Agroforestry Systems 22: 181—206, 1993.

Does 'jungle rubber' deserve its name? An analysis of rubber agroforestry systems in southeast Sumatra

A. GOUYON[1], H. DE FORESTA[2] and P. LEVANG[3]

[1] *CIRAD-CP, 12 square Pétrarque, 75116 Paris, France;* [2] *ORSTOM/SEAMEO-BIOTROP, PO Box 17, Bogor, Indonesia;* [3] *ORSTOM, BP 5045, 34032 Montpellier, France*

Key words: Indonesia, Sumatra, smallholder, rubber, fruit trees, timber, firewood, agroforestry, farming system, economics

Abstract. Jungle rubber is a balanced, diversified system derived from swidden cultivation, in which man-made forests with a high concentration of rubber trees replace fallows. Most of the income comes from rubber, complemented with temporary food and cash crops during the early years. Perennial species that grow spontaneously with rubber provide fruits, fuelwood and timber, mostly for household consumption. Jungle rubber enables lower incomes per land unit or man-day than weed-free plantations using selected rubber clones. Yet it requires much less input and labour since wild woody species protect rubber from grass weeds and mammalian predators. With a structure and biodiversity similar to that of secondary forest in its mature phase, jungle rubber belongs to complex agroforestry systems. It has accommodated increasing population densities, while preserving a forest-like environment.

Yet farmers' income from jungle rubber is declining due to the exhaustion of forest reserves and reduced land availability. New research and extension options could help in improving the productivity of jungle rubber. Better transportation and marketing are needed for increasing the income from non-rubber output. Short-term, small-scale credit schemes could help farmers adopt high-yielding rubber varieties. Research should participate in creating new management methods for selected rubber based on agroforestry to reduce maintenance costs, enabling smallholders to plant high-yielding rubber at lower cost, and without losing too much of the present biodiversity and economic diversity.

Résumé. Dérivées de l'essartage, les forêts à hévéa forment un système de culture équilibré et diversifié, où le recrû forestier est remplacé par une forêt anthropique à forte concentration d'hévéas. L'essentiel du revenu provient des hévéas, complétés par des cultures vivrières et commerciales pendant les premières années. Les espèces prérennes qui se développent spontanément avec les hévéas fournissent des fruits et du bois, principalement pour l'auto-consommation. Le revenu tiré de ce système est inférieur à celui de plantations d'hévéa clonal entretenues. Il nécessite cependant moins d'investissements en intrants et en travail grâce au rôle protecteur de couvert forestier vis-à-vis des adventices herbacées et des mannifères prédateurs. Avec une structure et une diversité d'espèces comparable à celles d'une forêt secondaire, ce système fait partie des agroforêts complexes. Il a fourni depuis 1910 l'essentiel du revenu d'une population en croissance rapide tout en préservant un environnement forestier.

Le revenu que tirent les paysans des forêts à hévéa est en déclin en raison de l'augmentation de la population. De nouvelles orientations de la recherche et du développement pourraient permettre d'améliorer la productivité de ce système. Le revenu tiré de la composante non-hévéa pourrait être augmenté grâce à une amélioration des transports et de la commercialisation. Le crédit à court terme et à petite échelle permettrait aux paysans d'adopter des variétés d'hévéa sélectionné et d'augmenter ainsi leurs revenus. La recherche devrait aider à mettre au point de nouvelles méthodes de gestion des hévéas sélectionnés, de type agroforestier, afin de

réduire les coûts d'entretien. Les paysans pourraient ainsi planter des hévéas hauts producteurs à moindres frais, et conserver partiellement la diversité économique et écologique du système actuel.

Introduction

Forests, rubber and people

The visitor to the southeastern plains of Sumatra may have heard that rubber is a major source of income in this area. While driving through miles of forest, however, he might wonder where the rubber trees are located. A closer look at these secondary forests will show him that they are actually rubber plantations, tangled with bushes and trees. He might even identify fruit trees within the thick cover and, talking to smallholders, might find out that they keep certain species as cover crops against grass weeds, that they use the sap of a given bush to cure mouth sores, or that they preserve certain trees as a source of timber.

This farming system is called jungle rubber (*hutan karet* in Indonesian) by farmers and extension officers, in the latter case with a negative connotation. It can be estimated to cover at least 2,000,000 ha in Indonesia, and to be a main source of income for nearly 5,000,000 people [Hendratno and Haryani, 1991]. This may well be underestimated. No accurate, reliable census of jungle rubber exists to date in Indonesia; jungle rubber is often mistaken for secondary forest on aerial or remote-sensing photographs, and farmers tend to understate their planted area when interviewed.

Economists and development officers often insist that jungle rubber is due to give way to high-yielding, weed-free plantations using selected varieties that could raise farmer income. Yet planting selected rubber, especially with current technical recommendations, requires overall changes in farm management that might not suit all smallholders. But will jungle rubber remain profitable under increasing land scarcity, labour opportunity costs and standards of living?

After providing background information, this paper uses input from ecology, botany, agronomy and socio-economics to analyse the ecological and economic functions of jungle rubber. The sustainability of this farming system is then assessed, as well as its potential for adjusting to environmental and economic changes. This analysis should contribute to the search for balanced farming systems and development policies to improve the livelihood of millions of rural dwellers in a sustainable way.

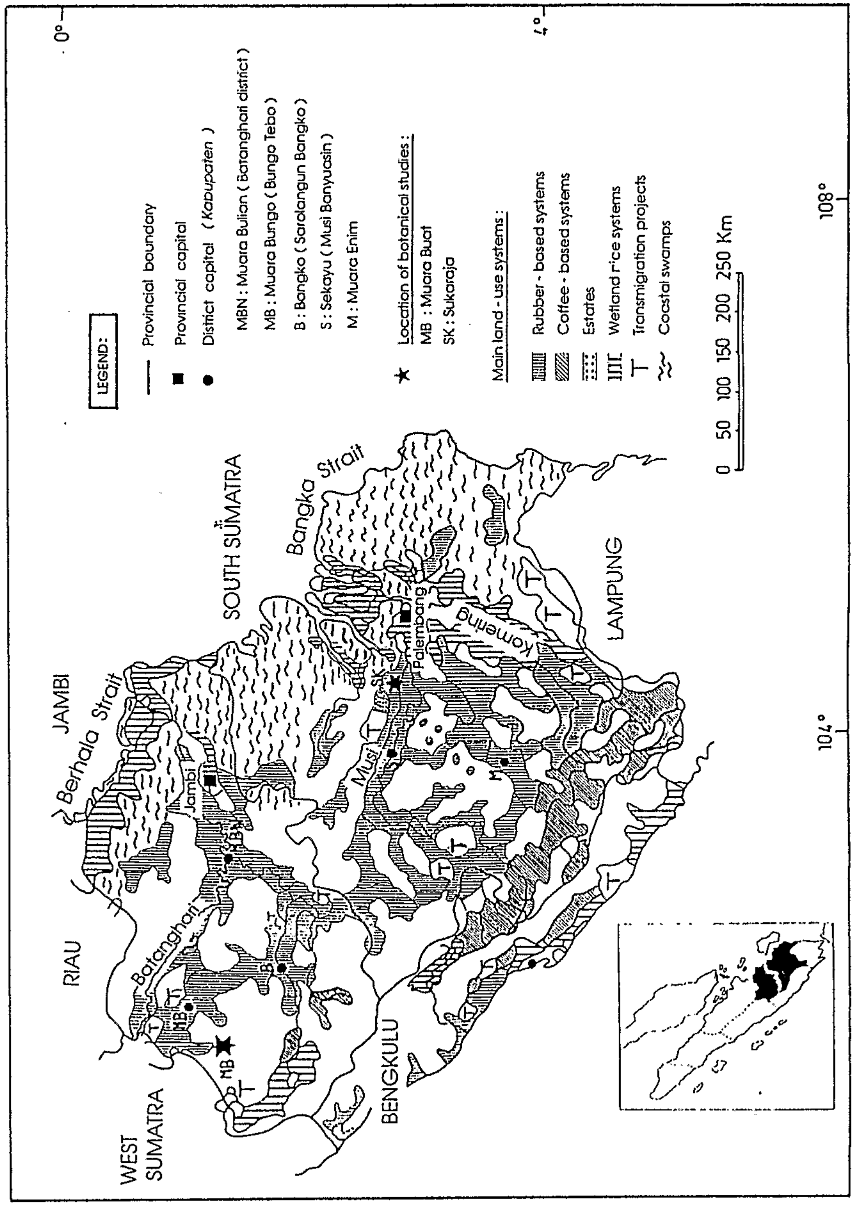

Fig. 1. Land-use map of South Sumatra and Jambi (based on Scholz [1988]).

1. A rainfed area with little agricultural potential

1.1. *The plains of the Musi and the Batang Hari*

Within the central peneplain of Sumatra [Scholz, 1983], the area studied stretches across two Indonesian provinces: Jambi and South Sumatra. The climate is wet tropical with 2,000 mm to 3,000 mm rainfall per year, yet dry seasons with less than 60 mm rainfall for at least three months occur about every five years [Laumonier, 1991].

The area is endowed with two major river basins: the Musi, the Batang Hari and their many tributaries (Fig. 1). Rivers were the only means of transportation for centuries, and still play an important role in this regard. Easy communications, alluvial soils and annual floods provide diverse livelihood opportunities for the riparian dwellers: wetland rice, vegetables, orchards, fishing, wood collecting, etc. (Fig. 2). Thus, the narrow riverside strips have long been the centre for permanent dwelling in southeast Sumatra.

This paper, however, concentrates on the rainfed area[1] (between 15 and 150 m), where most of the rubber is found. The soils there are considered poor, especially in the lowest part of the region (below 50 m). They are leached, acidic ferralsols. Communication is limited, with good main roads but poor access to the villages inland.

The rainfed area was sparsely populated before the introduction of rubber, and still has a relatively low population density; ranging from less than 30 per km^2 in the three districts of Jambi that are studied here (Sarolangun Bangko, Bungo Tebo and Batang Hari) to over 50 per km^2 in the two districts studied in South Sumatra (Muara Enim and Musi Banyuasin). Yet the population distribution is uneven, and most villages studied in South Sumatra have densities of over 100 per km^2. The fast rate of population growth since the 1970s (over 4% per year in some cases) has been largely due to government-sponsored and spontaneous immigration from other parts of Indonesia (mostly Java).

1.2. *Vegetation and land use in the rainfed area: an overview*

Although official figures indicate that 80% of the rainfed area is not *permanently* cultivated [Anon, 1989a, b], it has little forest left untouched.[2] The forest cover consists mostly of logged primary forest in Jambi province, and of secondary vegetation in South Sumatra (Fig. 1).

Primary cover (*rimba*) consists of mixed Dipterocarp rain forests, with a rather thick undergrowth [Laumonier, 1991] and a high diversity of species [Torquebiau, 1984]. Secondary forest differs from primary cover in its lower proportion of large trees, its higher proportion of pioneer species, and its less diversified species range. There is little secondary cover more than 20 years old (*hutan*) other than jungle rubber [Laumonier, 1991]. As a result of recent

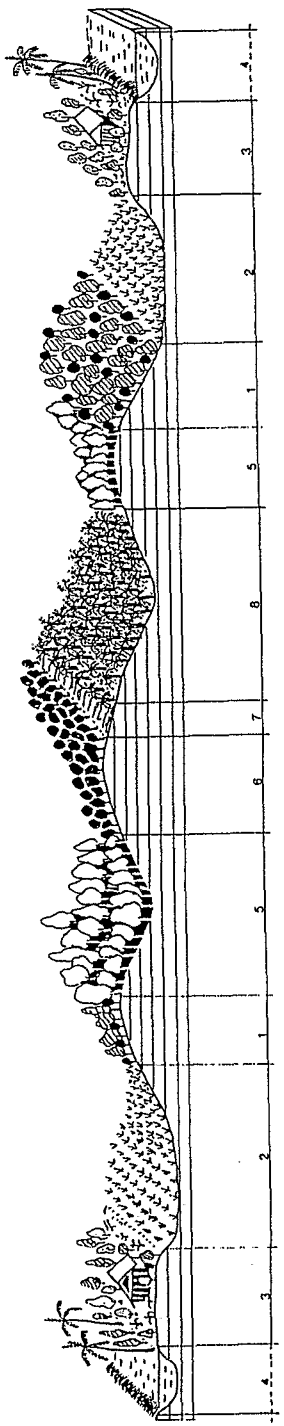

Fig. 2. Location of the main land-use systems along a transect between two major rivers (Jambi province, near Muara Bungo). 1: jungle rubber; 2: wetland rice and pastures; 3: settlement and fruit orchards; 4: river; 5: logged over forest; 6: rubber estate plantation (transmigration); 7: road; 8: oil-palm estate plantation.

or repeated slashing and burning, most of the spontaneous secondary cover is young and does not exceed 5 to 15 m high (*belukar*).[3]

Even more degraded are the *Imperata cylindrica* grasslands (*alang-alang*), sometimes mixed with a few bushes, which local farmers can hardly cultivate. Short fallows, as well as bush fires during sharp dry seasons, favour the spreading of such grasslands [Dove, 1980; Geertz, 1966; Levang, 1991].

Acidic, leached soils and grass weed competition make it difficult to cultivate annual crops in the rainfed area on a continuous or short fallow basis [Levang, 1991]. High input in labour and chemicals would be needed, and the return would not be profitable under present prices and costs — apart from narrow areas close to urban markets.

Thus, it is not surprising that smallholder perennials cover 84% of the cultivated area. Rubber remains the main crop in the peneplain (85% of the tree crop area), since it has low soil chemical fertility requirements. Fruit trees can also be found in house orchards or in small patches (*pulau*) in between rubber. Oil palm has recently been introduced by estates and government projects, but is not suited to self-reliant smallholders having no access to central processing facilities and marketing. A wider range of perennials including coffee, cinnamon trees, etc., can be found in association with rubber near the foothills, where soils seem to have better properties.

2. Jungle rubber as a low-input, complex agroforestry system

2.1. *From shifting cultivation to rubber*

South Sumatra was sparsely populated at the beginning of the century, with fewer than 13 people/km^2, and Jambi even less so, with a density of 6/km^2 [Pelzer, 1945]. The Malay people established permanent villages along the rivers [Geertz, 1963], and completed riverside agriculture with swidden cultivation in the rainfed area (*ladang*).

The pattern for *ladang* has been well documented [Dove, 1985; Freeman, 1955; Geertz, 1966]: rice and other food crops are cultivated after the forest has been slashed, felled and burnt. After the first year, farmers face increasing labour needs and decreasing yields due to weed competition as well as the exhaustion of mineral nutrients released by the burning. Thus, they abandon the swidden after one to two years of cultivation, leading to a fallow period of at least fifteen to twenty years.

Large areas are needed to support one family under this system (at least 15 ha including the fallow), with low labour and capital input per hectare. This is consistent with farmer resources at the beginning of the century, i.e., plentiful land, no capital and limited work force [Barlow and Jayasuriya, 1986].

Rubber seeds were introduced in the early 1910s from neighbouring Malaysia by merchants and farmers [Gouyon, 1991], attracted by the promise of high cash incomes at a time of peak rubber prices. Farmers quickly found ways to fit the new crop into the swidden. They developed a cropping system that has persisted with little change until now: rubber is planted shortly after rice, and develops with food crops and forest regrowth. Thus the secondary forest fallow in *ladang* is now replaced by a man-made forest in which rubber has been intentionally concentrated. After an average 10 year growth period, farmers can tap the rubber trees for more than 30 years.

This new cropping system gives higher income than *ladang* with no added establishment cost [Barlow and Drabble, 1990], and without putting farmers at risk: even if rubber failed to give satisfactory returns, farmers would be left with a rubber-based secondary forest that could be cleared for swidden like any fallow [Gouyon, 1991]. Thus, farmers developed large areas of jungle rubber following the usual rhythm of shifting cultivation, i.e. about one to three hectares every second year. Swidden is now rarely found without rubber, except in the case of minority ethnic groups such as the *kubu* [Laumonier, 1991].

2.2. *Rubber with forest — or forest with rubber?*

The structure and species distribution in adult jungle rubber plantations was studied in two locations in Jambi (Fig. 3) and South Sumatra (Fig. 4). One 1000 m^2 plot (50 × 20 m) was selected in each location as representatives of the physiognomy of jungle rubber. On these plots, vegetation was analysed using the profile method [Michon et al., 1983], in order to obtain a picture of spatial organization as well as structural and floristic data. In addition, and only on the Jambi site, all plant species whose canopy projection cuts a 100 m 'line-transect' were collected in order to assess plant diversity.

This analysis revealed that the structure of old jungle rubber is similar to that of a secondary forest, with rubber trees holding the ecological place of pioneer trees found in spontaneous secondary forests in the area (such as *Macaranga* spp.). It may be defined by two main strata as exemplified in the South Sumatra profile (Fig. 4):

- a more or less closed canopy between 20 and 25 m, heavily dominated by rubber trees (490 trees/ha), with 260 non-rubber trees of more than 10 cm Diameter at Breast Height (DBH) per ha in 10 species, and 50 rattan clumps/ha;
- a dense undergrowth layer between 0.5 and 10 m, dominated by numerous species of shrubs and small trees, but including many seedlings and saplings of canopy species.

In the Jambi profile (Fig. 3) the structure and physiognomy are globally identical, but in this older plot, rubber tree density falls to 200/ha, as the density of secondary and primary forest trees increases to more than 300/ha [Kheowvongsri, 1990].

Fig. 3. Architectural profile in a jungle rubber plantation in Muara Buat (Jambi). Based on a 50 × 20 m survey plot in a 40- to 45-year-old plantation in *desa* Muarabuat, *kecamatan* Rantau Pandan, *kabupaten* Bungo Tebo, Jambi province. Only trees of more than 10 cm Diameter at Breast Height (DBH) have been drawn. For a list of the species, see Appendix 1.

An assessment of biodiversity on the Jambi plot revealed 268 plant species other than rubber, all originating from natural forest, distributed into 91 tree, 27 shrub, 97 vine, 23 herbaceous, 28 epiphytic and 2 parasitic species (Table 1). This is equivalent to the plant diversity in an old secondary forest. A comparison with weeded, estate-like plantations that included only a few species other than rubber underlines the importance of jungle rubber for the conservation of forest plant diversity.

In short, a jungle rubber plantation presents the features of a rubber-based secondary forest that usually lasts up to 40 years or more before being replanted, while secondary regrowth seldom exceeds 20 years in a shifting cultivation cycle. This duration gives more chance to non-pioneering, primary forest species to develop. Old, abandoned jungle rubber plantations that are not replanted evolve towards mature forest, with fewer and fewer rubber trees per hectare. It is not surprising that usual methods of surveying have been unable to provide a reliable census of jungle rubber. More surveys and methodological research are needed for assessing the area covered by

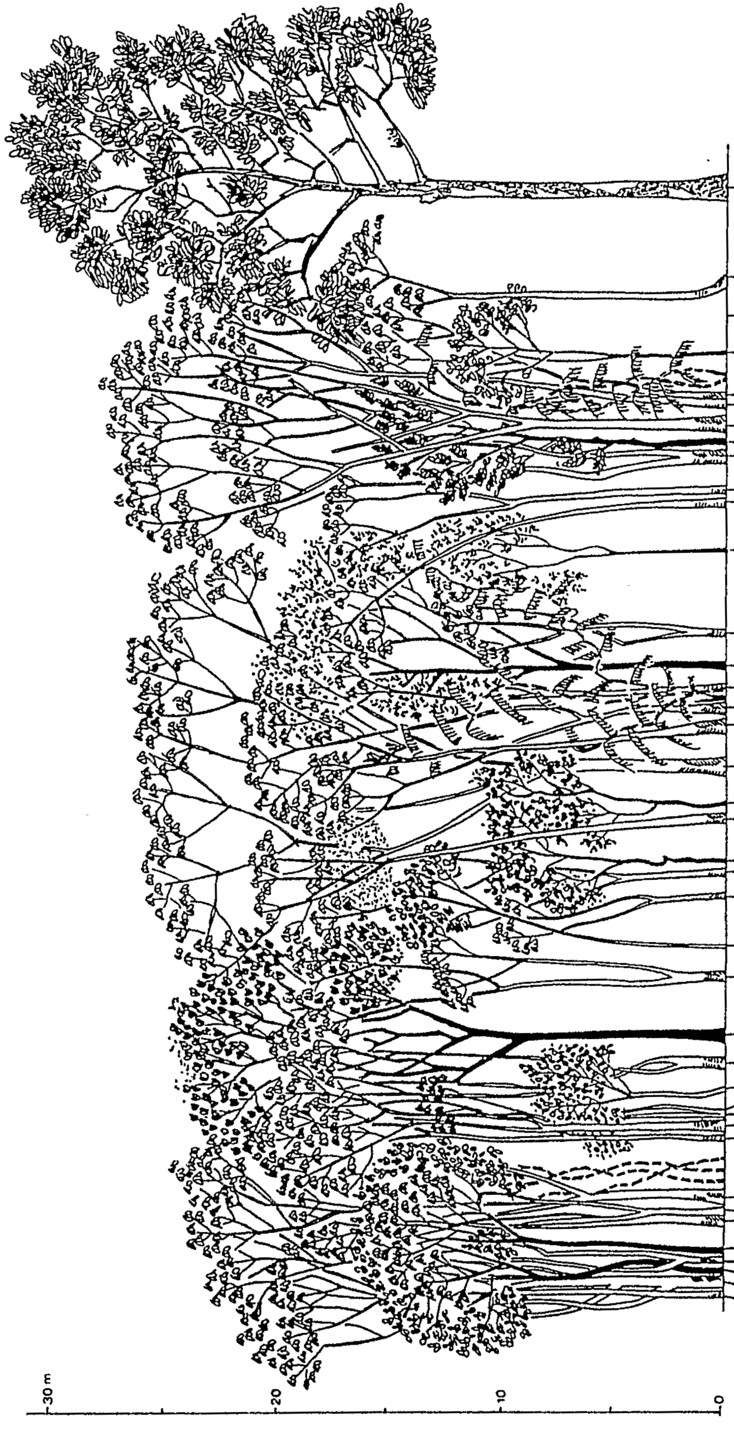

Fig. 4. Architectural profile in a jungle rubber plantation in Sukaraja (South Sumatra). Based on a 50 × 20 m survey plot in a 35- to 40-year-old plantation in *desa* Sukaraja, *kecamatan* Banyuasin III, *kabupaten* Musi Banyuasin, South Sumatra province. Only trees of more than 10 cm (DBH) have been drawn. For a list of the species, see Appendix 2.

Table 1. Main perennial species in jungle rubber and their uses.

Species	Family	Main uses	Locality	Local name
Mangifera spp.	Anacardiaceae	fruits, timber	M.B./S.	Mangga hutan
Alstonia angustiloba	Apocynaceae	timber, gum	M.B./S.	Pulai, Petai
Durio zibethinus	Bombacaceae	fruits, timber	M.B./S.	Durian
Flacourtia rukam	Flacourtiaceae	fruits, timber	M.B./S.	Rukem
Garcinia spp.	Guttiferae	spices, timber	M.B./S.	Kandis
Litsea spp., *Alseodaphne* spp. . . .	Lauraceae	timber	M.B./S.	Medang
Archidendron pauciflorum	Mimosaceae	vegetables, timber, dye	M.B./S.	Jengkol, Jiring
Parkia speciosa	Mimosaceae	vegetables, timber	M.B./S.	Petai
Artocarpus integer	Moraceae	fruits, timber	M.B./S.	Cempedak
Artocarpus elasticus	Moraceae	fibers, timber	M.B./S.	Terap
Eugenia spp.	Myrtaceae	timber	M.B./S.	Klat
Calamus spp.	Palmae	crafts	M.B./S.	Rotan
Arenga pinnata	Palmae	fruits, palm sugar, . . .	M.B./S.	Enau, Anau, Aren, . . .
Areca catechu	Palmae	stimulating, medicine, . . .	M.B./S.	Pinang
Milletia atropurpurea	Papilionaceae	timber	M.B./S.	Mibung, Meribungan
Vitex cf. *pubescens*	Verbenaceae	timber, medicine	M.B./S.	Leban
Peronema canescens	Verbenaceae	timber, hedges	M.B./S.	Sungkai
Dyera costulata	Apocynaceae	gums, timber	M.B.	Jelutung
Baccaurea cf. *reticulata*	Euphorbiaceae	fruits, rubber coagulant	M.B.	Lempaung
Pangium edule	Flacourtiaceae	medicine, timber	M.B.	Kepayang
Sonerilla sp.	Melastomaceae	ornamental	M.B.	?
Bulbophyllum lepidum	Orchidaceae	ornamental	M.B.	?
Salacca spp.	Palmae	fruits	M.B.	Salak hutan
Coffea canephora	Rubiaceae	stimulating, fuelwood	M.B.	Kopi
Dimocarpus longan	Sapindaceae	fruits, timber	M.B.	Mata kucing
Styrax benzoin	Styracaceae	resin, timber	M.B.	Komeyan, Kemenyan
Dillenia obovata	Dilleniaceae	timber	S.	Simpuh
Lithocarpus cf. *elegans*	Fagaceae	timber	S.	Lampening
Bellucia sp.	Melastomaceae	fruits, rubber collecting	S.	Jambu amerika
Helicia robusta	Proteaceae	timber, vegetables	S.	Seranto tua
Nephelium lappaceum	Sapindaceae	fruits, timber	S.	Rambutan
Schima wallichii	Theaceae	timber, fish poison	S.	Seru, Puspa

Survey location: M.B. = Muara Buat (Jambi); S. = Sukaraja (South Sumatra).

this land use system. This would probably require a large amount of cross-checking on the field, since aerial and remote sensing data distinguish poorly between rubber-based cover and wild regrowth.

2.3. *A large range of economic functions*

The information below was gathered through socio-economic surveys involving 350 farmers in 31 villages in South Sumatra, with agronomic recordings in 280 rubber fields [Gouyon and Nancy, 1989; Gouyon et al., 1990]. Additional data on family expenses have been recorded by interviewing 20 farmers in 2 villages, and family cash flow was monitored weekly for one year for 9 farmers in 2 villages. Data in Jambi were obtained by interviewing village informants in 90 villages [Gouyon et al., 1991].

Most of the literature on smallholders in Southeast Sumatra [Barlow and Muharminto, 1982; Cottrell, 1990; Thomas, 1957] concentrates on rubber and its intercrops during early stages. The non-rubber, perennial component has escaped attention since its output is mainly used for self-consumption, and since most agronomists or economists lack the necessary background to identify forest species of economic interest. The botanical contribution [De Foresta, 1992] has thus been essential in identifying this component. Yet the quantitative data presented here on the contribution of non-rubber perennials must be regarded as a rough estimate. A more reliable assessment of their output would require additional monitoring of farmer's self-consumption.

2.3.1. *Sources of income: rubber and more . . .*

If we consider one jungle rubber plantation throughout its economic lifetime, we find that rubber accounts for up to 85% of the average income per ha/year (Table 2). Trees are tapped 3 to 5 days a week. The output is sold weekly to local middlemen, providing cash throughout the year [Nancy et al., 1989].

Food and cash crops grown with young rubber such as rice, banana, pineapple, vegetables, etc., can provide significant income for one to three years, after which soil depletion, grass weeds and the shade from rubber trees prevent further cultivation. Although temporary, these crops are of key importance as the sole source of income during initial years. They cover the soil against weeds, and give an immediate return to weeding labour that is needed for protecting young rubber trees. They diversify farmer's incomes and allow them to be partly self-sufficient for their staple food, providing security in cases of falling rubber prices [Thomas, 1965].

The non-rubber component in older jungle rubber provides a variety of products of economic interest [De Foresta and Michon, 1991a]. A large range of fruit trees grow spontaneously owing to the numerous animal dispersers allowed by plant diversity in jungle rubber (Table 1). Their output is significant in household fruit consumption, of particular importance for child nutrition.

Table 2. Farmer's income from jungle rubber and selected rubber plantations (average net income computed throughout the economic life of a plantation).

	Jungle rubber[a]		Selected rubber (clones)[b]
	A	B	
Net income/ha/year, '000 Rp (%)	431 *(100)*	606 *(100)*	810 *(100)*
Of which: Rubber[c]	363 *(84)*	364 *(60)*	787 *(97)*
Rice	9 *(2)*	11 *(2)*	12 *(1.5)*
Other annual crops	9 *(2)*	10 *(2)*	11 *(1.5)*
Fruit trees	22 *(5)*	100 *(16)*	0 *(0)*
Fuelwood	6 *(2)*	51 *(8)*	0 *(0)*
Timber (non rubber)	22 *(5)*	70 *(12)*	0 *(0)*
Total man-days per ha/year	107	126	129
Net income per man-day, Rp	4030	4800	6280
Net income available[d]/ha/year, '000 Rp	270	417	617
Area needed per household[e], ha	2.8	2.0	1.5

Sources: Field surveys, except for fuelwood needs and prices which were found in a survey by the Directorate General of Forest Utilization and the FAO [Anon, 1990b].

[a] Two hypotheses for the contribution of non-rubber components:
A: minimal: low prices and output, all output for self-consumption;
B: maximal: high prices and output, part of the output sold.

[b] Based on costs and credit schedule of Smallholder Rubber Development Project, assuming an average yield of 1300 kg/ha/year throughout the tapping period.

[c] Rubber sold at Rp 1000/dry kg, farmgate.

[d] After deducting the reproduction cost of family work force:
(number of family man-days/ha × basic consumption needs/person/day, i.e., 1500 Rp).

[e] Total area needed to meet the basic needs of a household of five, i.e., 1,200,000 Rp per year.

Species that can be used for timber may be kept, and even sometimes maintained by circular weeding and branching — especially in regions where timber from 'natural' forests has become a scarce resource, like in Sukaraja. Farmers can also find the fuelwood needed for household consumption. When replanted, jungle rubber provides all the necessary wood for fencing the next crop, saving farmers the need to buy barbed wire which they could not afford in most cases. Timber and fuelwood from jungle rubber is growing in importance, since deforestation has deprived farmers of other sources.

Farmers also mention species that are used for traditional medicine. More investigations would be needed to assess their potential for development.

2.3.2. *Contribution to family assets: the need for land-titling*

Like most perennials, jungle rubber contributes to farmer wealth by providing assets as well as income. Most farmers in the area lack official land titles: yet rubber contributes to family wealth by bearing witness to land occupancy. An area covered with rubber is usually regarded by local land right as belonging to the planter, and as such it can be inherited or sold. Planted land can also be claimed as an individual asset in case of conflict over land property with the government or estate companies. In some areas, smallholders are planting rubber as fast as they can to occupy an uncultivated area before it is seized by such external bodies.

The value of a rubber plantation depends on the local land market but also on the capital value of the rubber trees, depending on their present and future production. Based on this, farmers can sell plantations to meet major family cash needs, weddings for example. Since rubber provides a regular income, plantations can also be used as a collateral for credit on the rural market.

However, most smallholders are unable to get official land titles because of the complex and costly procedure involved. Thus they feel insecure in the event of conflicts over land property with external bodies. The lack of official land titling also limits the use of planted land as collateral for formal bank credit.

2.3.3. *Minimal input through the use of bush cover against weeds and mammals*

Jungle rubber plantations are often considered by agronomists as badly maintained, since the bush cover slows the growth of rubber (8 to 12 years before tapping) compared with weed-free plantations on estates (5 to 7 years).

Yet farmers consider bush species as cover crops against worse competitors to rubber such as *Imperata cylindrica*, which would require costly herbicides to control it. Farmers point out that, compared with bush cover, rubber invaded by *Imperata* needs an additional 2 to 3 years before tapping, and has an approximate 1:3 probability of burning down in early years.

According to farmers again, bushes also protect rubber trees against tapir, deer or wild pigs that would otherwise feed on young rubber bark or shoots (probably by providing other species to be attacked). Wood fences erected by farmers usually last no more than two to three years. Without bush cover thereafter, farmers would have to maintain fences throughout rubber growth, at high cost.

A rough estimate indicates that bush cover saves farmers 500,000 Rp in materials, herbicides and labour that would otherwise be needed for crop protection before tapping — a significant amount when compared to farmers' incomes.

2.3.4. *Long economic life through spontaneous regeneration*

Trees in jungle rubber are often poorly tapped due to the use of unqualified family workers such as young children, and the preference given to fast execution to save labour. Therefore, each single tree can rarely be tapped for more than 20 years (while trees on carefully managed estates are usually tapped for 28 years or so).

Yet jungle rubber plantations can be exploited for more than 30 years: when the trees that were initially planted have decayed, smallholders tap younger seedlings that have grown spontaneously in between. Farmers encourage this regrowth by circular weeding, or by transplanting seedlings to empty spots left by the death of older trees. Since rubber grows poorly under shade, however, this regeneration does not prevent the overall tapped tree population falling from an initial 500 trees to 200 trees/ha after 40 years [Gouyon and Nancy, 1989]. Tapping is then no longer profitable, and farmers resort to overall replanting if they need the land.

2.4. *Conclusion: complex agroforests . . . what use for biodiversity?*

As a 'land use system [. . .] where woody perennials [. . .] are deliberately used on the same land-management unit as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence', with 'ecological and economic interactions between the different components',[4] jungle rubber belongs to agroforestry systems.

Moreover, as an agricultural system which preserves the features of a forest ecosystem, with a wide ecological and economic diversity, jungle rubber belongs to 'complex agroforests' — like the *damar* smallholder plantations in Lampung [Torquebiau, 1984; Michon, 1985] or the *durian* based agroforests in West Sumatra [Michon et al., 1986].[5] This type of agroforestry is especially common in the least populated areas of Indonesia (less than 200 people/km^2), where natural forest is nearby either in time or distance [De Foresta and Michon, 1991a], as is the case here.

Preserving biodiversity might be important for mankind as a whole — natural forests and agroforests being held as a reserve for species that could prove valuable in the future. However, this far-reaching goal is often in conflict with the emergent income needs of increasing populations in developing areas.

Complex agroforests may be examples of agricultural systems where biodiversity provides immediate economic returns. In the case of jungle rubber, the diversity of species has for a long time been performing two economic functions:

- supplementing farmer income with cash or self-consumed goods, enabling him to reduce his dependency on rubber;
- enabling farmers to expand their planted area with minimal capital and labour input.

Yet is this low-input, low-output system sustainable in view of changing economic conditions, especially with growing population pressure?

3. The challenge of ecological and economic change

3.1. *More people, new landscapes*

Although rubber seemed to fit easily into the existing shifting cultivation system in Southeast Sumatra,[6] it was soon to bring major changes in land-use patterns. With more and more land appropriated under jungle rubber, farmers had to move further inland to clear forest. This eventually led to the setting up of new permanent villages [Gouyon, 1991]. This move was accelerated by migrants from overcrowded Java, who found employment as tappers on smallholdings. Newcomers settled on secondary forest or jungle rubber land sold to them by the locals, who meanwhile went on clearing more primary forest.

This pattern can still be found in most of Jambi [Gouyon et al., 1991], and may even have accelerated recently. Selective industrial logging in natural forests creates roads, and indirectly helps farmers to move in. For the last few years local dwellers have felt an emergent need to occupy as much land as possible through rubber planting, in fear of losing their land rights to estate or government schemes. However, this pattern of extension will soon come to an end, since much of the area already belongs to individual farmers or has been given as concessions to private companies.

3.2. *Less land, decreasing incomes*

It seems that the forest conquest was over as early as the 1960s in the most crowded parts of South Sumatra (such as around Sukaraja, see Fig. 1). The observation of ecological, agricultural and socio-economic changes in those areas provides an insight into what happens to jungle rubber under an increasing population.

3.2.1. *More competitors: weeds and mammalian predators*

With no primary or old secondary forest and little scope for replanting on old rubber, farmers are driven to plant rubber on young forest regrowth. They then face higher competition from weeds — especially *Imperata cylindrica*. This means higher labour requirements per hectare and lower yields for the annual crops.

Farmers also mentioned a higher incidence of damage by pigs and other mammalian crop predators in the most densely populated areas; driven away from their forest habitat by land clearing, it seems that they multiply in jungle rubber where they feed on rubber seeds and food crops. Hence the need to erect fences (more than 1.5 m high) around the plantations to protect young rubber and annual crops, and to monitor the fields during the two first years.[7]

With reduced yields and additional crop protection, the return to labour tends to drop in the areas where no more mature forest is left for clearing and extension (124 man-days are needed to establish one hectare of jungle rubber in Jambi, compared to 384 in the most crowded parts of South Sumatra) [Gouyon, 1991].

3.2.2. *Smallholder differentiation*
The average area of rubber owned by farmers is declining since there is no more forest to accommodate younger generations. Our surveys indicate that while each household in the 'frontier' zones of Jambi might own at least 5 ha, smallholders in the most densely populated rubber areas of South Sumatra own an average of 2.5 to 3 ha, while 3 ha is the minimum to meet the average basic consumption needs per household under optimistic price hypotheses (Table 2). This means that the population density is slightly over what can be supported by jungle rubber.

Land distribution between smallholders, however, is more significant than average figures. With no more 'new frontiers', landless farmers have little hope of improving their situation. Differentiation has taken place between three types of farmers: (1) wealthy, large landowners who often engage in trade; (2) smallholders who have enough land to meet their family needs; and (3) deprived farmers who have to seek part-time employment outside their own property (working for the wealthy ones or outside the village). Official statistics and our own surveys suggest that this last category might be between 25% and 50% of rubber smallholders in South Sumatra [Anon, 1987].

Thus for a growing number of smallholders, current agricultural production based on jungle rubber on limited land is no longer sustainable, since it brings a lower income than farmers expect. It will be even more true in the future with growing living standards as a result of more contacts with the outside and rising wages in non-agricultural sectors.

Unless it is assumed that rural dwellers whose income is decreasing can all be employed outside the agricultural sectors — which hardly seems an option given present under-employment in Indonesia — this means that new solutions are needed to increase farmer income in jungle rubber areas.

4. Which future for rubber agroforestry systems?

Given natural conditions in the rainfed part of the region, it seems difficult to recommend other crops than the existing ones at present prices and costs. Sustainable cultivation of annual crops seems hardly profitable, and the range of perennials suitable for the area is limited to rubber, fruit trees and oil palm — the latter needing major agro-industrial investments. Alternatives for raising smallholder income are thus more likely to be based on rubber and the existing associated species. Potential economic improvements to the various system components are reviewed below.

4.1. *Improving the non-rubber components: a question of marketing*

Table 2 shows that better economic use of the non-rubber components, especially timber and fruit trees, can increase the return on farmers' labour and land — enabling a household to live on less than 2 ha. This somewhat theoretical computation assumes that a large part of this output can be sold outside the village. Until now, the limiting factors to developing these opportunities have been the lack of adequate transportation and marketing.

The outlet for timber from jungle rubber has expanded recently since timber from natural forests is becoming less abundant. It is now common to see logging within old rubber plantations that are close to a road. The majority of smallholder plantations, however, can be reached only by small footpaths. Since the timber sources from jungle rubber are spread over large areas with a small density of valuable trees, it would be difficult to organize marketing on a large scale.

Farmers who own fruit trees, often behind their house, can add to their yearly income by selling fruit (with a gross output of about 900,000 Rp per ha per year on average). It seems that these orchards supply more than can be channelled by local markets, with fruits rotting in the villages during peak harvest seasons (occurring every three years or so). Yet as soon as a village gets good road access, opportunities for marketing develop quickly due to the initiatives of traders often coming from other areas, who are able to build market channels reaching as far as Jakarta within a year.

A significant increase in farmer cash income during the first years after rubber planting can be derived from intercrops such as pineapple, banana, chili, watermelon, beans, etc. Again the main limiting factor is markets. Recent developments in the outlets for cash crops such as chili or watermelon in South Sumatra have enabled farmers with good road access to diversify their incomes (Agus Supriono, pers. comm.).

The fast development of marketing opportunities for fruits and vegetables seems to indicate that there is extensive demand for consumption in urban areas, where most of these products are sold now. However, this outlet might soon be flooded as transportation facilities improve in Sumatra. Developing the non-rubber component would require market studies with a prospective viewpoint, taking into account marketing opportunities within and outside Indonesia.

Farmers stress that cash crops other than rubber, i.e. fruits and vegetables, regularly suffer from depressed prices during peak production seasons. This indicates that market development for such crops should be combined with agricultural research for widening the harvest periods — a tough challenge in these areas where irrigation would be extremely costly.

4.2. *Improving the rubber component at low cost and risk?*

There is a ready outlet and marketing network for natural rubber. The less optimistic price prospects forecast a world price of US$ 0.70/kg by year 2000 [Landell Mills Commodity Studies, 1986] (compared with 0.85 to 1.15 during the last five years) while the most optimistic ones even forecast temporary rises [Hobohm, 1990]. Indonesia, and Sumatra in particular, has good comparative advantages for rubber [Hirsch, 1990; Landell Mills Commodity Studies, 1990] thanks to its cheap labour force. With increased productivity, Indonesian smallholders could reap substantial incomes from rubber since they would then produce at a lower cost than their main competitors in Malaysia or Thailand.

4.2.1. *The monocrop alternative*

Most current technical recommendations for improving rubber productivity rely on estate-like methods, i.e., the use of selected varieties propagated by grafting (*clones*) with intensive weeding. This leaves little scope for associated crops, with the possible exception of temporary intercrops that have proved to be feasible during the early years without slowing the development of clones [Keti and De La Serve, 1988; Lim Sow Ching, 1969; Rosyid et al., 1986; Sutrisno and Sastrosoedarjo, 1976].

Such plantations have been developed for smallholders in Sumatra by several government projects such as the Nucleus Estates and Smallholders schemes (NES) or the Project Management Units (PMUs). Successful schemes have relied on intensive supervision and comprehensive credit to farmers during the initial years. A computation of farmer cash flow and labour based on data from the Smallholder Rubber Development Project (SRDP), the best scheme so far, indicates that smallholders' net income has increased by nearly 100% per hectare and 60% per man-day with the project. This means that 1.5 ha could fulfil the needs of one household under similar schemes (Table 2).

Government projects have reached less than 20% of the total number of rubber smallholders. It seems unlikely that the Indonesian government, which has numerous other priorities, will invest much more in similar full-assistance projects. Thus other concepts are needed for the remaining majority of smallholders [Barlow et al., 1989; Bennett et al., 1991; Directorate General for Estates, 1991; Tomich, 1989; World Bank, 1989].

Smallholders around government projects have witnessed the high returns obtained using clonal varieties. Yet the majority still use unselected varieties for new plantations or replanting. The reasons for this gap are well known [Gouyon et al., 1991]:

— smallholders who have an opportunity to clear forest for new planting prefer unselected varieties since they require less input per hectare, enabling them to plant and occupy larger areas each year. Their priority is extending their property;
— smallholders with limited access to land are eager to use selected varieties, to raise their income per hectare. An increasing number of farmers are trying to adopt selected rubber outside government schemes. However, they face capital constraints on buying planting material and maintenance. Current technical recommendations for clones require heavy expenditure on herbicides, legume cover crops and fencing. Thus most smallholders, except the wealthy ones, feel either that they lack adequate capital, or that the risk taken is too high.

This means that without external financial input, only the wealthiest farmers are able to improve their productivity. Meanwhile, the others are facing declining income and employment opportunities at village level.

Proposals have been made for providing financial assistance to smallholders. Small-scale credit schemes such as the *Kredit Umum Pedesaan* managed by *Bank Rakyat Indonesia*, or the *Proyek Pengembangan Usaha Kecil* under *Bank Indonesia* could enable rubber smallholders to purchase planting material and inputs [Bennett et al., 1991; Bank Indonesia, 1992]. Repayments could start without waiting for tapping, since farmers usually have at least two plots of mature rubber and can rely on one for cash inflow while replanting the other. Yet rural credit facilities are lacking outside rice intensification programs. Moreover, smallholders have been suffering from the 'tight money' policy implemented by the government to limit inflation after several financial deregulations. High real interest rates, often over 20%, are hampering long-term investments such as the ones needed in the tree crop sector.

4.2.2. *Agroforestry alternatives?*

The adoption of selected varieties by farmers would be eased if technical options were available for reducing initial maintenance costs and preserving as much economic diversity as possible to alleviate risks. Since rubber research has long been carried out mostly for estates or government schemes, there is no such ready-to-use alternative. New directions for such research can be suggested.

Rubber planting material can be chosen according to farmer constraints for crop protection against *Imperata cylindrica* in early years, with preference given to cultivars with fast canopy development to cover the soil as soon as possible. Extension and support to nurseries are needed, however, to ensure that good quality planting material is made available to farmers [Barlow et al., 1989; Bennett et al., 1991; Gouyon et al., 1990]. Yet this might not be sufficient, since empirical data from estates and farmers indicate that the clones used until now do not perform well under jungle rubber management, with a high mortality rate and slow growth. Two reasons might explain this:

— these clones were selected in an estate-like environment, without weeds;
— the losses due to weed competition in jungle rubber are compensated by

high initial planting density (1000 to over 2000 seeds for tapping a final 500 trees per ha). This would be uneconomic with selected rubber due to the high cost of plant propagation (budgrafting and maintenance of nurseries or seed gardens).

Indeed any research on the use of selected rubber with agroforestry techniques would require better knowledge of the exact nature of the competition between rubber and other perennial species such as the ones in jungle rubber. This would make it possible among other things to select new clones that would perform better under low maintenance than the existing ones.

Several authors have advocated the use of varieties propagated from seeds instead of grafting [Barlow et al., 1989; Bennett et al., 1991], arguing that they would be more resistant to weed competition. Among such selected seedlings, *polyclonal seedlings* are costly to propagate, since they require large areas of seed gardens. Smallholders have come up with an innovation of their own; they often use *clonal seedlings*, collected under existing commercial clonal plantations. Farmers who have tried such clonal seedlings claim that their yield is 75% higher (instead of 100 to 200% with clones) than seedlings from jungle rubber, even with low maintenance. It is thus no wonder that such material is rapidly catching on among less wealthy farmers.

A better knowledge of the behaviour of selected rubber cultivars associated with perennial species would make it possible to propose new cropping methods using shrub or tree species as cover crops against grass weeds, and as perennial intercrops. This includes numerous potential species from natural bush cover to shrub legumes and fruit trees. Trials should enable to choose the optimal rubber planting density under such circumstances, the kind of species adapted to local conditions and the plant management techniques to reach the best compromise — in terms of farmers' net income — between input and output. This requires more cooperation between economists, agronomists, botanists and plant breeders.

Another research field combining agronomics with forestry has recently been opened with the widening of outlets for rubber wood — which can be used for making plywood or even furniture. Rubber wood, which was discarded for years as low quality, is hence gaining value. Recent studies from Malaysia quoted prices as high as M$ 380 to 489/m^3 for rubber wood in 1989, against M$ 350—450 for *Meranti* and similar hardwoods in the same year [Anon, 1992]. In Indonesia, farmers who have the opportunity of selling rubber wood to plywood factories can earn an average Rp. 600,000/ha when felling their old rubber plantation [Sumana, 1991].

Both the rarefaction of timber species from natural forests and the promotion endeavours (including research on end uses) by producer countries such as Malaysia or, more recently, Indonesia, might explain this market development [De Foresta and Michon, 1990, 1991b]. This could lead to planting rubber for industrial reafforestation [Bennett et al., 1991; Anon, 1989b]. Again crop management systems for an optimum balance between costs, rubber production and timber production are still to be found. Adequate marketing and processing facilities are also needed.

Conclusion

Jungle rubber is a balanced, diversified farming system developed by farmers outside extension and estate recommendations. By creating forest-like plantations which can be labelled as complex agroforests, farmers have been able to diversify their income with minimal establishment and maintenance costs. Yet changing economic conditions, especially the increasing population density in parts of Sumatra, are endangering the economic sustainability of this system. Present technical recommendations and policies will probably not enable farmers to meet these challenges. Indeed, until recently, only two options seemed possible:

— providing smallholders with the necessary technical and financial assistance to replace low-yielding jungle rubber with clonal plantations following the estate model, i.e., with high maintenance. This path has been followed by Malaysia and Thailand. It has succeeded in raising farmer wealth, while also increasing their dependency on rubber and replacing a diverse, forest-like environment with monospecies plantations. This could be an option for Indonesia if the necessary financial resources were made available from the government, which seems unlikely given the numerous other priorities faced by the country.

— *laissez-faire*: with no specific financial and technical assistance, only the wealthiest smallholders may be able to increase their income by adopting selected rubber cultivars. This would probably result in higher differentiation between well-off and poor farmers, with more young people being compelled to seek employment in towns — hardly a desirable option in a country facing rural poverty and overall under-employment.

New options are thus needed for improving farmer income with minimal call on government money. This could be done by trying to preserve some of the features of jungle rubber such as low maintenance and income diversity, instead of merely transferring the estate model to smallholders. This would, however, require new lines of research and new development schemes. Some of the most relevant proposals include:

— developing transportation, marketing and processing for the non-rubber output, such as timber and fruits;

— developing short-term, small-scale credit schemes to help farmers adopt high-yielding rubber varieties;

— research to develop new selected rubber management methods based on agroforestry to reduce maintenance costs. This could enable smallholders to plant high-yielding rubber without losing too much of the present biodiversity and economic diversity.

Acknowledgements

The Research Institute for Estate Crops of Sembawa, Palembang (Indonesian Planters Association for Research and Development) provided support throughout this study, within the framework of cooperation with CIRAD. GAPKINDO (Indonesian Association of Natural Rubber Industries) provided additional support. The eco-botanical study was undertaken as part of a joint project between SEAMEO-BIOTROP, Bogor, and ORSTOM, and received financial support from the French Ministry of the Environment. Dr Colin Barlow from the Australian National University provided guidance on several occasions, as well as Prof. Marcel Mazoyer and Marc Dufumier of the Institut National Agronomique Paris-Grignon.

Notes

1. Yet they are economic relationships between the riverside and rainfed areas. Some of the rubber farmers own wetland rice fields in riparian villages several kilometres away from their rubber plantations, while riverside farmers may occasionally work in rubber plantations.
2. Rain forest between 15 and 150 m was the major source for logging and conversion to large plantations; as a result, less than 3.5% of all Sumatra is covered with 'untouched' forest *at this altitude* [Laumonier, 1991].
3. As will be seen later, secondary forests can hardly be identified from old jungle rubber plantations. This leads to uncertainties in mapping and inventories.
4. Lundgren and Raintree 1982, in Nair 1989 [Nair, 1989].
5. As opposed to 'simple agroforests', with one herbaceous or shrub species associated with one tree species or little more, which as far as biodiversity is concerned, are "just as far from a natural forest than a paddy field" [De Foresta and Michon, 1991a; Michon and De Foresta, 1990]. In any event the generic term agroforest tends to be increasingly used for 'complex' agroforests alone.
6. And also in Malaysia, South Thailand, Liberia, etc., where the story of rubber cultivation started with jungle rubber.
7. Pigs are not hunted for human consumption in this muslim region. Villagers have tried to organize hunts to eradicate pigs, with seemingly little effect in the long run.

Appendix 1

List of species in the architectural profile of jungle rubber in Muara Buat (Jambi).

1	*Artocarpus* sp.	2	*Peronema canescens*
3	*Hevea brasiliensis*	4	*Hevea brasiliensis*
5	*Peronema canescens*	6	*Peronema canescens*
7	*Pternandra echinata*	8	*Peronema canescens*

9	*Hevea brasiliensis*	10	*Xerospermum?*
11	*Hevea brasiliensis*	12	*Ficus* sp.
13	*Hevea brasiliensis*	14	*Rotin 'Semambu'*
15	*Styrax benzoin*	16	*Milletia atropurpurea*
17	*Milletia atropurpurea*	18	*Milletia atropurpurea*
19	*Macaranga triloba*	20	*Hevea brasiliensis*
21	*Styrax benzoin*	21'	*Hevea brasiliensis*
22	*Peronema canescens*	23	*Hevea brasiliensis*
24	*Rotin 'Semambu'*	25	*Hevea brasiliensis*
26	*Hevea brasiliensis*	27	*Hevea brasiliensis*
28	*Peronema canescens*	29	*Peronema canescens*
30	*Milletia atropurpurea*	31	*Canarium patentinervium*
32	*Artocarpus*	33	*Styrax benzoin*
34	cf. *Drypetes longifolia*?	35	*Hevea brasiliensis*
36	*Payena* cf. *acuminata*	37	*Lauraceae?*
38	*Hevea brasiliensis*	39	*Hevea brasiliensis*
40	*Hevea brasiliensis*	41	*Hevea brasiliensis*
42	? *'Bintung'*	43	*Hevea brasiliensis*
44	*Hevea brasiliensis*	45	*Hevea brasiliensis*
46	*Eugenia?*	47	*Hevea brasiliensis*
48	*Pternandra echinata*	49	? *'Ntango'*
50	*Rotin 'Manau tebu'*	51	? *'Jangkang'*
52	*Pternandra echinata*	53	*Eugenia* sp. *'Kayu Klat'*
54	*Hevea brasiliensis*	55	*Hevea brasiliensis*
56	*Xerospermum noronianum?*	57	*Polyalthia hypoleuca*
58	*Eugenia* sp. ? *'Kayu Klat'*	59	*Milletia atropurpurea*
60	*Pternandra echinata*	61	*Hevea brasiliensis*
62	cf. *Porterandia?*	63	*Hevea brasiliensis*
64	*Hevea brasiliensis*	65	*Hevea brasiliensis*
66	*Styrax benzoin*	67	*Fagaceae?*
68	*Hevea brasiliensis*	69	*Styrax benzoin*
70	*Styrax benzoin*		

Appendix 2

List of species in the architectural profile of jungle rubber in Sukaraja (South Sumatra).

1	*Hevea brasiliensis*	46	*Hevea brasiliensis*
2	*Milletia atropurpurea*	47	*Rosaceae?*
3	*Milletia atropurpurea*	48	*Hevea brasiliensis*
4	*Hevea brasiliensis*	50	*Hevea brasiliensis*
5	*Hevea brasiliensis*	51	*Hevea brasiliensis*
6	*Hevea brasiliensis*	52	*Hevea brasiliensis*
7	*Hevea brasiliensis*	53	*Nephelium lappaceum*
8	*Hevea brasiliensis*	54	*Hevea brasiliensis*
20	*Lithocarpus (elegans?)*	61	*Hevea brasiliensis*
21	*Hevea brasiliensis*	62	*Hevea brasiliensis*
22	*Hevea brasiliensis*	63	*Hevea brasiliensis*
23	*Rosaceae?*	64	*Artocarpus* sp.
24	*Hevea brasiliensis*	65	*Hevea brasiliensis*
25	*Hevea brasiliensis*	66	*Hevea brasiliensis*
26	*Rosaceae?*	75	*Milletia atropurpurea*

28	*Hevea brasiliensis*	76	*Hevea brasiliensis*
29	*Schima wallichii*	79	*Lauraceae* sp.
30	*Hevea brasiliensis*	80	*Hevea brasiliensis*
31	*Nephelium lappaceum*	81	*Hevea brasiliensis*
33	*Hevea brasiliensis*	86	*Schima wallichii*

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