BIODIVERSITY LOSS, AGRICULTURAL DEVELOPMENT, AND SUSTAINABILITY

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ABSTRACT

Research by the Alternatives to Slash-and-Burn (ASB) Consortium in Sumatra provides little support for the original perception '*poverty causes people to migrate to the forests, but they don't know how to manage the soils, which forces them to move on and open new forest, leaving a trail of degraded lands behind*'. However, ASB research also shows that the land use systems that follow forest conversion differ significantly in their profitability and impacts on biodiversity. For example, farmers have developed agroforests, based on rubber, damar and other local or introduced trees, as sustainable and profitable alternatives to shifting cultivation, but these opportunities have stimulated rather than slowed down forest conversion in the absence of active boundary enforcement mechanisms for natural areas. Although agroforests can maintain part of the biodiversity of the original forests, they are no substitute for full protection of biodiversity in dedicated natural areas and conservation reserves. In fact all forest-derived land uses – even community-based forest management and 'sustainable' commercial logging – involve biodiversity loss. Much discussion of biodiversity loss focuses on existence values – i.e., preventing extinctions. Much less attention has been given to local functional values of biodiversity in the landscape (belowground as well as above), including the tangible (but not yet well-quantified) roles of biodiversity in sustainability and resilience of production systems. From this perspective, biodiversity is not just a global concern; it may also have local importance. Much more research is needed to expand the assessments of sustainability from plot-level agronomic issues to include functional roles of biodiversity at the landscape level in order to fully understand the sustainability of land use alternatives.

INTRODUCTION

The goals of the global Alternatives to Slash-and-Burn (ASB) research project are to identify means to reduce the rate of tropical deforestation driven by slash-and-burn and to reduce poverty of smallholders dwelling at the forest margins. This paper presents results from ASB study sites ('benchmark areas') in Jambi and Lampung provinces on the island of Sumatra in Indonesia, which are part of this ongoing global research project.[1] Measurement of differences among environmental consequences of the various land uses provides the basis for quantifying major tradeoffs involved in land use change. Assessment of the effects of alternative land use practices on biodiversity (richness above and belowground) was one of the main goals of the present phase of ASB. Detailed results of these studies, and the tools developed by ASB to obtain the necessary data, are reported in separate documents by their

[1] Results from ASB research at benchmark sites in Sumatra are reported in Van Noordwijk *et al.* 1995, 1996, 1997b, 1998; Tomich *et al.* 1998a, 2000.

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respective global working groups (Gillison 1998; Palm *et al.* 1998; Swift 1998; Tomich *et al.* 1998b; Vosti *et al.* 1998; Weiss 1998). This paper draws on these data to focus on links between biodiversity and sustainable alternatives to slash-and-burn.

DEFORESTATION IN THE ASB STUDY AREAS IN SUMATRA

The island of Sumatra was chosen to represent the lowland humid tropical forest zone in Asia for the global ASB project. Within Sumatra five major agro-ecological zones are identified with boundaries running from NW to SE approximately parallel to the coast:

1. a narrow western coastal zone,
2. a mountain zone, dominated by andosols and latosols of reasonable to high soil fertility
3. a narrow piedmont (foothill) zone, the lower slopes of the mountain range on the NE side, dominated by latosols and red-yellow podzolics;
4. a broad peneplain zone, almost flat land with Tertiary sediments, deposited in the sea; at present its altitude is less than 100 m above sea level and it consists of about 10% river levees and floodplains with more fertile alluvial soils and 90% uplands with a gently undulating landscape and mostly red-yellow podzolic soils
5. a coastal swamp zone with peat and acid sulphate soils.

Ongoing work seeks to span this full landscape gradient, but because of the global emphasis on lowland tropical rainforests (and derived land uses) in ASB, most of the work in Indonesia to date has focused on the peneplains and piedmont. Because they contain the most fertile soils, the western coastal plane, mountain zone, and the piedmont have been inhabited for a long time. Historically, the peneplain was inhabited sparsely with human population concentrated along the riverbanks on relatively favorable sites. With the advent of rubber a century ago, population spread in the peneplain but remained tied to the pattern of river transport until major road construction projects were completed over the past 25 years. In addition to road construction, 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. Ongoing forest conversion is a combination of logging, large plantation-style projects, government sponsored migration, and activities of both local and recent migrant smallholders. Much of the conversion is planned and sanctioned by the government.

Because of these activities, most remaining fragments of lowland tropical rainforest are in the piedmont zone and little natural forest remains in Sumatra's peneplains. This process of deforestation, which is almost complete in lowland Sumatra, seems likely to be repeated elsewhere in Indonesia. By understanding this process and its consequences in Sumatra, 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.

ASB 'META' LAND USES AND MAJOR LAND USES IN SUMATRA

Natural forests provide the basic reference point for biodiversity loss. Grasslands are included as reference points at the opposite ecological extreme. In between, a representative range of five generic upland, rainfed land use systems were selected for comparisons of alternatives: extraction of forest products; complex multistrata agroforestry systems, also known as 'agroforests'; simple treecrop 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 (Table 1). These 'meta land uses' were chosen to cover the spectrum of land use intensification and to provide counterpart land use types that can be found in the other ASB sites (Brazil, Cameroon, Thailand, and Peru) as well as Indonesia. The following operational definitions are used for the six land uses analyzed in the balance of this paper:

1. **Community-based forest management**, including extraction of non-timber forest products. Data for this study were collected in a community-managed forest in the Jambi ASB benchmark area.
2. **Large-scale commercial logging** was studied on forest concessions in Jambi. The Department of Forestry faces serious problems in regulating logging companies. This study emphasized concessions that were among the better managed. Data reported here are for a logging company that is (one of the few) to have its concession renewed, indicating better compliance with regulations for the 'Indonesian Sustainable Logging System.'
3. **Smallholder rubber**, including both **rubber agroforests** and **rubber monoculture.** The initial study of rubber agroforests ('jungle rubber') planted with seedlings was supplemented with data from another ongoing ICRAF study (Suyanto *et al.* 1998). Subsequently additional data from an ICRAF/ CIRAD project in Jambi (E Penot *pers comm*) were used to add an analysis of rubber agroforests planted with higher-yielding PB 260 clones. Since smallholder rubber monoculture is rare in Sumatra outside of government projects, the study of rubber monoculture is based on a specific project in Jambi province using GT1 seedlings. The data for rubber agroforests planted with clones and for rubber monoculture may *not* be widely representative of smallholder experience.
4. **Large-scale plantations of oil palm and industrial timber estates** have been established in Jambi and in Lampung, but none have reached maturity. These studies were conducted in Riau Province in Central Sumatra where these plantations were established earlier and already are productive. Conditions in Riau are similar to the forest margins of Jambi. Estimates for large-scale industrial timber are not yet available.
5. **Upland rice with bush fallow** has nearly disappeared from the peneplains and is only found in isolated pockets of Sumatra's piedmont, including some villages in the Jambi benchmark area where customary law prohibits tree planting on certain village lands. Two cases were studied, one is the short-fallow cycle of 5 years or less that now prevails, and which may not be sustainable, and one is the longer fallow cycle of 10 years or more, which no longer is feasible because of population pressure.
6. **Transmigration systems**, focusing on **cassava and *Imperata cylindrica*** (*alang-alang*) represent the continuous annual cropping and the grasslands 'meta' systems. Wet rice (*sawah*) is ubiquitous, but other forms of continuous annual cropping are rare in Sumatra except in transmigration settlement sites. On the transmigration site in Lampung, continuous monoculture of cassava and maize and rotations of cassava and maize are common. These fields often are plagued by *Imperata cylindrica.*

Table 1. Specifications for major land uses at the forest margins of the peneplains 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 mosaic	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 mosaic	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 mosaic	Reference point / best bet from official perspective: simulation of Indonesian 'sustainable logging system'; 40 yr cycle. Reference point: based on estimates of actual harvesting behavior for a concession that recently has been renewed; 20-25 yr cycle.
Complex, multistrata agroforestry systems	Rubber agroforests	Smallholders' plots of 1-5 ha	Indigenous smallholder landscape mosaic	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 mosaic	Possible ASB best bet: forest clearing followed by upland rice and planting of rubber clones, with natural regeneration of natural forest species.
Simple treecrop systems	Rubber monoculture	Smallholders' plots of 1-5 ha	Indigenous smallholder landscape mosaic	(Formerly) best bet from official perspective: upland rice and planting of rubber clones, with intensive use of inputs and labor 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 per year, often located in community land	Indigenous smallholder landscape mosaic	Reference point: One year of upland rice followed by bush fallow of 10 years of more. The dominant smallholder land use of 100 years ago, now rare. Reference point: One 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 *Imperata cylindrica* 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.

BIODIVERSITY LOSS FROM NATURAL FOREST EXTRACTION OR CONVERSION

ASB researchers have taken an innovative and eclectic approach to measurements of biodiversity in order to assess richness of the alternative land use systems for major groups of organisms above and belowground. Aboveground measurements are done for plant functional groups as well as the more conventional taxonomic approach. The techniques and protocols used are described in greater detail in Gillison (1998) and Swift (1998).

Belowground biodiversity assessments focus on organisms that influence agronomic sustainability, which will be taken up again later in this paper. Most of the belowground biodiversity falls in the 'spontaneous' and 'non-harvested' category. This does not mean that it is not an important part from a longer term perspective but it is little visible to farmers. There appears to be less variation among land uses in belowground biodiversity compared to aboveground biodiversity (Figure1), which supports our reliance on aboveground biodiversity as an overall indicator to distinguish species richness among the alternatives.

Alternative land uses at the forest margins differ significantly in their potential for conservation of aboveground biodiversity—using aboveground plant species as an indicator of richness--with a range of alternatives falling between the extremes of smallholders' complex, multistrata agroforestry systems (agroforests) and continuous foodcrops (Table 2). All of the forest-derived land uses in Table 2 have lower plant species richness than natural forest. Note that even community-based forest management and logging lead to signficant reductions in plant species richness compared to preexisting natural forest.

PROFITABILITY OF FOREST-DERIVED LAND USES

The policy analysis matrix (PAM) technique provided the framework for estimating profitability indicators as well as the indicators of labor requirements and cash flow constraints discussed below. The 'PAM' is a matrix of information about agricultural and natural resource policies and factor market imperfections that is created by comparing multi-year land use system budgets calculated at private and social prices.[2,3]

Estimates of returns to land valued at social prices (potential profitability) and returns to labor valued at private prices (smallholders' production incentives) are presented in Table 2. Returns to land are attractive the more they exceed zero; activities are socially unprofitable if returns to land are negative. Returns to labor are attractive to smallholders if they exceed the wage, which was Rp 4000 per day at the time of these studies.

Upland rice / bush fallow stands out as unprofitable, either in terms of potential profitability (returns to land at social prices) or smallholder production incentives (returns to

[2] Monke and Pearson 1989 is the basic reference. Tomich *et al.* 1998a provides details on application in Sumatra. See Aliadi and Djatmiko 1998; Arifin and Hudoyo 1998; Budidarsono 1998; Hadi and Budi 1998; Machfudh and Endom 1998; and Maryani and Irawanti 1998 for the specific studies.

[3] Private prices were those observed in mid-1997, before the monetary crisis and when Rp 2400 bought US$. The adjustments to derive social prices focus on policy distortions from trade restrictions. We use a lower real discount rate (15% instead of 20%) to capture the impact of capital market imperfections on the private cost of capital. The same wage rate is used in both sets of calculations, implicitly assuming that there are no imperfections in the market for unskilled labor. The main omission is that prices are not adjusted to reflect environmental externalities arising from these production activities, such as smoke, ecological changes, and loss of watershed functions.

Table 2. Biodiversity, Profitability, & Employment

Description	Scale of operation / evaluation	Biodiversity	Potential profitability	Smallholder production incentives	Employment
		Plant species/ standard plot	Returns to land (Rp 000 / ha) at social prices	Returns to Labor (Rp / day) at private prices	Time averaged labor input (days/ha/yr)
Natural forest	25 ha fragment / 1 ha	120	0	0	0
Community-based forest management	35,000 ha common forest / 1 ha	100	9.4 to 18	11,000 to 12,000	0.2 to 0.4
Commercial logging	35,000 ha concession / 1 ha	90	(32) to 2,102	(17,349) to 2,008	31
Rubber agroforest	1-5 ha plots / 1 ha	90	73	4,000	111
Rubber agroforest w/ clonal planting material	1-5 ha plots / 1 ha	60	234 to 3,622	3,900 to 6,900	150
Rubber monoculture	1-5 ha plots / 1 ha	25	(993)	3,683	133
Oil palm monoculture	35,000 ha estate / 1 ha	25	1,480	5,797	108
Upland rice / bush fallow rotation	1-2 ha plots / 1 ha	45	(180) to 53	2,700 to 3,300	15 to 25
Continuous cassava degrading to *Imperata*	1-2 ha plots within settlement project / 1 ha	15	(315) to 603	3,895 to 4,515	98 to 104

[1]Source: Tomich et al. 1998a.

labor at private prices). The small positive returns to land (Rp 53,000 per ha) are for fallow of ten years or more, which is no longer feasible due to population pressure. The lower (negative) number in the range is for short fallow shifting cultivation. These results are consistent with the disappearance of shifting cultivation in most of Sumatra's peneplains and piedmont.

Sustainable forms of continuous foodcrop production may be *technically* feasible in Sumatra's peneplains, but often are not financially attractive because they require too much labor and too many purchased inputs. Here, we focus on cassava, which may be among the

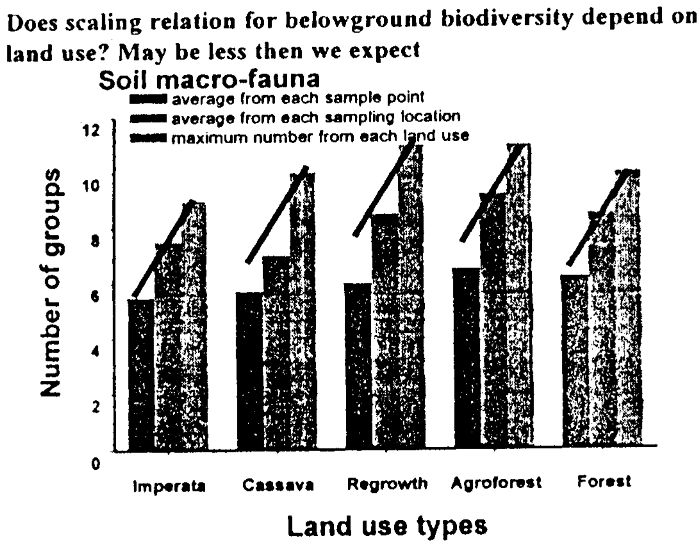

Figure 1. Belowground Biodiversity

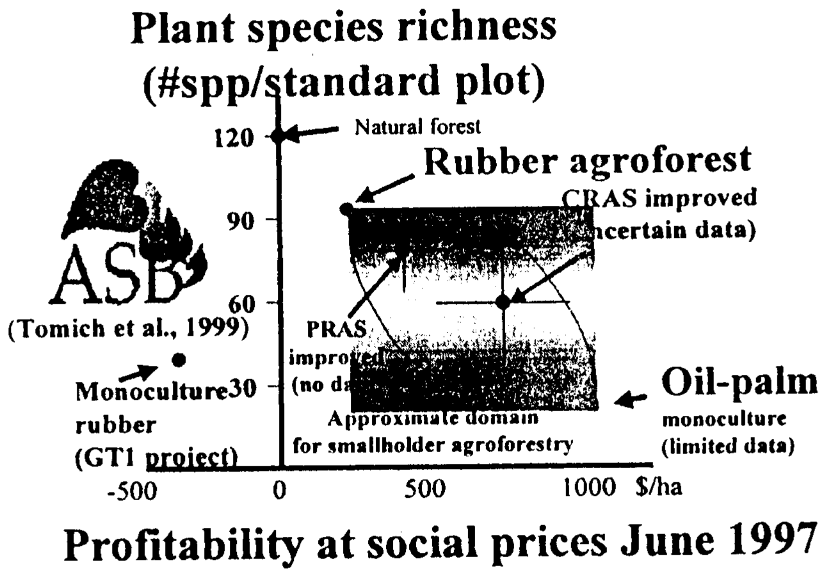

Figure 2. Trade off between biodiversity (as indicated by plant species richness) and profitability of tree crop production systems based on rubber or oil palm, with a current estimate of the domain of possible land use systems; PRAS refers to permanent rubber agroforestry systems (gap-level renewal, 'sisipan') and CRAS to cyclical systems, with slash-and-burn based land clearing at the end of each production cycle (Tomich et al., 1998a).

most profitable of the continuous foodcrop alternatives for the peneplains. The most profitable cassava system studied was an extensive fallow system without any fertilizer applications.

Profitability at private prices was estimated at over Rp 545,000 per ha. However, this example is not included in Table 2 because these systems mine nutrients, exhausting the soil and reducing the range of future land use options. Two cassava systems that use fertilizer are included in Table 2, one with fertilizer applications from the first year and one with fertilizer beginning in the seventh year after forest clearing. Application of fertilizer from the first year after clearing (30 kg N; 60 kg P; and 60 kg K per year) is not profitable socially (negative Rp 315,000 per ha). These treatments and the agronomic results are taken from experiments conducted at the Biological Maintenance of Soil Fertility (BMSF) research project at the ASB benchmark area in Lampung. An intermediate approach (also reported in Table 2) with fertilizer applications beginning in year seven (50 kg N; 50 kg P) does produce relatively attractive returns to land (Rp 603,000 per ha). However, the longer-run sustainability of this system requires further study.

Returns to labor are highest for community-based forest management (extraction of non-timber forest products, NTFPs), but these depend on some mechanism to exclude outsiders. Thus, this activity can play an important role for existing communities who can regulate access to forest lands. The relatively low returns to land – well below rubber agroforests – suggest that this is not a feasible alternative for large numbers of people, because there is not enough land for everyone to practice this extensive livelihood strategy. These results must be interpreted with some care, however. [4]

The results for commercial logging may appear paradoxical, but this is sustainable logging regulations – if they really are followed – reduce profitability, mainly by slowing timber extraction. However, timber companies can get around these regulatory 'problems'. First, many companies circumvent regulations on timber extraction. Second, these typically are vertically-integrated firms producing products like plywood for the export market. Therefore, the best indicator of profitability of these activities for logging companies is the figure of just over Rp 2.1 million per ha, valued at social prices that reflect world prices of forestry products. When comparable estimates are available for industrial timber plantations, it seems likely that these will be more profitable than logging.

Oil palm is widely viewed as the most profitable alternative for Sumatra's peneplains 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, either in terms of returns to land or returns to labor. The later measure is of limited relevance, however, because the official wages for plantation workers are well below these estimates of returns to labor. But, much as they had earlier in Malaysia (Barlow 1984), 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 from a national perspective with attractive returns to smallholders' labor.

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[4] These estimates are a lower bound for profitability of this land use for three reasons. First, it was not possible to cover all the myriad commodities collected from the forest by local villagers. Researchers focused on the commodities that villagers reported were most important to them. These included honey, fish, durian (*Durio zibethinus*) fruit, jengkol (*Pithecelobium jiringa*) pods, and petai (*Parkia speciosa*) pods, which appear to be harvested sustainably, and various species of song birds and rattan, which apparently are not. Second, because restrictions banning logging by villagers are enforced actively it was not possible to obtain data about villagers' timber extraction from this forest. Finally, it was not possible to put a value on timber extraction, but it is likely that this is significant.

The three contrasting rubber systems produce a wide range of results. First, as already noted, it is encouraging that returns to labor 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 are not much above upland rice with a long bush fallow rotation and are well below oil palm monoculture.

Perhaps the most striking result in Table 2 is the returns to land for rubber agroforests planted with PB 260 clones, which rival large-scale oil palm monoculture. This system also produces attractive returns to labor. These data must be treated with caution, however, 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 (E Penot *pers comm*). The big question is where the middle of the profitability distribution would be for this system – and that can only be answered through farmers' experience. But these results support the idea that potential profitability of rubber agroforests planted with clonal material (and other smallholder agroforests planted with appropriate. higher-yielding germplasm) may be comparable to 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 that was undertaken with high expectations. But the disappointing yields that were obtained because of institutional shortcomings involving supply of planting material (seedlings had to be planted instead of clones), technical information, and credit could not offset the high costs of that project's approach. Instead of the high-cost approach in this case of rubber monoculture, 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).

IS THERE A TRADEOFF BETWEEN BIODIVERSITY AND PROFITABILITY?

Some have argued that 'artificial' distinctions between global environmental interests and regional, national, and local concerns impede action (UNDP *et al.* 1994; p. 5), but the tradeoffs among objectives spanning these scales that should not be ignored. Pursuing global interests in conservation of endangered species and unique ecosystems involves a high-opportunity cost for local people because of land scarcity in SE Asia. Under these circumstances, it is clear that the feasibility of key conservation objectives rests on the ability to secure the boundaries of so-called 'protected' areas. Again, this requires capacities for conflict management, including a mechanism for compensating local people for foregone opportunities. If it is not feasible to realign incentives for local communities, it is inevitable that conservation areas will continue to shrink – ultimately to the point that they no longer function.

Raising productivity of rubber agroforests, which span millions of ha, offers a promising pathway in Sumatra. As noted above, there appears to be great potential for raising profitability of these systems though adaptation of existing higher-yielding clones within existing smallholder systems. It may be possible to combine these potential benefits from the perspective of smallholders and national policymakers with significant biodiversity conservation because the mix of planted species is augmented by natural regeneration of forest species (Michon and de Foresta; van Noordwijk *et al.* 1995b). 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. For assessments of higher plants made along 100 m line transects in Sumatra, over 350 species were found in primary forests while the number dropped to about 250 species for rubber agroforests. However, the richness remaining in agroforests still is much higher than the 5 or so species of higher plants found in rubber monoculture (Michon and de Foresta). Data in Table 2 indicate a reduction of 120 plant species for natural forest to 90 plant species for rubber agroforests in 'standard' plots (40m x 3m); with 25 species found in rubber monoculture using the same method.

A key unresolved question is whether the potential for development of smallholder rubber agroforests can compete with the profitability of large-scale alternatives, including oil palm plantations, industrial timber estates and logging concessions. These are viewed as 'best bets' for economic development by many policymakers and donors, in large part because of conventional wisdom of economies of scale in plantation development. If it turns out that large-scale development alternatives are more profitable—recall from Table 2 that this is not a foregone conclusion—an important tradeoff between global environmental benefits and national development objectives will have to be faced. This is because there is an important tradeoff with biodiversity conservation for large-scale plantation monocultures such as oil palm.

Even if further analysis of profitability shows that large-scale schemes hold no advantages compared to smallholders, a potential tradeoff between profitability and biodiversity conservation remains to be addressed concerning smallholder systems (van Noordwijk *et al.* 1997a). Farmer management aimed at increasing 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. Very little is known about the shape of the family of curves describing the trade-off function, or even whether a trade-off always exists (Figure 2). If the relationship is convex to the origin, even modest productivity gains cause great loss of biodiversity. If the relationship is concave, biodiversity loss is relatively slow for initial increases in productivity. In this case, raising productivity to an intermediate level may involve a modest trade-off in terms of biodiversity loss. Thus, two of the most important research questions regarding land use alternatives in Sumatra are: (1) what is the shape of this family of curves? and (2) what factors influence the biodiversity of these complex, multistrata systems as productivity of their components increases?

IS THERE A TRADEOFF BETWEEN PROFITABILITY AND POVERTY ALLEVIATION?

For the rubber and oil palm systems that were evaluated, total time-averaged labor requirements are similar, ranging between 100 and 150 person-days per ha per year. Harvesting labor is the biggest component in these systems. Because of lack of pronounced seasonality in much of Sumatra, harvesting of rubber and oil palm can go on roughly 10 months a year. At the opposite extreme, neither of the extractive activities (community-based forest management and commercial logging) nor the upland rice / bush fallow rotations can provide many employment opportunities.

If they really are more profitable than smallholder alternatives, all the large-scale systems involve tradeoffs with smallholder production incentives and household food security, since such projects often displace local smallholders with little or no compensation. (In the case of large-scale logging, there also is a tradeoff with employment creation.) The potential profitability of some tree-based alternatives for smallholders (viz., rubber agroforests planted with clones) appears to be comparable to large-scale estates and superior to 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 policymakers' concerns with potential profitability and smallholders' production incentives. It also suggests that policy concerns with 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.

Despite the conventional wisdom, the prevailing faith in economies of scale in production of so-called 'plantation' commodities receives little (if any) support from agricultural economics (Hayami 1994; Tomich, Kilby and Johnston 1995). This is, nevertheless, an empirical question that requires further investigation in the next phase of ASB research. Unlike production, marketing and processing of primary products often are characterized by increasing returns to scale. This is the case for three of the most important land use alternatives--rubber, pulp, and oil palm--in Sumatra. The natural rubber industry in Southeast 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 conventionally has been viewed as an estate crop in Southeast Asia (but not in Africa) because of its perishability. Outgrower schemes, contract farming, and other institutional arrangements all can help reduce transactions costs in linking efficient smallholder producers with efficient large-scale processors.

There are, however, some important institutional questions that must be addressed to enable widespread adoption of profitable alternatives by smallholders (Tomich *et al.* 1998a). The main concerns include problems in planting material supply, depressing effects of government restrictions on marketing and international trade on development of smallholder oilpalm and timber-based alternatives, and capital market imperfections (lack of credit and interest rates well above the social price of capital) that may constrain smallholders' nutrient purchases for cassava production, use of clonal rubber planting material, and certainly are a barrier to smallholder oil palm. And, in most cases, 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. The damar agroforests in Krui in Lapung exemplify this situation. Although developed and managed by smallholders for over a century, this land recently was classed as State Forest Land. A breakthrough came in this particular case with the former Minister of Forestry's decision to declare the damar agroforest as a 'Special Use Zone' (Kawasan dengan Tujuan Istimewa; KdTI) recognizing farmers' rights to manage these agroforests and enjoy the benefits derived from them. It is hoped that this approach can develop into a prototype for addressing this serious institutional problem.

AGRONOMIC SUSTAINABILITY

Agronomic sustainability refers to long-term production stability 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 seven components of agronomic sustainability (Weiss 1998). Although it has not been possible to arrive at a single summary indicator for agronomic sustainability, it has been possible to use a mix of indicators of this multidimensional issue to assess the major land use systems of Sumatra's peneplains. These assessments cluster in three main categories (Tomich *et al.* 1998a, part III):

- soil structure and biology, including adequate soil organic matter
- nutrient balance
- crop protection from weeds, pests, and diseases

Put simply, the original ASB perception of the problems in the tropical forest margins was that 'poverty causes people to migrate to the forests, but they don't know how to manage the soils, forcing them to move on and open new forest, leaving a trail of degraded lands behind'. This perception of the problems led to the 'intensification hypothesis' that 'intensifying land use as an alternative to slash and burn can reduce deforestation and reduce poverty' (van Noordwijk *et al.* 1995). However, there is little evidence from subsequent research that the original perception holds true in Sumatra. Unsustainable systems used by recent migrants are mostly found under the government sponsored transmigration programs, which are planned at government level, rather than due to spontaneous poverty-driven land-use practices (Tomich *et al.* 1998a). Small remnants of 'shifting cultivation' remain in Sumatra, but largely in the form of settled fallow rotation, and these do not lead to land degradation and people moving on to new forest margins.

All the tree-based systems (smallholder agroforests and monoculture as well as large-scale plantation monoculture) are agronomically sustainable in the sense that most farmers can manage the problems they currently face (Table 3). On the other hand, shortening of fallow rotations from 10 years or more to less than 5 years with rising land scarcity is undermining sustainability of shifting cultivation, which has been disappearing anyway as population pressure increases in Sumatra (van Noordwijk et al. 1995a). 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 since the collapse of the Indonesian currency over the past 12 months, which may reverse the long-term decline in shifting cultivation (Tomich *et al.* 1998, Part VI). Indeed, because of the collapse of the Rupiah in mid-1997 (just after these studies were conducted), potential profitability of many tree-based systems has increased substantially, which boosts incentives for forest conversion by smallholders and large-scale operators alike.

Continuous cultivation of cassava does not appear sustainable on this land because of depletion of nutrients and of soil organic matter. On these soils, marginal revenues from fertilizer applications to cassava often 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.

Table 3. Plot-Level Agronomic Sustainability

Description	Scale of operation / evaluation	Plot-level agronomic sustainability	
		Overall rating	Main sustain-ability issues
Natural forest	25 ha fragment / 1 ha	1	
Community-based forest management	35,000 ha common forest / 1 ha	1	
Commercial logging	35,000 ha concession / 1 ha	0.5	C
Rubber agroforest	1-5 ha plots / 1 ha	0.5	C
Rubber agroforest w/ clonal planting material	1-5 ha plots / 1 ha	0.5	C,K,W,P
Rubber monoculture	1-5 ha plots / 1 ha	0.5	C,W,P
Oil palm monoculture	35,000 ha estate / 1 ha	0.5	C,Fert
Upland rice / bush fallow rotation	1-2 ha plots / 1 ha	0.5	Fert,P
Continuous cassava degrading to *Imperata*	1-2 ha plots within settlement project / 1 ha	0	C,Fert,W

Legend:
Overall rating:
1 = no major problems; 0.5 = problems that farmers can manage;
2 0 = problems beyond what farmers can manage
Main sustainability issues:
C = soil compaction; K = potassium balance; Fert = cost of nutrients; W = weeds
P = pests or diseases ;
Source: Tomich *et al.* 1998a.

FROM PLOT-LEVEL SUSTAINABILITY TO SUSTAINABLE LANDSCAPE MOSAICS

To obtain estimates of regional or global impact directly from measures like those described here, which are estimated per ha, it is necessary to assume independence--and hence additivity--across space. This assumption is reasonable for some measures (e.g., carbon stocks), but it is only a first order approximation for others. Among these measurements, biodiversity is the most sensitive to scaling issues. For example, this research provides only a rough answer to the question of how much biodiversity will be lost for each hectare of forest converted to another land use. The main methodological gaps concern scaling over space and over time. As one samples biodiversity over larger and larger areas of a particular ecosystem, the number of additional species observed will increase, but at a decreasing rate. Some of the species found in each new sample plot already will have been encountered in previous plots; only a fraction will be observed for the first time and this fraction tends to decline as the sample size increases. This complementarity across space means that one cannot simply add biodiversity values across plots. Nor can the number of species seen on a small study area tell us how much land is needed to conserve those species. If that piece of land were to be surrounded by land under different uses, the number and type of species could change dramatically. These species' long-term survival prospects depend on the extent of their habitat, but this is influenced by the pattern of land cover in the landscape. For example, although the plots of Sumatran rubber agroforests studied so far may harbor half to two-thirds of the biodiversity of an equivalent area of natural forest, it is not known whether the same is true if one were to compare a million hectares of rubber agroforests to an equal amount of natural forest. Even less is known about what happens if these million hectares occur in a mosaic with undisturbed forest patches.

One of the key challenges of future ASB research is to develop methods and to extend existing databases to be able to assess these phenomena at the landscape level. Ultimately, instead of promoting a single 'best' land use system or technology, the most attractive way to achieve the various objectives is likely to come from combinations of complementary land use practices in a given spatial context (van Noordwijk *et al.* 1997). This whole-farm and landscape-level analysis is not feasible now. The land use-specific analysis presented here is a necessary precursor to that work.

FUNCTIONS OF BIODIVERSITY IN LANDSCAPE MOSAICS: UNANSWERED QUESTIONS

Much discussion of biodiversity conservation focuses on global existence values – in other words, preventing extinctions. Much less attention has been given to local functional values of biodiversity (belowground as well as above). Let us put aside, for the moment, legitimate global concerns with extinctions, in order to focus on local, functional roles of biodiversity in landscapes where people seek their livelihoods.

The role of biodiversity at the landscape level is difficult to grapple with conceptually because, while there is a consensus of concern, there is no clear consensus about the basic functions of biodiversity within landscapes that are mosaics of forest fragments and derived land uses. The Policy-makers' Guide of the Global Biodiversity Strategy (WRI et al., 1992, p. v) states that 'The conservation of biodiversity is fundamental to the success of the development process.' Perrings *et al.* (1997, p. 308) are a bit more specific: "What is becoming clear ... is that the sustainability of economic development implies ecological stabilization: the maintenance of the productive potential of ecosystems supplying essential ecological services either by the containment of stress levels or by the promotion of ecosystem resilience through biodiversity conservation." [5] But what does this mean in practice ... over what spatial and temporal scale should we be concerned?

Perrings (1998) has argued that '... the main external cost of biodiversity loss lies in the reduced resilience of agroecosystems in the face of environmental and market shocks.' Should national policy makers worry about loss of these ecological functions in the same way they seem concerned about loss of watershed functions? From a national perspective, how important are the stabilizing functions of biodiversity compared to other pressing national concerns? In contrast to well-recognized watershed functions, the ecological functions of biodiversity in the stability of local production systems have not been articulated clearly. For example, suppose for a moment that a perennial monoculture plantation provides watershed

[5] Perrings *et al.* (1997, p. 307) elaborate as follows: 'Loss of resilience implies a narrowing of the range of environmental conditions in which the system concerned can maintain its productive potential. ... Since all of the general circulation models (of climate change) predict and increase in the range of environmental conditions within which economic and ecological systems will have to function in the future, the loss of resilience in key ecosystems must be a matter for concern.'

services that are indistinguishable from natural forest. What, if anything, would be lost (or gained) on-site from conversion of natural forest to monoculture plantation in terms of stability of the production system? One tangible example is the increased risk of pest and diseases. Chinese officials are reconsidering monoculture plantations in watershed protection forests because of infestations of pine nematodes and other pests (The Economist, 9 January 1999, p. 75).

Perhaps an even more important question is what effect (if any) would conversion from natural forest to a monoculture plantation have on the level and stability of production off-site on land adjacent to the monoculture plantation? Would neighbors face fewer production options because of loss of wild seed sources? ... new difficulties in managing fallows or soil nutrients? ... would they suffer more (or fewer) outbreaks of pests and diseases of crops and livestock? ...or would familiar pests and diseases be replaced by exotics? More generally, how much (and what types) of biodiversity is needed within landscapes to maintain productivity and stability?

CONCLUSION: MANY QUESTIONS, FEW ANSWERS

Because any use of natural forests results in biodiversity loss, there are clear tradeoffs between global concerns with biodiversity conservation and local and national development objectives that involve forest extraction or conversion. If we take a narrow view of sustainability, focusing at the plot level and ignoring the broader ecological context, the data for Sumatra suggest little cause for concern. But are there threshold effects of biodiversity loss on stability of production such that land use change that could be sustainable for a limited number of actors on a limited area would be an ecological catastrophe if everyone did it? Work is only beginning to 'scale-up' to the landscape level in assessments of the effects of biodiversity loss. It is not yet feasible to go beyond plot-level measures of richness and to scale-up to examine the functional roles of biodiversity at the landscape level. Indeed, we do not even know the appropriate scales – in space and in time – for assessing the effects of biodiversity loss on stability of production systems. At present, we have very little idea of these functions and of the magnitudes of their effects; hence, we have no basis to assess tradeoffs with other public policy objectives. Perhaps insights from better understanding of the functional roles of biodiversity within plots and across complex landscapes can help guide priorities for measurement.

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