
12 Agricultural Intensification, Deforestation and the Environment: Assessing Tradeoffs in Sumatra, Indonesia

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Introduction

The conditions necessary for increased productivity of agroforestry and other land uses to jointly reduce poverty and deforestation are not well understood. The global Alternatives to Slash-and-Burn (ASB) Programme was founded to provide scientific insights and workable innovations for the simultaneous pursuit of precisely these two goals: poverty reduction and rainforest conservation in the tropics. This chapter summarizes results from study sites on the island of Sumatra, Indonesia, which were chosen to represent the lowland humid tropical forest zone in Asia for the global ASB project.¹

A clear gradient in population density in Sumatra occurs from Lampung Province at the southern tip (174 people km⁻² in 1993) to Jambi Province in the middle of the island (39 people km⁻² in 1993). Most of the ASB work in Sumatra has concentrated on study sites in Jambi and Lampung Provinces, both of which are located in Sumatra's broad peneplain agroecological zone. This region is almost flat land, less than 100 m above sea level, consisting of about 10% river levees and flood-plains with fertile alluvial soils and 90% uplands with a gently undulating landscape and mostly red-yellow podzolic soils.

The peneplains have been the focus of government-sponsored settlement schemes (called transmigration), large-scale logging and various large-scale public and private land development projects since the 1970s. Because of these

activities, little natural forest remains. The process of deforestation, which is almost complete in lowland Sumatra, seems likely to be repeated elsewhere in Indonesia. By understanding the factors contributing to this process and its consequences, ASB researchers hope to identify policies and technologies that can ameliorate the effects of deforestation and contribute to conservation of the remaining rainforests in Asia.

Conflicting interest groups

All ASB research seeks to integrate social and economic analyses with measurements of biophysical outcomes of land-use change, in order to understand conflicts and complementarities between development and resource-conservation objectives. The work in Indonesia is distinguished by including analysis of large estates as well as smallholder activities. This was necessary because Sumatra's dualistic development pattern – a continuing legacy of the colonial period – means that various actors' interests in land conversion, as well as the social, economic and environmental consequences of deforestation, differ substantially by scale of operating unit.

At least six distinct interest groups 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 of forest conversion:

- The international community, concerned with global climate change, extinction of species and loss of distinctive ecosystems.
- Several thousand hunter-gatherers,² who continue their traditional migratory lifestyle within remaining forest fragments and national parks in Jambi Province and elsewhere in central Sumatra.
- Millions of small-scale farmers – including local people, spontaneous migrants and government-sponsored settlers (transmigrants) – who depend primarily on land converted from forest in order to make a living.
- Large-scale public and private estates, operating forest concessions and plantations of 100,000–300,000 ha or more. Like smallholders, these large operators currently receive few, if any, incentives or sanctions regarding the environmental impacts of their activities. But large estates and smallholders compete for a limited area of land, which causes pressure for forest conversion. Moreover, the land uses and management strategies of large-scale estates differ significantly from those of smallholders.
- Absentee farmers with medium-sized holdings of 10–25 ha or more. These operators use similar technologies to smallholders, but are able to exert substantial influence, especially on local officials.
- Public policy-makers, who have a range of public policy concerns (discussed below) and whose official salaries are grossly inadequate, making them susceptible to influence by private interests, such as large-scale operators.

ASB 'meta' land uses and major land uses in Sumatra

'Meta' land uses were identified to facilitate cross-site comparisons among the national ASB research agendas. Because deforestation is among the primary concerns of this research, natural forests are the reference point here for global environmental concerns. Grasslands and pastures are included as reference points at the opposite ecological extreme. In between, a representative range of five generic upland, rain-fed land-use systems was selected for cross-continent comparisons of alternatives. These include: extraction of forest products; complex multistrata agroforestry systems, also known as 'agroforests' (Michon and de Foresta, 1995); simple tree-crop systems, including, but not limited to, monoculture; crop-fallow systems, which include the textbook version of 'shifting cultivation' or slash-and-burn agriculture; and continuous annual cropping systems, which may be monocultures or mixed cropping. This analytical scheme was chosen to cover the spectrum of land-use intensification alternatives and to provide counterpart land-use types that can be found in the other ASB sites.

Table 12.1 gives the general specifications for the six Sumatran land uses. Pastures are almost non-existent and, apart from wet rice – which is limited by soil, water supply and topography – continuous annual cropping is rare except in transmigration settlement sites. At the transmigration study site in Lampung, continuous monoculture of cassava and maize and rotations of cassava and maize are common. These fields are often plagued by *Imperata cylindrica*, which covers about 8.6 Mha in Indonesia (Garrity *et al.*, 1997). Estimates for continuous cassava monoculture degrading to *Imperata* are reported here for comparison with other ASB sites, where continuous annual cropping and grasslands are more prevalent than in Sumatra.

Criteria and Indicators for Assessment of Land-use Alternatives

Measurements of field-level differences in the economic, agronomic and global environmental consequences of the various land uses provide a starting-point for quantifying the tradeoffs involved in land-use change and for identifying alternatives that provide an attractive balance among competing objectives. The 'ASB matrix' approach was developed to link global benefits with sustainable alternatives that are adoptable by farmers (Tomich *et al.*, 1998b; Vosti *et al.*, 2000b). The matrix provides a framework for organizing data for the assessment of possible tradeoffs and complementarities across specific indicators representing broad criteria, which are discussed in the next section. The rows of the matrix correspond to specific land uses found in Sumatra, as described above. The columns correspond to various environmental, agronomic, economic and social criteria. Further details on ASB methodologies and data are presented elsewhere (Gillison, 1999; Palm *et al.*, 1999; Swift, 1998; Weise, 1998; Vosti *et al.*, 2000b).

Table 12.1. Specifications for major land uses at the forest margins of the penepains of Sumatra, Indonesia.

'Meta' land use	Corresponding land use in lowland Sumatra	Type/scale of operation	Landscape mosaic context	Description
Natural forest	Natural forest	25 ha fragment within a logging concession	Forest	Reference point: primary baseline for assessment of land-use alternatives. Undisturbed for at least 100 years
Forest extraction	Community-based forest management	Common forest-land of 10,000 ha to 35,000 ha	Indigenous smallholder landscape	Reference point/possible ASB 'best bet': products are honey (every 3 years), fish, petai Reference point/possible ASB 'best bet': products are honey (every 2 years), fish, petai, rattan and songbirds
	Commercial logging	Logging concession of 35,000 ha or more	Forest	Reference point/'best bet' from official perspective: simulation of Indonesian 'sustainable logging system'; 40-year cycle Reference point: based on estimates of actual harvesting behaviour for a recently renewed concession; 20–25-year cycle
Complex, multistrata agroforestry systems	Rubber agroforests	Smallholders' plots of 1–5 ha	Indigenous smallholder landscape	Indigenous system: forest clearing followed by upland rice and planting of 'unselected' rubber seedlings, with natural regeneration of forest species. This is the dominant smallholder land use
	Rubber agroforests with improved planting material	Smallholders' plots of 1–5 ha	Indigenous smallholder landscape	Possible ASB 'best bet': forest clearing followed by upland rice and planting of rubber clones, with natural regeneration of natural forest species

Simple tree-crop systems	Rubber monoculture	Smallholders' plots of 1–5 ha	Indigenous smallholder landscape	(Formerly) 'best bet' from official perspective: upland rice and planting of rubber clones, with intensive use of inputs and labour to prevent regeneration of natural forest species
	Oil-palm monoculture	Large-scale private estate of 35,000 ha or more	Monoculture plantation	'Best bet' from official perspective: plantation oil-palm grown in close association with processing mill (processing not included in the economic analysis)
Crop/fallow systems	Upland rice/bush fallow rotation (shifting cultivation)	Smallholders' plots of 1–2 ha year ⁻¹ , often located on community land	Indigenous smallholder landscape	Reference point: 1 year of upland rice followed by bush fallow of 10 years or more. The dominant smallholder land use of 100 years ago, now rare Reference point: 1 year of upland rice followed by a short bush fallow of 5 years or less. Now found only in isolated areas
Continuous annual crops/grasslands	Continuous cassava degrading to <i>Imperata cylindrica</i> grassland	Smallholders' plots of 1–2 ha within large-scale settlement project	Large transmigration project divided into small plots	Reference point: monocrop cassava with little use of purchased inputs Reference point: monocrop cassava with intensive use of purchased inputs

Global environmental criteria

Quantification of at least three indicators of the global environmental consequences of deforestation and other land-use changes is essential for formulating sound policy responses – or even for knowing whether intervention is needed. Two of these indicators are linked to global climate change: carbon (C) stocks and net absorption of greenhouse gases, including carbon dioxide, methane and nitrous oxide. Carbon stocks were measured for sample plots in natural forests, shifting-cultivation sites and five other major land-use alternatives in Sumatra's peneplains. The point data from the samples were used to estimate the 'time-averaged C stock' for major land-use systems (see Appendix 11.1 of Chapter 11). Land-use change can thus be translated into a net release or net sequestration of C.³ The third indicator is biodiversity. Above-ground measurements were made for plant functional groups, as well as the more conventional taxonomic approach. The number of plant species is used as an overall indicator of biodiversity richness that is suitable for cross-continent comparisons. Indicators of above- and below-ground biodiversity were studied for the same land uses where the C stocks and greenhouse-gas emissions were measured.⁴

Agronomic sustainability criteria

Agronomic sustainability refers to the long-term production capacity at the plot level, but researchers and farmers may differ in their assessment of what 'sustainable' means. Soil scientists and agronomists collaborating in ASB research identified a minimum set of seven components of agronomic sustainability; these include soil bulk density (indicating compaction), soil C saturation, active soil C, soil exposure to erosion, nutrient balance (nitrogen, phosphorus, potassium (N, P, K)), potential for weed problems and potential for pest and disease problems (Weise, 1998). Although it has not been possible to arrive at a single summary indicator for agronomic sustainability, it has been possible to use this mix of indicators to assess Sumatra's major land-use systems.⁵

Policy-makers' criteria

Before the severe economic setbacks of recent years, Indonesia's development strategy had simultaneously pursued growth, equity and stability – called the 'development trilogy' – with considerable success for over 30 years. Each of these broad goals yields criteria for the assessment of land-use alternatives, emphasizing the policy objectives most affected by land-use change.

Growth

What is the potential profitability of the activity, and does the country have a comparative advantage in it? If so, expansion of this activity can contribute to economic growth. Since many of the land-use alternatives in Sumatra involve perennials, the appropriate measure of profitability is the estimated net present

value (NPV) – the present discounted value of revenues less costs of tradable inputs (fertilizer, fuel, etc.) and of domestic factors of production (land, labour, management) over the full 25-year period considered in our analysis. The policy analysis matrix (PAM) technique provided the framework for estimating profitability indicators, as well as the indicators of labour requirements and cash-flow constraints discussed below. The PAM is a matrix of information about agricultural and natural resource policies and factor market imperfections, which is created by comparing multiyear land-use system budgets calculated at private and social prices (Monke and Pearson, 1989).

Social profitability, calculated at economic (shadow) prices – e.g. the NPV at social prices – is an indicator of potential profitability (or comparative advantage). If land is scarce, the NPV estimates returns to land. (To the extent that management is a scarce factor, it would also be included in the residual.) Land is certainly a constraint that should be considered by policy-makers in choices regarding development of large-scale estates versus smallholders (and there are other reasons for believing that these development strategies are mutually exclusive (Tomich *et al.*, 1995)). Returns to land valued at social prices will be used as the indicator for potential profitability evaluated from the policy-makers' perspective.

There is a long list of potential corrections necessary to arrive at social prices. The adjustments in these analyses focus mainly on policy distortions arising from trade restrictions. We also used a lower real discount rate (15% instead of 20%) to capture a rough approximation of the impact of capital market imperfections on the private cost of capital. We have used the same wage rate in both sets of calculations, implicitly assuming that there are no imperfections in the market for unskilled labour. While this is not completely true, it also seems that these imperfections do not have a significant effect in the unskilled labour market (see discussion of labour markets below). The main omission here is that, due to lack of data, prices are not adjusted to reflect costs and benefits of environmental externalities – such as smoke, ecological changes and loss of watershed functions – arising from agricultural and forestry production activities. In addition, a complete economic picture should also include assessing the private and social profitability of 'downstream' processing activities, especially for timber, rubber, cassava and palm oil.

Indonesian teams undertook studies of the six Sumatran land-use systems selected for study (Aliadi and Djatmiko, 1998; Arifin and Hudoyo, 1998; Budidarsono, 1998; Hadi and Budhi, 1998; Machfudh and Endom, 1998; Maryani and Irawanti, 1998). All of these studies use the macroeconomic parameters prevailing when the data were collected in July 1997, including a wage rate for unskilled labour of Rp 4000 day⁻¹. At that time, the exchange rate was about Rp 2400 per US dollar.⁶ To assess land-use alternatives over the longer term, the macroeconomic parameters existing in July 1997 are probably a better guide than those prevailing during the subsequent economic crisis of 1997/98.

Real interest rates – that is, interest rates net of inflation – are the discount factors used to value future cash flows in current terms. As in most developing

countries, capital markets in Indonesia are fraught with imperfections, some of which have been manifested in the financial crisis. Private interest rates (at least for smallholders, if not for large corporations, which could secure subsidized credit) have been very high in real terms. In July 1997, formal-sector lending rates were almost 30% year⁻¹ and annual inflation was under 10%. Thus, the private interest rate of 20% used in these analyses is a lower bound for the actual cost of capital for smallholders. The real social interest rate is less than the private rate and 10% is probably too low. So, somewhat arbitrarily, a rate of 15% has been used for the real social cost of capital, both as the interest rate and as the discount rate for calculating NPV at social prices.

This difference between private and social interest rates is the main cause of divergences between calculations at private and social prices for many of the land-use alternatives. The analyses are quite sensitive to the choice of discount rates, which unfortunately involves considerable uncertainty. Particularly for the private cost of capital, the subjective discount rate may be much higher (or lower) than the 20% real rate used here. Interest rates in the informal sector often exceed 100% year⁻¹. Holden estimated that the average subjective discount rate (rate of time preference) among transmigrants in Riau exceeded 90% (A. Angelsen, Bogor, Indonesia, 1998, personal communication). On the other hand, as Angelsen has pointed out, 'the desire to claim or secure land rights may modify the effect of high discount rates'.

Equity and stability

Would expansion of a given economic activity create employment opportunities, especially for unskilled rural workers? Or would it displace these workers, forcing more to migrate to Indonesia's cities? If an economic activity is profitable, is it adoptable by smallholders? If so, it may have the potential to contribute to poverty alleviation. Equity and stability are both affected, at least in part, by employment opportunities. The indicators of adoptability presented below are also relevant to poverty alleviation. From the perspective of policy-makers concerned with employment generation, total time-averaged labour requirements are good indicators and are also related to equity and stability criteria. Note, however, that, while labour-intensive alternatives should be attractive for policy-makers who are concerned with job creation, these alternatives will only be attractive to households if they provide attractive returns to labour. Neither this indicator nor other available data can shed much light on potential seasonal bottlenecks in labour demand.

Smallholders' socioeconomic criteria

Alternative systems and technologies must be profitable and socially acceptable for smallholders; if not, they have little prospect for adoption and, hence, impact. A minimum set of three quantifiable socioeconomic objectives were judged necessary for the assessment of land-use alternatives from smallholders' perspectives (Tomich *et al.*, 1998b; Vosti *et al.*, 2000b).

Smallholders' production incentives

Does it pay smallholders to invest in a particular production alternative compared with other options? Production incentives (financial profitability) for smallholders are measured as returns to labour valued at private prices. Private prices are the prices that households and firms actually face, so private profitability – e.g. the NPV at private prices – is a measure of production incentives. We also introduce a measure of returns to labour: the wage rate that sets the NPV equal to zero. This calculation converts the 'surplus' to a wage, after accounting for purchased inputs and discounting for the cost of capital; no surplus is attributed to land. This measure of returns to labour is valid when land is abundant and labour is scarce. Returns that exceed the wage (of Rp 4000 day⁻¹) mean the activity will be attractive to family members or would justify hiring labour.⁷ Returns to labour valued at private prices were selected as the indicator of profitability for smallholders' production incentives.

Household labour constraints

Is it feasible for these households to supply the necessary labour themselves or to hire workers? As shown in Table 12.2, two of the systems with the highest potential profitability – smallholder rubber agroforests planted with clones, and large-scale oil-palm – both have high labour requirements. However, each system also has high returns to labour. Thus, although problems in the labour market or credit market could impose a serious barrier to adoption, returns to labour itself are not a problem as long as they exceed the opportunity cost of family labour, taken as the market wage. More generally, returns to labour valued at private prices, which were selected above as an indicator of smallholders' production incentives, are also a good indicator for smallholders' concerns with labour constraints, if combined with assessments of institutional barriers in markets for labour and capital.

Household food security

Even if the alternative is profitable and feasible given household labour constraints and labour-market conditions, is it so risky (either in terms of variance in food yields or as a source of income) that adoption would jeopardize household food security? To accommodate land-use alternatives that do not involve food crops, our food security indicator is based on Sen's (1982) concept of risk of food-entitlement failure, which encompasses trade- and production-based entitlements to food, as well as security of property rights over productive assets (inheritance and transfer entitlements). One of the key dimensions of this analysis is the 'path' of food entitlement – is it derived from consumption of one's own food production, exchange of one's own production for food or working for wages to buy food?

Institutional and policy barriers to adoption

Quantitative measures of the concerns of smallholders and policy-makers need to be supplemented by assessment of institutional endowments as they affect

land, labour, capital and commodity markets, as well as the availability of information on production technologies. In turn, markets and other institutions affect the feasibility of adoption of technological innovations by smallholders. Problems in input supply, output, labour and capital markets are indicated respectively by I, O, L and K, respectively, in Table 12.2. The specific non-market problems and issues considered here are access to non-market information (N), regulatory issues (R), local environmental issues (E), insecure property rights (P), equity biases (B) and need for social cooperation (C). The use of upper-case letters in Table 12.2 denotes a serious constraint and lower-case letters denote a constraint that may be overcome by individuals and communities on their own.

Table 12.2. ASB matrix for the forest margins of Sumatra.

Description	Land use Scale of operation/ evaluation	Global environment		Agronomic sustainability: plot-level production sustainability	
		Carbon sequestration: time-averaged (Mg ha ⁻¹)	Biodiversity: plant species per standard plot	Overall sustainability rating	Main issues ^a
Natural forest	25 ha fragment/ 1 ha	254	120	1	
Community-based forest management	35,000 ha common forest/1 ha	176	100	1	
Commercial logging	35,000 ha concession/ 1 ha	150	90	0.5	C
Rubber agroforest	1–5 ha plots/ 1 ha	116	90	0.5	C
Rubber agroforest with clonal planting material	1–5 ha plots/ 1 ha	103	60	0.5	C, K, W, P
Rubber monoculture	1–5 ha plots/ 1 ha	97	25	0.5	C, W, P
Oil palm monoculture	35,000 ha estate/1 ha	91	25	0.5	C, Fert
Upland rice/bush fallow rotation	1–2 ha plots/ 1 ha	74	45	0.5	Fert, P
Continuous cassava degrading to <i>Imperata</i>	1–2 ha plots within settlement project/1 ha	39	15	0	C, Fert, W

^aPlot-level production sustainability: C = soil compaction; K = potassium balance; Fert = fertilizer cost; P = pest or disease problem.

^bMarket imperfections: I = input market problem; O = output market problem; K = capital market problem.

The ASB Matrix for the Forest Margins of Sumatra

The complete ASB matrix for Indonesia, as presented in Table 12.2, is the basic tool for an integrated assessment of options to balance environmental benefits with sustainable agricultural development. An alternative approach to analysing multiobjective criteria is to derive a set of weights for various indicators, often valued in terms of currency, as a basis for developing an index to rank alternatives. While it is possible to take this approach to estimating returns to land and imputed values for carbon sequestration services (for relevant examples, see Tomich *et al.*, 1997), it is problematic for other objectives (especially measuring biodiversity). The matrix of land-use alternatives (Table 12.2) is, then, a

Table 12.2. *Continued.*

National policymakers' concerns		Adoptability by smallholders			
Potential profitability: returns to land (Rp 1000 ha ⁻¹) at social prices	Employment: time-averaged labour input (days ha ⁻¹ year ⁻¹)	Production incentives: returns to labour (Rp day ⁻¹) at private prices	Household food security: food entitlement via:	Institutional and policy issues	
				Market imperfections ^b	Other institutional problems ^c
0	0	0	n/a		
9.4 to 18	0.2 to 0.4	11,000 to 12,000	Own production and exchange	o	N, R, P, C
(32) to 2102	31	(17,349) to 2008	Wages	O, K	N, R, E, P, B, C
73	111	4000	Exchange		P, b, c
234 to 3622	150	3900 to 6900	Exchange	l, k	N, P, b, c
(993)	133	3683	Exchange	l, k	N, P, b, c
1480	108	5797	Wages	l, o, K	N, R, e, P, B, c
(180) to 53	15 to 25	2700 to 3300	Own production		n, P, c
(315) to 603	98 to 104	3895 to 4515	Own production and exchange	o, K	n, E, p, c

^cOther institutional problems: N = non-market information problem; R = regulatory problem; E = local environmental problem; B = equity biases (gender or distributional); C = social cooperation required.

For market imperfections and other institutional problems: upper-case letters indicate more serious problems.

pragmatic attempt to circumvent this valuation problem and to organize information that incorporates competing objectives, wherein various groups can assign their own assessments of relative weights. With this array of indicators, it is possible to examine tradeoffs and complementarities across the various criteria.

Global environmental concerns and agronomic sustainability

Carbon sequestration

Carbon stocks of tree-based land-use systems depend largely on the typical cycle length of these systems, as annual C increments are similar. Thus, time-averaged C stocks are roughly similar for long-rotation tree-based systems, which are superior to all other land uses in this regard, except for natural forests themselves.

Biodiversity

Alternative land uses at the forest margins differ significantly in their potential for conservation of above-ground biodiversity. A range of alternatives are shown to fall between the extremes of smallholders' complex, multistrata agroforestry systems (agroforests) and continuous food-crop monoculture, as measured by the number of plant species per standardized plot.

Plot-level agronomic sustainability

All the tree-based systems included in Table 12.2 (smallholder agroforests and rubber monoculture, as well as large-scale plantation monoculture) are agronomically sustainable. On the other hand, the shortening of fallow rotations from 10 years or more to less than 5 years, along with rising land scarcity, is undermining the sustainability of shifting cultivation, which has been disappearing anyway as population pressure increases in Sumatra (van Noordwijk *et al.*, 1995). Prior to the monetary crisis that began in Indonesia in 1997, unsustainable shifting cultivation was not financially profitable in much of Sumatra. This appears to have changed during the collapse of the Indonesian currency in 1997/98, which (temporarily) may have reversed the long-term decline in shifting cultivation (Tomich *et al.*, 1998a, Part VI). Indeed, because of the collapse of the *rupiah*, the potential profitability of many tree-based systems has increased substantially, which may have boosted incentives for forest conversion by smallholders and large-scale operators alike.

Continuous cultivation of cassava does not appear sustainable on this land because of the depletion of nutrients and of soil organic matter. On these soils, marginal revenues from fertilizer applications to cassava do not cover fertilizer costs at current prices, which were near the world market price for most nutrients at the time of these studies, except nitrogen, which is subsidized in Indonesia. Moreover, extensive cassava systems mine nutrients, exhausting the soil and reducing the number of options for future land use. Local, regional and national environmental problems linked to land-use change still need to be addressed to fully understand the sustainability of these land-use alternatives beyond the plot level.

Concerns of smallholders and national policy-makers

Potential profitability and smallholders' production incentives

Estimates of returns to land valued at social prices (potential profitability or comparative advantage) and returns to labour valued at private prices (smallholders' production incentives) are presented in Table 12.2. The upland rice/bush fallow rotation stands out as being unprofitable, in terms of either potential profitability or smallholder production incentives. The high end of the range of estimated returns are for the fallow of 10 years or more, which is no longer feasible because of population pressure. The low end of the range corresponds to short-fallow shifting cultivation. These results are consistent with the disappearance of shifting cultivation in most of Sumatra's peneplains.

Sustainable forms of continuous food-crop production may be technically feasible in Sumatra's peneplains, but often are not financially attractive because they require too much labour and too many purchased inputs. Here, we focus on cassava, which may be among the most profitable of the continuous food-crop alternatives for the peneplains. Profitability estimates for two cassava systems are included in Table 12.2, one with fertilizer applications from the first year and one with fertilizer beginning in the seventh year after forest clearing. The latter system is shown to produce relatively attractive returns to land and labour, but its longer-run sustainability requires further study.

Estimated returns to labour are highest for community-based forest management (including extraction of non-timber forest products (NTFPs)), but these high returns are dependent on the existence of some mechanism to exclude outsiders. This alternative can thus play an important role for those communities which can regulate access to forestlands. If, on the other hand, communities cannot regulate access to their forests, one would expect the returns to labour from extraction of forest products to decline toward the wage rate. Even under 'open access', however, one would still expect returns to labour to exceed the wage rate by some margin equal to a risk premium. The risks involved include the possibility of failure to find products to extract and the risk (and associated costs) of detection by officials, since many of these activities are prohibited.

The relatively low returns to land – well below those in rubber agroforest systems – suggest that NTFP extraction is not a feasible alternative for large numbers of people, because there is not enough land for everyone to practise this livelihood strategy. These results must be interpreted with some care, however, for several reasons. First, it was not possible to include all the myriad commodities collected from the forest by local villagers. Researchers focused on the commodities that villagers reported were most important to them. Secondly, because restrictions banning logging by villagers are enforced actively, it was not possible to obtain data about villagers' timber extraction from the forest, and it is likely that this is significant. Thirdly, extractive activities are highly site-specific, and it may be that the study site was not representative. Finally, at least part of the forestland claimed by long-established communities is on designated government land and it is not clear how this problem of tenure insecurity might bias these results. Long-run profitability may be overstated because of unsustainable harvesting. However, if the community or individual

members had secure property rights, this might induce investment to increase productivity. Two estimates of profitability – one based on sustainable harvests only and a second higher estimate including products that may be depleted (songbirds and rattan) – are reported in Table 12.2.

A pair of profitability estimates are reported for commercial logging in Table 12.2; the lower estimate represents complete compliance with government regulations, the higher is closer to actual practice. The sustainable-logging regulations, if they are really followed, reduce profitability, mainly by slowing timber extraction and because high export taxes (effectively an export ban) for logs and sawn timber depressed the domestic prices of logs by 50–70%. However, timber companies can get around both of these problems. First, many companies circumvent regulations on timber extraction. Secondly, these are typically vertically integrated firms, producing products like plywood for the export market. Therefore, the best indicator of profitability of these activities is probably the figure of just over Rp 2 million ha⁻¹, valued at social prices reflecting world prices of forestry products.⁸

Oil-palm is widely viewed as the most profitable alternative for Sumatra's penneplains and Indonesia's oil-palm producers have the lowest unit costs in the world. Thus, it is no surprise that large-scale oil-palm monoculture is among the most profitable alternatives, evaluated either in terms of returns to land, valued at social prices, or returns to labour, valued at private prices. The latter measure is of limited relevance, however, because the official wages for plantation workers are well below these estimates of returns to labour. As occurred earlier in Malaysia (Barlow, 1986), plots of 2–5 ha of oil-palm planted by independent smallholders began to appear in Sumatra beginning in the 1980s. These merit study for their possibility to combine high potential profitability with attractive returns to smallholders' labour. For the time being, however, government development strategies discriminate against the emergence of independent smallholder oil-palm producers. For example, some provinces will not license palm oil mills unless the enterprise also has its own oil-palm plantation or smallholders are organized in nucleus estate/smallholder (NES) schemes. This is intended to prevent NES participants from selling their produce outside the project (as happened in the case of rubber) in order to avoid repayment of loans. But this practice also retards the development of the market for independent smallholder oil-palm producers.

The three contrasting rubber systems produce a wide range of results.⁹ First, as already noted, it is encouraging that returns to labour at private prices are virtually identical to the market wage for rubber agroforests planted with seedlings. Although these smallholders are the lowest-cost producers of natural rubber in the world (Barlow *et al.*, 1994), returns to land at social prices are not much above upland rice with a long bush fallow rotation and are well below oil-palm monoculture.

Perhaps the most striking result seen in Table 12.2 is the estimated returns to land at social prices for rubber agroforests planted with PB 260 clones, which rival large-scale oil-palm monoculture. This system also produces attractive returns to labour at private prices. These data must be treated with caution, since

they are based on projections from farmer-managed trials and have not been verified through broader experience by smallholders. The top of the range of profitability estimates might actually be attained by 10–25% of smallholders. However, the lower figure in the range represents an expert's best guess about a 'worst-case' scenario for yields in this system for the bottom quartile. A central question is where the middle of the profitability distribution would be for this system; this can only be answered through farmers' experience. But these results support the idea that the potential profitability of rubber agroforests planted with clonal material (and other smallholder agroforests planted with appropriate, higher-yielding germ plasm) may be comparable to that of large-scale oil-palm plantation monoculture.

The profitability estimates for smallholder rubber monoculture planted with GT 1 seedlings provide a cautionary tale to balance the encouraging projections for rubber agroforests planted with PB 260 clones. These monoculture plots were part of a government-sponsored rubber replanting project, which was undertaken with high expectations. But disappointing yields were obtained because of institutional shortcomings involving supplies of planting material (participants received seedlings instead of clones), technical information and credit, and these yields could not offset high project costs. Contrasted to this high-cost approach, the strategy to introduce clones into smallholders' agroforests seeks a moderate increase in yields at minimal incremental costs. Yet the costly lessons of earlier failures in smallholder rubber development should be borne in mind (Tomich, 1991).

Employment

For the rubber and oil-palm systems that were evaluated, total time-averaged labour requirements are similar, ranging between 100 and 150 person-days ha⁻¹ annually. Labour for harvesting is the largest component in these systems. Because of a lack of pronounced seasonality in much of Sumatra, the harvesting of rubber and oil-palm can proceed roughly 10 months year⁻¹. The two extractive activities – community-based forest management and commercial logging – fall at the opposite extreme. Neither of these extractive activities nor the upland rice/bush fallow rotations can provide many employment opportunities.

Household food security

Calculations presented in Tomich *et al.* (1998a) indicate that production risk for rubber agroforests may be less than for the upland rice/bush fallow rotation. The terms-of-trade risk for rubber, however, is about double the production risk, as measured by their respective coefficients of variation. Although these measures suggest that upland rice/bush fallow is, overall, less risky than rubber, the superior production incentives for rubber agroforests are the reason why rubber has displaced upland rice over the past century. Note that the large-scale alternatives – commercial logging and large-scale plantations of oil-palm or industrial timber – imply a shift to wage labour or migration for displaced local households.

Tradeoffs and Complementarities

Because of the multiple criteria regarding the production and environmental services of forests, 'deforestation' must be viewed as a multidimensional phenomenon. Sometimes the policy problems may be simplified to a few key dimensions (tradeoffs), which are highlighted here.

Is there a tradeoff between growth and poverty alleviation?

If they are really more profitable than smallholder tree-based alternatives, all the large-scale systems will involve tradeoffs with household food security, since such projects often displace local smallholders with little or no compensation. In the case of large-scale logging, there is also a tradeoff with employment creation in smallholder tree-based systems. The potential profitability of some tree-based alternatives for smallholders (namely, rubber agroforests planted with clones) appears to be comparable to that of large-scale estates and logging. However, this requires further verification through additional studies of smallholder rubber and other alternatives, such as smallholder timber and smallholder oil-palm. This result holds promise for complementarity between policy-makers' concerns with potential profitability and smallholders' production incentives. It also suggests that policy concerns regarding equity and mounting concerns about social and political instability can be addressed through a smallholder-based development strategy without a significant reduction in economic growth. If they can be adapted for smallholders, the tree-crop-based systems offer attractive production incentives. Since labour markets appear to work well, labour should not be a serious constraint to adoption. Thus, smallholder tree-crop systems also offer complementarity with employment creation objectives.

Are there tradeoffs between global environmental benefits and local objectives?

The relationship between potential profitability and C sequestration is dominated by cycle length (frequency of clear-felling for rejuvenation). Where tree-crop systems can be rejuvenated without clear-felling, a substantial increase in C stock may be possible. Moreover, there do not appear to be large differences between forest extraction and the other tree-based systems regarding C stocks and greenhouse gases. Thus, as far as agronomic sustainability and climate-change objectives are concerned, tree-based systems dominate among the alternatives.

Raising the productivity of rubber agroforests, which span millions of hectares, offers a promising pathway in Sumatra. There appears to be great potential for raising the 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 and de Foresta, 1995; van Noordwijk *et al.*, 1997). Indeed, these agroforests may approximate a number of forest functions, thereby providing the technical foundation for sustainable community-based forest and watershed management. But it must be emphasized that agroforests are not perfect substitutes for biodiversity conservation in natural forests. Indeed, conversion of natural forests to agroforests involves a significant reduction in species richness.

A key unresolved question is whether the potential development of smallholder rubber agroforests can compete with the (private and social) profitability of large-scale land uses, including oil-palm plantations, industrial timber estates and logging concessions. These large-scale alternatives are viewed as 'best bets' for economic development by many policy-makers and donors, in large part because of the conventional wisdom regarding economies of scale in plantation development. If it turns out that large-scale development alternatives are more profitable – recall from Table 12.2 that this is not a foregone conclusion – an important tradeoff between global environmental benefits arising from biodiversity conservation and national economic objectives based on large-scale plantation development will have to be faced.

Even if further analysis shows that the large-scale schemes hold no advantages in terms of private and social profitability compared with smallholder schemes, a potential tradeoff between profitability and biodiversity conservation remains to be addressed concerning smallholder systems (van Noordwijk *et al.*, 1997). Farmer management aimed at increasing the productivity of systems often decreases biodiversity. Whether or not this apparent trade off between productivity and biodiversity is inescapable is the subject of debate and further research.

Barriers to Adoption of Land-use Alternatives

Cash-flow constraints

Because perennials are so important among the Sumatran alternatives, our analysis of cash-flow constraints focused on multiyear (rather than seasonal) cash-flow constraints in order to assess whether the investments required by these systems represent barriers to adoption by smallholders. Table 12.3 takes two approaches to assessing multiyear cash-flow constraints: the number of years to positive cash flow and the NPV of establishment costs (defined as costs prior to positive cash flow). The imputed value of family labour is included in establishment costs, because these labour inputs presumably represent forgone earnings in other activities, even if they do not require cash outlays.

By either measure, community-based forest management is the only profitable system without any multiyear cash-flow constraints. For the other systems, years to positive cash flow range from 2 years for logging to 6–10 years for smallholder rubber and 10 years for large-scale oil-palm. Time is not a constraint by itself, as evidenced by almost 3 million ha of rubber agroforests

Table 12.3. Cash-flow constraints.

Land-use system	Years to positive cash flow at private prices (years)	NPV of establishment costs at private prices (rupiah ha ⁻¹)	Years to positive cash flow at social prices (years)	NPV of establishment costs at social prices (rupiah ha ⁻¹)
Community-based forest management	n/a	n/a	n/a	n/a
Commercial logging	2	820,669–869,199	2	716,917–764,238
Rubber agroforest (seedlings)	10	1,305,536	10	1,477,735
Rubber agroforest (clones)	6–7	2,593,458–2,862,422	6–7	2,950,338–3,303,338
Rubber monoculture	10	2,085,257	10	2,192,584
Oil-palm monoculture	10	8,041,847	9	8,182,015
Upland rice/bush fallow rotation	Never	n/a	Never	n/a
Cassava/ <i>Imperata cylindrica</i>	2	n/a	2	n/a

that have been planted by smallholders without any formal credit. The NPV of establishment costs at private prices is probably the best indicator of cash-flow constraints for smallholders. In interpreting these estimates, bear in mind that the existing rubber agroforests are evidence that the estimated Rp 1.3 million ha⁻¹ required for establishment has not been an insurmountable barrier for smallholders.¹⁰ These estimates suggest that replacing seedlings with higher-yielding clones in rubber agroforests more than doubles investment costs to roughly Rp 2.6–2.9 million ha⁻¹. Since there is no long-term institutional credit for smallholders in Sumatra, whether these investment requirements are barriers to adoption depends in large part on the divisibility of the activity (e.g. planting a bit at a time).

Investment costs for large-scale oil-palm plantations are the highest of all, at over Rp 8 million ha⁻¹. Investments of this magnitude would be difficult for many smallholders. But capital costs for large-scale plantations may be inflated for at least two reasons. First, these plantations formerly received heavily subsidized credit from the government, which tended to make them artificially capital-intensive. Secondly, it is our experience that respondents tend to overstate investment costs to mask profitability. None the less, adapting high-yielding oil-palm systems as alternatives for smallholders will require research to develop options that are less capital-intensive.

Market imperfections

Input-supply markets

Markets for supplying planting materials for clonal rubber and oil-palm represent a significant barrier to the adoption of profitable alternatives by smallholders. Farmers have little access to improved rubber planting material. The

Treecrops Advisory Service, virtually the sole provider of rubber budwood, has focused its efforts on supplying planting materials to project participants in the past and has largely ignored the much larger number of non-participants (Tomich, 1991). Except in a few areas of Sumatra, the private nursery industry has only begun to develop. For public and private sources alike, there are serious problems of reliability regarding the quality of planting material, which is difficult to assess until several years after planting. Current delivery pathways for improved planting material (and the information needed to use it) seem inadequate, but direct government intervention to supply germ plasm may be neither feasible nor desirable. For example, subsidizing germ plasm would hamper development of a private nursery industry.

Output markets

Government restrictions on marketing and international trade are perhaps the greatest barrier to the development of smallholder timber-based alternatives and also hinder community-based forest management. Beginning in 1998, the government agreed to deregulate exports of timber, abolish joint-marketing associations (which functioned as cartels) and end export quotas and numerous other restrictive marketing arrangements. Previous restrictive marketing practices damaged the marketing capacity of most timber companies by inhibiting the development of marketing networks that could respond to buyers' needs. The situation is particularly bad for rattan, since the export ban on raw rattan destroyed overseas markets and induced importers to seek alternative supplies. There is also concern that old rent-seeking practices (such as the plywood and clove cartels) will re-emerge under new guises. These risks are increased by a lack of market information on these commodities. The lack of information is probably worst for NTFPs, especially those occupying narrow market niches. Oil-palm has also been subject to export taxes and, at times, export bans (Tomich and Mawardi, 1995), which seriously depress farm-gate prices. For oil-palm and cassava, there are also some concerns about the development of local markets, which can link smallholders with processors. However, these markets seem to be emerging. Local markets for natural rubber have functioned for a century or more. Although they are characterized by distortions reflecting product quality and the effects of national policy, and the international buffer stock has at times depressed prices, local markets do transmit world price changes to the farm gate, with marketing margins reflecting transportation and other costs.

Labour markets

Although the complete analysis also includes skilled labour requirements, the summary analysis presented here focuses on unskilled labour. Instead of hiring permanent skilled workers, smallholders are more likely to develop certain technical skills themselves. So the relevant barrier is the acquisition of technical information, rather than the market for skilled labour. Although labour markets in Sumatra fall short of the theoretical 'ideal' of economics textbooks, recent empirical studies linked to the ASB project (Suyanto *et al.*, 1998a,b) indicate that these labour markets function reasonably well. None of the land-use

alternatives face problems regarding markets for unskilled labour. It is worth noting that casual markets for skilled labour (e.g. chainsaw operators) are also emerging.

Capital markets

No long-term institutional credit is available in rural Sumatra. Yet household savings, which have financed investments in existing smallholder agroforestry systems, such as rubber agroforests, are often underestimated. In rural Indonesia, farmers are able to receive considerable credit from informal sources (e.g. relatives, moneylenders). However, current economic hardships – especially rising food prices – may be straining these resources. Capital market imperfections (lack of credit and interest rates well above the social price of capital) may constrain smallholders' nutrient purchases for cassava production and the use of clonal rubber planting material, and are probably a barrier to smallholder oil-palm production. Whether or not smallholder timber extraction is constrained by capital market imperfections depends, in part, on the development of contract markets for chainsaw services and log transport.

Other institutional problems

Non-market information

Information acquired from research (e.g. new technologies) comes primarily from the government, and existing research facilities are inadequate to meet the research needs presented by diverse production conditions. This constraint is particularly severe for alternatives such as NTFPs and smallholder timber, which are not high priorities for the government, especially compared with rice, the main staple food. This bottleneck in technical information is a concern for all systems, except rubber agroforests using seedlings, where indigenous knowledge is well developed.

Regulatory issues

As discussed above, policies that restrict access to markets are a particular concern for timber and non-timber forest products and for oil-palm. This problem is compounded for timber and NTFPs by policies that attempt to restrict access to state forestland, even if it has been used by local people for generations (see below). Thus, especially for timber and NTFPs – but to a lesser extent for oil-palm – success in these land-use alternatives requires considerable investment of time (and often money) to 'work the system' under current policies.

Local environmental issues

Based on available data, the production of most of these systems seems benign. However, there may be water- and air-quality concerns arising from the processing of rubber, oil-palm and cassava. The exceptions are large-scale logging and continuous cassava cultivation, which are susceptible to erosion.

Further work is needed to assess the environmental impacts of expansion of particular alternatives, including air quality, landscape biodiversity and watershed functions.

Property rights

This is a highly charged political issue for all systems except the continuous production of food crops at a transmigration site; even here there can be problems of tenure conflicts with indigenous groups whose presence predates the settlement. In most cases, the tenure status of lands at the forest margins (and the products derived from those lands) needs to be clarified between the government and local communities.

Equity biases

The primary concern is that potential economies of scale will lead to concentration of land under commercial logging, for which scale economies have been documented elsewhere, and for oil-palm, where scale economies are probably not intrinsic but may result from current development policy. Despite the conventional wisdom, the prevailing faith in scale economies in the production of so-called 'plantation' commodities receives little (if any) support from agricultural economics (Hayami, 1994; Tomich *et al.*, 1995). This is, nevertheless, an empirical question that requires further investigation. Unlike production, the marketing and processing of primary products are often characterized by increasing returns to scale. This is the case for three of the most important land-use alternatives in Sumatra – rubber, pulp and oil-palm. The natural rubber industry in South-east Asia provides an excellent example of the efficiency with which markets can integrate low-cost production by smallholders with processing in factories that achieve economies of scale; similar marketing arrangements should work for pulp. Oil-palm has conventionally been viewed as an estate crop in South-east Asia (but not in Africa) because of its perishability. None the less, oil-palm production on independent plots as small as 1 ha began to emerge in Sumatra in the 1980s. Outgrower schemes, contract farming and other institutional arrangements can all help reduce transactions costs in linking efficient smallholder producers with efficient large-scale processors. There is some cause for concern regarding gender bias in tree-crop production, since recent studies have shown that tree planting induces a shift from matrilineal inheritance to patrilineal inheritance for some categories of trees in some areas of Sumatra (Suyanto *et al.*, 1998a).

Social cooperation

The main need for social cooperation concerns the two forest extraction alternatives, community-based extraction of NTFPs and logging. In each case, the sustainability of the land use is in doubt if communities cannot manage a system to restrict access to their common-property resources. Indigenous communities with their customary laws intact appear to have this capacity; communities of recent settlers may not. Collective action is also required for fire and pest control, and may be an emerging constraint in many agricultural systems.

Summary and Conclusions

The key hypothesis underlying ASB research in Indonesia has been that intensifying land use as an alternative to slash-and-burn can simultaneously reduce deforestation and reduce poverty. Poverty reduction in most of the tropics depends on finding ways to raise the productivity of labour and land through intensification of smallholder production systems. Thus, the intensification hypothesis hinges on the existence of opportunities to raise the productivity of smallholder systems at the forest margins without degrading forest functions. Although there may be (a few) 'win-win' opportunities to alleviate poverty while conserving tropical forests, it is naïve to expect that productivity increases necessarily slow forest conversion or improve the environment. Indeed, quite the opposite is possible, since increasing the productivity of forest-derived land uses also increases the opportunity cost of conserving natural forest. These increased returns to investment can spur an inflow of migrants or attract large-scale land developers and thereby accelerate deforestation.

Estimates of returns to land and labour presented in this chapter indicate that, from a purely private perspective, returns to forest conversion are high in Sumatra's peneplains. Because all derived land uses are inferior to natural forest, based on global environmental concerns (e.g. C stocks and biodiversity conservation), ASB research in Indonesia has shown that land-use changes involve tradeoffs between these environmental concerns and the objectives of poverty alleviation and national development. If there is no action on these tradeoffs – by identifying workable options either to change incentives for conversion or to restrict access to the remaining natural forests – these rainforests will continue to disappear.

This research also provides evidence that land-use alternatives differ significantly in their ability to substitute for the global environmental services provided by natural forests. So, although forest conversion has the largest negative effect on these environmental services, the alternative land uses matter too. Carbon stocks are similar for long-rotation tree-based systems, which are superior to all other land uses by this criterion except for natural forests themselves. Similarly, alternative land uses also differ significantly in their potential for biodiversity conservation, ranging between the extremes of smallholders' complex, multi-strata agroforestry systems (agroforests) and large-scale plantation monoculture. While there may be a tradeoff between potential profitability and biodiversity in tree-based production systems, this requires further verification. There may be little or no tradeoff between policy-makers' objectives and those of smallholder households, since the potential profitability of some tree-based alternatives for smallholders appears to be comparable to that of large-scale estates; however, this also requires further verification. There are also important institutional questions that must be addressed to enable widespread adoption of profitable alternatives by smallholders.

To obtain estimates of regional or global impacts directly from measures like those in Table 12.2, it is necessary to assume independence, and hence additivity, across space. This assumption is reasonable for some measures (e.g. C stocks), but it is only a rough approximation for others. Among these measures,

biodiversity is the most sensitive to scaling issues. While the agronomic sustainability measure used here concerns only on-site, field-level effects, the extent and spatial arrangement of land-use alternatives also produce environmental externalities (e.g. siltation, smoke, fire and floods). One of the key challenges of future research is to be able to assess these phenomena at the landscape level. Ultimately, instead of a single land-use system or technology, the most attractive way to achieve the multiple objectives is likely to come from combinations of complementary land-use practices within a varied landscape. This landscape-level analysis is not feasible now. The land-use-specific analysis presented here is a necessary precursor to that work.

Acknowledgements

The Alternatives to Slash-and-Burn (ASB) Programme has received financial support from the Global Environment Facility (GEF) under United Nations Development Programme (UNDP) sponsorship and from DANIDA. Additional sources of funding for ASB work in Indonesia include the Asian Development Bank (ADB), the Australian Centre for International Agricultural Research (ACIAR), the Ford Foundation, the Government of Indonesia, the Government of Japan and the US Agency for International Development (USAID). The authors thank Arild Angelsen and the editors for their helpful comments.

Notes

1 For further details on the Alternatives to Slash-and-Burn project, see Chapters 1, 11 and 13 of this volume. Detailed results of ASB's Indonesia work are presented in Tomich *et al.* (1998a).

2 These small family groups do not contribute to deforestation, so they have not been emphasized in the ASB research project.

3 Time-averaged C is annual average C stock over the production cycle (standardized at 25 years) and can be interpreted as the C stock of the land use at steady state (see Gockowski *et al.*, Chapter 11 of this volume, Appendix 11.1). Although timing is not considered, this measure is an indicator of net release or sequestration of C resulting from land-use change. Methane and nitrous oxide were measured for the same land-use systems studied for C stocks. Pronounced seasonality was discovered in greenhouse-gas emissions, so additional measurements will be necessary to derive reliable estimates of annual fluxes. However, these fluxes from living systems are a tiny fraction of the C release resulting from forest conversion (Tomich *et al.*, 1998a).

4 Below-ground biodiversity assessments focus on organisms that influence agronomic sustainability. There appears to be less variation among land uses in below-ground biodiversity compared with above-ground biodiversity, which supports our reliance on above-ground biodiversity as an overall indicator of richness.

5 Most of the indicators could be measured relatively easily, often using data collected as part of the surveys of biodiversity, C stocks and greenhouse-gas emissions or other aspects of the analysis of the land uses (for details, see Tomich *et al.*, 1998a). Indicators for weeds, pests and diseases, however, are based on expert opinion rather than field data. The overall ratings in Table 12.2 are also based on expert judgement, with '1' indicating

'no major problems'; '0.5' meaning 'problems that farmers can manage'; and '0' meaning 'problems beyond what farmers can manage'.

6 By most assessments of economic fundamentals (e.g. purchasing-power parity), the Indonesian *rupiah* was not greatly overvalued at that time. The consensus was that the overvaluation of the *rupiah* relative to the dollar may have been 10–15% in June 1997. Some expert analysts even expected the *rupiah* to appreciate if it were floated in 1997 (McLeod, 1997). During the economic crisis of August 1997 to 1998, the Indonesian *rupiah* was undervalued, by any economic measure.

7 Although local land abundance with household labour scarcity has prevailed historically and certainly continues in the ASB sites in Brazil and Cameroon, this fundamental relationship seems to be shifting in Sumatra. Nevertheless, it still is reasonable to believe that local land abundance and household labour scarcity continue in the forest margins, at least from the point of view of smallholder households in central Sumatra. This is supported by the result that returns to labour for rubber agroforests, the predominant smallholder land use, are almost identical to the wage rate (Table 12.2). This implies that no 'rent' accrues to land under the dominant system and is consistent with land abundance.

8 One could argue that the estimated NPV of logging activities of over Rp 2.1 million ha⁻¹ – about US\$875 in mid-1997 – should be added to the social profitability for all the other activities, at least for large-scale estates, which can often market the timber felled as a by-product of land clearing. All of the forest-derived land uses (rubber, oil-palm, cassava and even upland rice) started out with the felling of forest timber. There is also substantial (but as yet unquantified) timber felling in conjunction with NTFP extraction. Thus, in many cases, it would be appropriate to add the value of the harvested wood to the profitability of each activity. However, this was not done in Table 12.2, because the one-off value of timber extracted as a by-product of land clearing often exceeds the value of the other land uses. Although technically correct to do so, adding the value of timber would simply obscure differences in profitability among the other land uses. This problem is linked to one in conservation: if regulations can be circumvented, forest conversion is privately profitable simply for the value of timber, regardless of the subsequent land use. Of course, for the social profitability calculations, timber values would have to be balanced against the losses stemming from ecological and other environmental functions of natural forests.

9 The initial study of rubber agroforests planted with seedlings ('jungle rubber') was supplemented with data from another ongoing International Centre for Research in Agroforestry (ICRAF) study (Suyanto *et al.*, 1998b). Subsequently, additional data were added from an ICRAF/CIRAD project in Jambi, analysing rubber agroforests planted with higher-yielding PB 260 clones (E. Penot, 1998, Montpellier, France, personal communication). Since smallholder rubber monoculture is rare in Sumatra outside government projects, the data for rubber monoculture are based on a specific project in Jambi Province. The estimates for rubber agroforests planted with clones and for rubber monoculture may not be widely representative of smallholder experiences.

10 At an exchange rate of Rp 2400 per US dollar, the rate prevailing in July 1997, just prior to the economic crisis.