What Drives Deforestation in Sumatra?

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Why a presentation about Sumatra at a symposium on mainland Southeast Asia? A parallel research programme is about to be replicated at sites in Northern Thailand and this is a good opportunity to share experience that may be relevant. The first phase of research in Sumatra has certainly deepened our appreciation of the complexity of the driving forces of land use change and forest conversion. This paper discusses the issues that have emerged from the initial work on these 'driving forces'.

Conversion of tropical forests, regardless of the technique used, leads to a loss of biodiversity and release of stored carbon. Slash-and-burn agriculture contributes to a portion of this global problem of tropical deforestation (Bandy and others 1993). The Alternatives to Slash-and-Burn project (ASB) was formulated to address these issues in various parts of the tropics, since slash-and-burn is practiced by different actors and deforestation is driven by different forces in different places.

Of course, it is inaccurate to equate 'slash-and-burn' with permanent forest conversion and unsustainable land use. Traditional shifting cultivation of foodcrops, as practiced for generations by local people in Sumatra, obviously was sustainable, at least as long as population densities were low enough to allow long fallow rotations. But other land uses involving slash-and-burn, such as continuous growing of foodcrops on fragile upland soils, probably are not sustainable.

The search for 'alternatives' to unsustainable slash-and-burn derives from global problems (climate change due to greenhouse gas emissions; loss of biodiversity), but poverty alleviation, household food security, and other more localized issues are central concerns of ASB too. Since many of the small-scale farmers practicing slash-and-burn worldwide appear to do so because they lack feasible livelihood options, providing them with sustainable land use practices that are viable alternatives to 'slash-and-burn' could reduce deforestation.

Universal alternatives probably do not exist. Before specific alternatives can be formulated and tested, however, a better characterization and diagnosis of the forces driving deforestation is needed, combining perspectives from many groups including local people, non-governmental organizations, and policymakers. ASB researchers are drawn from national and international institutions to provide a diversity of disciplinary perspectives (social, economic, agronomic, biophysical, ecological, and environmental).

Indonesia was chosen as one of three countries (along with Brazil and Cameroon) for the first phase of ASB research. The Indonesian benchmark sites in Sumatra were chosen to represent the humid lowland tropical forests of Asia. In Sumatra, as in most places it is found, 'slash-and-burn' is both a *technique* for land clearing and a land use *system* ('slash-and-burn agriculture', 'shifting cultivation').

Slash-and-burn as a technique of land clearing produces visible smoke and invisible emissions of the greenhouse gases: methane, nitrous oxide, and carbon dioxide. Land clearing using fire is extensively practiced in Sumatra by virtually all actors (public and private, large and small-scale) contributing to forest conversion. Slash-and-burn is attractive to all these actors because fire is the cheapest, most effective means to clear land.

In the long dry season of 1994 large amounts of smoke, released by forest fires, slash-and-burn, and other activities in Sumatra and Kalimantan caused problems of poor visibility and air pollution for neighbouring countries (Singapore and Malaysia). A lively debate followed on who were the main culprits (forest concessions, traditional shifting cultivators, recent 'forest squatters') and what can be done to reduce the problem. But in the debate, the focus was on the smoke and thus on slash-and-burn as technique and not on the broader aspects of land-use change. Technical alternatives such as 'slash-and-mulch' or biomass utilization may reduce the most visible part of the problem (and thus improve visibility for air traffic), but may have a small effect on net emissions of greenhouse gasses and no impact on biodiversity conservation. New government regulations were issued ('slash-and-burn practices are no longer allowed...'), but they will be difficult (if not impossible) to implement and do little to address policy objectives regarding rural poverty, global warming, and biodiversity loss. And, it now appears that some large-scale operators have resumed use of bulldozers and other heavy equipment for forest clearing, with the perverse result of much greater damage to the soil than occurs with slash-and-burn.

Characterization of ASB-Indonesia Benchmark Sites

Key objectives of characterization are to *identify* the dominant land uses within benchmark sites for major agroecological zones; to *quantify* the extent of these land uses, including (but not limited to) the extent of unsustainable slash-and-burn agriculture; to *understand* the biophysical, socioeconomic, and policy determinants of changing land uses within benchmark sites; and to *exchange* information across benchmark sites to obtain a global picture of land use patterns at the forest margins.

ASB started in Indonesia with a review of the available evidence and with detailed characterization of a number of 'benchmark areas' in Sumatra, chosen to represent land use change at the forest margins under a range of environmental and socioeconomic conditions. The guidelines for characterization and diagnosis developed at the global level (Izac and Palm, 1995) were adapted to the Indonesian situation through collaboration among members of the ASB Indonesia Consortium. Partners were found for the various aspects of the characterization work through competitive, peer-review of research proposals. Two training courses/workshops were held to strengthen the scientific base of the work on carbon dynamics and greenhouse gas emissions and on participatory rural appraisal methods. At the end of Phase 1 a national workshop was held to review the results obtained and prepare plans for Phase 2. Three sites were characterized in detail, with additional work at two secondary sites, in order to cover the various ecological zones and the major expected gradients within these zones (Figure 1). (See van Noordwijk and others 1995a for a summary of the process and highlights of the results.)

Unsustainable slash-and-burn agriculture is *not* the sole subject of the ASB characterization activities; it is not even the main focus. Characterization activities at benchmark sites are intended to develop as complete a picture as possible of prevailing land use patterns, including forest concessionaires, industrial forest plantations, treecrop estates, and large-scale absentee owners as well as smallholders (Figure 2). Similarly, community and household-level characterization covers the range of smallholder farming systems, including not just shifting cultivation mosaics of upland plots (*ladang*) and bush fallow (*belukar*), but also wet rice (*sawah*), home gardens (*pekarangan*), and mosaics of agroforests and secondary forest.

During the second half of 1994 characterization work was started at the benchmark sites in Sumatra (Figure 3). The Rantau Pandan area in the piedmont zone, neighbouring the Kerinci Seblat national park, has a fairly stable population, without much inflow of migrants, and its land use is dominated by agroforests (mainly 'jungle' rubber) with recent increases in the share of cinnamon (*Cinnamomum*, locally *kayu manis* or *cassiavera*).

The nearby peneplain site in the Bungo Tebo area has at least six groups of actors relevant to ASB: 1. a small number of Kubu hunter-gatherers, 2. local Jambi farmers with jungle rubber as their main land use, 3. government-sponsored transmigrants at Kuaman Kuning, who emphasize foodcrop production, 4. a forest concession held by Gadjah Mada University, 5. 'forest squatters' who entered logged-over forest to plant rubber, and 6. a recently-started oil palm plantation. The dominant land use system at Bungo Tebo and Rantau Pandan is to clear old rubber agroforest or logged-over forest to plant upland rice mixed with young rubber trees. Upland rice or other foodcrops may be grown in the second year, but the emphasis is on establishing the treecrop.

The North Lampung benchmark area in the peneplain has a much higher population density and appears to be an out-migration area. (Data for 1993 indicate Lampung Province had an average population density of 174 persons km^{-2} while the figure for Jambi Province was only 40 persons km^{-2}.) Dramatic changes in population pressure due to the inflow of government-sponsored transmigrants as well as spontaneous migrants over the past 15 years led to disappearance of nearly all forest remnants and to a clear need for development of more sustainable (probably tree-based) cultivation systems to prevent further degradation of the land. The most common land use system in the North Lampung benchmark area has been to clear secondary (or logged-over) forest or bush fallow to plant foodcrops. Government schemes also have promoted sugarcane production. Recently, however, interest is growing in planting rubber, oil palm, and fast-growing timber species.

Traditional 'shifting cultivation' (Figure 4) has virtually disappeared in Sumatra, but all households, whether local farmers, government-sponsored transmigrants, or spontaneous migrants, use slash-and-burn for land clearing. Large-scale operators also use slash-and-burn because it is the cheapest method to clear land.

For small-scale farmers the dominant land use is rubber, mainly in extensive agroforests ('jungle rubber') but with some area in plantation monoculture (Figure 5). Food crops can be grown during the first years, but some (migrant) farmers depend fully on cash income to provide their food. When slash-and-burn is employed by smallholders in Sumatra's peneplains, it often is to clear and replant old rubber agroforests. Transformation of secondary and logged-over forests into agroforests can serve as an example for development elsewhere.

Spontaneous migrants (mainly from Java) have been quick to adopt rubber-based systems similar to those developed and employed by the indigenous Sumatran population since early in the 20th century. Adoption of tree-based systems appears to have been slower on government-sponsored transmigration projects. Soil fertility constraints are most obvious on the sites where transmigrants have attempted continuous foodcrop production. Vertebrate pests (wild pigs, monkeys, rats--even elephants) are perceived by farmers as major constraints to foodcrop production. (Wild pigs also are an important threat to young rubber trees.)

Low-management intensity rubber agroforests ('jungle rubber') allow the survival of a considerable part of the original forest biodiversity (Figure 6). These agroforests are not monoculture plantations. They contain considerable biodiversity since the planted trees are augmented by natural invasion of species from the original forest (Michon and de Foresta, 1992, 1994). Besides ecological advantages, including a forest-like environment that retains biodiversity, rubber agroforests are suited to smallholder management. They involve minimal additional investment in labor and capital and typically are established in conjunction with upland foodcrops. A major issue for further research is whether the introduction of higher-yielding rubber germplasm can allow intensification without much loss of the remaining biodiversity (van Noordwijk and others 1995b).

Analysis of recent remote sensing data and comparison with the vegetation map made in the early 1980's confirms that substantial changes have occurred over the last decade and allows estimates of the net C emission due to land use change in the benchmark areas (Wasrin 1995). A net carbon release of 6.8 and 9.0 t C ha^{-1} yr^{-1} was estimated for the Bungo Tebo and North Lampung benchmark areas, respectively, and a net C sequestration of 3.1 t C ha^{-1} yr^{-1} in Rantau Pandan. Changes in below-ground C stocks due to land use changes are likely to be small in comparison with above-ground changes. However, preliminary measurements suggest agroforests and secondary forests may be significant sinks for methane (Murdiyarso and Husin 1995; van Noordwijk and others 1995a).

The Intensification Hypothesis

Key hypotheses underlying the ASB project can be summarized as: *Intensifying land use as an alternative to slash-and-burn agriculture can reduce deforestation (thereby conserving biodiversity and reducing greenhouse gas emissions) and alleviate poverty.*

Under which conditions does this intensification hypothesis appear to be reasonable; under which ones is it not? Where the hypothesis holds, ASB research can focus on 'agroforestry technology development' to respond directly to farmers' needs. But for conditions where the hypothesis does not apply, technology development alone may not reduce deforestation--and may even accelerate it. Under such circumstances, a much broader range of issues need to be on the research agenda.

The intensification hypothesis can be summarized in a simple relationship: $Y = 1/X$, where Y is the amount of land (ha) needed for a given amount of agricultural output and X is the productivity per unit of land (kg of product per ha) (Figure 7). Comparing rice yields in a traditional shifting cultivation system (say 1.5 and 0.5 t ha^{-1} in two years of cultivation, alternating with 28 years of fallow: this leads to $2/30 = 0.067$ t ha^{-1}) with the 10 t ha^{-1} that is possible in intensive irrigated rice fields (at least two crops of rice per year at 5 t ha^{-1} each, no extended fallow periods), it is easy to see that practicing intensified rice production on irrigated fields instead of shifting cultivation under rainfed conditions gives a 150-fold increase in production per ha and a commensurate reduction of the amount of land needed to feed one person (say, if all nutrients come from rice, 250 kg per person per year) from 3.7 to 0.025 ha. If it is technically possible and economically feasible--two big 'ifs'--intensification can reduce the land needed for agriculture and thereby allow more forest to be conserved.

But can it happen that way? There is only limited scope for sensible expansion of irrigated agriculture in Sumatra (Tomich 1992). And while continuous foodcrop production may be sustainable on soils in Sumatra's uplands from a *technical* perspective, the costs of the necessary inputs may mean these land use systems are not *financially* feasible. So, while continuous-foodcrop systems are of scientific interest, their practical implications as a means for smallholders to earn a livelihood may be quite limited in Sumatran uplands. Large-scale block-planting schemes that were intended to achieve big productivity increases for smallholder rubber have faced similar problems. Moreover, the high costs and administrative intensity of conventional smallholder rubber projects restricted coverage to a small proportion (only 15%) of rubber smallholders in Indonesia (Tomich 1991). Large-scale oil palm plantations and, perhaps, industrial timber estates may have better prospects for profitability. But even institutional arrangements like the Nucleus Estate/Smallholder (NES) model have not enabled participation of a significant proportion of local farmers in these schemes. Constraints on public funding restrict scope for government sponsorship to a much smaller role in Indonesia compared to Malaysia. And the preference of large-scale private investors often is for something akin to a hacienda system, with the result that local farmers are displaced and forced to make a living in other locations, including in some cases, forest margins. Thus, an intensification pathway that concentrates control of land is likely to make it even more difficult to enforce forest boundaries.

Raising productivity of existing agroforestry systems offers another intensification pathway (Hayami 1994, van Noordwijk and others 1995a). For example, a workable strategy to raise productivity of rubber agroforests could play an important role in poverty alleviation in Sumatra. But the rapid spread of rubber as a smallholder crop in Sumatra since the beginning of the 20th century has contributed to large scale forest conversion. Logging concessions, especially of the 1960's-1980's, followed by an inflow of spontaneous settlers attracted by opportunities in rubber and other perennial-based agriculture have completed the process to the point that there is hardly any lowland primary forest left.

Thus probably the most important weakness in the simple model of intensification is the possibility (indeed the likelihood) of migration, either spontaneous or government-sponsored. Provincial-level data for Sumatra show a strong relationship between population density and forest encroachment (Figure 8). An important body of theory predicts intensification will occur only *after* the 'extensive margin' of readily-available, productive land has been exhausted (Boserup 1965, Hayami and Ruttan 1985).

One of the main lessons from Sumatra for the global ASB project is that this applies to all intensification pathways, including agroforestry. Indeed, the experience of the rubber agroforests in Sumatra, which go back to the start of the 20th Century, shows that:

- Treecrop-based systems exist that are economically-attractive alternatives to extensive foodcrop-based systems.

- These 'alternatives to slash-and-burn' help to alleviate poverty.

- But they can speed up rather than slow down the rate of natural forest conversion, especially because they attract an inflow of migrants seeking a share of the economic benefits of these profitable systems.

Other reasons under which the central ASB hypothesis would not hold true are that the driving forces of forest conversion may have little to do with agricultural production. Within smallholder communities, slash-and-burn followed by tree planting is the chief means to establish private claims over (formerly) communal land. This is one reason for the existence of extensively-managed 'jungle rubber'. This 'speculation' appears to be an important driving force, whether the objective is a quick profit or a legacy for future generations. Then there are other uses (logging, mining), engaged in by smallholders and large-scale operators alike, that have no direct link to agricultural production.

In summary, at least three necessary conditions can be identified for validity of the intensification hypothesis:

- First, at the *field level*, the intensification techniques must be ecologically and agronomically sound, socially acceptable, and financially profitable for smallholders.

- Second, at the *community level*, there must be effective monitoring and enforcement of the boundaries of the forest that is to be saved from conversion to other uses.

- Third, at the *benchmark/national level*, attention must be given to reducing the broader forces that drive deforestation. In particular, an inflow of migrants driven by lack of economic opportunity elsewhere can swamp the effects of field level and community level interventions.

In the beginning, ASB mainly emphasized the first requirement (see Van Noordwijk and others 1995a for more on field-level issues). One of the key results of Phase I is the need to incorporate the second and third aspects in the ongoing ASB research in Indonesia.

Driving Forces and Policy Problems

Some of the major forces that could drive deforestation are shown schematically in Figure 9, arrayed around an ellipse that depicts smallholders' production decisions. There are four clusters of phenomena in the figure:

- *field/household-level* phenomena
- 'neighborhood effects' on natural resource management at the *community level*
- driving forces operating at the *benchmark level and above*
- some of the environmental consequences of deforestation

Table 1 summarizes the policy research agenda for the various scales, which differ not only in terms of policy questions but also regarding research methods, policy instruments, and the 'clients' of this effort to produce viable policy options.

Driving forces at the household level

If smallholders contribute significantly to deforestation it is important to know why if one wants to identify options for slowing forest conversion. The ASB Global hypotheses are that conversion of forest by smallholders is driven by (a) food production insecurity and/or (b) poverty. Three groups of smallholders were studied in detail during the first phase of ASB research in Indonesia: local people, spontaneous migrants, and government-sponsored transmigrants. The general features of the livelihood strategies of these three groups are remarkably similar. Although foodcrops are produced after initial forest conversion, food production *per se* does not appear to be the primary objective. Hence, 'food production insecurity' does not seem to be the driving force in Sumatra. And while poverty clearly plays a role as a driving force, for reasons elaborated below, it is clear that certain measures to raise income run the risk of increasing deforestation. Thus, 'poverty' alone is too simplistic and will be replaced later in this section with a number of hypotheses regarding 'push' and 'pull' factors affecting migration.

The twenty ASB-Indonesia researchers who participated in a two-day 'driving forces' working group during the ASB planning workshop in June 1995 endorsed the following two working hypotheses for research in Phase 2. Each is derived from a fact that is obvious at all of the ASB sites in Sumatra: establishing treecrops is the primary objective of smallholders employing slash-and-burn. (Household and community-level characterization in Phase 1 supports these two hypothesis, but it is not possible to discriminate between them with the available data.)

Household-level Hypothesis 1: Profitable treecrops drive deforestation. Deforestation caused by slash-and-burn by Sumatran smallholders is driven by profitable income-generating opportunities, specifically production of treecrops. These tree-based systems are an indirect means of attaining food security, but food production *per se* is not the driving force. Indeed, continuous foodcrop production in these settings may be neither profitable nor agronomically sustainable. The double-headed arrow connecting 'on-site sustainability' with production decisions in farmers' fields in Figure 9 indicates the interaction between smallholders' agricultural practices, on the one hand, and soil organic matter levels, below ground biodiversity, and other field-level phenomena. (The other environmental consequences depicted in Figure 9 are regional--floods, siltation, smoke--or global--biodiversity, GHG emissions; the latter are discussed in the concluding section.)

- **Policy issue: profitability and sustainability of agroforestry systems.** Agroforestry systems, especially ones like Indonesia's agroforests, can be an important component of a sustainable land use mosaic in the uplands. **Is it economically feasible to raise productivity of these smallholder systems? If so, what are the environmental consequences?**

Household-level Hypothesis 2. Planting treecrops to strengthen informal land claims drives deforestation. Deforestation caused by slash-and-burn by Sumatran smallholders also is driven by their desire to establish claims over land. Planting treecrops such as rubber is a well-established mechanism for securing informal land tenure in Sumatra. Where communal forest land has to be cleared before it can be claimed by individual families, this tenure arrangement accelerates forest conversion.

- **Policy issue: land and tree tenure.** Formal and informal institutions affect resource access and property rights and are a key determinant of incentives (and disincentives) for sustainable resource management. **What (if anything) can governments do to better support efficient and equitable functioning of tenure institutions?** These policy questions appear at the community-level in Table 1 since property rights are determined by a variety of institutional arrangements; with local customary practices (*adat*) at least as important as government policy.

Community-level natural resource management issues
Smallholder production decisions are at the center of Figure 9 because of an implicit ASB hypothesis that 'Smallholders account for a significant share of deforestation in Sumatra.' Whether or not this is the case is an empirical question that is being addressed as part of characterization activities that will continue in Phase 2. The answer is likely to depend on the type of forest.

Figure 10 indicates the various types of forest land in Indonesia, including 'village land' and 'government forest land'. It is not surprising that areas where these categories overlap are prone to land disputes. (So too for areas of overlap between transmigrants, who receive formal land certificates, and village lands, where customary tenure prevails.) The main classes of government forest land in Indonesia are:

- conservation forest, national parks, and nature reserves
- (watershed) protection forest
- (limited) production forest
- conversion forest

It may be that smallholders account for much of the conversion at the margins of conservation and protection forests, where (at least formally) large-scale actors are not supposed to operate. In the case of production forest, conversion often occurs because of interaction between logging companies (which build roads) and the smallholders occupying this land as 'spontaneous migrants'.

One important issue is how (or whether) one counts 'conversion forest' as 'deforestation'. 'Conversion forest' is state forest land that is officially-designated for conversion to other uses, usually involving agricultural production (such as transmigration projects and large-scale plantation agriculture). In terms of official policy, this land use change is viewed as an element of economic development strategy rather than (uncontrolled) 'deforestation'. Nevertheless, land use in these large projects often sacrifices much of the forests' environmental functions.

Policy objectives regarding the mix of forests' environmental and production functions and policy problems differ by forest policy domain. One task in the characterization activity for Phase 2 is to attempt to pull together the data on deforestation by forest class for the various actors involved in forest conversion in order to estimate, for example, the relative shares of officially-sanctioned forest conversion and conversion by smallholders to establish treecrops. To a large extent, the 'conversion forest' policy problem rests with a global market failure: lack of mechanisms to compensate resource users (including national governments, companies, and smallholders) for supplying global public goods.

Neighbourhood effects. As emphasized above, smallholders are not the only actors converting forest nor are they the only group employing slash-and-burn in Sumatra. Forest concessionaires, industrial timber estates, treecrop plantations, and transmigration projects all have played a role too. Even if we retain the ASB focus on smallholder land use choices, it is impossible to ignore the potential for impact of the large-scale actors, whether public or private, on smallholders' opportunities and constraints. These *neighborhood effects* are depicted by the arrows running to the smallholder community from 'government projects' (e.g., transmigration projects) and 'large-scale private enterprises' (including forest concessions and treecrop estates) in the 'natural resource management' cluster in Figure 9. Appropriation of large tracts of land for projects effectively increases the local population density (since land that once was accessible now is closed to the local population or its use entails new risks for production and investment). Even the expectation of new projects can accelerate forest conversion as a preemptive strategy to retain control of land. Other implications depend on who the large-scale actors are in the smallholders 'neighborhood'. The following community-level hypotheses are organized by policy domain (see Table 2).

Community-level Hypothesis 1. 'Bufferzone agroforestry' is not sufficient to protect national parks and nature reserves because forest encroachment can be pulled by profitable agroforestry innovations (see migration hypothesis 3 below). Productivity-increasing agricultural innovations that can be applied profitably within the forest margins will accelerate forest encroachment unless clear property rights can be established over forest lands. While clear property rights are necessary to establish incentives for natural resource management, they may not be sufficient to protect all of the functions of parks and nature reserves.

- **Policy issue: Incentive structures and/or regulations that minimize costs of monitoring and enforcement of forest boundaries probably also are required for effective protection of national parks and nature reserves.**

Community-level Hypothesis 2. Management of Production Forests by local communities can be a more effective means of monitoring and enforcing restrictions on forest encroachment by spontaneous migrants ('forest squatters'). Tenure conflicts between concession holders and local smallholders undermine natural resource management incentives for each group, resulting in degradation of forest resources. Under these circumstances, devolution of rights and responsibilities of production forest management (including logging) to local communities would improve natural resource management compared to the *status quo ante*. But the first generation of 'community forestry' reforms may spawn a second generation of environmental problems. By itself, simple devolution of control is not likely to create sufficient incentives for local communities to supply some classes of forest services, including abatement of externalities felt at the regional level (flooding, some types of siltation, smoke that impedes aviation) and global public goods (carbon sequestration and major aspects of biodiversity conservation).

- **Policy issue: What policies and institutional mechanisms are compatible with profitable and sustainable forest management by local people while, at the same time, addressing regional externalities and supplying global public goods?** At this stage, little is known about tradeoffs and complementarities among these multiple goals in the implementation of programmes. Indonesia's agroforests give some cause for optimism that systems exist where there may be complementarities among these objectives--or at least the tradeoffs may not be too large.

Community-level Hypothesis 3. Secure property rights over land or trees are a prerequisite to rehabilitation of degraded production forests (Imperata grasslands) by smallholders. Property rights over all products, including timber, create incentives necessary for local people to do the hard work to re-establish trees on land that formally is classed as production forest but, in fact, is covered by extensive *Imperata* grasslands. Clear rights of ownership of the trees they plant will create incentives for local people to cooperate in fire prevention and to take the lead in fire control. Without local cooperation and community involvement to control fire, sustainable rehabilitation of *Imperata* grassland is extremely difficult (see van Noordwijk and others 1995a, section 5.16).

- **Policy issue: What policies and institutional mechanisms can remove disincentives to reforestation?** The crucial elements probably are: secure property rights and marketing opportunities, which depend on infrastructure investments discussed below.

Forces operating at the benchmark level (and above)

Many of the forces driving natural resource degradation arise outside the forest sector; hence beyond the control of forestry officials. Of the forces operating on deforestation and land use change from the benchmark level up to include national policies (Figure 9), priorities for ASB-Indonesia Phase 2 research may be grouped in two sets: road construction and migration pressure. Each is tied closely to the profitability of forest conversion by smallholders.

Road construction. Secondary roads built by logging companies, transmigration projects, and other large-scale actors contribute to forest conversion by making forest access easier for spontaneous migrants. Construction of main roads (such as the Trans Sumatra Highway) and other infrastructure investments probably have even more powerful effects on peoples' access to forest resources and the marketing links that condition land use choices.

Road construction hypothesis. Patterns of land use change resulting from construction of a major road through a particular site depend on biophysical determinants of production potential (e.g., soil fertility), land tenure, access to markets, and migration pressure.

- **Policy issue. Public investment in infrastructure.** Obviously, it matters where infrastructure is built; but **how do interactions with other factors (markets, property rights, sectoral policies, biophysical characteristics) affect whether an infrastructure investment will be a boon for regional development or an environmental catastrophe?**

Migration pressure. Migration to urban and industrial areas is a major escape route from rural poverty, and may be a direct consequence of improved site accessibility, as shown in Elmhirst's (1995) case study at the North Lampung ASB benchmark site (summarized in van Noordwijk and others 1995a, section 5.13). Links with the rural areas may persist, however, as it is common for young people to spend time away from home, but return at a later stage in the family cycle. Remittances from urban workers to rural family members also are an important link. Such links facilitate capital investment in agriculture (and other rural economic activities). Elmhirst's data suggest, however, that money earned was mainly invested outside agriculture; for example, in sibling education (in- or outside the village). Migration choices at the household level still are poorly understood and deserve priority for further research on forces driving deforestation.

Migration Hypothesis 1. Unsustainable agricultural practices increase migration pressure in the forest margins. Land use practices that create significant negative externalities at the watershed level (siltation, flooding, etc) and, thereby, significantly undermine land productivity, will contribute to migration. Under some circumstances, it can be true that 'Alternative production techniques that maintain or enhance soil fertility and diminish weed invasion will prolong the productivity of recently cleared land, thereby reducing forest encroachment' (ASB Global Hypothesis on Food Security/Human Welfare). However, this is not always the case: compare migration hypotheses 2 and 3 below.

Migration Hypothesis 2. Sustainable productivity increases in irrigated lowlands reduce migration pressure in the forest margins. Some productivity-increasing agricultural innovations (for example new rice varieties for irrigated lowlands) should unambiguously reduce forest encroachment because they expand income-generating opportunities for the rural population but cannot be applied profitably in the forest margins.

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Migration Hypothesis 3. Upland productivity increases (including agroforestry innovations) increase migration pressure in forest margins. Productivity-increasing agricultural innovations that can be applied profitably within the forest margins will accelerate forest encroachment unless clear property rights can be established over forest lands (see community-level hypotheses 1 and 2 above.)

Migration Hypothesis 4. Growth of employment opportunities in other sectors is the most important force reducing migration pressure in the forest margins of Sumatra. Expansion of employment opportunities in manufacturing and services, which depends mainly on sound macroeconomic management, has greater potential to reduce forest encroachment by smallholders than sectoral policies in agriculture or forestry. Of course, this result depends on the structure of the economy. Industry's share of GDP surpassed agriculture in 1992 (Tomich 1992) and export-oriented manufacturing now is the engine of growth in the Indonesian economy. The effect of growth in other sectors on migration pressure in the forest margins would be much less if (a) industrial growth were stagnant or (b) agriculture dominated national income and employment generation today as it did only 25 years ago.

- **Policy issue. Macro-micro links affecting migration and marketing.** Macroeconomic policies affect households' livelihood options and, thereby, reduce (or intensify) forces that push migrants to forest margins; macroeconomic, trade, and sectoral policies also affect resource management decisions once they get there. Migration flows influenced by these policies can swamp capacity of technical solutions and local institutions to cope. **What macroeconomic regimes are compatible with improved natural resource management by households? When is this hopeless?**

Conclusion: Integrating Biophysical, Land Use, and Policy Research

The preceding section was devoted to analysis of the forces that link policy choices to land use change. But we also need a comprehensive set of biophysical measurements to understand the "who cares" question: are the consequences of these land use changes big or little? When we know how big the differences are among environmental consequences of the various land use systems (and we already have a good idea), we will have a basis for identifying the major opportunities to make a difference and, hence, to provide a more precise focus for priorities for policy research.

Except for biodiversity assessment and measurement of certain regional externalities, methodological foundations and research teams for key biophysical indicators were established in the first phase of ASB work in Indonesia. Planning is going on to identify the biophysical measurements that deserve priority for replication in Phase 2 and to clarify where additional work will focus. With the Centre for International Forestry Research (CIFOR) joining as an active partner in the ASB-Indonesia consortium for Phase 2, we now have the basis to begin biodiversity assessment. All three of the ASB global hypotheses can be linked directly to land use changes and have been adapted to the Sumatran benchmark sites. The revised hypotheses are:

ASB-Indonesia hypothesis on food security/human welfare: Continuous, intensive foodcrop production is not agronomically sustainable in the forest margins of Sumatra while perennial-based systems (including agroforests) are sustainable and offer profitable alternatives for smallholders. Soil organic matter (SOM) measurements are the key biophysical indicator for agronomic sustainability.

ASB-Indonesia hypothesis on global warming: Major land use systems in Sumatra differ significantly regarding greenhouse gas emissions and sink strength. Specifically, complex agroforests, industrial timber estates, and treecrop monoculture sequester more carbon than foodcrop-based systems, thereby reducing net greenhouse gas emissions as a result of deforestation in Sumatra. Measurements of greenhouse gas emissions and sink strengths and measurements of biomass (above- and below-ground) are the key biophysical indicators for global warming.

ASB-Indonesia hypothesis on biodiversity conservation: Major land use systems in Sumatra also differ significantly regarding biodiversity. Specifically, complex agroforests preserve much greater biodiversity than other land use alternatives at the forest margins (including industrial timber estates, treecrop monoculture, and foodcrop-based systems) thereby reducing biodiversity loss as a result of deforestation. A key question is how much of the existing biodiversity can be maintained while productivity is increased through introduction of higher-yielding germplasm in complex agroforestry systems, such as rubber agroforests. Work to develop indicators of the biodiversity of various groups (plants, soil microorganisms, etc.) will begin in Phase 2.

The ultimate goal is to obtain a comprehensive set of estimates of these biophysical parameters for the major land use categories for the benchmark sites in the peneplains and the piedmont zone of Sumatra. For some biophysical indicators, it may be necessary to look more closely at variation resulting from elevation, soils, climate, and other factors. Particular attention needs to be given to developing clear operational definitions for forests, agroforests, plantations, and other tree-based systems. Rubber agroforests--a category covering millions of ha in Sumatra--are a candidate for special attention.

Policy research is integrated with these measurements of changes in carbon pools, greenhouse gas emissions, biodiversity loss, and other biophysical outcomes of land use change at the ASB-Indonesia benchmark sites and with efforts to identify opportunities for improvements in indigenous production systems. Taken together, these activities provide an opportunity to quantify policy problems and tradeoffs at the landscape level and to identify meaningful policy recommendations. Available data indicate that alternative land uses at the forest margins differ significantly in their ability to substitute for forests as sources of environmental externalities: biodiversity conservation, carbon sinks, and soil and water conservation. Complex agroforests, in particular, approximate a number of these forest functions. While conversion of primary forest has the major effect on the supply of forest functions, the resulting land uses also matter a great deal for the supply of environmental externalities. The environmental implications of the mix of forest and derived land uses and the forces driving these land use choices are a major focal point of Phase 2.

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Captions for figures

Figure 1. Landscape ecology of Sumatra and transect through ecological zones on northeast sid(of the Barisan mountain range.

Figure 2. Major groups of land users.

Figure 3. Ecological zones of Sumatra and ASB research sites.

Figure 4. Fallow rotation systems, including traditional shifting cultivation.

Figure 5. Tree-based systems ranging from agroforests, which begin with intercropped annuals, to tree monoculture.

Figure 6. Comparison of plant biodiversity of primary forest, rubber agroforest, and rubber monoculture.

Figure 7. The amount of land need per unit output is the inverse of the yield per hectare.

Figure 8. Relationship between population density and 'forest damage' (percent of state forest land that is deforested), based on RePPProT (1990) and Haeruman (1992).

Figure 9. Driving forces of deforestation and other changes in land use/land cover, with some c the environmental consequences.

Figure 10. Forest land use categories in Indonesia. The area of overlap between village forests and state forest land is a zone of debate and often of contradictory resource management incentives.