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Environmental benefits and sustainable land-use options in the Jambi transect, Sumatra, Indonesia

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Abstract

Loss of environmental services provided by forests is a non-linear process in Jambi Province, Sumatra, Indonesia. Intermediate-intensity land-use types in the form of complex agroforests have maintained global environmental benefits under a sustainable and profitable land use regime. Conversion to tree crop monocultures, however, poses a challenge to the environmental stakeholders and an opportunity from to stakeholders in the private economy. We quantified environmental indicators, as well as profitability and sustainability of a range of existing and possible production systems. Criteria and indicators were used at plot to landscape scales, taking into account local, national and global perspectives. Agronomic sustainability and profitability were assessed at plot level as they are of primarily local concern, while environmental services of forests, such as plant species and functional type richness, carbon stocks, greenhouse gas emissions, and transboundary haze, which are of national and global concern, were assessed at landscape level. Quantitative tradeoffs and complementarities were analyzed between global environmental benefits and local profitability. The current trend towards simplification of the complex agro-ecosystems and inherent loss of environmental services of forests is driven by profitability. The sequence in which environmental services of forests are lost is: standing carbon stocks, biodiversity, and low or negative greenhouse gas emissions.

Keywords: agronomic sustainability, profitability, biodiversity, carbon stocks, greenhouse gas emissions, tradeoff analysis

1. Introduction

Global concerns about 'deforestation' often are expressed as if a binary classification ('forest' *versus* 'non -forest') is sufficiently informative regardless of the land-use type that follows forest conversion, or the consequences to forest health under low-intensity use. The Jambi transect in Sumatra was set up to explore the consequences of a gradual loss of environmental services of forests under intensifying land-use rather than ‘black-or-white’ deforestation, and the conditions under which that occurs in the humid tropics.

Characterisation of land-use change in Jambi was first carried out by multi-disciplinary research teams that took part in the global Alternatives to Slash-and-Burn (ASB) project, followed by a comprehensive comparison of land-use options (Van Noordwijk *et al.*, 1995, 1998a; Tomich *et al.*, 1998a,b, 2001). In this overview, Jambi Province is placed within the context of a transect for global land-use change research, that was established by a consortium of national and international research organizations. The transect offers a 'laboratory' for understanding the ongoing land-use change. It also offers an opportunity to study agroforests as a land-use system that is distinctive in the degree to which allows for a 'cohabitation' of biodiversity and directly productive trees. The term ‘agroforest’, as defined by de Foresta and Michon (1996) captures the mixed heritage of the ‘wild’ and the ‘domesticated’ aspect of these systems, and highlights an intermediate stage between natural forest and agricultural plantations.

In this paper we 1) describe the biophysical and socio-economic setting of the Jambi transect, and 2) provide a systematic evaluation of land-use options on the basis of (2a) local and national criteria and indicators, such as, agronomic sustainability and profitability, and (2b) the global environmental perspectives, such as, biodiversity loss, carbon stocks, greenhouse gas emissions, and transboundary haze pollution.

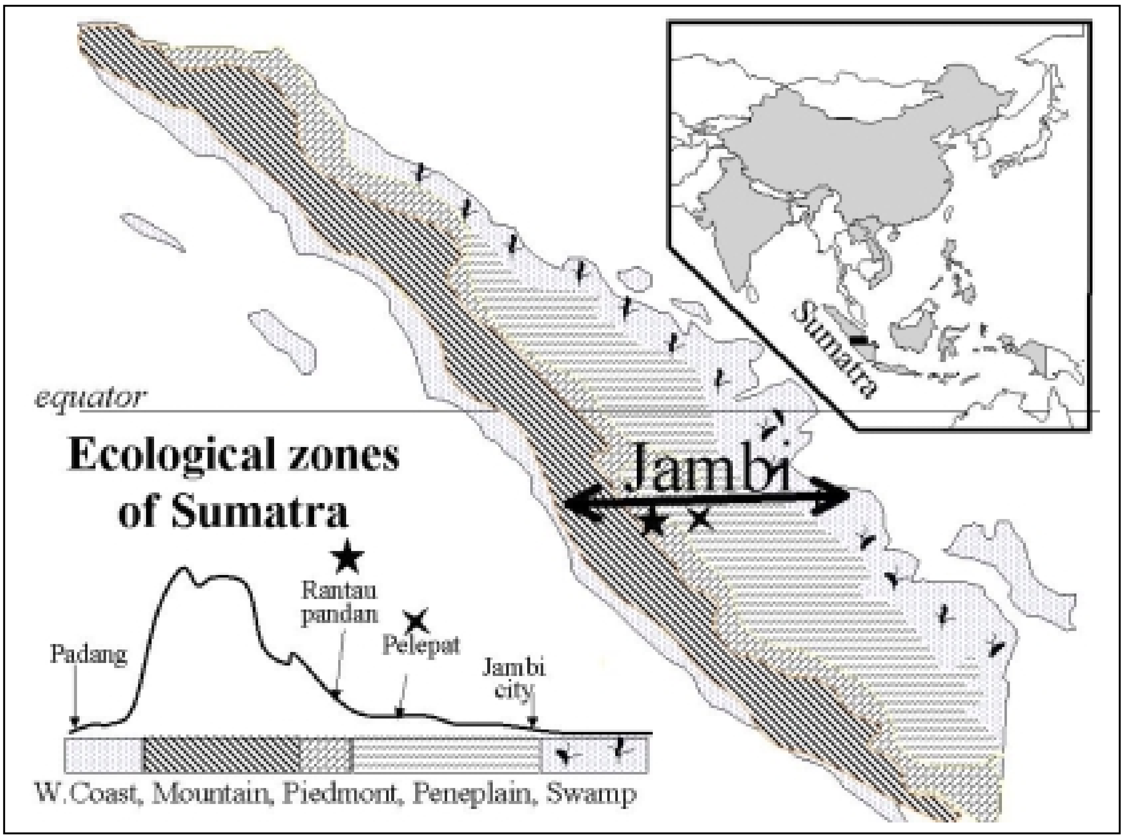

Figure 1. The Jambi global change transect and benchmark areas of the Alternatives to Slash-and-Burn (ASB) project described here.

2. Biophysical and Socio-economic Setting of the Jambi Transect

2.1. Ecological zones and benchmark sites

The island of Sumatra extends from 5^o N to 5^o S is in the lowland humid tropical forest zone in insular Asia. Its land-use intensity is intermediate between the densely populated islands of Java and Bali, and the more sparsely populated islands of Borneo, Sulawesi and Papua. As shown in Figure 1 there are five major ecological zones identified with boundaries running from northwest to southeast approximately parallel to the coast. It is shown that Jambi transect is dominated by peneplain zone with Tertiary sediments, deposited in the sea, the altitude is less than 100 m above sea level and it consists of about 10% river levees and floodplains with more fertile alluvial soils and 90% uplands with a gently undulating landscape and mostly red-yellow podzolic soils, Jambi, with an area of 49,578 km2 is sparsely populated relative to the rest of Sumatra. Within Sumatra, a clear gradient in population density occurs from Lampung Province at the southern tip of Sumatra (174 and 188 people km^{-2} in 1993 and 2000, respectively) to Jambi Province in the middle of the island (42 and 54 people km^{-2} in 1993 and 2000, respectively).

To understand biophysical and socio-economic processes two contrasting benchmark sites were initially selected, one in the piedmont zone and one in the peneplain zone. These experience different land-use intensity. The piedmont site (Rantau Pandan) ranges from 100 to 500 m.a.s.l., and was built mainly from granite and andesitic lava. Soils in Rantau Pandan are varied and complex, ranging from shallow to very deep, with moderate to fine texture. Soils are moderately to to excessively well drained, but also are very acid with low fertility. The peneplain site (Pelepat) is a dissected lowland, consisting of tuffaceous acid sediments, generally below 100 m.a.s.l. Soils in Pelepat are very deep, well drained, very acid, with low fertility. A third site in the coastal swamp zone (Berbak National Park and surrounding low-lying peat-swamp) was added to help understand recurrent forest and land fires. The depth of peat varies with the distance from river tributaries but is mostly up to 3m deep. Jambi Province experiences, on average, 7-9 wet months (> 200 mm rainfall) and less than 2 dry months (100 mm rainfall) per year, with annual rainfall in the range of 2100-3000 mm (Oldeman and Las, 1975).

2.2. Brief land use history

Much of the land is within reach of the river and human settlements spread over most of the lowland peneplain. Small groups with a hunter/gatherer lifestyle (*suku dalam*, *orang rimba* or indicated with the derogatory name *Kubu* which literally means 'confined') continued to make a living in the core forest areas of the interfluves, exchanging forest products for rice with surrounding villages (Persoon, 1984). Trade in forest products was augmented by participation in the international spice trade, with Jambi mentioned in the 18th century as one of the centres of pepper production (Kathirithambi-Wells, 1996).

In the second half of the 19th Century 'para' rubber, *Hevea brasiliensis* was introduced from Brazil; this could thrive in the similar soil and climate of Sumatra and rapidly replace all local, partially domesticated, latex producing trees and vines. In the beginning of the 20th century, extensively managed rubber 'agroforests' (Gouyon et al., 1993) replaced the 'shifting cultivation' systems of local food production and became the dominant land-use in the lowland peneplain of Jambi, as in neighbouring provinces. This attracted labour from Java and elsewhere in Sumatra, especially during the initial boom in

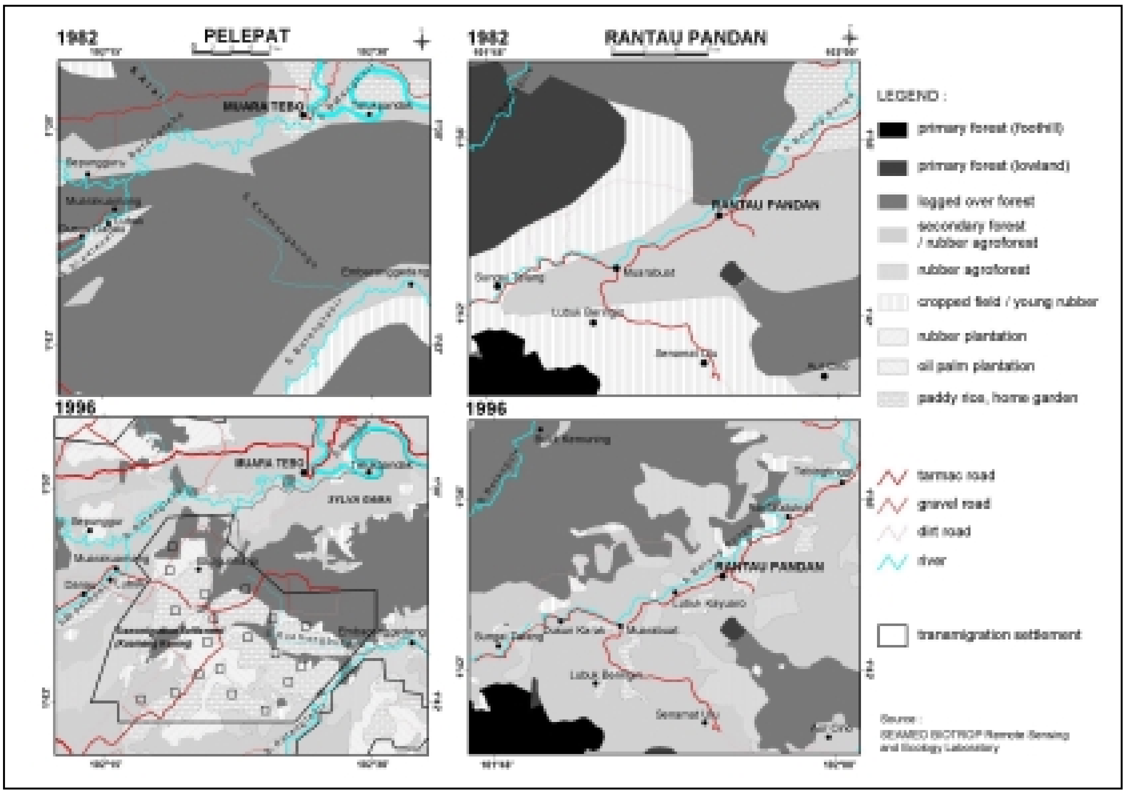

Figure 2. Land-use change in Jambi benchmark areas (Rantau Pandan in the piedmont zone and Pelepat in the lowland peneplain) of the ASB project.

rubber after World War I. The main reason for the economic success of rubber in Southeast Asia was the abundance of cheap labour, the good access, harbours and trade system and the absence of diseases that occur in the original area of the rubber tree. The plantations in Southeast Asia quickly out yielded the rubber production of the Amazon, where rubber essentially remained as a 'non-timber forest product'. Rubber fitted easily into what was essentially still a long-fallow shifting cultivation system based on upland rice as major food crop.

The transformation of the forests into 'agroforests' was facilitated by the local rules that assigned property rights where trees had been planted, while shifting cultivation plots without planted trees returned to the community land pool after the cropping years.. The former provincial road network essentially follows the rivers, but the construction of the Trans-Sumatra Highway in the 1970's radically changed the land-use pattern providing access to much further areas from the rivers. Commercial logging, government-sponsored resettlement schemes and spontaneous migrant flowing along the new road created a second period of rapid change, with increasingly drastic consequences for biodiversity and other environmental services. Moreover, the opening up of the coastal peat swamp forest zone for oil palm and resettlement schemes were responsible for most of the smoke and haze pollution during the 1997/1998 *El-Niño* episode. The event was world-wide publisize as it become a major health hazard in Sumatra and in neighbouring Singapore and Malaysia (Tomich *et al.*, 1998c).

2.3. Vegetation cover and land-use intensity

According to a map published in 1986 based upon imagery and field work, in the early 1980's the vegetation cover in the province was still dominated by lowland tropical forest but was replaced by settlements, secondary crops or monoculture plantations in early 1990's (Figure 2). Of the two benchmark areas shown, the piedmont benchmark of Rantau Pandan has developed on the basis of pre-existing patterns of rubber agroforests, while the lowland peneplain benchmark of Pelepat has been more drastically changed by the externally-driven transmigration and oil palm plantation schemes.

Table 1 shows the generic land-uses that were recognized for a global comparison of tropical land-use types in the ASB project, and the specific types present in Jambi transect. These include *natural forest* (included a fragment within a logging area in

Table 1**.** Land-use types studied in the Jambi transect in the landscape context related to their intensity and potential trajectory for global comparison purposes (Modified from: Tomich *et al.*, 1998b, 2001)

Main products	Land-use type	Representative form in the lowland peneplains of Sumatra	Type, scale, and intensity of operations	Landscape mosaic context of actual samples
Forest products	Natural Forest, F_n	Natural forest, undisturbed for the last 100 years	Small reserves within logging concession	25 ha patch in Forest mosaic
	Managed Forests, F_m	Community-based forest management; producing non-timber commodities and wood for local use	Community-based forest management, 10,000 to 35,000 ha	Indigenous smallholder landscape
	Logged Forests, F_l	Commercial logging (large scale); heavily logged with a (theoretical) cutting cycle of 25-30 years	Commercial logging, 35,000 ha or more, large scale	Forest mosaic
Tree crops	Extensive Agroforests (complex, multistrata agroforestry systems), T_e	Rubber agroforests planted with rubber seedlings; dominating the landscape	Rubber agroforests (seedlings), 1 to 5 ha, extensive, with some internal rejuvenation	Indigenous smallholder landscape
	Intensive Agroforestry, T_m	Rubber agroforestry with clonal (PB 260 and similar) rubber; recently introduced and expanding	Rubber gardens (clone), 1 to 5 ha, intensive but not a monoculture	Indigenous smallholder landscape

	T_s Simple, intensive treecrop systems	Rubber monoculture (smallholders) Labour intensive, compete with other plantations	Rubber monoculture, 1 to 5 ha, high inputs	Monoculture plantation
		Hybrid oil palm monoculture (large-scale enterprise**);** Labour intensive, mixed ownership, processing mills	Oil palm, monoculture, private estate, 35,000 ha or more, large scale, high intensity, high inputs	Monoculture plantation
		Fast-growing tree species for pulp industry	Timber estate, monoculture, private estate, 35,000 ha or more, large scale, medium intensity, low input	Forest mosaic
Annual crops	Extensive crop/ long fallow systems, C_e	Upland rice (2 years) with fallow rotation of 10 years or more	Upland rice with fallow rotation of 10 years or more, low intensity, low inputs	Indigenous smallholder landscape
	Medium intensity crop/ fallow systems, C_m	Upland rice with fallow rotation of 3-5 years	Upland rice with fallow rotation of 3 to 5 years, medium intensity, medium inputs	Indigenous smallholder landscape
	Intensive, crop/ short fallow systems, C_I	Practiced by migrants; Monoculture cassava degrading to *Imperata cylindrica*	Cassava, monoculture, 1 to 2 ha, within large scale settlement project, high intensity, low inputs	Transmigration project divided into small plot
	Continuous annual cropping systems, C_p	Tends to expand with purchased inputs, depending on local market		Transmigration project divided into small plots
Animal products	Pasture/ Grasslands, A_e	*Imperata cylindrica;* Abandoned, may cause disputes	*Imperata cylindrica*, within large scale settlement project	Transmigration project divided into small plots
	Intensive Pasture, A_I	*No representatives found*		

lowland forest to represent 'pristine' conditions); c*ommunity-based forest* (included extraction of non-timber forest products, such as, fruit, honey, birds and rattan); *large-scale commercial logging (*included concessions that were relatively well managed, as they comply with regulations); *smallholder rubber* (included both rubber agroforests and rubber monoculture); *large-scale plantations* (included oil palm and industrial timber estates); *upland rice with bush fallow* (found in isolated pockets of Sumatra's piedmont); *cassava and Imperata cylindrica* (represent the continuous annual cropping category and were observed in transmigration areas).

2.4. Land tenure and occupations

After the completion of the Trans Sumatra Highway in the 1980s, Jambi became a popular destination for migrants. Characterization studies in the ASB benchmark area indicate that more than 25% of spontaneous migrants arrived between 5-15 years ago and almost 40% less than five years ago. Over 80% of spontaneous migrants are from Java and less than 20% came from other areas in Sumatra. Government-sponsored migrants obtained land title a few years after they established their own income and stopped receiving supplies provided by the scheme.

Only less than 10% of households of local farmers and spontaneous migrants engage in non-agricultural activities. This is in strong contrast to transmigrants. Although non-agricultural activities may not be the main occupation of transmigrants, 75% of these households reported non-agricultural work (in trading, services, and paid labour). The logging and the rubber processing industry (crumb rubber) contributed to most of the exports (99%) from Jambi province in 1993. In the rubber industry, smallholder rubber plays an important role. The total area of rubber cultivation in Jambi in 1993 was 502,642 ha, of which only 3,447 ha were planted with high-yielding varieties under intensive management and the rest was 'jungle rubber' (the rubber agroforests).

There are at least six distinct interest groups who have a stake in the trajectory of land-use change in Sumatra, but there are crucial differences among them in the weights they place on the various economic and environmental outcomes. These include international community, hunter-gatherers, small-scale farmers, large-scale public and private estates, absentee farmers, and public policymakers (Tomich *et al*., 1998b).

3. Sustainability of Land-use Practices

3.1. Smallholders' and national perspectives

Agronomic sustainability

The main question underlying the sustainability assessment was whether continued farming is likely to degrade the resource base to a level that impairs future productive use of the land. Three aspects were considered, via a number of subcriteria: *Maintaining soil of sufficient structure and biological activity*, which is expressed in terms of soil compaction (A1), soil carbon saturation (A2), active soil carbon (A3), soil exposure to rain, wind or sun (A4), essential symbionts present (A5); *Balancing the nutrient budget*, which is indicated by the net nutrient export (B1), net depletion time (B2), and relative nutrient replacement costs (B3); *Managing biotic interactions*, by preventing weeds to reach unmanageable proportions (C1), and pests and diseases problems to become major constraints (C2).

The methods for assessment of agronomic sustainability of different land-use practices are documented in Tomich *et al*. (1998b), as are the basic field data used in the assessment. The rating results shown in Table 2 address 'threats' to persistence of current farming practices at two levels: sustainability problems that farmers can probably address by adaptive management, and sustainability problems that are probably beyond the reach of future adaptations.

Table 2. Agronomic sustainability rating of land-use types for criterion A (maintenance of soil structure and biological activity), B (nutrient balance), and C (crop protection) (Modified from: Tomich *et al.*, 1998b)

Land-use type	**Overall rating**			**Issues requiring attention**
	A	B	C	
F_n	0	0	0	-
F_m	0	0	0	-
F_l	-0.5	0	0	soil compaction in ramps and trails
T_e	-0.5	0	0	• soil compaction • output increased at low input; K supply needs attention • pigs & monkeys at replanting; fungal diseases when sensitive clones are used
T_m	-0.5	-0.5	-0.5	soil compaction
T_{s_rubber}	-0.5	0	-0.5	• soil compaction • fungal diseases, pigs and monkeys at replanting; ferns as ground cover may be problematic
$T_{s\_oilpalm}$	-0.5	-0.5	0	• soil compaction • assumed fruits sold rather than bunches
C_e/C_m	0	-0.5	-0.5	• Fertilizer use required for intensification • vertebrate and insect pests are a constraint
C_i/A_e	-0.5	-1	-0.5	• soil compaction; low C_{org}, lack of soil cover • nutrient balance can not be attained at current prices; K in short supply • *Imperata* fallows are a weed problem unless farmers have draught power available

Note:
0 = no problems outside normal farmer management domain,
0.5 = problem that may challenge farmers' adaptive capacity,
-1 = serious problem, probably beyond farmers' ability to respond

Soil degradation (criteria A and B) limits the options for farmers trapped in the cassava/*Imperata* cycle compared with those in the forest margin. The forms of soil organic matter that can provide nutrients to crops or young trees have been depleted as a result of mineralisation. However, on the basis of our measurements (Hardiwinoto and Prijono, 1999; Simanungkalit, 1999; Setiadi, 1999) we conclude that the soil is not significantly depleted of soil organisms, including micro-symbionts such as mycorrhiza and N-fixing microbes.

Ongoing research on various forms of rubber agroforestry demonstrates that selected high-yielding clones can be successfully established in smallholder systems at substantially reduced management intensity, compared with the monoculture plantations for which they were originally selected. Weeding intensities of 1-3 times per year are sufficient for good rubber growth, and this need only be done within the rows of rubber trees. It was also found that fertilizer application could be reduced or eliminated. The main constraint to rubber establishment appears to be pig and monkey damage, which can be controlled by fences, bamboo shafts around individual trees, or regular guarding of the plots.

Development of tree-based production systems can be hindered by the landscape context of such plots, with a high risk of fire in plots where individual farmers would plant trees. The soil seed bank can become nearly exhausted and only a limited array of tree species can reach the plot to initiate the succession to forests.

Profitability

Economic and social aspects of the alternative systems and technologies are assessed with the underlaying questions whether they are profitable and acceptable, since they will determine the prospect for adoption. In the global ASB project standardized procedures were used to obtain quantitative indicators of profitability, in both social and private terms (details are given in Tomich *et al.* 1998b; 2001). Returns to labour, defined as the wage rate that would lead to a net present value (NPV) of zero, with discounting of all future revenues and cost to the starting point of a land-use type. The assessment was made at 'private' prices for inputs, outputs, labour and capital (as actually experienced by farmers) and at 'social' prices that remove taxes and subsidies form the prices and take world markets as point of reference. Discount rates used for the social and private analysis are 15% and 20% per annum, respectively. The results shown in Table 3 indicate large differences in returns to labor among the land-use alternatives, especially for the community-based forest management, based on extraction of tradable non-timber forest products. This extensive land-use practice can give rewards up to three times the average market wage rate, yet according to these data, only for situations of abundant land (say population density of less than 1 person per km^2). In the early 1990's, the population density was 18 people km^{-2} in Rantau Pandan and 12 people km^{-2} for Pelepat, respectively (Van Noordwijk *et al.*, 1995). Tree crop production systems can provide

Table 3. Returns to labour, labour requirements for establishment of the various land use type and average annual labour requirements in the operational phase and the human population density that can be supported assuming 150 work days per year per average person and 80% of the land area available for productive land use (Modified from: Tomich *et al.*, 1998b, 2001)

Land-use type	**Returns to labour, relative to minimum wage rate**		**Labour requirement (Person-days ha^{-1})**			**Equivalent population density, people km^{-2}**
	Private prices	**Social prices**	**Establish-ment phase**	**Operation phase**	**Total**	
F_m	2.9	2.8	Na	0.2 - 0.4	0.2 - 0.4	0.2
F_l,	-4.3 - 0.5	2.0 - 7.8	15 - 100	17 - 41	31	17
T_e	1.0	1.0	271	157	111	59
T_m	1.0 - 1.7	1.1 - 1.9	444	74	150	80
T_{s_rubber}	1.7	0.7	344	166	133	71
$T_{s\_oilpalm}$,	1.5	2.5	532	83	108	58
C_e/ C_m	0.75	0.95	Na	15 - 25	15 - 25	11
C_i/A_e,	1.05	1.05	Na	98 - 104	98 - 104	54

attractive employment for 60-80 people km^{-2} at wages prevailing at the time of this study, slightly more than the intensive cassava production system included in the assessment. This system clearly cannot provide adequate livelihoods at population densities found in the transmigration villages, with a local population density of around 200 people km^{-2}, for 2.5 ha farms and an average household of 5 people.

3.2. Global environmental perspectives

Biodiversity loss

Much discussion of biodiversity conservation focuses on existence values – *i.e.*, preventing extinction. From a global perspective, the potential contribution of any area to the global goal depends on the 'uniqueness' of its flora, fauna, gene pools or ecosystems, not on its local diversity *per se*. Much less attention has been given to the local functional values of biodiversity in the landscape. These values range from the tangible (but not yet well quantified) roles of biodiversity in supporting sustainability and resilience of production systems, to less tangible aesthetic and spiritual roles of biodiversity for local people (Van Noordwijk and Swift, 1999). Local values may be more strongly related to local species richness, but should account for the different utilitarian values of different groups of species. Table 4 shows the plant species richness per standard (40 x 5 m^2) plot in each land-use type under current study.

Agroforests allow a substantial part of the local flora and fauna to survive within the context of an extensively managed land-use type. However, agroforests are not perfect substitutes for biodiversity conservation in natural forests. Conversion of natural forests to agroforests usually involves a significant reduction in overall species richness. For assessments of higher plants made along 100 m line transects in Sumatra, over 350 species were found in primary forests while the number dropped to about 250 species for rubber agroforests (Michon and de Foresta, 1995).

The ASB data confirm this relative ranking of extensive rubber agroforests, along with logged-over forests and community-managed forests at about three-quarter of the richness of primary forest plots. Plant species diversity per standard plot as used in the assessments for the ASB project was related to stand age, as reflected in the total tree basal area. Figure 3 shows no difference in this relation between rubber agroforests and secondary and logged-over forests.

Carbon stocks

How would the aboveground carbon stocks (C-stocks) be depleting or increasing in the changing land-use and what would be the consequences on soil emission are among the questions that are addressed in this exercise. Averaging the C-stocks over the life span of a system was used to give a simple measure of its role in the global C balance, as long as different stages of the system may be expected to occur in roughly proportional areas at any point in time. If we assign a typical 'time-averaged C-stocks (Mg ha^{-1})' to each land-use type, we can directly evaluate how 'land-use change' will lead to net C release or net C sequestration, depending on the sign of the difference of 'Cstocks (after) – Cstocks (before)'. This means an evaluation of the C-stocks of a land-use depends on the context and the types of comparisons made.

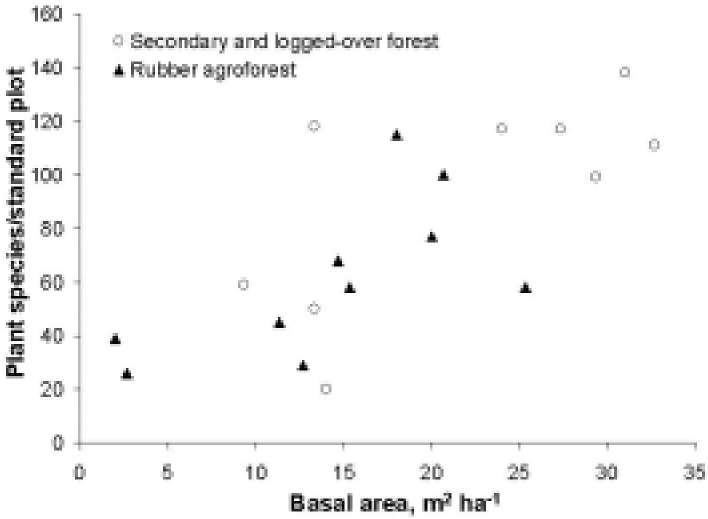

Figure 3. Relationship between plant species richness in standardised (40 x 5 m^2) plots and total tree basal area in Jambi and Lampung, comparing secondary forest and fallow plots (open symbols) with rubber and fruit-based agroforests (closed symbols); Unpublished data A. Gillison and N. Liswanti.

Compared to natural forest all other land-use types lead to net C release to the atmosphere. Compared to continuous annual crops, all other land-uses lead to C sequestration. On the basis of these results, time-averaged C-stocks of the chosen land-use types are summarised in Table 4. Lowland tropical rain forests have the highest standing biomass and aboveground carbon stocks (C-stocks) of any vegetation in the world, and total C-stocks of rain forests are only equaled by the deepest peat soils. Measurements in Jambi (Hairiah *et al.*, 2000) indicate total carbon stock of natural forests on the peneplain can be up to 500 Mg ha^{-1}, with roughly 80% in live trees, 10% in dead wood and 10% in the upper 20 cm of soil. In logged forests (about 10 years after the logging event), live tree biomass is substantially reduced, but there is more C in dead wood and at least as much in the soil. In cassava fields, total C-stocks can be reduced to about 10% of those in the forest, but soil stocks are still at least half of those in the forest. Moreover, there appear to be few significant differences among forest extraction and the other tree-based systems regarding carbon stocks and greenhouse gases.

Greenhouse gas emissions

It is interesting to assess the trajectory of land-use change and its effects on the emission of greenhouse gases from soil. Measurements of the fluxes of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) were made across a range of land-use types in our current evaluation using closed-chamber method. Table 4 shows the mean flux obtained from a two years monthly measurements. CO_2 flux decreased with decreasing C-stocks and plant species richness. Likewise, the same factors correlated with decreasing sink strength for CH_4. Further analysis shows that CH_4 flux is also correlated with soil clay content: the higher the clay content the less CH_4 will be oxidised by the soil (Ishizuka *et al*., 2002). The flux of N_2O from lowland tropical forest soil in Jambi (Figure 4) is relatively low compared to data from Costa Rica and Amazonia, mainly due to low nitrification rates (Ishizuka *et al*., 2002). The highest fluxes of N_2O were measured when one of the logged-over forest plots was slashed and burnt (27 µgN $m^{-2}h^{-1}$) and in an oil palm plantation (55 µgN $m^{-2}h^{-1}$) where nitrogen fertiliser was regularly applied.

Table 4. Time-averaged carbon stocks, average plant species richness per standard plot for land-uses and GHG fluxes of the lowland peneplain of Jambi (Source: Tomich *et al.*, 1998b, Ishizuka *et al*., 2002 and Murdiyarso *et al*. 2002c).

Land-use type	**Maxi-mum age (yr)**	**Plant species richness per 40 x 5 m^2 plot**	**Time averaged C-stocks (Mg ha^{-1})**	**Mean GHG fluxes**		
				CO_2 (mg C $m^{-2}h^{-1}$)	**CH_4 (µg C $m^{-2}h^{-1}$)**	**N_2O (µg N $m^{-2}h^{-1}$)**
F_n	>100	120	254	66.49	-19.65	0.71
F_m	60	100	176	-	-	-
F_l	40	90	150	101.92	-17.55	5.02
T_e	40	90	116	-	-33.86	2.08
T_m	30	60	103	-	-	-
T_{s_rubber}	25	25	97	73.89	-12.77	0.23
$T_{s\_oilpalm}$	20	25	91	-	-16.24	55.15
$T_{s\_pulptree}$	10	-	60	46.19	-5.42	1.04
C_e/C_m	7	45	74	-	-	-
C_i/A_e	3	15	39		-11.03	1.90

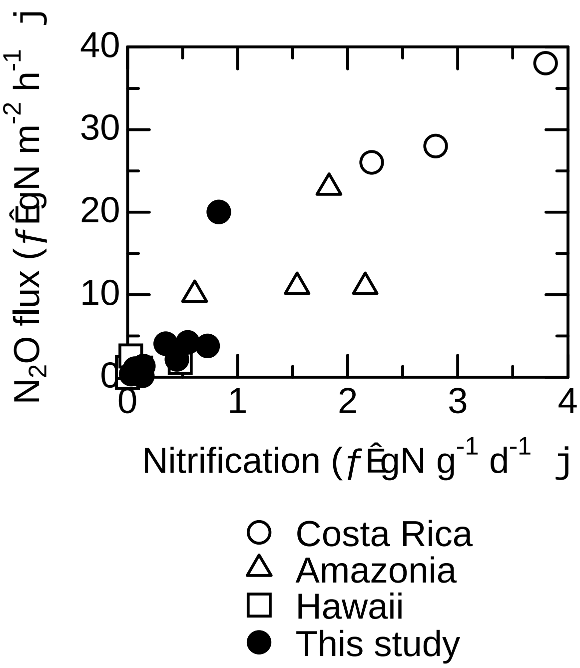

Figure 4. Relationships between N_2O flux and nitrification rate in three lowland tropical forest soils in Costa Rica (Matson and Vitousek, 1987), Amazonia (Livingston *et al*., 1988 and Keller *et al*., 1988) and in Jambi, Sumatra (Ishizuka *et al*., 2002).

Transboundary haze pollution

The underlying questions in assessing the impacts of transboundary haze are whether there are policy areas that need to be changed and how effective the changes would be. Therefore, it is necessary to address the causes of fires including smallholder fires and a substantial contribution from large-scale land clearing activities. *El-Niño* was repeatedly quoted by officials as the cause of fires, and therefore, a natural disaster , which we can do nothing to prevent. *El-Niño* provided conditions suitable for generating transboundary haze pollution but it is hardly the underlying cause (Murdiyarso *et al*., 2002a). Fires were mostly deliberately lit to take advantage of the dry conditions to clear land or used as weapon in land disputes.

Method of burning used by smallholder farmers for land clearing was observed by (Ketterings *et al.*, 1999). Fires were used to provide space since they offer cheap and effective means to remove the debris before new plantations are established. Furthermore, fires also provide ash, which contains readily available nutrients and control pest and diseases. The practise is slightly different compared with that used in the peatland. They burn much more belowground biomass and as the combustion is usually incomplete they tend to produce a lot more haze over longer periods (Murdiyarso *et al*., 2002b).

Knowing the variety of fires, policy interventions are needed but they cannot be generalised since each level requires a specific intervention. Table 5 summarises the range of interventions from regional to household level involving modern as well as grassroots institutions. It confirms the erlier finding that quick fixes to ban fires would not be successful unless they properly address the underlying causes and provide alternatives (Tomich *et al*., 1998c).

Table 5. Policy intervention at various levels on land-use planning and management (Modified from: Murdiyarso *et al*., 2002a)

Policy area	Suggested changes
Regional Environmental Regime	• Need a more binding agreement with a realistic compliance mechanisms • Use industry-level actions rather than nation-state to avoid problems of “interference”
Land development policy	• Incorporate negative ecological and social affects of increased plantation areas in overall land development policies • Reduce or completely remove incentive systems for plantation land development
Land-use planning	• Improve land information systems as basis for decision-making • Improve accountability of land classifications and allocations
Land tenure	Compatibility of government-granted land-uses with rights of forest-dependent people
Reduced impacts logging	Improve forest management
Use of fire for land clearing	• Regulate conversion of forests to plantations • Control access to logged-over forests

During 1997/1998 fire episode, the peatlands surround Berbak National Park the area burnt it is associated with fuel load, where natural forest is the most severe (83,743 ha), followed by secondary forest (34,666 ha), crop and plantation (1,424 ha), and shrubs (4,412 ha). The amount of carbon released during the fire event from this area was estimated as 7 Mt (Murdiyarso *et al.*, 2002b*)*.

4. Tradeoffs and Complementarity

To evaluate the impacts of implementing land-use options requires hands-on expertise to ensure decisions are technically feasible, economically viable and environmentally sound. Figure 5 shows the relationships between returns to labour, time-averaged C stocks and plot-level plant species richness. In some of the comparisons there may be 'win-win' solutions. For example, plant species richness is high in the community-managed forests where non-timber forest product (NTFP) collection leads to high returns to labour. In the case of C-stocks, they drop substantially as soon as forests are logged or utilized, giving the upper right corner is empty and there are no win-win solutions. We emphasise these measured attributes may not be necessarily 'caused' by the current land-use. For example, the reduction in C- stocks of the community-managed NTFP collection system is probably due to past logging activities.

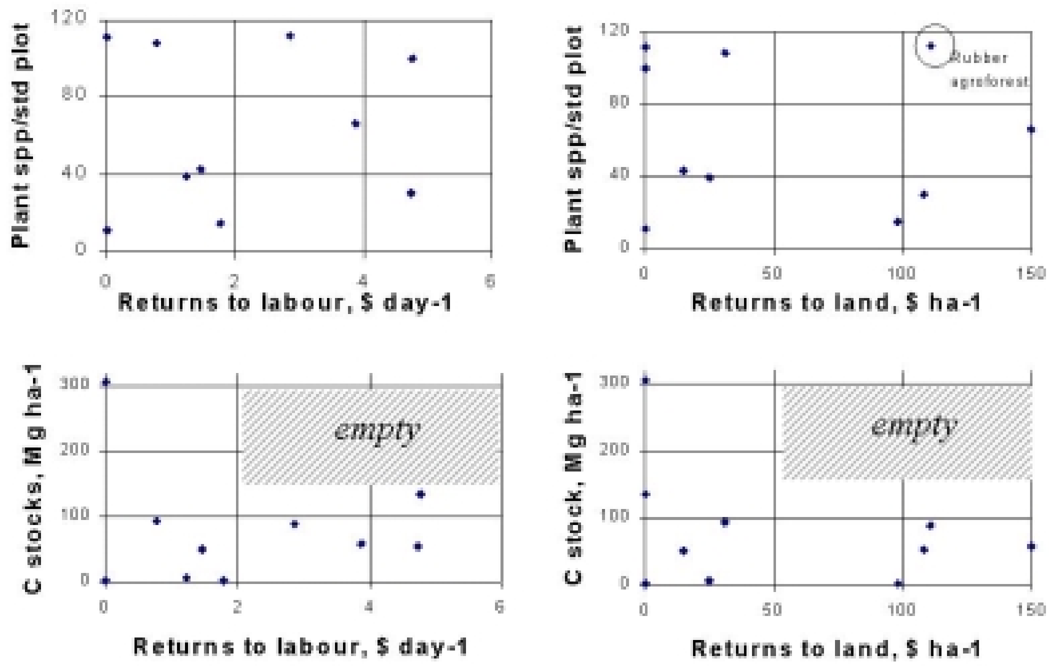

Figure 5. Tradeoffs between plot level environmental indicators (C-stocks and plant species richness) and profitability (returns to land) for Jambi benchmark areas.

Across all these systems we can compare the relative loss of plot-level plant species richness and loss of time-averaged C-stocks if we take into account the forest-derived land-use types with the forests that they replaced. Data from the three continents may indicate that the rate of loss of C-stocks could be greater than that plant species richness (Figure 6).

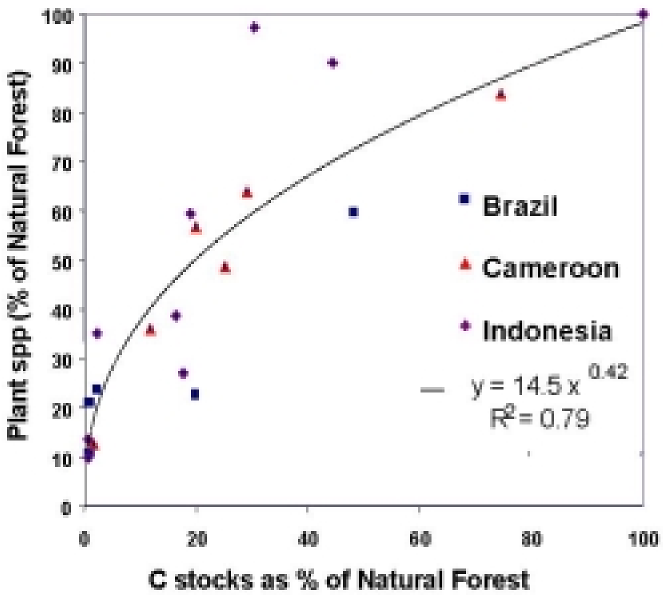

Figure 6. Relative loss of C-stocks and plant species richness for forest-derived land use practices in the Jambi transect, with similar data for the ASB benchmark areas in Cameroon and the western Amazon in Brazil.

Raising productivity of rubber agroforests, which span millions of hectares, offers a promising pathway to balanced management in Sumatra. There appears to be great potential for raising profitability of these systems though adaptation of existing higher-yielding clones within existing smallholder systems, which would also enhance household food security and expand employment opportunities. It may be possible to combine these potential benefits from the perspective of smallholders and national policymakers with significant biodiversity conservation because the mix of planted species is augmented by natural regeneration of forest species (Michon and de Foresta, 1995; Van Noordwijk *et al.*, 1995). These agroforests may enhance CH_4 sink potential in the landscape. So far efforts to introduce higher-yielding rubber germplasm into these extensively managed agroforests in Jambi have met with only partial success (Williams *et al.*, 2001).

Even if further analysis shows that the large-scale schemes hold no advantages in terms of private and social profitability compared to smallholder schemes a potential tradeoff between profitability and biodiversity conservation remains to be addressed concerning smallholder systems (Tomich *et al.*, 1998b). Farmer management aimed at increasing productivity of systems often decreases biodiversity.

5. Concluding Remarks

In Jambi the human population is ten to one hundred times greater than in the Amazonian forests, where rubber is still 'non-timber forest product'. Under these conditions biodiversity-friendly rubber agroforests should have a strong appeal for global communities where the aim is to provide more sustainable management options.

In Jambi Province, a gradient of land use intensity exists along the Batanghari River towards the mountains of Bukit Barisan range. This gradient resembles Von Thunen's 'spheres of economic activity', with plantation style enterprises gradually giving way to extensive rubber agroforests, but with many large areas recently slashed-and-burned for transition into oil palm plantations. A gradual simplification of complex agro-ecosystems of rubber agroforests with increasing profitability might be threatened by the radical change to the oil-palm style plantation industry. In Peninsular Malaysia, oil-palm plantings promoted in early 1960s have virtually replaced lowland rubber.

At plot level the richness in plant species and stocks of carbon in the above ground biomass have direct effects on CO_2 and CH_4 fluxes. These merit further studies to scale-up the estimates at landscape level. Significantly low N_2O flux in Jambi compared with currently known flux in Latin America challenges a further evaluation of nitrogen budget in the tropics.

Smoke resulting from biomass burning associated with large-scale land clearing has become a major policy concern. The current management response is still not sufficiently integrated to reduce the risks of serious transboundary haze . The emphasis has been on monitoring, early-warning systems, and fire-fighting. To be effective management must also address the underlying causes of fires, in particular, land development strategies, through improvements in land-use planning and management. These require policy intervention and institutional reform to ensure that the future pollution and emissions of greenhouse gases will be reduced, thus benefitting local, regional and global communities.

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