

Analysis

Upland agricultural and forestry development in the Amazon: sustainability, criticality and resilience

Emmanuel Adilson S. Serrão^a, Daniel Nepstad^b, Robert Walker^{c,*}

^a CPATU / EMBRAPA, Trav. Eneas Pinheiro s/n, Belem, Para, Brazil 66095-100

^b Woods Hole Research Center, P.O. Box 296, Woods Hole, MA 02543, USA

^c Department of Geography, Florida State University, 358 Bellamy Building, Tallahassee, FL 32306, USA

Received 31 March 1995; accepted 24 August 1995

Abstract

This paper provides an overview of agricultural and forestry development in the Amazon basin, and presents and discusses the main land use systems in evidence today in that region. These are logging, shifting-cultivation and ranching. The issue of sustainability is addressed, and current Amazonian land use is interpreted in light of ecological impacts and long-run viability. Also considered are the ecological notions of criticality, endangerment, impoverishment and resilience. After addressing the threats of land use encroachment to the forest resource base, the paper identifies sufficient conditions for regional ecosystem sustainability and considers desirable technological and policy-oriented responses in this regard. The paper concludes with a call to future research on land use systems, noting, however, that the greatest challenge is the design of equitable government policy for the adoption of sustainable systems.

Keywords: Amazon basin; Agricultural development; Forestry development; Land use; Criticality; Resilience; Sustainability

1. Introduction

Tropical forests constitute an ecological biome of global importance to carbon cycles, patterns of climate and biodiversity. These ecosystems make up 40 percent of the terrestrial stock of plant biomass, and they are extremely productive, yielding between 30 and 42 percent of the terrestrial total of net primary productivity (Whittaker and Likens, 1973; Malin-greau and Tucker, 1988). It should come as no surprise then that tropical deforestation is implicated

in processes of global environmental change. Much of the discussion in this regard has focused on the controversy of CO₂ emissions and accumulation in the atmosphere (Schneider, 1989). Forest vegetation stores large quantities of carbon as biomass, and its exchanges of CO₂ with the atmosphere are an order of magnitude greater than the contribution from human activities (Dickinson, 1989; Houghton and Woodwell, 1989). On the other hand, deforestation releases between 1.6 billion tons of carbon each year, an amount that is about 30 percent of the flux associated with fossil fuel consumption (Houghton, 1995). Moreover, tropical forests exert an important influence on regional climate (Shukla et al., 1990; Salati and Vose, 1992) and may contain up to two-

* Corresponding author. Tel.: (1-904) 644-8379; Fax: (1-904) 644-7360; e-mail: rwalker@garnet.acns.fsu.edu

Table 1
Deforestation in the legal Amazon through 1990

State	Original forest area (km ² [in thousands])	Deforested area (km ² [in thousands])		Deforested area (percent of area originally in forest)		Rate of deforestation (km ² [in thousands]/year)	
		1978	1991	1978	1991	1978–1988	1989–1991
Acre	154	2.5	10.7	1.6	6.9	0.6	0.4
Amapá	132	0.2	1.7	0.1	1.3	0.1	0.4
Amazonas	1561	1.7	20.8	0.1	1.3	1.6	1.0
Maranhão	155	63.9	94.4	41.2	60.7	2.7	0.7
Mato Grosso	585	20.0	86.5	3.4	14.8	5.1	2.8
Pará	1218	56.3	146.0	4.6	12.0	7.3	4.9
Rondônia	224	4.2	34.2	1.9	15.3	2.3	1.1
Roraima	188	0.1	4.2	0.1	2.2	0.2	0.4
Tocantins/Goiás	58	3.2	23.4	5.4	40.3	1.7	0.4
Amazônia Legal	4175	152.1	421.6	3.6	9.9	21.6	11.1

Adapted from Fearnside (1995).

thirds of the 10–15 million species existing in the world today (Williams, 1989).

Some deforestation is necessary for agricultural development, as was the case in many temperate countries during early phases of economic growth (Cronon, 1983; Walker, 1994). Nevertheless, a sizeable component of the current rate of conversion is attributable to an excessive intrusion of the extensive margin of market agriculture into forestry land use and long-fallow farming. These intrusions have been associated with government actions such as the provision of subsidies and infrastructure (Repetto and Gillis, 1988), with contractual failures between loggers and resources owners, including states (Walker, 1987; Walker and Smith, 1993), and with the use of inappropriate farming technologies and systems (Janzen, 1973).

The role of incentives and subsidies on cattle ranching in the Brazilian Amazon has been well documented. Between 1974 and 1979, the Amazonian development agency (SUDAM) subsidized a considerable number of large, corporate ranching operations. Partly as a consequence, the deforestation rate in Brazil grew from 8000 to 10000 square kilometers annually in the 1970s (Mahar, 1988) to 35000 square kilometers in the 1980s (Fearnside, 1989). Twenty-four million hectares of forest were cleared in the Brazilian portion of the basin alone by 1988 (Skole and Tucker, 1993). Although current rates of land clearance have slowed with the reces-

sion in Brazil and changed development policies, a huge area of the original forest is cleared, an area approximately seven times the size of Costa Rica (see Table 1). The Brazilian Amazon contains perhaps 10 million hectares of pasture, about half of all pasture in Latin America (Serrão and Toledo, 1992).

Given the importance of Amazonia to the global environment, sustainable use of resident ecosystems is of great importance. The purpose of this paper is to address agricultural and forestry development in the Amazon basin, both of which exploit the region's renewable resources. The paper is organized as follows. Section 2 provides an overview of this development and presents the main land use systems in evidence today. Section 3 considers the sustainability of these various systems and the concepts of criticality and resilience. Section 4 outlines the policy context for sustainable development in the Amazon basin and Section 5 concludes the paper.

2. Agricultural and forestry development

Agriculture and forestry development in the Amazon have been driven both by geopolitical concerns (Hecht, 1985) and by socioeconomic factors linked to the demand for food and fiber. One dramatic outcome of this development process has been considerable change—especially in the last 30 years—in land cover from tropical moist forest to human-

dominated systems and to forms of secondary vegetation (*capoeira*) following field and pasture abandonments. Although farming successes have occurred, the consensus is that agricultural exploitation of the Amazon basin has not led to widespread social gain (Browder, 1986; Mattos and Uhl, 1994).

A typical resource-using agent in the Amazon currently pursues a strategy of portfolio diversification of economic activities in order to spread the risks of an extremely variable environment (Homma et al., 1994b; Walker et al., 1994). For this reason, distinctions between shifting cultivators, loggers and ranchers may be somewhat artificial. Nevertheless, individual households often focus on a primary activity, despite diversification both on and off farm; we refer to these activities as “land use systems” (LUSs). The most important LUSs contributing to recent deforestation in the Amazon have been, in ascending order of importance: logging, contributing about 10 percent; shifting agriculture, contributing between 30 to 35 percent; and extensive cattle ranching whose contribution has exceeded 50 percent. Millions of hectares of degraded land have been abandoned in the wake of ranching operations, considered by many to be the premier factor of environmental change in Amazonia (Downing et al., 1992).

Logging, shifting cultivation and ranching are linked in a dynamic process driven by frontier movement into old-growth forest. This process manifests a spatial pattern of land cover ranging from settled and open urban spaces to long-fallow agriculture mixed with selective logging. Although there are many variations to the sequencing of the developmental land dynamic, loggers often represent the most advanced front of resource exploitation. Following them come shifting cultivators who enter selectively logged areas abandoned by the loggers. These farmers practice diversified agriculture with a substantial annuals component, but they also clear portions of their land to pasture as an investment strategy (Homma et al., 1993). Large land owners often aggregate such small holdings, through market exchanges or the exercise of political power, into large ranches with little diversification beyond basic food production for ranch hands (Rudel, 1993). Small producers also aggregate land holdings to form pasture and cattle herds (Homma and Walker, unpublished data).

This process of land use change carries with it

considerable environmental impact which has been well documented. These impacts are local, regional and even global in nature; they include soil and water degradation; loss of nutrients, biomass and biodiversity; climate changes; and increased frequency and severity of wildfire. In a transect from primary forest to settled area, typically associated with roads (Fig. 1), impacts grow in severity, reflecting the intensity of human efforts to alter the natural land cover. With respect to current circumstances in Amazonia, small producers using slash-and-burn technology are concentrated along roads opening relatively new frontiers such as the Belém–Brasília, Transamazônica and Cuiabá–Porto Velho Highways. Typically, ranching operations are found near urban centers in the remote regions these highways traverse, and along older and settled stretches of road. Much of the logging activity takes place beyond the forest margins occupied by the small producers.

It is necessary to draw a distinction between the slash-and-burn activities of small producers, typically migrants and indigenous peoples practicing long-fallow agriculture. The farming systems of indigenous peoples, practiced at low population densities and with specialized ecological knowledge accumulated through the ages, are thought to be relatively sustainable, as compared to the practices of the migrants (Vayda, 1979; Hames and Vickers, 1983; Dove, 1986; Posey and Balée, 1989; Moran, 1990). On the other hand, small producers are often held responsible for excessive forest clearance. In an oft-told story, small farmers follow loggers and roads into primary forest and engage in shifting cultivation. As soil fertility declines, they allegedly move to new parts of the forest in a never-ending cycle of forest destruction and soil degradation (Schmithusen, 1977; Leslie, 1980; Myers, 1980; Office of Technology Assessment, 1984; Walker, 1987; Repetto and Gillis, 1988; Fearnside, 1993; Walker and Smith, 1993). As many have noted, much Brazilian deforestation is accounted for by large ranches (Browder, 1988; Mahar, 1988; Fearnside, 1993), while slash-and-burn operations may be more stable than commonly thought (Walker et al., 1993).

The attribution of deforestation *culpability* to the various agents involved is a controversial and unproductive task. We view the land cover conversion process in Amazonia as a dynamic series of stages,

ENVIRONMENTAL IMPLICATIONS OF DEFORESTATION

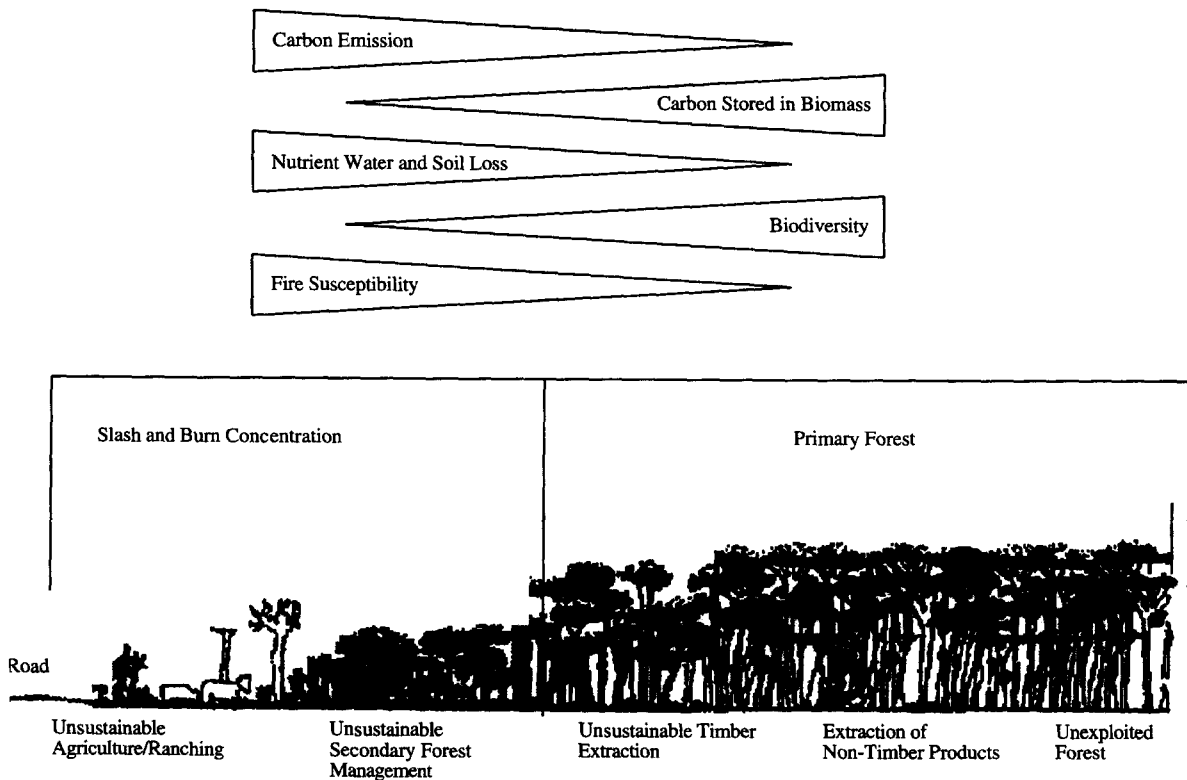


Fig. 1.

driven by structural necessities in the aggregate economy and integrating the activities of many economic agents. Agricultural use of land is a profound human necessity, particularly in developing countries with large and growing rural populations. Consequently, the human habitation and development of tropical forest areas is likely to carry on with certain in-built demographic inertia. While stopping continued land clearance is politically impossible in most tropical countries, mitigation is feasible at least in the short run through the development of alternative LUSs that economize on land and soil resources. The great ecological challenge to scientific, institutional and political organizations in the tropical world today is the identification and implementation of such relatively *sustainable* uses of agricultural and forest resources.

3. System change and sustainability

3.1. Sustainability, criticality and resilience

Sustainability is not a myth, and must be activated into a development paradigm in tropical forest areas. In the interest of advancing this discourse, we put forward the following definitions. Following Kasperson et al. (1995), we define *environmental sustainability* as the circumstance in which nature–society relations are so structured that the environment can support the continuation of human use systems, an adequate level of human well-being and the preservation of options for future generations over long time periods. An important component of this is *land use sustainability*; a land use is *sustainable* when its productivity is economically adequate, and the land

use itself is ecologically acceptable, socially just and culturally viable (National Research Council, 1993).

In the Amazonian situation, neither form of sustainability as defined is consistent with highly mobile agriculture leading to long-term field abandonments, either by small producers of rice, corn and beans, or by large-scale ranchers. Moreover, the maintenance of human well-being is contradicted by the proletarianization that may attend the aggregations of slash-and-burn properties into large ranches under the so-called *colono* system of frontier development. Finally, logging without planned rotations represents an untenable liquidation of the resource base that is unsustainable by definition. *Sustainable* agricultural development represents a form of human agency that maximizes both environmental and land use sustainability along agro-technical, economic, ecological and social dimensions, among others

(Homma, 1991). As such, sustainable development involves a complex societal equilibrium in which economic and demographic forces are confronted and mitigated by ecological awareness and constraints. The dominant forms of land use in the region, often simple to implement and in little need of advocacy or government support, meet certain sustainability criteria, but not all. Presented in Table 2 are sustainability potentials associated with these systems (Serrão and Homma, 1993).

Sustainability cannot be understood without reference to *environmental criticality*, a state of nature in which the extent and/or rate of environmental degradation passes a threshold beyond which current human use systems or levels of social welfare may be supported, given society's ability to respond (Kasperson et al., 1995). Sustainability remains intact so long as a state of environmental criticality has

Table 2
Sustainability of current land use systems

System and region	Present sustainability level			
	Agronomic	Ecological	Economic	Social
Non-timber extraction; Acre, Amapá, Rondônia, Pará	Very high	Very high	Low	Low
Timber extraction; Pará, Rondônia, Mato Grosso	Low	Low (?)	Low	Low
Upland shifting agriculture; Amazon region	Low/medium	Low	Low/medium	Low/medium
Upland perennial and semi-perennial crop production; Pará, Rondônia, Mato Grosso	Low/medium	Low/medium	Low/medium	Medium
Agroforestry systems (Nippo-Brazilian type); Pará	Medium/high	Medium/high	Medium/high	Medium
Cattle production on first-cycle forest-replacing open pastures; Amazon region	Low	Low	Low/medium	Low
Cattle production on second-cycle forest-replacing open pastures; Amazon (Pará, Mato Grosso, Tocantins)	Medium	Low/medium	Low/medium	Low/medium
Cattle production on forest-replacing, pasture-based agrosilvopastoral systems; Pará	Medium/high	Medium/high	Medium	Medium
Cattle production on native <i>várzea</i> floodplain grassland; Pará, Amazonas, Amapá	High	Medium/high	Medium	Medium
Cattle production on native, well-drained savannah grassland; Amapá, Roraima, Rondônia	Medium/high	Medium/high	Medium	Medium
Cattle production on native, poorly drained savannah grassland; Pará, Mato Grosso, Maranhão	Medium/high	Medium/high	Medium/high	Low

Note: Other regions may have a particular land use system, but at reduced scale.

Adapted from Serrão and Homma (1993).

not been reached. A related notion is *environmental endangerment*, a natural condition less urgent perhaps than criticality, but no less worrisome; the environment is endangered when environmental degradation threatens the continuation of human use in both the short and mid-run (current and next generation). Finally, we refer to a state of *environmental impoverishment* as the condition in which long-run human use and welfare are threatened.

These three measures taken together provide a scale of environmental impact applicable to regional ecosystems. In this regard, the Amazonian situation is worth considering. Presently available knowledge suggests an impoverishment process is underway, but that economic/ecological threats to residents stemming from resource degradation are unlikely in the short to mid-term. This is in large part due to the abundance and inaccessibility of the resource base. A great deal of forest remains in place, and infrastructural development of the region is minimal. In addition, certain LUSs have shown unexpected stability over the short run. Residence times of slash-and-burn agriculturalists, for example, may be much longer than popular images of this farming activity suggest (Walker et al., 1993, 1994). On the other hand, localized instances of endangerment and criticality are frequent. The most notable instances occurring in the Amazon basin are not linked to agricultural and forest land uses, and derive from mining activities and threats to local water supplies and fish populations through mercury contamination.

That Amazonia presently is not endangered due to resource abundance offers little solace, given current land use and demographic conditions, that together contain the seeds of future endangerment. Just what this endangerment represents, and how soon it will be manifested, remain empirical questions, although current rates of LUS expansion and deforestation suggest generational time frames in the unfolding of degradation processes in the Amazon basin. Part of this knowledge-base uncertainty stems from lack of information on *resilience*, the ability of ecosystems to maintain basic structure and function during perturbations, and to recover from them (Kasperson et al., 1995). With respect to current concerns about Amazonia, a key question relates to resilience of the region's ecosystems in the face of human encroachment.

A number of indications exist that the Amazonian upland forest ecosystem is fairly resilient to current uses. Degraded pastures in the northeastern Amazonian county of Paragominas have been shown to accumulate 50–60 tons of above-ground biomass through secondary forest regrowth during the first 8 years following abandonment (Uhl et al., 1988). Even after 7 to 8 cycles of slash-and-burn agriculture involving forest cutting, crop production and field abandonment, secondary forests regrow at a rate of approximately 4 tons of above-ground biomass each year (Vieira et al., 1995). Beyond the recovery of above-ground biomass, secondary forest regrowth gradually recovers the evergreen leaf canopy behavior of the primary forest (Nepstad et al., 1995a). This behavior is important for reducing the flammability of grass and shrub-dominated fields, and for recovery of the dry season flux of water vapor to the atmosphere lost when deeply rooting forests are replaced by shallow-rooted, drought-sensitive pasture grasses (Uhl and Kauffman, 1990; Nepstad et al., 1994). The evaporation of water from Amazonian forests is an important source of the moisture that returns to the land as rainfall (Salati and Vose, 1992). Some native plant and animal populations also recover in secondary forests that emerge on abandoned pastures. One-fourth of forest tree, bird and ant species, and one-half of forest bat species were found in secondary vegetation neighboring remnants of primary forest (Nepstad et al., 1995b).

Against this evidence of upland forest resilience, there is reason to believe that the forest of eastern and southern Amazonia, where evapotranspiration is greater than rainfall for 3 to 6 months per year on average, is vulnerable to displacement by fire-adapted scrub. Indeed, Meggers (1994) has compiled evidence from ceramic charcoal dating, linguistics diversification, sediment dating and charcoal of extensive fires in Amazonia that may have been related to “mega El Nino” events occurring over 100-year cycles in the past. It is possible that reductions of rainfall such as those predicted as a consequence of the replacement of primary forests with pasture and crop vegetation (Lean and Warrilow, 1989; Nobre et al., 1991), and such as we are currently observing in the high frequency and severity of El Nino-related drought, may exceed the capacity of primary forests to retain leaves through dry periods. If rainfall were

to fall below this threshold of “evergreeness,” the resistance of primary forests to fire might be lost, leading to an increase in forest fire and further rainfall reductions (Nepstad et al., 1995a). Given potential positive feedback between deforestation, rainfall reduction and fire, the eastern and southern flanks of Amazonia could develop a high level of endangerment.

3.2. Sustainability conditions

The impoverishment processes currently unfolding in the Amazon basin can be mitigated and ultimately reversed through sustainable agriculture and forestry development. Sufficient conditions to accomplish this goal include deforestation reduction, intensification of current land use, diversification of agricultural crops, increased efficiency in factor utilization, industrial development (agro- and bio-industry) and improved income distribution. Deforestation reduction implies reduced forest clearance, a major factor in ecological impoverishment. Agricultural intensification involves technological adoptions (e.g., use of modern inputs) that reduce the demand for land and, hence, forest clearance. Diversification of crops leads, potentially, to greater income stability for small producers, as does improved efficiency in production factor utilization. Such stability lessens the likelihood of farm failure and therefore reduces the incidence of invasive forest mobility. Industrialization and the achievement of greater social equity through income convergence across wealth classes also enhance the material circumstances of small producers.

Clearly, deforestation reduction is key to the conservation of forest resources. In this regard, use of previously altered land and degraded pastures offers an obvious substitute for new land clearance. Intensification of land use also represents a land and forest conserving measure, as do the production gains stemming from the efficient use of other factors. Resource conservation is maximized by intensification based on human as opposed to physical capital (Homma et al., 1994a). In addition, crop choices can themselves be expanded and modified to minimize environmental disturbance. Considerable scope exists for domestication of native Amazonian plants, very few of which have been adopted, considering that

more than 3000 plants have been domesticated in the world to date. Although not a panacea to environmental impoverishment in the region, agroforestry does provide for some degree of soil resource stability.

Sustainability in the region would also be advanced by industrial development, particularly in food processing. Agro- and bio-industry add value, create jobs and help alleviate rural poverty, perhaps the greatest current impediment to reversing the present degradation trends evident in the region. About 500 000 small producer households practice slash-and-burn agriculture due in part to absence of economic opportunity. Manufacturing-led rural development, with its service spinoffs and backward and forward linkages, would provide employment alternatives for this population. Efficient and competitive markets for production factors (labor, capital, inputs) and agricultural commodities would maximize the employment gains and income improvements of rural industrialization.

Certain of these conditions are beginning to emerge in the Amazon Basin. Although the area affected by timber highgrading may be increasing (Verissimo and Uhl, unpublished data), considerable decline in the rates of deforestation has been observed recently, as is evident in Table 1. In addition, new farming systems seem to show enhanced sustainability features, particularly when compared to agricultural development occurring in the 1960s and 1970s. Fertilized and mechanically renovated cattle pastures that employ new forage species are emerging as a profitable and possibly long-lived production system in degraded and abandoned lands (Mattos and Uhl, 1994). Such systems require enhanced financial and human resources, and are drawing heavily on extension and the knowledge base of appropriate Brazilian agencies.

4. The policy context of sustainability

Increasing the sustainability of agriculture and forestry development in the Amazon Basin will require the maintenance and extension of the current knowledge base, continuing support of agricultural research tuned to the region, policy approaches promoting the adoption of appropriate technology and

informed resident populations. A substantial stock of relevant scientific knowledge has been accumulated to date by government and non-governmental organizations on the soils, vegetation, climate, genetic resources and agrosystem dynamics of the region. Presumably, these data already provide a base for supporting the development and implementation of sustainable LUSs. A knowledge base also exists for production technologies involving forestry (natural forest management, plantation forestry, enrichment of secondary forests, propagation and agroforestry), agricultural systems (polycropping, improved crop varieties, agroforestry systems) and animal production (restoration of degraded pastures, integrated dairy and beef systems). The present knowledge base already indicates approaches to reducing environmental risks associated with continued human occu-

pation and settlement in both completely deforested and logged areas, and at mining sites.

In particular, the best replacement for current slash-and-burn practices in already deforested areas, close to highways, is given by a mosaic of production systems involving mono- and poly-cropping, semi-intensive pastures, agroforestry and social forestry (see Fig. 2). Presumably, the stock of secondary forest along these highway corridors could be maintained in rotational systems for some time, but eventually a phased withdrawal from low-input agriculture should place a component of regrowth under economic/ecologic management for the extraction of non-timber resources, the maintenance of organic recycling pathways, and enrichment with economically valuable plants. In areas that to date have endured only timber extraction (and other forms of

ALTERNATIVE LAND USE SYSTEMS FOR INCREASING SUSTAINABILITY AND CONTAINING DEFORESTATION IN TROPICAL MOIST FORESTS

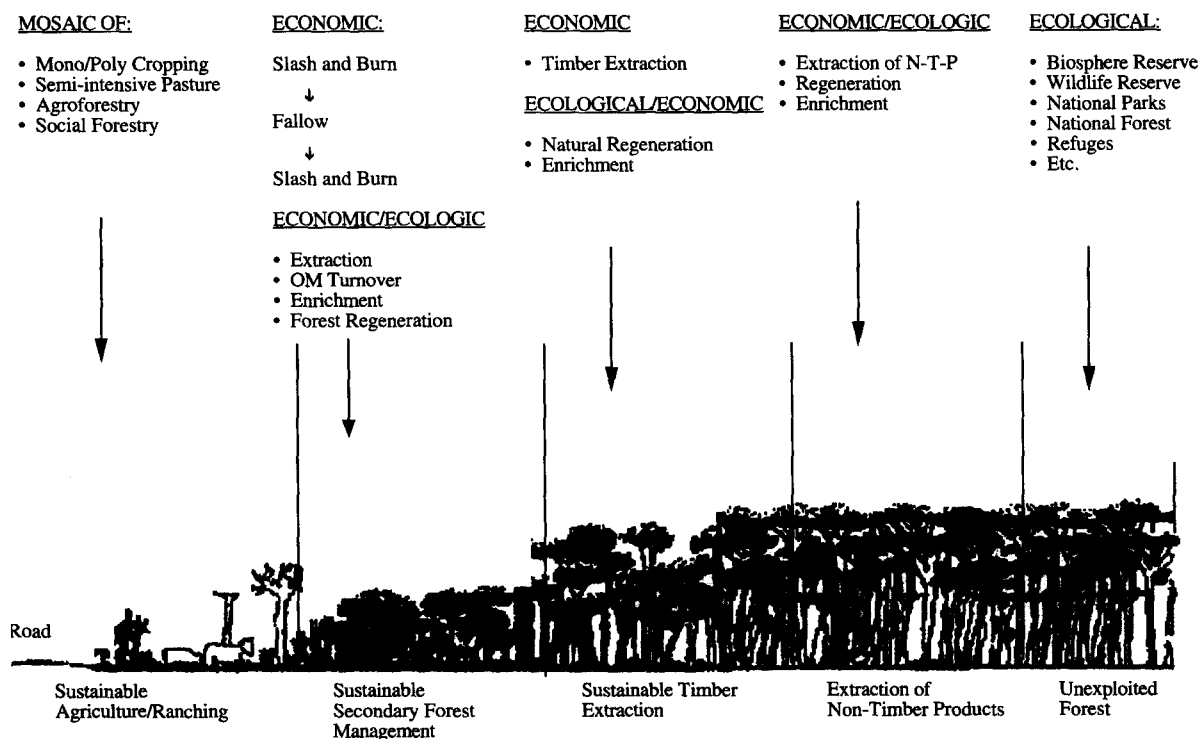


Fig. 2.

resource exploitation), an effort toward sustainability could also be made. For the case of tree harvesting, a rotational concept can be introduced, which takes as a management assumption forest regeneration and continued use over the long run. Areas of intense mineral extraction could be reclaimed and turned over to successional processes of surrounding forest land. Of course, remaining unexploited land of low fertility should be placed under management as ecological/wildlife preserves, national parks and national forests in order to preserve the local, regional and global ecological values of the tropical forest.

The overall strategy of the Brazilian government vis-à-vis natural resources and the environment is to promote effective management of land and forest resources. However, a sustainability outcome is impossible without strong emphasis on the implementation of appropriate agro-ecosystems. This is because demographic and social forces reliant on Amazonian resources will continue to mount. While some information exists about the appropriate form of land use in this regard, much research remains to be done. In addition, certain specific policy questions remain unanswered. In particular, once LUSs best suited for the region have been identified, how can they be efficiently disseminated? Such a question represents an intrinsic challenge, given that the region of concern is relatively undeveloped, rural and populated by individuals with low educational attainment living in highly dispersed communities and farmsteads.

It is critical that sustainable LUSs be implemented in an equitable fashion, and that *agricultural* policy complement all sustainability concerns. It has been argued that policy focused solely on an ecological reserve concept leads to social inequity, since small producers are most likely to suffer losses by the incorporation of remote forest lands into managed ecosystems. The proper mix of taxes and subsidies, on the other hand, can re-allocate land uses at minimal costs, among both small and large operations, in a manner that relieves pressure to convert forest through decentralized decision-making (Homma et al., 1994a).

The achievement of sustainability is not merely a technical question. It will involve coordination and cooperation between public and private sectors of the economy, and active participation on the part of the population at large. For some years to come, the

private sector will have a considerable influence over rural development in Amazonia. Timber harvesting and mining represent roughly two-thirds of the gross domestic product of the State of Pará, and both industries operate with a great deal of autonomy. Although current law requires that highgrading and mining operations be approved by government agencies through environmental impact assessment (EIA), there has been little effect on private sector decision-making.

“Forest Management Plans” generally are not used in rural Amazonia, and mining companies often acquire permission to extract minerals with inadequate planning. A recent EIA for a \$300 million kaolin mine was only 28 pages long. The proposed operation would have involved a 180 km pipeline, the yearly release of 7 tons of sulfuric acid to the environment, and the hourly withdrawal of 600 cubic meters of water from regional aquifers. The mine’s permit was denied after concerns were expressed at a public hearing. The company subsequently prepared a 300-page EIA that responded adequately to public concerns, on the basis of which the operation was approved (Mattos et al., 1994). This example points to the critical importance of an informed citizenry and administrative processes open to public review in promoting sustainable development in Amazonia.

5. Conclusions

The values provided by intact stands of tropical forest are well-established, but the public nature of the goods and services they provide leads to excessive land clearance. From the perspective of optimality, at both national and global scale, it behooves governments and the world community to reduce rates of deforestation in the interests of preserving these important resources from over-exploitation. Evidently, the LUSs currently found in the Amazon Basin, and the dynamic of their interactions, constitute threats to the tropical forest biome.

Sustainability of agriculture and forestry development in the uplands of Amazonia have been low, and the current equilibrium among the agrotechnical, social, economic and ecological components of the regional system is a fragile one. As of yet, the Amazonian regional system is not in a state of

criticality, but a process of impoverishment is clearly underway. That the natural components of Amazonia are fairly resilient should not serve to assuage present-day concerns about the future status of the Amazonian environment. Moreover, much remains unknown about the region's soil resources, vegetation, biodiversity, water, climate and ecosystem interactions.

Alternative LUSs are presently available which, if disseminated widely through the Basin, could increase sustainability and reduce criticality. Nevertheless, more research needs to be done to identify optimal LUS configurations for the many sub-regions of Amazonia. In addition, the knowledge base is itself not sufficient to engender a reversal of degradation processes throughout the region. The greatest challenge, which has remained in many respects unaddressed in this paper and by the public at large, is the design of equitable government policies to encourage the adoption of sustainable systems.

References

- Browder, J., 1986. Logging the Rainforest: A Political Economy of Timber Extraction and Unequal Exchange in the Brazilian Amazon. Ph.D. Thesis, University of Pennsylvania.
- Browder, J., 1988. Public Policy and Deforestation in the Brazilian Amazon. In: R. Repetto and M. Gillis (Editors), *Public Policies and the Misuse of Forest Resources*. World Resources Institute and Cambridge University Press, Washington, DC, pp. 247–298.
- Cronon, W., 1983. *Changes in the Land: Indians, Colonists, and the Ecology of New England*. Hill and Wang, New York, NY.
- Dickinson, R.E., 1989. Amazon deforestation: predicting climate effects. *Nature*, XLI: 343–344.
- Dove, M.R., 1986. The ideology of agricultural development in Indonesia. In: C. MacAndrews (Editor), *Central Government and Local Development in Indonesia*. Oxford University Press, Singapore, pp. 221–247.
- Downing, T.E., Hecht, S., Pearson, H. and Garcia-Downing, C., 1992. *Development or Destruction: The Conversion of Tropical Forest to Pasture in Latin America*. Westview Press, Boulder, CO.
- Fearnside, P.M., 1989. A prescription for slowing deforestation in Amazonia. *Environment*, 31(4): 17–20, 39–40.
- Fearnside, P.M., 1993. Deforestation in Brazilian Amazon: the effect of population and land tenure. *Ambio*, 22(8): 537–545.
- Fearnside, P.M., 1995. Quem está desmatando a Amazônia: os ricos ou pobres? *Ciência Hoje*, 19(143): 26–33.
- Hames, R. and W. Vickers (Editors), 1983. *Adaptive Responses of Native Amazonians*. Academic Press, New York, NY.
- Hecht, S., 1985. Environment, development and politics: capital accumulation and the livestock sector in Eastern Amazonia. *World Dev.*, 13(6): 663–684.
- Homma, A., 1991. Será possível a agricultura auto-Sustentada na Amazônia? In: E.C. Teixeira (Editor), *A Política Agrícola na Década de 90*. Universidade Federal de Viçosa, Minas Gerais, pp. 129–173.
- Homma, A., Walker, R., Scatena, F., Conto, A., Carvalho, R., Rocha, A., Ferreira, C. and Santos, A., 1993. A dinâmica dos desmatamentos e das queimadas na Amazônia: uma análise microeconômica. In: *Congresso Brasileiro de Economia e Sociologia Rural*, 31: 663–676.
- Homma, A., Walker, R., Scatena, F., Conto, A., Carvalho, R., Ferreira, C. and Santos, A., 1994a. Redução dos desmatamentos na Amazônia: política agrícola ou ambiental? In: *Proceedings, The Third International Conference on Systems Integration*, August, 1994, São Paulo.
- Homma, A., Rocha, A., Santos, A., Conto, A., Rodrigues, C., Ferreira, C., Oliveira, P., Walker, R., and Carvalho, R., 1994b. *Dinâmica dos Sistemas de Produção na Transamazônica*. EMBRAPA/CPATU, Belém.
- Houghton, R.A., 1995. Balancing the global carbon cycle with terrestrial ecosystems. In: R. Zepp (Editor), *The Role of Non-living Organic Matter in the Earth's Carbon Cycle*. Wiley, New York, NY.
- Houghton, R.A. and Woodwell, G.M., 1989. Global climatic change. *Sci. Am.*, 260(4): 36–44.
- Janzen, D.H., 1973. Tropical agroecosystems: these habitats are misunderstood by the temperate zones, mismanaged by the tropics. *Science*, 182: 1212–1219.
- Kasperson, J.X., Kasperson, R.E. and Turner, B.L., 1995. *Regions at Risk: Comparisons of Threatened Environments*. United Nations University Press, Tokyo.
- Lean, J. and Warrilow, D.A., 1989. Simulation of the regional climatic impact of Amazon deforestation. *Nature*, 342: 411–413.
- Leslie, A.J., 1980. The government–TNC relationship in tropical timber concession contracts. Paper delivered at: The Asia and Pacific Regional Workshop on Negotiations with Transnational Corporations in the Tropical Hardwoods Sector, Pattaya, Thailand.
- Mahar, D., 1988. *Government Policies and Deforestation in Brazil's Amazon Region*. World Bank, Washington, DC.
- Malingreau, J. and Tucker, C.J., 1988. Large scale deforestation in the southeastern Amazon basin of Brazil. *Ambio*, 17: 49–55.
- Mattos, M.M. and Uhl, C., 1994. Economic and ecological perspectives on ranching in the eastern Amazon. *World Dev.*, 22(2): 145–158.
- Mattos, M.M., de Negreiros, G.H., Nepstad, D.C., Benatti, J.H. and Hehn, I.M., 1994. Uma experiência—uma perspectiva—uma sociedade civil discutindo o futuro da Amazonia. In: *Encontro Brasileiro de Ciências Ambientais*, Rio de Janeiro.
- Meggess, B.J., 1994. Archeological evidence for the impact of Mega-Nino events of Amazonia during the past two millennia. *Climate Change*, 28: 321–338.
- Moran, E.F., 1990. *The Ecosystem Concept in Anthropology*. American Association for the Advancement of Science, Washington, DC.

- Myers, N., 1980. The present status and future prospects of tropical moist forest. *Environ. Conserv.*, 7: 101–114.
- National Research Council, 1993. Sustainable Agriculture and the Environment in the Humid Tropics. National Research Council, Washington, DC.
- Nepstad, C., de Carvalho, C.R., Davidson, E.A., Jipp, P., Lefebvre, P., Negreiros, G.H., da Silva, E.D., Stone, T., Trumbore, S. and Vieira, S., 1994. The role of deep roots in the hydrological and carbon cycles of Amazonian forests and pastures. *Nature*, 372: 666–669.
- Nepstad, D.C., Jipp, P., Moutinho, P., Negreiros, G. and Vieira, S., 1995a. Forest recovery following pasture abandonment in Amazonia: canopy seasonality, fire resistance and ants. In: *Evaluating and Monitoring the Health of Large-Scale Ecosystems*. NATO ASI Series, Springer-Verlag, New York, NY.
- Nepstad, D.C., Vieira, I.C., Moutinho, P.R., Uhl, C.F. and da Silva, J.M.C., 1995b. The ecological importance of forest remnants in an eastern Amazonia frontier landscape. In: J. Schelhas and R. Greenberg (Editors), *Forest Patches in Tropical Landscapes*. Island Press, Washington, DC.
- Nobre, C.A., Sellers, P.J. and Shukla, J., 1991. Amazonian deforestation and regional climate change. *Climate*, 4: 957–988.
- Office of Technology Assessment, 1984. *Technologies to Sustain Tropical Forest Resources*. U.S. G.P.O., Washington, DC.
- Posey, D. and Balée, W. (Editors), 1989. *Resource Management in Amazonia: Indigenous and Folk Strategies*. New York Botanical Garden, *Advances in Economic Botany Monographs*, No. 7, New York.
- Repetto, R. and Gillis, M. (Editors), 1988. *Public Policies and the Misuse of Forest Resources*. Cambridge University Press, Cambridge.
- Rudel, T.K., 1993. Tropical Deforestation: Small Farmers and Land Clearing in the Ecuadorian Amazon. Columbia University Press, New York.
- Salati, E., and Vose, R., 1992. Amazon basin: A system in equilibrium. *Science*, 225: 129–138.
- Schmithusen, F., 1977. Forest Utilization Contracts—A Key Issue in Forest Policy and in the Development of the Tropical Hardwoods Sector. FAO Paper 5, Pattaya, Thailand.
- Schneider, S.H., 1989. The greenhouse effect: science and policy. *Science*, 243: 771–781.
- Serrão, E. and Homma, A., 1993. Brazil country profile. In: *Sustainable Agriculture and the Environment in the Humid Tropics*. National Research Council (NRC), Washington, DC, pp. 265–351.
- Serrão, E. and Toledo, J., 1992. Sustaining pasture-based production systems for the humid tropics. In: T.E. Downing, S. Hecht, H. Pearson and C. Garcia-Downing (Editors), *Development or Destruction: The Conversion of Tropical Forest to Pasture in Latin America*. Westview Press, Boulder, CO, pp. 257–280.
- Shukla, J., Nobre, C.A. and Sellers, P., 1990. Amazon deforestation and climate change. *Science*, 247: 1322–1325.
- Skole, D. and Tucker, C., 1993. Tropical deforestation and habitat fragmentation in the Amazon satellite data from 1978 to 1988. *Science*, 260: 1905–1910.
- Uhl, C. and Kauffman, J.B., 1990. Deforestation effects on fire susceptibility and the potential response of tree species to fire in the rain forest of the eastern Amazon. *Ecology*, 71: 437–449.
- Uhl, C., Buschbacher, R. and Serrão, E.A.S., 1988. Abandoned pastures in Eastern Amazonia. I. Patterns of plant succession. *J. Ecol.*, 76: 663–681.
- Vayda, A.P., 1979. Human ecology and economic development in Kalimantan and Sumatra. *Borneo Res. Bull.*, 11: 23–32.
- Vieira, I.C.G., Nepstad, D.C. and Solomo, R., 1995. A flora Amazônica após de um século de agricultura: o caso da Zona Bragantina. In press.
- Walker, R.T., 1987. Land use transition and deforestation in developing countries. *Geogr. Anal.*, 19(1): 18–30.
- Walker, R.T., 1994. Deforestation and economic development. *Can. J. Reg. Sci.*, 16(3): 481–497.
- Walker, R.T. and T.E. Smith., 1993. Tropical deforestation and forest management under the system of concession logging: a decision-theoretic analysis. *J. Reg. Sci.*, 33(3): 387–419.
- Walker, R.T., Homma, A., Scatena, F., Conto, A., Carvalho, R., Rocha, A., Ferreira, C. and Santos, A., 1993. Sustainable farm management in the Amazon Piedmont. In: *Congresso Brasileiro de Economia e Sociologia Rural*, 31: 706–720.
- Walker, R.T., Homma, A., Conto, A., Carvalho, R., Ferreira, C., Santos, A., Rocha, A., Oliveira, P. and Scatena, F., 1994. Farming systems and economic performance in the Brazilian Amazon. In: *Congresso Brasileiro sobre Sistemas Agroflorestais*. Anais, EMBRAPA, Colombo, pp. 415–429.
- Whittaker, R.H. and Likens, G.E., 1973. Carbon in the biota. In: G.M. Woodwell and E.V. Pecan (Editors), *Carbon and the Biosphere*. U.S. Atomic Energy Commission, Symposium Series 30, National Technical Information Service, Springfield, VA, pp. 281–302.
- Williams, M., 1989. Deforestation: past and present. *Prog. Hum. Geogr.*, 13: 176–208.