Deforestation and Land Use in the Amazon

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University Press of Florida
Gainesville · Tallahassee · Tampa · Boca Raton
Pensacola · Orlando · Miami · Jacksonville · Ft. Myers

Introduction

Land Use and Deforestation in the Amazon

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Dramatic images of the Amazonian rain forest in flames have become etched in the minds of people throughout the world, even among those who otherwise know little about the Amazon and probably less about Latin America. By virtue of their power to simplify a complex story, alarming scenes of burning trees and charred landscapes are readily invoked by concerned citizens and scientists in venues that range from grade school classrooms to the bargaining tables of international organizations. So pervasive is the perceived threat that it is easy to forget that the deforestation alarm was sounded rather recently and that, despite all of the attention it has received in the meantime, the socioeconomic causes and the environmental consequences of deforestation are as yet only partially understood.

How Deforestation Became a "Problem"

As late as 1982 the National Research Council in the United States published an influential book called *Ecological Aspects of Development in the Humid Tropics* (NRC 1982) that showed little concern over deforestation in the Amazon (cited in Moran 1996). In retrospect this lack of concern was hardly surprising since, until the mid-1970s, the amount of land that had been deforested in the region was small and mostly limited to the southern rim of the basin. The concern about deforestation that existed in the late 1970s focused mainly on the Asian and African tropics, which by then had suffered decades of destruction that started soon after World War II.

The attention given to South America, and to Brazil in particular, picked up in the 1980s as a result of apparently disparate events. When a

German scientist described the Amazon as the "lungs of the world," the compelling analogy, though scientifically invalid, was effective in bringing home the idea that far-off happenings had implications for all of us, perhaps even threatening our very capacity to breathe (Moran 1996, 157–59). More sober analyses of the atmosphere showed that, because the Amazon recycles 50 percent of its precipitation through evaporation and evapotranspiration (Salati 1985), the basin is thought to have important consequences for stabilizing global climate and correcting for the pollutants generated by the industrial world. At about the same time, Norman Myers (1984), in his widely read book *The Primary Source: Tropical Forests and Our Future*, assembled a plethora of data to support his argument that humankind was headed down a thoughtless and potentially dangerous path when it allowed deforestation to destroy as-yet undiscovered medicinal plants and pest-resistant genetic materials.

Others, mainly in the social sciences, focused on the centrally planned development projects that were aggressively promoted in the 1970s by Brazil's military regime. By stimulating land conflicts and violent confrontations over timber and gold, the road construction and colonization schemes visited devastating effects on vulnerable indigenous and peasant populations (Moran 1981; Schmink and Wood 1984). By the late 1980s, the concerns emanating from the natural and the social sciences converged, not only with the growing worldwide attention to "the environment," but also with the actions of a host of newly formed nongovernmental organizations (NGOs) whose persistent advocacy, and often outrageous antics, made it virtually impossible for politics to continue on a "business as usual" basis.

In 1992, rather than buck the trend, Brazil opted to host the United Nations Conference on Environment and Development. The Earth Summit, as it is commonly known, was the largest gathering of heads of state in history (approximately 100), and was distinguished by its inclusiveness. Around 1,000 NGOs were officially registered (one-third of them from developing countries), and close to 35,000 people attended, including 8,000 journalists from 111 nations (Preston 1994). Following on the heels of the Soviet collapse and the decline of bipolar confrontations between the superpowers, the conference advanced a notion of global security that gave less emphasis to military strategy and more to the world's environment and economy.

The degree to which the tenor of the discussions in the 1990s departed from previous decades can be readily appreciated by recalling the 1972 United Nations Conference on the Human Environment, held in Stockholm. During that contentious encounter, developing countries rejected environmental concerns as little more than a malicious distraction fostered by rich countries bent on keeping the Third World in its place. Taking a page from the history of the industrialized countries, Third World delegates argued that pollution was a necessary step along the road to economic growth. To claim otherwise, they contended, was to condemn poor nations to perpetual poverty.[1]

Today, fundamental differences continue to divide North and South. Nonetheless, there is a recognition on all sides that environmental problems—whether at the local, national, or global level—must be identified, monitored, and understood. Equally important is the greater appreciation of the complexity of the environmental issues we face, and a growing realization that the rigid boundaries that separate the natural and the social sciences have rendered both ill suited to address the research needs of the emerging environmental agenda. These days there is little doubt that, in addition to the perennial call for more data, there is a critical need to develop truly interdisciplinary strategies for analyzing the interplay of socioeconomic and biophysical factors that drive the process of environmental change.

With these priorities in mind, the Center for Latin American Studies at the University of Florida devoted its 48th annual conference to the "Patterns and Processes of Land Use and Forest Change in the Amazon." The event featured a keynote address by Dr. Carlos Nobre, of Brazil's Instituto Nacional de Pesquisas Espaciais, and thirty presentations by researchers and practitioners representing different countries as well as a wide range of disciplines. The goal of the conference was to promote a constructive dialogue among specialists who interpret satellite images, researchers who focus on the processes that drive resource use decisions, and scholars and activists engaged in community mapping efforts. This volume includes selected essays from that conference as well as contributions specially written for this publication.

To set the stage for the chapters that follow, in the next section we present estimates of the magnitude of deforestation in Brazil and show how the rate of deforestation has fluctuated over time. We then present a conceptual framework that uses a three-tiered hierarchical approach to depict the socioeconomic and biophysical drivers that lead to deforestation. By conceptualizing the factors operating at the micro, meso, and macro scales, the framework serves to organize a review of the literature on the determinants of land use and land cover change in the Amazon, and to conceptually position the studies included here.

The Magnitude of Deforestation in the Amazon

The Amazon basin is a vast area of approximately 6,600,000 square kilometers that includes land in Brazil, Colombia, Ecuador, Peru, Bolivia, and Venezuela. Although forest clearing is happening in all of these places, most deforestation has occurred, and continues to take place, in Brazil, the country that also produces the most accurate information on land cover change in the region. Estimates of the magnitude of deforestation in the Amazon are routinely generated by Brazil's Instituto Nacional de Pesquisas Espaciais (INPE) using data provided by orbiting satellites.[2] Despite debates among specialists concerning technical aspects of measuring deforestation from satellite images, the INPE data provide a good idea of how much land has been cleared and of the variation in the rate of deforestation from one year to the next.[3]

In the ten years between 1988 and 1998, deforestation in the Brazilian Amazon averaged around 15,000 square kilometers per year.[4] Troubling as this observation may be, the average figure for the decade disguises the fact that the annual rate has been twice as high. The data in figure 1 show that the amount of land cleared ranged from a low of 11,130 square kilometers in 1990–91 to a high of 29,059 in 1994–95.[5]

The rates for the region as a whole also disguise marked differences in the spatial distribution of deforestation. Rather than being randomly dis-

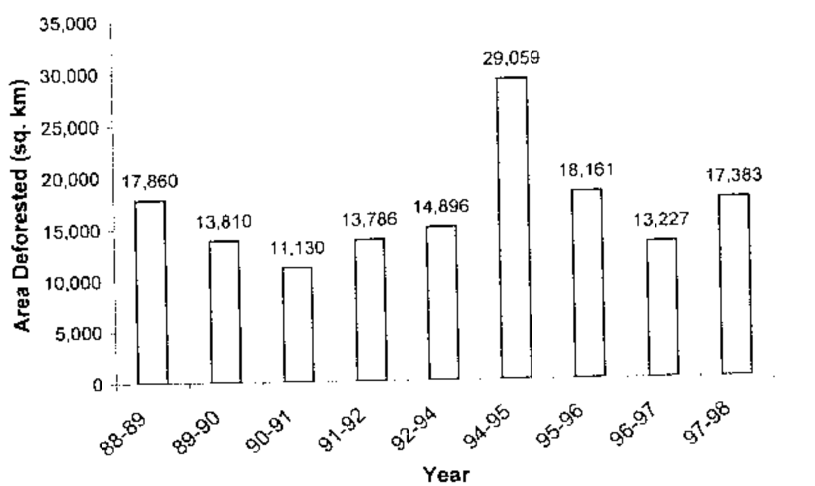
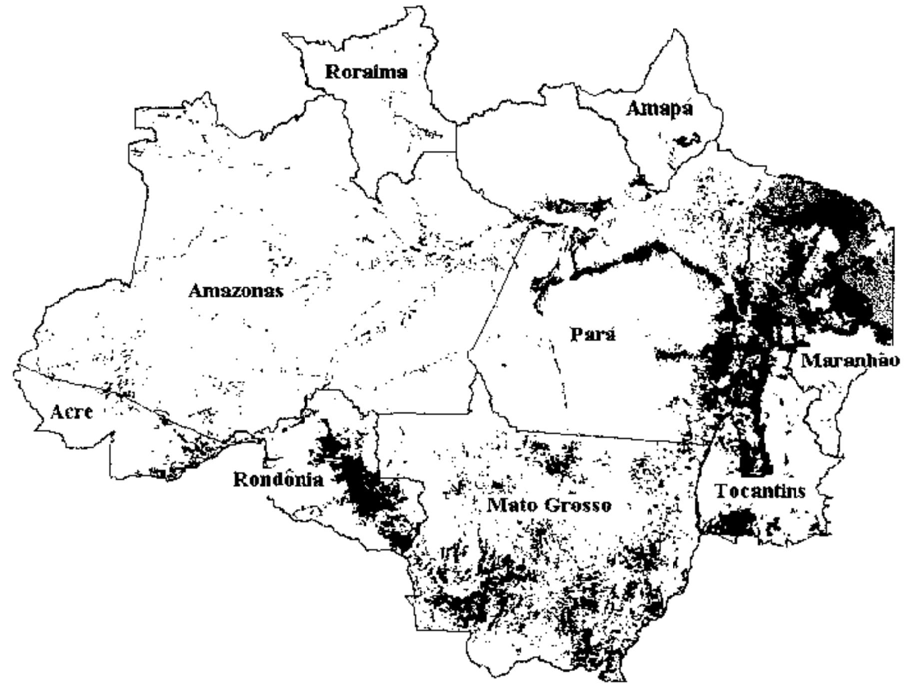


Fig. 1. Area deforested in the Brazilian Legal Amazon, by year (1988–98). *Source:* INPE <http://www.inpe.br/Informacoes_Eventos/amz1998_1999/pagina7.htm>



Map 1. Spatial representation of deforestation in the Brazilian Amazon

persed across the basin, land clearing mainly coincided with the agricultural frontier as it advanced northward through the states of Pará, Tocantins, Mato Grosso, Rondônia, and Acre. As farmers and ranchers clear the forest cover to make way for agriculture and cattle ranching, the movement of people into the lower rim of the basin has left its mark on the landscape in the form of the crescent-shaped "arc of deforestation" shown in map 1.

As in the case of Bolivia (see Kaimowitz et al., chap. 1 in this volume), forests are more likely to be cleared when they are close to roads in physical distance and in terms of traveling time. Moreover, the effects of road and environmental conditions often interact such that roads induce greater forest clearing in areas with good soils. The heavy line of deforestation that cuts across the state of Pará in map 1 is a clear indication of the effect of the Transamazon Highway on deforestation in Brazil.

Table 1 offers more precise estimates of the spatial concentration of deforestation in the frontier states. In the decade 1988–98, approximately 174,000 square kilometers were deforested in the region. Most of it took

Table 1. Total area of deforestation, 1988–98, by state

State	Total km² deforested by		
	April 1988	August 1998	1988–98
Acre	8,900	14,714	5,814
Amapá	800	1,962	1,162
Amazonas	19,700	28,866	9,166
Maranhão	90,800	100,590	9,790
Mato Grosso	71,500	131,808	60,308
Pará	131,500	188,372	56,872
Rondônia	30,000	53,275	23,275
Roraima	2,700	5,791	3,091
Tocantins	21,600	26,404	4,804
Total	377,500	551,782	174,282

Source: INPE <http://www.inpe.br/Informacoes_Eventos/amz1998_1999/pagina7.htm>.

place in the state of Mato Grosso (around 60,000 square kilometers), followed by Pará (57,000 square kilometers) and Rondônia (23,000 square kilometers). The magnitude of deforestation was much lower in Amapá, Amazonas, and Roraima—states that were more distant from the agricultural frontier.

Whereas early treatments of deforestation often stressed a single causal factor, such as the effect of population growth, today it is increasingly understood that an array of variables accounts for the scope, pace, and pattern of land use and land cover change. Environment, history, economics, politics, and demography are thoroughly implicated, as are exchange rates, currency inflation, legal institutions, road construction, colonization schemes, tax laws, financial markets, commodity prices, and tenure security, to name only the more salient variables noted in the literature. It is also recognized that the biophysical context—defined by such variables as soil quality, water availability, temperature range, and the presence of pests and pathogens—mediates the way that socioeconomic drivers play themselves out in a particular location. The image that emerges from these considerations is that of a complex web of interrelations that are prone to lag effects and emergent properties, and that are characterized by nonlinear processes occurring at different spatial and temporal levels to produce a dynamic system that is far from an equilibrium state.

The daunting complexity of the image underscores the critical need to develop a conceptual framework capable of organizing (apparently) disparate observations and processes into a more coherent picture of the causes and the consequences of land use change and deforestation. To advance this objective, the section that follows makes use of a hierarchical approach to conceptualize the various levels of the social and natural systems that are relevant to the study of the land use decisions made by firms and households in rural areas. To develop this framework, we join insights drawn from the social and natural sciences to basic concepts taken from "hierarchy theory" in ecology (see Allen and Starr 1983; Ahl and Allen 1996; Gibson, Ostrom, and Ahn 1998).

Although not a testable theory in its own right, the model's utility can be assessed in terms of its effectiveness as a guide to data collection and analysis, its ability to generate hypotheses that can be subjected to empirical test, and its capacity to organize existing information into a coherent understanding of how global, regional, and local events are related. To illustrate its applicability, we will use the framework to review the literature on land use and environmental change in the Amazon, and to show how each of the chapters presented here contributes to an overall understanding of deforestation in the region.

Conceptualizing the Determinants of Land Use and Environmental Change

The proposed three-tiered hierarchical approach treats land cover outcomes as the direct effect of the land use decisions made by rural households and by firms whose decisions are embedded in contexts that operate at higher levels of the system. The higher-level contexts consist of the proximate, intermediate, and distant drivers that comprise the socioeconomic and biophysical subsystems. The analytical focus is on the relationships that take place within each level, as well as the cross-level dynamics that link one level to another.

Elements of the Framework

Figure 2 presents the main elements of the proposed conceptual framework. The model draws a broad distinction between two classes of variables—the "socioeconomic drivers," shown in the upper portion of the diagram, and the "biophysical drivers," shown in the lower portion. To conceptualize the hierarchy of driving forces within each domain, the framework further distinguishes between the "Proximate," "Intermediate," and "Distant" scales.[6] At the heart of the model is the simple assumption that the land use decisions made by firms and households in the countryside can be seen as the net result of a complex interplay of a large number of variables that operate both directly and indirectly at various levels within the social and natural system. The box labeled "Land Use/ Land Cover Outcomes" is therefore positioned to the right of the figure in order to convey the idea that deforestation, as well as other forms of land cover change, are the direct result of decisions made by farming house-holds and commercial firms.

Land Use/Land Cover Outcomes

Each land use/land cover outcome is associated with different kinds of economic activity, and therefore with different social groups. Rubber tap-pers, farmers, ranchers, and loggers all engage in clearing the forest cover, but they do so in varying degrees depending on their respective objectives, resources, and decisions. The box farthest to the right in figure 2 lists the re-main land use/land cover outcomes that are the direct result of the out-source allocation decisions made by rural households and firms. The out-comes can be arranged more or less in order of intensity with respect to deforestation, ranging from undisturbed forest to the clear-cutting associ-ated with agriculture and cattle ranching.[7] A discussion of each land use/ land cover outcome illustrates the social and biophysical drivers that lead to deforestation and environmental change.

Undisturbed Forest

In studies of land cover change in the Amazon, such as those based on satellite images, evidence of disturbance is usually measured against "un-disturbed forest," or what is sometimes referred to as "primary forest." While such designations have a prima facie appeal, the terms are poten-tially misleading when the temporal scale stretches to several centuries. Contrary to prevailing notions of a pristine Amazonian environment, much of the region's forest has felt the influence of foragers and farmers for a considerable length of time (Denevan 1992; Turner and Butzer 1992). Indeed, estimates of human populations in the Amazon around 1500 range from one million to six million. Figures of this magnitude suggest that it is possible that the overall cleared area at that time may have come close to that observed in 1990, and that forest fires in the region may have been as common then as they are at present, albeit more dis-bursed and on a smaller scale (Smith et al. 1995, 13).

Extraction of Nontimber Products

Long-time residents of the Amazon obtain a wide range of foods, medi-cines, and building materials from the forest, including Brazil nuts and

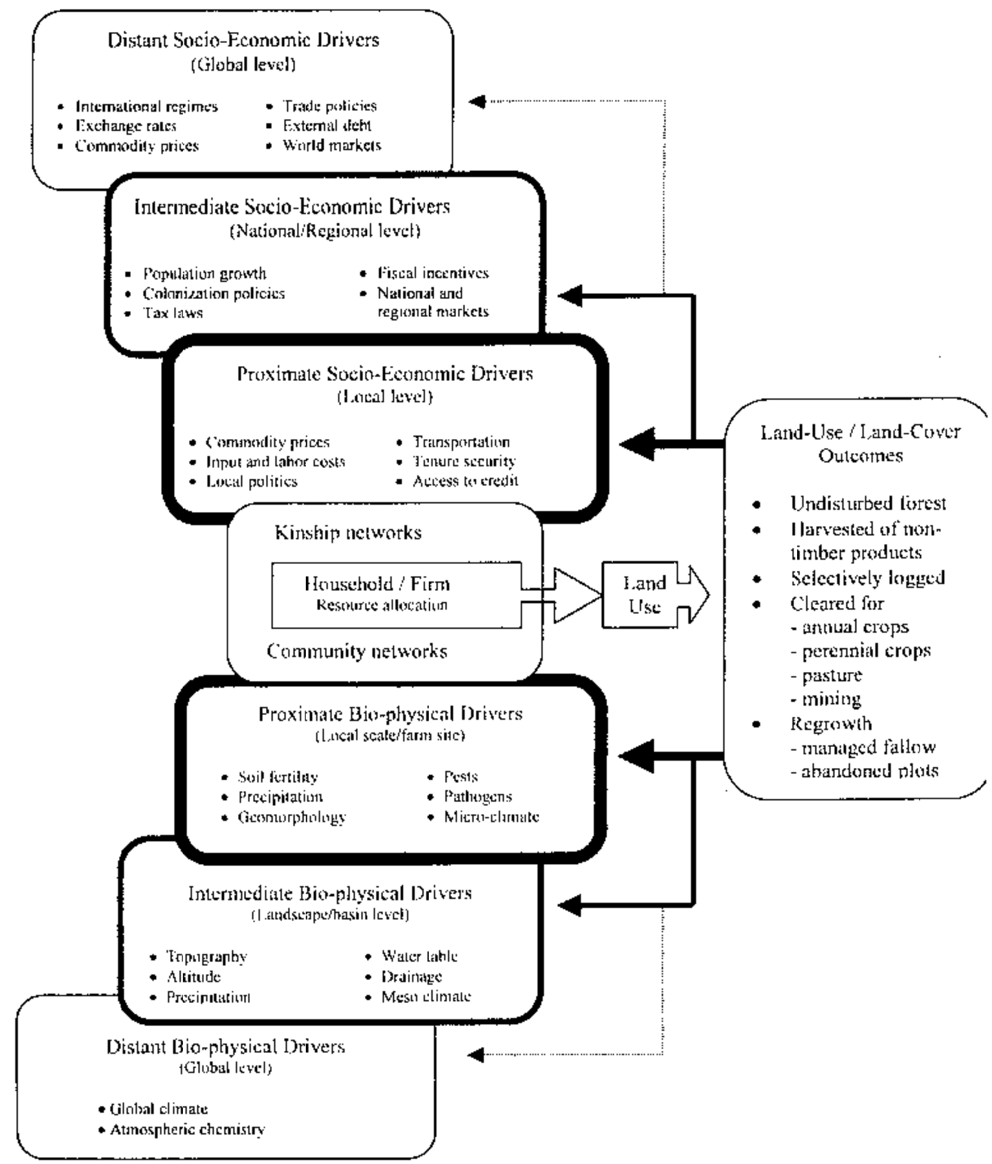


Fig. 2. Socioeconomic and biophysical drivers of land use and environmental change

rubber. The extraction of nontimber forest products, for example, largely describes the sustenance activities carried out by indigenous populations, as well as by rubber tappers and Brazil-nut collectors.[8] Noting the relatively benign consequences of this form of production, environmentalists have claimed that the commercial extraction of nontimber forest products can provide an important incentive to prevent deforestation. A widely cited article by Peters, Gentry, and Mendelsohn (1989) argued that revenues generated by forest products may be two to three times higher than those resulting from forest conversion. Findings such as these provided the rationale for initiatives to legally recognize "extractive reserves" as valid forms of land tenure, and to establish the economic incentive to resist deforestation by developing markets for nontimber forest products.[9]

Selective Logging

Next along the scale of land use intensity and environmental impact is the selective extraction of logs. Because it appears to leave much of the forest unaltered, selective logging was once regarded as relatively benign. Only recently has the magnitude of the destruction become clearer. Because of the construction of trails and log yards, and because of the presence of thick vines that are bound to neighboring trees, up to twenty trees can be knocked down or damaged for every individual that is harvested (Uhl and Vieira 1989).

The destructive effects of selective logging are compounded by increased susceptibility to fire. Dense forests are naturally resistant to burning because their dark, shady interiors maintain moisture in the soil and in the dead leaves and twigs on the forest floor. But the firebreak function of the forest is severely compromised when logging operations cut gaps in the forest canopy and drying occurs.[10] Nepstad and his colleagues (Nepstad et al. 1999) estimated that fires ignited on agricultural lands can penetrate logged forests, killing 14 to 50 percent of the living biomass. The result is a positive feedback between forest fires, future fire susceptibility, and fire intensity that poses a significant threat to the region's forests. Evidence provided by Cochrane and colleagues (chap. 10 in this volume) shows that fire affected 50 percent of the standing forest in two study regions in the Brazilian Amazon. They conclude that the current fire regimes in the two sites are capable of eradicating the remaining forest in less than fifteen years.

Clearing for Agriculture and Pasture

The small and mostly temporary clearings made by traditional Amazonian dwellers, like the roads and clearings made by loggers, stand in sharp contrast to the clear-cutting carried out by newly arrived settlers who deforest large areas of land for annual and/or perennial crops and for pastures to raise cattle. Pasture comprises the primary form of deforested land use in the Amazon, growing from 42.3 to 50.1 million hectares between 1985 and 1996 (IBGE 1990, 1998). By 1996, the number of hectares that had been cleared for pastures was approximately nine times larger than the area under annual and perennial crops (IBGE 1998). The expansion of pastures has been linked to growing urban demand for beef (Faminow 1998), new lines of credit (Toni 1999), and diseases among cash crops that make cattle ranching a desirable investment (Serrão and Homma 1993).[11]

Much of the deforestation that has taken place in the Amazon was carried out by middle- and large-scale ranchers who converted the forest cover to pasture, often with the support of fiscal incentives from the Superintendency for the Development of the Amazon (SUDAM; Fearnside 1993). Yet small farmers were also implicated in the process, as evidenced by the typical cycle of land use. Small farmers commonly clear two to three hectares of land, which they then cultivate for as long as soil fertility remains high. In most areas soil fertility is depleted in two to three years, requiring the clearing of more land. Since there are approximately 500,000 small farmers in the region, these figures imply a demand for an additional 500,000 hectares of cleared land per year (Homma et al. 1992, 9).

Beyond these generalizations, it has proven to be difficult to determine with precision the relative proportion of total deforestation that can be attributed to small farmers compared to ranchers, who generally have larger landholdings and often benefit from government subsidies. Studies that have attempted to answer this question come up with different conclusions. Fearnside (1997) estimated that about 70 percent of Amazonian deforestation can be attributed to large-scale ranchers. Faminow (1998, 119–20), on the other hand, presented a much lower estimate when he concluded that "it is likely that no more than 25 percent of total deforestation can be traced to subsidies for large-scale ranches." The lower estimate of the subsidy effect is more or less consistent with the results published by Yokomizo (1989), who found that subsidized ranching projects accounted for 21 percent of the deforestation in Mato Grosso but only 7.5 percent in Pará. The geographic variability is similarly emphasized by

Walker, Moran, and Anselin (2000), who noted that the relative proportion of deforestation due to ranching varied from 100 percent in the municipality of Santana do Araguaia to a mere 8 percent in the Altamira region (both located in the state of Pará).

Secondary Growth

Over time, a portion of the areas that were originally cleared for pasture or agricultural crops often converts to secondary forest (regrowth). The transition from cleared land to secondary growth can occur either as the outcome of a deliberate land management strategy that allows for a fallow period, or as the result of the abandonment of pastures or agricultural plots. The area under secondary growth in the Amazon rose from 7.5 to 10.7 million hectares between 1986 and 1992 (BSRSI 2000), mostly in older settlements, but increasingly in frontier areas as well (Perz 2000). Secondary forests in the Amazon provide important environmental services, including the recuperation of nutrients and humidity in the soil (Jipp et al. 1998), protection against erosion (de Rouw 1995), and the sequestration of atmospheric carbon (Houghton et al. 2000).

Feedback Effects

To one degree or another, each of the various land cover outcomes has feedback effects to the biophysical and socioeconomic domains. These effects are depicted by the return arrows in figure 2. The varying thickness is intended to capture the idea that the feedbacks are most intensively manifested at the local/regional level and become progressively weaker at the national and global scales.

The feedback arrows noted in the upper portion of the figure refer to the effects that land cover outcomes at the local level can have on the intermediate and distant socioeconomic drivers. One example was the high rate of deforestation caused by cattle ranchers who benefited from fiscal incentives. The growing awareness of this land cover outcome, both in Brazil and internationally, led to mounting criticism that prompted the government to withdraw the incentive programs that were thought to promote deforestation. More generally, public concern over the observed high rates of deforestation in the Amazon was one of the factors that stimulated an intense international outcry. The latter partly accounts for Brazil's decision to host the Earth Summit in 1992, and to introduce new policies and legislation designed to reduce deforestation in the Amazon.

For a very different example of a feedback effect to the socioeconomic domain, we can point to the rather sudden political importance that was

given to the low rates of deforestation characteristic of social groups such as rubber tappers, who survive by harvesting nontimber forest products. By virtue of their active opposition to forest clearing, rubber tappers in Acre became known worldwide. Under the initial leadership of Chico Mendes, they were able to enlist the support of NGOs and environmental activists in the developed world to enhance their ability to preserve their way of life. The result was a change in Brazilian law that now recognizes "extractive reserves" as a legitimate form of land tenure (Schmink and Wood 1992). What these examples illustrate is how variations in land cover outcomes—that is, high deforestation in the case of ranchers, low deforestation in the case of rubber tappers—can initiate responses that alter the intermediate and distant drivers within the socioeconomic domain.

The literature on feedback effects is more advanced with respect to the biophysical consequences of land cover change. At the local level, attention has focused on the reduced biodiversity caused by habitat destruction and landscape fragmentation associated with deforestation (Ehrlich and Wilson 1991; Ehrlich and Ehrlich 1981; Wilson and Peter 1988). Deforestation can also affect the regional environment by increasing erosion and altering flooding patterns. More recently, studies have focused on the possible effects of deforestation on global climate change by altering sensible and latent heat flux, planetary albedo, and surface roughness at the planetary boundary layer (Shukla, Nobre, and Sellers 1990). The burning of biomass in the tropics also results in the release of radiatively important carbon trace gases that contribute to the so-called "greenhouse" effect. While these observations hardly constitute a comprehensive review of the sizeable literature on this topic, the examples nonetheless illustrate the main point of this discussion—namely that variations in land cover outcomes can initiate responses that alter the intermediate and distant drivers within the biophysical domain.

More complex relationships emerge when the feedback effects within the socioeconomic and the biophysical domains interact with one another. An example can be taken from Nepstad's research on "surface fires." In contrast to the intense blazes deliberately set to burn trees felled to clear land, unintentional low-intensity surface fires escape into the forest understory (Cochrane et al., chap. 10 in this volume). Surface fires take advantage of drier areas within the forest caused by the greater penetration of sunlight into areas where loggers built trails and where they extracted trees. Surface fires increase the subsequent flammability of the landscape, especially during dry years associated with the El Niño Southern Oscillation (ENSO). During the 1997–98 ENSO episode, approximately 15,000 square kilometers of standing forest were burned in the northern Amazonian state of Roraima (Nepstad et al. 1999), intensifying the national and international concern about logging activities and deforestation in the region. These relationships show how human-induced changes carried out at the local level can interact with intermediate and global patterns in ways that lead to biophysical and socioeconomic outcomes that cannot be explained in isolation of each other.

Resource Allocation Decisions by Households and Firms

Understanding the factors that produce the observed land use/land cover changes requires that we move backward in the causal chain to address the resource allocation decisions that take place within households and firms. Households and firms are positioned at the center of the framework, wedged, as it were, between the socioeconomic context on the one hand, and the biophysical context on the other. This depiction is intended to capture the idea that firms and households determine how to allocate the resources at their disposal by engaging in a complex decision process that takes into account (however imperfectly) the opportunities and constraints, and the incentives and disincentives, presented to them by the proximate socioeconomic and biophysical drivers.

The findings presented by Brondízio and his colleagues in chapter 5 show how land use decisions are influenced by temporal and spatial aspects of farm families, as well as by the biophysical characteristics of the farm plot. McCracken and his coauthors (chap. 6) similarly note that the changes in labor supply that occur over a family's life cycle have a significant effect on land use decisions. By drawing on the distinction between "age, period, and cohort effects," they provide a conceptual approach to the household that clarifies the temporal changes in the interplay of internal and external factors that influence the choice of different farming systems as the household ages.

Community and Kinship Networks

In many instances, the influence of the proximate drivers is mediated by kinship institutions, community organizations, and other forms of collective social action at the local level.[12] By placing the household/firm within a larger box labeled "community and kinship networks," figure 2 depicts the idea that, rather than acting in isolation, landholders are embedded in formal and informal networks at the local level that influence the way resources are allocated. Formal means of community organization are

represented in producer cooperatives that enable farmers to share storage and transportation costs, and to obtain cheaper credit lines and other advantages, including the purchase of basic supplies at lower cost and the opportunity to avoid the onerous transaction terms imposed by middlemen. In addition to enhancing the profitability of particular commodities (and therefore influencing the choice of investments), one study of small farmers in Rondônia found that when a family participates in a cooperative, the probability of adopting sustainable agricultural technology increases (Caviglia and Kahn n.d.).

Informal methods of community cooperation are more common, such as the tradition in rural Brazil of labor sharing, called *mutirão*. During periods of peak labor demand—when land must be cleared or when a crop needs to be harvested—family, friends, and neighbors are recruited for the task. The informal pooling effort, based on community and kinship networks, increases the quantity of labor available to the household, thus enabling forms of land use that would be precluded if the household operated independently. In some cases people exchange labor for products such as milk, meat, or even calves. Although these payments do not always reflect the amount of work performed, by stimulating this form of transaction some activities, such as ranching, can redistribute capital and commodities within a social group, thus enhancing the community's livelihood. Customs and practices like these evidence a moral system of mutual obligations in which the better off assist those in need, thereby maintaining social life through functional relationships (Porro 2000a, 17).

Community networks and collective action serve to link households to external institutions, often with implications for land use and land cover change. The mobilization of peasant communities in the state of Pará, for example, was often instrumental in defending small farmers from land expropriation by ranchers and speculators. The result perpetuated small farming activities in areas that would otherwise have been converted entirely to pasture (Schmink and Wood 1992). Collective actions in Maranhão similarly played a major role in struggles for the access to and control over land and resources, and served to rearrange livelihood strategies after the resolution of conflicts (Porro 2000a, 28–30; chap. 12 in this volume). By the same token, it was the absence of a collective ability to protect themselves from expropriation that led many migrants to Pará to deforest more land than they could economically exploit. Knowing that they had little chance of holding land for very long, deforestation became a means of increasing the market value of land that was sold at the first opportunity (Schmink and Wood 1992). The process would be repeated as the agricultural frontier progressed, resulting in what came to be known as the *indústria da posse* (landclearing industry).

Examples of collective action in the Amazon and elsewhere in the developing world have prompted a striking and somewhat ironic resurgence in the attention paid to community. Whereas rural communities were once seen as an impediment to progressive social change, today they have become the focal point for achieving conservation goals, meaningful social participation, and the devolution of political power. The profound and widespread disenchantment with the state and the market as agents of environmentally sound development strategies has compelled conservationists, academics, NGOs, and policymakers alike to imbue community with high promise. International agencies such as the World Bank, the Worldwide Fund for Nature, Conservation International, the Nature Conservancy, the Ford Foundation, and the John D. and Catherine T. MacArthur Foundation have all "discovered community" (Agrawal 1997, 8).

The idea that communities can be mobilized to achieve positive social and environmental goals is the premise of numerous initiatives, including participatory approaches to resource management and land use planning. The case studies presented by Viana and Freire (chap. 13) and Saragoussi and colleagues (chap. 14) provide telling examples not only of the successes that can be achieved using participatory methods, but also the challenges that confront the participatory approach to community-based conservation and planning efforts.

The potential significance of community networks for achieving positive development and conservation goals is the basis for the World Bank's Social Capital for Development program. Social capital refers to the institutions, relationships, networks, and norms that allow actors to mobilize greater resources and achieve common goals.[13] The idea is present in Principle 22 of the 1992 *Rio Declaration on Environment and Development*, which states that "Indigenous people and their communities, and other local communities, have a vital role in environmental management and development because of their knowledge and traditional practices." The same notion is repeated in the 1994 *Baguio Declaration*, Philippines, which argues that "state-centric strategies have been marked by widespread failure, in large part due to the lack of appropriate and fair involvement by affected communities . . ." (cited in Agrawal 1997, 10). The importance of community involvement is similarly embodied in the term "productive conservation," which is based on the assumption that "a significant share of the responsibility for protecting the Amazon environment should be entrusted to those whose livelihoods depend on its preservation" (Hall 2000, 107).

While these lofty expectations have been greeted with skepticism (see Agrawal 1997; Krishna and Shrader 1999), the newfound interest in communities and social capital is consistent with an assumption present in the proposed framework for analyzing the determinants of deforestation—namely, that kinship and community networks often mediate the relationship between rural households and the immediate contexts within which they operate. Figure 2 represents these relationships by embedding the household/community within the proximate biophysical and socioeconomic drivers. This depiction is based on the hypothesis that the incentives and disincentives present at the local level are those that have the most decisive influence on resource use decisions made by rural landholders. As one conceptually moves "outward," from the proximate to the intermediate and distant drivers, the analytical trajectory progressively encompasses successively higher levels of social organization, larger areas of geographic coverage, and longer temporal horizons with respect to the processes at work.[14]

Biophysical Drivers

Proximate Biophysical Drivers

The influence of the proximate biophysical drivers on land use decisions is clearly evidenced in studies that document small-farmer responses to the generally poor soils in the Amazon. With the exception of the rich sediments carried down from the geologically young Andes and deposited along the floodplains (*várzeas*), most of the soils in the region are highly weathered and not very fertile. Approximately 90 percent are phosphorous deficient, 73 percent suffer aluminum toxicity, and 50 percent have low potassium reserves (Cochrane and Sanchez 1982). When you add other afflictions such as poor drainage and erosion to the list, it turns out that only about 7 percent of the Amazonian soils lack major constraints to conventional agricultural production (Hecht and Cockburn 1989, 34).

While there is considerable microlevel variation in quality, the generally poor condition of Amazonian soils has had a profound effect on the farming systems landholders have developed in the region. When trees are felled and burned there is a nutrient flush as elements held in plant materials are released into the soil. The surge in fertility permits the cultivation of food crops such as rice and beans, but the gain in fertility is short-lived. At the end of three to four years the soils are depleted to the point where other land use options are required. In most cases, landholders seed the area with pasture grasses in order to raise cattle themselves, or rent pastures to ranchers. It does not take long (between five and ten years) before the soil nutrients decline to levels below those necessary for maintaining pasture production. Shrubby weeds begin to invade, soil becomes compacted, and productivity drops, prompting landholders to abandon degraded pastures and deforest new areas. Low soil fertility is therefore one of the major factors that drives the evolution of the farming system from food crops to pasture to fallow, and to a new round of deforestation.

The peasant production cycle described here is a generalization that obscures significant regional variations. Moreover, the cycle that leads to deforestation can be offset by investing in perennial crops, by applying fertilizers, and by adopting proper pasture management technologies. While such strategies can be employed to good effect, the cost and knowledge required to implement them are often lacking.

In addition to soil fertility, proximate biophysical drivers include precipitation, geomorphology, and microclimate, as well as the presence of pests and pathogens. The latter have had a profound impact on rural production in the Amazon, as illustrated by the infamous South American leaf blight (*Microcyclus ulei*) that doomed attempts to establish commercial rubber plantations (Smith et al. 1995, 122). Other pathogens, such as fusarium (*Fusarium solani*) and witches' broom (*Crinipellis perniciosa*), periodically destroy pepper and cocoa plantations, forcing landholders to explore other options such as coffee, fruit trees, or, as is more often the case, converting land to pasture for cattle ranching. The main point of these examples is perhaps obvious—that the resource allocation decisions made by landholders are conditioned by the limits and opportunities imposed by the local biophysical context within which households and firms operate.

The relationships between soil quality, forest succession, and land use decisions among small farmers in Amazonia are illustrated by Moran and colleagues in chapter 7. Whereas many studies have noted that early settlers to a region are soon replaced by those who arrive later, Moran and his coauthors show that the turnover rate is higher among those who farm poorer soils. One consequence of this relationship is that the tendency toward land concentration occurs more rapidly in areas where the land is less fertile. These findings reveal some of the mechanisms by which a biophysical characteristic (in this case, soil quality) can have important socioeconomic outcomes (such as the concentration of landownership in the region).

Intermediate and Distant Biophysical Drivers

The influence of intermediate-scale biophysical drivers has been documented by geographers who have proposed a range of models to estimate the best or most probable use of agricultural land based on climate, soils, and topography in a number of regions of the world. The early efforts by Clark (1967) and Revelle (1976) to estimate the areas of productive land on a global scale have been the basis for region-specific studies of the food production potential of land in the developing world (Linnemann et al. 1979). Similar studies (Harrison 1983), which incorporate varying levels of technological inputs (for example, fertilizer, irrigation), concluded that Latin America was using only 11 percent of its potentially arable land.

More detailed case studies of the process of frontier expansion in the Brazilian Amazon show how regional landscapes influence not only the choice of agricultural activities but also the socioeconomic characteristics of newly established rural communities. The influence exerted by the vast stretches of natural savanna that characterize the lower rim of the Amazon basin is a case in point. Savanna lands were especially attractive to newly arrived cattle ranchers, who could establish pastures without incurring the expense of clearing the forest (Schmink and Wood 1992). During the period of heavy in-migration to the region in the 1970s and 1980s, large-scale cattle ranching and the associated concentration of landownership came to dominate the savanna lands in the southern portion of the state of Pará, as well as in the northern regions of Tocantins and Mato Grosso.

Today, a new type of production has become increasingly evident in the southern Amazon. In response to changes in international commodity prices, landholders have turned to the cultivation of soybeans—an activity also well suited to the savanna. As in the case of the earlier expansion of cattle ranching into the savanna, the conversion to soybean cultivation in these regions cannot be explained by referring only to the natural agricultural potential of the land, or solely to economically driven changes in relative prices. Instead, the geography of land use/land cover is the net result of complex interactions between the proximate, intermediate, and distant drivers within both the biophysical and the socioeconomic domains.

Socioeconomic Drivers

Proximate Socioeconomic Drivers

Empirical studies based on survey data of farming households have documented the relationship between deforestation and a host of socioeconomic variables that operate at the local level. Models that include trans- portation costs find that cheaper access to market promotes deforestation (Ozorio de Almeida and Campari 1995). In their survey of a small-farmer colonization site in the Amazon, Wood and Walker (2000) measured transportation costs in terms of the distance between the farm site and the main road and found a strong inverse relationship with the number of hectares converted to pasture, the number of head of cattle, the probabil- ity of using fertilizers, and the probability of investing in reforestation. Computer-based simulations similarly found that a 20 percent reduction in transportation costs for all agricultural products from the Amazon in- creased deforestation by 33 percent (Cattaneo n.d.). Other studies showed that increases in off-farm employment reduced the tendency to deforest (Pichón 1997), as did increases in the local wage rate (Ozorio de Almeida and Campari 1995). The availability of credit was associated with more deforestation (Ozorio de Almeida and Campari 1995), even after intro- ducing statistical controls for other variables such as length of residence and distance to the road (Wood and Walker 2000). In areas where tenure security is low, higher timber values increase the net benefit of land clear- ing and hence encourage deforestation. Similarly, technological changes that make agricultural lands more valuable promote forest clearing (Southgate 1990). More generally, the expansion of agriculture has been attributed to the abundance of land and the scarcity of every other factor of production, the more important of which are labor and capital. Under such circumstances, producers are induced to maximize returns to scarce labor and capital through extensive (rather than intensive) land use and the deforestation of larger areas (Kyle and Cunha 1992).

The survey-based results are generally consistent with hypotheses de- rived from economic optimization models of household behavior. In most cases, the approach treats the household or firm as an independent unit that responds to externally imposed costs and prices. By managing the landscape as they would any other resource, farmers are assumed to "maximize their utility" in the face of exogenous and endogenous con- straints. While this model arguably represents the most influential ap- proach in analyses of land use in the Amazon, Browder (chap. 8 in this volume) notes that land managers often base their decisions on subjective "utilities" that do not necessarily derive from a strict economic calculus. He advocates instead a more pluralistic conceptual approach that should be tailored to what works best in specific local circumstances. The nuances involved in land use decisions are evident in Browder's case studies of

small farmers in Rondônia and in the analysis by Pichón and others (chap. 9 in this volume) of settlers in the Ecuadorian Amazon.

Other studies focus less on the behavior of individual actors by paying more attention to the broader socioeconomic and political changes that influence the profile of costs and benefits that landholders confront. Fac- tors such as these carry the analysis into the domain of demographic history, macroeconomic policies, and the state-sponsored development initiatives represented by the "Intermediate Socioeconomic Drivers" in figure 2.

Intermediate Socioeconomic Drivers

A good example of a socioeconomic study cast at the intermediate level is the analysis presented by Pacheco in chapter 2, which traces the historical events that influenced the rate of deforestation in Bolivia. Whereas the magnitude of forest clearing was relatively low compared to that in other countries, deforestation in Bolivia rose when the import substitution growth model that once dominated development policy gave way to more recent development policies based on market liberalization strategies.

In Brazil, the contemporary movement of people into the Amazon be- gan in the 1970s when the agricultural frontier moved into the northern states of Pará, Tocantins, and Rondônia. Whereas earlier periods of ex- pansion were relatively spontaneous, in the 1970s the exploitation and settlement of the Amazon was aggressively promoted by the federal gov- ernment, then in the hands of the Brazilian military. Development policies designed to populate the region included credit and tax incentives to at- tract private capital to the region, the construction of the Transamazon Highway, and the colonization of small farmers on 100-hectare plots along both sides of the new road (Fearnside 1986; Moran 1981; Smith 1982). Sawmill owners benefited from similar measures designed to pro- mote the export of valued hardwoods (Browder 1986; Uhl et al. 1991). The rationale for the various programs designed to populate and develop the Amazon was upheld on the grounds of national security and were implemented in a way that established a military presence in the region that continued even after the transition to a democratic regime in 1985.

Stephen Perz's contribution to this volume (chap. 4) provides estimates of the magnitude of net migration into the Brazilian Amazon since 1970. In addition to providing valuable measures of the size of the migrant flow, his findings call into question those explanations of deforestation that overemphasize the role played by migration to the frontier. Although population growth is clearly implicated, his data show that deforestation rates remained high even as migration slowed. He concludes that population growth due to net migration does not automatically lead to deforestation.

Many of the small farmers and landless poor who migrated to the Amazon came from central and southern Brazil, where they had been displaced by the mechanization of agricultural production and the switch from labor-intensive coffee plantations to labor-saving soybean cultivation (Wood and Carvalho 1988).[15] Many more came from the poverty-stricken and densely populated northeast, where most of the productive soils were owned by a landed elite. In the meantime, well-financed investors took advantage of profitable tax and credit programs to convert huge tracts of land to pasture, and to buy land to hold in investment portfolios as a hedge against future inflation (Hecht and Cockburn 1989). Cattle ranching alone benefited to the tune of over U.S.$5 billion from 1971 to 1987. In the 1980s, the purchase of land in the Amazon was particularly attractive given that the income earned from the sale of one hectare in the south was enough to purchase fifteen hectares in the Amazon (World Bank 1992, 12–13). Once the investment was made, the incentive to deforest was high because of Brazil's Land Statute, which levied a 3.5 percent tax on lands that were classified as "unused" (that is, forested).

Macroeconomic variables also appear to exert a decisive role on the rate of deforestation in the Amazon (see Fearnside 2000; Smeraldi 1996). The decline of deforestation in the late 1980s, for example, has been attributed to the deep recession Brazil suffered at the end of the decade, brought on by the country's debt crisis, a growing fiscal deficit, and the resulting inflationary spiral. Ranchers simply did not have the money to invest in clearing land to the extent that they did in the past, and state governments cut back on highways and settlement projects. Brazil was forced to rely on emergency adjustment policies of the International Monetary Fund and the World Bank, which meant that subsidies to the agricultural sector were rolled back and many of the fiscal incentives that had stimulated deforestation were suspended. Coupled with an increase in the government's capacity to enforce restrictions on deforestation, the economic and policy changes are thought to be the main factors that contributed to the decline in deforestation in the 1989–91 period (Smeraldi 1996, 30).

Explanations for the surge in deforestation in 1994–95 follow a similar macroeconomic reasoning, this time pointing to implementation of a radically new monetary policy called the *Plano Real*. The policy reduced inflation from a staggering 2,500 percent a year to an annual rate of less than 20 percent. The policy also boosted spending power, evidenced by the 30 percent increase in real income between 1993 and 1995 (IBGE 1997, 126). People responded to monetary stability and higher incomes by increasing consumption and by investing in agricultural activities that led to greater deforestation (Smeraldi 1996). Evidently prosperity for people spells trouble for the forest.

In recent years the domestic and international criticism of the high rate of deforestation in the Amazon prompted the federal government to take a number of initiatives to slow the process of land clearing. Many of the subsidized credit and fiscal incentive programs for cattle ranching were withdrawn,[16] and the proportion of land on a property that could be legally deforested was reduced to 20 percent.[17] Fines were imposed on landholders caught in the act of burning forest without having received the appropriate permission from the Brazilian Institute for the Environment and Renewable Resources (IBAMA), a federal regulatory agency.[18] Other policies were designed to reduce deforestation indirectly by supporting groups with a vested interest in maintaining the forest. The concept of "extractive reserves" was introduced as a legal form of land tenure in an attempt to recognize the tenure situation of rubber tappers. This new form of land tenure was complemented by various programs to support rubber tappers economically through price supports for natural rubber, a main source of the tappers' income.

These incentives were complemented in the mid-1990s by the introduction of technologically sophisticated systems to monitor deforestation. The most significant new mechanism was the "Surveillance System for Amazonia" (*Sistema de Vigilância da Amazonia*, or SIVAM). Costing around U.S.$1.7 billion, SIVAM involves a satellite and radar surveillance network implemented in order to strengthen military defense of the region, to improve air traffic control, and to enhance environmental protection by monitoring logging and burnings (Hall 2000).[19]

Distant Socioeconomic Drivers

Explanations cast at the global level suggest various ways that distant drivers influence national events in Brazil. The end of the Cold War, deepening economic globalization, and the worldwide concern about "the environment" were among the broad transformations that redefined fundamental aspects of the world system. At the risk of overstating the case, one can point to the 1992 United Nations Conference on Environment and Development (the Earth Summit) held in Brazil as an epochal event that altered the terms of the scientific and policymaking discourse. Over-arching concepts such as sustainable development and global climate became organizing principles for discussions that addressed more specific issues, including biological diversity and deforestation.

The Earth Summit was a concrete manifestation of the emergence of what international relations specialists call an "international regime." An international regime is a set of principles, norms, and rules that converge in a given issue area (in this case, the environment) in a way that constrains the behavior of actors involved, even when there is no central authority (Krasner 1983). "Regimes promote order, not through force or power, but because actors—most significantly sovereign nation-states—support and voluntarily comply with them" (McCoy 1997, 16).

The demand for international regimes arises from tasks that are thrust upon states when they have to cope with interdependence and the problems and conflicts that arise from it (List and Rittberger 1992, 86). In identifying a regime, one looks for the existence of hierarchically linked principles (beliefs of fact and causation), norms of behavior (acknowledged rights and obligations), and procedures (practices for making and implementing collective decisions). To one degree or another, all of these elements are present in the new environmental regime.

The issues addressed at the Earth Summit were articulated in five documents: the conventions on *Climate Change* and *Biological Diversity*, the *Statement of Forest Principles*, the *Rio Declaration*, and *Agenda 21*. The two conventions are "binding," meaning that nations are expected to fulfill the obligations outlined in the treaties without legal enforcement. The statement on forests is a controversial set of principles on forest conservation practices, while the *Rio Declaration* is a list of guidelines for global sustainable development. Similarly, *Agenda 21* is a blueprint for implementing the *Rio Declaration* (Preston 1994).[20] A subsequent meeting in 1994 called the Summit of the Americas, held in Miami, elevated sustainable development to the status of a hemispheric principle. More recently, the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), which was adopted in December 1997 in Kyoto, contained, for the first time, quantified, legally binding commitments to limit or reduce greenhouse gas emissions by industrialized countries. It also recognized the function of biological systems as sources and sinks of greenhouse gases.[21]

In the process of these negotiations, imaginative proposals have emerged, such as the Clean Development Mechanism (CDM) defined by

the Kyoto Protocol (Article 12). The CDM is a cooperative mechanism whereby certified carbon emission reductions accruing from sustainable development projects in developing countries can be used by developed countries to meet part of their reduction commitments, as specified in Annex B of the Protocol (see Goldemberg 1998). The CDM arose from a Brazilian proposal for a "Clean Development Fund" that was intended to provide an incentive for developed countries to comply with the Convention and provide a source of revenue for developing countries to implement the Protocol.[22] Under the CDM, projects that involve "certified emission reductions" count toward compliance. Emission reductions can be certified only if the reductions are "additional to any that would occur in the absence of the certified project activity (Article 12.5)."

The CDM can be applied to the forest and land use sector that can provide carbon sequestration through the adoption of sustainable forest management techniques, the curbing of deforestation, and the provision of incentives for reforestation. Actually realizing that potential will depend on the outcome of an ongoing debate about the precise role that the forest and land use sector will play. Because land and forests are not explicitly mentioned in the Protocol text, some parties conclude that they are not to be included. Others insist that, since there are no explicit limits placed on the mechanism, any and all forest and land use projects are eligible (Brown, Kete, and Livernash 1998, 164).[23] Such controversies notwithstanding, the CDM exemplifies an agreement—cast at the global level and comprising multinational participants—that has the potential to alter land use outcomes in ways that meet desirable environmental goals.

The Rio, Miami, and Kyoto meetings set forth ambitious goals that are far from being fully implemented. The assemblies nonetheless reflect the new perceptions and priorities that have redefined discussions of development, the environment, and the balance between national sovereignty and international cooperation. The various meetings and the widely shared awareness of and interest in environmental issues, especially with respect to deforestation, have converged to produce a political and ideological discourse that has enhanced the efficacy of some actors in the global arena and profoundly conditioned the behavior of those at the national level.

While environmentalists may properly look upon these events with some encouragement, it is risky to assume a firm consensus at the international level, or to expect that international agreements are necessarily greeted with enthusiasm at the national level. The Brazilian military, for example, has expressed alarm over threats to their nation's sovereignty from "international greed and attempts to interfere in the Brazilian Amazon area" (Loveman 1999, 270). In the military's view the threat was serious enough to justify the "extreme expedient of war" against smugglers, drug traffickers, and indigenous and environmental organizations (cited in Schmink and Wood 1992, 122). That environmental organizations should be included in such disreputable company is a telling indicator of attitudes within some sectors of Brazilian society concerning the growing influence of NGOs and activists of various stripes. More generally, the military's reaction exemplifies the tendency to position environmental issues at the flash point between a nationalist commitment to sovereign authority on the one hand, and the reality of increasing global constraints on national policymaking on the other.

The global/national tension is plainly evident in the ongoing debate about the relationships between the environment and international trade. Proponents of free trade endorse the simplistic proposition that increased trade is good because it boosts economic growth. On the basis of this arguable assumption, *The Economist* (1999, 17) goes on to conclude that "As people get richer, they want a cleaner environment—and they acquire the means to pay for it."[24] Sweeping generalizations of this kind are equally popular among many in the environmental community who claim that increased international trade invariably promotes deforestation and environmental destruction. Dogmatic and poorly articulated stances such as these are hardly conducive to rational dialogue, as evidenced by the public commotion that disrupted the 1999 meeting of the World Trade Organization (WTO) held in Seattle.

Empirical studies of the impact of trade and exchange rates on deforestation are few in number and preliminary in their conclusions. Capistrano's (1994) analysis of forty-five countries around the world found that the increase in the value of tropical wood on the international market from 1967 to 1971 was associated with greater deforestation. During later periods, forest depletion was most strongly linked to currency devaluations, presumably the result of complex relationships between economic conditions within a country and the larger global context. When the exchange rate is overvalued—for example, when domestic inflation exceeds world inflation—resources tend to move away from export-producing sectors of the economy. Exportable products such as agricultural commodities and tropical hardwoods suffer a setback, thereby lowering deforestation. Alternatively, currency devaluations favor the export of agricultural commodities and timber. The consequent increase in the demand for cultivable lands and logging is thought to stimulate deforestation.

Currency devaluations are especially relevant in the case of Brazil given the magnitude of exchange rate fluctuations in recent years. In 1999, for example, the currency crisis in that country caused widespread fear that states might default on their debt to the central government. The rumor sent foreign investors fleeing from Brazilian capital markets. To counteract this trend, the government decided to float the exchange rate, causing a 70 percent nominal devaluation over a period of only three weeks. Computer simulations based on far more moderate devaluations in the 20 to 40 percent range produced increases in the deforestation rate as high as 35 percent (Cattaneo n.d.).

Conclusion

If one were to review the vast literature on the topic of deforestation with the simple intent of compiling an inventory of explanations that have been advanced, the list would amount to a bewildering jumble of disparate observations scattered across multiple levels of analysis. The daunting complexity of such a list would clearly violate Stigler's lemma that "there are not ten good reasons for anything." Perhaps so, but Stigler, after all, did not have in mind the kind of complex systems that have been the focus here. The question, then, is how to proceed in a manner that accounts for the presence of many variables and relationships, yet at the same time takes to heart Stigler's plea for conceptual simplification. Put another way, if it turns out that there are in fact "ten good reasons" for something (arguably in the case of deforestation), we would be well advised to find some way to group those reasons into a smaller number of processes in such a way that we can treat each grouping on its own terms, and in relation to the others that comprise the system.

Our attempt to construct such a framework draws from hierarchy theory in ecology, which provides guidelines for grouping both social and natural phenomena along spatial, temporal, and organizational scales. The concepts and relationships shown in figure 2 present a multileveled hierarchical model, the objective of which is to characterize the interplay of socioeconomic and biophysical drivers that influence land use decisions made by households and firms. The land use decisions are treated as the direct causes of land cover changes that produce numerous environmental outcomes, some of which have feedback effects on the very socioeconomic and biophysical processes that produced the land cover changes to begin with. The framework makes explicit the notion that different kinds of hierarchical systems are involved, thereby requiring different conceptual and methodological strategies. Finally, the model predicts differences in the strength of cross-scale relationships such that the effect of distant driv- ers is weaker compared to the strength of intermediate and proximate drivers, just as feedback effects are strong at the local level but then be- come progressively weaker at the national and global levels.

Although the hierarchical approach assumes a degree of stability across levels, stability is not assumed to be permanent. Social and natural systems can remain relatively unchanged if subjected to minor disturbances, but may cross a critical threshold and undergo radical change in the face of larger shocks (Gunderson et al. 1997, 3). Nor does the framework intend to suggest that there is a perfect compatibility between the socioeconomic and the biophysical domains at each level of the three analytical tiers. An ecological zone, for example, does not necessarily conform to national political boundaries. Indeed, much of the literature on global environmen- tal issues notes the lack of congruence that often exists between such en- tities as the political boundaries of the state system on the one hand, and the boundaries of ecological systems on the other (Hurrell 1992, 401).

Treated as a heuristic generalization, the framework nonetheless illus- trates a style of multileveled reasoning that can be adapted to different circumstances and research objectives. The approach is essentially a point of view that can be applied to different phenomena, some of which may call for more or fewer tiers in the hierarchy depending on the issue at hand. By the same token, the variables listed in figure 2 are presented as illustra- tions of the kinds of factors to be taken into account within each level of analysis, not as a complete and finite set of variables that influence land use choices. Finally, the proposed framework, like all conceptual orienta- tions, is not a testable theory in its own right. Instead, the model's utility lies in its ability to organize existing information into a coherent under- standing of how global, regional, and local events interact with one an- other to produce the environmental outcomes observed in the field.

Notes

1. Despite its name, the conference primarily dealt with the environmental problems of the industrialized world, such as pollution and acid rain. Little

thought was given to reconciling or integrating development with environmental concerns.

2. These data, and additional information, can be found on INPE's website: <http://www.inpe.br/amz-01.html>. For another excellent source of information on deforestation in the Amazon and elsewhere, see the Michigan State University website for the Tropical Rain Forest Information Center: <http://www.bsrsi.msu.edu/trfic/index.html>.

3. The estimates of deforestation produced by INPE (used in table 1, figure 1, and map 1) refer to the "Legal Amazon," a federal planning region that corre- sponds more or less to the Amazon watershed. It consists of the states of Acre, Amapá, Amazonas, Pará, Rondônia, and Roraima (often referred to as the "Clas- sical Amazon"), as well as Mato Grosso, Tocantins, and Maranhão west of the 44th meridian.

4. Source: <http://www.inpe.br/Informacoes_Eventos/amz1998_1999/pagina8.html>.

5. Estimates of deforestation in the Amazon are politically sensitive. The figures are often used to blame one group or another for the destruction of the forest. When the deforestation rate declines, government officials are quick to take credit for the lower rate, pointing to the effectiveness of the policy changes they have enacted. When the rate rises, critics seize upon the numbers to bolster their conclu- sion that government actions are ineffective and that more aggressive policies are called for.

6. Although the distinction between proximate and underlying causes is not new to the study of land use change (see Kaimowitz and Angelsen 1998, 75; Turner et al. 1990; Turner et al. 1995, 33; Moran, Ostrom, and Randolph 1998), the proposed framework seeks to advance this line of reasoning by providing a more complete inventory of the relevant variables and by explicitly addressing the con- ceptual issues that confront multileveled research designs.

7. The discussion addresses each land cover outcome separately. In reality the various outcomes are often present within the same landholding. Multiple land use patterns within the same property produce complex agroforestry systems that simultaneously include annual and perennial crops, pasture for cattle ranching, the selective extraction of timber, and the retention of some primary forest (Smith et al. 1995, chap. 6). The issue is further complicated by the fact that the economic activities that lead to land cover change are often related to each other, as in the synergy between loggers who build roads into the forest and farmers who are in search of land.

8. Smith et al. (1995, 89–91) provide a sample list of the nontimber forest products collected by peasants in the Brazilian Amazon.

9. In recent years, the sustainability of small-scale swidden agriculture and traditional extractivism have become rallying points for conservationists, who have sought alliances with indigenous groups and rubber tappers as a means to protect the forest from the more destructive forms of deforestation carried out by

peasant farmers and cattle ranchers. A dramatic example is that of Chico Mendes, a rubber tapper and community organizer who galvanized the support of environmental and labor groups in favor of legal recognition of a new form of land tenure, called "extractive reserve." In an extractive reserve, local communities own and control the harvesting of forest products. The idea is to establish a form of communal ownership that permits people to manage the forest without destroying it. Whether extractive reserves are economically viable alternatives to other forms of land tenure and land use is a debated issue (Allegretti 1989; Browder 1992; Smith et al. 1995, 77–88). Attempts to strengthen the contribution of extractive reserves to the income of local people include the marketing of forest products through nonprofit trading companies that repatriate a percentage of the profits to members of the reserve. Through the efforts of Cultural Survival, a human rights organization, Brazil nuts can be found in ice cream, cereals, and cookies (Pearce 1990). Mendes's opposition to encroaching cattle ranches led to his murder in December 1988. His death catapulted the issue of extractive reserves to the forefront of the discussion of development policies for the Amazon, eventually leading to the creation of twelve extractive reserves covering over 3 million hectares.

10. "Surface fires" that escape into the forest burn with less intensity but nonetheless cause severe damage to the understory and to tree species with fire-sensitive barks, causing the forest to become increasingly flammable. It turns out that surface fires that go undetected by satellites affect about 1.5 time more forest than the amount of land directly affected by deforestation fires associated with clear-cutting and burning (Nepstad et al. 1999).

11. Pastures are very difficult to maintain in the Amazon (Serrão and Toledo 1992). After about five years, pastures become increasingly susceptible to nutrient leaching and the invasion of weeds, some of which are poisonous to cattle. Although estimates vary, one study concluded that approximately half of the pastures in the region are "degraded" (Serrão and Homma 1993, 317–18).

12. In the face of the state's declining ability to govern, many analysts contend that community-level organization is the only legitimate focus for the devolution of power and for achieving the meaningful grassroots participation deemed critical to successful resource management and conservation (see Agrawal 1997).

13. Background literature and sample questionnaires can be obtained from a World Bank website
(<http://www.worldbank.org/poverty/scapital>).

14. Scale can thus be temporal, spatial, or both. Temporal scale refers to the frequency of behavior, specifically to the amount of time it takes for a cycle to be completed and start again. Particular entities behave with their own characteristic frequencies (Ahl and Allen 1996, 60).

15. The prospect of earning foreign exchange through the export of soybeans justified a host of aggressive state-financed crop credit programs to modernize the agricultural sector, largely financed by international lending. The availability of this funding, in turn, was greatly facilitated by the "petrodollars" that flooded the

international money market following the OPEC-induced oil price increase in the early 1970s (Skole et al. 1994, 319–20). Among the consequences of these changes was the out-migration of people from Paraná, many of whom headed northward to the Amazon (Wood and Carvalho 1988, 219).

16. Nevertheless, the suspension of incentives applies only to new projects, not to projects that are currently being implemented or that have already been fully implemented (Smeraldi 1996, 98).

17. Provisional Measure (PM) 1511 stipulates that clear-cutting is not permitted in more than 20 percent of a property in the north region and in the northern part of the center-west region. PM 1511 modifies the 1965 Forest Code, which required forest reserves of at least 50 percent on a rural property. The PM differs in that the 50 percent figure in the Forest Code was based on the total area of each property, while the more recent 20 percent figure is based on the area with forest cover (Smeraldi 1996, 99–100).

18. The majority of those who commit infractions get away without paying fines, often due to loopholes in federal laws and the lack of personnel to properly monitor activities in an area as large as the Amazon.

19. The degree to which these initiatives may have reduced deforestation is hotly debated. The Brazilian government is quick to extol the effectiveness of public policies, at least when deforestation rates are on the way down, as they were between 1988–89 and 1990–91. Critics, on the other hand, bolster their argument that public policies have been ineffective by pointing to later increases in the deforestation rate. Most skeptics probably agree with Fearnside (2000) when he concluded that landholders continue to deforest despite the withdrawal of incentives, inspections from helicopters, the confiscation of chain saws, and the imposition of fines for illegal burning.

20. Precursors to the Summit include the G-7 Pilot Program to Conserve the Brazilian Rainforest (PPG7), launched in Houston, Texas, in 1992 at the request of the Group of Seven industrialized countries, spearheaded by Germany (see Smeraldi 1996). The U.S.$300 million aid package is designed to support conservation and sustainable development within the Amazon and Atlantic rainforest while strengthening institutional capacity and environmental policymaking for the region.

21. Emissions of greenhouse gases, mostly carbon dioxide, methane, and nitrous oxide, result from human activities in the energy sector, land use change, and forestry sectors, and from industry and waste management (IPCC 1996a, 1996b). However, the forestry sector also has the ability to remove carbon dioxide from the atmosphere through photosynthesis. As such, the possibility of emission reductions in forestry and the potential for increasing carbon sequestration give the sector an elevated role in measures to mitigate climate change as envisaged in the Kyoto Protocol.

22. In the original proposal, financing was to come from noncompliance fees from developed (Annex I) countries that exceeded their assigned amounts of

greenhouse gas emissions in a given budget period. The punitive nature of the proposal was modified after intensive negotiations.

23. Several key issues drive the debate about the role of the forest and land use sector (Brown, Kete, and Livernash 1998). (a) Some governments oppose the inclusion of the forest and land use sector because they do not want the focus of the negotiations to shift from fossil fuel to forest-sector emissions. (b) Forest options could become a loophole as governments try to claim "credit" for activities they would have done anyway, regardless of the Protocol. (c) Some carbon storage projects, such as the conversion of natural forests into fast-growing plantations, can have negative environmental outcomes in other areas such as biodiversity. And (d) although conservation offers the greatest emission reduction opportunities, some seek to exclude conservation projects because it is too difficult to determine whether deforestation would have occurred in the absence of the CDM.

24. A rise in income can have contradictory effects on deforestation. On the one hand, an increase in purchasing power implies a greater demand for wood and agricultural products, which, in turn, increases the opportunity cost of keeping the forest unexploited. On the other hand, if the pristine quality of the forest is a normal good whose demand increases with income, deforestation would decline as income rises. The net effect of income on deforestation, therefore, is an empirical question (Capistrano 1994, 74).

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