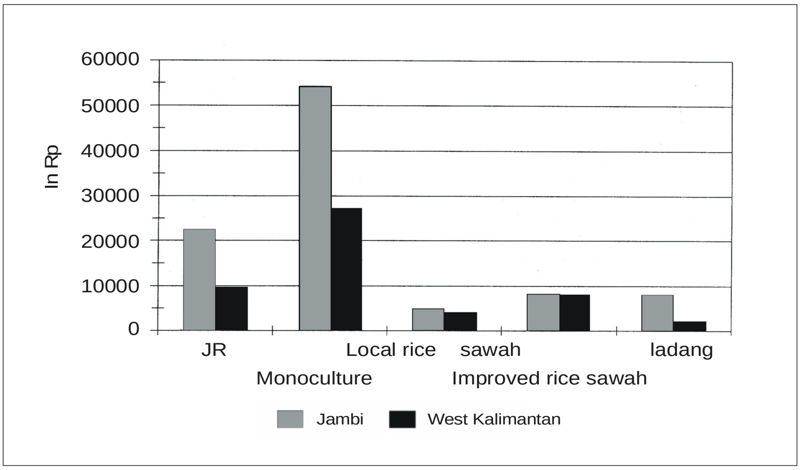
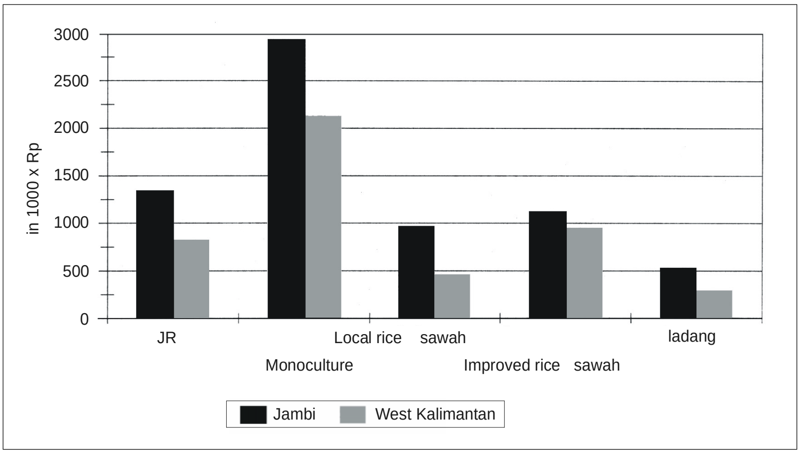
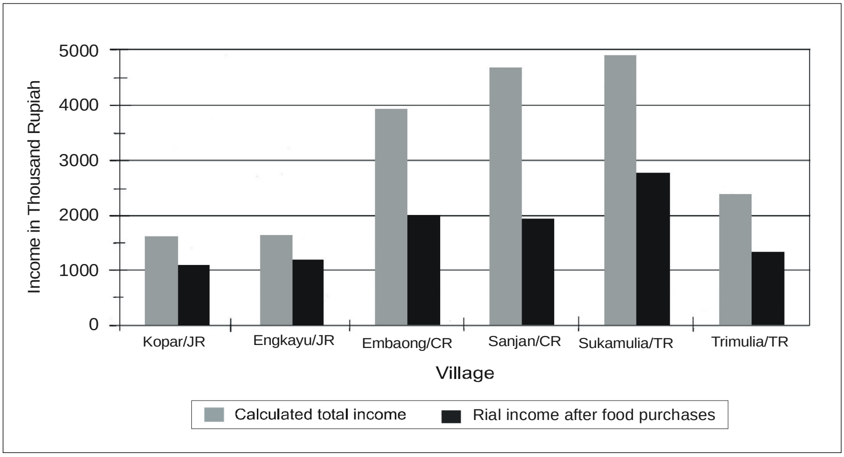


Figure 3. Comparison of income/ha in different cropping systems in Jambi and West Kalimantan, 7/97.



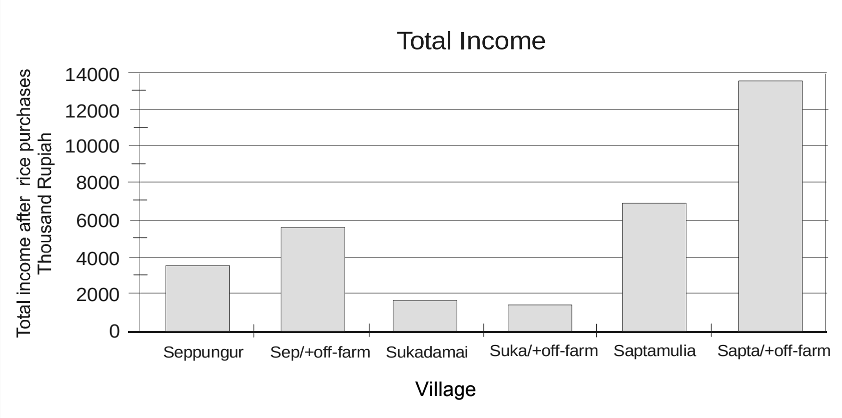
In West Kalimantan, farmers using clones (Embaong, Sanjan), receive three times the income of those with jungle rubber (a similar trend was found in Jambi in the villages of Saptamulia), enabling them to invest in monocultures or RAS (Figures 4 and 5). The annual income of farmers relying on jungle rubber in Jambi can still be sufficient to enable a small investment, while it seems out of reach for the same type of farmers in West Kalimantan. Off-farm activity also provides a large part of the total income for some farmers (25-75%) that can be re-invested in RAS (see Annex 1).

Figure 4. Farm income in West Kalimantan, 7/97.
Total calculated income & real income.



JR = Jungle rubber; CR = Clonal rubber.

Figure 5. Farm income in Jambi, 7/97.



The costs of establishment for RAS over the first three years vary with the individual systems (Table 1). In the case of RAS 1, the closest to jungle rubber, these costs are mainly in the first year. They are relatively small and achievable for most farmers for a step-by-step replanting, such as 0.25 or 0.5 ha per year.

Table 1. Cost of establishment of RAS per ha (x 1000 Rp) for the first 3 years.

RAS type	Year 1	Year 2	Year 3	Total
RAS 1	500	200	200	900
RAS 2	850	400	300	1 500
RAS 3	850	150	150	1 150

Note: Cost of intercrop inputs are included for RAS 2 and 3.

Farmers with clonal rubber plots (generally in monocultures) seem to be able to afford to invest in new RAS plantations on a step-by-step approach. This also appears to be the case for farmers relying on jungle rubber in Jambi, on a smaller scale, but not for those living in West Kalimantan. However, 2-3 ha of improved CAF would provide a sufficient household income, as productivity is similar to that of monocultures. If taking into account the 'long-term sustainability of farms', and the amount of additional land necessary for a second generation, the real area required per farm might be 6-8 ha per family. The increased income achieved through higher productivity and the improved returns to labour from CAF will limit land requirements per family, allowing a higher population density and better land allocation at the community level.

Conclusions and Discussion

Rubber productivity and biodiversity conservation: RAS as a promising system

Conserving biodiversity within cropping systems is not a new concept. It has been practised in traditional CAF all over Indonesia. However, the new approach of SRAP was the integration of high-yielding varieties into traditional management systems, considering agroforestry systems as real agronomic practices. This approach aims to maximise both yields and returns to labour. Biodiversity through spontaneous secondary regrowth is an incidental result of this system, but the farmers' ability to select economically valuable biodiversity is being recognised and supported. This has been previously overlooked by agriculturalists when dismissing traditional jungle rubber as a source of biodiversity.

RAS 1 is likely to exhibit the same type of natural vegetation in the inter-row as that of jungle rubber. In RAS 2 and 3, the expected plant richness is limited to the planted tree crop (i.e., 550 rubber tress and 250 associated fruit and timber trees per ha in RAS 2, or to a very limited poor secondary vegetation in the specific case of RAS 3 in *Imperata* grasslands. Gardens intended for future production usually receive regular weeding during the immature period as well as selective cutting of vegetation to favour the growth of crop trees. This approach has been further developed through SRAP with the introduction of innovations such as line planting and use of round-up herbicide in the first two years to control *Imperata* along the rubber lines only. After cleaning measures are stopped because weeds no longer pose a threat to rubber growth, plant diversity increases over time to reach that of secondary vegetation levels in old rubber gardens. It is expected that RAS 1 will show the same pattern of plant diversity dynamics as that observed in traditional rubber agroforests.

Rubber agroforests certainly cannot preserve all forest biodiversity, especially that of primary forests. RAS offer a refugium for part of the forest biodiversity as a complement to existing conservation areas. However, old rubber gardens, which have not been cleaned for several years, allow conservation of a good part of animal and plant diversity (de Jong 1997; Michon and de Foresta 1997, 1999). An improved RAS, such as those trialled in SRAP, is not cleaned regularly except along rubber lines to preserve access to trees for tapping. Therefore there is no constraint on biodiversity evolution in either case. On the other hand, rubber agroforestry systems have a different future after the productive life of rubber has ended; evolution from rubber-based CAF to *tembawang* and later to old secondary forests, or slashed and burned again for establishment of a new RAS. In the latter case, which is probably the most common, the system is clearly disruptive with an initial phase of biodiversity destruction and reconstruction. However, as all fields are not slashed at the same time, it does not seem to be a major problem, at least at a regional level. The potential land area to be converted from old traditional rubber agroforests into RAS covers at least 800 000 ha in Sumatra and probably as much as 150 000 ha in West Kalimantan. RAS are able to offer a favourable net present value of production and incremental benefit compared to that of jungle rubber.

CAF and the problem of official recognition

Complex agroforestry systems using clonal rubber are potential alternatives to oil palm or rubber monocultures provided they are accepted and promoted as cropping systems by governments as well as research and development agencies. In the last decades, the government policy promoted monoculture systems using costly technology packages on extensive areas. Adoption at the national level has been relatively low outside projects because the intensity of extension and timely provision of inputs required for establishment could not always be implemented in the field (Barlow and Tomich 1991). High prices of improved planting material and other inputs, while credit facilities are still inadequate, hamper the spread of improved varieties outside government programmes (Barlow and Jayasurija 1986; Gouyon *et al.* 1993).

The lack of support for jungle rubber by the national institutions can be also linked to the government policy of controlling production through the establishment of government-supervised units or the support of commercial plantations (Dove 1993a). As a result, until the 1980s, government support for tree crop development mainly focused on the estate sector. Although smallholders dominated rubber production, only 11% participated in government programmes to improve productivity (Penot 1995).

In introducing clonal material to improve productivity, SRAP promotes cost-effective and easy-to-establish RAS within an integrated traditional management system. Extensive monoculture is not suitable for smallholder tree crops, where susceptibility to diseases and sensitivity to poor management becomes important. In 1995 a change in official policy seems to indicate recognition of alternatives, with the Tree Crop Service (Dinas Perkebunan or DISBUN) emphasising annual intercropping in rubber monocultures. The integration of food plants as intercrops during the immature period of rubber is a traditional practice that can be easily blended with improved rubber varieties. There are no significant labour constraints facing the farmer as it is a traditional practice.

Access by farmers to improved cropping technologies as well as a related recognition of land and tree tenure have been the critical issues for RAS and other CAF. These constraints, however, are institutional or political rather than practical. At the farm level, capital is not the main constraint for improved but less expensive systems, such as RAS trialled within the SRAP project (Penot *et al.* in press). Land is only a constraint in transmigration areas.

Agroforestry practices are also considered as labour-saving agricultural practices and as the best anti-*Imperata cylindrica* strategy in some cases. In an environment of decreasing land availability for local agricultural expansion, improved RAS also reduce the amount of land required per family by supplying a variety of marketable as well as subsistence crops within a single system. RAS offer income diversification and household needs which otherwise would have to be sought elsewhere, thereby contributing to local economic sustainability.

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Annex 1

Total Income of Farms

1. Jambi

Total farm income (x 1000 Rp/year) including incomes from agricultural activities (type A) and incomes from off-farm activities (type B). (Sukadamai: recent transmigration site; Saptamulia: old transmigration site).

	Types	# of farms	Income (Agriculture)	*% of total*	Income (Off-farm activities)	*% of total*	Total incomes
Sepunggur	*A*	19	3 546	*100.0*	0		3 546
Traditional	*B*	10	2 938	*52.0*	2712	*48.0*	5 650
Sukadamai	*A*	1	1 660	*100.0*	0		1 660
(recent)	*B*	9	366	*24.9*	1101	*75.1*	1 467
Saptamulia	*A*	4	6 954	*100.0*	0		6 954
(old)	*B*	3	10 026	*73.4*	3640	*26.6*	13 666

Total farm incomes, average per village (x 1000 Rp/year).

	Sepunggur	Sukadamai Young Plantation	Saptamulia Mature plantation
Total farm incomes (average)	4325	1679	9831

2. West Kalimantan

Total farm income: Calculated farm income is the sum of incomes from all cropping systems.

Village Net income	Kopar	Engkayu	Embaong	Sanjan	Sukamulia	Trimulia
Calculated total income	1613	1627	3940	4701	4914	2414
Real cash flow	1058	1094	3553	4127	4231	1970
Income after food purchases	1079	1173	2007	1954	2783	1345
Main source of income	Jungle rubber	Jungle rubber	Clonal rubber	Clonal rubber	Off farm	Off farm

4. The Impact of Management Practices on Species Richness within Productive Rubber Agroforests of Indonesia

Silvia Werner[1]

Abstract

With the growth in the deforestation rate in Indonesia over the last decades, jungle rubber is likely to be the main reservoir of lowland forest biodiversity in the plains of Sumatra and probably West Kalimantan. Biodiversity and structure of these complex agroforestry systems are similar to old secondary forests. The impact of selective cleaning of rubber gardens on biodiversity and composition is assessed by comparison with undisturbed secondary vegetation. Results show that regularly cleaned plots have a distinctly lower plant richness than those not cleaned. The presence of rubber in itself has no impact on plant diversity and composition. The main conclusion therefore is that management intensity determines biodiversity and species composition of complex agroforestry systems. Although traditional complex agroforestry systems in many cases could not compete with modern monocultures, current research results show that species richness can be combined with higher revenues through the use of improved varieties.

Introduction

Rubber Agroforestry Systems (RAS) have been extensively studied as one of the major cash-oriented strategies in Indonesia (Barlow and Muharminto 1982; Kheowvongsri 1990; de Foresta 1992; Dove 1993; Gouyon *et al.* 1993; Werner 1993). Jungle rubber, or rubber agroforests, is estimated to cover more than 2.5 million ha in Indonesia and provide 80% of the rubber production of the country (Penot this volume). With a continuing decline in natural forests, these productive systems are considered as potential reservoirs for biodiversity conservation (de Foresta 1992; Michon and de Foresta 1997, 1999). During the establishment of a rubber garden, cleaning occurs at certain intervals until the trees are mature and production commences. At this time, cleaning will be limited to keeping the tapping routes and the mature rubber trees themselves free of lianas and other vegetation disturbing the harvesting process. This is when the rubber garden is about 10 years old and when plant diversity starts to increase rapidly. Among this spontaneous vegetation, many plants are used by farmers for various purposes (fruits, medicinal, handicraft; e.g., Denevan and Padoch 1987; Unruh 1988).

The aim of this paper is to present the main results of a study comparing the botanical composition of rubber gardens of different ages with natural secondary vegetation of

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similar ages. The potential of rubber gardens to be a reservoir of biodiversity is also discussed.

Study Area and Methods

Study site and definition of vegetation types

The study was carried out in three Sumatran villages, two in Jambi province (Pemunyian and Dusun Birun) and one in West Sumatra province (Lubuk Malakko). This allowed comparison of the impacts of different management systems on vegetation structure and plant diversity. In each village inventories were made in a total of 14 to 16 different vegetation plots of ages from one to more than 60 years. All villages are approximately 350 m a.s.l. and located in the lowland boundary zone of the Kerinci Seblat National Park. Although located only 150-300 km apart from each other, there were marked differences in floristic composition between villages.

For the purpose of this study, the following four different vegetation types were distinguished:

- natural secondary vegetation;
- unmanaged secondary vegetation containing rubber;
- regularly cleaned, young rubber gardens; and
- uncleaned, mature rubber gardens.

Vegetation age was determined through information collected from the villagers with a good knowledge of the history of landscape use. However, for plots older than 10 years, the age was estimated. In some cases, the exact age could be determined because people could still remember particular outstanding events, like a long drought period. In general, unmanaged secondary vegetation older than 20 years was seldom found, because vegetation of that age has usually been cut again for setting new upland fields. Four main age classes were defined:

- very young regrowth (1-2 years);
- young secondary regrowth (3-7 years);
- medium-aged secondary forest (8-19 years); and
- old secondary forest (≥ 20 years).

Methods

In vegetation sites of at least 20 years old, surveys were carried out in plots of 1000 m². In 10 and 15 year old sites, plots of 200 m² and 400 m² respectively were considered sufficient because of the higher vegetation density. This range of plot size was formerly used by authors for the analysis of old-growth tropical complex agroforestry (Küchler and Zonneveld 1988; Gouyon *et al*. 1993). Diameter and height of all trees with dbh ≥ 10 cm were measured, whereas plants between 1 and 10 cm dbh were recorded in 10 sub-plots representing 20% of the total plot area. The same was done for trees of dbh < 1 cm at a 10% sampling rate within the plots.

Because young fallow vegetation up to the age of about 7 years showed very high density, transects of 10-70 m long and 2 m wide were used in preference to plots. All plants were recorded and their respective cover percentages were recorded following the Braun-Blanquet method (Kreeb 1983).

Forest Regrowth Dynamics in the Study Area

Very young secondary regrowth (1-2 years)

The early stage of secondary vegetation is the most dynamic one, characterised by quick changes and major developments. Shrubs, herbs and grasses are the dominant plant forms (Table 1). These plants have generally light and wind dispersible seeds, allowing them to capture exposed sites such as upland fields. The tree community, representing only about half of all species, is mainly characterised by several fast-growing pioneer species such as: *Macaranga* spp. (*Euphorbiaceae*), *Trema orientalis* (*Ulmaceae*), *Commersonia bartrama* (*Sterculiaceae*), *Mallotus* spp. (*Euphorbiaceae*), *Homalanthus populneus* (*Euphorbiaceae*), *Endospermum diadenum* (*Euphorbiaceae*), *Breynia* sp. (*Euphorbiaceae*) and *Chisocheton erythrocarpus* (*Meliaceae*). Less frequent species include several *Saurauia* species (*Actinidiaceae*), *Aporusa octandra* (*Euphorbiaceae*), several *Leea* species (*Leeaceae*), *Mimosa* sp. (*Mimosaceae*) and *Dysoxylum* spp. (*Meliaceae*). Non-pioneer species are still restricted to some isolated trees not felled during the opening of the field. Vegetation height of one-year old fallow varies from 1-3 m in one-year old secondary vegetation to 4 m in two-year old vegetation. Similar growth rates have also been reported from other regions. Young secondary vegetation in East Kalimantan grew an average of 82 cm in height and 0.5 cm in diameter per year (Riswan and Abdulhadi 1992). In Amazonia, very young fallow was about 2-3 m tall (Uhl 1987).

Young secondary regrowth (3-7 years)

This early successional process is typical for young fallow vegetation and has been described by several authors (e.g. Seavoy 1973; Ewel 1980; Uhl 1987; Riswan and Abdulhadi 1992). Species richness rose by about one-third to an average of 41 different plants compared to very young secondary regrowth (Table 1). Whereas during the first two years the vegetation was mainly dominated by herbaceous plants, after three years the trees develop and start to shade out the non-woody vegetation. The high abundance of herbs and shrubs declines while lianas and ferns are more abundant than in the previous stage (Table 1). For *Eupatorium odoratum*, a weedy coloniser from Latin America, Ramakrishnan (1992) reported maximum populations in 3 year old fallow and a sharp decline after a fallow age of five years. Typically, herbaceous vegetation becomes less vigorous in growth with declining reproductive potential in fallows beyond a maximum of 5-6 years.

Vegetation height is 3-6 m at three years and reaches 6-9 m at 7 years (Table 1). Similar heights and average dbh of 5-10 cm have been reported by Laumonier (1997) for secondary vegetation of the same age in East Kalimantan. Uhl (1987) referred to a height of 12 m in Amazonia for this age, whereas Seavoy (1973) found 2-5 year old vegetation reaching 5 to 12 m in West Kalimantan.

The plant community at this stage is totally dominated by several pioneer trees (*Anisophyllea disticha, Artocarpus* spp., *Carallia* spp., *Eugenia* spp., *Ficus* spp., *Macaranga* spp.) and the number of plant species is rising. This typical, pioneer tree-dominated composition was also observed by Djailany (1987), who studied a 7 year

Table 1. Biodiversity and structural composition of the different vegetation types in the village land of Dusun Birun, Kec. Sungai Manau, Kab. Sarolangun-Bangko, Jambi

age	plot size	plot type[a]	geo.pos.[b]	utilisation	av. dbh	veg. height	tree species		herbs & shrubs[c]		lianas		ferns		grasses		palms		total species
	m²				(cm)	(m)	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.
1	10	Transect	ls	fallow	1	1	12	*31.5*	12	*31.5*	9	*23.7*	2	*5.3*	3	*7.9*	-	-	38
2	20	Transect	s	fallow (r) [d]	2	2-3	17	*47.2*	7	*19.4*	6	*16.7*	2	*5.6*	4	*11.1*	-	-	36
3	30	Transect	f	rubber*	7	6	6	*37.5*	3	*18.8*	3	*18.8*	2	*12.5*	2	*12.5*	-	-	16
3	30	Transect	s	fallow	2.5	3-4	14	*35.0*	7	*17.5*	10	*25.0*	4	*10.0*	4	*10.0*	1	*2.5*	40
5	50	Transect	f	fallow	5-6	6-8	15	*57.7*	3	*11.5*	3	*11.5*	2	*7.7*	3	*11.5*	-	-	26
7	70	Transect	ls	rubber*	10	8	15	*46.9*	5	*15.6*	6	*18.8*	4	*12.5*	2	*6.3*	-	-	32
7	70	Transect	ls	fallow	5	6	29	*72.5*	3	*7.5*	3	*7.5*	3	*7.5*	1	*2.5*	1	*2.5*	40
7	70	Transect	s	fallow	8-10	6-7	28	*59.6*	8	*17.0*	6	*12.8*	2	*4.3*	2	*4.3*	1	*2.1*	47
10	200	Plot	s/t	fallow (r)	5	8	39	*73.6*	4	*7.6*	5	*9.4*	3	*5.7*	2	*3.8*	-	-	53
15	200	Plot	ls	rubber **	25	10-15	24	*49.0*	9	*18.4*	9	*18.4*	5	*10.2*	2	*4.1*	-	-	49
20	1000	Plot	s	rubber & fruits	40-50	7-15	25	*51.0*	11	*22.5*	3	*6.1*	6	*12.2*	4	*8.2*	-	-	49
20	1000	Plot	s	fallow (r)	25	30	47	*71.2*	5	*7.6*	10	*15.2*	1	*1.5*	1	*1.5*	2	*3.0*	66
25	1000	Plot	s	rubber **	30-40	25-30	25	*62.5*	5	*12.5*	4	*10.0*	3	*7.5*	3	*7.5*	-	-	40
33	1000	Plot	s	fallow	20	20-30	36	*66.7*	4	*7.4*	8	*14.8*	5	*9.3*	1	*1.9*	-	-	54
42	1000	Plot	s	fallow	30	30	36	*67.9*	3	*5.7*	7	*13.2*	5	*9.4*	-	-	2	*3.8*	53
50	1000	Plot	s	rubber ***	30	30	36	*59.0*	8	*13.1*	12	*19.7*	5	*8.2*	2	*3.3*	-	-	61

[a] t = vegetation transect, p = vegetation plot

[b] Geomorphologic position: f = flat/level area, ls = lower slope, s= slope, t = hilltop

[c] Incl. bamboo and Pandanus species

[d] Some scattered rubber trees

* Rubber is not yet productive. Cleared regularly of weeds and secondary regrowth

** Cleared regularly of weeds and secondary regrowth

*** No longer productive (no tapping for one or two years) old secondary stand in the same area. This pioneer-tree dominated of secondary vegetation development lasts until the age of five to seven years. After that age, a distinct change is taking place. Differences in recovery speed and resulting duration of the respective fallow stage is partly due to the impact of soil fertility (Inoue and Lahije 1990). In one of the three research sites, young secondary vegetation was strongly dominated by *Bellucia axinanthera*, a South American pioneer tree. Large, localised formations of this Melastomataceae in eastern Central Sumatra, at the feet of the Barisan mountain range, were also mentioned by Laumonier (1997).

Medium-aged secondary forest (8-19 years)

In this stage, while total species numbers on average have not yet risen dramatically, there is a clear shift in life form dominance towards trees (Table 1). The diversity of non-woody species remains more or less constant, with a rise in species richness mainly taking place among trees (Table 1). Typical tree species are: *Koilodepas glanduligerum* (*Euphorbiaceae*), *Macaranga hullettii* (*Euphorbiaceae*), *Dialium* sp. (*Leguminosae*), *Millettia atropurpurea* (*Leguminosae*), *Pongamia* sp. (*Leguminosae*), *Aglaia leucophylla* (*Meliaceae*), *Ochanostachys amentacea* (*Olacaceae*), *Eurycoma longifolia* (*Simaroubaceae*) and *Gironniera hirta* (*Ulmaceae*). Dominant genera are *Durio* (*Bombaceae*), *Elaeocarpus* (*Elaeocarpaceae*), *Aporusa* (*Euphorbiaceae*), *Baccaurea* (*Euphorbiaceae*), *Pternandra* (*Melastomaceae*), *Artocarpus* (*Moraceae*) and *Streblus* (*Moraceae*). Other typical families in this stage are *Anacardiaceae, Annonaceae, Clusiaceae, Fagaceae, Lauraceae, Myristicaceae, Myrtaceae, Rhizophoraceae, Rubiaceae, Sapindaceae and Sapotaceae*. Mean height in 7 year old secondary vegetation reaches 7-9 m and 15-20 m at 19 years (Table 1). Secondary vegetation already shows a significant canopy closure and a high proportion of larger trees with dbh ≥ 10 cm.

Old secondary forest (20 years and older)

When the secondary vegetation has reached at least 20 years, its structure becomes more complex and the canopy can be 35 m in height (Table 1). In a 35 year old secondary forest in East Kalimantan, Riswan and Abdulhadi (1992) found secondary forest trees still dominant, but almost all early colonisers such as *Macaranga* had disappeared. Tree species composition is typical of medium-aged to old secondary vegetation. These species are *Dillenia* sp. (*Dilleniaceae*), *Archidendron* sp. (*Leguminosae*) as well as members of the *Myrsinaceae* and *Rutaceae* families. Vegetation height in 20 year old secondary vegetation and rubber gardens is between 20 and 30 m, with emergent trees up to 35 m. The oldest secondary forests investigated in this study were 60-65 year old rubber gardens with an average height of 25-35 m, but with some emergent species as tall as 55 m.

Impact of Rubber Garden Management on Plant Species Diversity

There are many other factors influencing the composition of secondary vegetation besides vegetation age. The most obvious and the one man has most influence on is how the garden is managed. Management practices, which mainly consist of cleaning undesirable species, have an important impact on species composition during the dynamics of rubber gardens. However, there are also other biophysical and human factors influencing the flora. One is the cultivation history of a site, which determines the composition of the soil seed bank. Frequent burning destroys the seeds of species sensitive to fire. Short fallow cycles prevent the regeneration of those species with reproduction cycles exceeding those of the fallow length (Egler 1954; De Rouw 1991). Plots that have been cultivated only a few times since they have been opened from primary forest have a higher biodiversity and a larger number of primary forest species than plots that have been cultivated frequently. Soil fertility, which may vary with geomorphologic position, also influences vegetation composition (Kellman 1980; Werner 1993). All these factors contribute to the variation in vegetation composition and diversity. Physical and chemical properties of the soil as well as geomorphological position are important variables, under which different species grow at different rates. Moreover as Ewel (1980) noted 'Any one or more of a number of species might capture a given site, and the outcome is more likely to be determined by timing, location and dispersal than by site differences.'

Based on differences in management practices, apart from mainly unmanaged secondary vegetation, three types of rubber gardens could be observed. Notwithstanding the magnitude of factors influencing fallow composition, there was a selective occurrence of several species related to the management regime present. As the structure and composition of lowland secondary vegetation has already been described, the following section concentrates on the differences caused by the variations in management intensities.

Regularly cleaned, rubber gardens

Differentiation between rubber gardens and undisturbed secondary growth was most obvious where rubber gardens were still cleaned regularly. In young, cleaned rubber gardens of Dusun Birun, spontaneous pioneer species such as *Macaranga, Elaeocarpus palembanicus*, *Aporusa octandra* and *Ficus grossularioides*, which were dominant in natural secondary forests plots, were totally absent.

Calophyllum canum, *Baccaurea sumatrana*, *Koilodepas glanduligerum*, *Lithocarpus urceolaris*, *Casearia* sp., *Millettia atropurpurea*, *Pternandra* sp. and *Artocarpus* spp., all species common in medium-to-old secondary vegetation, were not found in cleaned 15 and 20 year old rubber gardens. They also occurred more rarely in older rubber gardens that were no longer cleaned than in unmanaged old fallow of Dusun Birun. Other species had a lower frequency in the cleaned rubber gardens, or occurred with a only few individuals at some sites.

At Dusun Birun a 3 year old, regularly cleaned rubber garden had a total of 16 plant species including 6 species of tree. Secondary vegetation of the same age had almost twice the number of species – 40 species, including 10 tree species (Table 1). In 7 year old vegetation, the same feature was observed. The cleaned garden included 32 species, whereas the two fallow sites contained 40 and 47 species (Table 1). The differences were more apparent for tree species diversity. In the cleaned garden only 15 tree species were present, whereas in the secondary vegetation plots 29 and 28 tree species could be found (Table 1).

Old rubber gardens, 20 and 25 years old, which had been cleaned only occasionally, exhibited a much lower species richness, especially of tree species, than undisturbed secondary vegetation of a similar age (Table 1).

This kind of rubber garden should no longer be classified as 'enriched fallow' (Irvine 1989), because management has had large impact on vegetation composition. In plots where secondary regrowth was slashed every year, succession was 'frozen' at an early stage. This becomes particularly obvious when looking at the high number of herbs and shrubs present in medium-aged rubber gardens as compared to secondary forest (Table 2).

In rubber gardens up to 25 years old and regularly cleaned, pioneer species and species of early succession were still abundant, whereas in unmanaged vegetation of the same age, they were already strongly decreasing. Grasses, herbs and shrubs especially were not shaded out because of the lack of undergrowth and a closed tree canopy. Some young rubber gardens had a dense undergrowth of vigorously growing ferns that had been favoured by the altered succession process.

Although less rich than secondary vegetation, these regularly cleaned gardens still harbour a considerable amount of biodiversity, setting them distinctly apart from rubber monocultures. During cleaning farmers do not cut a large number of useful plants and spare many, which are not particularly useful but neither are disturbing. These species include spontaneous fruit trees, medicinal plants, valuable timber species and other plants with special uses (e.g., resin-producing trees or bird-dispersed coffee seedlings).

Medium-aged and old rubber gardens

In Lubuk Malakko, the comparison of two old rubber gardens (20 years old) with a different history showed the impact of human management on plant species richness (Table 3). Garden A was a well and intensively managed rubber garden whereas garden B was opened from primary forest, planted with rubber, but never cleaned. Plot B had a total of 93 species (67 trees) whereas plot A had only 48 species including 28 tree species (Table 3). In this case, the difference in frequency of cultivation also influenced species richness. This feature is related to the 'all-importance of the pre-existing seed bank' (De Rouw 1991: 222), which is strongly linked to the cultural history of the site.

Another rubber garden in the same village also demonstrated the influence of management practices. The garden was about 65 years old, partly located on a hill (plot C) and partly on lowland (Plot D, Table 3). The upland plot included 73 plant species (39 trees) whereas the lowland plot had only 40 species (20 trees, Table 3). The undergrowth of the lowland plot, was dominated by coffee seedlings – about 1000 saplings/100 m^2. Although the coffee was no longer managed, this section had been cleaned longer than the uphill rubber garden with no coffee. After being left fallow, the high abundance of coffee undergrowth might also have prevented tree regrowth.

The rubber gardens in Jambi are a good example of increased plant species richness after cleaning has ended (Table 2). Both the 20 and 60 year old rubber gardens showed no signs of recent cleaning measures. It was found that site plant diversity steadily increased with age, both when comparing rubber gardens to each other as well as to undisturbed fallow vegetation (Table 2).

Table 2. Biodiversity and structural composition of the different vegetation types of the village land of Pemunyian, Kec. Tanah Tumbuh, Kab. Bungo Tebo, Jambi.

age	plot size	geo. pos.[a]	utilisation	av. DBH	veg. height	tree species		herbs & shrubs[b]		lianas		ferns		grasses		palms (incl. rattan)		total species
	(m^2)			(cm)	(m)	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.
15	400	f	fallow	25	15	22	81.5	-	-	2	7.4	1	3.7	2	7.4	-	-	27
15/20	1000	t-s	fallow	25	25	36	10.6	2	3.9	9	17.6	1	2.0	1	2.0	2	3.9	51
20	1000	f	rubber	25	25	41	74.5	2	3.6	8	14.5	2	3.6	1	1.8	1	1.8	55
20	1000	f-ls	rubber	30	20	31	64.6	5	10.4	7	14.6	3	6.2	-	-	2	4.2	48
36	1000	t-s	fallow	30	35	39	69.6	2	3.6	7	12.5	6	10.7	-	-	2	3.6	56
60	1000	s	rubber	35	25	41	67.2	4	6.6	8	13.1	4	6.6	1	1.6	3	4.9	61
60	1000	s	rubber	40	35	32	64.0	4	8.0	9	18.0	3	6.0	-	-	2	4.0	50
60	1000	f	rubber	30	30	47	64.4	6	8.2	15	20.5	1	1.4	1	1.4	3	4.1	73

a. Geomorphologic position: f = flat/level area, ls = lower slope, s= slope, t = hilltop.

b. Bamboo and pandanus.

Table 3. Biodiversity and structural composition of the different vegetation types of the village land of Lubuk Malakko, Kec. Sangir, Kab. Solok, West Sumatra.

age	plot size	geo. pos.[a]	utilisation	average DBH	veg. height	tree species		herbs & shrubs		lianas		ferns		grasses		palms		total species
	(m^2)/plot			(cm)	(m)	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.
20	1000 / A	ls	rubber	25-30	20	28	58.3	9	18.7	5	10.4	3	6.2	3	6.2	-	-	48
20	1000 / B	t/s	fallow (r)[b]	20-25	20-25	67	72.0	2	2.2	13	14.0	6	6.5	2	2.2	3	1.2	93
65	1000 / C	ls	rubber (fruits, coffee)[c]	35-40	25-35	20	50.0	5	12.5	7	17.5	6	15.0	2	5.0	-	-	40
65	1000 / D	t/s	rubber (fruits)	25-35	20-30	39	53.4	5	6.8	16	21.9	7	9.6	4	5.5	2	2.7	73

a. Geomorphologic position: ls = lower slope, s= slope, t = hilltop.

b. This site has been used only once since primary forest has been cut down. Some scattered rubber trees.

c. Because of low productivity due to the age of the garden, rubber has not been tapped for about one year, whereas coffee is not cared for anymore since a long time. However, the coffee still bears a few fruits that are collected by children.

Uncleaned, mature rubber gardens

Undergrowth, lianas and unwanted spontaneous tree species are usually cut down only in young rubber gardens. The age at which farmers stop slashing depends a lot on the proximity of the garden to the village and the amount of family labour available. Household interviews also showed that, on average, the gardens are cleaned regularly up to an age of 5.5 years. Gardens close to the village are cleaned for longer; about 10 or in certain plots close to the village sometimes 20 years, distant ones more seldom. In mature rubber agroforestry systems (RAS), secondary growth usually is no longer considered a danger to rubber productivity. Within a few years, succession catches up. Plant composition and structure of old rubber gardens and old fallow therefore become very similar (see Annex 1; cf. Gouyon *et al.* 1993). As time is needed for establishment after cleaning has ceased, in some cases the abundance of certain species is lower than in unmanaged old fallow. For species where only several individuals have been available in the soil seed bank at the end of the rice cultivation period, regular cleaning in the early years of the garden might have made the re-establishment of the plant impossible. The same is true for species that cannot resprout from stumps after they have been slashed, and may also be absent in old rubber gardens.

Unmanaged secondary vegetation containing rubber

This type of vegetation can barely be defined as a rubber garden because, apart from the very few scattered rubber trees, there is no significant difference to natural secondary vegetation. The 'gardens' have not been managed since the trees were planted and, in many cases, mature rubber is not tapped, especially if the plots are far from the village. Land ownership claims are frequently the reason for rubber planting in these cases rather than the intention to establish a rubber garden (Dove 1993; Gouyon *et al*. 1993). Penot (1997) also observed this kind of process in areas where land had been allocated to large oil palm plantations, as in the Sanggau and Sintang areas of West Kalimantan and the Muara Bungo area of Jambi. Immature gardens are also abandoned due to failures of rubber growth.

Conclusions and Discussion

This study demonstrated that management practices in rubber gardens have an important impact on both plant species and richness if compared to that of natural secondary forest regrowth. Those management practices also have an impact on the forest structure. Because rubber is a fast-growing pioneer tree, young, regularly cleaned rubber gardens are on average distinctly taller and thicker than unmanaged secondary vegetation. Between the ages of 7 and 10 years, however, this situation changes and secondary vegetation is taller. This is probably due to tall trees being cut down within rubber gardens to prevent shading. Rubber does not grow well under conditions of shade. Rubber gardens always show a higher average diameter than secondary forests because rubber trees have a relative high diameter as compared to trees of the same height.

The most obvious difference between managed rubber gardens and unmanaged fallow (including the secondary vegetation directly abandoned after rubber planting), however, is in species richness. In general, the biodiversity of rubber gardens is lower than those of unmanaged fallow. Young rubber gardens have only half the number of species than secondary vegetation of the same age, and still less than 1-2 year old fallow. Differences between the abundance of the different life forms are most distinct for tree species, whose species richness is higher for unmanaged vegetation through all stages. As already mentioned, this is different for the non-woody component. Only lianas are more abundant in fallow vegetation, clearly because they too are cut during cleaning interventions. Even for old secondary regrowth the average species diversity of fallow vegetation is about 20% higher than of rubber gardens.

Uncleaned rubber gardens merely experience an enrichment planting which results in the development of a 'secondary vegetation with rubber' (Laumonier *et al.* 1986). Except for the few remaining scattered rubber trees, only slight differences to unmanaged fallow could be observed. After cleaning measures are stopped because weeds pose no further threat to rubber growth, forest species diversity and composition of old rubber gardens develops towards natural secondary vegetation. The longer a garden is left uncleaned, the more biodiversity levels approach those of uncleaned fallow.

A problem in evaluating the impact of regular cleaning on species abundance in rubber gardens as compared to secondary vegetation is the variety of factors, both biophysical and human, influencing the species composition of a given site.

At a time of decreasing primary and unmanaged secondary forest, it is important to study which species may survive under certain management regimes, and which do not tolerate disturbance. This knowledge may be vital for those species sensitive to interventions, because their survival then has to be guaranteed within protected areas. Secondly, we need to assess the abundance of used and potentially useful species within RAS, as well as the economic potential of these gardens beyond their rubber component. Complex agroforestry systems, and in particular highly productive rubber gardens also called rubber agroforestry systems, represent economically and ecologically sustainable cropping systems for smallholders (Penot, this volume). Although rubber agroforests certainly cannot preserve the whole species diversity of secondary and especially primary forests, RAS offer a refugium complementary to existing conservation areas. Improved RAS appear as potential sustainable alternatives for both productivity and biodiversity maintenance.

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5. Silviculture of Productive Secondary Forests in Gabon (Central Africa)

M. Fuhr [1] and M.-A. Delegue[1]

Abstract

The different types of secondary forests are not equally distributed across Africa. In West Africa, most secondary forests are young, corresponding to forest fallows or logged-over residual forests. Secondary successions of these types are generally not favourable either to regeneration of high commercial value species or to conservation of biodiversity. To offset economic and ecological threats the use of Reduced Impact Logging is crucial. In Central Africa, there is less human pressure for cultivation and logging is generally very selective (less than one tree per ha). Secondary succession as described above is fairly limited. Most secondary forests are old forests and generally they result from the very slow colonisation of savannas, to which the present climate is favourable. They cover a large area, and are thought difficult to evaluate. These forests are sometimes rich in 'long-life' pioneer species with high commercial value; *Aucoumea klaineana (Burseraceae)* in Gabon is a well-known example. When they reach maturity these species are unable to find favourable conditions (mainly light) without human intervention. Forest management in stages of succession must have clear objectives and should encourage durability of long-life pioneer species if necessary.

Origin of Secondary Forests in Africa

In West and Central Africa, secondary forests result from paleoclimatic changes and from forest fallows colonising abandoned agricultural lands. Logging is actually very selective and in Central Africa scarcely removes more than one tree per hectare. Such a removal of seeders may become a threat for the logged species.

Transgressive forests

The climatic variations during the late Quaternary period led to successive fragmentations and extensions of the Guinea-Congo rainforest (Maley 1991, 1992, 1996; Schwartz 1992). Two fragmentations have taken place during the last 30 000 years. The first, the major forest regression, occurred about 20 000-15 000 years before present (BP), during a period of global cooling associated with the last ice age. The second fragmentation occurred during the late Holocene period about 4 000-2 000 years BP. The arid climate and cooling might have led to the major forest regression. The second fragmentation can be explained by aridity and by large forest fires.

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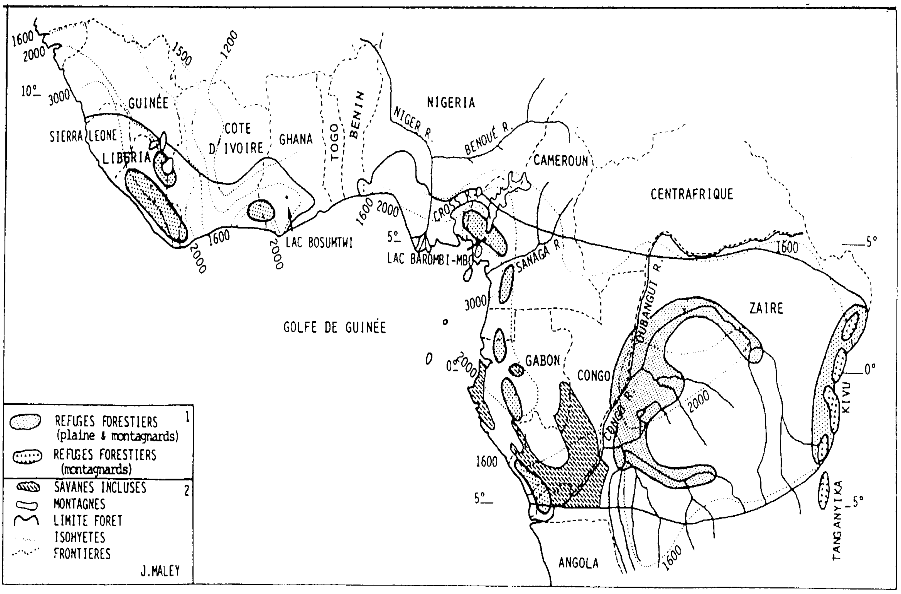
The forest remained in only a few, relatively small and isolated patches called forest refuges. They are characterised by a high biodiversity and a lot of endemic taxa. Although there is some argument about their precise locations (Rietkerk *et al.* 1995), the various studies enable a sketch map of possible forest refuges in Wet Tropical Africa to be drawn (Figure 1). The extension of mountain vegetation to medium and low altitudes is associated with these periods.

Figure 1. Reconstruction of forest refugia during the last major arid phase (c. 18 000 years P) (from Maley 1996).

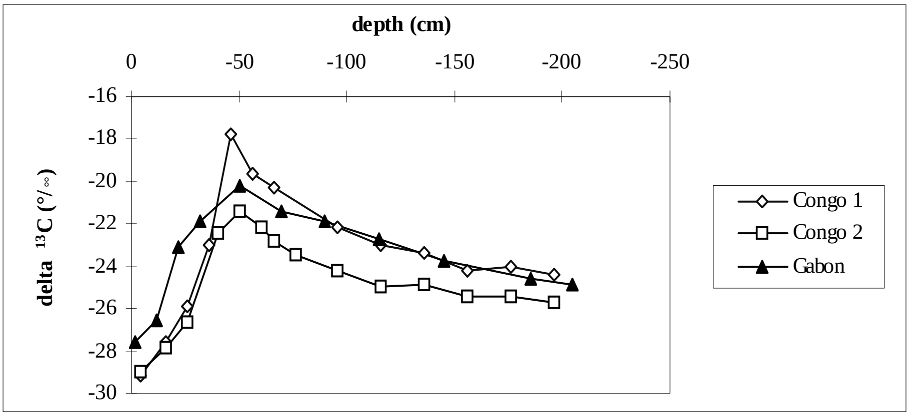


A forest transgression occurred between these two fragmentations in the early and middle Holocene period. The forest cover stretched beyond its present day limits. The Dahomey Gap disappeared, but forest colonisation was not complete, and open areas persisted. Since 2000 years BP, the climate has been wetter and the forest has expanded again over part of the region, but not to the extent reached in the early and middle Holocene period. At present, we are in a forest extension period despite, or thanks to, human activities such as fire, grazing and cultivation (Spichiger and Pamard 1973; Letouzey 1985). During the forest transgressions, semi-deciduous rainforest species (*Celtis* sp., *Triplochiton* sp., *Piptadeniastrum* sp.) and natural secondary species (*Alchornea cordifolia*, *Macaranga* sp.) appeared and tended to replace evergreen rainforest species (*Caesalpiniaceae*).

The forest colonises open areas, which are created or enlarged during previous fragmentations. As a secondary succession occurs, resulting forests are called secondary forests. These large fluctuations of the Guinea-Congolean forest, due to climatic variations, may explain part of the present extension of secondary forests in moist tropical Africa. Some forests are an obvious result of palaeoclimatic savannah recolonisation. For some authors (de Foresta 1990; White *et al.* 1995), open forests with *Marantaceae* and *Zingiberaceae* close to the forest-savannah boundary are a derivative of savannahs that were once closed by forest regeneration.

The secondary origin of the littoral forests, with *Aucoumea klaineana* (okoumé, *Burseraceae*) in Gabon or *Lophira alata* in Cameroon, is more evident. Pure okoumé stands can either be settled in abandoned cleared areas or in palaeoclimatic-enclosed savannas (Schwartz 1991; Delegue, unpublished data). Delta ^{13}C profiles found in okoumé coastal forests in Gabon and in Congo (Figure 2) are very similar. In Congo, these results were derived from palynological data, macroremain determinations and radio carbon dating. Thus we were able to reconstruct the history of the vegetation; the data indicate that forest covered almost all the littoral during the early Holocene period until 3000 BP. A savanna period extended from about 3000 to 2500-2000 BP, followed by a new forest extension.

Figure 2. Delta ^{13}C profiles from Okoume coastal forests in Gabon and in Congo (modified from Schwartz, pers. Comm.).

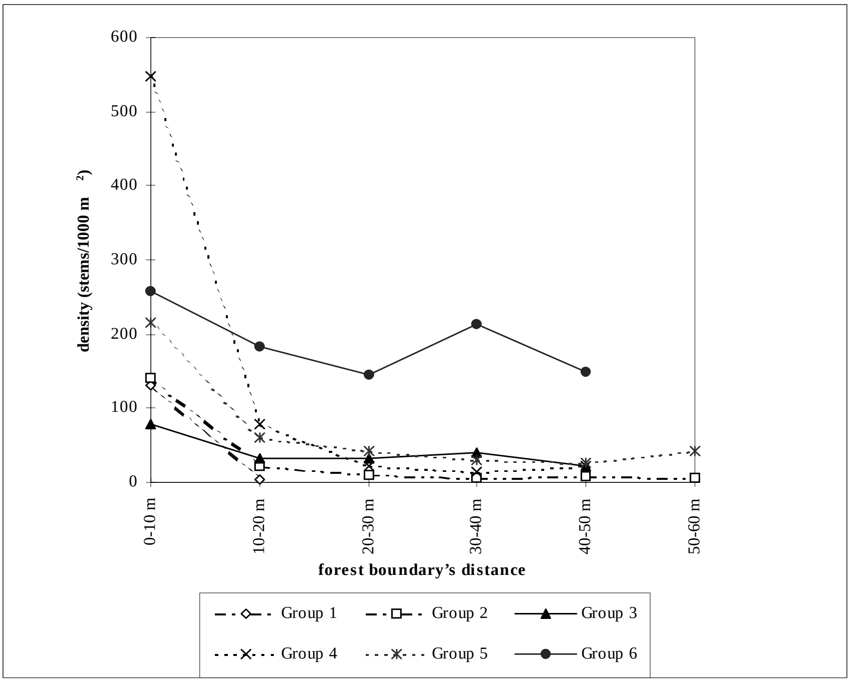


The consequences of the main climatic influence on vegetation cover include large areas covered with more or less old secondary forests which are often rich in commercial species. Human interventions are limited when climatic changes are a general trend, but as these forests have an economic value, foresters hoped to enlarge them at the expense of the savannahs. The slowness of the transgression diminished this objective. The present rate of forest encroachment over savannahs was measured in the Congolese Mayombe, where it ranges from 20-50 m per century (Schwartz *et al.* 1996). In the coastal region of Gabon, after seven years of measurements, the forest extension is noticeable only where fire is excluded. The establishment of tree plants, largely dominated by the okoumé in fire-protected savannas (Figure 3), occurs either up to 10 m in the so called ‘palaeoclimatic’ savannahs (groups 1, 2, 4 and 5), or up to 40-50 m in the case of ‘anthropic’ savannah (groups 3 and 6).

Forest fallows

For a long time, a very large agricultural population has inhabited Wet Tropical Africa. Although migration has occurred in the past, today traces can be found everywhere, even in remote primary forests. The impact of agriculture on natural vegetation has been higher in Africa than in the Amazon Basin or in Asia (ORSTOM-UNESCO 1983). At present, such activities are mainly recorded in West Africa. Of the 12 million hectares of forest found in Côte d’Ivoire in 1956, only 2.2 million remained in 1992, the balance having been converted to cocoa plantations.

Figure 3. Colonization of fire-protected savannas by woody plants (4 years of protection).



Secondary Succession

A general successional sequence can be observed in most of the so-called secondary forests. Mature forests cleared for cultivation or destroyed by natural events (fires) recover through successive stages dominated first by herbaceous plants, then by bushes and small pioneer trees, larger trees of secondary forest, and finally by trees of primary or mature forest (climax).

The following observations are common in most cases.

- Each stage is longer than the previous one, the first stages may overlap.
- The history of cultivation, the time between cultivation periods, and the degree of disturbance of the cleared vegetation are key determinants of the length and development of each stage (Mitja and Hladik 1989).
- Beyond a threshold of successive perturbations, the dynamic sequence may cease and forest may regress to savanna.

Several authors reported cases of dynamics interruption which maintain the forest at a particular stage of the succession. Low-density forests dominated by *Marantaceae* and *Zingiberaceae* are well-known examples; these large monocotyledons form a dense understorey which stops ligneous regeneration. This phenomenon could be the result of ancient natural disasters such as forest fires in secondary vegetation (Swaine 1992). The forest's retreat may be obvious in the course of dry periods during which fire could have spread into the forest. Other interruptions in the succession can occur when lianas invade declining monospecific bush stages (Kahn 1982).

Aucoumea klaineana (okoumé) is a large dioecious tree of the Guinea-Congo rainforest with a confined repartition area located mainly in Gabon, Equatorial Guinea and in the littoral areas of Cameroon and Congo. For these countries, okoumé represents the largest part of the logged volume exported (80% in Gabon), mainly for plywood. This species is a typical long-life pioneer species dominating the secondary forests and able to colonise large open areas at the early stages. In the older stands (30-60 years) okoumé is the dominant tree species representing more than 80% of the total tree population (Nasi 1997). Optimum conditions for their establishment include enough mother trees, open area greater than 0.25 ha, clean soils with few herbaceous plants or lianas, and seeding just after the opening of the area (Biraud 1959). Stands are established within 5-10 years during forest regrowth after shifting cultivation, more slowly during colonisation of fire-protected savannas. They dominate the secondary succession for at least 100 years, forming a monodominant forest. After a senescent phase, during which most of the okoumés die, stands evolve into the surrounding mature forest. In the coastal forests of Gabon, okoumé stands may be harvestable at around 60 years. Annual growth rings are discernible because of severe dry seasons and allow estimations of age (Mariaux 1970, Detienne 1989).

A Case Study in Gabon: Research on the Dynamics of Okoumé Secondary Forest

Objectives, study site and methods

This study is based on research carried out in a Forest Management Project in the coastal savannas of Gabon. Okoumé stands originate from natural regeneration after shifting cultivation and are distributed within the mature forest. Climate is equatorial with an average annual rainfall of 1750 mm and a very pronounced dry season.

The project, located in Oyan (55 km South of Libreville), started in 1987 with the following main objectives:

- to reconstruct the evolution of the structure of control stands from initial to mature stages;
- to quantify the impact of thinning on the dynamics of the stands; and
- to study natural regeneration after logging.

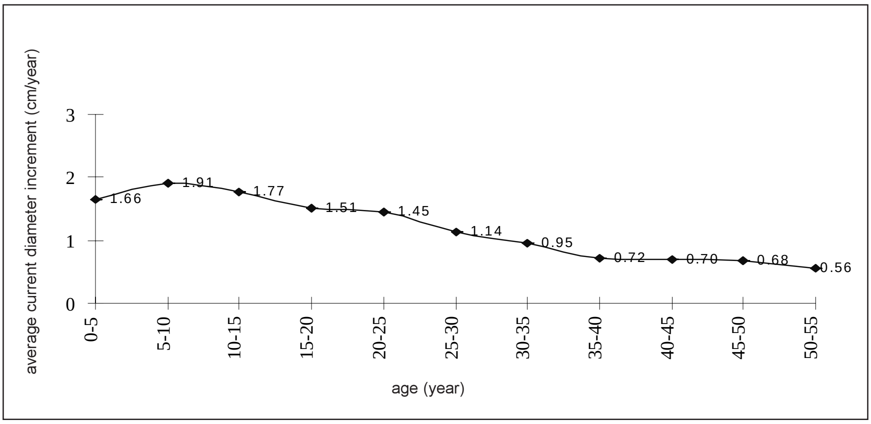
The experimental design consisted of 34 permanent sample plots established in pure okoumé stands, ranging from 0.38 to 1.5 ha (total area around 22 ha), and including the entire succession process, from an initial stage (5-10 years old) to a harvestable stage (60 years old). In young stands (less than 10 years, 7 plots), all individuals taller than 1 m were identified, numbered and measured in height (up to 10 m) and/or girth at breast height (if gbh ≥ 10 cm). In older stand (27 plots), all trees with gbh ≥ 30 cm were identified, numbered and mapped. During the study period girth was measured every successive year. In 1989, 13 plots were thinned. The silvicultural treatment was a single selective thinning to benefit dominant okoumés selected as promising trees (about 80 stems/ha). It was carried out in the upper storey by eliminating supernumerary dominant okoumés and a few secondary species. To eliminate those trees without involving damage to the residual stand, Garlon (triclopyr) was used as arboricide associated with girdling. In 1995, two plots (plot 23 and plot 3), more than 50 years old, were experimentally logged with conventional harvesting techniques by a local logging company. During and after harvesting operations, logging damage and post-logging regeneration were assessed. Tree saplings (more than 30 cm high) were annually counted on 64 circular sub-plots, distributed systematically within each plot.

Results

Dynamics of control stands (Nasi 1997)

- Most of the individuals were established within 5 years at the end of cultivation. At age 5, the stand's density was around 4000 stems/ha with 50% of okoumé associated with other pioneer species. The canopy was closed (6-8 m high).
- Up to 25-30 years, density changed only as a result of natural mortality (from 50 to 100 stems/year/ha). The other pioneer species disappeared gradually. The hierarchical structure of the okoumé stand had yet to develop between dominant, codominant and dominated. At 30 years, the okoumé represented 80% of total density and 95% of the dominant individuals. The average increment in diameter of dominant okoumé was 1.1 cm/year (Figure 4).
- A dendrometrical equilibrium appeared to occur at 40-45 years; density = 400-450 stems/ha with 100 dominant okoumés/ha, total basal area = 45 m^2/ha with 70% represented by dominant okoumés. The average increment in diameter of dominant okoumés decreased to + 0.70 cm/year (Figure 4).
- Around 60 years, the stands may be harvestable.

Figure 4. Mean diameter increment of dominant Okoumé according to their ages (95 % confidence interval).



Impacts of thinning

Two groups of stands were formed based on their ages: young (15-30 years) and old stands (37-52 years). The main results are presented in Fuhr *et al*. (1998):

- The dominant population was not significantly weakened: there was no increase in mortality.
- Young and old trees reacted positively (Figure 5): the gain in average current diameter increment was around 25% for the dominant okoumés. It was more than 100% for the dominated ones.

- The benefit existing at the individual level did not exist at the stand level (Figure 6): the improved growth of the remaining trees allowed the stand's growth to remain constant but it did not balance the loss of the basal area due to the thinning of dominant okoumés.

Figure 5. Impact of thinning on the mean diameter increment (95 % interval confidence).

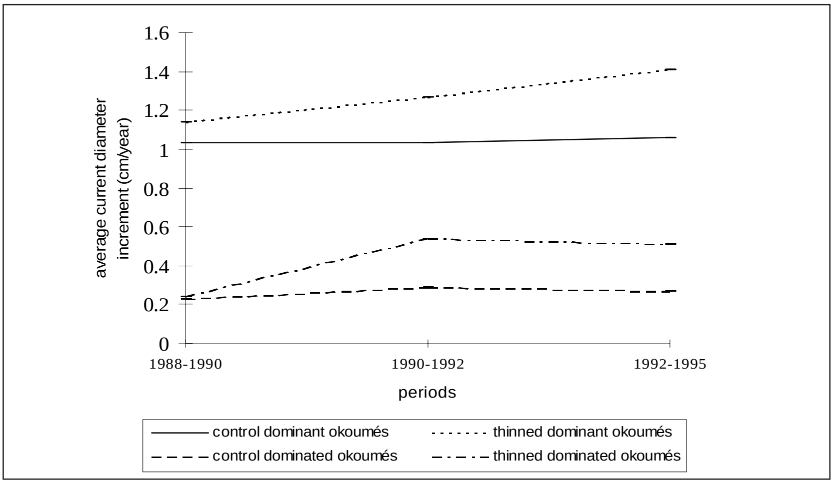
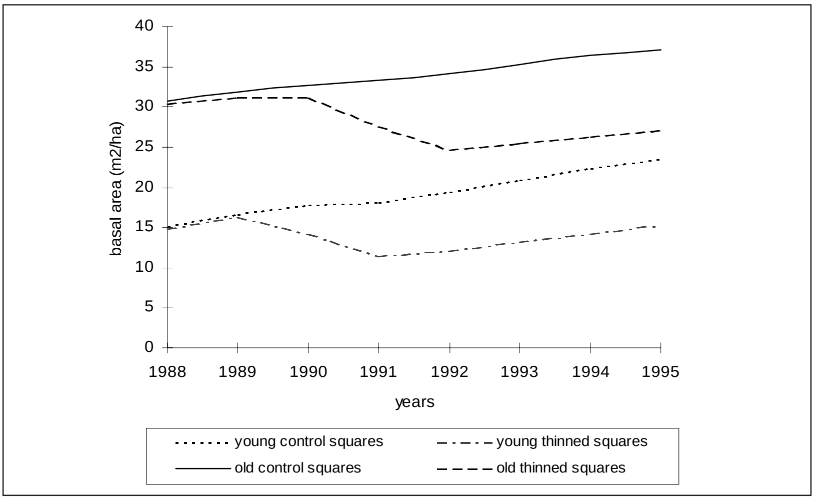


Figure 6. Impact of thinning on total basal area of dominant okoume stands.



Logging impacts and post-logging regeneration

Before logging, there were 78 dominant okoumés in plot 3 and 99 in plot 23. In plot 23, 22 okoumés were felled and the resulting commercial volume was 94.5 m^3/ha (basal area: 13.2 m^2/ha). In plot 3, fewer okoumés (15 or 7.1 m2/ha) were felled, and the commercial volume was 50.3 m^3/ha. These values are much higher than the national average of 1-3 stems/ha. The extraction was, however, not maximised. The number of okoumés with diameter at breast height (dbh) greater than 70 cm (the minimum legal timber diameter), was 38 in plot 23 and 27 in plot 3.

Felling and skidding damages affected 100 stems (27.1% of the initial tree population) in plot 23 and 69 stems (19.8%) in plot 3. Felling damaged more trees than skidding: in plot 23, 79 stems (21.8%) were damaged by felling and 53 stems (15.2%) by skidding; in plot 3, the respective figures were 25 (6.8%) and 19 stems (5.4%). Felling both injured and killed the trees with equal frequency, whereas skidding seemed more to injure trees than kill them. Numerous small trees (< 30 cm gbh) were often uprooted or broken during skidding, but as their girth was below the limit they were not recorded.

The area damaged was estimated on the plot maps, after joining preserved trees. It reached 64% of the total area in plot 23 and 48% in plot 3. Logging created large opened areas that were bigger than the minimum opening necessary for the natural regeneration of okoumé trees. Natural regeneration was measured after logging. Three years after logging, okoumé was the most abundant species in the sub-plots of the damaged area in plot 23 (11% of the saplings), and seventh in plot 3 (5%). In fire-protected savannas the density was higher (31.5%), but in large treefall gaps it was less than 1%.

Discussion and Conclusions

In Gabon, secondary forests dominated by okoumé have a very high commercial value. Because of the high density of this very valuable species, extracted volumes reaching 50 m^3/ha are similar to those harvested in Asia (Bertault and Sist 1997). This is a very unusual figure for African tropical forests where harvested volumes are very low. However, the conditions favourable for establishment of these stands in the coastal area of Gabon are progressively disappearing. In fact, the region has been quite heavily populated since prehistoric times but is now more or less deserted (Merlet 1990). Most inhabitants left at the end of the last logging operations in the 1960s so that areas affected by rapid colonisation, called ‘anthropic savannas’, have become rarer and smaller.

In tropical forests of Africa, harvesting intensities are generally low and impact of logging on the stand is reported to be small (de Chatelperron and Commercon 1986; Forni 1994; White 1994; Doucet 1996). In the case of rich (or pure) okoumé forests, the harvesting intensity is much higher (around 10 stems/ha) and similar to that recorded in Asia (Bertault and Sist 1997). However, the resulting damage recorded in okoumé stands is lower than in Asia. In plot 23, where 22 okoumés were cut, 27% of the initial tree population was affected by logging. In East Kalimantan (Indonesia), where the mean harvesting rate is around 10 stems/ha with conventional techniques, logging is responsible for damaging 48% of the original tree population (Bertault and Sist 1997). The diameters of the harvested okoumés are nevertheless close to the diameters of the *Dipterocarpaceae* harvested in Indonesia. The lower damage may be related to the slender form of okoumé crowns in such secondary stands, where intraspecific competition is high.

It is now widely assumed that Reduced Impact Logging (RIL) is a priority for sustainable management, particularly to ensure future timber production, to protect ecosystem functions and to maintain biological diversity in production forests. This might not however be the case for rich okoumé stands. In the present study, open areas resulting from the harvesting intensities were large enough to allow natural regeneration of okoumé in places, suggesting that logging might be used as a silvicultural treatment to delay the increasing rarity or disappearance of okoumé and to ensure future timber production. To reduce the impact of logging would certainly accelerate the evolution of the stands into the surrounding mature (primary) forest but would also considerably reduce surfaces of open areas where okoumé can regenerate. Based on management objectives, foresters may prefer not to reduce damage in terms of area.

The economic value of thinning seems to be debatable, at least for old stands. Young stands will reach their maturity in at least 20 years; it is possible that the stimulation of growth may accelerate this and that the loss of workable trees might be recovered. Nevertheless, in stands where the species accounts for 35-80% of the total basal area (Mellinger 1993), it is possible to thin in the upper storey without removing dominant okoumés so that the benefit to diameter increment should induce a significant increase in marketable volume.

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6. Growth Response of Wild *Shorea* Seedlings to High Light Intensity

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Abstract

Wild *Shorea johorensis* seedlings growing in logged-over forest in Central Kalimantan were found to reach maximum growth rates at only moderate light intensities (< 50% full sun, 5-10 mol m^{-2} day^{-1} Photosynthetic Photon Flux Density). Seedling growth at higher light intensities in large canopy gaps was the same or even decreased compared to the growth of seedlings in smaller gaps. Seedling growth may be limited by the inherent maximum growth rate of the species, or by external factors such as soil nutrient availability and soil compaction. Measurement of photosynthetic acclimation after logging showed that seedlings adjust well to open conditions, with significant changes in leaf nutrient partitioning. Rates of carbon loss through dark respiration were increased in exposed plants. It is hypothesised that a high rate of dark respiration is an inherent feature of dipterocarp seedlings growing in exposed sites which contributes to the growth limitation observed in these sites. Canopy opening of secondary forest for enrichment planting or the release of seedlings using artificial gaps should aim to provide only moderate light intensities at the forest floor. Greater canopy opening will promote competition from undesirable pioneer species and prolong the length of time that pioneer species will persist.

Introduction

Timber from the lowland dipterocarp forest of Indonesia dominates both the domestic market in Indonesia and the international trade in tropical timber. A large proportion of Indonesia's forests has now been logged or is designated as production forest. In 1996 there were over 400 logging concessions operating on approximately 54 million ha of forest land (Sunderlin and Resosudarmo 1996). In addition to logged-over production forest, there is now estimated to be at least 39 million ha of degraded forest resulting from repeated selective logging, burning and shifting cultivation (Adjers *et al.* 1995). The density of residual trees, saplings and seedlings of commercial dipterocarp species in logged-over forest is often low, especially if the forest has been subjected to heavy logging or burning (Adjers *et al.* 1995). Interest in silvicultural treatments, planting and tending techniques appropriate for the rehabilitation of logged-over and degraded forest is now increasing as the amount of timber extracted from primary forest falls.

Existing methods for natural and artificial regeneration of dipterocarp timber species include:

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- little or no intervention (where there are adequate numbers of residual and seed trees);
- uniform liberation thinning (cutting or girdling of competing non-commercial species; Kuusipalo *et al.* 1996);
- localised opening of canopy gaps above pre-existing shade suppressed seedlings (Tuomela *et al.* 1996);
- line planting where wild seedling regeneration is inadequate (Adjers *et al.* 1995); and
- the recently proposed lane planting system, where seedlings are planted into clear-felled 10 m strips cut 15 m apart in secondary forest (*Tebang Tanam Jalur*).

There have been few long-term studies of the effects of these treatments and, under certain conditions, the chosen treatment may not always achieve the intended result. For example, Kuusipalo *et al.* (1996) found that uniform liberation thinning of an area of logged-over forest in South Kalimantan actually prolonged the phase of dominance by pioneer species, rather than achieving the desired effect of promoting dipterocarp regeneration. There is clearly a need for further applied research and refinement of current methods for the management of secondary forest for timber production.

All dipterocarps have seeds that can germinate and establish as seedlings beneath the shade of a closed canopy, and they are therefore classified as climax species (Newman *et al.* 1996; Whitmore 1996). Within the family there is a wide variation in shade tolerance, from slow-growing, more shade-tolerant heavy hardwoods to faster-growing, more light-demanding light hardwoods. At present the most valuable species belong to the medium and light hardwood groups such as the light red merantis (Newman *et al.* 1996). It is the relatively more light-demanding seedlings, saplings and poles of these timber groups that are the target of silvicultural treatments.

In this study the growth and photosynthetic characteristics of wild light red meranti seedlings were examined after logging disturbance and related to the microclimate of logged forest. The aim of this paper is to describe the seedling height growth response to light and determine the physiological basis of the observed response. The implications of the observed growth response for logging techniques and managed canopy opening of logged forests are discussed.

Methods

All measurements were taken in logged forest near Wanariset Sangai, a forest research station established in Central Kalimantan by the Indonesian Ministry of Forestry and the United Kingdom Department For International Development (DFID).

Dipterocarp seedling population growth was monitored in 2 m x 2 m seedling plots located within a 1 ha permanent sample plot in logged forest. The location of seedling plots was determined after first stratifying the entire 1 ha plot according to canopy cover and dipterocarp seedling density. A grid pattern was established across the 1 ha plot using string at 10 m intervals. Canopy cover was assessed subjectively using a 5 m x 5 m grid and recorded as open space, partially open or closed. Seedling density was assessed at the same time and recorded as no seedlings, few seedlings (1-5), or many seedlings (> 5 seedlings). Thirty seedling plots were distributed within areas that were classified as containing dipterocarp seedlings, with ten seedling plots located in randomly selected grid squares from each of the three canopy classes. A further 5 seedling plots were located on skid trails to follow the development of pioneer vegetation. Stratifying the location of seedling plots according to canopy cover ensured that measurements of seedling growth were made in sites ranging from closed, undisturbed canopy to large, open logging gaps.

All dipterocarp and pioneer seedlings within each seedling plot were identified, tagged, and their height and number of leaves recorded. Measurements were first made 6 months after logging, and repeated 10 months and 18 months after logging. A seedling was defined as a plant below 1.2 m in height, although all regenerating dipterocarps were included even though some were between 1.2 and 2.0 m by the time of the first measurement. Common dipterocarp taxa were *Shorea johorensis*, *Shorea leprosula*, *Shorea ovalis* ssp. *ovalis* and *Shorea parvifolia*. All are fast-growing species belonging to the commercially important light red meranti timber group. Common pioneer taxa were *Anthocephalus chinensis* and various *Macaranga* species.

Estimates of daily total Photosynthetic Photon Flux Density (PPFD, photosynthetically active radiation) were made from hemispherical photographs of the canopy above the centre of each seedling plot. Photographs were also taken at 20 m intervals in a grid pattern over the entire 1 ha plot. Estimates of PPFD from photographs were calibrated against direct measurements made using quantum sensors (Nifinluri *et al.* this volume).

The capacity of pre-existing seedlings to adjust their photosynthetic apparatus to post-logging conditions was examined by measuring the photosynthetic response to light of leaves of wild *S. johorensis* seedlings in areas logged two weeks and three months earlier. All measurements were made in April 1996 during a period of high rainfall. The initial effects of canopy opening on pre-existing, shade-adapted leaves were assessed from measurements made on five randomly selected seedlings in a large logging gap in the area logged two weeks earlier. The photosynthetic response of leaves that had developed since logging was recorded in the area logged three months earlier. In this area, measurements were made on five randomly selected seedlings growing beneath each of the three canopy classes described earlier (closed, partially open and open; 15 seedlings in total).

Photosynthetic measurements were made on the uppermost fully expanded leaf of each seedling using a portable, closed photosynthesis system (LI-6200, LI-COR Instruments, Nebraska) with light provided by a red light emitting diode light source (Q-Beam 2001-A, Quantum Devices Inc., Barneveld, Wisconsin). The CO_2 concentration and humidity of the incoming air stream was controlled using a gas mixing system (CIRAS, PP Systems, Hitchin, Herts., UK). PPFD incident on the leaf was varied from 0-1200 $\mu mol\ m^{-2}\ s^{-1}$. Leaves were first allowed to reach a constant rate of photosynthesis at a PPFD of 250-500 $\mu mol\ m^{-2}\ s^{-1}$, then stepped up to light saturation and back down to darkness over a period of approximately 2 hours, allowing photosynthesis and stomatal conductance to reach a steady state at each intermediate PPFD. Estimates of the rate of dark respiration were obtained after the leaf had been darkened for at least 15 minutes. Parameters describing the photosynthetic response were estimated by fitting a non-rectangular hyperbola to the response curve for each plant (Ogren and Evans 1993). Estimates of total daily carbon gain on a leaf area basis were made by combining direct measurements of PPFD from a range of sites using quantum sensors (Clearwater 1997) with the average photosynthetic light response curve for seedlings from each canopy environment. Instantaneous measurements of PPFD were used to predict instantaneous steady state rates of photosynthesis, and the results (including night time respiration) integrated over a one-week period.

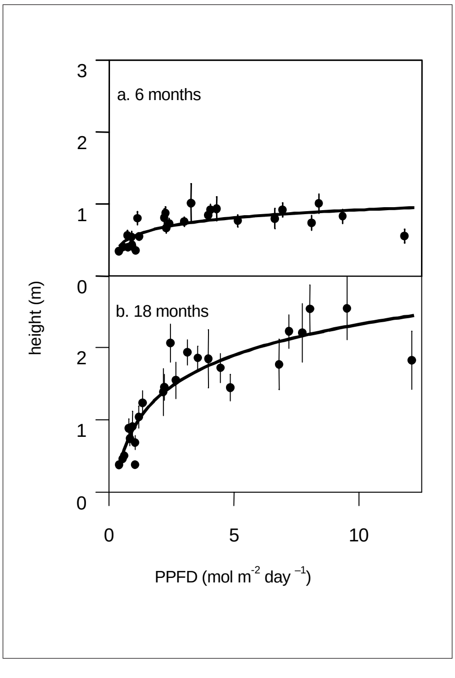
Hemispherical photographs were taken above each seedling on which photosynthetic measurements were made. Total nitrogen content was determined for all leaves used in exchange measurements. The leaves were harvested, dried at 80° C, ground, and 0.1 g samples wet digested in a mixture of concentrated H_2SO_4 and H_2O_2 (Grimshaw *et al.* 1989). Total nitrogen content of the digest was determined by gas diffusion using a flow injection analyser.

This paper represents a summary of the results from a larger study. More detailed descriptions of methodology and the results obtained are presented elsewhere (Clearwater 1997).

Results and Discussion

Six months after logging, *Shorea johorensis* seedlings had responded to small increases in light availability with significant increases in height. This response was observed to saturate above approximately 5-10 mol m^{-2} day^{-1} PPFD, and there was little further increase in seedling height with increasing PPFD above 5-10 mol m^{-2} day^{-1} (Figure 1). Total leaf number showed a similar saturating response to PPFD, suggesting that total above-ground biomass was following a similar pattern to seedling height. A similar saturating growth response was observed for the other *Shorea* species, with no clear differences between species (data not shown, see Clearwater 1997). The growth of seedlings that had established from seed into disturbed soil also saturated at 5-10 mol m^{-2} day^{-1} and then declined at higher PPFDs (data not shown, see Clearwater 1997). Pioneer seedlings were smaller than the dipterocarp seedlings and were only found in the most open areas. Eighteen months after logging, mean dipterocarp seedling height had reached 2 m but was still limited with respect to light availability (Figure 1). The height of pioneer seedlings growing on skid-trails had by now exceeded the height of the dipterocarp seedlings, with *Anthocephalus chinensis* reaching a mean height of 4.5 m.

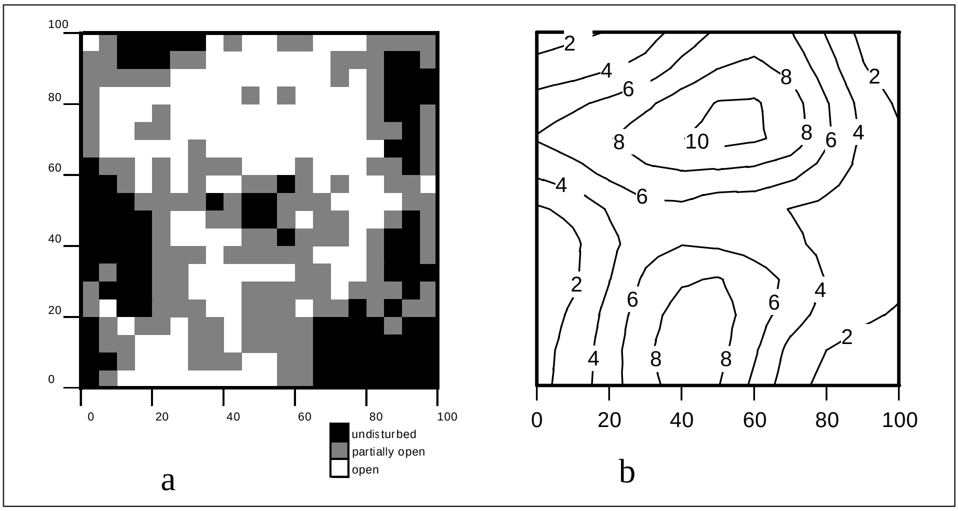
Figure 1. Height of *S. johorensis* seedlings as a function of average daily PPFD, (a) 6 months and (b) 18 months after logging. Each point is the mean height for a seedling plot, ± 1SE. Lines represent a linear regression between seedling height and the natural logarithm of PPFD.



PPFD measured near the centre of natural, single tree-fall gaps in tropical forest is commonly between 3 and 8 mol m^{-2} day^{-1}

(Bellingham *et al.* 1996). Gaps in logged lowland dipterocarp forest are frequently caused by the felling of more than one tree and may be further enlarged by the activity of the tractor during skidding of the log. Felling intensity in the 1 ha plot included in this study was high, but was typical of conventional selective logging operations in the region (38% of the canopy was classified as completely open; Figure 2). Where large canopy gaps were formed, daily PPFD in the understorey frequently exceeded the threshold required to saturate the dipterocarp seedling height growth response (Figure 2). The average daily PPFD incident above the canopy at Wanariset Sangai was 24 mol m^{-2} day^{-1} (Clearwater 1997).

Figure 2. The distribution of (a) remaining canopy cover and (b) mean daily PPFD (mol m^{-2} day^{-1}) over one hectare of logged forest, 6 months after logging. PPFD was estimated from hemispherical photographs taken at a height of 1.2 m and at 20 m intervals across the plot, with linear interpolation between photosites. Axes are distances in metres.



Potential explanations for the limited growth response of seedlings to increased PPFD above 5 mol m^{-2} day^{-1} include limitations imposed by soil nutrient and water availability, and inherent seedling characteristics such as their maximum potential growth rate and their capacity to acclimate to open conditions. There have been few studies of the nutrient requirements of wild dipterocarp seedlings. Fertilisation has usually had no effect, suggesting that seedlings growing in undisturbed soil are not strongly nutrient limited (Nussbaum *et al.* 1995). Even less is known about the water use characteristics of wild seedlings but, given the normally high rainfall, it is possible that water availability only limits seedling growth for short periods during the annual dry season.

The leaves of wild *S. johorensis* seedlings were found to be capable of significant photosynthetic acclimation to high PPFD. Yellowing and necrosis of pre-existing shade leaves was observed in newly exposed seedlings two weeks after logging. Light saturated rates of photosynthesis were lower in these leaves (Figure 3), but the seedlings were surviving and new leaf emergence was beginning. The photosynthetic rates of leaves that developed after logging in areas with moderate canopy opening were double the rates of shaded leaves (Figure 3). Photosynthetic rates were further increased in the most open areas, but varied more between seedlings (Figure 3). Seedlings in the most open areas were receiving an average of 13 mol m^{-2} day^{-1} PPFD, higher than the threshold required for saturation of the growth response and higher than might be expected in natural gaps in unlogged forest (Table 1). Significant differences between environments were also found when photosynthetic rates were expressed per unit mass of leaf tissue and per unit total leaf nitrogen (thus eliminating the effects of increases in leaf mass per unit area in high PPFDs). Acclimation was therefore also occurring at the biochemical level, with increased concentrations of nitrogen in the leaf and increased partitioning of leaf nitrogen to the carbon fixing components of the photosynthetic apparatus.

Figure 3. The response of photosynthesis (A area) to PPFD, for the leaves of Shorea johorensis seedlings after logging. a). Seedlings left exposed in a logging gap, two weeks after logging (open circles). The response of seedlings beneath undisturbed canopy is drawn for comparison (squares). b). Seedlings beneath open (circles), partially open (triangles) and undisturbed (squares) canopy, 3 months after logging. Note the difference in vertical scale between a. and b.

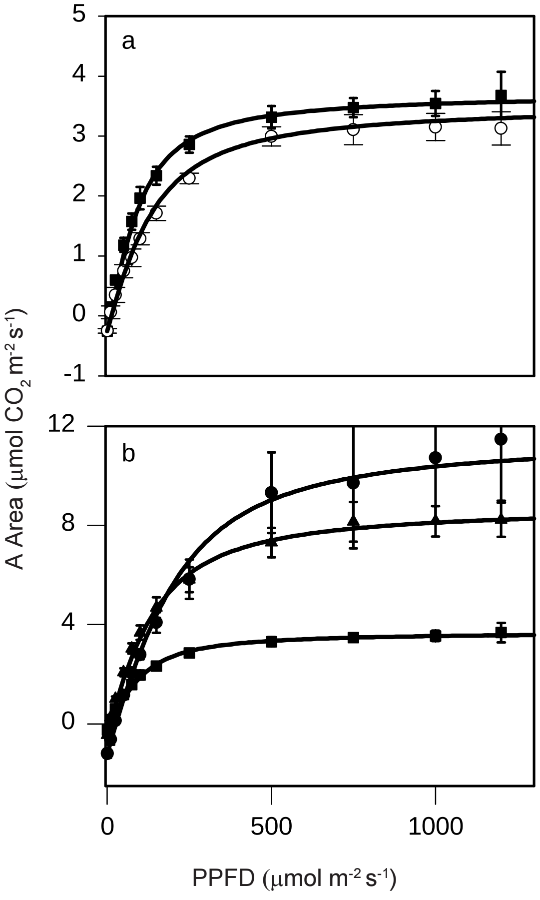
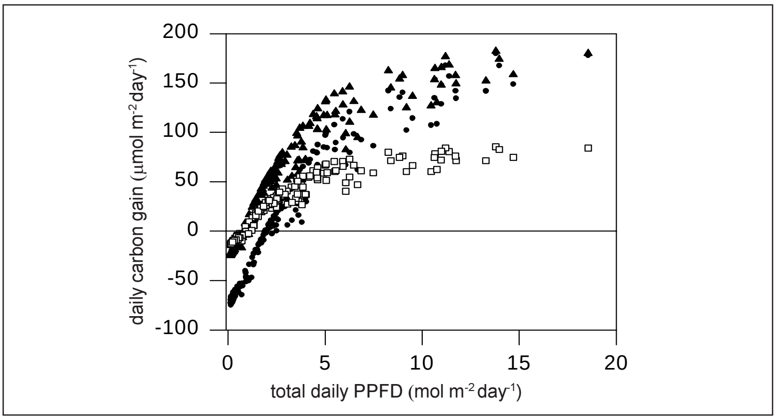


Table 1. Daily PPFD, leaf nitrogen concentrations and light saturated rates of photosynthesis (*A* max) expressed per unit leaf mass and per unit total leaf nitrogen, for seedling leaves that developed after logging three months earlier.

Parameter	Environment		
	Undisturbed	Moderately open	Open
Daily PPFD ($\mathrm{mol\ m^{-2}\ day^{-1}}$)	< 0.5	3.0	13.0
Leaf nitrogen per unit mass ($\mathrm{mg\ g^{-1}}$)	16 ± 1	16 ± 1	21 ± 1
A max per unit mass ($\mathrm{\mu mol\ CO_2\ m^{-2}\ g^{-1}\ s^{-1}}$)	81 ± 4	141 ± 11	201 ± 34
A max per unit Nitrogen ($\mathrm{\mu mol\ CO_2\ mol^{-1}\ s^{-1}}$)	71 ± 4	126 ± 13	135 ± 25

An important feature of the photosynthetic response of seedling leaves in the most open areas was a large increase in the rate of dark respiration (Figure 3). The relative increase was greater than the corresponding increase in maximum photosynthetic rates, suggesting that increased respiration was not just the result of increased concentrations of photosynthetic proteins. Increased dark respiration offset gains in daily carbon gain resulting from increased maximum rates of photosynthesis. Even though plants in the open were receiving higher daily PPFD and had higher maximum rates of photosynthesis, their predicted rates of carbon gain per unit leaf area per day were the same as leaves acclimated to moderately open environments (Figure 4). It is proposed that increased rates of dark respiration are the result of the development of photoprotective mechanisms (Demmig-Adams and Adams 1992) which prevent long-term damage during periods of high PPFD, low wind speed, and high leaf temperatures (Clearwater 1997). It is concluded that seedlings of fast-growing dipterocarp species are capable of significant acclimation to very open conditions, but that the respiratory cost of acclimation contributes to the observed limitation of growth under these conditions. Further research is required to examine other aspects of the seedling carbon budget (stems and roots), and the effects of increases in leaf area and self shading as the seedling grows larger.

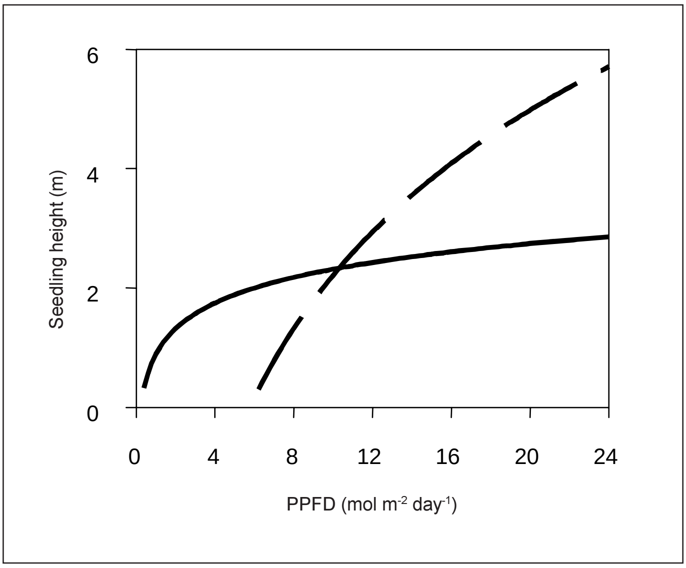
Figure 4. Modelled daily carbon gain as a function of daily PPFD, for leaves of *Shorea johorensis* seedlings acclimated to sites with open (circles), partially open (triangles) and undisturbed (squares) canopy after logging.



Implications for Management

Fast-growing dipterocarp seedlings are well adapted for rapid height growth in sites receiving moderate daily PPFDs (5-10 mol m^{-2} day^{-1}). In more exposed sites they are capable of photosynthetic acclimation to high daily PPFDs, but their growth rates may not be any higher. In contrast, pioneer species are thought to require at least 8 mol m^{-2} day^{-1} for establishment (Whitmore 1996) and it is likely that their growth rates will increase more linearly with further increases in daily PPFD (Figure 5). Differences between dipterocarps and pioneers in their growth response to light provides a possible explanation for the observation of Kuusipalo *et al.* (1996) that general liberation thinning resulted in prolonged dominance by pioneer species rather than faster recruitment of dipterocarps – the degree of canopy opening was above that required to saturate dipterocarp seedling growth and was sufficient to promote rapid growth of pioneers (Figure 5). Management techniques which use canopy opening to increase dipterocarp seedling growth rates should aim for moderate daily PPFDs which are sufficient to saturate the dipterocarp seedling growth response but which do not result in unnecessary release of pioneer species. Examples include the cutting of lanes for line planting (Adjers *et al.* 1995) and the creation of artificial canopy gaps (Tuomela *et al.* 1996). The size of canopy gap required to achieve moderate PPFDs beneath lowland dipterocarp forest is considered by Nifinluri *et al.* (this volume).

Figure 5. Comparison of the height versus PPFD relationship of fast-growing dipterocarp seedlings with that of a hypothetical pioneer species, 18 months after logging. The line for dipterocarp seedlings is taken from Figure 1. The line for pioneers is drawn from the observation that pioneers require approximately 8 mol m^{-2} day^{-1} to establish, but grow rapidly at higher PPFDs (see text).



Changes in patterns of leaf nitrogen partitioning during acclimation suggest that seedling nutrient status is an important component of acclimation to very open sites. A reduced acclimation capacity resulting from poor nutrient status may explain the low or more variable growth rates of seedlings planted or establishing from seed in open areas with high PPFDs and disturbed soil. Treatments with mycorrhizal inocula, addition of forest topsoil or fertilisation may be required before full acclimation can occur.

Acknowledgements

Support for research at Wanariset Sangai was provided by Balai Penelitian Kehutanan (RI) and the Department For International Development (UK). PHT Kayu Mas gave permission for research within their concession, and Runci Susilawaty and other Kayu Mas employees provided valuable assistance in the field. M. Clearwater gratefully acknowledges financial assistance from the Association of Commonwealth Universities.

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7. Measurement of Gap Size and Understorey Light Intensities after Logging in Central Kalimantan

T. Nifinluri[1], M.J. Clearwater[2] and P. van Gardingen[2]

Abstract

The aim of the study was to provide a simple measure of the size of artificial gaps in dipterocarp forest that could be related to the availability of light and hence seedling growth near the gap centre. The size of canopy openings in secondary forest can then be controlled to achieve the optimum light levels for regeneration of timber seedlings. Hemispherical photography was used to estimate light availability in logging gaps of a range of different sizes in Central Kalimantan. Predictions from photographs were calibrated against direct measurements of light availability using light sensors. Simple physical measurement of gap size and orientation were taken at the same time and compared to the estimates of light availability. The best index of gap size was found to be the multiple of gap area and the ratio of gap length in two cardinal directions (East–West/North–South). When the results of this study are combined with the results of a study of seedling growth rates, it can be concluded that light intensities near the centre of relatively small gaps will be sufficient for the maximum growth of wild *Shorea* seedlings.

Introduction

Tree regeneration following logging in Indonesia is stimulated by light reaching the forest floor through canopy gaps created by the logging operation. The management of secondary forest for timber production usually involves some form of deliberate canopy opening to increase seedling growth rates and promote the recruitment of valuable dipterocarp species (Adjers *et al.* 1995; Kuusipalo *et al.* 1997). The creation of canopy gaps is therefore an important silvicultural technique, but for logged-over and secondary forests in Indonesia there is little published information on possible methods for gap creation and their effects on forest regeneration (Adjers *et al.* 1995). Many ecological studies in temperate and tropical forests have investigated the relationships between gap size, gap microclimate and regeneration dynamics of tree seedlings within gaps. It was hypothesised that differences in light requirements for growth resulted in the partitioning of species between gaps of different sizes, and that the prevailing natural disturbance regime would therefore influence the species composition of the forest (Denslow 1987).

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It is now known that there is no simple relationship between gap size and microclimate within the gap. There is often strong spatial variation in conditions within single gaps (Brown 1993). For example, light intensity may vary between the centre and edge of the gap in a complex fashion which depends on gap size, orientation and latitude (Canham *et al.* 1990). Species composition within the gap may also be affected by chance variation in seed sources near the gap, or in species of seedling pre-existing at the time of gap formation (Schupp *et al.* 1989; Whitmore and Brown 1996). Measures of gap 'size' are complicated by variation in gap shape and orientation, and difficulty in defining the edges (Green 1996). However, for management purposes, there is still a need for a simple measure that can be used to predict the conditions within artificial gaps. The problem may be simplified if observations are restricted to near the centre of the gap, if the gap is deliberately located above pre-existing seedlings of the desired species, or if seedlings are planted and subsequently tended within the gap.

The aim of this study was to provide a simple measure of gap size in lowland dipterocarp forest that could be related to the light environment prevailing near the gap centre (Nifinluri 1996). The light environment was measured as the integrated daily photosynthetic photon flux density (PPFD) using hemispherical photography, after first calibrating the technique against direct measurements of PPFD made using quantum sensors (Clearwater 1997). A related study at the same site found that the increase in height of commercially important, wild dipterocarp seedlings tended to be maximised at moderate daily PPFDs of 5-10 mol m^{-2} day^{-1} (compared to average above-canopy totals of 24 mol m^{-2} day^{-1}; Clearwater *et al*. this volume). The present study attempts to answer the following questions:

- What is the maximum size a logging gap can be before PPFD near the gap centre exceeds that required to maximise dipterocarp seedling growth?
- How wide should lanes and gaps be cut for enrichment planting treatment of logged-over forest?

Methods

All measurements were made in logged forest near Wanariset Sangai, a forest research station established in Central Kalimantan by the Indonesian Ministry of Forestry and the United Kingdom Department For International Development (DFID).

Nine logging gaps were chosen to represent a range of gap sizes. A transect was established along the longest axis of each gap. A second transect was established at the widest point in the direction perpendicular to the first. The intersection of these two initial axes was defined as the centre of the gap, and was used as the reference point for mapping using a compass and tape measure. The size and shape of the gap was mapped by measuring the distance to the edge of the gap in 16 compass directions (N, NNE, NE, and so on), with the edge defined as the boundary formed by the canopies of surrounding undisturbed canopy or emergent trees (Battles *et al.* 1996; Green 1996). The area of the gap was estimated by manually plotting these vectors and estimating the sum of the areas of the resulting triangles (Green 1996). The ratio of the lengths of the two initial axes (length–width ratio), and the ratio of the lengths of the two axes in the East–West and North–South directions (length EW–length NS ratio) were calculated as measures of gap shape.

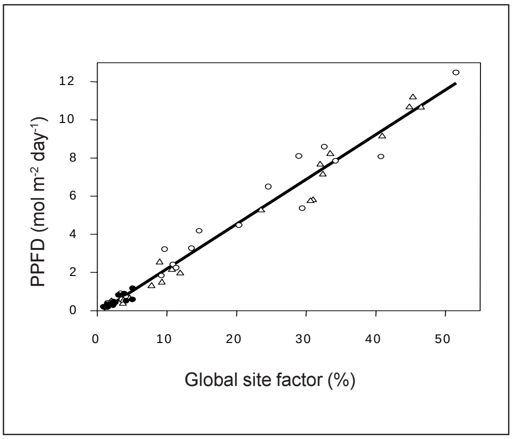
The analysis of hemispherical photographs is a technique which is now widely used to record information on canopy structure and the proportion of above-canopy light that is transmitted to the point of the photograph (Rich *et al.* 1993; Easter and Spies 1994). The proportions of direct and diffuse light transmission are estimated separately. Diffuse transmission is estimated by dividing the hemisphere into annuli of equal area and estimating the proportion of open sky within each annuli. A weighted average for all annuli (the diffuse site factor) is calculated after accounting for the cosine correction for a horizontal surface and the Standard Overcast Sky assumption (assumes more diffuse light is received from directly above). Direct transmission (the direct site factor) is estimated by using standard equations to predict the path of the sun across the hemisphere, and estimating the proportion of the path that is open sky. Contributions from each time step along the path are also weighted for a horizontal surface. With knowledge of the prevailing conditions above the canopy (the degree of cloudiness or the proportion of total light that is diffuse), the direct and diffuse site factors can be combined as a weighted average to give an estimate of total transmission (the global site factor). The global site factor (e.g., 25%) can be calibrated against direct measurements of PPFD using light sensors positioned at the same sites as the photographs, or multiplied by measurements of total above-canopy PPFD, to provide absolute estimates of transmitted PPFD (e.g., 6 mol m^{-2} day^{-1} PPFD). The advantage of hemispherical photography is that a single photograph can be taken quickly and used to predict long-term light availability at that site. Errors resulting from variation in sky condition, exposure levels and photograph analysis are sometimes large. Results can be good if careful attention is paid to methodology.

Hemispherical photographs were taken of the canopy at 10 m intervals along each of the two initial gap axes. Photographs were taken on Kodachrome 200 ISO film under overcast conditions in the early morning or late afternoon, using a Nikkor 8 mm fish-eye lens. Exposure levels were set at two f-stops below (over-exposed) a reading of unobstructed sky given by a photographic spotmeter (Minolta Spot Meter F). Grey scale images were digitised directly from film using a slide scanner (Microtek 35T) to give a final image diameter of 1000 pixels. The images were analysed as described above using customised software (Optimas 5.0, Optimas Co., Washington) to give estimates of the proportion of above-canopy light transmitted through the canopy. Estimates of total transmission were calibrated against direct measurements of PPFD distributed over three locations (two logged forest sites) and over a range of climatic conditions (Clearwater 1997). Mean PPFD for the gap centre was calculated from the four photographs taken 10 m from the gap centre on each of the initial axes.

Results and Discussion

The global site factor estimated from photographs was a good predictor of daily PPFD received below the canopy in logged and unlogged forest (Figure 1). The relationship between photographic estimates of transmission and direct measurements of PPFD was the same for the three photograph calibration sites (Figure 1). A least squares linear regression of measured PPFD against the global site factor from these sites could therefore be used to predict average daily PPFD received at the position of each photograph within the nine study gaps (Figure 1).

Figure 1. PPFD measured with quantum sensors was a linear function of the global site factor estimated from hemispherical photographs, regardless of canopy condition and season. Open symbols are for the two logged forest calibration sites, closed symbols are for the unlogged forest calibration site. Regression: y = 23.5 x – 0.16, n = 58; r^2 = 0.98.



PPFD near the centre of logging gaps was significantly correlated with the total gap area, with higher daily PPFDs measured near the centre of larger gaps (Figure 2). The relationship was variable for gaps with irregular shapes, especially long narrow gaps. The relationship improved when gap area and the ratio of gap lengths in the EW to NS directions were multiplied to provide an index which integrated aspects of gap size, shape and orientation (Figure 3). Note the effect of gap shape on the light environment near the centre of one gap with an area of 1100 m^2 and an unusually low PPFD (marked with an arrow in Figures 2 and 3). This gap was long and narrow in the NS direction. The EW to NS ratio was a better index than the simple gap length to width ratio (along the two longest axes, regardless of orientation; data not shown). This result demonstrates the effects of solar geometry and gap orientation on the proportions of above-canopy PPFD that are transmitted through canopy gaps. Oblong gaps oriented with their long axis in the east to west direction receive more direct sunlight than gaps of similar shape oriented north to south.

Figure 2. PPFD and the global site factor (both predicted from hemispherical photographs) as a function of total gap area. Each point is the mean of four photo-sites near the centre of the gap. Regression: y = 0.00558 x + 4.45, n = 9; r^2 = 0.74. The dotted line marks the maximum gap area required for maximum dipterocarp seedling growth (5-10 mol m^{-2} day^{-1} PPFD; Clearwater *et al.* this volume). The arrow indicates a gap with unusually low PPFD.

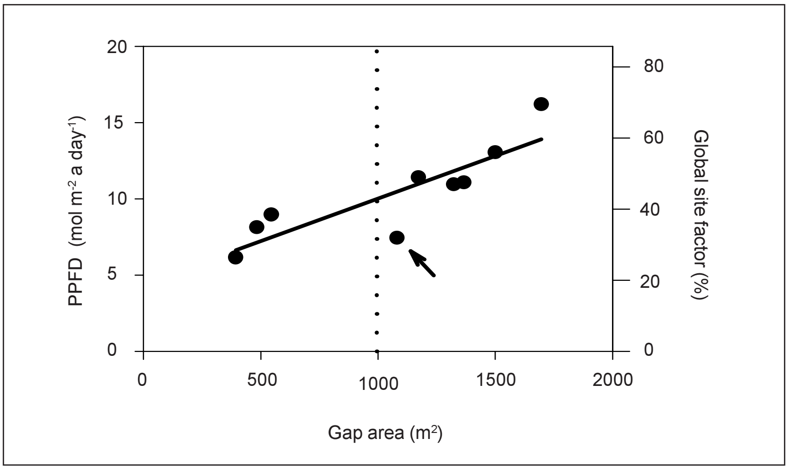
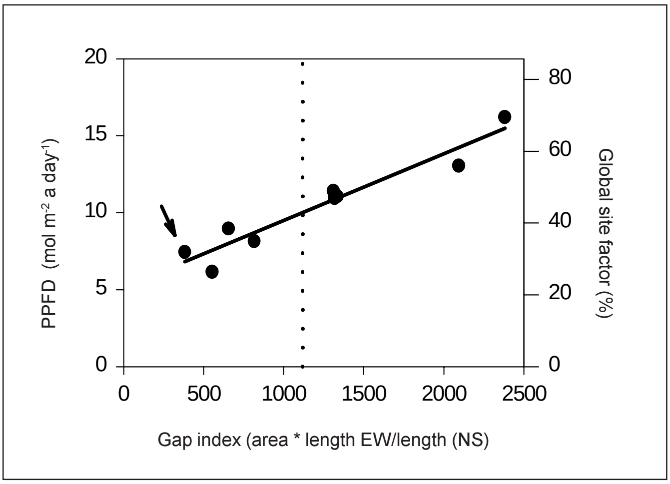


Figure 3. PPFD and the global site factor as a function of gap area multiplied by ratio of gap lengths in the EW to NS direction. Each point is the mean of four photosites near the centre of the gap. Regression: y = 0.00433 x + 5.16, n = 9; r^2 = 0.92. The dotted line marks the maximum gap index required for maximum dipterocarp seedling growth (5-10 mol m^{-2} day^{-1} PPFD; Clearwater *et al.* this volume). The arrow indicates a gap with unusually low PPFD.



Measurements of gap area and length in two directions, combined with a regression similar to that presented in Figure 3, can be used to assess the type of light environment created by logging operations. The relationship between gap size and PPFD will vary with prevailing weather conditions and forest type, but can easily be developed for other sites. Mean canopy height in logged-over forest is lower and PPFD for a given value of the 'gap index' is therefore likely to be higher.

PPFD near the centre of relatively small gaps was within the range found earlier to be sufficient for maximum growth of fast-growing dipterocarp seedlings (indicated by the vertical dotted lines in Figures 2 and 3). The four smallest gaps in this study were created by the felling of one or two commercial trees, and were generally less than 1000 m^2 in area (Nifinluri 1996). The five larger gaps were created by the felling of three or more trees, often combined with significant tractor activity (Nifinluri 1996). PPFD near the centre of the larger gaps exceeded that required for maximum dipterocarp seedling growth. Seedling growth near the centre of these gaps may still be rapid, but competition from pioneer vegetation is also more likely to occur (Kuusipalo *et al.* 1996; Clearwater *et al.* this volume). The relationship between gap size and PPFD was not determined for logged-over forest but, because of the lower canopy height, the gap size required to reach optimum levels of PPFD will probably be smaller. Adjers *et al.* (1995) found that a lane width of 2-3 m was sufficient for good growth of *Shorea* seedlings using line planting in logged-over forest. They also found that the response of each *Shorea* species varied with lane width and direction, and suggested that tending methods could be modified for each species. An index of light availability similar to that presented here, but based on lane width and direction, could be used to quantify the requirements for each species.

Acknowledgements

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8. Experiences with Logged Forest Enrichment through Rattan Planting in Sabah (Malaysia)

R. Bacilieri[1], D. Alloysius[2], B. Maginjin[2], P. Pajon[1] and C. Garcia[2]

Abstract

In 1987, Innoprise Corporation Sdn Bhd (ICSB) embarked on a large-scale project for the enrichment of a logged-over forest through planting rattan. In 1989, CIRAD-Forêt joined the project to bring scientific assistance to the research on rattan silviculture and genetics. The method consisted of rattan line plantings under logged-over forest. This system showed some limitations, mainly due to the lack of control on competitors (such as surrounding trees, bamboo and lianas) and on environmental variability (extremely large at the site), that resulted in rattan stands with heterogeneous growth.

Studies of the effect of environmental variability on rattan growth, and of methods to control it, began in 1994. A first study focused on the correlation between rattan growth and a number of environmental variables. The results showed that competition from surrounding dipterocarp trees was the main factor in the variability of rattan growth. It allowed definition of which forest types are most suitable for rattan enrichment. Another study focused on the effect of light on rattan growth. Trials were established both in the nursery and in the field. The nursery trials showed that each rattan species has special requirements in terms of light. The field trials allowed quantification of the gain in rattan growth that can be obtained through shade adjustment interventions. Both these studies provided important information to the ICSB's rattan project for improved planting management.

Introduction

Secondary forest rehabilitation will be one of the main concerns of tropical forestry in the future. The common experience of Innoprise Corporation Sdn Bhd (ICSB) and CIRAD-Forêt in Sabah (Malaysia), focusing on a non-timber forest products such as rattan, may cast some light on the problems of forest enrichment techniques, and be of interest to researchers and foresters involved in this field.

ICSB is a Sabah-based company, managing a forest concession of about 900 000 hectares. In 1987, as part of its forest management effort, ICSB embarked on a large-scale rattan planting project; 40 000 ha of a logged-over dipterocarp forest were to be enriched with rattans. CIRAD-Forêt joined the project in 1989, bringing scientific assistance to the research on rattan silviculture and genetics. The collaboration was

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strengthened by the creation of a research structure called the Plant Improvement and Seed Production Project (PISP), based in Luasong. (Nasi and Monteuuis 1992; Nasi 1994).

For commercial planting, rattans were established in lines under the logged-over forest. This system was adopted because a number of large trees that could support the rattans without suffering damage were still present in the forest, and no silvicultural treatment that could disturb or be rendered difficult by the thorny rattans was planned for this area. However, the method showed some limitations, resulting in rattan stands with heterogeneous growth.

Rattans have a peculiar pattern of growth. In the first stage of development, called the establishment (or rosette) phase, the stem diameter and the number of roots increase, but stem elongation is negligible; once the stem has attained a maximum, the second phase of development may start with a significant aerial growth of the stem. The establishment phase may last from a few months up to several years according to species and environmental conditions.

Regular checking in Luasong showed that, together with ‘normal’ growing rattans, 5 or 6 years after the planting there was quite a large proportion of rattans still in the establishment phase, i.e., with almost no elongation. Even where it was common to find fast and slow-growing plants side by side, some planted compartments were doing significantly better than others.

With the objective of understanding the reasons behind such variability, PISP began to study the effects of environmental conditions on rattan growth. Preliminary observations seemed to point to canopy opening, and hence to the light reaching the planted rattans, as an important element for rattan growth. Little was known, at that time, about the optimal shade requirement for rattans. In nature, rattans are found under forests with a Relative Light Intensity (RLI) as low as 0.5-5%. However, the pattern of growth of rattans in these conditions was not known. At early stages, the optimum RLI requirement seems to be higher, between 50% and 85% (Budiman and Nana 1988). Finally, no information at all was available on the effect of competition from surrounding trees and of environmental variability on rattan growth. The study reported in this paper focused on the correlation between rattan growth in the commercial plantings and a number of physical environmental variables, such as light, soil and slope, and biotic variables, such as stand density, species composition and competition.

Material and Methods

The logged-over forest and the rattan planting technique

The Luasong rattan planting was carried out under a logged-over forest that was harvested about 20-25 years ago. The forest is composed of a variable ratio of dipterocarps and pioneer trees; some compartments, only lightly logged-over, are now largely dominated by dipterocarps, while others, where the harvesting had been more intensive, contain mostly pioneers. The elevation is 50-450 m a.s.l, average annual rainfall is 2500 mm, topography is very irregular, often with steep slopes, and the soils belong to the Orthic Acrisol and Distric Nitosol families (FAO/UNESCO classification 1974).

The nursery technique for rattans consisted of:

- germination of the rattan seeds in sand beds;
- transplanting the seedlings in plastic polybags under Sarlon nets, 1 to 3 months after germination; and
- planting the seedlings in the field, 9 to 18 months after transplanting.

For planting, strips of 4-5 m width were opened under the logged-over forest by cutting all plants but the commercial trees. Two lines of rattan were then planted within the strip. The spacing along the row was 2.5 m, and the distance between strips 5-6 m, giving a planting density of 800 plants/ha.

Effect of light on rattan growth in the nursery

The experiment was aimed to assess the light requirement at the nursery stage for the following four commercial large-diameter rattan species: *Calamus ornatus*, *C. merrillii*, *C. manan* and *C. subinermis*. Relative Light Intensity (RLI) of the three Sarlon nets used in the experiment was measured using 10 calibrated LICOR quantum sensors combined with a data logger. Eight sensors were installed under each of the nets for a whole day. Two sensors were installed in a fully open space and used as an open-sky reference. Five-second interval readings were then integrated over the 12 hours of measurement. This gave accurate estimates of the RLI for each Sarlon net of 22%, 42% and 61% respectively. The variation of RLI within each Sarlon net was about 5% of the total variation.

Each treatment for all species included 33 plants and was repeated three times. The seedlings were transplanted in polybags when they were about 1 cm tall. The plants received a slow release fertiliser. The first measurement occurred eight months after transplanting, followed by another measurement one year after transplanting. In this experiment only the shoot length (length between the collar base and the insertion of the last leaf) was measured.

The different RLI treatments and the repetitions were compared using a variance analysis, and their ranking tested with a Duncan test. The statistical model used for each species included 2 factors:

$$Yijk = X... + Xi.. + X.j. + Xij. + error$$

where $X...$ = general mean, $Xi..$ = RLI effect, $X.j.$ = repetition effect, $Xij.$ = interaction RLI*repetition, *error* = residual.

Effect of light on rattan growth in the field: shade adjustments

In 1996, a study was carried out to evaluate the effect of canopy cover on rattan growth. In a compartment planted in 1993 with *C. subinermis,* three plots (A2, A4, A6, each 60 m x 70 m) received a shade adjustment treatment. Twenty metres away from each of the three plots, control plots of the same size were established (A1, A3, A5).

The following shade treatment was carried out in September 1996:

- all non-commercial trees with a diameter as breast height (dbh) less than 15 cm were felled;

- all non-commercial trees with a dbh larger than 15 cm were girdled;
- all lianas and bamboos that could affect rattan growth were eliminated; and
- all small commercial trees (dbh < 20 cm) with bad form were eliminated.

In the centre of the six plots, smaller subplots of 30 m x 30 m were set up for the following measurements:

- light, using LICOR quantum sensors;
- rattan length; and
- mortality of the girdled trees.

The light measurements were obtained by placing eight LICOR sensors along a planting line, one every four rattans, for a 12-hour period. The measurements were carried out before the shade treatment (August 1996), just after the treatment (October 1996) and one year after the treatment (August 1997).

Environmental variability and rattan growth

These series of observations were carried out between 1995 and 1996 on a *C. subinermis* stand, planted in 1991. One hundred sampling points were established over a compartment of about 150 ha. A stratified sampling (where two strata of canopy opening were established in order to avoid over-representation of very shaded situations) and a random sampling within each layer were used to select each point. The mid-point of each plot was established on the middle line between the two rattan lines. In each sampling the following measurements were taken:

- length [LEN] and survival of the two nearest rattans;
- slope [SLO], bearing [BEA], aspect [ASP];
- light, with the help of pictures taken by a Fish-eye [SH1] and read by digital scanning;
- soil conditions (three horizons: Ao [SOM], A1 [SOA] and B [SOB]);
- forest type [FOR], percentage of dipterocarps [DIP], other timbers (OT) and pioneer trees (100-DIP-OT); and
- species, diameter and distance (from the centre of the sampling point) of each tree within a circle of 10 m radius.

For each sampling circle, a competition index (CI) was calculated as follows:

$$CI = \Sigma(diam_i / dist_i),$$

where $diam_i$ and $dist_i$ are respectively the diameter and the distance from the centre of the plot of each *i*th tree within the sampling circle. The number of trees/ha (NT) and the basal area/ha (BA) were also calculated. This index allows weighting of the competition from a neighbouring tree based on its diameter and distance from the rattan. The nearer and larger the tree, the larger its CI weighting, and vice versa.

Unfortunately, in November 1996, elephants destroyed about 10% of the plants in two plots, A2 and A4 (both treated by shade adjustment). Because of the extent of the damages, these plants had to be discarded from subsequent measurement and analysis. The damages were concentrated on the tallest rattans; thus the results of these two plots were in some way biased downward.

Results

Effect of light on rattan growth in the nursery

In the nursery, significantly different responses ($p < 0.01$) to light treatments were detected for all species (Table 1). The repetition effect was generally not significant, except for *C. ornatus*. *Calamus manan* clearly grew better under low light intensities, while *C. merrillii* preferred more light. The gain in growth under the best treatment was 48% for *C. manan* and 45% for *C. merrillii.* For *C. ornatus* and *C. subinermis*, the light requirements seemed to change over time. In the first measurements these species did better under low light, while later they required more abundant light.

Table 1. Response of rattan seedlings to different shade regimes, 8 and 12 months after transplanting. Shoot length, measured (in cm) from the base of the collar to the last leaf insertion.

8 months after transplanting	*C. ornatus*	*C. merrillii*	*C. manan*	*C. subinermis*
RLI = 61%	10.9 a*	12.7 a	5.6 a	9.8 a
RLI = 42%	10.0 b	11.2 b	6.5 b	9.4 a
RLI = 22%	11.5 a	10.0 c	10.4 c	10.4 b
LSD	*0.6*	*0.6*	*0.7*	*0.5*

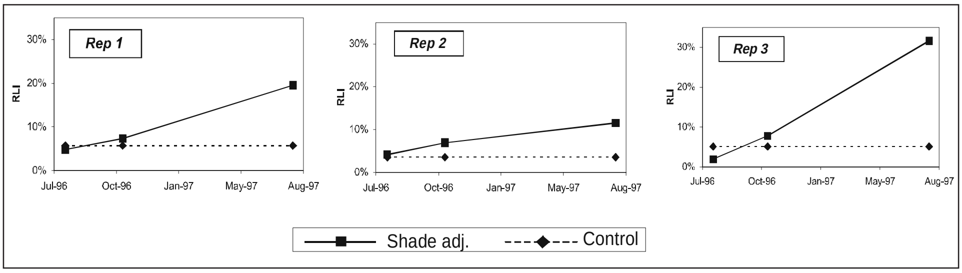
1 year after transplanting	*C. ornatus*	*C. merrillii*	*C. manan*	*C. subinermis*
RLI = 61%	18.1 a*	21.1 a	9.8 a	17.4 a
RLI = 42%	15.9 b	15.6 b	10.2 a	14.7 b
RLI = 22%	14.8 c	14.6 c	14.5 b	14.4 b
LSD	*0.8*	*1.0*	*1.2*	*0.6*

Note: * Duncan ranking (two treatments are significantly different if they have a different letter).
LSD: Least significant difference between two treatments.

Effect of light on rattan growth in the field: shade adjustment

The girdling of all adult non-commercial trees was quite effective, gradually killing about 80% of the treated trees (most of the trees died within a six-month period). The death of the girdled trees brought a major change in the amount of light reaching the soil, and hence the young rattans (Figure 1). By contrast, cutting the small non-commercial trees, the small commercial trees with bad form and lianas and bamboo, did not have a significant effect on the canopy opening.

Figure 1. Effect of shade adjustment on the relative light intensity (RLI) within plots (24 sampling points and one measurement every hour over a 12-hour period, per plot) as compared to open conditions (reference sensor on the roof of the nursery building).



On average, the RLI at the seedling level before the shade adjustment treatment was only 3% (standard deviation, sd = 3.9%); one year after the treatment, the RLI averaged 20.7% (sd = 15.4%). The shade adjustment was most effective in plot 2, where the RLI increased from 2% to 31%.

In the three plots, before treatments, the rattan lengths were substantially different (two-way ANOVA analysis), probably due to the heterogeneous environmental conditions. Consequently, the three 'plots' could not be regarded as repetitions of the same treatment. Therefore, they were analysed by three independent one-way ANOVA tests (Table 2).

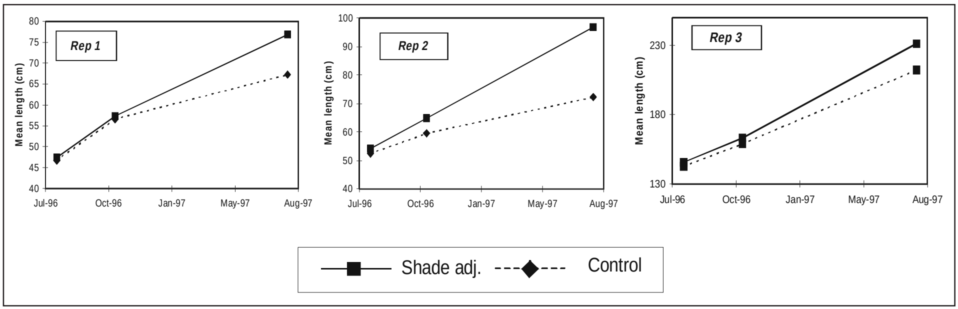
Table 2. Effect of shade adjustment on rattan growth, one year after the treatment.

	Control (1)	Shade adjustment (1)
Repetition 1	Plot A1: 67.2	Plot A2: 76.8 (ns)
Repetition 2	Plot A3 66.6	Plot A2: 96.8 (*)
Repetition 3	Plot A5: 212.3	Plot A2: 231.4 (ns)

(1) Significance level of the difference between the treatment and control
ns = not significant; * = 0.01

The gain in rattan growth induced by shade adjustment was 18% over the whole experiment (Figure 2), but this difference was not statistically significant. One of the main reasons for the lack of significance is that, even within plots, there was still a lot of variability both in the environment and in rattan size. However, all three plots showed the same pattern, i.e., rattans responded positively, even if to a small degree, to the increased light. The exclusion of the tall plants destroyed by elephants without doubt lowered the average of plots 2 and 4, resulting in less difference between treatments. Finally it has to be noted that, at the time of the experiment, this rattan was already three years old, and many plants had been stagnating for a long time at the rosette stage. Probably the rattan response would have been more pronounced had the treatment been applied earlier.

Figure 2. Effect of shade adjustment, as compared to control, on rattan growth. Means for each plot (control and treatment) within each repetition (1, 2 and 3).



Environmental variability and rattan growth

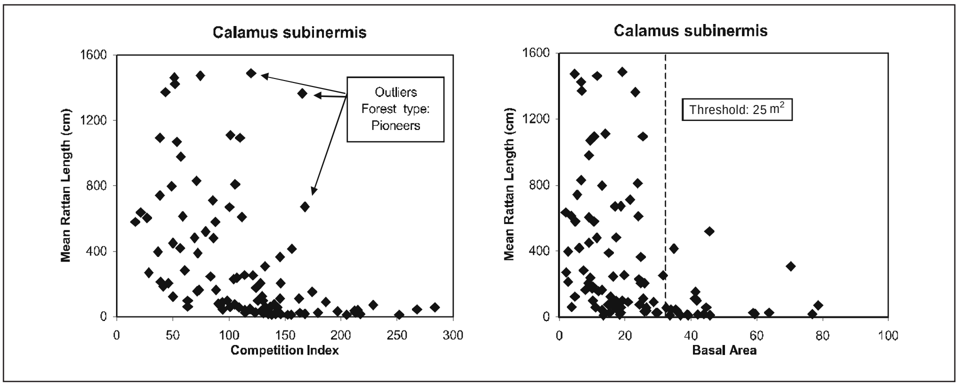
A standard analysis of variance revealed that the differences in rattan length among the 100 plots were significant at the 0.001 level. Multiple regressions between the rattan length and the whole set of the characteristics specified above, resulted in a correlation coefficient of 0.48 (Table 3). This means that 23% of the variation in rattan growth can be predicted by using the environmental variables.

Table 3. Multiple regression results of rattan growth against environmental variables.

Variable	Correlation with rattan length	Significance level
CI	-0.45	0.0001
BA	-0.35	0.001
NT	-0.33	0.01
SH1	0.31	0.01
DIP	-0.31	0.01
FOR	0.20	ns
ASP	-0.19	ns
SOA	0.16	ns
BEA	-0.13	ns
OT	0.09	ns
SLO	-0.09	ns
SOM	0.07	ns
SOB	0.01	ns

The characteristics linked to forest density (BA, NT and DIP), and in particular the Competition Index (CI), were closely linked with rattan growth. Light (SH1) was also related to growth, but was less significant. In general, the lower the competition, the density, the shade and the percentage of dipterocarps, the better the rattan growth (Figure 3).

Figure 3. Relationships between rattan length growth and two forest descriptors, the basal area and the competition index. The relationship with CI is improved if only dipterocarp trees are considered.



Calamus subinermis

Calamus subinermis

There was a threshold in stand density (around 25 m^2/ha of basal area) and competition (CI = 125) beyond which the rattan cannot grow (Figure 3). The rattans in this compartment were planted five years before the observations. Below this threshold rattan growth can be improved significantly; however, it is not worth planting where the stand is denser. Improvements in rattan growth were achieved in the Luasong conditions by selecting the forest stands to be planted according to their density (Table 4). Another way to view these results is to consider the capital that can be saved by not planting those points were the stand is too dense and rattan growth is expected to be poor.

Table 4. Gain in rattan growth achieved in Luasong by selecting the points to be planted according to density.

Sampling Point Basal Area	Mean rattan length	% improvement (compared to the general mean of compartment)	% of sampling points in category
less than 15 m^2	518 m/ha	55	38
less than 20 m^2	432 m/ha	39	57
less than 25 m^2	441 m/ha	32	66
less than 30 m^2	410 m/ha	23	75
less than 35 m^2	394 m/ha	18	80
less than 40 m^2	372 m/ha	11	85

Rattan should not be planted in forest compartments or sub-blocks with a basal area exceeding 25 m^2/ha (in our sample, 34% of the sampling points had a basal area above 25 m^2/ha). A gain in the rattan growth of 32% may be predicted if these points are avoided.

A second group of variables (ASP, SOA, BEA, OT, SLO, SOM and SOB) showed no significant effect on rattan growth. A factorial correspondence analysis (not shown) confirmed this pattern.

The specific contribution of dipterocarp and pioneer trees to the competition index and to rattan growth has been explored elsewhere. Competition from dipterocarp trees has a much more important effect on rattan growth than competition from pioneer trees (pers. obs.)

Conclusions and Discussion

The present studies revealed that the two key factors having a major impact on rattan growth in the enrichment plantings were light and competition from surrounding trees. No effects resulting from other factors as slope, topography and soil composition were detected. Furthermore, the study of the effect of environmental variation on rattan growth showed that competition from surrounding trees (especially dipterocarps) was more important than the effect of light. One reason for this may be that light is a difficult parameter to measure, because of its variation around the year, the difficulty of knowing which radiation length is most used by the plant, and problems of measuring the diffuse radiation. Another important reason may be that competition, in addition to the light effect, may include other effects due to competition for nutrients, water and space availability, etc.

Estimating competition in the forest with an adequate approximation seems not to be a very difficult task. In addition, the competition index and basal area on small plots are closely correlated, and by measuring the local basal area with classical methods (both in the field and/or by using aerial photos) can give a good estimation of local competition. Advance marking of the area to be planted based on forest density was tested and was shown to be feasible. In practice, a trained forest ranger walks along the lines and labels the points to be planted; the workers then follow with the planting operation. On a larger scale, aerial photo interpretation can discriminate among compartments according to their suitability for planting.

The results of the nursery experiment will allow definition of optimal light treatments specific to each species. Furthermore, even if the light requirements change over life stages, some rattan species appear to be more shade tolerant than others. Planting can thus adjust the species distribution in the field by matching the species light requirements with the compartment characteristics. Although rattan growth was stimulated by canopy opening, a better response might be expected if the treatment was applied just after planting rather than several years after, as was the case in this study. Shade adjustment may also benefit other valuable tree species in the forest. The costs and benefits are currently under evaluation at Luasong.

Combining the information on competition and light effects will help to optimise the rattan planting technique. An accurate choice of the compartments and points to be planted, together with appropriate shade adjustments, may significantly improve rattan performances in the ICSB's commercial plantation.

Acknowledgements

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9. Secondary Logging in Natural Forests in Central Kalimantan: Operational Design, Production and Damage Assessment

Nunuk Supriyatno[1] and Gero Becker[1]

Abstract

The aim of this study was to define an optimal way to harvest logged-over forest through detailed pre-felling planning and careful logging operations. Three experimental logging plots, each 4 ha, were located within a logged-over lowland dipterocarp forest in Central Kalimantan. Intensity of timber extraction at the first cutting, 11 years prior to the study, was an average of 6.1 stems/ha, with a commercial timber volume of about 38 m³/ha. The density of old skidding trails was 282.5 m/ha. Before secondary logging, all trees (dbh ≥ 20 cm) were measured, numbered and mapped. Mean tree density and basal area were 170.7 stems/ha and 21.16 m²/ha, respectively. Commercial species represented 41.3% of the total tree population and 55.9% of the basal area. An average 19.5 stems/ha of harvestable trees (commercial species, dbh ≥ 50 cm) were present, but only 15.7 stems/ha (80.4%) were of good stem quality. The minimum diameter of trees to be felled was 60 cm with a cutting intensity 20-25% of harvestable trees.

To minimise soil disturbance and damage to the remaining stand, the skidding trail network and landings were carefully planned, initially on a map and then in the field. Felling direction was prescribed prior to harvesting. A average of 3.6 stems/ha were extracted with a commercial timber volume of 27.75 m³/ha. Dipterocarps contributed 90% of extracted timber. Secondary logging damage affected only 8.7% of the original tree population or 6.7% of the original basal area. Felling was more damaging than skidding. The area of soil disturbed by skidding was 5.6%. Density of skidding trails in the secondary logging totalled 123.9 m/ha, consisting of 73% old and 27% new skidding trails.

Introduction

Natural production forests in Indonesia are selectively harvested under the *Tebang Pilih Tanam Indonesia* (Indonesian Selective Cutting and Planting System) or TPTI. In Sumatra and Kalimantan, 56% of the production forest has been exploited (Direktorat Jenderal INTAG 1996) and could be classified as logged-over forest. Most of the remaining virgin forest (44%) lies in remote and inaccessible areas.

Under TPTI regulations, logged-over areas can be harvested again 35 years after the first cutting. Increasing demand for timber as a raw material for wood-based industries, developments in wood-processing technology and changes in wood market requirements

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(species, dimensions, etc.) has expanded the potential for the utilisation of logged-over forests. In the next few years the role of logged-over forests in providing raw materials for wood-based industries will be of growing importance.

Harvesting, as a component of forest management and silviculture, should be conducted efficiently with regard to environmental protection and conservation. Conventional logging methods as used in virgin forests were very often inadequate, in terms of both efficiency and environmental impact. There is an urgent need to improve harvesting methods to sustain the productivity of the forest and to reduce impacts on the environment. In South-east Asia, such improved harvesting techniques (known as controlled logging, reduced-impact logging, low-impact logging) have been developed in recent years (Bol and Beekman 1988; Setyarso 1989; Sumitro 1989; Hendrison 1990; Ruslim 1994; Bertault and Sist 1995, 1997; Cedergren *et al.* 1995; Elias 1995; Pinard *et al.* 1995; Dykstra and Heinrich 1996; Marsh *et al.* 1996, Sist *et al.* 1998). The impact of re-logging can be reduced even more significantly if the ‘old’ secondary roads and skidding trails are used again. Directional felling techniques must be executed to take advantage of the existing openings in the upper storey of the canopy.

The main objective of this study was to develop an adapted low-impact harvesting method for logged-over forests in Central Kalimantan. This paper presents the structure of the logged-over forest, timber production of the forest and an assessment of harvesting impacts on the remaining stand and forest soils.

Study Area

The study was conducted in a forest concession operated by PT. Dwimajaya Utama (DU) in Central Kalimantan, situated about 150 km north-west of Palangkaraya. Three experimental plots of 4 ha each (200 m x 200 m) were located within a logged-over forest, in the 1985-1986 annual coupe of the concession. Before this first logging, the original forest was a lowland evergreen, mixed dipterocarp forest.

The average annual rainfall for the area over the period 1983-92, taken from the climate station Cilik Riwut near Palangkaraya, was approximately 3000 mm. July was the driest month with a mean of 12.4 rainy days and an average rainfall of 113 mm. The wettest month was December with a mean of 24.9 rainy days and an average rainfall of 363 mm. The average annual temperature was 27° C, ranging from 22° to 33° C. The relief of the area is flat to gentle with elevations ranging from 90 to 140 m asl. Soils in the area are red-yellow podzolics, lateritic type.

Methods for Controlled Logging Implementation and Damage Assessment

Pre-felling inventory

In the three experimental plots and prior to logging, all tree species (dbh $\geq$ 20 cm) were measured, numbered and mapped. Stem quality, especially of mature trees (dbh $\geq$ 50 cm), was noted. Additional observations to describe the characteristics of the first logging were made. Cut stumps were counted and mapped, and old skidding trails were measured, using changes in vegetation structure and composition as indicators, and also mapped.

Natural regeneration (seedlings, saplings and poles) was estimated through systematic sampling. Poles (trees with dbh ranging from 10 to 19 cm) were recorded in 100 sub-sample plots (10 m x 10 m each) set up along cruising line within each experimental plot and at 20 m intervals. In each of these sub-plots, a quadrat for saplings (5 m x 5 m) and seedling (2 m x 2 m) was also set up. A topographic survey was conducted simultaneously with the timber cruising. An altimeter (ALPIN EL, precision ± 8 m, resolution 0.5 m) was used to measure the elevation of deflection points along the cruising and border lines. Other important physical features (river, swamp area) were recorded and mapped.

Harvesting planning

Harvesting diameter limit

According to TPTI regulations, all marketable timber trees with a minimum diameter of 50 cm can be felled in production forests. To reduce damage on the forest ecosystem, only about 20-25 % of harvestable trees, with a minimum dbh of 60 cm, were extracted in this study.

Planning: roads, landings, skidding trails and felling

The layout for opening the forest was designed prior to harvesting, based on the still-existing infrastructure (forest roads, log landings and skidding trails), topography, location of trees to be felled, and the optimal possible felling direction. Two to three layout variations were prepared for each experimental plot, first on a map, then checked in the field and evaluated. The selected opening up layout, including the felling directions, was marked in the field and mapped. The direction of fall for each tree was determined based on the position and condition of the tree to be felled, prevention of damage to neighbouring trees and the position of skidding trails

Logging operations

Felling was carried out by one chainsaw operator and one helper using a chainsaw STHIL 070. Skidding was operated with a crawler tractor (CAT D7G, 200 HP) equipped with angle blade and winch. Before logging commenced, a discussion about the harvesting plan was conducted with the logging team.

A combination of short-log and tree-length logging was executed. The felling sequence involved trees at the border of the transport line or furthest from the landing being cut and skidded first. Bucking was done at the stump area if the log weighed over the skidding capacity or if the log length was more than 25 m. Dozing of top soil and soil vegetation during the opening of skidding trails was prohibited. The tractor manoeuvred only on skidding trails or landings, no manoeuvring in the stand was allowed. Stationary log pulling (winching) from stump area to skidding trail was practised. Hooking could be done at the bottom or top of the log. The log was skidded as close as possible to the winch in order to avoid the front end of the log ploughing the soil along the skidding trails. Logging operations were allowed only during dry weather.

Assessment of logging damage

In the 3 plots, damage assessment to the residual stand was carried out immediately after felling (felling damage) and then again after skidding operations were complete (skidding damage). Two types of damage (crown and stem damage) each including 5 categories (Tables 1a and 1b) were adopted based on the damage classification set up by Nicholson (1958). Trees with two different types of damage were put into the most damaged category. Re-inventory of natural regeneration was done in the same sub-plots in order to quantify the damage to regeneration.

Table 1a. Crown damage.

Code	Categories	Description
1	Light	Crown injury up to 25%
2	Moderate	Crown injury 25 - 50%
3	Heavy	Crown injury 50 - 75%
4	Severe	Crown injury > 75%
5	Death	Broken trunk

Table 1b. Stem damage.

Code	Categories	Description
1	Light	bark and wood injury up to 30 cm
2	Moderate	bark and wood injury 31 - 150 cm
3	Heavy	bark and wood injury 151 - 300 cm
4	Severe	bark and wood injury > 300 cm
5	Death	Uprooted, broken bole

Source : developed from Nicholson (1958).

Areas affected by skidding operations were also measured in each plots. Criteria of soil disturbance developed by Dyrness (1965) and Ruslim (1994) were used to assess the degree of soil surface disturbance (Table 2).

Table 2. Soil surface disturbance categories and description.

Code	Categories	Description
0.	Undisturbed	Vegetation and litter still in place and no evidence of compaction
1.	Light disturbed	Vegetation and litter removed, undisturbed top soils exposed
2.	Deeply disturbed	Top soil removed and subsoil exposed
3.	Compacted	Obvious soil compaction due to passage of skidding equipment and logs
4.	Earth moving	Cut and fill of earth surface during the construction of skidding trails

Source : developed from Dyrness (1965) and Ruslim (1994).

Results

Characteristics of the first logging

Existing roads and skidding trails

Existing main roads in the research area are still used and regularly maintened. The still-existing secondary roads opened during the first logging operation in 1985 were covered by pioneer vegetation and could not be used. Landings and old skid-trails were also covered by pioneer vegetation. There was no longer any bare soil surface. The former skidding trail network used during the first logging operation was on average 282.5 m/ha (Table 3). This converts to an average skidding distance to the trail of approximately 35 m. The skidding trails were poorly aligned, not regularly distributed and mostly concentrated towards harvested trees. This is a typical picture of uncontrolled conventional selective logging practices. All the old skidding trails could be potentially used in the second harvesting operation.

Table 3. The existing skidding trail density in the three experimental plots (4 ha each).

Plot number	Old skidding trails	
	Length (m)	Density (m/ha)
01	1 115	279
02	1 195	299
03	1 080	270
Mean±SD	1 130± 58.9	282.6±14.8

Intensity of timber extraction in the first harvest

According to the concession annual report, the area of the annual coupe for 1985-86 was 1040 ha, with a commercial timber production of 38.3 m^3/ha. Before the first logging in 1986, average volume of harvestable standing stock (commercial species, dbh ≥ 50 cm) in the area was 65.6 m^3/ha. Logging intensity in the first cutting was not intensive since only 58% of the harvestable standing stock was extracted. It was a 'high graded logging' where only the best timber trees with a minimum diameter of 70 cm were harvested. In the experimental plots, the average number of cut stumps in the first cutting over three plots (12 ha) was 6.1 stems/ha, ranging from 0 to 12 stems/ha. Based on an average volume of 8m^3/tree, merchantable volume extracted can be estimated as 49 m^3/ha.

Log production during the second logging cycle

Eleven years after the first logging, mean tree density (dbh ≥ 20) was 171 stems/ha (SD = 23, n=12) ranging from 138 to 210 stems/ha. The mean total basal area was 21.2 m^2/ha (SD = 3.7, n =12). Commercial species represented an average of 41.3% of the total tree population or 55.9% of the basal area. The mean number of potential crop trees (dbh 20-49 cm), which are the expected timber resource for the next cutting, was 54 stems/ha (Table 4).

Table 4. Diameter distribution of the stand before second cycle logging.

Species	Diameter class						Total	
	20 – 49 (cm)		≥ 50 cm		≥ 60 cm		≥ 20 cm	
	N/ha	V (m³)	N/ha	V (m³)	N/ha	V (m³)	N/ha	V (m³)
I. Protected tree species	4.67	4.04	3.25	18.25	2.00	14.81	7.92	22.29
II. Commercial								
Dipterocarp	45.25	36.47	16.33	94.26	10.83	80.03	61.58	130.74
Non Dipterocarp	8.75	7.26	3.17	14.98	1.83	10.71	11.92	22.24
Total II	54.00	43.73	19.50	109.24	12.67	90.74	73.50	152.97
III. Non commercial	83.33	53.06	5.83	24.08	3.08	16.85	89.17	77.14
Total I, II, III	142.00	100.82	28.58	151.58	17.75	122.40	170.58	252.40

Before the second logging operation, in the three plots, the average number of mature trees (dbh ≥ 50 cm) of commercial species was 19.5 stems/ha with a mean volume of 109.24 m³. Due to their position within the block and/or terrain difficulties, as well as poor stem form and damages, not all mature trees of commercial species were harvested. On average there were only 15.7 stems/ha, or about 80% of total mature trees with good stem quality, selected for extraction during the second harvesting operations (Tables 4 and 5). Among these best quality timbers, only 43 trees were extracted in the three plots during the secondary logging operation. Mean number of felled trees was 3.6 trees/ha representing a mean extracted volume of 27.75 m³/ha (Table 6). Dipterocarps of the genus *Shorea* and *Dipterocarpus* represented 93% (40 trees) of all the harvested trees (Table 6). The low harvesting intensity resulted from our set of criteria to select or reject a tree for felling. When possible, only the best quality stems (prime and first grade) were felled and priority was given to the most valuable species such as *Shorea lamellata* or *S. johorensis*. Moreover, trees on steep slopes (> 40%), trees with potential risk for the fellers, or trees located in opened areas were not felled.

Clear bole volume averaged 7.81 m³/tree. The biggest tree extracted was *Shorea lamellata*, with a bottom diameter without bark, clear bole length and clear bole volume of 130 cm, 26.2 m and 27.67 m³ respectively.

Table 5. Mean number of harvestable trees per ha in the three experimental plots before logging.

	Total	Defective		Harvestable	
	n	n	%	n	%
Min	10	1	5.9	9	64.3
Max	34	8	35.7	27	94.1
Mean ± SD	19.5 ± 6.7	3.8 ± 2.3	19.6 ± 10.9	15.7 ± 5.6	80.4 ± 10.9

Table 6. Harvested tree species and extracted volume in the three experimental plots (12 ha).

Species	Number	Volume (m³/12 ha)	
	(12 ha)	Felled	Extracted
I. Dipterocarps			
Shorea spp.	36	271.8	268.9
Dipterocarpus spp.	4	37.8	37.8
Total I	40	309.6	306.7
II. Non-dipterocarps	3	26.3	26.3
Total I & II	43	335.9	333.0
Mean/ha ± SD	3.6 + 1.6	28.0 + 13.3	27.7 + 13.2

Characteristics of the opening for secondary logging

Skid-trail density averaged 123.9 m/ha, consisting of 73% old and 27% new skid-trails. Average distance or spacing between skid-trails was derived theoretically from skid-trails density, to describe the layout of the skid-trail network. Skidding distances within a plot were measured from the hooking point of each log to the outlet at the border of the plot. Average skidding distances within a plot and in total to the log landing were 173 m and 354 m respectively (Table 7).

Table 7. Skid-trail density and average skidding distance.

Skid-trail	Minimum	Maximum	Mean ± SD
Density (m/ha)	107.0	141.3	123.9
Old skid-trails (m)	83.1	93.8	89.7 + 5.8
New skid-trails (m)	13.3	48.9	34.2 + 18.6
Skid-trail spacing (m)	71	93	81 + 11
Average skidding distance (m)			
Within a plot	0	317	173 + 85.6
To landing	60	587	354 + 134

Logging damage

Damage to residual stand

Logging damage affected an average of 8.7% of the original tree population and 6.9% of the original basal area. The proportion of injured and dead trees was the same in terms of tree numbers and basal area. An average of 89% of the original tree population was not damaged by secondary logging (Table 8). Overall, 77% of all damaged trees (injured and dead) were in the 20-40 cm diameter class, consisting of 31% commercial species and 46% other species (Figure 1). Felling was more destructive than skidding.

An average of 63% of total damaged trees and 73% of total dead trees was caused by felling operations (Figure 2).

Table 8. Damage to residual stand (dbh³ 20 cm) based on tree number (N) and Basal Area (BA).

	Mean/ha ± SD (N=12)			
	N	%	BA (m²)	%
Original tree population	170.6 ± 23.0	100	21.2 ± 3.7	100
Felled	3.6 ± 1.6	2.1	1.8 ± 0.8	8.7
Injured trees	8.7 ± 4.5	5.1	0.8 ± 0.4	3.7
Dead trees	6.6 ± 5.1	3.8	0.7 ± 0.6	3.3

Figure 1. Diameter distribution of damaged (injured and dead) trees.

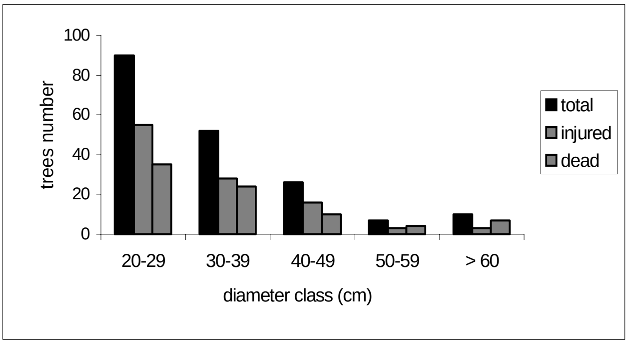
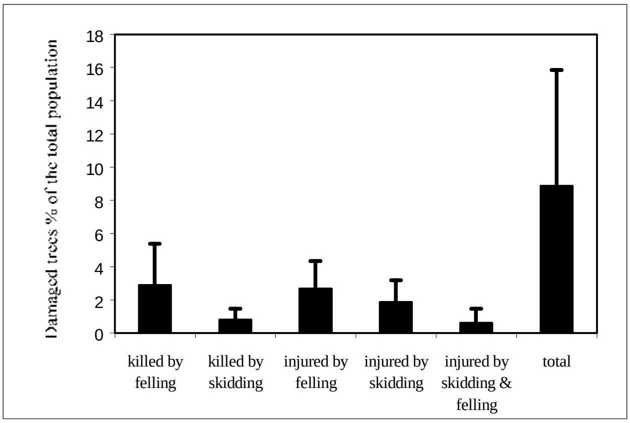


Figure 2. Proportion of trees (% of the original population) injured and killed during harvesting according to the logging operation (injured by felling, killed by felling, injured by skidding, killed by skidding, total damage).



Damage to natural regeneration

Damage to seedlings, saplings and poles of all species (total) averaged 17%, 16% and 14% of the original population, respectively. Damage to regeneration of commercial species in each stage was about 1% below this average for all species (Table 9).

Table 9. Regeneration status before and after secondary harvesting (n/ha).

	Before harvesting N/ha + SD		After harvesting N/ha + SD		Damage (%) + SD	
	Com.	All	Com.	All	Com.	All
Seedlings	4592 ± 2012	10400 ± 4400	3858 ± 1662	8658 ± 3363	16 ± 14	17 ± 11
Saplings	980 ± 574	2824 ± 257	831 ± 471	2375 ± 475	15 ± 7	16 ± 9
Poles	149 ± 37	383 ± 38	130 ± 29	330 ± 39	13 ± 9	14 ± 8

Disturbed areas

On average, 5.6% of the total area of the plots was affected by skidding. Of the total affected area, 41.4% was seriously disturbed (disturbance categories 2 to 4, Table 10). Most new skidding trails were in disturbance category 4, because they were constructed using cut and fill techniques, whereas the soil was less severely affected where old skidding trails were used.

Table 10. Soil disturbance and disturbance categories.

	Average		Minimum		Maximum	
	m^2	%	m^2	%	m^2	%
Affected area in plot	2244.4	5.6	1967.0	4.9	2494.8	6.2
0. undisturbed	182.5	7.6	0.0	0.0	315.1	12.6
1. light disturbed	1141.9	51.0	819.7	36.1	1150.4	58.5
2. deeply disturbed	373.7	17.5	163.7	6.6	535.0	27.2
3. compacted	172.1	7.2	0.0	0.0	250.7	11.0
4. earth moving	374.3	16.7	295.0	11.8	546.2	24.0

Discussion and Conclusion

Repeated logging in natural forests has much higher impact than first harvesting operations in primary forest. Repeated logging over short time periods will compromise both natural regeneration and commercial tree regrowth (Korsgaard 1985; Whitmore 1990). For this reason, it is very important during secondary logging to reduce as much as possible the damage on the forest ecosystem. A detailed pre-felling inventory, including a topographic survey and tree location map, provides a good basis for the preparation of a better harvesting plan. A careful pre-planning of felling operations and skid-trail networks leads to a significantly lower level of damage to the residual stand and forest soil (Hendrison 1990; Bruenig 1996; Sist *et al.* 1998). Moreover, experienced or trained workers, adequate supervision and adapted logging equipment are also important to support low-impact logging operations (Hamilton 1987; Becker 1995; Dykstra and Heinrich 1996; Sist *et al.* 1998). This study demonstrated that logging damage can be substantially reduced if the pre-harvesting operations outlined are carried out.

Eleven years after first harvesting, the logged-over forest contains a sufficient number of mature trees to be harvested. The results from this study are similar to others on the condition of logged forest from the South-east Asian region (for South Kalimantan, see Setyarso 1989 and Sumitro 1989; for West Kalimantan, see Cannon *et al*. 1994; for Sabah, see Appel 1996). This relative high density of harvestable trees must be correlated to the logging practices occurring in the past. During the previous decade (roughly 1980-1990) only the best quality timber trees were harvested, mainly red meranti. As a result forests logged about ten years ago still show very high commercial potential in regard to the present market demand which now includes all the meranti (red, yellow and white) as well as Keruing (*Dipterocarpus* spp.), which were rarely harvested until the late 1980s. In the study area, the standing stock was still very high with a mean of about 81m^3/ha. However, reduced-impact logging efficiency in reducing the damage on residual stand is limited by felling intensity (Sist *et al.* 1998). Therefore, in order to minimise negative logging impacts, only about 20-25% of standing stock was extracted. It resulted that logging intensity was low (3.6 stems/ha on average) and logging impact significantly reduced. Stand structure after secondary logging showed no significant deterioration. It still consisted of more than 10 stems/ha of harvestable trees, more than 35 stems/ha of undamaged potential crop trees (commercial species, dbh 20-49 cm) and an adequate amount of natural regeneration (seedlings, saplings and poles). In these conditions, continuous and sustainable log production could be expected on a long-term basis. However, long-term research on monitoring forest dynamics is still needed to analyse forest regeneration and productivity after logging.

Compared with so-called conventional logging operations in virgin forests, logging damage both in terms of damage to the residual stand and disturbance to forest soils was low. Based on reports of damages in secondary logging from other places (Hendrison 1990 in Suriname; Setyarso 1989 and Sumitro 1989 in Pulau Laut, South Kalimantan; and Appel 1996 in Sabah, Malaysia), the figures for logging damages in this study are considered to be relatively low. Clearly logging damage can be successfully reduced through an adequate logging plan, directional felling and careful control of logging operations. Low intensity selective logging on a polycyclic system closely mimics the natural processes of forest dynamics and scarcely alters composition (Whitmore 1990).

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10. Contribution of Radar Imagery to Tropical Forest Monitoring and Management

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Abstract

A general state-of-the-art assessment is presented of the possible usefulness of radar images for tropical forest inventory and monitoring, using examples from Indonesia.

This decade has seen the launch of new spaceborne sensors using synthetic aperture radar (SAR) technology: ERS-1 and ERS-2 (European Space Agency), J-ERS (NASDA, Japan) and Radarsat (Canadian Space Agency). These tools offer new opportunities to monitor land surfaces and particularly tropical forests, although it has not yet been used operationally for applications at local and regional scales. In addition to their all-weather capabilities, ensuring repetitive acquisition day or night, microwaves used by SAR can probe vegetation covers and are sensitive to some extent to cover structure, biomass and water status. In addition, multi-temporal use of SAR images allows monitoring of environmental and man-made changes such as clear-cutting of primary forest or burnt areas such as were the result of the large Indonesian fires that occurred in 1997. However, this technology is relatively new and the information content relative to tropical forest characteristics and their dynamics still need to be understood for the development of robust applications useful for tropical forest management. In addition, significant limitations, specific to SAR images, exist for which recent research results can hopefully provide operational solutions with in-house or commercial image processing software: availability of 1 channel for a given sensor speckle noise and image distortions in hilly terrain situations.

This paper discusses the main areas where SAR images can play a role in the monitoring of tropical forests: land cover and forest type mapping; forest monitoring and mapping of clear-cutting; and the construction of Digital Elevation Models.

Introduction

Most studies of tropical forests using remote sensing have been conducted mainly because of the important role that large extents of forest play in global cycles and climate change issues (for example, the TREES project: Malingreau *et al.* 1989, 1995a,b; Malingreau and Duchossois 1995); the latter expressing the need for major scientific research efforts. For more local or immediate contributions in tropical forestry, the use of remote sensing has generally been limited, in contrast to temperate regions where high resolution optical satellite data (SPOT, Landsat TM) have found routine

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applications in forestry (Leckie 1990). The main reason is the difficulty to acquire cloud-free high resolution images in tropical regions. The probability of obtaining clear images can increase with a shorter revisiting period, as with the NOAA AVHRR sensor and its daily cycle. However, the better temporal resolution is obtained at the expense of spatial resolution (~1 km), undermining applications apart from those carried out at regional to global scales. Now that an international agreement has been reached on the necessity for timber production to originate only from sustainably managed forests by year 2000, cost-effective tropical forest monitoring and management tools are essential, and remote sensing could be one of them.

A technological solution to the problem of cloud coverage is the use of Synthetic Aperture Radar (SAR) systems. These active microwave sensors use electromagnetic radiation within a range of wavelengths (2-70 cm) to which atmospheric bodies like cloud, haze or even smoke are mostly transparent. Another interesting feature of microwaves is their ability, depending on the wavelength used, to penetrate a forest canopy. The radar echo measured by the sensor, called the backscattering coefficient, therefore carries some information about the canopy (biomass content, structure, water status). Moreover, multi-temporal use of SAR images allows monitoring of environmental and man-made changes such as logging of primary forest or burnt areas. The fact that data availability is not subject to weather conditions makes possible the planning of data acquisition at particular times during the year when forest information is needed.

For the last five years, the most notable progress in the field of earth observation by satellite has been the availability of SAR images. To date, three different civilian satellite SARs are operational (European ERS-2, Japanese JERS-1 and Canadian RADARSAT) ensuring an almost global coverage on a regular basis. Research on the potential use of SAR images for forest monitoring have started well before the launch of ERS-1 in 1992. It was based on data acquired by the Seasat satellite during its three month operating period, during the three Space Imaging Radar shuttle missions (SIR-A, SIR-B and SIR-C), or with airborne SARs, most of which were experimental systems to help define future spaceborne SARs. However, today's airborne systems offer great opportunities to map tropical forests with a high resolution, often more adapted to local management problems.

Due to the specific nature of SAR data, their use in tropical regions has not yet spread to meet the role played by optical images in temperate regions. In this paper we present a brief overview of the actual limits of this promising tool as applied to tropical forest studies, while focusing on the proven applications which are potentially operational and based on presently available satellite SAR data.

Radar Principles

As an active microwave sensor, a Synthetic Aperture Radar sends microwave (frequency modulated) pulses towards the surface to be observed, and receives the wave backscattered from that surface. The SAR system is composed of two main parts. The first is the instrument itself, on board a moving platform (i.e., orbiting satellite) and generally presenting one single antenna for transmission and reception.

The antenna is side-looking (perpendicular to the trajectory of the platform) and points obliquely to the observed surface. The other part is called the 'SAR processor' which is responsible for synthesising image data from backscattering information received by the instrument during operation. Imaging radars are considered advanced systems which rely on sophisticated signal-processing techniques to achieve a relatively good spatial resolution of the images.

The configuration of a SAR system is defined by many parameters, of which the following are the most important:

- frequency/wavelength of the microwave band (for example, L band ~23 cm, C band ~5 cm)
- polarisation of the transmitted and received waves (for example, VV, HH or HV; V: vertical and H: horizontal)
- spatial resolution (10 m to 100 m)
- incidence angle (between 20° and 60°).

Radar Image Characteristics

The backscattering coefficient $\sigma°$, which depends on the SAR configuration, is also a function of the geometric and dielectric properties of the observed surfaces. SAR image analysis and exploitation is therefore based on a basic understanding of the scattering properties of the surface with respect to the SAR configuration used. In terms of more familiar parameters used to describe land surfaces, the geometric and dielectric properties translate into surface roughness and soil moisture for sparsely vegetated land, and into vegetation water content, biomass and canopy structure for vegetated surfaces. However, as this technology is relatively new, the information available on tropical forest characteristics and their dynamics still need deeper understanding before robust applications can be developed, which are useful for tropical forest management. This is a field where research is already active (Ahern 1993; van der Sanden and Hoekman 1993; Freeman *et al*. 1994; Floury *et al*. 1995; Le Toan 1995; Luckman *et al*. 1995; Hoekman 1997; Luckman and Baker 1997) and for which end-user requirements are pressing. The use of SAR images have the following specific constraints:

- All the present spaceborne SARs operate in one single configuration (one combination of frequency, incidence angle and polarisation; see Table 1). In this case, discrimination of land surfaces is generally poor. Methods exist to avoid this limitation either by using multi-temporal data (images of the same area acquired at different dates), or by combining imagery data from different sensors (Le Toan *et al.* 1994).

Table 1. Main configuration parameters of operating satellite SAR systems.

Satellite	Lifetime	Freq. (GHz)	Polarisation	Incidence (deg)	Resolution (m)	Revisit (days)
ERS-2 (ESA)	1995-	C	VV	23°	25	35
JERS-1 (NASDA)	1992-	L	HH	35°	20	44
Radarsat-1 (CSA)	1995-	C	HH	20-50°	10-100	26 to 1

- The radar waves used by the sensors are by nature coherent, causing the radar images to show a characteristic ‘salt-and-pepper’ noise effect called speckle. This noise is directly responsible for the degraded radiometric resolution of the images and calls for specific image processing techniques. To date, numerous spatial and temporal filters exist to reduce the inconvenient effects of speckle (Lopes *et al.* 1993; Lee *et al.* 1994; Bruniquel and Lopes 1997).
- Radar imagery is known to be particularly sensitive to relief, such that serious image distortions may occur in hilly terrain situations. This problem has been addressed by different research teams (Holecz *et al.* 1993; Van Zyl 1993; Stussi *et al.* 1995) and new methods now exist to remove as much as possible these distortions. The methods either use a Digital Elevation Model (DEM) or are based on channel ratioing.

As the methods mentioned are relatively new, only some of them have yet been incorporated into the Radar Modules of commercial remote-sensing image analysis software. The increasing availability of such tools will certainly favour the utilisation of SAR images for operational purposes in the near future.

Examples of current applications

Although all the three presently operating satellite SARs have been designed primarily for ocean studies, radar imagery has proved useful in numerous land applications, including the observation of forests. SAR images can play a role in a number of fields related to the monitoring of tropical forests in the South-east Asian context.

Land cover mapping

For optical satellite images (i.e., SPOT, Landsat TM), one of the main applications of radar imagery remains land cover mapping including forest type discrimination. However, as already noted, it is necessary to compensate the constraint due to the single configurations of the existing SAR systems by adopting either a multi-sensor approach (e.g., Nezry *et al*. 1993) or a multi-temporal approach (e.g., Le Toan 1995). In the multi-sensor approach, land cover discrimination is made either using radar responses measured by SAR sensors with different configurations (waveband C or L, polarisation VV or HH, and different incidence angles), or by combining optical and radar images. In both cases, the methodology requires a very good geocoding of the images, together with efficient speckle filtering and image classification.

In the multi-temporal approach, the land cover classes will be discriminated not only by their radar backscatter intensity, but also by the temporal variability of these values. For example, it is known that dense primary forest has a very stable radar response compared to agricultural lands, grasslands, swamps or water bodies, and as such can be discriminated from the latter. In a study based on ERS-1 images acquired over nine areas in China, Thailand, Indonesia (Sumatra) and Vietnam, Le Toan (1995) presented promising results obtained using multi-temporal images for land cover mapping in forested regions. Using a methodology based on speckle reduction filtering and temporal image ratioing (taking the ratio of backscatter intensities from images of the same area taken at different dates), it was possible to map evergreen forests, deciduous forests and non-forest areas. Compared to the multi-sensor approach, the implementation of temporal image ratioing is straightforward and has also another non-negligible advantage of drastically reducing relief-induced perturbations. The subsequent segmentation of the ratio images into classes is therefore facilitated. Care must also be taken while selecting the acquisition dates of the images, as this often influences the quality of the results obtained. As a rule-of-thumb, one image acquired during the wet season and the other one during the dry season is generally a minimum.

Another new approach based on multi-temporal ERS SAR data is the interferometric technique, which use the interferometric coherence, that is the modulus of the complex correlation (amplitude+phase) between a pair of SAR images (ERS.SLC), in addition to usual backscatter information. The coherence contains information about the geometric stability of the targets between the two acquisition dates. It was shown that through this physical dependence, coherence added to backscatter information can increase the discrimination, for example between clear-cut or plantations and forest areas (Stussi *et al*. 1996; Ribbes *et al*. 1997). However, this discrimination is best when the time interval between the two acquisitions is small, such as during the ERS-1/ERS-2 tandem mission in 1995-96, or during previous 3-day phases of ERS-1. Unfortunately, such configurations will not be repeated for a long time.

To summarise, spaceborne SAR images can be used to perform land cover mapping at a medium scale (1:100 000), but discrimination is possible only among broad classes such as primary forests, logged-over forests, planted areas (young and mature growth stage), swamp and mangrove forests, urban and cultivated areas. Research is going on to improve land cover discrimination.

Forest monitoring

When two or more SAR images are available over the same forested area, the multi-temporal approach used in land cover mapping can be extended to more forest-specific monitoring applications. Once the forest classes are identified, their extension/regression or significant modification can be assessed using the same technique. Changes like those occurring as a result of shifting cultivation, intensive logging or large forest fires can be followed to some extent in this way (Grover *et al*. 1995; Malingreau *et al*. 1995a,b; Ribbes *et al*. 1997). Mapping of recent secondary forests is therefore possible by combining radar images acquired before and after the start of logging activities. While SAR data cannot be used for fire detection, they are quite appropriate for following the monthly progression of fires (even in the presence of smoke), and for an *a posteriori* evaluation of the surface cleared by fires, as is currently being attempted for the recent fires in Indonesia.

A further area of application where SAR data proved to have good potential is biomass retrieval, as reported, for example, in temperate coniferous forests by Le Toan *et al*. (1992) and Beaudoin *et al*. (1994). Unfortunately, the backscattering coefficient saturates at low levels of biomass (L-band: 75-100 tons dm/ha), which is a major drawback in tropical forests showing much higher biomass levels. However, L-band could be useful for monitoring young regrowth with low biomass using for example temporal JERS-1 SAR data (Luckman *et al*. 1995; Luckman and Baker 1997).

DEM generation

A special application of radar imagery is the construction of Digital Elevation Models (DEM) using the radargrammetry technique, which is based on a pair of SAR images taken at two significantly different incidence angles. This technique is already operational using airborne SAR data but, among the present satellite SAR systems, only RADARSAT with its multi-incidence capability can deliver such images. Marinelli *et al*. (1997) have developed software which uses operational RADARSAT image couples to construct DEMs of large areas (about 100 km x 100 km) with a pixel spacing of 20 m and an altitude accuracy which can be better than 20 m RMS. This functionality is being integrated as a new radar module into the commercial digital cartography software 'GEOimage'. A DEM and particularly the slope layer derived from it are without doubt very important pieces of information, which needs to be accounted for in the management of forested areas.

Discussion and Conclusion

A major limitation of spaceborne SAR data for forest mapping and monitoring is the spatial resolution (20-30m) in the presence of speckle noise. For example, clear-cut areas of less than a few hectares are not readily detected. Similarly, selectively logged forests and skid/timber roads are difficult to identify on images with this range of spatial resolution. Radar images with better spatial resolution are available with airborne SAR systems. This emphasises that spaceborne SAR imagery should not be considered as a stand-alone tool for a variety of applications. In the presentation of a radar monitoring system for sustainable forest management given by Hoekman (1997), the need for an operational 'end-to-end' system including both satellite and airborne systems, interpretation and processing capabilities, as well as education and training, is clearly expressed in the Indonesian context. Spaceborne SAR images could be used to identify and map areas which need further detailed attention, and for which airborne SAR data should be very useful, in particular due to improved resolution (down to a few metres) and the availability of multi-configured systems (see examples by Ahern 1993; Beaudoin *et al.* 1993; van der Sanden and Hoekman 1993; Hoekman and Quiñones 1997). Of particular interest is the increasing availability of airborne interferometric SAR systems (TOPSAR, DOSAR, AeS-1) that can produce both high-resolution radar images useful for forest mapping and very accurate DEMs (Hoekman 1997).

In conclusion, spaceborne SAR images can prove effective when preliminary forest information are needed and when optical images cannot be timely acquired due to adverse visibility conditions. Although the SAR technology is relatively recent, research is being carried out to propose efficient radar applications in tropical forest monitoring. Examples show that possibilities based on available data and existing methods are real; however, spaceborne SAR imagery should be considered as one element of a forest management system that could also include other higher resolution remote-sensing data, together with GIS tools. The prospect of new spaceborne SARs, the increasing availability of high-performance airborne systems and the development of more adapted methodologies make SAR applications to tropical forest monitoring very promising.

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11. Regional Economic Development and Transition to Secondary Forests in Indonesia

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Abstract

In recent decades, Indonesia has faced increasing rates of forest resource depletion. While economic development has been uneven across the 27 provinces of the country, this has not been considered as an important issue when analysing forest transformation. Economic theory provides some explanations for uneven regional development within a nation. It can also explain some aspects of regional differentiation between the Inner Islands and Outer Islands of Indonesia. An historical analysis of economic development in two provinces (Riau and East Kalimantan) can provide a better understanding of the main factors influencing regional development and the extent to which this development has taken place at the expense of forests. The present analysis emphasises factors such as regional biophysical characteristics, geographical position and road infrastructure. The consequences of industrial decentralisation in the Outer Islands for the rate of forest transformation are discussed, as well as some possible impacts of the transition from primary to secondary forests in one region, in light of its limited industrial sector diversification.

Introduction

In recent decades, Indonesia has faced an increasing rate of forest resource depletion. The timber boom that started in 1967 and agricultural development of the Outer Islands – more important since the beginning of the 1970s – have led to important transitions of former primary forests to secondary forests and to conversion of forests into temporary or permanent agricultural land. Studies of these issues have often focused either on macroeconomic aspects of economic development and forest utilisation (World Bank 1990; Dick 1991; Barbier *et al.* 1993; Prakosa 1994; Sunderlin and Resosudarmo 1996) or microeconomic characteristics of sustainable or unsustainable forest management and conversion (Angelsen 1995; Kosonen 1996). Although economic development has been unevenly spread across the 27 Indonesian provinces (Hill and Weidemann 1991), a regional analysis has not yet been considered important for the issue of forest modification. Information to explain and assess the full impact of different policies on the regional dynamics of the Outer Islands is still lacking. Policies that aim to balance inequalities between regions (transmigration, fiscal redistribution) were not all successful. Moreover official information on the effects of regional development on forest resources is limited.

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Using case studies of two Indonesian provinces, East Kalimantan and Riau, this paper aims to answer the following questions: What are the main explanatory influences on economic development in the Outer Islands of Indonesia? What are the consequences of these different regional development patterns on forest use and change? The first section presents briefly the main features of regional economic development in Indonesia while the second part analyses in detail the economic development patterns of the two case study provinces. In a third section, the main parameters involved in the process of regional differentiation are discussed.

Spatial Disparities of Economic Development in Indonesia

Background information

Economic development in Indonesia has shown a strong regional divergence between the Inner Islands (Java/Bali) and the Outer Islands. While Java and Bali were intensively developed in their early history, economic development in the Outer Islands such as Sumatra and Kalimantan was promoted only recently. Although almost all provinces experienced quite strong economic growth during the 1960s, variations in economic development between the provinces are still present. In 1990, Java produced 63% of the national domestic product and around 60% of the Indonesian population live on this island which covers less than 7% of the archipelago. Although the country has now reached the industrialisation phase of its economic development, 75% of manufactured production comes from Java. Spatial economic inequalities are therefore likely to be greater in the future. Moreover, the Outer Island economies are mainly based on exploitation of renewable and non-renewable natural resources (timber, oil, gas). In 1985, oil and gas represented 86% of East Kalimantan’s export value, and oil and residues comprised 96% of Riau’s exports (Hill and Weidemann 1991).

An historical analysis of economic development in Indonesia shows that the higher soil fertility of Java that allowed the development of a more dynamic agricultural sector (Geertz 1963), could be the underlying cause of economic inequalities between Java and the Outer Islands. The colonial period (1619-1945) began with the control of Java by the Dutch who only later extended their authority over most of the Outer Islands. Irrigation and road infrastructure were developed almost exclusively in Java. The province of North Sumatra is an exception since large estate rubber plantations were established in this region.

Until the mid-1980s, import substitution and food self-sufficiency policies enhanced Inner Island advantages (Hill and Weidemann 1991). During this period, export promotion policies were more differentiated; development of the Outer Islands was mostly based on the primary sector (wood, cash crops) whereas industrial activities remained located mainly on Java. Forestry and agricultural development took place at different rates in the outer provinces. Cash crop development was more important in Sumatra than in Kalimantan, which mainly favoured the forestry sector, except for West Kalimantan where there was a rapid development of rubber agroforestry systems. Until the end of the 1980s, most of the eastern part of the archipelago (Maluku, Irian Jaya) remained outside both of these economic development strategies. This has led to different industrial dynamics that are mostly restricted to primary processing sectors.

Institutional and fiscal centralisation has tended to favour activities in Java, but the impacts of these policies are not yet clear (Azis 1992; Henderson and Kuncoro 1996).

Economic theory and regional development differentiation within a country

In order to explain the level of development of the primary sector (agriculture, forestry) in the different regions of a country, regional resource endowment (land, forests) and production factor mobility (labour, capital) are key variables to be addressed. According to neoclassical theory, improved inter-regional mobility of goods and production factors can accelerate the convergence of per capita income growth rates among the different regions and allow each region to maximise its comparative advantages. The level of regional transport infrastructure is also important because agricultural and forestry output must be transported to urban centres in order to be processed. Costs for transport of rural production may explain distribution of these resources around urban centres. An increase, or a decrease, of these transport costs can thus affect land use distribution.

Industrial activities, which do not usually use any immobile factors such as land or forest, are *a priori* mobile and can be established in different areas based on regional production factor endowments, and demand for raw materials supply (timber, agricultural goods). However some centripetal forces, linked to increasing returns to scale or agglomeration economies, tend to favour concentration of these activities in a limited number of regions. Increasing returns to scale are related in particular to indivisibilities associated with capital investments – not only in manufacturing but also in infrastructure. This has two main consequences. First, the activity will only be established in a limited number of regions. For example, a firm that has the choice to locate in Java or in Kalimantan will choose one of these two regions, say Java, and from there will supply demand to Kalimantan or process its raw materials. Secondly, output demand or input supply for this activity must be sufficient to cover the fixed costs associated with the indivisibilities.

In a dynamic context, these characteristics allow for inter-regional labour mobility. For example, some circular processes can lead to divergence between ‘core-regions’, where most activities and population are concentrated, and peripheries, where development remains limited.

Industries tend to concentrate in a few sites because of increasing returns to scale; they tend to locate near the demand to minimize transport costs; but the demand, since coming, amongst others, from labour working in the industrial sector – tends to be larger where the manufacturing concentrates. This kind of backward linkages can then be reinforced by forward linkages – the labour might be attracted by the place where manufacturing started to concentrate because it will be less expensive to buy the goods this place provides (Krugman 1991).

Regional development scenarios in such core-periphery models are thus very sensitive to initial conditions, and path-dependent processes make historical events determinants of the current distribution of regional development inside a country. When such a dynamic has led to a concentration of most activities in one region (core) at the expense of the others (peripheries), decentralisation of firms depends not only on economic parameters in the peripheries, but also on transport costs between regions, economic parameters in the core region, returns to scale in the industrial sector, and intersectoral and domestic demand linkages. Research is currently being conducted in economic geography in order to better understand the different regional dynamics inside a country,[2] and particularly how cumulative processes can spill over between regions.

Indonesia's historical development, summarised above, reveals such processes that have been reinforced over time and have tended to concentrate activities and population in Java (colonial period, import-substitution, food self-sufficiency). A number of policies have already led to the decentralisation of some activities, such as export promotion, but which have not developed at the same rate across the various Outer Islands. The following case studies will try to identify more precisely the parameters involved in these regional dynamics. Moreover, these results illustrate that: 1) primary sector development in the Outer Islands will not necessarily lead to dynamic industrial sector growth, which is why forest transformation could have dramatic consequences in these regions; 2) determinants of industrial decentralisation among the Inner and Outer Islands must be considered in explaining the rate of forest transformation. Transport costs for some agricultural and forest outputs are too high to allow these goods to be processed in Java. Therefore urban migration and infrastructural development in the Outer Islands could have a significant impact of the rate of forest transformation by reducing constraints to industrial sector development.

The two provinces selected for this study, Riau and East Kalimantan, are both rich in natural resources with important endowments in oil, gas and timber. In 1993, East Kalimantan's Regional Gross Domestic Product (RGDP) amounted to 17.2 billion Rupiah and that of Riau was 6 billion Rupiah (BPS 1996). Even without the contribution of oil and gas, the RGDP of these two provinces are among the highest of the Outer Provinces, with East Kalimantan in second position and Riau in third. However, their RGDP are much lower than most of the Javanese provinces, with approximately 50 billion Rupiah. Since the beginning of the 1970s, wages and prices remained significantly higher in these two provinces than in Java,[3] reflecting pressures in goods and production factor markets. Both provinces have experienced high population growth rates, particularly through substantial spontaneous and assisted migrations. In 1990, the migrants made up 30% and 17%, respectively, of East Kalimantan and Riau's populations (Population Census 1990).

Different Regional Economic Dynamics: Riau and East Kalimantan

The forestry sector

Mechanised large-scale logging operations started in both provinces in 1967, with the basic forestry and new investment laws, making foreign investment easier. Allocation of forest concessions (HPHs) grew rapidly, particularly in East Kalimantan where 85% of those still operating at the beginning of the 1990s were allocated before 1980. Allocation began a little later in Riau but also proceeded quickly. Consequently, timber exports increased rapidly. In East Kalimantan they grew twenty-fold in only three

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[2] A survey of recent results on this issue can be found in Fujita *et al.* 1997 and Piketty 1999.

[3] Wages were 50% higher in both provinces than in Java (Sakernas Census) and the price of rice was 20% and 60% higher in East Kalimantan and Riau, respectively (Bappenas regional database, 1994).

years, between 1968 and 1971. At the beginning of the 1970s, East Kalimantan provided 50% of the national timber exports (Daroesman 1979; Manning 1971). In Riau, between 1970 and 1974, timber exports expanded by two and one-half times, lifting the province to third place among exporting provinces, after East and West Kalimantan (Esmara 1975).

In the early 1980s, both provinces still had large areas of production forests. However, by 1990 East Kalimantan had only 9.7 million ha of production forests (48% of the province's land area) while Riau retained 3.7 million ha of these forests (38% of land area) (RePPProt 1990). In 1990, forest concessions (HPH) covered 11 million ha in East Kalimantan and 5.6 million ha in Riau. Most of these concessions included not only production forests but also conversion forests that are intended for permanent agricultural land or industrial plantations. For example, in Riau conversion forests provided 63% of the log production in 1995 (Departemen Kehutanan 1996, unpublished data). It is therefore difficult to relate forest changes with provincial timber production based on concession areas only. However, examining the changes in the forest concessions that are currently due for renewal, allows a rough assessment of the transition process from primary forests to logged/secondary forests and to plantations.

The majority of concessions in Indonesia were allocated between 1970 and 1980 and for a 20 year period. Most are now approaching the renewal process, which could result in any of the following scenarios:

- the concession is renewed for a new 20 year period (renewal);
- the concession becomes a joint venture with one of the State Forest Companies (INHUTANI);
- the concession is taken over by the State Forest Companies (revocation); or
- the concession is converted to other uses.

The amount of virgin forest left in the concession as well as the financial capacity of the firm are important criteria in the renewal decision process. Although renewals are just beginning and only concerns a few concessions at present, it provides a good picture of the current situation in the forestry sector. Most of the concessions involved in the renewal process were not re-newed (Table 1). This is an alarming indication of how the forests have been poorly managed in these two provinces.

Table 1. Revocation, joint venture and renewal of concession lands in the 1990s.

	Area surveyed	Revocation	Joint venture	Renewal	Other uses
	(x 1000 ha)	%			
East Kalimantan	2 800	45	18	27	8
Riau	800	46	-	30	24

Source: Departemen Kehutanan, Jakarta 1994, unpublished data

Forest inventories carried out by state-owned companies in their newly allocated concessions (Table 2), showed that more than half of the forests in both provinces had already been logged, with a very high proportion in East Kalimantan (74%). In 1990, 48% and 27% of the production forests in East Kalimantan and Riau respectively were already logged. This confirms the higher rate of logging in that province (Sutter 1989). Moreover, in East Kalimantan, a substantial part of the production forests have been or will be converted into pulp plantations, whereas conversion into cash crops estates (oil palm) will be more important in Riau.

Table 2. Distribution of unlogged forests and forest utilisation in concessions taken over by INHUTANI companies (1996). (Cash crops: cash crops farming systems).

	Land surveyed	Unlogged	Plantations	Cash crops	Trans.	Other uses
	(x 1000 ha)	%				
East Kalimantan	600	26	51	34	6	9
Riau	600	46	15	72	13	-

Source: Departemen Kehutanan, Jakarta 1994, unpublished data.

In East Kalimantan, establishment of tree plantations began only in the early 1990s and they were planned to cover an area of 1.5 million ha (Departemen Kehutanan 1996). Most of these plantations (66%) will be composed of fast-growing tree species (*Acacia mangium* or *Eucalyptus* spp.), to supply almost exclusively the pulp industry. In East Kalimantan, most of the pulp industry plants are still to be established and only PT Kiani Lestari has just recently started pulp production in the Berau district. Moreover, 87% of the area planned for plantations are still to be planted. Hardwood plantations are foreseen to cover only 311 809 ha but until now, only 30% of this area has been effectively planted. In Riau, plantations were established a little earlier, at the end of the 1980s, but were planned to cover a smaller area of about 600 000 hectares, which are not yet completely planted. They are also mostly destined to supply pulp factories (74%) that are already established in the region. Because these plantations will not provide raw material for the plywood industry, pressure on natural forests for log supply is likely to remain important in the future.

Although the Government of Indonesia has identified the establishment of plantations on degraded lands as a priority, regulations are still very vague about the definition of a minimum level of degradation before conversion into timber plantations is allowed. In reality, industrial plantations seem to be set up mainly after clearance of secondary or logged-over forests. These forests provide raw material to the pulp industry during the unproductive period of plantation establishment, which requires several years (7-12), depending on soil fertility before harvesting.

Agents in the agricultural subsector are the other main actors responsible for the transition of primary forests or secondary forests, either into temporary or permanent agriculture. Even if it is difficult to deduce exactly how far agricultural expansion has been at forests' expense, the evolution of land use gives some indication of land pressure and indirectly of forest conversion (Piketty and Laumonier 1998).

The agricultural sector

Because an important part of the dryland rice production in the Outer Islands is based on shifting cultivation, an increase in harvested areas can be regarded as representative of farming systems based on a temporary but extensive use of former unused land (like forests). In contrast, wetland rice production is usually more labour intensive, more permanent and involves a smaller area of land. Between 1980 and 1990, East Kalimantan showed a significant growth in dryland rice areas (4.1% per year for 1980-1990; Arif *et al.* 1996), and a rapid increase of fallow land. Wetland rice areas have also increased but at a slower rate (1%/year). Riau, on the other hand, has been characterised by a semi-intensification, especially during the 1980-1990 period. Harvested areas of dryland rice have increased only very slowly – 0.8% per year. Fallow land has tended to decrease and areas of wetland rice have increased more rapidly. Moreover, average yields are higher in Riau than in East Kalimantan but remain much lower than in Java. In 1994, average wetland rice yields were 2764 kg/ha, 3293 kg/ha and 5236 kg/ha, respectively in East Kalimantan, Riau and West Java (Arif *et al.* 1996).

Another important difference between the two provinces is the development of the cash crops subsector such as rubber and oil palm plantations (Table 3). In the early 1980s, Riau experienced very strong development in this sector with two different dynamics: traditional crops like rubber expanded slowly, while growth in oil palm plantations was more rapid. During the last two decades, only two new crumb rubber factories were set up in the region. In contrast, between 1988 and 1994, oil palm production capacity has been expanded tenfold (DJP 1995). Compared with Riau, and despite high growth rates of planted areas, oil palm plantations do not cover extensive areas in East Kalimantan and performance in this sector has been relatively unsuccessful until recently.

Table 3. Recorded cash crops plantations in Riau and in East Kalimantan (1980-1990).

	Rubber (ha)		Oil Palm (ha)	
	1980	1990	1980	1990
Riau	276 097	415 253	10 967	238 181
East Kalimantan	10 460	39 895	25	23 742

Source: DJP 1980-1990.

The cash crop farming systems can be described as follows:

- Oil palm is an industrial crop, mainly developed and managed by state or private companies but usually integrated within Nucleus Estate Smallholder projects which are transmigration projects based on establishment of estate crops, whose labour comes from Java with assistance from the government. Oil palm plantations have been often developed on former forested land. An unexpected expansion of independent smallholders began in North Sumatra near palm oil mills and spread to Riau. These smallholder systems are expanding with improved infrastructure and market oriented buying policies of mills (C. Bennett, pers. comm.).

- Rubber is mainly a smallholder crop, usually established on shifting cultivation fallow lands, particularly in Riau. In most of the Sumatran traditional shifting cultivation systems, fallow land has been enriched with rubber and it is only when latex starts to be harvested that the former fallow lands are recorded as smallholder plantations. In Riau, the increase of smallholder lands has been the most significant. This suggests that an important transition of logged and unlogged primary or secondary forests into rubber agroforestry systems has occurred in this province.

The industrial sector

The second major element in the analysis of regional development processes is the extent to which expansion of the industrial sector has followed primary sector development, and its main characteristics. For large and medium-scale manufacturing (i.e., factories with more than 20 employees), the share of wood-processing activities appears important in both provinces, but East Kalimantan is much more dependent on them than Riau (Table 4).

Table 4. Structure of the large and medium-scale manufacturing sector in Riau and East Kalimantan (1990) – excluding oil and gas sectors.

	Share of the wood-processing sector			
	Number of factories	Labour	Output	Employment
			%	
Riau	214	44 832	43	57
East Kalimantan	119	43 696	75	86

Source: Departemen Perindustrian Kalimantan Timur dan Riau 1990.

The wood-processing subsector displays a high degree of specialisation in a few activities. In East Kalimantan, 70 companies including 41 sawmills, 26 plymills and 3 mouldings units were operating in 1990 (Departemen Perindustrian Kalimantan Timur 1990). Plymills employed 71% of the labour force of the wood-processing subsector. In Riau, there were 99 companies including 71 sawmills and 12 plymills. In contrast to East Kalimantan, activities in secondary wood-processing were more important in Riau: 7 moulding factories, 7 decorative plywood factories and 7 furniture factories (Departemen Perindustrian Riau 1990). However, in both provinces, plymills represent the largest share of employment in the sector. The plywood industry only started in the early 1980s, after the government implemented log export quotas to promote domestic transformation. From this period, most of the American and European companies ceased activities and were replaced by Asian companies (from Taiwan, Hong Kong, Japan, South Korea). The main constraints to industrialisation, especially in East Kalimantan, were the lack of skilled labour and infrastructure in the log-producing regions (Manning 1971). An alternative could have been the location of factories in Java, but transportation costs were probably too high for this to be a viable alternative compared with log exports. It is also important to note that East Kalimantan is not adjacent to a more developed province with adequate road and other transport connections, in contrast to Riau where development has been significantly related to its proximity and easy access to the plantation province of North Sumatra.

After 1992, performance in the wood-processing subsector in the two provinces showed an alarming decline in production. During this period, several sawmills in Riau closed while plywood production considerably decreased to reach the level of the late 1980s, after a peak in 1990-91 with an annual production of 911 100 m^3. In East Kalimantan, although no plymill has yet closed, annual production decreased from 1 975 547 m^3 in 1990 to 1 389 312 m^3 in 1997 which was the level of production in the province in 1987. At the same time, this decrease in plywood and sawnwood production was balanced to a certain extent with an increase in blockboard and pulp production, particularly in Riau. Plantations of fast-growing species provided raw materials for these latter two industries. This suggests that production of logs from natural forests has dropped dramatically and cannot entirely support the sawnwood and plywood industries.[4] This may lead to a greater reliance on timber plantations, which in turn will require new wood-processing technologies.

In both provinces, economic development has relied on the primary sector. Whereas in East Kalimantan only the forestry sector has been developed, in Riau, there was also a rapid expansion of cash crops. Consequently, permanent land use in Riau covers larger areas than in East Kalimantan where secondary, logged-over forests and shifting cultivation fallows are dominant. In comparison, the secondary sector has developed slowly and involved mainly primary processing activities. Moreover, the wood-processing subsector seems to be currently in need of a technological shift in both provinces. The industrial sector in Riau has been more diversified particularly in the food and the cash crop processing subsectors, but also more recently in the electronic components subsector on Batam Island. Rubber processing has been a traditional activity in the region and was the first industrial activity before the timber boom (Esmara 1975). The most spectacular evolution is the increasing palm oil production, whose capacity has grown by ten times between 1988 and 1994 (DJP 1995).

Regional Differentiation and Forest Utilisation: Some Explanatory Factors

Soil fertility

As already noted, a major difference between the Inner and Outer Islands is the much poorer soils in the latter region, including East Kalimantan and Riau. This may be one of the reasons for the lack of intensification, especially in rice production compared with the very fertile soils of Java and Bali. Except for wetland rice production – Riau has a large area of wetland soils – soil properties do not seem to have been a major determinant of the different paths of regional agricultural development in the two provinces, especially in the case of cash crops. Another physical feature, which may have had an impact, is the topography. Important areas of East Kalimantan are very steep and are not suitable for the development of estate cash crops. Moreover, the drier climate of East Kalimantan, with periods of severe drought, may have been a limiting factor for the expansion of cash crops. In the case of forest resources, differences in regional endowments are more significant. Production forests cover a larger area in

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[4] One has to be careful on this subject, since policies were set up at the beginning of the 1990s, in order to promote secondary processing activities (sawnwood export tax, regulations on plywood licensing) which also influenced sawnwood and plywood production in these regions.

East Kalimantan, and the timber stocking volume is also higher; commercial stocking volume in East Kalimantan forests is around 80 m^3/ha, but only 56 m^3/ha in Riau (Sutter 1989; Sist *et al.* 1998).

Geographical position

Like the provinces of the east coast of Sumatra and the west coast of Borneo, Riau had very early contact with foreign trade. In the fifth century, expanding trade between China and India had already accelerated the development of economic activities in these regions because ships had to anchor in their ports, waiting for the new monsoon (Cleary and Eaton 1992). This initial advantage was later reinforced with the settlement of Singapore, Riau being the closest Indonesian province to this port. For any kind of economic activity involving foreign capital or labour, proximity to the origin of these production factors is an advantage compared with more remote areas, especially because the controlling cost might be less important for owners of the production factors.

In the process of regional differentiation, accessibility to other Indonesian provinces must also be considered. Riau is close to two densely populated provinces, North Sumatra and West Sumatra, which facilitates labour migration, whereas East Kalimantan is more isolated. The province of North Sumatra was one of the few Outer provinces developed during the colonial period by the Dutch who established estate plantations there. This has had two consequences for cash crops development in nearby provinces, including Riau. First, it partly explains the rapid adoption of rubber by smallholders who mainly planted this crop on shifting cultivation fallow land. Rubber was particularly well-adapted innovation for this farming system because it required only a small amount of extra labour or capital and it also maintained the fallow land by restoring soil fertility (Scholz 1983). Secondly, when rubber prices increased, production from those regions could also increase rapidly because many secondary forests were already planted with rubber and market infrastructures were already in place. East Kalimantan did not benefit from a similar advantage. Moreover, Medan, the capital of North Sumatra became one of the most important research centres for cash crops, particularly rubber and oil palm. Proximity to this centre and the availability of skilled labour trained in Medan are other advantages and explain the greater success of oil palm estate development in Riau.

Road network

The final major difference related to accessibility is the road network within the provinces; East Kalimantan is twice as big as Riau but has only one-quarter of the road infrastructure. In 1992, average road density in Riau was 12 km per 100 km^2 and only 3 km per 100 km^2 in East Kalimantan (Direktorat Jenderal Bina Marga 1993). Road infrastructure in Riau might have been developed sooner because most oilfields are located inland while in East Kalimantan they are mainly offshore. The trans-Sumatra highway development started at the end of the 1970s and was almost completed by the middle of the 1980s, whereas the trans-Kalimantan highway still needs to be improved. By decreasing transportation costs within the province and with neighbouring regions, road infrastructure facilitates transportation of goods, population migration and access to natural resources. River density also allows good boat transportation and both provinces are well endowed with rivers. Timber transport is often still by river in East

Kalimantan, and it is very cheap. However river transportation is not well-suited to and can become expensive for more perishable goods, such as food and agricultural goods.

Conclusions and Discussion

Better accessibility has increased the rate of agricultural development in Riau compared with East Kalimantan. It has been reinforced by spontaneous and assisted migration, such as transmigration and other government projects, important in the oil palm subsector. Labour migration has occurred simultaneously with the development of roads, which can both have effects on the rate of agricultural development. A simulation model applied to East Kalimantan shows that rural labour force growth explains development of rubber farming systems because transport costs for rubber are low, but it does not guarantee palm oil plantation development. On the contrary, an investment in road infrastructure, that would decrease internal transport costs, may lead to a strong development of palm oil plantations, to a certain extent, at the expense of rubber farming systems (Piketty 1999).

In the industrial sector, diversification in the two regions has been limited to primary processing – crumb rubber, sawmills, plymills and palm oil – which are raw material intensive activities, i.e., input costs are high share compared with labour and capital. These production inputs are fixed by land and forest availability. Raw material transportation costs are then the determinants in the choice of a factory location. If these activities were set up in Java, they would benefit from lower production factor costs (labour, capital) but they would pay a high cost to transport raw material from these two regions. Moreover, since these primary processing activities usually supply the export market, they do not have to pay for transport of their output to satisfy domestic demand. This facilitates decentralisation compared with industries in the consumption subsector, which are more attracted to consumption centres (Java). Finally, secondary processing activities usually have higher labour and capital costs compared to raw material costs, which makes Java a more profitable location. This has led, especially in the case of East Kalimantan, to a very limited specialisation in wood primary processing activities. Policies, such as those established at the beginning of the 1990s (see footnote 4) to promote secondary processing activities, will not necessarily lead to their development in East Kalimantan. If instead they locate in Java, the implementation of an export tax on primary processing of wood could reduce international demand, and be followed by a sudden drop in incomes in this region. In the long term, this could result in a significant increase of rubber and palm oil plantation development, at the expense of forests, if the population do not migrate out of the region (Piketty 1999).

This scenario is not the only possible outcome, as has already been noted. Cumulative processes of industrial decentralisation and population migration could take place in these regions in the future, but the resulting situations will also depend on the economic environment in other regions as well as within the province. For example, the current financial crisis that led to high unemployment rates in Java could accelerate migration to the Outer Islands, where the cash crops sector is benefiting from the current devaluation of the Rupiah. Therefore it is necessary to take into account such interactions between regions in order to forecast primary and secondary forest modifications as well as regional development in the Outer Islands. If decentralisation of manufacturing is based on activities processing wood or agricultural products, it will accelerate transformation of forest resources. The process seems to have already begun in Riau, where independent oil palm smallholders are likely to expand near palm oil mills and where the established pulp and paper factories tend to reinforce pressure on forests conversion.

Studies of regional development differentiation within a country are relatively recent and research is still needed to understand the processes and consequences of regional disparities. Moreover, these new developments have yet not incorporated specific environmental issues, which indeed might refute some of the classical results in the field. Regional development in Riau and East Kalimantan has been based on significant irreversible modifications to forests, which will most likely have some consequences for the future development of these regions. The decline in plywood production seems to confirm this fact. The capacity of production forests, and particularly of logged forests, to supply the plywood industry in the future remains unknown. In the near future, the industry may have to rely on industrial plantations. However, a technological shift will be necessary because timber from industrial plantations cannot be directly substituted for the same processing activities.

An important question for a province like East Kalimantan that depends so much on traditional wood processing activities, is to what extent the likely decreased yield of production forests will affect the entire regional dynamic. Sawnwood and plywood firms may find secondary forest harvesting unprofitable and move their factories to other regions where there is still primary forest (as in Irian Jaya). Populations working in the timber sector might stay or migrate out of the province, depending on job opportunities in East Kalimantan and elsewhere. If migration takes place, East Kalimantan could become a ‘boom-and-bust’ economy, and there could be a regrowth of secondary and depleted forests in the long term. If people remain in the province, this supply of unemployed labour can encourage development of timber and estate plantations, which would in turn accelerate conversion of logged and depleted forests. The development of such plantations depends also on the opportunity to establish processing activities, such as oil palm or pulp and paper factories in East Kalimantan rather than in other regions of the archipelago. How the process would be initiated, whether by establishment of new factories or because the population does not emigrate, is unclear. However it emphasises the necessity to precisely identify this kind of dynamic in order to accurately forecast the consequences of forest transformation.

The same issues can be addressed in the case of transition from natural forest to agricultural uses. As has already been stated, soils in the two provinces are poor and permanent cultivation may lead to rapid decline in agricultural yields. Until recently, most of the permanent farming systems have relied on initial fertility from primary or old secondary forest conversions, with benefits for yields. These problems have already been identified for food crop systems but the same might apply – even if with less dramatic effects – for some cash crop farming systems that are based on complete forest removal.

The two case studies analysed here show that specific economic mechanisms at the regional level must be considered to predict the possible consequences of macroeconomic choices on forests changes. Soil fertility, external accessibility (proximity to densely populated areas and to foreign countries) and internal accessibility (transport infrastructure) are important parameters in the processes of agricultural dynamics of the two provinces. Moreover, despite important transformations of former primary forests into secondary forests and agricultural land, regional development outside the primary sector has remained limited. Outer regions thus depend on a very small number of industrial sectors, as has been shown in East Kalimantan. These transformations may be characterised by an irreversible decline in forestry and agricultural yields in the future, whose magnitude will depend partly on current management. The inclusion of these ecological parameters into a more general economic framework, i.e., one that takes account of specific economic dynamics at the regional level, is necessary to better assess the benefit – or alternatively the futility relative to other economic mechanisms – of a more sustainable management of forest resources.

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