

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

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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 trans-boundary haze, which are of national and global concern, were assessed at landscape level. Quantitative trade-offs and complementarities were analysed 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; Biodiversity; Carbon stock; Emission; Greenhouse gas; Trade-off analysis

Abbreviations: ASB = Alternatives to Slash-and-Burn; NTFP = Non-timber forest product.

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.

Characterization 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 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 & 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.

We (1) describe the biophysical and socio-economic setting of the Jambi transect, and (2) evaluate land-use options on the basis of (2a) local and national criteria and indicators, such as, agronomic sustainability and profitability, and (2b) global environmental perspectives, such as biodiversity loss, carbon stocks, greenhouse gas emissions, and trans-boundary haze pollution.

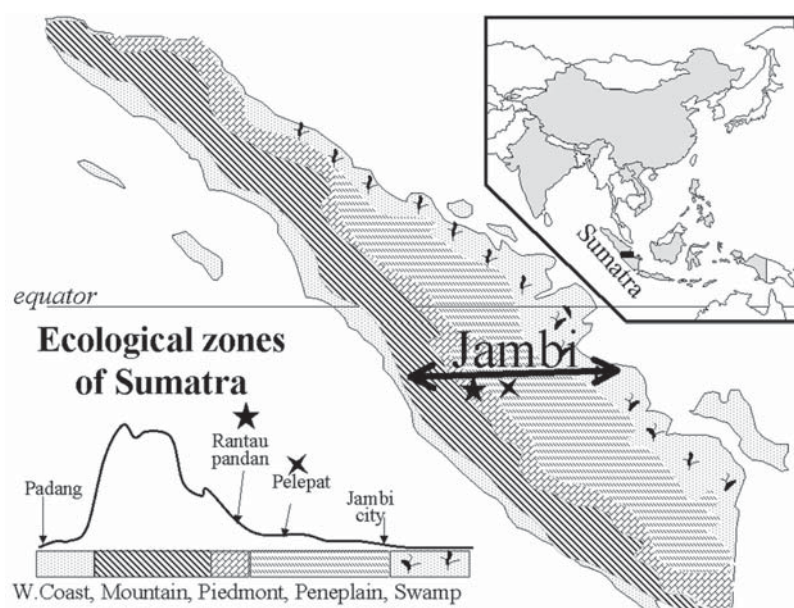


Fig. 1. The Jambi global change transect and benchmark areas of the 'Alternatives to Slash-and-Burn' (ASB) project described here.

Biophysical and socio-economic setting of the Jambi transect

Ecological zones and benchmark sites

The island of Sumatra extends from 5° N to 5° S 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 Fig. 1 there are five major ecological zones identified with boundaries running from NW to SE, approximately parallel to the coast. It is shown that the Jambi transect is dominated by a peneplain zone with Tertiary sediments, deposited in the sea; the altitude is less than 100 m above sea level and it consists of ca. 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/km² 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. They are moderately to very 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 100m 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 3 m 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 & Las 1975).

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 life-style (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 interfluvies, 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 rubber after World War I. The main reason for the economic success of rubber in SE 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 SE 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 forests into agroforests was facilitated by local rules assigning 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 1970s changed the land-use pattern providing access to areas much further from the rivers. Commercial logging, government-sponsored resettlement schemes and spontaneous migrant flowing along the new road created rapid changes again, 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 publicized worldwide as it became a major health hazard in Sumatra and in neighbouring Singapore and Malaysia (Tomich et al. 1998c).

Vegetation cover and land-use intensity

Imagery and field work from the 1980s showed that the vegetation in the province was still dominated by lowland tropical forest but was replaced by settlements, secondary crops or monoculture plantations in the early 1990s (Fig. 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-use types 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 (including a fragment within a logging area in lowland forest to represent 'pristine' conditions); community-based forest (including extraction of non-timber forest products, such as, fruit, honey, birds and rattan); large-scale commercial logging (including concessions that were relatively well managed, as they comply with regulations); smallholder rubber (including both rubber agroforests and rubber monoculture); large-scale plantations (including oil palm and industrial timber estates); upland rice with bush fallow (found in isolated pockets of Sumatra's piedmont); cassava and *Imperata cylindrica* (representing the continuous annual cropping category being observed in transmigration areas).

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 yr ago and almost 40% less than 5 yr 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 3447 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).

Sustainability of land-use practices

Small-holders' - 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 disease 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.

Soil degradation (criteria A and B) limits the options

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 peatlands 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 yr | Small reserves within logging concession | 25 ha patch in forest mosaic |
| | Managed forests, F _m | Community-based forest management; producing non-timber commodities | Community-based forest management, 10 000 to 35 000 ha and wood for local use | Indigenous small-holder landscape |
| | Logged forests, F _l | Commercial logging (large scale); heavily logged with a (theoretical) | Commercial logging, 35 000 ha or more, large-scale cutting cycle of 25-30 yr | Forest mosaic |
| Tree crops | Extensive agroforests, T _e (complex, multistrata agroforestry systems), | Rubber agroforests planted with rubber seedlings; dominating the landscape | Rubber agroforests (seedlings), 1 to 5 ha, extensive, with some internal rejuvenation | |
| | 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 small-holder landscape |
| | Simple, intensive tree-crop systems, T _s | Rubber monoculture (small-holders); labour-intensive, competing 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 yr) with fallow rotation of 10 yr or more | Upland rice with fallow rotation of 10 yr or more low intensity, low inputs | Indigenous small-holder landscape |
| | Medium intensity crop/fallow systems, C _m | Upland rice with fallow rotation of 3-5 yr | Upland rice with fallow rotation of 3-5 yr, medium intensity, medium inputs | Indigenous small-holder landscape |
| | Intensive, crop/short fallow systems, C _i | Practiced by migrants; monoculture cassava degrading to <i>Imperata cylindrica</i> | Cassava, monoculture, 1 to 2 ha, within large scale settlement project, high intensity, low inputs | Transmigration project divided into small plots |
| | 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 | <i>Imperata cylindrica</i> ; Abandoned, may cause disputes | <i>Imperata cylindrica</i> , within large-scale settlement project | Transmigration project divided into small plots |
| | Intensive Pasture, A _i | No representatives found | | |

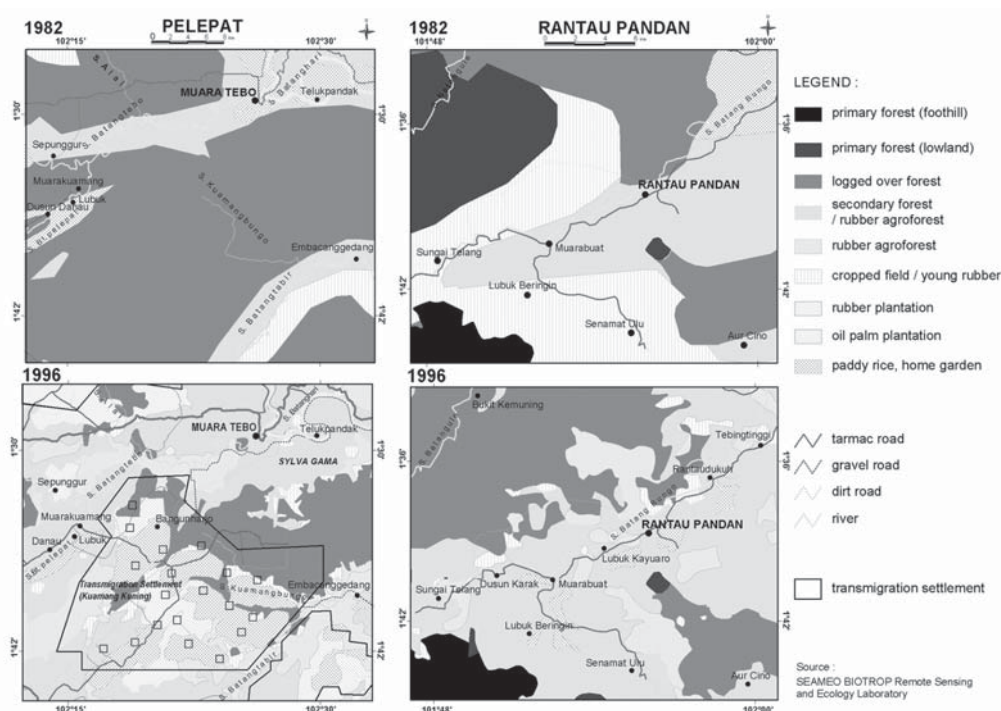


Fig. 2. Land-use change in Jambi benchmark areas (Rantau Pandan in the piedmont zone and Pelepat in the lowland peneplain) of the ‘Alternative Slash-and-Burn’ project.

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 & Priyono 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 ¥ per yr 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.

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 and 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/C_m | 0 | -0.5 | -0.5 | Fertilizer use required for intensification Vertebrate and insect pests are a constraint |
| C_l/A_e | -0.5 | -1 | -0.5 | Soil compaction; low C_{org} , lack of soil cover Nutrient balance cannot be attained at current prices; K in short supply Weed problem in <i>Imperata</i> fallows unless farmers have draught power available |

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.

Profitability

Economic and social aspects of the alternative systems and technologies are assessed with the underlying 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 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 from the prices and take world markets as point of reference. Discount rates used for the social and private analysis are 15% and 20%/yr, respectively. The results shown in Table 3 indicate large differences in return to labour 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 < 1 person/km²). In the early 1990s, the population density was 18/ km² in Rantau Pandan and 12/km² for Pelepat, respectively (Van Noordwijk et al. 1995). Tree crop production systems can provide employment for 60-80 people/ km² 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 ca. 200 people/km², for 2.5-ha farms and an average household of five people.

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 & Swift 1999). Local values may be more strongly related to local species richness, but should account for the different utilitarian

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 (persons per day) | | | Equivalent population density people/km ² |
|--------------------------------|---|---------------------|--------------------------------------|-----------|---------|--|
| | Private prices | Social prices phase | Establishment phase | Operation | Total | |
| F _m | 2.9 | 2.8 | Na | 0.2-0.4 | 0.2-0.4 | 0.2 |
| F _h | -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 |

values of different groups of species. Table 4 shows the plant species richness per standard plot (40 m × 5 m) 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, 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 ca. 250 species for rubber agroforests (Michon & 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. Fig. 3 shows no difference in this relation between rubber agroforests and secondary and logged-over forests.

Carbon stocks

How would the above-ground 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)' 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 'C-stocks (after) – C-stocks (before)'. This means an evaluation of the C-stocks of a land-use type depends on the context and the types of comparisons made.

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 summarized in Table 4. Lowland tropical rain forests have the highest standing biomass and above-ground carbon stocks (C-stocks) of any vegetation in the world, and total C-stocks of rain forests are only equalled by the deepest peat soils. Measurements in Jambi (Hairiah et al. 2000) indicate total carbon stock of natural forests on the peuplain can be up to 500 Mg/ha, with roughly 80% in live trees, 10% in dead wood and 10% in the upper 20 cm of soil. In logged forests (about 10 yr 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 (CO₂), methane (CH₄), and nitrous oxide (N₂O) were made across a range of land-use types in our current evaluation using the closed-chamber method. Table 4 shows the mean flux obtained from two years of monthly measurements. CO₂ flux decreased with decreasing C-stocks and plant species richness. Likewise, the same factors correlated with decreasing sink strength for CH₄. Further analysis shows that CH₄ flux is also correlated with soil clay content: the higher the clay content the less CH₄ will be oxidized by the soil (Ishizuka et al. in press). The flux of N₂O from lowland tropical forest soil in Jambi (Fig. 4) is relatively low compared to data from Costa Rica and Amazonia, mainly due to low nitrification rates (Ishizuka et al. in press). The highest fluxes of N₂O were measured when one of the logged-over forest plots was slashed and burnt (27 mgN.m⁻².hr⁻¹) and in an oil palm plantation (55 mgN.m⁻².hr⁻¹) where nitrogen fertilizer was regularly applied.

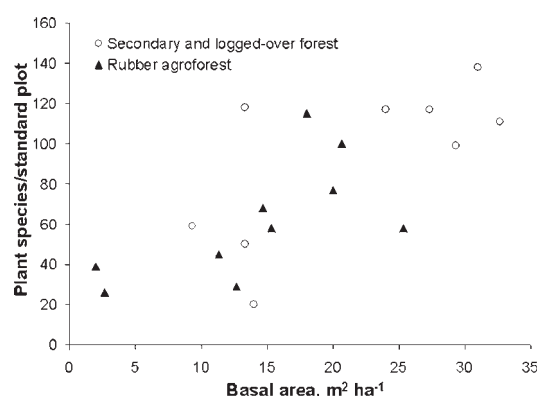


Fig. 3. Relationship between plant species richness in standardized (40 m × 5 m) plots and total tree basal area in Jambi and Lampung, comparing secondary forest and fallow plots (open symbols) with rubber and fruit-based agroforests (closed symbols); unpubl. data from A. Gillison and N. Liswanti.

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 cannot prevent. El-Niño provided conditions suitable for generating transboundary haze pollution but it is hardly the underlying cause (Murdiyarso et al. in press a). Fires were mostly deliberately lit to take advantage of the dry conditions to clear land or used as weapon in land disputes.

Methods of burning used by smallholder farmers for

Table 4. Time-averaged carbon stocks, average plant species richness per standard plot (40 m × 5 m) for land-uses and GHG (greenhouse gas) fluxes of the lowland peuplain of Jambi (Tomich et al. 1998b; Ishizuka et al. in press; Murdiyarso et al. in press c).

| Land-use type | Max. age (yr) | Plant species richness | C-stock (Mg ha ⁻¹) | Mean GHG fluxes | | |
|--------------------------------|---------------|------------------------|--------------------------------|--|--|---|
| | | | | CO ₂ (mg C m ⁻² .h ⁻¹) | CH ₄ (mg C m ⁻² .h ⁻¹) | N ₂ O (mg 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_pulmtree} | 10 | - | 60 | 46.19 | -5.42 | 1.04 |
| C _e /C _m | 7 | 45 | 74 | - | - | - |
| C _v /A _e | 3 | 15 | 39 | - | -11.03 | 1.90 |

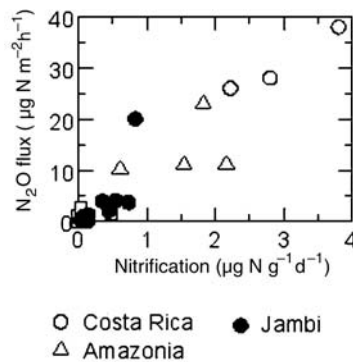


Fig. 4. Relationships between N_2O flux and nitrification rate in three lowland tropical forest soils in Costa Rica (Matson & Vitousek 1987), Amazonia (Livingston et al. 1988; Keller et al. 1988) and in Jambi, Sumatra (Ishizuka et al. in press).

land clearing were 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 pests and diseases. The practice is slightly different compared with that used in the peatland. They burn much more below-ground biomass and as the combustion is usually incomplete they tend to produce a lot more haze over longer periods (Murdiyarso et al. in press b).

Knowing the variety of fires, policy interventions are needed but they cannot be generalized since each level requires a specific intervention. Table 5 summarizes the range of interventions from regional to household level involving modern as well as grassroots institutions. It confirms the earlier 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).

During the 1997/1998 fire episode, the peatlands surround Berbak National Park the area burnt 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 (1424 ha), and shrubs (4412 ha). The amount of carbon released during the fire event from this area was estimated as 7 Mt (Murdiyarso et al. in press b).

Trade-offs 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. Fig. 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, give the upper right corner is empty and there are no win-win solutions. We emphasize that 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.

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 of plant species richness (Fig. 6).

Raising productivity of rubber agroforests offers a promising pathway to balanced management in Sumatra. There appears to be great potential for raising profitability of these systems through 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 with significant biodiversity conservation because the mix of planted species is augmented by natural regeneration of forest species (Michon & 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 germ plasm into these extensively managed agroforests in Jambi have met with only partial success (Williams et al. 2001).

Table 5. Policy intervention in land-use planning and management (modified from Murdiyarso et al. in press a).

| Policy area | Suggested changes |
|-------------------------------|--|
| Regional environmental regime | <ul style="list-style-type: none"> • Need a more binding agreement with realistic compliance mechanisms • Use industry-level actions rather than nation-state to avoid problems of 'interference' |
| Land development policy | <ul style="list-style-type: none"> • Incorporate negative ecological and social effects of increased plantation areas in over- all land development policies • Reduce or completely remove incentive systems for plantation land development |
| Land-use planning | <ul style="list-style-type: none"> • 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 of logging | Improve forest management |
| Use of fire for land clearing | <ul style="list-style-type: none"> • Regulate conversion of forests to plantations • Control access to logged-over forests |

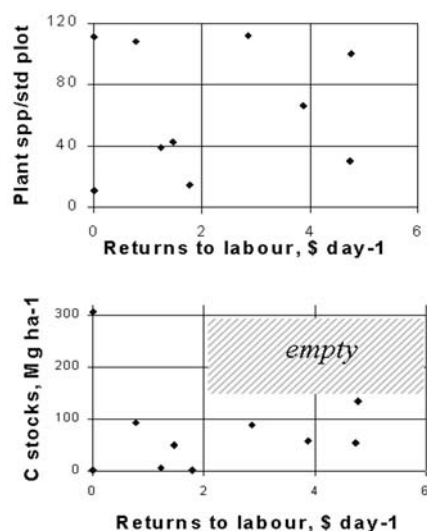


Fig. 5. Trade-offs between plot level environmental indicators (C-stocks and plant species richness) and profitability (returns to land) for the Jambi benchmark areas.

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 trade-off 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.

Concluding remarks

In Jambi the human population is 10-100 ¥ greater than in the Amazonian forests, where rubber is still a 'non-timber forest product'. Under these conditions biodiversity-friendly rubber agroforests should have a strong appeal where the aim is to provide more sustainable management options. In Jambi, a gradient of land use intensity exists along the Batanghari River towards the mountains of the 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 agroecosystems 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 the 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 CO₂ and CH₄ fluxes. These merit further

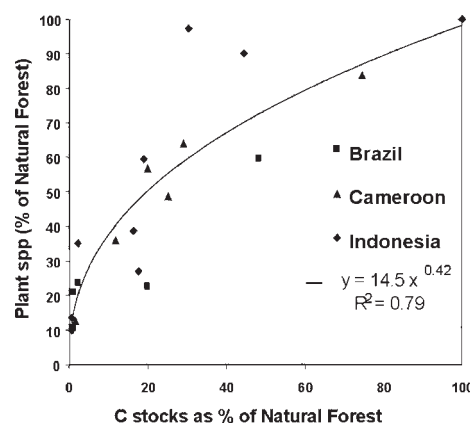


Fig. 6. Relative loss of C-stocks and plant species richness for forest-derived land-use practices in the Jambi transect, with similar data for the ASB benchmark areas in Cameroon and the western Amazon in Brazil.

studies to scale-up the estimates at landscape level. Significantly low N₂O 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 trans-boundary 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 benefiting local, regional and global communities.

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