Deforestation
and Land Use
in the Amazon

Edited by Charles H. Wood and Roberto Porro
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Introduction

Land Use and Deforestation in the Amazon

Charles H. Wood

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 Stock-
holm. 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. 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.

In the ten years between 1988 and 1998, deforestation in the Brazilian Amazon averaged around 15,000 square kilometers per year. 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.

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

<table>
<thead>
<tr>
<th>State</th>
<th>Total km² deforested by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acre</td>
<td>8,900</td>
</tr>
<tr>
<td>Amapá</td>
<td>800</td>
</tr>
<tr>
<td>Amazonas</td>
<td>19,700</td>
</tr>
<tr>
<td>Maranhão</td>
<td>90,800</td>
</tr>
<tr>
<td>Mato Grosso</td>
<td>71,500</td>
</tr>
<tr>
<td>Pará</td>
<td>131,500</td>
</tr>
<tr>
<td>Rondônia</td>
<td>30,000</td>
</tr>
<tr>
<td>Roraima</td>
<td>2,700</td>
</tr>
<tr>
<td>Tocantins</td>
<td>21,600</td>
</tr>
<tr>
<td>Total</td>
<td>377,500</td>
</tr>
</tbody>
</table>

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. 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 households 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 tappers, 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 main land use/land cover outcomes that are the direct result of the resource allocation decisions made by rural households and firms. The outcomes can be arranged more or less in order of intensity with respect to deforestation, ranging from undisturbed forest to the clear-cutting associated with agriculture and cattle ranching. 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 “undisturbed forest,” or what is sometimes referred to as “primary forest.” While such designations have a prima facie appeal, the terms are potentially 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, medicines, 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. 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.

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. 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).

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 Oscilla-
tion (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. 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. 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 environ-
ment 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 socioecono-mic 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 socioeco-
nomic variables that operate at the local level. Models that include transporta-
tion 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 probability 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 increased 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 introducing 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 clearing 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 derived 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 constraints. While this model arguably represents the most influential approach 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. Factors 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 began in the 1970s when the agricultural frontier moved into the northern states of Pará, Tocantins, and Rondônia. Whereas earlier periods of expansion were relatively spontaneous, in the 1970s the exploitation and settlement of the Amazon was aggressively promoted by the federal government, then in the hands of the Brazilian military. Development policies designed to populate the region included credit and tax incentives to attract 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 promote 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). 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 infla-
tion 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, and the proportion of land on a property that could be legally deforested was reduced to 20 percent. 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. 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).

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 be-
came 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 prob-
lems 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 (acknowl-
edged 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 docu-
ments: 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 ful-
fill the obligations outlined in the treaties without legal enforcement. The
statement on forests is a controversial set of principles on forest conserva-
tion practices, while the Rio Declaration is a list of guidelines for global
sustainable development. Similarly, Agenda 21 is a blueprint for imple-
menting the Rio Declaration (Preston 1994). A subsequent meeting in
1994 called the Summit of the Americas, held in Miami, elevated sustain-
able development to the status of a hemispheric principle. More recently,
the Kyoto Protocol to the United Nations Framework Convention on Cli-
mate Change (UNFCCC), which was adopted in December 1997 in
Kyoto, contained, for the first time, quantified, legally binding commit-
ments to limit or reduce greenhouse gas emissions by industrialized coun-
tries. It also recognized the function of biological systems as sources and
sinks of greenhouse gases.

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. 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). 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 agricul-
tural 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 drivers is weaker compared to the strength of intermediate and proximate drivers, just as feedback effects are strong at the local level but then become 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 environmental issues notes the lack of congruence that often exists between such entities 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 illustrates 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 illustrations 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 orientations, 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 understanding of how global, regional, and local events interact with one another 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 corresponds 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 “Classical Amazon”), as well as Mato Grosso, Tocantins, and Maranhão west of the 44th meridian.


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 conclusion 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 conceptual 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).


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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Part I

National Policies and Regional Patterns
International interest in the issue of tropical deforestation has grown rapidly during the last twenty years, but major uncertainties persist regarding when, where, and why it occurs. In a recent survey by Kaimowitz and Angelsen (1998), the authors identified more than 150 quantitative models that researchers have developed to answer these questions, most of them since 1990. These models assess the impact of 115 variables that potentially influence deforestation, but in many instances the direction and magnitude of their effect on deforestation remain uncertain. This uncertainty reflects the issue’s inherent complexity and limited data availability, as well as methodological weaknesses.

The Kaimowitz and Angelsen study evaluated the potential of different modeling approaches for improving our understanding of tropical deforestation and concluded that household and regional-level studies showed more promise than national and global models. It expressed particular enthusiasm for the opportunity presented by the growing availability of spatially referenced information for examining the relation between deforestation and spatial variables such as access to markets, land tenure, land use zoning policies, and ecological factors. Most spatial models use relatively reliable data and large samples and are particularly suited for predicting where deforestation will occur. Researchers can often test the models’ robustness by measuring what percentage of the time they accurately predict which areas will be deforested.

This chapter presents a spatial econometric model of deforestation in the Department of Santa Cruz, Bolivia, between 1989 and 1994. We chose Santa Cruz for several reasons: first, the Bolivian tropics have historically had low deforestation, but this has changed rapidly in recent years,
particularly in Santa Cruz. Spatial models may be able to help us understand why. Second, unlike in many Latin American regions, in Santa Cruz large-scale mechanized agriculture plays a major role in forest loss. Thus the causal pathways that influence deforestation there may differ greatly from those in other locations. Third, the government of Santa Cruz (prefectura) had an existing Geographic Information System (GIS) with much of the data we needed to model the influence of spatial variables on deforestation trends.

To the best of our knowledge this chapter represents the first time that spatial econometric regression models have been applied in an Amazonian region. We first briefly describe spatial econometric deforestation models and review the conclusions of previous models made for other tropical areas. Then, we give background information on deforestation in Santa Cruz. Next, we present the model and data we used in this study, and finally we discuss our results.

**Spatial Econometric Deforestation Models**

Spatial econometric regression models measure the correlation between land use and other georeferenced variables such as transportation costs (using proxies such as distance from markets and roads, railways, and rivers), ecological conditions (topography, soil quality, precipitation, and forest fragmentation), and land tenure and land use zoning categories (national parks, forest concessions, colonization areas, and indigenous territories).

The models can either focus on land use in a single time period or the change in land use over two or more periods. The majority of models relate the state of the explanatory (independent) variables in the first period to the probability that the forest in that location is removed between the first and second periods. Some of these models use samples that include only locations covered with forest during the initial period. Model makers can then analyze what portion of that area remains in the second period. Others use samples that include both forested and nonforested locations in the initial period and examine what happens to each of them in the second period.

Based on economic theory, model makers hypothesize that farmers decide whether to deforest an area based on whether the net present value of the returns they receive from putting the land into agriculture outweighs the cost of forest clearing and any benefits they might obtain from
forest products and services. Areas with soils, rainfall, and topography more suited to agriculture should provide higher returns to farming, and thus farmers would be more likely to deforest them. Likewise, government subsidies for deforestation in colonization areas increase the likelihood farmers will clear forests there. On the other hand, higher transportation costs reduce the net returns from converting an area to agriculture. Government land use restrictions such as designating a location as a protected area or forest concession should raise the expected cost to farmers of deforesting the area and discourage forest clearing there.

The data used in spatial econometric models come from maps. Most models have obtained those data by selecting a random sample of locations (points on the map) and determining the state of each variable in that location. They then treat the characteristics of that point as one observation, as if it were one individual in a household survey.

Typically, modelers use samples of several thousand points or more. Chomitz and Gray (1996), for example, used a random sample of 10,000 data points for their Belize study. Tom Tomich of the International Center for Research on Agroforestry (ICRAF) worked with 49,000 points in his model of Jambi, Sumatra (personal communication 1998). Gerald Nelson from the University of Illinois made a similar study with raster data that yielded 25,000 sample points (personal communication 1998).

Most land use information comes from national forest inventories, remote sensing, aerial photographs, and ground truthing. GIS programs generate the information on distance to roads and markets using the maps in their databases. The remaining information comes largely from local government departments.

**Previous Model Results**

Previous models have generally confirmed the hypothesis that landholders convert more forest to agricultural use in locations that have better access to markets, ecological characteristics more favorable for farming, and no government restrictions on forest clearing (see table 1.1).

Forests are more likely to be cleared when they are closer to roads in physical distance and traveling time (Chomitz and Gray 1996; Deininger and Minten 1999; Liu et al. 1993; Ludeke et al. 1990; Mamingi et al. 1996; Mertens and Lambin 1997; Nelson and Hellerstein 1997; Roser-Bixby and Palloni 1996; Sader and Joyce 1988). Most studies show that forest clearing declines rapidly beyond distances of two or three kilome-
ters from a road. The Liu et al. (1993) study of the Philippines and the Mamingi et al. (1996) study of Cameroon and Zaire, however, report that forest clearing and distance to roads remain strongly correlated at much greater distances in those countries. Proximity to railroads is also positively associated with deforestation in Cameroon and Zaire (Mamingi et al. 1996).

Chomitz and Gray (1996) found that in Belize locations near urban markets have less remaining forest, and Mertens and Lambin (1997) say that in Eastern Cameroon most deforestation occurs less than ten kilometers from the nearest town. Nelson and Hellerstein (1997) found that distance to villages had a much more significant effect on land use than distance to urban areas.

The studies also found that farmers are more likely to clear areas with higher quality soils (flat, adequate drainage, and high soil fertility) and drier climates (Chomitz and Gray 1996; Gastellu-Etchegorry and Sinulingga 1988; Rosero-Bixby and Palloni 1996; Sader and Joyce 1988). One would expect to find the most forest clearing in areas with moderate rainfall levels, which are neither too high nor too low for cultivation. However, since most studies have been carried out in moist tropical countries,

### Table 1.1. Conclusions from previous spatial regression models about the effects of different variables on deforestation

<table>
<thead>
<tr>
<th>Study</th>
<th>Country</th>
<th>More roads</th>
<th>Closer to markets</th>
<th>Better soils &amp;/or drier</th>
<th>Nearer forest edge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown et al. (1993)</td>
<td>Malaysia</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>Increase</td>
</tr>
<tr>
<td>Chomitz and Gray (1996)</td>
<td>Belize</td>
<td>Increase</td>
<td>Increase</td>
<td>Increase</td>
<td>NA</td>
</tr>
<tr>
<td>Deininger and Minten (1996)</td>
<td>Mexico</td>
<td>Increase</td>
<td>NA</td>
<td>Increase</td>
<td>NA</td>
</tr>
<tr>
<td>Gastellu-Etchegorry and Sinulingga (1988)</td>
<td>Indonesia</td>
<td>NA</td>
<td>NA</td>
<td>Increase</td>
<td>NA</td>
</tr>
<tr>
<td>Liu et al. (1993)</td>
<td>Philippines</td>
<td>Increase</td>
<td>NA</td>
<td>NA</td>
<td>Increase</td>
</tr>
<tr>
<td>Ludeke et al. (1990)</td>
<td>Honduras</td>
<td>Increase</td>
<td>NA</td>
<td>Increase</td>
<td>Increase</td>
</tr>
<tr>
<td>Mamingi et al. (1996)</td>
<td>Cameroon and Zaire</td>
<td>Increase</td>
<td>Increase</td>
<td>Increase</td>
<td>Increase</td>
</tr>
<tr>
<td>Mertens and Lambin (1997)</td>
<td>Cameroon</td>
<td>Increase</td>
<td>Increase</td>
<td>NA</td>
<td>Increase</td>
</tr>
<tr>
<td>Nelson and Hellerstein (1997)</td>
<td>Mexico</td>
<td>Increase</td>
<td>Increase</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Rosero-Bixby and Palloni (1996)</td>
<td>Costa Rica</td>
<td>Increase</td>
<td>NA</td>
<td>Increase</td>
<td>Increase</td>
</tr>
<tr>
<td>Sader and Joyce (1988)</td>
<td>Costa Rica</td>
<td>Increase</td>
<td>NA</td>
<td>Increase</td>
<td>NA</td>
</tr>
</tbody>
</table>

a. Only in Cameroon. No effect in Zaire.
their findings do not reflect the possibility that rather arid climates might also discourage deforestation.

Forest fragments have a higher risk of being lost than forests in large continuous areas, with those close to the forest edge especially likely to be cleared (Brown et al. 1993; Liu et al. 1993; Ludeke et al. 1990; Mertens and Lambin 1997; Rosero-Bixby and Palloni 1996). Forest edges are more easily accessible. In addition, deforestation processes tend to have a strong degree of inertia, so places close to locations that have been deforested in the past have a greater probability of being deforested in the future, even when one holds other factors constant.

The effect of roads and environmental conditions interact, so roads induce greater forest clearing in areas with good soils and favorable climatic conditions. In Belize, for example, Chomitz and Gray (1996) show that the probability of an area being used for agriculture (rather than natural vegetation) on high quality land next to a road was 50 percent, while lands next to roads with marginal soils had only a 15 percent probability of being deforested. Mamingi and his colleagues (1996) obtained similar results in Cameroon and Zaire.

Mertens and Lambin (1997) note that variables affect forest clearing differently depending on the type of deforestation process. In peri-urban deforestation, forest clearing exhibits a circular pattern around the towns, and distance to towns and roads strongly affects forest clearing but proximity to forest edge does not. Along roads a “corridor” pattern of deforestation occurs in which proximity to roads and forest edges is a significant determinant of forest clearing, but distance to towns is not. Finally, in areas where diffuse shifting cultivation dominates, proximity to forest edge increases the probability of forest clearing, whereas distance to roads and towns is less important.

Deininger and Minten (1999) and Chomitz and Gray (1996) show that protected areas were deforested less than other locations with similar attributes in Mexico and Belize respectively. We were unable to locate any spatial regression studies that examine the statistical relations between other zoning or tenure classifications and land use.

**Deforestation in Santa Cruz, Bolivia**

The department of Santa Cruz extends some 900 by 800 kilometers and occupies 36.4 million hectares. Of these, 30.7 million hectares (84.3 percent) were still in forest in 1994 and 3.2 million hectares (8.8 percent)
were in pasture or savanna, most of which is natural and has not been forested for a very long time. Farmers used 2.1 million hectares (5.8 percent) for agriculture, and most of the remaining 0.4 million hectares was covered with water (Morales 1993 and 1996).

As late as 1950, Santa Cruz had less than 60,000 hectares under cultivation. Construction of a road connecting Cochabamba and Santa Cruz in the early 1950s and government policies encouraging agricultural colonization and sugar and rice cultivation in the 1960s gradually changed that. These trends accelerated in the 1970s, as did subsidized agricultural credit (Pacheco 1998).

Most deforestation prior to 1980 occurred in the “integrated zone,” composed of the provinces of Andrés Ibáñez (where the city of Santa Cruz is located) and Warnes, and the eastern portions of Ichilo, Obispo Santiesteban, and Sara provinces (Pacheco 1998). The eastern portion of the integrated zone, located roughly between the Pirai and Grande rivers, was the traditional center of Santa Cruz’s large-scale commercial agriculture. This area has moderate rainfall (1,000–1,500 millimeters), some of the department’s best soils, and the most complete transportation infrastructure. In the 1970s, large Bolivian landholders and agricultural colonies populated by Japanese, Okinawan, and Mennonite settlers grew sugar cane, maize, cotton, and sorghum and grazed cattle there. More recently, cotton has lost importance and wheat and soybeans have emerged as major crops (CAO 1997).

Small-farm colonists dominate in the west and north of the integrated zone (Thiele 1995). Government-sponsored settlement there dates back to the 1960s. This area has a more humid climate (with an average annual rainfall of 1,500–2,000 millimeters), is better suited for rice production, and has generally poorer soils.

Since the mid-1980s, the majority of forest clearing has shifted to the east, into the so-called “expansion zone,” which covers the western portion of Chiquitos province and the south of Nuflo de Chavez province. Construction of a bridge over the Grande River and the implementation of structural adjustment policies that encouraged nontraditional exports such as soybeans encouraged that process (Kaimowitz, Thiele, and Pacheco 1999).

The expansion zone also has two subregions. Large mechanized soybean and wheat farmers dominate in the south, which has lower rainfall (900–1,000 millimeters), while small agricultural colonists have rice-based systems farther to the north. Both areas have moderately fertile
soils, but they are highly susceptible to compaction and soil erosion (Barber 1995). The integrated and expansion zones combined account for only 19 percent of the area of Santa Cruz, but 70 percent of the area deforested prior to 1994 (Pacheco 1998).

As one moves east and northeast from the expansion zone, one reaches the “Brazilian shield,” characterized by infertile and acidic soils. Cattle ranching and logging are the main activities there, although some small-farm agriculture exists as well. A large portion of the land was in timber concessions prior to 1996. Ranchers have probably cleared a moderate amount of forest for pasture, but it is difficult to distinguish these areas from savanna in the satellite images.

To the south, in the Chaco region, where annual precipitation often falls below 800 millimeters, the dry climate discourages crop production. Dry forest and scrub make up a large portion of the vegetation. In the provinces of Caballero, Florida, and Valle Grande, the area southwest of Santa Cruz City, steep slopes limit agricultural development. This area has some of the department’s oldest settlements but lacks economic dynamism and has a poor road network (Davies 1994).

Overall, annual deforestation rates have increased rapidly since the mid-1980s. Between 1986 and 1990, CUMAT (1992) found that 38,000 hectares of forest were cleared annually in the Amazonian portion of Santa Cruz (the area north of the 18° parallel). That region covers 61 percent of Santa Cruz, but accounts for a much higher percentage of forest clearing, as most of the rest of the department is in the dry south and mountainous southwest. Between 1989 and 1992, deforestation rose to around 78,000 hectares annually in the entire department of Santa Cruz. From 1992 to 1994, the yearly total reached 117,000 hectares (Morales 1993 and 1996).

The Data

The model we created to estimate the influence of different spatial variables on deforestation in Santa Cruz uses information on (a) land use in 1989 and 1994, (b) “land use potential” (soil quality and topography), (c) rainfall, (d) roads and railways, (e) urban areas, (f) forest concessions, (g) colonization zones, and (h) protected areas.

We drew our data from a GIS database produced by the Santa Cruz Natural Resource Protection Project. The government of Santa Cruz implemented that project with funding and technical assistance from a
consortium composed of various consulting companies. The initial objective of that GIS was to develop a land use plan (PLUS) for all of Santa Cruz. Henceforth, we will refer to it as the PLUS GIS.

The PLUS GIS was compiled from several sources. Most data were digitized from 1:250,000 maps, but some layers were captured at other scales and obtained from other sources. Land use and potential land use data were provided in raster form and were converted to vector format. Maps 1.1 to 1.4 depict deforestation, land utilization, precipitation, and soils of the Department of Santa Cruz.

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The 1989 land use data delineate forests, deforested areas, savanna and pastures, areas with little or no vegetation, water, and urban areas. Ivan Morales, a remote sensing expert contracted by the Santa Cruz Natural Resource Protection Project, produced the data based on Earthsat satellite images by revising a previous analysis of the same images by the CUMAT consulting company (Morales 1993).

Our present study focuses only on determining why certain areas in forest in 1989 were cleared between 1989 and 1994. Hence, we omitted all areas from our sample that were not classified as forest in 1989, including those areas for which we had no data. The main location where no data were available was a region of about 10,337 square kilometers in northwest Santa Cruz.

The 1994 land use data are based on Landsat images that Ivan Morales also analyzed. The data subdivide deforested areas into traditional agriculture, commercial agriculture, anthropogenic pastures, mixed agriculture, and agriculture with forests (Morales 1996). As its name implies, agriculture with forests includes some small forest areas, but Morales classified it as “deforested.” Cloud cover was minimal in the 1994 images; even so, no data were available for certain parts of eastern Santa Cruz.

The land use data set we used in our analysis combines all land classified as forest in 1989 for which information was also available in 1994. This forest land covers a total area of 302,000 square kilometers, or 82 percent of Santa Cruz.

Both the 1989 and 1994 land use data have a resolution of 0.5 x 0.5 kilometers. This relatively low resolution implies that the data cannot be used to detect deforested areas smaller than 12.5 hectares. Thus, our conclusions better reflect the factors influencing forest clearing for mechanized agriculture and ranching than for shifting cultivation. We should also point out that our analysis does not allow us to say anything about forest degradation—as opposed to the complete removal of forest cover.
Map 1.1. Deforestation map of department of Santa Cruz, Bolivia
Map 1.2. Land utilization map of department of Santa Cruz, Bolivia
Therefore we cannot address the issue of the possible negative effects of unsustainable timber harvesting. This consideration is particularly relevant with regard to our later discussion of forest concessions.

The land use potential data follow the United States Department of Agriculture (USDA) classification scheme, which classifies land on a scale from I to VIII, with I representing areas with the highest agricultural potential and VIII representing the lowest. This classification takes into account soil fertility, depth, texture, slope, salinity, and chemical toxicity, and we are confident that it was applied uniformly over the whole department. The Santa Cruz Natural Resource Protection Project team assembled the data using secondary sources, satellite interpretation, aerial photography and observation, ground truthing, and soil sampling (Prefectura del Departamento—Consortio IP/CES/KWC 1996).

Rainfall refers to average annual precipitation and has been divided into discrete classes by rounding off to the nearest 100 millimeters. We have no information regarding the sources the government of Santa Cruz used to prepare its rainfall map.

The information on roads, railroads, and trails was assembled by the Santa Cruz Natural Resource Protection Project based on secondary sources and ground truthing. The road data include all classified roads. Although it would have been preferable to use road data from 1989, the only data available were for 1993. The “trails” data include temporary petroleum exploration and logging roads.

The PLUS divided Santa Cruz’s forty-one urban areas into four categories based on their population and infrastructure (education, health and banking facilities, agricultural markets, and telephones). We have considered these categories as proxies for the size of the towns’ markets for foods (Prefectura del Departamento—Consortio IP/CES/KWC 1996). The first category includes only the city of Santa Cruz. The second and third categories include medium-sized towns, and the fourth category smaller towns.

The forest concession boundaries used in the analysis were obtained from the GIS database of the Sustainable Forestry Management Project (BOLFOR) and come from Bolivia’s Forestry Development Center (CDF), a government agency. During the period covered, forest concessions frequently overlapped with other types of property, including private landholdings, indigenous territories, mining concessions, and on occasion even protected areas. We have no information regarding the specific years
the Bolivian government allocated these concessions, but we understand that it allocated practically all, if not all, of them prior to 1989.

Santa Cruz has government-sponsored small farm colonization zones and Mennonite and Japanese agricultural colonies. Our colonization zone data include both and come from a map produced by the Center for Research on Management of Renewable Natural Resources (CIMAR). The map has a scale of 1:1,000,000 and should be considered a first approximation (de Vries 1994).

In the early 1990s, Santa Cruz had three protected areas with forest: the Amboro National Park, the Noel Kempff Mercado National Park and Biological Reserve, and the Rios Blanco y Negro Wildlife Reserve. The Bolivian government established both Amboro and Noel Kempff Mercado prior to 1989, although it expanded Amboro in 1991. The Rios Blanco y Negro Wildlife Reserve was created in 1990. In our analysis, we classified the buffer zone of the Noel Kempff Mercado National Park as a protected area. This classification did not significantly affect our results since none of the buffer zone was deforested during the 1989–94 period.

Our Sample: The Polygon Approach

As noted earlier, most previous studies using spatial econometric models have worked with a set of systematically selected points taken from a GIS grid as their sample. Systematic selection of sample points ensures a compact data set and simplifies analyses, but fails to make full use of the available information.

Some researchers prefer to sample tiles rather than points. Each tile is a square or rectangular area, just like a tile in a bathroom floor. These researchers argue that tiles are more appropriate in fragmented landscapes where correct alignment of the various GIS layers may be problematic. If the alignment is slightly off, a single point has a higher probability than a tile of being mistaken for having some characteristic that it does not have. In cases where researchers take the tile approach, they typically use the proportion of the land area still in forest as their dependent variable, rather than a discrete (forest or nonforest) variable.

One way to make better use of information is to first stratify the sample into different relevant segments (for example, forested versus deforested, and close to versus distant from town/road) and then sample more intensively in strata of particular interest. One can then correct for the difference in sampling intensities used for each stratum when doing the regres-
sion analysis by weighting the data drawn from each stratum by the sampling intensity used.

Another alternative to working with a sample based on points is to use polygons occurring spontaneously within the GIS. Rather than using square or rectangular tiles, the modeler uses areas that have whatever shape best fits the data. This approach reduces the unnecessary proliferation of sample units since it combines areas that share the same major characteristics. It is important, however, to select the variables chosen to create the polygons carefully to ensure meaningful polygons and avoid problems with omitted variables. Additional problems may occur if some polygons become excessively large, since they may no longer be homogeneous (especially with regard to distance to roads and towns) and since this size may mask important relationships.

In this study we chose to adopt the polygon approach. We first divided Santa Cruz into areas that were deforested between 1989 and 1994 and those that remained in forest. Next, we separated out all of the areas inside colonization areas, protected areas, and forest concessions from those outside such areas. Then, we further divided those areas based on USDA soil quality classifications. To eliminate slivers, we combined any polygons smaller than 0.1 hectare with the adjacent polygon. We further fragmented large polygons using a regular grid to improve homogeneity with respect to distances.

Using this method, we obtained our sample of 24,208 polygons. For each polygon in the GIS we computed 20 potential explanatory variables and transferred these to the statistics package S-plus for further analysis. To calculate the distance from the polygons to roads, railroads, trails, and markets we took the geometrical center ("centroid") as our reference point.

The Model

Our model analyzes the determinants of deforestation in Santa Cruz between 1989 and 1994. The dependent variable we used is the probability that a given location covered with forest in 1989 still had forest in 1994. Thus our model is not designed to tell us anything about what factors might have determined forest clearing prior to 1989. These factors may or may not be the same as during the 1989–94 period. One might argue that this method introduces "selection" bias in our sample, since areas most suitable for being deforested were probably more likely to have already
been cleared by 1989. From a policy perspective, however, the key question is not how different variables affected deforestation in the past but rather how they are likely to affect it in the future. Recent deforestation patterns are more likely to give us relevant insights into future deforestation than deforestation patterns that occurred in the distant past.

The independent variables we examined include distance to roads, trails, and markets; “land use potential”; rainfall; whether or not a location falls within a protected area, colonization zone, or forest concession; and distance to the nearest area deforested prior to 1989.

The initial specification of the model, based on theoretical considerations and data availability, was

\[
\text{Forest} = \text{Intercept} + \beta_1 \text{Conc} + \beta_2 \text{Prot} + \beta_3 \text{Colon} + \beta_4 \text{Soil} + \beta_5 \text{Rain} + \beta_6 \text{DR} + \beta_7 \text{DT1} + \beta_8 \text{DT4} + \beta_9 \text{DLRo} + \beta_{10} \text{DRR} + \beta_{11} \text{DDF} + \text{error term}
\]

where

- **Forest** (1 if forested in 1989 and still forested in 1994, 0 if forested in 1989 and not forested in 1994)
- **Conc** (1 if inside forest concession, 0 if outside)
- **Prot** (1 if inside protected area, 0 if outside)
- **Colon** (1 if inside colonization zone, 0 if outside)
- **Soil** (USDA soil group, from I–VIII)
- **Rain** (precipitation, hundred millimeters)
- **DR** (the inverse of the distance to classified roads, kilometers)
- **DT1** (distance to Santa Cruz, kilometers)
- **DT4** (distance to nearest small town, kilometers)
- **DLRo** (the inverse of the distance to nearest temporary logging or mining trail)
- **DRR** (the inverse of the distance to nearest railroad)
- **DDF** (the inverse of the distance to nearest area deforested prior to 1989)

We did not include medium-sized towns in our analysis since almost all of them are very close to the city of Santa Cruz. Hence, it would be practically impossible to distinguish between their separate effects.

We included the quadratic rainfall term because we expected that deforestation would be highest at medium rainfall levels. Thus, we were look-
ing for a functional form that would allow deforestation to first rise with additional rainfall and then fall.

We fitted the model as a logistic model weighted by polygon area using generalized least squares. Economists generally favor the use of logarithmic, rather than logistic, transformations since parameter estimates can then be interpreted directly as elasticities (that is, a unit change in an independent variable always causes the same percentage change in the dependent variable). While logarithmic transformations are quite helpful when all independent variables are expressed in the same units, they become less relevant when the nature of the independent variables varies greatly, as in our case.

Statisticians prefer logistic and probit transformations for binomial data because standard assumptions are better satisfied and predictions are constrained correctly. The logistic and probit transformations are similar in many respects, but previous work by Jerry Vanclay led us to favor the logistic transformation. Fortunately for economists, the logistic is very similar to the logarithmic transformation if rates of change do not exceed 0.25. So provided deforestation rates remain modest, parameter estimates may still be interpreted as elasticities.

Two common statistical problems in models such as these are multicollinearity and endogeneity. Variables such as soil quality and distance to different types of roads and markets tend to be highly correlated with each other. This high correlation can make it difficult to distinguish between their separate effects. To avoid potential multicollinearity, we have tried to be parsimonious in our use of explanatory variables and to monitor how the inclusion or exclusion of particular variables affects our results.

The endogeneity problem arises because it is hard to distinguish situations where human settlements, productive activities, and infrastructure are located in certain places because of environmental conditions that make them good to deforest from those situations where deforestation occurs because people settle, build roads, or make specific zoning decisions. We have attempted to reduce this problem by controlling for agricultural suitability and using independent variables from a time period prior to that of the dependent variables.
Results

Before discussing the fitted model, it is worth briefly analyzing the simple correlations that exist between deforestation and the independent variables and among the independent variables themselves (see fig. 1.1). Negative numbers imply that deforestation rises when the independent variable takes on higher values.

The simple correlations reaffirm most of the conclusions drawn from previous spatial regression studies. They show that the forests still around in 1989 were more likely to be deforested over the next five years if they were closer to roads, trails, railways, markets, and areas that had already been deforested in 1989 and had better soils. Colonization areas were more likely to be deforested, and forest concessions and protected areas less likely. Unlike in previous models, however, in Santa Cruz lower rainfall correlates with less deforestation. Santa Cruz’s large areas of dry forest in semiarid regions, where cultivation is difficult, can probably explain this correlation.

As expected, the figure also shows that locations near Santa Cruz tend to have better soils and road infrastructure and to be closer to colonization areas and areas already deforested in 1989. Protected areas and forest concessions tend to be located in places farther away from roads, towns, trails, railways, and previously deforested areas.

<table>
<thead>
<tr>
<th></th>
<th>Forest</th>
<th>Conc</th>
<th>Prot</th>
<th>Colon</th>
<th>Soil</th>
<th>Rain</th>
<th>DR</th>
<th>DRLo</th>
<th>DRR</th>
<th>DT1</th>
<th>DT4</th>
<th>DDF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conc</td>
<td>0.14</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prot</td>
<td>0.08</td>
<td>0.10</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colon</td>
<td>-0.19</td>
<td>-0.19</td>
<td>-0.07</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil</td>
<td>0.13</td>
<td>-0.01</td>
<td>0.08</td>
<td>-0.14</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rain</td>
<td>-0.03</td>
<td>0.37</td>
<td>0.05</td>
<td>0.09</td>
<td>0.02</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DR</td>
<td>0.23</td>
<td>0.12</td>
<td>0.19</td>
<td>-0.18</td>
<td>0.14</td>
<td>-0.04</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DLRo</td>
<td>0.24</td>
<td>0.30</td>
<td>0.37</td>
<td>-0.18</td>
<td>0.15</td>
<td>0.11</td>
<td>0.22</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRR</td>
<td>0.16</td>
<td>0.24</td>
<td>0.20</td>
<td>-0.15</td>
<td>0.16</td>
<td>0.14</td>
<td>0.42</td>
<td>0.21</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DT1</td>
<td>0.27</td>
<td>0.19</td>
<td>0.12</td>
<td>-0.34</td>
<td>0.23</td>
<td>-0.06</td>
<td>0.23</td>
<td>0.42</td>
<td>0.16</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DT4</td>
<td>0.19</td>
<td>0.08</td>
<td>0.02</td>
<td>-0.28</td>
<td>0.18</td>
<td>-0.18</td>
<td>0.26</td>
<td>0.04</td>
<td>0.10</td>
<td>0.88</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>DDF</td>
<td>0.27</td>
<td>0.18</td>
<td>0.30</td>
<td>-0.21</td>
<td>0.07</td>
<td>-0.05</td>
<td>0.56</td>
<td>0.37</td>
<td>0.21</td>
<td>0.45</td>
<td>0.45</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Fig. 1.1. Correlation matrix between deforestation and independent variables
In general, distance to areas deforested prior to 1989 is more highly correlated with the other variables than deforestation between 1989 and 1994, perhaps reflecting a weakening of the association between the different variables over time. Another possibility is that the current pattern of roads, markets, parks, concessions, and colonies has been more endogenously determined by deforestation prior to 1989 than by recent deforestation.

We get a slightly better feeling for these results by looking at some simple descriptive statistics. Tables 1.2, 1.3, 1.4, and 1.5 show that protected areas and forest concessions were much less likely to be deforested during the study period than nonprotected areas and that very high levels of deforestation occurred in colonization zones. Class II and III soils had

Table 1.2. Proportion of forested area in 1989 in Santa Cruz cleared between 1989 and 1994 by zoning category

<table>
<thead>
<tr>
<th>Category</th>
<th>Protected Areas</th>
<th>Forest Concessions</th>
<th>Colonization Zones</th>
<th>Not Protected, Concession, or Colonization Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage</td>
<td>0.6</td>
<td>0.8</td>
<td>21.2</td>
<td>2.4</td>
</tr>
</tbody>
</table>

a. We excluded from the analysis areas with overlapping zoning categories.

Table 1.3. Proportion of forested area in 1989 in Santa Cruz cleared between 1989 and 1994 by USDA land use potential class

<table>
<thead>
<tr>
<th>Class</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>% cleared</td>
<td>4.3</td>
<td>5.9</td>
<td>1.2</td>
<td>4.1</td>
<td>0.7</td>
<td>2.1</td>
<td>0.7</td>
<td>2.0</td>
</tr>
</tbody>
</table>

a. There was no forested land with type I land use potential in 1989.

Table 1.4. Proportion of forested area in 1989 in Santa Cruz cleared between 1989 and 1994 by distance to Santa Cruz and distance to the nearest classified road

<table>
<thead>
<tr>
<th>Distance to Roads</th>
<th>&lt;1 kilometer</th>
<th>1–5 kilometers</th>
<th>&gt;5 kilometers</th>
<th>Any distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;50 kilometers</td>
<td>47.7</td>
<td>19.0</td>
<td>21.4</td>
<td>21.1</td>
</tr>
<tr>
<td>50–99 kilometers</td>
<td>56.6</td>
<td>20.4</td>
<td>10.5</td>
<td>14.7</td>
</tr>
<tr>
<td>100–149 kilometers</td>
<td>18.2</td>
<td>6.3</td>
<td>2.4</td>
<td>3.3</td>
</tr>
<tr>
<td>150–99 kilometers</td>
<td>8.9</td>
<td>2.3</td>
<td>0.5</td>
<td>0.9</td>
</tr>
<tr>
<td>200+ kilometers</td>
<td>5.0</td>
<td>1.1</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Any distance</td>
<td>11.6</td>
<td>4.9</td>
<td>1.3</td>
<td>2.0</td>
</tr>
</tbody>
</table>
a higher probability of being deforested than poorer soils, although the
difference between class II and class V is rather small. Contrary to expec-
tations, class III soils had a slightly higher probability of being deforested
than class II soils. This higher probability is related to the fact that most of
the Santa Cruz expansion zone has class III soils. Deforestation rates were
much higher in locations within 100 kilometers from the city of Santa
Cruz and less than 1 kilometer from the nearest road. Little deforestation
occurred in the most arid areas. The areas with rainfall optimal for soy-
beans had the highest deforestation, while wetter areas had the lowest.

Since these descriptive statistics could potentially mask important inter-
actions between the variables, we must look at the regression results to get
a better idea of each variable's contribution. The first regression model we
ran showed clearly that distance to small towns and distance to railroads
had no significant relation to deforestation. Most of the small towns and
railroad lines are rather far from Santa Cruz and located in places with
poor soils. Hence, in that case the descriptive result that small towns had
lower than average deforestation may simply have reflected their greater
distance and poorer soils.

We present a slightly more parsimonious model in table 1.6. This model
was significant at a 99.9 percent confidence level and explains about 35.6
percent of our total variation. (This can be thought of as our “r².”) Each
individual variable has the expected sign and was statistically significant
with at least a 99 percent confidence level. Protected areas and forest
concessions have lower forest clearing and colonization zones have higher
forest clearing even after one takes into account soil quality, rainfall, and
distance to roads, trails, Santa Cruz, and previous deforestation. Loca-
tions farther from Santa Cruz, roads, trails, and previous deforestation are
less likely to be deforested.

To get some feeling for the relative magnitude of the coefficients in this
model, we looked at the impact of changing each independent variable in
an otherwise “typical” or “representative” case. The case we chose was a
location 200 kilometers from Santa Cruz and 20 kilometers from the near-
est classified road, the nearest trail, and the nearest previous deforestation,
with average soils (USDA category = IV) and an annual precipitation of
1,100 millimeters, that was neither a forest concession nor a colonization
area. Table 1.7 shows how different changes in each variable could be
expected to change deforestation in that context. It shows that, all other
things being equal, making a typical area a forest concession would have
reduced the probability of its being cleared by half, while making it a
Table 1.5. Proportion of forested area in 1989 in Santa Cruz cleared between 1989 and 1994 by precipitation level

<table>
<thead>
<tr>
<th>Rainfall (mm)</th>
<th>300–899</th>
<th>900–1199</th>
<th>&gt;1200</th>
</tr>
</thead>
<tbody>
<tr>
<td>% cleared</td>
<td>1.5</td>
<td>3.6</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Table 1.6. Regression results for the probability of a forested area in Santa Cruz in 1989 remaining forested in 1994

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>t-statistic</th>
<th>Statistical Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2.8630</td>
<td>10.63</td>
<td>.001</td>
</tr>
<tr>
<td>Colonization zone</td>
<td>-0.4247</td>
<td>2.84</td>
<td>.01</td>
</tr>
<tr>
<td>Protected area</td>
<td>1.4750</td>
<td>2.83</td>
<td>.01</td>
</tr>
<tr>
<td>Concession</td>
<td>0.7899</td>
<td>5.14</td>
<td>.001</td>
</tr>
<tr>
<td>Soil</td>
<td>0.1442</td>
<td>3.92</td>
<td>.001</td>
</tr>
<tr>
<td>Rainfall</td>
<td>-0.0529</td>
<td>3.51</td>
<td>.001</td>
</tr>
<tr>
<td>Distance to Santa Cruz (DT1)</td>
<td>0.0080</td>
<td>12.05</td>
<td>.001</td>
</tr>
<tr>
<td>Distance to roads (DR)—the inverse</td>
<td>-0.2135</td>
<td>8.06</td>
<td>.001</td>
</tr>
<tr>
<td>Distance to trails (DRLRo)—the inverse</td>
<td>-0.4072</td>
<td>3.55</td>
<td>.001</td>
</tr>
<tr>
<td>Distance to previous deforestation (DDF)—the inverse</td>
<td>-0.2554</td>
<td>13.03</td>
<td>.001</td>
</tr>
</tbody>
</table>

Table 1.7. The expected percentage of forest clearing between 1989 and 1994 for different values of the independent variables in an otherwise typical case

<table>
<thead>
<tr>
<th>Variable</th>
<th>% Deforested</th>
<th>% Deforested as of Typical Case</th>
<th>Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical case</td>
<td>1.36</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Protected area</td>
<td>0.31</td>
<td>23</td>
<td>Make the location a protected area</td>
</tr>
<tr>
<td>Concession</td>
<td>0.62</td>
<td>46</td>
<td>Make the location a forest concession</td>
</tr>
<tr>
<td>Colony</td>
<td>2.06</td>
<td>152</td>
<td>Make the location a colony</td>
</tr>
<tr>
<td>Soil</td>
<td>1.56</td>
<td>115</td>
<td>Improve the soil quality by one class</td>
</tr>
<tr>
<td>Rainfall</td>
<td>1.51</td>
<td>111</td>
<td>200 mm more of rainfall</td>
</tr>
<tr>
<td>Distance to roads</td>
<td>1.48</td>
<td>109</td>
<td>10 km instead of 20 km</td>
</tr>
<tr>
<td>Distance to trails</td>
<td>1.46</td>
<td>107</td>
<td>10 km instead of 20 km</td>
</tr>
<tr>
<td>Distance to Santa Cruz</td>
<td>2.01</td>
<td>149</td>
<td>150 km instead of 200 km</td>
</tr>
<tr>
<td>Distance to previous deforestation</td>
<td>1.60</td>
<td>118</td>
<td>10 km instead of 20 km</td>
</tr>
</tbody>
</table>

a. Typical case is a location 200 kilometers from Santa Cruz and 20 kilometers from the nearest classified road, the nearest trail, and the nearest previous deforestation, with average soils (USDA category IV) and an annual precipitation of 1,100 millimeters, that was neither a concession nor a colonization area.
protected area would have reduced the probability by three-quarters. Building roads and trails has somewhat smaller but still considerable effects.

Because of the relatively high level of correlation between distance to previously deforested land and a number of the other independent variables, our model has a certain degree of multicollinearity. Indeed one would expect *ex ante* that many of the same variables that influenced recent deforestation also affected previous deforestation, as reflected by the fact that when we tried regressing all of the other independent variables on distance to previous deforestation we got a statistically significant equation with an $r^2$ of around 0.3. We considered omitting the variable but decided against it since doing so would have given us biased estimates, because distance to previous deforestation probably plays an important role in its own right. As noted earlier, several studies have shown that farmers are more likely to deforest places closer to where they have deforested in the past, even when other variables are held constant.

Fortunately, the practical effects of the multicollinearity seem reasonably small. When we ran the same regression without the “distance to deforestation” variable, the estimated standard errors did not change much and all of the coefficients retained the same sign, although in general they became slightly larger (except soils). From a practical standpoint this finding implies that most of the other independent variables probably have a slightly larger effect on deforestation than shown in our previous discussion.

**Conclusions and Topics for Future Research**

We consider these results preliminary, yet suggestive. We are currently in the process of validating the results using smaller polygons and alternative sampling procedures. By focusing on different subregions within Santa Cruz, we should be able to get a sense of how our independent variables affect deforestation differently in regions dominated by large-scale mechanized farmers and in those where small-scale agricultural colonists are more prevalent. One good way to check the reliability of spatial deforestation models is to produce maps of where the predicted deforestation will occur and compare them with where it actually took place. We plan to do that. We also wish to examine specific aspects of soil quality that cannot be gotten by using the USDA’s general eight-class typology, including erosion susceptibility, drainage, salinity, alkalinity, depth, nutrient status, and presence of hardpans.
Spatial autocorrelation is a common problem when one does statistical analysis using geographic data, since nearby locations are more likely to be more similar than distant ones. This can lead to biased coefficients, inefficient parameters, and inaccurate measures of statistical significance (Chomitz and Gray 1996; Rosero-Bixby and Palloni 1996). Unfortunately, we have so far been unable to test our model for spatial autocorrelation because our initial data set did not include the x and y coordinates. We hope to do these tests in the future. Nevertheless, we believe that our model has probably done a good job of incorporating the main spatial variables that affected deforestation in Santa Cruz between 1989 and 1994. If that is the case, we do not expect spatial autocorrelation to be a major problem.

None of the conclusions from our model comes as a surprise. For the most part they simply reaffirm previous spatial econometric studies in other regions. Farmers clear more forests in more accessible locations with environments more favorable for agriculture and where no one restricts them from doing so. They will increase their forest clearing still further where—as in the colonization zones—the government subsidizes their farming activities.

What theory alone cannot predict is the size of the coefficients. Being able to predict how much we can expect deforestation to increase in a location if we create a protected area, give out a forest concession, or build a road there provides us with a powerful new tool for environmental impact assessment. To date, these tools have apparently not been used in the Amazon. But they should be.

Acknowledgments

This essay represents a collaborative effort between the Center for International Forestry Research (CIFOR) in Bogor, Indonesia; the Natural Resources Department of the Government (Prefectura) of Santa Cruz, Bolivia; and the Bolivian Sustainable Forest Management Project (BOLFOR). The authors wish to express their gratitude to individuals in each of these institutions who have contributed to our efforts, including Sergio Antelo, Andreas Carstens, Osvaldo Escalante Saldaña, Francisco Kempff, John Nittler, and Roderich von Offen. Other useful comments and suggestions have come from Greg Amacher, Luc Anselin, Ken Chomitz, Jeffrey Sayer, Ivan Morales, Gery Nelson, William Sunderlin, Tom Tomich, and Cristian Vallejos.
References


Deforestation and Forest Degradation in Lowland Bolivia

Pablo Pacheco

This chapter analyzes the causes of deforestation and forest degradation in the Bolivian Amazon. The study is predicated on the assumption that the factors involved have less to do with the forest sector itself than with events that take place within the country’s political, economic, and social arenas.

The conclusions of numerous studies agree that the main causes of forest clearing and degradation can be traced to pressures that originate in economic and demographic growth, in public policy, and in the nature of political structures and institutional systems (Brown and Pearce 1994; Dorner and Thiesenhusen 1992; Gregersen 1992; Laarman 1995; Montalembert 1992). The factors associated with these various dimensions are closely connected to each other, interacting in ways that involve complex causal relationships and sometimes producing contradictory outcomes (CIFOR 1995). While demographic, economic, and policy trends in recent decades have led to deforestation and forest degradation, this has not been the result in all cases (Kaimowitz 1997; Kaimowitz and Angelsen 1998).

Few reliable estimates exist with respect to land cover change in Bolivia, and the information that does exist is fragmented in time and uneven in geographic coverage. Existing data suggest that the level of deforestation remained relatively low up to the decade of the 1960s, after which it increased moderately over the next two decades, then rose sharply beginning in the early 1990s. The evidence of forest degradation is less consistent, although the data suggest that degradation has intensified markedly over time.

In light of this evidence, we assume that deforestation in the lowlands of Bolivia is related to the styles of economic development that were asso-
related with a period of state capitalism from 1952 to 1985. This period was followed by a period of structural adjustment policies characterized by market liberalization, cutbacks in public spending, and an increase in external commerce.

The first section of this chapter reviews the situation of land tenure in the Bolivian lowlands and summarizes the information about the magnitudes of deforestation and forest degradation, noting their principal causes. The second part presents an analysis of the condition of the forests until 1985, followed by the third section that evaluates the changes in forest cover associated with structural adjustment policies. The fourth part describes the current situation generated by new land and forest use regulations. The last section presents the main conclusions of this investigation.

**Deforestation and Forest Degradation**

**Land Tenure and Lowland Forests**

As seen in map 2.1, the lowlands of Bolivia (as defined in this study) include the entire departments of Beni, Pando, and Santa Cruz and the tropical areas of Cochabamba and La Paz. The majority of the region lies less than 500 meters above sea level, with the exception of the much higher areas in the Yungas of La Paz and Cochabamba (Montes de Oca 1989). The total area covered is 763,000 square kilometers, of which 445,000 square kilometers is forest (58 percent of the total area) (MDSMA 1995).

Official statistics indicate that, between 1955 and 1994, the Bolivian government took 28.9 million of the 76 million hectares that comprise the region and distributed the land to different groups. Approximately 23 million hectares were allocated to large- and medium-sized farms. Another three million hectares were distributed to farmer colonists located in newly settled areas (see table 2.1), although a much larger proportion of the land is illegally held by large farmers and cattle ranchers.

In 1990 pressure generated by the indigenous movement compelled the Bolivian government to enact a decree that created four indigenous territories. Five others were established between 1992 and 1993, bringing the total to around three million hectares. In addition, acting under the current National Agrarian Reform Law (no. 1715, October 1996), the National Agrarian Reform Institute (INRA) “immobilized” another 11.7 million hectares. This action forbade the further distribution of land in any
Map 2.1. Lowland Bolivia
of the sixteen areas claimed by indigenous communities (*Tierras Comunitarias de Origen*, TCOs). Indian villages will receive title to a portion of these lands, although the size of the areas so designated is as yet unknown.

In 1994, a total of 20.7 million hectares had been granted under forest use contracts to 173 business enterprises, although only 3 million hectares were actually being harvested (Hunnisett 1996, 7). Of this total area, just

Table 2.1. Land tenure and other use rights

<table>
<thead>
<tr>
<th>Distribution of Land by Type</th>
<th>Area (1,000 ha)</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total lowland area</td>
<td>76,300</td>
<td></td>
</tr>
<tr>
<td>Forested area</td>
<td>44,500</td>
<td></td>
</tr>
</tbody>
</table>

**Individual and Communal Properties**

- Commercial farms\(^a\): 22,853
- Small farmer colonists\(^b\): 3,192
- Community lands (TCOs)\(^c\): 15,976
  - Titled: 2,860
  - Title requested\(^d\): 11,747
  - Title pending: 1,369

**Areas of Forest Use**

- Long-term contracts for forest use (until 12/1996): 20,700
- Forest concessions (after 12/1996): 5,800
- Forested area released under new regime: 14,900

**Protected Areas**

- Total lowland area under protected status: 12,800
- Protected areas not legislatively defined: 1,900


- b. Lands distributed by INC (1961–94); includes land with titles and pending titles.
- d. Areas claimed by indigenous groups, titles pending.

Additional areas have been illegally or semilegally occupied, primarily by medium and large producers, and by de facto colonists in coca-producing areas in Chapare. Reliable data do not exist.

Reduction due to the conversion of long-term forest use contracts into concessions, by the new forest law (no. 1700) of 1996.

Refers exclusively to designated protected areas in the lowlands that may or may not have management plans in place.
over 6 million of the designated hectares fell within areas classified as permanent production forests. The remaining 70 percent fell within other classes of forests, generally on private property, or were superimposed on lands occupied by indigenous populations. This situation provoked frequent land conflicts between logging companies, indigenous groups, colonists, and commercial farmers (Quiroga and Salinas 1996; World Bank 1993).

The profile of forest rights was modified by the new Forestry Law (Ley Forestal, no. 1700, July 1996) that changed the concession system from one based on the volume of timber extracted to one based on the size of the area to be harvested. The result has been a 70 percent decline in the areas under concession. Currently eighty-nine timber companies hold the rights to 5.8 million hectares, which were legalized in August 1997 (SF 1998b).

Since the mid-1980s, the proportion of lowlands held in protected areas has emerged as an important issue. By 1995, 12.8 million hectares, or 17 percent of lowland Bolivia, had come under some form of legal protection, although the legal status of 1.9 million of these hectares has yet to be established. In practice, only a small fraction of the total area is actually protected (Pacheco 1998).

It should be noted that the lowland areas of Bolivia are characterized by conflicts between different groups over access to forest resources, largely as a consequence of the superimposition of contradictory rights and boundaries. Although it is difficult to quantify the magnitude of this phenomenon, it is evident that overlapping land and forest use rights have been given to farmers, ranchers, and timber companies. Other sources of conflict are related to the competition for land held by indigenous groups, the establishment of protected areas in places already occupied by small farmers, and the penetration of timber companies into protected forests (Pacheco 1998; World Bank 1993).

The Magnitude of Deforestation

In Bolivia, the amount of deforestation that has taken place in lowland areas has been relatively low compared to other countries with tropical forests, although forest clearing and forest degradation in Bolivia have risen over time. In the early 1980s the estimated deforestation in all of Bolivia was 87,000 hectares per year, equivalent to an annual rate of 0.2 percent (Bakker 1993, 3). This value is less than half the average observed in other Amazonian countries (0.5 percent), and one-third the average for Latin American countries as a whole (0.6 percent). Other sources indicate that the area of Bolivia that was deforested up to the end of the 1970s and
into the early 1980s varied between 50,000 and 90,000 hectares per year (FAO 1983; Stolz 1978).

According to available data (Mapa Forestal del MDSMA 1995), approximately 3.02 million hectares of forest cover were lost between 1975 and 1993 (168,000 hectares per year, or 0.3 percent annually). This estimate for the country as a whole is an average for the eighteen-year period, but if we assume that deforestation grew exponentially during this period, the actual current rate would be higher. Despite these considerations, it is likely that deforestation in Bolivia in the late 1980s and early 1990s has been below that observed in other countries with tropical forests: the size of the forest cover in Central America and Mexico declined at an annual rate of 1.5 percent, while the figure for tropical South America was 0.7 percent (see table 2.2).

Since 1990, deforestation in the department of Santa Cruz has significantly increased. The total deforested area averaged 78,000 hectares per year in the 1989–92 period (Morales 1993). In the years that followed (1992–94), an additional 235,000 hectares were cleared in Santa Cruz (117,000 hectares per year), representing a 50 percent increase over the previous years (Morales 1996). Although the majority of this deforestation took place in Pailón–Los Troncos, forest clearing has also expanded into colonization areas located in northern Santa Cruz, Chapare, and northern La Paz. Cattle ranching has been one of the factors that has contributed to increased deforestation in Santa Cruz.

**Evidence of Forest Degradation**

The kind of forest extraction practiced in Bolivia is highly selective. With rare exceptions, no more than five trees are harvested per hectare. The actual volume of timber harvested is generally lower than the quantity harvested per hectare in southwestern Asia and parts of Africa (World Bank 1993, 20). The most commonly harvested species are mahogany (*Swietenia macrophylla*), ochoó (*Hura crepitans*), cedar (*Cedrela* sp.), roble (*Amburana cearensis*), serebó (*Schizolobium* sp.), almendrillo (*Dipteryx* sp.), and tajibo (*Tabebuia* sp.) (López 1993). The degree to which logging activities have destructive effects is related to the density of the target species within the harvested forests (Jiménez et al. 1996). A study of the Chimanes forest, where density is only 0.12 trees per hectare, noted relatively low damage caused by the construction of logging roads (3.92 percent) and by the cutting operations themselves (0.47 percent) (Gullison and Hardner 1993, 5–6).

The rate of timber extraction is taking place faster than the forest can
Table 2.2. Available estimates of deforestation in Bolivia

<table>
<thead>
<tr>
<th>Source</th>
<th>Geographic Coverage</th>
<th>Method</th>
<th>Period</th>
<th>Area Deforested (1,000 ha)</th>
<th>Rate of Deforestation (ha/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.31%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Total by 1990:</td>
<td>0.19%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2,397.49</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Total by 1992/93:</td>
<td>0.25%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,862.19</td>
<td></td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Total by 1991:</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2,097.67</td>
<td>0.38%</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.43%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.5%</td>
</tr>
</tbody>
</table>
regenerate itself, thereby posing a long-term threat to the forest’s capacity to recover naturally from the disturbance. A more recent study of the Chimanes forest indicated that the reserves of mahogany are nearly exhausted (Gullison et al. 1996). A similar analysis (Jiménez et al. 1996) found that the mahogany trees in the Chore forest were not regenerating at a rate sufficient to maintain the stands.

Agents of Deforestation

Because the various social groups in lowland areas employ distinct practices of land use and resource exploitation, each type of actor has different effects in terms of deforestation and forest degradation. This scenario is further complicated by the fact that there is little information about the interrelationships among the various actors that depend on the land and forests for their livelihoods, thereby making it difficult to isolate the particular impact that any one group might have. Some of these interactions involve competition for forest resources, as when colonists and independent loggers compete with timber companies (Thiele 1990). In other situations, these same actors establish complementary relationships, as when timber companies hire loggers to extract wood from colonization sites, protected areas, and forest reserves (Kraljevic 1996). Although no precise data exist on the exact number of these producers or the area that they occupy, some referential information is presented in table 2.3.

The principal direct cause of deforestation in Bolivia is the conversion of forests to agricultural use by small, medium, and large farms. Large cattle ranches are not very common in the area, and indigenous groups have only a limited impact on forests (Goitia and Gutiérrez 1992; Hunnissent 1996; World Bank 1993). The logging industry plays an active role in the degradation of forests and is responsible for some deforestation. As has been noted, logging operations themselves have a relatively small direct impact on the loss of forest cover, but indirectly facilitate the conversion of forests into agricultural uses (Anderson et al. 1995).

The Period of Economic Diversification, 1952–1985

Policies for Agricultural and Forest Development

The period from 1952 to 1985 was associated with a pattern of economic development and capital accumulation known as the “Model of 1952,” which lasted until the mid-1980s. Exports from the nationalized mining sector were the main source of profit and public revenue. The attempt to
### Table 2.3. Actors that influence land and forest use in Lowland Bolivia

<table>
<thead>
<tr>
<th>Actor</th>
<th>Location</th>
<th>No. of Producers</th>
<th>Estimated Area(^a) (1,000 ha)</th>
<th>Type of Intervention</th>
<th>Incidence of Deforestation/Degradation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small farmer/colonist</td>
<td>Yungas &amp; North La Paz (La Paz)</td>
<td>36,000</td>
<td>1,300</td>
<td>Predominantly slash-and-burn agriculture for commercial crops; non-diversified subsistence crops; mechanized production, diversified crops, and pasture conversion in some areas; occasional timber extraction.</td>
<td>Modest deforestation; greater proportion of fallow and secondary growth in older settlement areas; forest holdings already degraded due to selective harvesting in the past.</td>
</tr>
<tr>
<td></td>
<td>Chapare (Cochabamba)</td>
<td>34,000</td>
<td>1,640</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Llanos Cruceños &amp; Chiquitania</td>
<td>23,000</td>
<td>6,660</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Santa Cruz)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Riberálta-Guayaramerín (Beni)</td>
<td>3,600(^b)</td>
<td>2,240</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium and large farmers</td>
<td>Mainly in plains of Santa Cruz (Integrated Zone). Increased mechanization of production east of the Rio Grande (Expansion Zone)</td>
<td>50,000–70,000(^c)</td>
<td>N/A</td>
<td>Mostly highly mechanized firms that apply advanced production technologies to diversified cropping systems, although soil conservation is infrequent.</td>
<td>Nearly all land cleared in Integrated Zone. Mechanized deforestation accelerated in the Expansion Zone and in frontier areas.</td>
</tr>
<tr>
<td>Large cattle ranches</td>
<td>Beni Savannas</td>
<td>10,000–12,000(^d)</td>
<td>31,814</td>
<td>Medium- and large-scale ranches; low level of beef productivity and inefficient use of natural resources.</td>
<td>Natural savannas in Beni do not require forest clearing; mechanized deforestation more pronounced in Chiquitania</td>
</tr>
<tr>
<td></td>
<td>Chiquitánia Plains (Santa Cruz)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chaqueña Plains (Santa Cruz, Chuquisaca &amp; Tarija)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Amazonia (Pando)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indigenous subsistence agriculture</td>
<td>Dispersed throughout lowlands in departments of Pando, Beni, &amp; Santa Cruz,</td>
<td>30,000–50,000(^e)</td>
<td>18,250</td>
<td>Small-scale slash-and-burn agriculture with frequent rotation of fallow areas.</td>
<td>Limited impact on forests. Cultivation system allows for regeneration of forest in areas temporarily used for agriculture.</td>
</tr>
</tbody>
</table>
northern La Paz & Cochabamba, & in eastern Chuquisaca & Amazonia (Pando)

<table>
<thead>
<tr>
<th>Effects due to Timber Harvesting</th>
<th>Forest companies</th>
<th>Informal logging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concessions located principally in departments of Santa Cruz, Beni, and northern La Paz, and currently in Pando. In Chapare, wood harvested mainly by farmer colonists.</td>
<td>In 1994, 20,700 in concession 173</td>
<td>In 1996, 5,800 in concession 89</td>
</tr>
<tr>
<td>Selective logging in the absence of rational forest management. Harvest rates closely associated with the availability, accessibility, and price on the international market. and on biodiversity.</td>
<td>Selective logging has a relatively moderate effect on forest structure due to the dispersal of extracted species, but a high impact on regeneration of target species.</td>
<td>Small logging operations using chainsaws. Current activities limited by the distance to harvest areas that increases the cost of extraction. Effects on the forest have not been sufficiently determined, although the high level of timber extraction in some areas impedes the regeneration of some valuable species.</td>
</tr>
</tbody>
</table>

**Sources:** Adapted from López 1993; Mancilla 1994; MDSMA 1995; Muñoz 1996; PAF 1990; SNAE 1994; Thiele 1995.

a. Areas based on Muñoz 1996.
b. Estimates based on squatter settlements with census data as base (INE 1993), Chapare data adjusted to census data (INE 1996).
d. Producers affiliated with ranching federations.
e. Based on SNAE data (1994).
diversify the economic structure, and policies that promoted import substitution development, led to the growth of the petroleum industry and to the expansion of agriculture in eastern Bolivia (Dandler 1984; Grebe 1983; Reye 1970; Wennergren and Whitaker 1975).

Macroeconomic policies favored exchange and tariff mechanisms in order to generate capital from the mining sector. A portion of the profits was to be used to invest in the construction of roads. The government also carried out direct investments in state-owned oil companies and established credit policies that favored commercial agriculture (Lazarte and Pacheco 1992; World Bank 1978). Because these policies were adopted within a context of limited revenues and tight budgets, a substantial portion of the required capital was obtained through foreign loans (Arze 1979).

The majority of public investments went to lowland areas due to the existence of oil reserves in this region and the availability of new lands for agricultural and forest use (Nelson 1977; Reye 1970). A portion of these resources was used to open the agricultural frontier to the production of crops that could substitute for agricultural commodities that were imported into the country, thereby saving foreign exchange (Arrieta et al. 1990). With this goal in mind, the government set out to construct new roads and to freely distribute forested lands. Colonization schemes were adopted, as well as internal price controls and selective credit policies that favored large-scale agricultural enterprises (Arrieta et al. 1990; Eastwood and Pollard 1985; Pacheco 1998). Only later, in the mid-1970s, would a forest law be put into effect (World Bank 1993).

The development model adopted during this period led to the progressive decline in Bolivia’s national economy, which, in the early 1980s, assumed crisis proportions. The economic downturn, and the political instability associated with it, lasted through the middle of the decade. The factors that contributed to the economic crisis, included (a) a decline in revenues produced by the mining sector; (b) an export economy that was not sufficiently diversified; (c) a drop in the international prices paid for Bolivia’s main export commodities; (d) an increase in the interest rate applied to the foreign debt; (e) a decline in the sources of international funding; and (f) a drop in government revenues that depended heavily on the value of exports and the influx of foreign capital (Morales and Sachs 1987).
Agricultural Expansion and Forest Extraction

The colonization programs that were adopted during this period had a decisive influence on the pattern of internal migration in the country as migrants began to leave the highlands and head toward forested areas located in lowland Bolivia. Other factors that stimulated new settlement sites included the road construction projects that facilitated access to markets, as well as the land distribution policies that were adopted. The relative prices of inputs and outputs in the agricultural sector further benefited small farmers, as did the increase in the demand for labor by rural enterprises (Albó 1983; Blanes et al. 1985; Vilar 1981; Zeballos 1975).

In a two-decade period colonization areas had absorbed around 250,000 small farmers. Another 50,000 were employed as day laborers in the rural areas of the department of Santa Cruz. Net immigration also occurred in rural Yungas and Chapare. By the end of the 1970s, the rural population in the colonization zones reached 290,000 people (58,000 families), a figure that amounted to around 6 percent of the country’s total population (Blanes et al. 1985; Zeballos 1987).

Colonization played a major role in deforestation, although it is difficult to measure its effect with precision. It seems clear that there was a direct relationship between population growth in frontier areas and the quantity of land that was deforested, yet this relationship was not linear over time, making it difficult to establish the precise association between colonization and land clearing. According to Castro’s (1986) estimates, colonists had to clear about three hectares for every one that was put into production. Likewise, it is known that a portion of the lands that were cleared later reverted to secondary growth (Hoyos et al. 1991).

By the end of the 1980s the area cultivated by rural farmers increased (Pacheco 1998). The factors that explained this growth were associated with the external demand for coca and the increased internal demand for agricultural goods such as rice and corn. It is reasonable to assume that a good portion of the expansion of coca-producing areas was at the expense of primary forest, but it is not known how much of the expansion of other crops may have had the same effect. The latter depended on a number of factors, including the age of settlements, the access that farmers had to primary forests, and the intensity with which farmers used their land (Thiele 1993).

For its part, the policy of distributing free land in the plains of Santa Cruz favored the consolidation of medium and large properties. These enterprises developed a production structure that was not very diverse,
partly due to the subsidies given to farmers who planted sugar, rice, and corn, and partly to numerous government programs that promoted their cultivation, including cheap credit, guaranteed prices, and technical assistance. The commodity that experienced the most rapid increase was sugar, a crop that benefited from favorable domestic prices and high import tariffs. However, by 1964 the oversupply of sugar prompted the government to apply production quotas to sugar mills and to limit the amount of sugarcane that any one farmer could sell to the mills (Escobar and Samaniego 1981; Reye 1970). A portion was exported to the United States due to the existence of a small preferential quota for sugar produced in Bolivia.

Forest clearing by medium and large agricultural companies accelerated during the 1970s. The increase was due to the expansion of commercial agriculture in the Santa Cruz region, where expansion of cotton production was especially rapid. The quantity of land devoted to cotton increased from 8,000 hectares in 1970 to 68,000 hectares in 1973, making it one of the most significant advances in mechanized agriculture in the country. In little over two years, new cotton fields occupied an area nearly as large as the total amount of land devoted to cotton in previous decades.

In the second half of the 1970s, cotton was no longer profitable as a result of several factors, including increased production costs caused by a rise in cost of inputs, an increase in commercial interest rates, and declining harvests in those areas where soils were poor and rainfall was inadequate (Arrieta et al. 1990; Escobar and Samaniego 1981). The area devoted to sugarcane grew more slowly than cotton, but continued to increase at a steady pace until 1977, when it reached a maximum of 60,000 hectares. This increase was due to higher international prices, although it too was influenced by subsidized bank credit and increased consumer prices (Suárez 1992). The decline in the international price of sugar after 1975 led to a decline in sugar exports, yet production continued to increase as a result of government-sponsored domestic price guarantees.

In the beginning of the 1980s, the area devoted to commercial agriculture expanded at a rate of 6,500 hectares annually (Pacheco 1998). This figure was slightly less than what was observed during the previous decade. It was a period characterized as much by a change in the structure of production as in the profile of the people involved (Vilar and Kuper 1995). Sugarcane and cotton, which were grown exclusively by Bolivian producers, came to a standstill, thereby reducing their importance among commercial crops. At the same time, Japanese and Mennonite farmers increased the area planted in soybeans and sorghum (Thiele and Farrington 1988).
Development projects during this period did not consider forestry to be an important component of the plan to diversify the economy. During the 1970s, the forestry sector experienced a degree of activity, yet there is little reliable information regarding the areas involved or the quantity of timber that was produced. Before then, during the 1960s, the harvesting of timber was mainly located near the city of Santa Cruz. Hardwoods were extracted from an 80-kilometer radius around the capital city (Stearman 1983). The extension of roads to the north from Santa Cruz in the decade of the 1960s permitted access to new areas for logging operations, as did the construction of oil prospecting trails. Wood was also extracted in areas of colonization in northern Santa Cruz (Thiele 1990). Much of the most valuable hardwoods was harvested during this period.

Production data show a greater than 100 percent increase in timber production between 1970 and 1979, from 23 to 65 million square feet. Dramatic as these figures may be, it is likely that they are underestimates given that a great deal of timber was illegally exported (Stearman 1983). In spite of the fact that the extraction of wood products was legally confined to areas classified as forest reserves, much of the harvesting that occurred took place in nonclassified areas (Stolz 1986). Large firms operated within the reserves, while small and medium-sized firms purchased timber from colonists (Stolz 1978).

The economic crisis that took place in the early 1980s was reflected in the decline in the production of timber for the domestic market, and a sharp drop in the amount of wood sold on the international market. Data on the export trade show that the value of wood products fell from U.S.$31 million in 1980 to U.S.$5.8 million in 1985. Anderson and colleagues (1995) contend that much of the decline could be attributed to the large disparities between the official and the unofficial exchange rates, which made the legal export of wood an unattractive option. Another consequence of the exchange rate problem was evident in the expansion of contraband exports to Brazil (Stolz 1986).


Stabilization and Adjustment Policies

Beginning in 1985, the Bolivian government embarked on a program designed to reverse the deteriorating condition of the national economy. This reversal was carried out via stabilization policies and the implementation of a structural adjustment program (Morales 1991). To stabilize the economy, the government devalued the Bolivian currency, reduced public
expenditures, and tightened monetary policy. Exchange rates were unified, and the markets for goods, capital, and labor were liberalized (Arze et al. 1994). Restrictions on the commercial sector were eliminated, and uniform policies were adopted with respect to tariffs and interest rates (Arze et al. 1994; Morales 1991).

Once the economy was stabilized, the government sought ways to stimulate the more dynamic sectors of the economy. This stimulation was accomplished through fiscal incentive programs designed to promote the export of nontraditional commodities. A “draw-back” scheme was implemented as a means to reduce the price of imported capital equipment involved in the production of export commodities. Other initiatives sought to further the economic integration of the Andean region. To complement these programs, the government invested in the construction of new roads, refinanced credit for designated economic activities, and lowered freight charges for agricultural export commodities transported on the public railroad system (Carreón and Pinto 1997).

In the 1990s these structural adjustments were further complemented by reforms in the financial sector, the privatization of public enterprises, a reform of the educational system, and a process of political decentralization. New policies were introduced with respect to landownership, and a new regulatory scheme was adopted to address environmental issues and the management of natural resources. The policies carried out in the 1990s (except those dealing with the environment) are generally referred to as “second generation reforms” within the structural adjustment agenda.

Important changes occurred with respect to the colonization of land and with respect to landownership. In the first ten years of the structural adjustment period, the only market that was not subject to liberalization reform was the market for land. In practice, rural properties continued to be bought and sold and the government continued to hand out large tracts of land. Under these circumstances, the lack of secure title promoted a lawlessness that contributed to the accumulation of rural lands for purely speculative purposes (Muñoz and Lavadenz 1997).

The institutional practice of handing out large areas of land had the effect of closing the frontier to small farmers (Thiele 1995). State funds intended to support the colonization of Bolivia’s lowlands were eliminated, and the plans devised in the first half of the 1980s to support small-farmer colonization projects were abandoned. Nonetheless, this was also a time when, contrary to the noted trends, the government recognized the rights of indigenous people to nine territories, opening the possibility for new ethnic groups to present new land claims.
Structural Adjustment Policies and Deforestation

The sharp increase in mechanized agricultural production in Santa Cruz between 1986 and 1995 became the main cause of deforestation in Bolivia. The area subjected to mechanized production grew from 177,000 to 670,624 hectares, which represented an eightfold increase compared to the 1970s. The amount of deforestation that was associated with this trend rose from 25,000 hectares in 1989–92 to 42,000 hectares in 1992–94, and reached approximately 100,000 hectares by 1995.

Much of the forest clearing took place in the so-called “expansion zone” (zona de expansión) east of the Grande River. It is an area of deciduous forests where soils are fertile yet vulnerable to compaction and erosion. The deforestation that has taken place in this area was primarily associated with the expansion of soybean production. The summer crop alone grew from 55,000 hectares in 1986 to 339,326 hectares in 1995. These figures imply a rate of increase of around 32,000 hectares per year. By 1997, another 100,000 hectares were cleared to make way for the soybean crop (CAO 1997, table 61). Increases were also recorded in the area devoted to other crops such as wheat, sorghum, and sunflowers, which were planted during the winter rotation (Vilar and Kupfer 1995).

The expansion of the agricultural frontier was carried out by both domestic and foreign producers, although the latter were more active. A key feature of the foreign presence in the zone of expansion was the striking increase in the role played by Brazilians. By 1995–96, Brazilians controlled about 27 percent of the land under soybean production in the department of Santa Cruz. While domestic producers cultivated an area that was equivalent in size to that of the Brazilians, the pace of increase was slower (Baudoin et al. 1995; CAO 1997).

Numerous studies concluded that the increase in deforestation was associated with various policy and market-based incentives. The principal factors included (a) the effects of currency devaluation and economic stability; (b) policies that stimulated exports and subsidized the public railroad system; (c) the construction of new roads and the maintenance of existing ones; (d) policies that made new lands available at low cost to large landholders; and (e) the international demand for soybeans and, especially, market conditions that favored the export of Bolivian vegetable oils to countries in the Andean region (Baudoin et al. 1995; Hecht 1997; Kaimowitz et al. 1999; Pacheco 1998).

Davies and Abelson (1996) maintain that the economic benefits derived from the production of soybeans were sufficient to justify the re-
duced extraction of timber and nontimber forest products, as well as the soil degradation and carbon release associated with soybean cultivation. Similarly, Kaimowitz et al. (1999) note that the expansion of the soybean crop took place mainly in areas where soil fertility and precipitation rates were appropriate for agricultural development.

But deforestation has also taken place beyond those areas that were designated for agricultural development. In addition to causing environmental problems, the expansion of agriculture into fragile lands calls into question the long-run sustainability of these activities (World Bank 1993). In this regard, Baudoin and his colleagues (1995) note that the cultivation of annual crops in such areas will have negative medium-term effects if landholders do not carry out soil conservation practices.

Another concern focuses on biodiversity. While the expansion of mechanized agricultural production benefits a small number of producers and exporters, society at large suffers the consequences of the loss of biodiversity and reduced carbon sequestration. At the same time, the government experiences a potential reduction in revenues from the rent that could be obtained from forest concessions. Moreover, since individual landholders are the ones who bear the costs of soil degradation, the motivation to reinvest in land is reduced by the fact that they received land at low cost to begin with. In the aggregate, this means that the country as a whole sustains a high opportunity cost due to the misallocation of land (Kaimowitz et al. 1999). Finally, since mechanized agriculture is labor-saving, the expansion of intensive forms of production has not increased the demand for labor in the agrarian sector (Pacheco 1999; Vilar and Kupfer 1995).

The proportion of the deforestation that can be attributed to small farmers located in colonization areas has been below that associated with commercial agriculture. The reasons are many: in recent years the number of colonization settlements has grown at a slower pace compared to previous periods; peasant-produced agricultural commodities have progressively become a smaller proportion of the internal market; in many of the older colonization areas there is little primary forest left to clear; and there are fewer opportunities to expand into new areas. Since the second half of the 1980s, internal demand for food crops has been sluggish, probably as a result of stagnant wage levels and the lack of effective policies to stimulate investment in this sector (COTESU/MACA/ILDIS 1990; Godoy and De Franco 1991).

According to official statistics, between 1986 and 1995 the quantity of land cultivated by peasant farmers increased by around 5,000 hectares per
year. This figure is substantially below that observed during the 1980s. The data further show a decline in the area devoted to the cultivation of coca. USAID estimates (1996), on the other hand, show that coca lands grew by 38,000 hectares from 1986 to 59,000 in 1990, followed by a slight decline to 54,000 hectares by 1995. However, the total area devoted to coca production has progressively been decreasing as a result of state programs seeking to eradicate cultivation of this crop.

The deforestation that took place among small farmers was due less to demographic pressure on new lands as a consequence of migration than to changes in land use in already-settled areas. Although migration rates did increase after the structural adjustment policies were put into place, the flow of migrants into the areas of frontier agriculture was relatively small compared to the flow of migrants that headed toward the city of Santa Cruz and into urban areas generally. This pattern is less evident in the coca-producing zone of Chapare, where rural population growth was high (Pacheco 1999). Moreover, much of the deforestation that does take place occurs in the interior regions of the colonization zones. Although data are scarce in this respect, various studies (Baudoin et al. 1995; Thiele 1995) suggest that land has become scarce. The virtual closing of the agricultural frontier to small producers has reached a point where peasant farming has begun to move into protected areas and forest conservation zones (Pacheco 1998).

The effect of public policies on deforestation in colonization areas was limited. By dampening the prices paid for the commodities produced by small farmers, the structural adjustment policies provided little incentive for small farmers to expand the areas that they cultivated. By the same token, cutbacks for rural credit and extension services meant relatively little since peasant farmers were historically excluded from these programs anyway.

Structural Adjustment Policies and Forest Degradation

By promoting the export of timber products extracted from unmanaged forests, structural adjustment policies have increased the rate of forest degradation. Following a period of decline, wood exports grew from $22 million in 1986 to $79 million in 1996. The increase was partly due to currency devaluation, fiscal incentives, export subsidies, and the construction of new roads (Kaimowitz et al. 1999).

The increase in the extraction of wood was also due to an expansion in internal demand, primarily from the construction industry. The internal market absorbed about 30 percent of wood produced, making the con-
struction industry an important complement to export activities (World Bank 1993). According to available data, the total volume of wood produced in the country reached 320,000 cubic meters in 1986, and increased to 448,000 cubic meters in 1995. Impressive as this increase may seem, it is worth noting that the level of production in 1995 was only about 3,700 cubic meters greater than the level of production recorded in 1980 (CNF 1996).

About two-thirds of the production between 1986 and 1995 involved only five species: mahogany (*Swietenia macrophylla*), ochoó (*Hura crepitans*), cedar (*Cedrela* sp.), *roble* or *tumi* (*Amburana cearensis*), and *serebó* (*Schizolobium* sp.). The extraction of mahogany declined during the period due to the increasing scarcity of mahogany trees, while the production of the other species increased. Although the harvest of species besides these five has been modest, the trend is on the rise. Other species are gradually assuming importance such as fig (*Ficus* sp.) and *yesquero* (*Cariniana* sp.), which is used primarily in construction (López 1993).

The growth in timber exports was due primarily to the new exchange rates and to policies that were designed to stimulate exports. Anderson and colleagues (1995) concluded that structural adjustment policies led to increases in the harvest of timber and to the degradation of forest stands. According to this study, the currency devaluation that took effect in 1985 accounted for about 25 percent of the increase in timber exports between 1984 and 1991. Another 25 percent was due to higher prices on the international market, while the remaining 50 percent of the increase could be attributed to improvements in the process of registering wood exports. Improved reporting was achieved because of the elimination of the previous differences between the official and unofficial exchange rate, which reduced the incentive for illegal exports.

In a similar analysis of the export trade, Kaimowitz et al. (1999) drew on the same data as Anderson, but based their interpretation on different assumptions. According to Kaimowitz, the structural adjustment policies could have accounted for 25 to 75 percent of the increase in exports between 1984 and 1991. These estimates imply that the size of the harvested area during the period may have increased somewhere between 13,000 and 39,000 hectares. They further suggest that the 40 percent increase in the volume of sawn timber between 1991 and 1994 implied that an additional 27,000 hectares of forest may have been harvested.

The expanded extraction of valued timber products has contributed to forest degradation because the volume of the harvests has exceeded sus-
tainable limits, and because the methods used to extract timber pay no attention to the principles of sustainable forest management. Explanations for these practices follow different plot lines. One argument contends that sustainable management practices entail opportunity costs that are simply too high for such practices to be adopted (World Bank 1993). Others argue that the lack of proper management can be attributed to the absence of effective control, to biases in forest policy, or to the lack of confidence in the legal system (Andaluz et al. 1996; Stolz and Quevedo 1992; Szwagrzak 1994).

Recent Natural Resource Policies and Their Effects on the Forest

Since the 1990s, environmental legislation and laws to regulate the use of natural resources have formed part of the new development strategy, although these initiatives were considered separately from economic and social reforms. Among the most important accomplishments was the approval of land and forestry laws, as well as initiatives to decentralize the administration of natural resources (see table 2.4).

It is likely that policies regarding exchange rates, commercial investments, and road construction will continue to stimulate the expansion of mechanized agriculture and will create conditions that favor the export of agricultural commodities. In so doing, the economic benefits of these trends are likely to accrue to medium- and large-scale landholders. It is also possible that with policies designed to lower the incentive to occupy frontier lands, and the effort to establish more secure forms of land tenure security, farmers and ranchers may be more inclined to invest in the maintenance of the lands that they own. Foreign investments in agriculture, however, suggest an expansion in the production of export commodities. The latter will depend on the establishment of and investment in export corridors, whose potential implications remain uncertain.

There is little reason to believe that the pressure that small farmers exert on forest resources will diminish. Given limitations on the availability of new lands, it is likely that small landholders will continue to exploit protected areas. To the extent that current legislation encounters obstacles when it comes to addressing the informal appropriation of forest resources by small operators, the pressure on forest reserves may shift to places not held in forest concessions. On the other hand, the fact that local organizations have access to the commercial exploitation of municipal forest reserves is something that could reduce the intensity of informal extraction
Table 2.4. Effects of new natural resource policies on forest use

<table>
<thead>
<tr>
<th>Policy</th>
<th>Effects</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Land Policies</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market liberalization (except communal and community properties)</td>
<td>(+)(-)</td>
<td>Effects could be positive or negative</td>
</tr>
<tr>
<td>Secure property rights for medium and large landholders</td>
<td>+</td>
<td>Includes agricultural, forestry, and conservation activities</td>
</tr>
<tr>
<td>Recognition of land rights and exclusive forest access by indigenous groups</td>
<td>+</td>
<td>Promotes forest conservation while allowing commercial use</td>
</tr>
<tr>
<td>Distribution of land to landless groups</td>
<td>(+)(-)</td>
<td>Effects could be positive or negative</td>
</tr>
<tr>
<td>Value of distributed land set to market price</td>
<td>(+)(-)</td>
<td>Effects could be positive or negative</td>
</tr>
<tr>
<td>Abandoned land reverts to the state</td>
<td>+</td>
<td>Limits concentration of idle land</td>
</tr>
<tr>
<td>Indemnification of farmland</td>
<td>+</td>
<td>Established property rights</td>
</tr>
<tr>
<td><strong>Forest Management</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forty-year renewable forest concessions</td>
<td>+</td>
<td>Eliminates uncertainty of use rights; promotes long-term management and investment</td>
</tr>
<tr>
<td>Forest use authorized on private properties and in TCOs</td>
<td>+</td>
<td>Promotes sustainable management of forests and standardizes forest and land rights</td>
</tr>
<tr>
<td>Municipalities granted 20% of public forests destined for concession by local social associations</td>
<td>+</td>
<td>Permits the distribution of forested land to small timber producers</td>
</tr>
<tr>
<td>Required forest management plan approval</td>
<td>+</td>
<td>Promotes forest management according to technical criteria</td>
</tr>
<tr>
<td><strong>Taxes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taxed value of rural properties established by appraisal</td>
<td>-</td>
<td>Leads to land prices that are artificially low</td>
</tr>
<tr>
<td>Payment of taxes signals that property was not abandoned</td>
<td>-</td>
<td>Legitimates speculative appropriation of land</td>
</tr>
<tr>
<td>Small producers exempted from taxes</td>
<td>(+)(-)</td>
<td>Effects could be positive or negative</td>
</tr>
<tr>
<td>Forest concession taxed by size of area</td>
<td>+</td>
<td>Improves harvesting and promotes integrated management</td>
</tr>
<tr>
<td>Private owners and TCOs taxed only on area used per year</td>
<td>(+)(-)</td>
<td>Effects could be positive or negative</td>
</tr>
<tr>
<td>Decentralization of land and forest use policies, and devolution of rural property taxes to municipalities</td>
<td>+</td>
<td>Promotes a more equitable distribution of benefits and improves spending efficiency</td>
</tr>
<tr>
<td>Decentralization</td>
<td>+</td>
<td>Effects could be positive or negative</td>
</tr>
<tr>
<td>Departmental governments in charge of investigations</td>
<td>(+)(-)</td>
<td>Effects could be positive or negative</td>
</tr>
<tr>
<td>Transference of some forest supervision responsibilities to municipal governments</td>
<td>(+)(-)</td>
<td></td>
</tr>
<tr>
<td><strong>Territorial Planning</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formulation of regional land zoning plans</td>
<td>+</td>
<td>Permits the identification of limitations and opportunities for the use of natural resources</td>
</tr>
<tr>
<td>Formulation of land use plans at the departmental and municipal level</td>
<td>+</td>
<td>Permits land classification and recommended use of farmland</td>
</tr>
<tr>
<td>Formulation of plans for rural properties</td>
<td>+</td>
<td>Permits use-zoning of farmlands</td>
</tr>
</tbody>
</table>

*Sources:* Laws no. 1715; no. 1700; no. 1551; no. 1654; no. 1333. Adapted by author.
of timber. The likelihood of this taking place will depend on a number of factors, including the degree to which local groups have access to the resources, as well as technological and financial considerations.

It is evident that new settlement schemes promoted by the availability of state lands are likely to increase the pressure on forested areas. Similarly, policies to subsidize land prices only stimulate an increase in the demand for land by small farmers. Land auctions, settlement programs, and subsidized prices lead to market distortions. This means that relative prices are prevented from reflecting the true market value of land and natural resources, which, in turn, leads to inefficiencies and to the destruction of forested areas. These policy mechanisms nonetheless play an important role in democratizing access to land and forest resources.

At the municipal level, the results of initial analyses indicate that nearly all political and economic groups have adopted environmental slogans, yet despite their professed concern for the conservation of natural resources, there is little evidence that their actual behavior has changed very much. Before making any real commitment to long-term sustainable development, the majority of the stakeholders involved are more interested in securing their continued access to resources and maximizing short-term profit.

Relatively little is known about the effect that new policies may be having on the patterns of resource use by indigenous groups, small farmers, loggers, and others engaged in various extractive activities. Much will depend on their own level of internal organization and the degree to which they receive technical assistance for the implementation of resource management plans. The fact that indigenous lands have been officially recognized and indigenous groups have been granted exclusive rights to forest resources opens new possibilities for indigenous populations to administer their resource base. Their capacity to do so will depend on their ability to deal with the external pressures that seriously challenge the sustainable management of areas under their control.

The topic of protected areas is highly controversial. By restricting access to natural resources, protected areas sometimes enter into conflict with local populations. In other cases, indigenous groups and peasant farmers have become committed to protecting environmental resources that will benefit them in the future. Furthermore, land management is often highly centralized and delegated to outside agencies that rarely incorporate local perspectives in the formulation of investment plans. Limiting the involvement of local communities ultimately jeopardizes the effective implementation of any management agenda.
Conclusion

Deforestation rates in lowland Bolivia have been relatively low compared to those observed in other countries where tropical forests are found. Over time the tendency in Bolivia has been for the pace of land clearing to increase and for forest degradation to intensify. These trends are associated with fundamental changes in the model of development endorsed by the Bolivian government. The changes are reflected in a shift from economic growth policies that once emphasized import substitution industrialization, to neoliberal policies endorsed since the 1980s that emphasized open markets and structural adjustments.

The Bolivian case underscores the relationship between public policies and the loss of forest resources and shows how the relative importance of the various actors involved changed over time. Development priorities gradually came to stimulate the expansion of an agricultural frontier characterized by the dominance of large-scale and highly mechanized production systems. Similarly the extraction of timber came to be dominated by large commercial enterprises. In addition to their negative effects on deforestation and forest degradation, these policies were also associated with sharp inequalities in the distribution of the economic benefits that accrued from the new development strategies.

Against this background, recent policies to stimulate the export of soybeans and wood products have had important positive effects, at least in the short run. However, long-term benefits could have been greater, and environmental costs could have been lower, if development policies had been linked to initiatives that led to a more equal distribution of land and forest resources and that slowed the expansion of the agricultural frontier into fragile environments. Some environmental policies designed to address these problems have been implemented, yet up to now they have had contradictory effects on Bolivia’s tropical lowlands.

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Total deforested area in the Brazilian Amazon is estimated to have increased from less than 10 million hectares in the 1970s to more than 53 million hectares by 1997 (INPE 1999; Tardin et al. 1980). Such estimates have been derived from comprehensive surveys that have helped to monitor the evolution of the deforestation process in the region by using high-resolution satellite imagery (Fearnside 1993; INPE 1999; Skole and Tucker 1993).

Analyses of the geographical distribution of the deforestation process obtained from the results of such surveys are essential to understanding the social and environmental impacts of deforestation (see, for example, Gash et al. 1996; Liverman et al. 1998; Schimel et al. 1995; Smith et al. 1995). Such analyses have rarely appeared in the literature. The goal of the present work is to help fill this gap by contributing to the identification of areas where the intensity of the deforestation process can cause more significant impacts.

This chapter describes a simplified analysis of the geographical distribution of the deforested areas in the Brazilian Amazon. The work was based on 1:250,000-scale deforestation maps obtained from Landsat Thematic Mapper (TM) imagery in comprehensive surveys covering the 1991–96 period. Regions of more intense deforestation were identified, and the fraction of deforestation observed near areas of pioneer settlement and the region’s most important roads was estimated.

The study area consists of the region defined as the Brazilian “Legal Amazon,” an area of approximately 5 million square kilometers comprising the states of Acre, Amapá, Amazonas, Maranhão (west of 44°W), Mato Grosso, Pará, Rondônia, Roraima, and Tocantins. The region en-
compasses the major parts of the Amazonas and Tocantins river basins, including a variety of ecosystems from forests to savannas. Because of Legal Amazon’s dimensions and the lack of systematically collected ground data on land use, satellite imagery has been a major source of data for tracking the evolution of deforested areas during the last three decades. During this period, a variety of initiatives from road building to subsidizing the agrarian sector to establishing settlement projects led to the uninterrupted increase in population and forest clearing in the region (IBGE 1992; INPE 1999; Tardin et al. 1980).

During the 1988–97 period, total deforested area is estimated to have increased from 38 million hectares to 53 million hectares in the area monitored by Instituto Nacional de Pesquisas Espaciais (INPE) surveys (INPE 1999). This area corresponds to regions presenting forest physiognomy on color composites of TM channels 3, 4, and 5, totaling approximately four million square kilometers or 80 percent of Legal Amazon’s territory. Areas of savannas and other nonforest vegetation are not included in INPE surveys.

Methods

Data used in this work are part of a collection of digital maps of the Amazon developed at INPE (Alves et al. 1992), including 1:250,000-scale deforestation maps for the 1991–96 period derived from Landsat TM imagery and 1:500,000-scale deforestation maps derived from 1970s Landsat Multi-Spectral Scanner imagery by Tardin et al. (1980). Deforestation maps covered the entire territory of the Legal Amazon, excluding areas of savannas and other nonforest vegetation, and areas that did not present cloud-free imagery in each period of study.

Analysis of the geographical distribution of the deforested areas in the 1991–96 period was performed in four major steps. The first step was the production of deforestation maps for each Amazonian state. This was done by converting the Universal Transverse Mercator (coordinates) (UTM) 1:250,000-scale deforestation maps into cylindrical, equal-area projection and subsequently assembling digital mosaics of the deforested areas for each state. Deforested areas in these maps corresponded to four different periods of analysis: 1991–92, 1992–94, 1994–95, and 1995–96. The second step was the stratification of the deforested area by municipal administrative limits and 1/4° grid cells. This step used the 1994 municipalities map produced by the Instituto Brasileiro de Geografia e Estatística.
(IBGE n.d.). The third step was estimation of deforestation for areas near pioneer 1970s deforestation and major roads, based on deforestation maps produced by Tardin et al. (1980) and roads mapped by the Fundação Instituto Brasileiro de Geografia e Estatística (FIBGE 1995). Areas within 25 and 50 kilometers of these features were determined by buffering and intersecting operations. The fourth and final step of the analysis consisted of identifying the $1/4^\circ$ grid cells that contained the largest fractions of the 1991–96 total observed deforestation. These cells were divided into four major categories that are frequently referred to in the following discussion: the 25% minimal subset (MSS), the 50% MSS, the 75% MSS, and the 95% MSS. The 25% MSS was defined as the minimal subset of $1/4^\circ$ grid cells that represented 25 percent of the total deforestation, that is, the set formed by the cells that presented more deforested area and amassed 25 percent of total deforestation. The 50% MSS, 75% MSS, and 95% MSS were similarly defined.

Results and Discussion

Total Observed Deforestation and Distribution of the 25% and 50% Minimal Subsets

Total observed deforestation amounted to 9.2 million hectares during the period of study. The percent fraction of this area observed in Acre, Amazonas, Amapá, Maranhão, Mato Grosso, Pará, Rondônia, Roraima, and Tocantins corresponded, respectively, to 3.4, 4.3, 0.1, 6.5, 36.1, 30.2, 15.4, 1.5, and 2.4. Approximately one-sixth of the area of study was covered by clouds in the first three surveys. In the 1995–96 survey, 30 percent of the area of study was not observed because of clouds. Cloud-covered areas appeared predominantly in Amapá, Roraima, and some areas near the Atlantic Ocean in Maranhão and Pará. The state of Amapá was excluded from the present analysis because of repeated cloud cover over 60 percent or more of its territory.

Important fractions of the total deforestation were observed in relatively few $1/4^\circ$ grid cells, as can be seen in figure 3.1 and map 3.1. The 40 percent of the grid cells with the most deforestation accounted for 95 percent of the total observed deforestation; 19.4 percent of these cells accounted for 75 percent of total deforestation, forming the 75% MSS; 9.7 percent accounted for 50 percent of total deforestation (forming the 50% MSS); and 3.8 percent accounted for 25 percent of total deforestation
tion (forming the 25% MSS). These results show that the deforestation process tended to be concentrated over some regions.

This concentration of the deforestation process can be seen in the distribution of the 25%, 50%, 75%, and 95% MSS shown in map 3.1 and in the contribution of the different states to these subsets shown in figure 3.2. The three states presenting more deforestation—Mato Grosso, Pará, and Rondônia—also included most of these subsets, accounting, respectively, for 93.5, 91.5, and 87.8 percent of the deforestation in the 25% MSS, 50% MSS, and 75% MSS. Conversely, Amazonas, Roraima, and Tocantins represented less than 3.5 percent of the deforestation in the 75% MSS. These results generally agree with the spatial distribution of the 1991–94 deforestation rates presented elsewhere (Alves et al. 1998), indicating that such behavior has probably been persistent over time.

Municipalities included in the 25% and 50% MSS areas are presented in table 3.1. Again, the concentrated pattern of the deforestation process is reflected in the relatively small number of municipalities forming the 25% and the 50% MSS—129 and 201, respectively. Further analysis showed that half of the contribution of the 25% MSS was observed in the territories of twenty-one municipalities (Água Azul do Norte, Alta Floresta, Brasnorte, Campo Novo de Rondônia, Confrésia, Corumbiara, Cumurú do Norte, Eldorado dos Carajás, Guarantã do Norte, Jarú, Juína, Marabá, Nova Canã do Norte, Santa Luzia, São Félix do Araguaia, São Félix do Xingu, Sorriso, Tabaporã, Tapurah, Tucumê, and Vila Bela da Sant Trindade).

![Fig. 3.1. Cumulative distribution of the observed deforested areas in 1/4° grid cells. Deforestation is accumulated starting with highest values.](image)
Deforestation in the Brazilian Amazon, 1991–1996

Fig. 3.2. Contribution of the different states to the 25%, 50%, and 75% MSS. Mato Grosso, Pará, and Rondônia concentrated approximately 90% of the deforestation in these subsets. Amazonas, Roraima, and Tocantins represented 3 percent of the deforestation in the 75% MSS.

Map 3.1. Distribution of deforestation in the 1991–96 period showing the 25% minimal subset (MSS), the 50% MSS, the 75% MSS, and the 95% MSS. These subsets were composed by the 1/4° grid cells accumulating more deforested area and accounting, respectively, for 25%, 50%, 75%, and 95% of total observed deforested area. Accumulated deforestation in areas marked by dots represented less than 5% of the total. Cells covered by a minimum of 50% of clouds also shown. Projection: Equal-area cylindrical.
<table>
<thead>
<tr>
<th>State</th>
<th>25% MSS municipalities</th>
<th>50% MSS municipalities, 25% MSS excluded</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Acrelândia, Plácido de Castro, Porto Acre, Rio Branco, Senador Guiomard</td>
<td>Brasiléia, Bujari, Capixaba, Xapuri</td>
</tr>
<tr>
<td>AM</td>
<td>Boca do Acre, Lábrea</td>
<td>Apuí</td>
</tr>
</tbody>
</table>
RO
Alta Floresta d'Oeste, Alto Paraíso, Alvorada d'Oeste, Ariquemes, Cabixi, Cacaieiros, Cacaulândia, Cacoal, Campo Novo de Rondônia, Candeias do Jamari, Castanheiras, Cerejeiras, Colorado do Oeste, Corumbiara, Espigão d'Oeste, Governador Jorge Teixeira, Jamari, Jarú, Ji-Paraná, Machadinho d'Oeste, Mirante da Serra, Monte Negro, Nova Brasilândia d'Oeste, Ouro Preto do Oeste, Pimenta Bueno, Presidente Médici, Rio Crespo, Rolim de Moura, Santa Luzia d'Oeste, São Miguel do Guaporé, Seringueiras, Theobroma, Urupá, Vale do Paraíso, Vilhena

TO
Arapoema, Bernardo Sayão

Costa Marques, Guajará-Mirim, Ministro Andreazza, Nova Mamoré, Porto Velho

Axixá do Tocantins, Couto de Magalhães, Darcinópolis, Itaguitins, Itaporã do Tocantins, Juarina, Pau d'Arco, Pequizeiro, Piraquê, Praia Norte, Riachinho, São Miguel do Tocantins, Sítio Novo do Tocantins, Wanderlândia

a. AC = Acre, AM = Amazonas, MA = Maranhão, MT = Mato Grosso, PA = Pará, RO = Rodônia, TO = Tocantins.
b. Half of the contribution of the 25% MSS was observed in Água Azul do Norte, Alta Floresta, Brasnorte, Campo Novo de Rondônia, Confresa, Corumbiara, Cumurú do Norte, Eldorado dos Carajás, Guarantã do Norte, Jarú, Juína, Marabá, Nova Canãã do Norte, Santa Luzia, São Félix do Araguaia, São Félix do Xingu, Tabaporã, Tucumã, and Vila Bela da Santíssima Trindade.
c. In the 50% MSS, Água Boa, Arame, Axixá do Tocantins, Boca do Acre, Bom Jesus do Tocantins, Brejo Grande do Araguaia, Campo Novo do Parecis, Capitão Poço, Carutapera, Cotriguáçu, Couto de Magalhães, Darcinópolis, Glória d’Oeste, Guajará-Mirim, Indiavaí, Jauru, Juarina, Juscimeira, Lábrea, Lucas do Rio Verde, Luciara, Medicilândia, Mirassol d’Oeste, Palestina do Pará, Pau d’Arco, Pedra Preta, Porto Estrela, Praia Norte, Riachinho, Rondonópolis, Salto do Céu, Santa Carmem, Santa Terezinha, Santarém, São João do Araguaia, São José do Povo, São José dos Quatro Marcos, São Miguel do Tocantins, Sítio Novo do Tocantins, Tucuruí, Vera, Wanderlândia, and Xapuri jointly accounted for less than 1% of the 50% MSS deforestation.
Observed Deforested Areas near Major Roads

The concentration of deforestation appeared to be closely related to road location. Three major road corridors were identified as concentrating important fractions of total deforestation: (1) a western road network, the Cuiabá–Porto Velho–Rio Branco road link, including federal highways BR-174, BR-070, and BR-364; (2) an eastern road network, including major roads in eastern parts of Mato Grosso, Pará, Maranhão, and Tocantins, such as BR-010, BR-153, BR-158, and PA-150; and (3) a central road network, including the Cuiabá-Santarém road link (BR-163), the Transamazon highway (BR-230), and roads linking northern-central Mato Grosso ("Nortão") to the BR-163 and Cuiabá. Most interstate links in these corridors (BR-070, BR-163, BR-174, BR-230, BR-364, and PA-150/BR-158) were put in place in the framework of Programa de Integração Nacional (PIN) and other programs starting in the early 1970s. The Belém-Brasília (BR-010) road link and some other roads in the eastern Amazon were established in the 1960s. Many of the state and federal roads in the considered corridors were already paved in the early 1990s, with most notable exceptions being in the central road network outside BR-163 in Mato Grosso and the eastern road network inside Mato Grosso.

The fractions of total deforestation in the proximity of the three road networks are reported in table 3.2. Map 3.2 shows the distribution of 25% MSS, 50% MSS, and 75% MSS cells relative to the roads considered in the analysis.

Regions within 25 kilometers of the analyzed roads contained important fractions of the 25% and 50% MSS. Approximately half of the deforestation observed in these categories occurred inside these regions. Finally, more than three-quarters of the contribution of the 50% MSS occurred within 50 kilometers of the three major road networks.

Deforestation near Pioneer Deforestation

As pioneer deforestation, this study analyzed areas mapped by Tardin et al. (1980) through interpretation of Landsat Multi-Spectral Scanner imagery from the 1974–78 period. Approximately 69 percent of the total 9.2 million hectares of deforestation was found to occur in the same grid cells where Tardin et al. (1980) had mapped deforested areas. A larger fraction of the total deforestation (86 percent) was found within 25 kilometers of pioneer deforestation.
Table 3.2. Deforestation within 25 and 50 km from the western, eastern, and central road networks

<table>
<thead>
<tr>
<th>Distance from Network (km)</th>
<th>Western Network(^a)</th>
<th>Eastern Network(^b)</th>
<th>Central Network(^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>10.1</td>
<td>20.7</td>
<td>16.1</td>
</tr>
<tr>
<td>50</td>
<td>16.6</td>
<td>32.7</td>
<td>24.0</td>
</tr>
</tbody>
</table>

\(^{a}\) The western road network includes the Cuiabá–Porto Velho–Rio Branco road links, including BR-070, BR-174, and BR-364.

\(^{b}\) The eastern road network is formed by the major roads in Maranhão, Tocantins, and in eastern parts of Mato Grosso and Pará, including BR-153, BR-158, BR-010, and PA-150.

\(^{c}\) The central road network includes the Cuiabá-Santarém road link (BR-163), the Transamazon Highway (BR-230), and roads linking northern-central Mato Grosso (“Nortão”).

Map 3.2. Distribution of the 25%, 50%, and 75% MSS and 50-kilometer buffers around the western, eastern, and central road networks. The western road network is formed by the Cuiabá–Porto Velho–Rio Branco road link, including federal highways BR-174, BR-070, and BR-364. The eastern road network includes major roads in eastern parts of Mato Grosso, Pará, Maranhão, and Tocantins, such as BR-010, BR-153, BR-158, and PA-150. The central road network included the Cuiabá-Santarém road link (BR-163), the Transamazon Highway (BR-230), and roads linking northern-central Mato Grosso to the BR-163. Cells covered by a minimum of 50% of clouds also shown. Projection: Equal-area cylindrical.
The relationship between the pioneer deforestation and the more recent one still needs detailed analysis. However, the large amount of recent deforestation occurring near pioneer areas indicates that the deforestation process has been concentrated around areas of pioneer settlement.

A second aspect of the concentration of the deforestation process was that deforestation tended to be more intense in relatively limited areas near pioneer settlements or major road networks. This aspect can also be viewed as an inertial characteristic of deforestation, which may manifest itself more intensely and continually in regions with more developed infrastructure.

Conclusion

This analysis of the geographical distribution of the deforestation process in the Brazilian Amazon has been based on the observed deforested area during the period between 1991 and 1996. The results show an important association between pioneer settlement, roads, and deforestation. Areas of more intense deforestation appeared to be concentrated in certain regions, inertially growing around areas of pioneer deforestation and major roads. The association between areas of more intense deforestation and roads indicates that regions more closely linked to economic and social processes at the national scale are subject to more intense pressures to clear forest. The effect of road development and improvement on deforestation should be of particular interest with respect to refining of development policies, particularly the recently launched Brazil in Action (Brasil em Ação) program (<http://www.brazil-in-action.gov.br> 1999), which includes significant improvement of the existing road network and infrastructure.

The more immediate effect of the highest incidence of deforestation in certain regions is the impact on social and environmental issues. This effect has been shown in some regions where important forest impoverishment and reduction have already been reported (Alves et al. 1999; Gascon et al. 1998; Nepstad et al. 1999).

To conclude, the results presented here are indicative of the areas of more intense deforestation and should be further refined. Data reported for municipalities used Brazilian territorial division of 1994 as a geographical reference and did not take into account more recently created municipalities. The analysis was developed using observed deforested area as an indicator of the intensity of the deforestation process. Such an approach was used to simplify the analysis and did not take into account the
differences in periods of image acquisition. More complex indicators could be used, such as the rate of deforestation or landscape changes induced by deforestation. Use of different indicators might lead to different perceptions of the spatial or geographical distribution of the deforestation process and thus provide results different from those presented here. It should be noted, however, that pioneer settlement and location of roads have influenced many deforestation indicators during the last quarter of a century, when the forests of the Brazilian Amazon were subjected to important changes.

Acknowledgments

This work was made possible by the contributions of several organizations and individuals. First of all, current results were made possible by the work of an entire generation of INPE researchers, whose contribution allowed consolidation and provided a methodology for mapping deforestation using satellite imagery since the mid-1970s (Tardin et al. 1980) and, more recently, development of a digital dataset of deforestation maps (J. C. L. d’Alge, L. G. Meira Filho, J. S. de Medeiros, U. Palme, J. R. dos Santos, and R. M. C. de Souza). The ideas that led to this work are also the result of land use dynamics research that has been funded through several projects by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (National Council of Scientific and Technological Development) (CNPq), Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), Financiadora de Estudos e Projetos (FINEP), G-7 Pilot Program to Conserve the Brazilian Rainforest (PPG7), and the Brazilian Greenhouse Gases National Inventory Program. The author would also like to acknowledge valuable comments made by professors B. Becker and E. Novo.

References


Each year in the Brazilian Amazon between 1978 and 1988, from 15,000 to 21,000 square kilometers of rain forest were cleared (INPE 1998; Skole and Tucker 1993). Deforestation since then has remained high but variable, averaging 18,000 square kilometers per year between 1991 and 1996, and ranging from 13,800 square kilometers cleared in 1991–92 to 29,000 square kilometers in 1994–95 (INPE 1998). The alarming environmental consequences of forest clearing have prompted many analysts to turn their attention to studying the forces driving land cover conversion in this region (for instance, Brown and Pearce 1994; Downing et al. 1992; IBGP/HDP 1993, 1995; Lambin 1994; Painter and Durham 1995; Sponsel, Headland, and Bailey 1996). Among the driving forces often enumerated, demographic factors—particularly migration—play a central role. The rapid influx of people into the Amazon from other regions of Brazil has often spurred rural land settlement and rapid forest removal. However, estimation of migration in the Amazon is extremely difficult, and this difficulty hinders both the appraisal of migration patterns in the region and the establishment of empirical links to land cover conversion.

This chapter draws on Brazilian demographic census data to show how populations have grown in the Amazon between 1970 and 1996, with emphasis on how migration has contributed to this growth. The first part of the analysis focuses on population growth for the region overall as well as for its rural and urban components. I compare population changes during the 1970–80, 1980–91, and 1991–96 periods to show when growth was most rapid. In addition, I compare population change among states in the Amazon in order to highlight where growth was fastest. The second and larger part of the analysis focuses on net migration, a measure that indicates the net change in population size due to in- and out-migration.
The analysis of net migration compares state-level estimates for the 1970s, 1980s, and early 1990s, in order to show when and where demographic growth occurred due to population movement. The migration analysis also incorporates mapping of net migration during the 1980s for the municipalities of the region, mapping that yields the greater spatial detail necessary to reveal important within-state differences in population gains and losses. Together, the findings show that (a) the population of the Brazilian Amazon grew by over 3 percent per year between 1970 and 1996; (b) the annual rate of population growth exceeded 3 percent during the 1970s and 1980s, but declined to only 2 percent in the early 1990s; (c) the rural growth rate was lower, at approximately 1 percent per year during the 1970s and 1980s, and became less than 1 percent during the early 1990s, indicating rural population declines; (d) population gains due to net migration largely occurred in the “frontier crescent” states of Rondônia, Pará, and Mato Grosso during the 1970s and 1980s; and (e) net migration gains ceased in these and most other states during the 1990s. These results raise questions about the continuing deforestation in the Amazon during the 1990s, a discussion I return to in the closing section.

Background

It is a common intuition that population growth and migration in the Amazon lead to deforestation. While a well-rounded review of the literature on Amazon land settlement is beyond the scope of this essay, it is illustrative to briefly focus on areas that have experienced rapid population growth due to migration, followed by substantial land cover conversion. The link between migration and deforestation in the Amazon is often made on the basis of the following three sites: Altamira, in the Transamazon Highway corridor in the state of Pará; São Felix do Xingú, in the frontier of southeastern Pará; and the area around Ariquemes, in the BR-364 road corridor in the state of Rondônia. Map 4.1 situates these areas in the Legal Amazon of Brazil, a government planning region. The Legal Amazon includes the states of the “Classical” Amazon—Rondônia, Acre, Amazonas, Roraima, Pará, and Amapá—as well as “Other” Amazon states on the basin’s periphery, namely Maranhão, Mato Grosso, and Tocantins.

In the first case, the Transamazon colonization projects around Altamira were begun in the early 1970s under the auspices of Brazil’s then-military government. The state directed all aspects of settlement, but cost overruns forced withdrawal of government support for the many colonists
who flooded the roadsides seeking land (for example, Moran 1981; Smith 1982; Wood and Carvalho 1988, chap. 10). In the mid-1980s, high prices in cocoa and black-peppers encouraged further migration and land settlement (for instance Hamelin 1991). According to a detailed land cover inventory of the Transamazon segment west of Altamira, over 40 percent of the original forest had been removed by 1991 (Moran et al. 1994, 334; 1996, 47).

A second case, the southeastern part of Pará, experienced relatively disorderly settlement along newly constructed roads, as migrant farmers and ranchers competed for land (Schmink and Wood 1992). The region just east of São Felix do Xingu became notorious for its rural violence as ranchers seeking to secure large properties attempted to oust small-scale farmers (see Almeida 1995). By the late 1980s, the landscape in southeast-
ern Pará was a patchwork of large clearings for pasture, evident in substantial deforested areas in satellite images (Schmink and Wood 1992, 173; Skole and Tucker 1993, 1907).

The third case, Rondônia, is perhaps the best known. The discovery of relatively good soils along BR-364, the highway leading from southern Brazil, occurred at a time when family farms were being squeezed out of southern agriculture by corporate firms (for example, Martine 1980). This spurred a massive redistribution of population northward along BR-364, and many families settled in the region around Ariquemes in central Rondônia (see Goza 1994). Rapid in-migration and land settlement there led to some of the Amazon’s highest deforestation rates during the 1980s (see Browder 1994; Millikan 1992). By 1988, between 24,000 to 30,000 square kilometers, or 11 to 14 percent of the original forest in Rondônia, had been cleared (INPE 1998; Skole and Tucker 1993, 1906).

While these sketches are only the briefest of caricatures, they reveal a common process of rapid population growth due to migration, followed by substantial deforestation. It is important, however, to recognize that migration and other demographic processes are indirect rather than direct drivers of land cover conversion in the Amazon (Wood 1992; Wood and Perz 1996). This is acknowledged by the international land use/land cover change community, which regards land use activities—for instance, crop cultivation, pasture formation, and logging—as proximate drivers of land cover change and conceptualizes demographic processes such as migration as more distant drivers (IGBP/HDP 1993, 1995). Put another way, in the cases of the Transamazon, southeastern Pará, and Rondônia, migration led to land use, which led to land cover change, of which deforestation is an example.

Recognition of land use as an intervening factor between migration and deforestation raises the question of whether migration nonetheless automatically leads to land cover conversion. In the three cases noted above, rapid population growth due to migration led to deforestation because many migrants settled rural plots and cleared forest for agriculture. If one assumes that these linkages represent a general pattern, it implies a simple direct effect of migration on agricultural land use, which has a direct effect on land cover conversion. Following this logic, and given observations of high deforestation in the Amazon during the early 1990s (INPE 1998), one would be led to presume that migration into the region proceeded simultaneously at a rapid pace.

But this is not the only possible course of events following migration. One can imagine a situation where most migrants settle in urban areas and
engage in industrial or service activities that do not involve land use, and therefore create little or no land cover change.\textsuperscript{1} This situation is a likely prospect, as the population of the Amazon has become more urbanized since 1970 (for instance, see Browder and Godfrey 1997, chap. 1; IBGE 1992, 206–7). We must therefore think of the effect of migration on land use, and therefore land cover, as variable.

In another scenario, rural frontier areas no longer receiving migrants may continue to exhibit land cover conversion due to the expansion of land use on long-established rural properties. This course of events presumes little or no in-migration, a possibility of equal importance to the previous scenario. Many observers knowledgeable of population changes in the Brazilian Amazon anticipated a slowdown in migration to frontier areas during the 1990s (see Martine 1990, 37, 39; 1994, 15, 36–38; Ozorio de Almeida and Campari 1995, chap. 2). Moreover, preliminary analyses of recent census data suggest that this slowdown is in fact the case (Caetano 1997; Moura and Moreira 1998). Thus, it is not only important to recognize that migration has a variable linkage with land use and land cover; we must also acknowledge the possibility that migration to the Amazon has declined.

The possibility of declining population growth due to migration in the Brazilian Amazon bears important implications for our understanding of the drivers of deforestation. Given that annual deforestation has remained more or less as high during the 1990s as it was during the 1980s, a finding that migration has declined from the earlier to the later period would suggest an historical alteration in its linkage with land use and land cover conversion. This finding would imply that the impact of migration on deforestation, in the case of the Brazilian Amazon, is not only indirect, but also historically specific to earlier periods of frontier expansion.

The analysis that follows pursues the question of whether population growth due to migration in the Amazon has actually declined over time, particularly in areas exhibiting rapid deforestation. To that end, I employ a crude periodization of the 1970–96 interval, during which deforestation in the Amazon has risen, to see how migration has proceeded. Specifically, I divide this twenty-six-year interval into the 1970–80, 1980–91, and 1991–96 periods. While they are delineated on the basis of the availability of demographic data for the region, the 1970s, 1980s, and early 1990s provide the means to compare migration over time.

The analysis also pays attention to geographic differences in migration patterns in the Amazon. For the most part, I adopt the Brazilian state as the unit of analysis, which allows crude but telling distinctions between
areas that did and did not grow due to population migration. This method allows for observation of migration patterns over time in different parts of the Amazon.²

**Population Growth in the Brazilian Legal Amazon, 1970–1996**

The first component of the analysis provides an overview of changes in human populations of the region, which can occur via fertility, mortality, or migration. Population data come from the Brazilian demographic censuses of 1970, 1980, and 1991, and the population count of 1996 (IBGE 1973, 1982, 1991, 1997, 1999). Table 4.1 presents population estimates for the states of the Legal Amazon for the four time points, as well as annual percentage growth rates for the three intervening periods.³ Populations in 1970, 1980, 1991, and 1996 appear in odd-numbered columns (1, 3, 5, and 7, respectively), while growth rates between census years appear in even-numbered columns (2, 4, and 6). Overall, the population of the region grew from 11 million in 1970 to 25 million in 1996, at an average rate of 3.14 percent per year. However, the annual rate of population growth has declined over time, from 3.78 percent during the 1970s to only 2.02 percent during the early 1990s.

These figures hide considerable heterogeneity within the Legal Amazon. States on the periphery of the region (the “Other” Amazon) are former frontiers from the 1950s and 1960s, while states in the Classical Amazon constituted much of the frontier in Brazil during the 1970s and 1980s. Given that population growth can be very rapid in frontier areas, we should expect growth rates to be higher in the Classical than in the Other Amazon states. This is in fact the case, as the Classical Amazon grew from 3.6 million to 10.2 million between 1970 and 1996, at an average rate of 4.02 percent per year, while the Other Amazon states grew from 7.5 million to 14.95 million, at an average rate of 2.64 percent per year.

Among individual states of the Legal Amazon, there are large disparities in rates of population increase. Rondônia is famous for its high growth rates, at 14.86 percent per year during the 1970s and 7.58 percent per year during the 1980s, which increased its population tenfold in two decades. Pará, the other state with heavily studied agricultural frontier zones, also grew rapidly, at 3 to 4 percent per year during the 1970s and 1980s, more than doubling its population between 1970 and 1991. Other states with growth rates above the Legal Amazon’s overall level include Roraima, Amapá, and Mato Grosso. In contrast, Maranhão and Goiás
Table 4.1. Population growth in states of the Brazilian Legal Amazon, 1970–96

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Classical Amazon</td>
<td>3,603,790</td>
<td>4.90</td>
<td>5,880,268</td>
<td>3.98</td>
<td>9,105,640</td>
<td>2.35</td>
<td>10,241,451</td>
</tr>
<tr>
<td>Rondônia</td>
<td>111,064</td>
<td>14.86</td>
<td>491,069</td>
<td>7.58</td>
<td>1,130,874</td>
<td>1.70</td>
<td>1,231,007</td>
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<td>Acre</td>
<td>215,229</td>
<td>3.36</td>
<td>301,303</td>
<td>2.96</td>
<td>417,165</td>
<td>2.96</td>
<td>483,726</td>
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<td>Amazonas</td>
<td>955,235</td>
<td>4.04</td>
<td>1,430,089</td>
<td>3.51</td>
<td>2,102,901</td>
<td>2.55</td>
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<td>Roraima</td>
<td>40,885</td>
<td>6.61</td>
<td>79,159</td>
<td>9.12</td>
<td>215,950</td>
<td>2.70</td>
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<td>Pará</td>
<td>2,167,018</td>
<td>4.51</td>
<td>3,403,391</td>
<td>3.41</td>
<td>4,950,060</td>
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<td>Amapá</td>
<td>114,359</td>
<td>4.27</td>
<td>175,257</td>
<td>4.54</td>
<td>288,690</td>
<td>5.47</td>
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<td>Other Amazon</td>
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<td>3.20</td>
<td>10,364,264</td>
<td>2.51</td>
<td>13,662,972</td>
<td>1.80</td>
<td>14,950,741</td>
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<td>Maranhão</td>
<td>2,992,686</td>
<td>2.89</td>
<td>3,996,404</td>
<td>1.91</td>
<td>4,929,029</td>
<td>1.16</td>
<td>5,222,565</td>
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<tr>
<td>Mato Grossob</td>
<td>1,597,090</td>
<td>4.51</td>
<td>2,508,258</td>
<td>3.78</td>
<td>3,801,265</td>
<td>1.82</td>
<td>4,163,666</td>
</tr>
<tr>
<td>Goiás</td>
<td>2,938,677</td>
<td>2.73</td>
<td>3,859,602</td>
<td>2.23</td>
<td>4,932,678</td>
<td>2.41</td>
<td>5,564,510</td>
</tr>
<tr>
<td>Legal Amazon</td>
<td>11,132,243</td>
<td>3.78</td>
<td>16,244,532</td>
<td>3.07</td>
<td>22,768,612</td>
<td>2.02</td>
<td>25,192,192</td>
</tr>
</tbody>
</table>


a. Pará’s 1991 population is lower than original estimates due to correction for fraudulent overcount (IBGE 1991, 15–17, 137; 1999).
b. Includes Mato Grosso do Sul to ensure comparability.
c. Includes Tocantins and excludes Brasília, the Federal District, to ensure comparability.
show population growth around 2 percent per year, below the regional rate.

The expansion of populations in the Legal Amazon slowed precipitously from the 1980s to the 1990s. Between 1991 and 1996, Rondônia grew at only 1.70 percent per year, while Pará grew at only 2.15 percent per year. Mato Grosso, which had the fastest-growing population among the Other Amazon states, grew at only 1.82 percent per year. These findings indicate that the slowdown in the Amazon’s population growth reduced disparities in rates of increase among states, because the deceleration was particularly pronounced in areas often considered frontiers, such as Rondônia and Pará.

One might object that examination of overall populations obscures differences between their rural and urban segments. Table 4.2 explores this possibility. Rural and urban growth rates for 1970–80 appear in columns 1 and 2, respectively, followed by corresponding rates for 1980–91 in columns 3 and 4, with rates for 1991–96 in columns 5 and 6. A comparison of rural and urban growth rates in each of the three time periods shows that urban rates exceed rural rates in virtually every instance. In the Legal Amazon as a whole during the 1970s, urban populations grew by 6.54 percent per year, compared to only 1.55 percent for rural populations. Among the states, only in Pará did the rural growth rate approach the urban rate, and only in Rondônia did the rural rate exceed the urban rate. Given that these two states show rapid deforestation beginning in the late 1970s, this finding is consistent with the assumption of a direct effect of rural population growth on land use and land cover conversion. During the 1980s, urban populations in the Legal Amazon continued growing at 4.80 percent per year, trailed by rural rates at only 0.83 percent. In Rondônia, Pará, and Roraima, rural rates approached but did not exceed urban growth rates. During the early 1990s, urban population growth in the Legal Amazon continued at 3.76 percent per year, while rural growth became negative, indicating that rural populations actually shrank at 1.12 percent per year. Between 1991 and 1996, the only state where rural growth approached urban growth was Pará—even in Rondônia, rural growth was negative. This finding is not consistent with assumptions that rapid population growth invariably leads to land use and land cover conversion, as we know that deforestation continued during the early 1990s in Rondônia and Mato Grosso (INPE 1998) while rural populations declined in those states.

The results of the rural/urban differential in population growth appear in columns 7 and 8 of table 4.2, which present the percentage of the total
Table 4.2. Rural and urban population growth and urbanization in states of the Brazilian Legal Amazon, 1970–96

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\(^a\) Pará’s 1991 population is lower than original estimates due to correction for fraudulent overcount (IBGE 1991, 15–17, 137; 1999).
\(^b\) Includes Mato Grosso do Sul.
\(^c\) Includes Tocantins and excludes Brasília, the Federal District.
population residing in urban areas in 1970 and 1996, respectively. In 1970, less than 40 percent of the Legal Amazon’s population resided in urban centers. At that time, only in Rondônia and Amapá did more than half of a state’s population live in towns or cities. By 1996, over 67 percent of the population lived in urban areas, and the urban share was over 50 percent in every state.

The findings in table 4.1 could imply that population growth due to migration slowed over time in the Amazon, and the figures in table 4.2 add the possibility that migration may have particularly slowed down in rural areas, especially during the 1990s. Together, these implications raise the question of whether decelerated population growth actually does reflect a slowdown in gains due to net migration.

**Net Migration in the Legal Amazon, 1970–1996**

Empirical analysis of migration in the Amazon poses serious methodological challenges, as it is very difficult to gauge migration in frontier contexts where people may move repeatedly (see, for example, Browder and Godfrey 1997, chap. 8). Brazilian demographic censuses include many questions that can be used to directly observe human relocation, such as duration of present residence and place of last previous residence (IBGE 1996). But because census information is collected only once a decade, and because census questions only capture a migrant’s last move, estimates from direct questions in censuses can underestimate migration to a considerable degree.

In lieu of direct estimates, it is possible to use indirect techniques available from demography in order to estimate net migration without actually having to observe population movement. This is because population change can only occur through natural increase (gains due to births minus losses due to deaths) or net migration (gains due to in-migration minus losses due to out-migration). If we know the size of a population at the beginning of a time interval (t1), and if we obtain fertility and mortality estimates for that population during the interval, we can project the population to the end of that interval (t2). The projection accounts for the initial population size, its age and sex composition, and fertility and mortality. It therefore produces a projected population on the basis of natural increase. The actual population at the end of the interval reflects changes due to natural increase as well as net migration. Hence, the difference between the projected and actual populations at the end of the period must be due to net migration. If the actual population is larger than the
projected population, net migration will be positive, indicating a net gain. But if the actual population is smaller than the projected population, net migration will be negative, indicating a net loss.


Table 4.3 presents net migration estimates for the 1970–80 period, which witnessed the onset of colonization projects in the Legal Amazon. Column 1 shows the state populations enumerated in 1970, and column 2 does the same for 1980. Column 3 displays the projected populations based on the 1970 age and sex composition and the fertility and mortality assumptions for the 1970–80 period. Taking the 1980 enumerated population (column 2) minus the projected population (column 3) yields net migration, in column 4. During the 1970s, the Classical Amazon gained nearly 450,000 people due to net migration, a clear indication of frontier expansion there, while the Other Amazon states lost almost 260,000 people due to net migration, suggesting frontier closure. Overall, the Legal Amazon gained approximately 190,000 due to net migration, but the accumulation was much greater in specific states. Rondônia posted a net gain of approximately 318,000, while Pará accumulated over 191,000 and Mato Grosso accrued over 250,000. The net migration gains in these three states suggest frontier expansion there during the 1970s.

Table 4.4 repeats the net migration analysis for the 1980–91 period and reveals somewhat different migration patterns from those of the 1970s. First, the Legal Amazon posted a net loss of over 400,000 due to net migration. This loss was not due to the Classical Amazon, which gained
### Table 4.3. Estimates of net migration in states of the Brazilian Legal Amazon, 1970–80

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<tr>
<td>Classical Amazon</td>
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<td>Legal Amazon</td>
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<td>16,055,048</td>
<td>+189,484</td>
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</table>

*Sources: IBGE 1992, 206, 228, 231; 1996.*

a. Includes Mato Grosso do Sul.

b. Includes Tocantins, and excludes Brasília, the Federal District.

...nearly 400,000, almost as much as during the previous decade. Rather, the overall losses were due to tremendous net declines of over 800,000 in the Other Amazon states. Among individual states, Rondônia continued to accumulate population, gaining over 400,000, even more than during the previous decade. But in contrast to the previous decade, Pará shows a net loss of 40,000 due to net migration, whereas Roraima shows a net gain of 100,000 and Amapá accrued 24,000. Among the Other Amazon states, Mato Grosso continued to gain population by migration, accumulating nearly 400,000, while Maranhão and Goiás show large net losses.

Map 4.2 helps us to better understand the spatial pattern of net migration in the Legal Amazon by presenting estimates of net migration rates at the municipal level. Municipalities (municípios) are local administrative units similar to U.S. counties, and observation of net migration at this level reveals within-state distinctions in population gains and losses. Map 4.2 shows that all of the municipalities in Rondônia and Roraima experienced net migration gains. However, in Pará, we find considerable within-state heterogeneity. While the northern reaches of the state show net migration losses, the southwestern municipalities along the Transamazon Highway and the southeastern municipalities in the frontier zone east of São Felix do Xingu both continued to accumulate population due to net migration. Net migration gains in the Amazon during the 1980s—in Rondônia,
southern Pará, and northern Mato Grosso—exhibit a spatial distribution very similar to that of areas experiencing deforestation between 1978 and 1988 (Skole and Tucker 1993, 1907). This broad spatial correspondence suggests that net migration in the Legal Amazon was related to land use and land cover conversion at a regional level during the 1980s.

Table 4.5 advances the analysis further in time by presenting state-level estimates of net migration for the Legal Amazon between 1991 and 1996. The findings indicate a pattern of net migration that differs substantially from those of the 1970s and 1980s. Overall, the Legal Amazon lost nearly 470,000 people due to net migration, but this time net losses occurred throughout the region. The Classical Amazon lost 185,000 while the Other Amazon states lost 280,000. States known for frontier expansion show net losses of population due to migration during the early 1990s. Rondônia lost nearly 50,000, Pará lost nearly 135,000, and Mato Grosso lost 75,000. The only states posting noteworthy net gains were Amapá, which accumulated nearly 40,000, and Goiás, which accrued nearly 140,000. These findings reinforce preliminary analyses of migration data from Brazil’s 1996 population count, which suggest that migration into the Amazon slowed to a trickle during the early 1990s (Caetano 1997;
Map 4.2. Net migration rates: municipalities, Brazilian Legal Amazon, 1980–91
Moura and Moreira 1998). The results also provide demographic evidence that substantiates broader claims that the Amazon is becoming a postfrontier region (see Cleary 1993; Martine 1990, 39).

Table 4.6 places the findings of tables 4.2, 4.3, and 4.4 in a larger perspective by presenting net migration estimates for the 1970s, 1980s, and early 1990s together in comparable form. I annualized the state-level net migration estimates by dividing the net gain or loss by the number of years in the interval. This yielded average net migration volumes per year, a measure comparable across the unequal periods between Brazil’s last four population enumerations. The annualized estimates for the three periods appear in columns 1, 2, and 3, respectively. The Legal Amazon shows annual gains of 19,000 during the 1970s, annual losses of nearly 40,000 during the 1980s, and much larger annual losses of over 90,000 during the early 1990s. The Classical Amazon exhibits gains of nearly 45,000 per year during the 1970s, similar gains at 36,000 per year during the 1980s, and equivalent losses of 37,000 per year during the early 1990s. The Other Amazon states lost population most rapidly during the 1980s, at 74,000 per year, which declined to losses of only 56,000 per year between 1991 and 1996. These results indicate the onset of significant population losses due to net migration in the 1990s in the Classical Ama-

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\(a\) Pará’s 1991 population is lower than original estimates due to correction for fraudulent overcount (IBGE 1991, 15–17, 137; 1999).
\(b\) Includes Mato Grosso do Sul.
\(c\) Includes Tocantins and excludes Brasília, the Federal District.
Examination of the figures for key frontier states in table 4.6 places their net migration in a broader temporal perspective. In Rondônia, net migration added 32,000 people per year during the 1970s and 38,000 per year during the 1980s, and subtracted 10,000 per year during the 1990s. In Pará, annual gains were nearly 20,000 per year during the 1970s, large compared to the losses during the 1980s of 3,700 per year, but smaller than the annual losses during the early 1990s of 27,000 per year. Mato Grosso shows significant frontier expansion via net migration gains of 25,000 per year during the 1970s and 36,000 per year during the 1980s, turning to losses of 15,000 per year during the 1990s. These findings confirm that net migration losses did not become significant in these “frontier” states until the early 1990s.

Column 4 presents an average of annual net gains for 1970–96, computed using gains or losses in each interval, weighted by its corresponding

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</table>


a. Annual net migration from 1970 to 1996 is a 26–year average of annual net change in the three periods, weighted by the length of each period.

b. Pará’s 1991 population is lower than original estimates due to correction for fraudulent overcount (IBGE 1991, 15–17, 137; 1999).

c. Includes Mato Grosso do Sul.

d. Includes Tocantins and excludes Brasília, the Federal District.
number of years. This weighted annual average provides a single measure of population change due to net migration over the twenty-six years up to 1996. Overall, the Legal Amazon lost nearly 27,000 per year during this period, because the average annual gain of 25,000 in the Classical Amazon was more than offset by annual losses of 52,000 in the Other Amazon states. Turning to important individual states, Rondônia shows an overall average net gain of 26,000 per year between 1970 and 1996, Mato Grosso shows an average net gain of 22,000 per year, and Pará shows an average annual net gain, though it is less than 1,000 per year. These findings suggest that net migration losses outweighed gains in the Legal Amazon as a whole, but not in selected states where the frontier continued to expand until the 1990s.

Discussion

In the Brazilian Legal Amazon, the 1970s witnessed a period of rapid population growth, due in part to net migration. The 1980s were also a period of positive net migration, with spatially correspondent land cover conversion. This correspondence led many observers to call attention to the flood of migrants into the Amazon as a driver of deforestation. During the 1990s, population growth slowed precipitously as net migration turned negative in most states. However, deforestation has continued at a level comparable to that of the previous decade. The recent divergence in population growth, migration, and deforestation in the Amazon raises doubts about the validity of the intuitive links often made between them.

One might be led to dispose of such intuitions in the face of contradictory empirical evidence, but it is also important not to assume that migration is no longer important for land use and land cover change in the Brazilian Amazon. Rather, we need to more carefully specify the linkages between migration, land use, and land cover change in the context of the recent history of Brazil’s northern frontiers. On the one hand, it is clear that population growth due to net migration does not automatically lead to deforestation. In the case of the Amazon, the impact of net migration is not only indirect but also historically specific. During the 1990s, population growth and net migration slowed, yet deforestation continued, likely because of intervening processes involving changes in patterns of land use.

On the other hand, migration may play a different role with respect to land use in the region now than before. It is generally believed that as migration to the Amazon frontier has slowed, circulation within the region has increased (Ozorio de Almeida and Campari 1995, chap. 2).
Available evidence confirms the existence of frequent local movement in frontier towns (Browder and Godfrey 1997, chap. 8). Hence, it is possible that new deforestation is driven indirectly by intraregional rather than interregional movement as populations circulate locally between towns and their surrounding rural areas. As some analysts have noted, urban residents often own rural properties where they engage in land use, made possible by seasonally pendular local migration (Browder and Godfrey 1997, chap. 10). This movement often reflects a migrant’s seasonal shifts between different economic activities, where earnings in one, such as gold mining, are invested in another, such as pasture formation for cattle (MacMillan 1995). This finding suggests that more emphasis needs to be placed on the economic strategies of urban populations in the Amazon for understanding contemporary rural land use and land cover change.

In addition to taking such a “supply-side” focus on urban-based land use, it may be important to explore related “demand-side” aspects. The rapid growth of urban populations in the Amazon has created growing markets for regional produce, at least in the case of beef (Faminow 1998). Because land clearing for cattle pasture is the primary direct driver of deforestation in the Amazon, and because pasture maintenance practices are generally considered unsustainable (see Downing et al. 1992), the expansion of ranching alongside urban population growth deserves further attention. This is one of many possible rural activities—other examples are soybean cultivation and timber extraction—that may now be closely linked to urban populations and local migration, and together may help explain contemporary deforestation in the Brazilian Amazon.

Historical changes in population movements raise questions about exogenous factors that may alter the linkage between migration and land cover change. The apparent slowdown of interregional migration to the Amazon begs for explanations as to why traditional sending regions, such as the Brazilian northeast and south, are sending fewer migrants to the frontier, and why the Amazon seems to be expelling greater numbers than before. Modifications in migration patterns in Brazil may reflect regional changes in the Amazonian economy as well as new processes proceeding at the national level. Further, alterations under way in Brazil may reflect new circumstances outside the country (for example, Skole et al. 1994; Wood et al. 1996). Regardless of what these exogenous factors might be, their importance as explanations for historical variations in linkages between migration and land cover change in the Amazon should not be underestimated. Conceptual models of the drivers of deforestation—demographic and otherwise—must somehow account for the intervention of
exogenous forces in order to anticipate changes in linkages with land use and land cover through historical time. The need for models that recognize punctuations induced by exogenous shocks is likely to grow as the Amazon adopts dynamics at ever greater variance from those of previous periods associated with frontier expansion.

Notes

1. In fact, the picture is considerably more complicated, as urban growth is often closely tied to rural expansion, and migration within the Amazon often involves seasonal pendular movement between rural and urban areas (Browder and Godfrey 1997; MacMillan 1995). However, this is not inconsistent with the idea that migration does not automatically or generally lead to land use and deforestation.

2. This chapter attempts to provide a macro-level (that is, regional) perspective on migration in the Brazilian Amazon. There are three reasons to adopt such an approach. First, a regional assessment of migration complements the many local case studies accumulated in existing literature (see, for instance, Barbira-Scrazzocchio 1980; Henriques 1988; Léna and Oliveira 1991; Lisansky 1990; Moran 1981, 1985; Schumann and Partridge 1989; Schmink and Wood 1984, 1992). By focusing on migration and observing it over a large area, we can situate one important process of frontier expansion occurring in well-known study areas within the larger regional context. Second, a macro-level assessment of migration complements existing region-wide appraisals of deforestation. Given estimates of deforestation for Brazilian states and the entire Amazon region, migration estimates for the same spatial units yield a limited but viable set of cases in which we can observe both a key driver and outcome of land use. And third, a macro-level approach allows use of Brazilian census data, which are available for several points in time and are collected in a standardized fashion. Use of these data affords an opportunity to observe migration during a sequence of periods in order to make comparisons over time, particularly in light of changes in deforestation.

3. The “Legal Amazon” as defined for the state-level analysis also includes Mato Grosso do Sul (included in Mato Grosso) and Goiás (included in Tocantins). While these states extend the area considered to be outside the official limits of the Legal Amazon, their inclusion was necessary for maintaining direct comparability across all census dates, for Mato Grosso do Sul was not separated from Mato Grosso until the 1980 census, and Tocantins was not separated from Goiás until the 1991 census.

4. For fertility estimation, I made use of information on children born during the year prior to the census and tabulated this by the mother’s age into seven age categories: 15–19, 20–24, 25–29, 30–34, 35–39, 40–44, and 45–49 years. This information served as input for calculation of age-specific and total fertility rates.
I used the $P_2/F_2$ method to correct for reference period errors in reporting (see, for example, Wood and Carvalho 1988, 261–62).

5. For mortality estimation, I employed the Preston-Trussel variant of the Brass indirect technique, outlined for the Brazilian case in Wood and Lovell (1990). The census data include information on children ever born and children surviving to women ages 20–34, by state. Survival rates of children born to women ages 20–24 correspond to child survival to age 2; similarly, child survival among women ages 25–29 corresponds to child survival to age 3, and child survival among women ages 30–34 corresponds to child survival to age 5. Each estimate can be applied to a model life table, where the child survival rate falls on an age-specific mortality curve with a corresponding level of life expectancy. I employed the “South” model life table that fits the Brazilian mortality pattern (Wood and Lovell 1990, 257). The estimates of child survival to ages 2, 3, and 5 each yielded an estimate of life expectancy based on the South model life table. For populations in each state, I took an unweighted average of the three estimates of life expectancy to obtain an overall estimate. From a state’s overall life expectancy I derived corresponding male and female life expectancies (Wood and Lovell 1990, 258). Because the child survival data are retrospective, the resulting life expectancies refer to a point in time approximately five years prior to the census date. The 1970 life expectancies refer to 1965, 1980 estimates refer to 1975, and 1991 estimates refer to 1986. To obtain 1980, 1985, and 1990 life expectancies, I conducted algebraic interpolations.

6. Results derived from a population projection with alternative assumptions (of 20 percent declines in fertility and two-year rises in life expectancy by 1996) do not alter the substantive conclusions drawn in this essay.

7. The assumptions vary somewhat from those of earlier analyses of net migration in the Amazon, with the result that net migration estimates will differ. The present estimates, while crude, constitute improvements over previous efforts (Wood and Wilson 1984; Wood and Perz 1996) due to the incorporation of additional information from more recent censuses.

8. The net migration rates are calculated as the enumerated 1991 population minus the projected 1991 population, divided by the projected 1991 population, multiplied by 100.

9. To obtain municipal net migration estimates for the 1980s, I aggregated municipalities that changed during the decade to render them into compatible units (IBGE 1995). This aggregation was necessary in order to project 1980 populations to 1991 and have geographic areas directly comparable to those for the enumerated populations.

References


Part II

Land Use Decisions and Deforestation
The Colonist Footprint

Toward a Conceptual Framework of Land Use and Deforestation Trajectories among Small Farmers in the Amazonian Frontier

Eduardo S. Brondízio, Stephen D. McCracken, Emilio F. Moran, Andrea D. Siqueira, Donald R. Nelson, and Carlos Rodriguez-Pedraza

During the past few years, studies on farm-level land use processes have emerged as an important component in understanding deforestation dynamics in the Amazon (Brondízio et al. 1994; McCracken et al. 1999; Pichón and Bilsborrow 1992). It is becoming clear that to study deforestation and land use as processes requires looking at the variables working at the very local level, such as the link between household composition, soil fertility, and farm dynamics (Moran, Brondízio, and McCracken, chap. 7 of this volume), as well as regional socioeconomic factors motivating household decisions, such as credit policies, market opportunities, and inflation rates (Mahar 1979, 1989; Wood and Skole 1998). Attention to farm- and regional-level processes has brought a new perspective to the analysis of deforestation: how do these two levels inform each other in seeking better understanding of the causes and consequences of deforestation? This is a question that will be answered only with advances in the uses of remote-sensing data in fine tune with field-based assessment/interview techniques and spatially and temporally related sampling.

Most conceptual models that purport to explain deforestation and land use change in the Amazon may be grouped according to the use of one of four large sets of variables: demographic (population growth and migration, for instance, McCracken et al., chap. 6 in this volume; Pichón 1997; Wood and Skole 1998); socioeconomic (fiscal incentives, inflation, market, for instance, Hecht 1985; Kaimovitz and Angelsen 1998; Moran et al. 1994); political-institutional (colonization and legal restrictions, for instance, Browder 1988; Ozorio de Almeida 1992; Schmink and Wood...
Evaluation of deforestation rates used in conceptual analysis has been carried out at four broadly defined scales: regional (ranging widely from basin, state, or a Landsat footprint), municipality, community, and farm levels. Successful linking of conceptual models to these scales of analysis has been less common given the occasional tendency to use unclear units of analysis in estimating deforestation rates and a variety of spatial and temporal resolutions. Conceptual models also tend to focus on level-specific variables and are often forced to use socioeconomic and demographic data without an explicit link to the deforestation analysis scale. In part, this focus is due to the fact that the Amazon region often faces serious constraints of compatible and multiscale socioeconomic and land cover data. The chapters in this volume provide excellent examples of strategies to overcome these problems.

Sliding between scales of analysis and mismatch between spatial and temporal resolution often lead to a variety of explanations of deforestation processes, producing different political and social implications. For instance, small farmers are being increasingly blamed as the major agent of deforestation in the Amazon, despite the unsuitability of regional-based estimation to capture inter-annual deforestation at this level.

However, in addition to “frontier politics” and misinterpretation of regional deforestation data, we still lack good understanding of land use trajectories among frontier farmers. Consolidating a farm in an Amazonian frontier puts colonists in a paradox: having to open a rural property, consolidating its land use, and at the same time “avoiding” deforestation. This is an awkward position wherein they are either victims or aggressors depending on one’s perspective. These issues raise questions about the role of small farmer colonists in frontier areas, the role of government policies, and the role of the scientific community in evaluating the causes and consequences of frontier occupation. By comparing rate, extent, and direction of land cover change among colonist farms started during the past twenty-eight years along a section of the Transamazon Highway, we aim to contribute to a better understanding of deforestation trajectories as they relate to processes of opening, expanding, and consolidating a farm in the Amazonian frontier—what could be called “the colonist footprint.”

In the Amazonian frontier, older and emerging colonization areas exist side by side, often closely connected physically through roads and socially by property regimes and family networks. So, how does the understanding
of the trajectories of previously settled colonists help to inform the outcomes of new settlers? This chapter discusses links between farm and regional scales. Moreover, it will seek to explore similarities and differences in deforestation trajectories among small farmer colonists as they relate to farm cohort arrival, farm “aging,” and “period effects” (credit and inflation periods). An integrated analysis of deforestation and land use is carried out at three different levels.

1. **Regional (the colonization landscape).** The colonization area as a whole is analyzed in relation to its trends in farm occupation and deforestation rates during the life of a twenty-eight-year-old frontier area. Subject to government-sponsored and independent colonization since 1970, the study area cuts across the municipalities of Altamira, Brasil Novo, and Medicilandia, encompassing 3,718 farm lots in an area of 355,295 hectares.

2. **Cohorts of farm lots (groups of farm lots occupied during the same time).** The colonization landscape is stratified according to cohorts of farm lots distinguished by time of arrival and initial deforestation of at least 5 percent of a farm lot. Colonist arrival, an ongoing process since 1970, is nonetheless characterized by different intensities, as expressed by farm cohorts. In this chapter, eight colonization cohorts are distinguished and analyzed.

3. **Farm level across cohorts (the farm landscape).** Farm lots across cohorts (n = 3,718) are analyzed in relation to deforestation and land use trajectories since the time of their initial clearing (at least 5 percent of the farm lot).

Time series remote-sensing data allow us the required multitemporal perspective of these processes, one that captures the arrival of colonization cohorts and the simultaneous process of farm consolidation and frontier expansion. This chapter relies on the possibilities offered by remote-sensing data to pursue an understanding of agro-pastoral development trajectories and to frame key components underlying deforestation processes in frontier areas. Data derived from Landsat Multi-Spectral Scanner (MSS) and Thematic Mapper (TM) images as well as from aerial photography are used to examine land use and deforestation in the study area during the period of 1970 to 1996. Image classifications and maps representing 1970, 1973, 1975, 1976, 1978, 1979, 1985, 1988, 1991, and 1996 are georeferenced to a property grid covering 3,718 farms (approximately 100 hectares each) settled during the past twenty-six years. The data set covers the entire period of colonization and links fine-scale property-level
boundaries to landscape-based maps, providing a baseline to examine four questions: (1) What are the rates and patterns of deforestation, at the landscape and farm-lot levels, associated with different colonization cohorts? (2) What are the main land use trajectories and levels of fallow management associated with it? (3) How does farm-level analysis of land use and deforestation help us to understand the deforestation process perceived at the landscape level? (4) How are deforestation processes at these levels related to cohort effects, cohort aging and dynamics, and period effects?

Toward a Conceptual Model of Land Use and Deforestation Trajectory in the Amazonian Frontier

Explanation of land use intensification is usually based on conceptual models using parameters such as fallow cycle (Boserupian models), or variables based on factors of production, for instance, labor, energy input, technology, and/or capital—so-called “input factors.” Alternatively, “output factors” (for example, the maintenance of productivity over time) are often used as a complementary measure of agro-pastoral intensification (for review see Brondízio and Siqueira 1997). However, models of fallow cycle offer limited explanation of agricultural systems in frontier areas where land occupation is primarily based on cycles of progressive expansion of the use area. Even more common is the coexistence of intensive and extensive activities that guarantee farm consolidation and expansion simultaneously. This pattern of coexistence actually contradicts the so-called “peasant pioneer cycle” model that links colonist farmers to inexorably high and linear trajectory of increasing deforestation. In the frontier, agricultural systems combine activities that aim to increase land value, consolidate tenure rights, and expand activities to minimize risks and to allow experimentation in a new environment. By the same token, intensification models based on factors of production are also limited when not taking into account the lack of infrastructure and technologies (for instance, availability of crop varieties). Studying land use intensification in the frontier requires a combination of models that take into account factors such as time of settlement and stage of farm consolidation, and also infrastructural and institutional variables that are “filtered” by household factors (including labor, experience, access to credit, and biophysical characteristics of the farm such as soil, topography, access to water, and distance from the market).

One of the most significant characteristics of a frontier area is the level
of variability in deforestation and land use across farm lots of similar age and environmental conditions. To address these problems, we use a nested approach to study land use and deforestation by linking, spatially and temporally, farms, cohorts of farms, and the colonization landscape of a frontier area. These are key components in understanding deforestation as a process. A nested-sampling design that takes into account at least these two levels—the farm and the colonization landscape—offers an opportunity to estimate regional change while understanding the process behind it (McCracken et al. 1999). Observations of patterns of use and patterns of changes in use at the property level will aid us in developing a better understanding of trajectories of land use and land cover among properties. We anticipate that land use/land cover trajectories will be related to temporal and spatial aspects of settlement of farm families (for example, length of use), timing of arrival, and period effects (for instance, credit), while shaped by biophysical characteristics of the farm lot. We can begin to understand these patterns of use and patterns of change by studying individual farms.

Figure 5.1 provides a conceptual model linking household composition and domestic life cycles to transformation of individual farms and local environment (for a detailed description of this model, see McCracken et al. 1999). This model represents a demographic and a land use transition on the frontier. These transitions are hypothesized to have distinct implications for land use outcomes (these issues are also explored in chapters 6 and 7 of this volume).

The model anticipates that all settler families will be involved in the conversion of forest into annual cash crop production upon arrival. Slowly families will begin to diversify into cattle grazing (often simply as a capital-saving strategy) and perennial crops (such as black-pepper, fruit crops). Perennial crops require a relatively long period before they produce and substantial labor investment on the part of households. The question remains as to how different families pursue agro-pastoral activities while envisioning their farm development in the long term. The factors affecting the outcomes include (1) the soils, water availability, and topography of their farmlands; (2) distances to markets, credit, infrastructure, and agricultural produce prices; and (3) farmers’ experience, technical support, and household and other labor availability. By looking in detail at farm- and household-level variables and nesting them in regional, spatial, and temporal scales, we aim to understand deforestation and land use processes by disentangling (1) the “cohort effect”: deforestation associ-
Fig. 5.1. Linking a conceptual framework of household stages and land use trajectories to a remotely-sensed-based assessment of farm-level multitemporal analysis of deforestation events.
ated with the process of frontier farm occupation as groups of colonist migrants arrive in different periods; (2) the “aging effect”: deforestation associated with the process of a farm consolidation as cohorts age in the frontier and as second-generation families take a role in using the farm lot or in the process of property turnover; and (3) the “period effects”: deforestation associated with external events such as national policies (for example, credit incentives), market incentives, and economy (inflation, prices), among others.

Methods

Study Area Definition

The study area is defined by the group of 3,718 farm lots, averaging 95.5 hectares in size and ranging from 40.3 to 195.5 hectares, that are arranged according to different colonization projects implemented by the Brazilian National Institute for Agrarian Reform (INCRA) during the past thirty years. It cuts across the municipalities of Altamira, Brasil Novo, and Medicilândia in the state of Pará and encompasses an area of 355,295 hectares stretching approximately from kilometer 18 to kilometer 140 of the Transamazon Highway west of Altamira. In this study, all landscape-level estimates of deforestation and land use are based on the total area of colonization (that is, 355,295 hectares), whereas farm-level estimates are based on the relative area of each farm lot. The study area is shown in figure 5.2.

Technical Notes: Data Processing and Extraction

This study is part of two projects, one of which closely related to the Large Scale Biosphere-Atmosphere Experiment (LBA) in Amazônía, aiming to study deforestation and land use as processes underlined by multiple-scale environmental and socioeconomic variables. The integrated methodological strategy of these projects combines farm-level field surveys, multiple source remote-sensing data, and biophysical maps (topography, drainage, roads, properties, distance) into a Geographic Information System (GIS) structure and a referential database.

Software

Data processing, integration, extraction, and analysis are carried out by combining several software packages: Erdas Imagine 8.3.1 (for image processing and analysis), ArcInfo 3.0 (for property grid development, digital elevation model [DEM], and drainage), ArcView 3.1 (for integration of
image data and property grid and extraction of property-level deforestation and land cover estimates), Stata 5.0 (for statistical analysis and cohort stratification), Excel 98 (for data manipulation), Adobe Photoshop (for scanning and preprocessing of MSS-derived maps), and IDRISI 2.0 (for complementary GIS processing).

Remote-Sensing Data

The study is based on the analysis of land cover data for ten different dates and derived from four main sources including aerial photography, maps, and satellite imagery, described below.

*Aerial photo (1970), scale 1:60,000, acquired from Cruzeiro Aereolevantamentos Ltda.* Visual interpretation was carried out following standard procedures for class recognition, mosaic, and geometric correction. The derived land cover classification was scanned and preprocessed in Adobe Photoshop and exported to Erdas Imagine 8.3.1 for recoding and georeferencing using a Landsat TM image of
1991 as reference. Four classes were mapped: forest, nonforest, water, and roads.

_Instituto Brasileiro de Geografia e Estatística (IBGE) map (1978), six maps of scale 1:100,000._ These maps contain forest and agro-pastoral classes derived from interpretation of aerial photos of 1978. Maps were scanned and preprocessed in Adobe Photoshop. Recoding and georeferencing were performed in Erdas Imagine 8.3.1. Aerial photographs of the same date were used to check the accuracy of land cover classification. Four classes were mapped: forest, nonforest, water, and roads.

_Landsat MSS (1973, 1975, 1976, and 1979) analogic images (scales 1:250,000 and 1:500,000) from the archives of SUDAM (Superintendência do Desenvolvimento da Amazônia, Belém, Pará)._ These images were visually interpreted into forest and nonforest. The resulting maps were scanned and preprocessed in Adobe Photoshop and exported to Erdas Imagine 8.3.1 for recoding and georeferencing using a Landsat TM image of 1991 as reference. Three classes were mapped: forest, nonforest, and water. Two of the Landsat MSS images (1975 and 1979) do not cover the entire colonization area, but property-level estimates take that into account. These dates were combined with the nearest date (for example, 1975 and 1976, 1979 and 1978) during deforestation estimation for the whole area.


It is important to mention that we were unable to classify an important land cover class existing in the study area, which is the area of cocoa plantation. Despite our effort and careful collection of field data, cocoa plantations are not distinguished from intermediate and advanced stages of secondary vegetation. In order to improve our farm-level analysis we used cocoa production and plantation area data derived from the offices
of CEPLAC (Comissão Executiva do Plano da Lavoura Cacaveira, the Cocoa Extension Agency), which are responsible for the municipalities of Altamira, Brasil Novo, and Medicilândia. These data include location of the farm (gleba and lote) and area (and number of trees) planted in different years. A section of these data is presented by Moran and his colleagues in chapter 7 of this volume.

Property Grid

The property grid of the colonization area was developed by integrating three main processes: digitalization of existing INCRA colonization maps using ArcInfo and IDRISI (original and recent maps provided by the INCRA office in Altamira), screen digitizing based on spatial characteristics of farm lots as visible in multitemporal composite Landsat TM images (1985 + 1988 + 1991) using Erdas Imagine 8.3.1, and extensive GPS field surveys. Preliminary property grid maps were subjected to field-based differential GPS correction using farm lot boundary landmarks (more detail can be found in McCracken et al. 1999).

Each farm lot was tagged with a unique identification (ID) associated with the INCRA system composed of gleba (area), travessão (feeder road), and lote (farm lot number). Although not used in the analysis presented in this chapter, this compatible ID system is used to create a referential database integrating farm-level field surveys on demography and land use, remote sensing, and other spatial layers of data with secondary data (for instance, CEPLAC cocoa production areas).

Data Recoding

The complete data set used in this study is comprised of georeferenced land cover data for 1970, 1973, 1975, 1976, 1978, 1979, 1985, 1988, 1991, 1996, and the property grid overlaying it. The data set was organized into two main groups. First, all the land cover data were recoded to three classes: forest, nonforest, and background (classes of cloud and cloud shadow and unclassified pixels). This recoding allowed direct comparison of land cover classes across all ten dates. Second, the Landsat TM-based land cover data were recoded into five main classes: forest, secondary succession (SS 1 + SS 2 + SS 3), production areas (bare soil + pasture), water, and background (classes of cloud, cloud shadow, and unclassified pixels). This recoding allowed the evaluation of trajectories, for instance areas changing from deforested to secondary succession or to production.
Transition Matrices—Temporal Trajectories

Starting with 1970, each land cover map representing a point in time was compared to the following date, and for each pair a transition image was produced using the Matrix command in Erdas Imagine 8.3.1. For instance, between 1970 and 1973, a transition image was produced showing the area remaining in forest, the area deforested in the first date (that is, 1970), the area deforested in the second date (1973), and the areas of inconsistency (area deforested in 1970 that returned to forest in 1973). Inconsistent classes can be a product of data interpretation error or georeferencing accuracy. These areas were reclassified to their original state in order to avoid overestimation of deforestation. For example, a transition from nonforest to forest was reclassified back to forest (this process favors a conservative estimate of deforestation between dates).

Following this procedure, deforestation maps were produced based on all possible transitions and showing the deforestation sequence from 1970 to 1996, at three- to five-year intervals. A final map showing each stage of deforestation in the area from 1970 to 1996 was produced (see figure 5.1, for example, showing deforestation from 1970 to 1991 in a subset of the study area as it related to our conceptual model of household stages).

A second set of transition matrices was produced using the more detailed land cover classification of the Landsat TM images. These transitions aim to capture the land use trajectories between the maps of 1970, 1973, 1976, 1978, and 1979, and the maps of 1985, 1988, 1991, and 1996. Transition maps were produced showing the areas deforested in a particular date and the percentage of them converted to secondary succession (an aggregation of SS 1 + SS 2 + SS 3) or to production areas (bare soil + pasture, and bare soil + sugarcane in the case of 1985 and 1991 images). These are useful transition maps for an analysis of land use trajectories and the level of land use extensification in each farm lot and in the colonization area as a whole. Ongoing analysis is refining these transitions to the level of each stage of secondary succession, pasture, and bare soil.

Farm-Level Data Extraction

The farm lot grid was overlaid in the maps representing the overall land cover transitions and deforestation trajectories from 1970 to 1996 using ArcView 3.1, allowing the extraction of all transition classes for each farm lot in the colonization area—that is, 3,718 farm lots. These data were imported into Excel 98, cleaned, and prepared for use in the statistical package Stata 5.0.
Cohorts Definition and Extraction

The data on farm lot deforestation and land use trajectories were imported into Stata 5.0 and tabulated into summary statistics. Using Stata logical operations, farm lots were stratified into cohorts based on the criterion of 5 percent initial deforestation. This criterion means that a farm lot is considered as part of a cohort once it has at least 5 percent of the total area deforested. This criterion is used to indicate when a farm lot is beginning to be occupied. Eight cohorts were generated based on this criterion.

Results

Units of Analysis: Landscape, Cohorts, and Farm Levels

Deforestation estimates are carried out in three different units of analysis: the colonization landscape (the entire colonization area), farm-lot cohorts (groups of properties representing time of arrival), and farm lots across cohorts. These levels are analyzed in relation to three main components: deforestation trajectories, secondary succession trajectories, and production trajectories.

Definition of the unit of analysis in the estimation of deforestation is a key element for facilitating comparison and characterization of processes. It has been common to use Landsat footprints as units of analysis in the absence of accurate boundary definition. Although informative, using these units limits the association of socioeconomic and environmental variables underlying deforestation in a particular area. This limitation has justified our effort in dedicating two years of laboratory studies and fieldwork to ensure an accurate property grid that defines our units of analysis in these projects.

Distribution of Farm-lot Cohorts: Deforestation and Land Use Trajectories in the Colonization Landscape

Table 5.1 shows the distribution of farm lots into cohort groups. About 52 percent of the farm lots were occupied by 1979, whereas another 20 percent were added during the 1980s and 14 percent between 1991 and 1996; another 14 percent were in the initial stages of settlement by 1996. The cohorts of the 1970s and 1990s are dominant in this colonization area. The category “new” cohort, representing 14 percent of the total farm lots, indicates that occupation of farm lots is still ongoing at a progressive rate.

The deforestation trajectory of the whole colonization area is presented in figure 5.3, which shows deforestation rates and cohorts of arrival at
approximately five-year intervals. Of the total area deforested until 1996, about 13 percent occurred up to 1975 and a total of 38 percent up to 1979. The 1980s show continued increase in deforestation rates, adding another 23 percent by 1985, but decreasing sharply by 1991 to about 13 percent. As a whole, up to 1991, deforestation accumulated to about 74 percent of the deforested area. A sharp increase is then noticed through 1996, an increase that represents 25 percent of the total deforestation occurring in the area from 1970 to 1996.

Despite the high rates of deforestation during this period, 61 percent of the total colonization area examined remained in forest by 1996, whereas total deforestation added up to 37 percent and nonclassified areas represented about 2 percent. Figure 5.4 shows the composition of the 1996 colonization landscape by disaggregating deforested area into classes of secondary succession and production areas. By taking into account areas of bare soil, pasture, and cocoa plantations (as estimated by CEPLAC), our estimate shows that about half of the area deforested from 1970 to 1996 remained in production by 1996, whereas half of it had been taken over by different stages of secondary vegetation. It is important to mention

<table>
<thead>
<tr>
<th>Cohorts</th>
<th>Freq.</th>
<th>Percent</th>
<th>Cum.</th>
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</thead>
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<td>1970–73</td>
<td>121</td>
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</tr>
<tr>
<td>Total</td>
<td>3,718</td>
<td>100.00</td>
<td></td>
</tr>
</tbody>
</table>

a. Definition of cohort groups:

- Cohort 1 (70–73) = farm lots with initial clearing between 1970 and 1973
- Cohort 2 (75–76) = farm lots with initial clearing between 1973 and 1976
- Cohort 3 (78–79) = farm lots with initial clearing between 1976 and 1979
- Cohort 4 (79–85) = farm lots with initial clearing between 1979 and 1985
- Cohort 5 (85–88) = farm lots with initial clearing between 1985 and 1988
- Cohort 6 (88–91) = farm lots with initial clearing between 1988 and 1991
- Cohort 7 (91–96) = farm lots with initial clearing between 1991 and 1996
- Cohort 8 (new) = farm lots with initial clearing smaller than 5% but larger than zero, based on 1996 data.
again that cocoa area is not estimated using remotely sensed data, but is based on farm-level CEPLAC data. Cocoa areas represent a total of 13,842 hectares, or about 3.7 percent of the total deforested area and 15.9 percent of the area in secondary succession.

**Deforestation Trajectories across Cohorts**

Variation in total forest cover in 1996 by cohort-based farm lots is shown in figure 5.5a. A strong relationship exists between time of settlement and forest cover; that is, older cohorts have, on average, less forest cover than younger cohorts (adj. $r^2 = 0.58$, significant at 95 percent confidence interval) with strong internal variation. Three main groups can be distinguished according to forest cover and time of arrival. Cohort farm lots of the 1970s present similar averages in forest cover—about 40 percent forest on the farms—but with strong variation within cohorts, ranging from 0 to 90 percent forest. Cohort farm lots of the 1980s show on average about 60 percent of forest cover in their lots, but ranging from about 30 to 90 percent forest cover. Cohort farm lots of the 1990s show on average more than 75 percent of forest cover by 1996, but ranging from about 60 to 95 percent of the farm lot.

![Graph showing deforestation trajectories by cohort](image-url)
Variation in total deforested area from 1970 to 1996, total secondary succession area in 1996, and total production area in 1996 are shown in figure 5.5b. As a “mirror” of figure 5.5a, this figure shows that total deforestation increases with time of settlement (adj. $r^2 = 0.60$, significant at 95 percent confidence interval). However, the area in secondary succession and production presents less significant correlation with time of settlement.

Whereas secondary succession (adj. $r^2 = 0.27$, significant at 95 percent confidence interval) and production (adj. $r^2 = 0.31$, significant at 95 percent confidence interval) increase with time of settlement, differences among cohorts are less marked. Older cohorts have a larger variation in secondary succession and production areas. Cohorts of the 1970s have on average about 8 to 10 percent of the farm area in secondary succession, varying between 0 and 50 percent of the total property in fallow. Cohorts of the 1980s have an average 5 percent in secondary succession, varying within cohorts from 0 to 20 percent of the total property in fallow.

Similar distribution is perceived in production areas. The 1970s cohorts have 6 percent of their farm lots in production, with variation among farm lots ranging from 0 to 25 percent of the property. Cohorts of the 1980s present on average 4 percent of the farm lot in production, but show smaller variation within cohorts—that is, production areas ranging from 0 to 8 percent of the farm lot.
Fig. 5.5a. Total forest cover (%) in 1996 by farm cohorts

Fig. 5.5b. Total deforestation, secondary succession, and area in production (%) in 1970–96 by farm cohorts
Farm-Level Deforestation Trajectory Across Cohorts

The deforestation trajectory of each cohort is presented in figures 5.6a–h, which show variation in cohort-specific deforestation rates for six dates: 1973, 1978, 1985, 1988, 1991, and 1996. Deforestation trajectories present a clear pattern across cohorts. Older cohorts, for instance those presented in figures 5.6a–d, show pulses of deforestation trajectory reflecting increasing rates of deforestation during the first five years of settle-

Figs. 5.6a–h. Deforestation trajectories (quartiles) for each cohort


5.6h. Deforestation trajectory [73-96] of Cohort [8] new
ment followed by progressively decreasing rates and a second “wave” of deforestation in more recent years.

The increasing rates of deforestation during the first five years of settlement are also consistent with more recent cohorts (figs. 5.6e–h). However, these cohorts (cohort 5 [1988], 6 [1991], and 7 [1996]) present a slower rate of initial deforestation when compared to older cohorts. Deforestation in the first four cohorts averages about 10 percent of the property, whereas cohorts 5, 6, and 7 show on average 5 percent of deforestation per year during the first five years, although variations within cohorts range from 0 to more than 35 percent of deforestation per farm lot. Figure 5.7 summarizes deforestation trajectories by taking into account average deforestation on farm lots across cohorts. The trajectories portrayed in this figure represent the arrival and aging aspects of the colonist footprint as it characterizes fluctuations in deforestation rates related to opening, expansion, and consolidation of farms.

Farm-Level Land Use Trajectory Across Cohorts

The farm-level post-deforestation trajectory is examined in more detail for two periods of the area’s colonization history, 1973 and 1985. Farms that deforested land during these years are analyzed in relation to the condition of the deforested area in 1996. For instance, deforested areas in 1973 are reexamined in 1996 to estimate the amount of land that remained in production and the amount of land in secondary vegetation—that is, in fallow. Figures 5.8a and b show the analysis of deforested areas in 1973 and their condition in 1996: how much of the deforested area was in secondary succession and/or production, respectively (n = 802 farm lots). Figures 5.9a and b show the same analysis for areas deforested in 1985 and their condition in 1996 (n = 3,288 farm lots), respectively.

With the two cases, there is a strong correlation between the amount of deforested area and the amount of secondary succession resulting from it. High amount of deforestation leads to a larger area in secondary succession despite time of settlement (adj. $r^2$ in 1973 = 0.7; adj. $r^2$ in 1985 = 0.7, significant at 95 percent confidence interval). Deforestation rate is a good predictor of secondary succession rate. Once an area is deforested, it has more chances to present a higher rate of abandonment in the future.

Deforestation amount is also positively correlated with production areas, although to a lesser degree and with strong variation among farm lots. Deforested areas in 1973 are largely being used as production areas in
Fig. 5.7. The colonist footprint: Average deforestation trajectories by colonization cohorts

1996. This conversion is not as clear for areas deforested in 1985 (adj. $r^2$ in 1973 = 0.6; adj. $r^2$ in 1985 = 0.38, significant at 95 percent confidence interval).

Discussion

Colonization and Farm Cohorts

Frontier occupation is an ongoing dynamic process in which “old settlers” coexist with new ones, the last being recent migrants or second-generation colonists taking over new lots. Colonization rates decreased after the withdrawal of government support in 1974 for about fifteen years, returning to an increased rate after 1991. At this level of analysis, cohort arrival and period effects underline the process of deforestation. Fluctuation of deforestation rates after 1985 coincides with national-level economic indicators. On the one hand, economic depression and high inflation rates during the second half of the 1980s, and the withdrawal of cattle ranching incentives, are potential explanations for the sharp decrease in deforestation rates perceived between 1985 and 1991. On the other hand, the sharp increase in deforestation perceived in 1996 is likely to be associated with economic stabilization and lower inflation rates achieved after Plano Real
Fig. 5.8a. Deforested area in 1973 turning into secondary succession in 1996; farm level (n = 802)

Fig. 5.8b. Deforested area in 1973 turning into production in 1996; farm level (n = 802)
Fig. 5.9a. Deforested area in 1985 turning into secondary succession in 1996; farm level (n = 3288)

Fig. 5.9b. Deforested area in 1985 turning into production in 1996; farm level (n = 3288)
was implemented in 1994 and with the return of credit incentives such as FNO (Fundo Constitucional para a Região Norte).

Areas in secondary vegetation and areas in production similarly cover the deforested area. Annual crops and pasture dominate, although cocoa also represents an important crop. However, there is a clear variation within the colonization area in relation to the dominance of these land cover classes. The western part is largely covered by forest, given the dominance of new settlers, whereas forest cover falls to less than 50 percent in the eastern section closer to Altamira (McCracken et al. 1999). Land use composition of farms is likely different between these two sub-regions given variation in time of settlement, differences in soil fertility, and proximity to an important regional market.

Although period effects are likely to explain part of the variation in deforestation rates during this time, processes working at the farm and family level, the “age effect,” add complexity to the explanation. First, there is a lag in time between initial settlement and farm consolidation that is likely to lead to a differential spike in deforestation after initial settlement. Second, age effect is characterized by changes in household socio-economic conditions that interact with period effect. Field observations in 1997 and 1998 show that the introduction of a new grass (locally called *braquierão* [Brachiaria brizantha]), well adapted to the region and highly competitive with secondary species, has sparked a new wave of clearing (in both secondary vegetation and forests) aimed at pasture formation. This is an example where opportunity-seeking and risk-taking households have taken advantage of both new technology and a period of economic stability to expand and consolidate their farms. In summary, regional-level deforestation is a combination of age and period effects, with internal variation at the cohort level.

**Deforestation Trajectories by Cohorts**

Whereas positive significant correlation exists between time of settlement and deforestation, this correlation is offset by the internal variability within cohorts, which is stronger than across cohorts. Such variability is even stronger in older cohorts, suggesting variation in land use systems probably associated with different trajectories in household economic strategies and composition, and in farm production potential. Another likely component of this variation is the high rate of property turnover among old cohort farm lots. Unfortunately, property turnover is a still scantily studied process despite its rate of occurrence (see Moran et al., chapter 7 in this volume).
It is interesting to note that, although the cohorts of the 1990s (cohorts 7 and 8) represent an important expansion into new lots (resulting both from migration and acquisition of new lots by settled farmers), colonists during the 1970s were arriving in much higher numbers in a shorter period. On the other hand, the amount of land that took ten years to deforest in the 1970s took only five years during the 1990s. This is a result of both an increase in the average size of cleared area and a larger number of established farmers taking advantage of a period of economic stability.

Older cohort farm lots also present larger areas in secondary succession and production, but this is less significant in relation to time of settlement, varying more within cohorts than across older cohorts. Decisions regarding deforestation may be made to seize a “period” opportunity, but do not necessarily focus on long-term investments. For instance, deforestation takes advantage of a credit opportunity that was discontinued after subsidies ran out, and is therefore likely to lead to an increase in the area of secondary succession.

Farm-Level Deforestation Trajectories across Cohorts

Average size of deforested area by farm lot has increased steadily since the beginning of the colonization process. Regional familiarity, knowledge of deforestation practices and technology, and the lack of law enforcement of land clearing are factors that help to explain this trend. Interesting to note is the variation in the size of area cleared between 1988 and 1996. The average size of deforested areas dropped twofold in 1988 and 1991 but increased twofold in 1996, achieving the highest average of cleared area since the beginning of settlement. Period effect, characterized by changes in national economy, is likely to explain most of such variation.

Deforestation is an important investment from a farmer’s perspective, and as such, it is likely to diminish in times of economic depression (for example, between 1988 and 1994) or increase during periods of economic stability (for example, after 1994’s Plano Real). However, there is a wide range in the size of cleared areas during the whole period of colonization, varying from about 5 percent to almost the whole farm lot. This range indicates strong variability in household decisions about investment and risk, and highlights the importance of age effect as an important dimension to explain this process.

The data suggest that deforestation trajectories across cohorts are marked by successive periods of cyclical pulses of deforestation, associated with processes of expansion and consolidation of the farm lot, called here the “colonist footprint” (fig. 5.7). The consistency of deforestation
trajectories across cohorts is, however, differentiated within cohorts (intra-cohorts) by variations in rate, extent, and direction—variation related to expansion and consolidation of land use activities as it reflects the coexistence of extensification and intensification of agro-pastoral strategies. The initial stage of progressive increments in deforestation seems consistent across cohorts, and one can expect similar behavior among colonists settled after 1996. This reinforces the idea posed by the conceptual model presented in figure 5.1, that farmers tend to deforest as much area as possible to establish their farms, followed by a consolidation period characterized by investment in perennial crop and secondary succession management. However, period effects add another important component to these trajectories, such as periods of credit availability and economic stability. In older cohorts, a period of low deforestation rates (1988 and 1991) and a more recent spike in deforestation (1996) coincide with overall trends perceived at the regional level and with national economic trends. These cyclical pulses of deforestation trajectories, consistent across older cohorts, combine factors associated with age and period effects.

The amount of deforestation on a particular date is a stronger predictor of future increases in area of secondary succession than of future area in production. These results are associated with two important processes of frontier farming. First, they highlight the extensive nature of most farms, the lack of support for farmers, and consequently their dependency on fallow management as part of the production system. Second, they show the difficulty of maintaining areas planted in pasture or annual crops free of secondary vegetation. It is likely that most farmers deforest more than they can manage, but the availability of a broad array of secondary forest also represents capital in a system dominated by shifting cultivation practices. Furthermore, “cleared” areas may add value to the land in the short term. These tendencies in secondary succession and production areas add another dimension to the farm trajectory model discussed above. Whereas deforestation follows ups and downs according to time of settlement, household aging, and period effects, secondary vegetation seems to be more incremental across time and an important part of farm consolidation. Further analysis is required to grasp management of fallow of different ages, but field information suggests that colonist farmers managed fallow differentially according to their production system. Whereas older fallows are favored for annual crops, younger fallows are frequently preferred for pasture formation. The ability to balance the amount of fallow in different stages of regrowth is an important element of farm management in the frontier.
The association between deforestation and production areas is far stronger for the 1973 cohort. In this case, the amount of deforestation seems to be a good predictor of the amount of production area in 1996. Two factors may help to explain this pattern. First, as the 1973 cohort had access to better soils, it is likely that areas deforested by these farmers can be maintained in production for a longer period as suggested by these data (see chapter 7 in this volume). Second, the pattern suggests that their longer experience in the frontier may be a key element in consolidating their farms and maintaining their production areas.

Final Remarks

Frontier areas challenge the application of conventional models of land use intensification based on fallow cycle and factors of production frequently used in other areas to explain the association between agro-pastoral systems, population and socioeconomic factors, and deforestation. The colonist footprint is characterized by the coexistence of extensification and intensification of production strategies marked by cycles of expansion and consolidation of farm operations. These cycles, however, are characterized by high variation within farm cohorts resulting from differential rate, extent, and direction of land cover change across farm lots. Understanding deforestation trajectories and the colonist footprint requires a combination of variables related to time of settlement (cohort effect, for example), cohort and household dynamics (such as aging, household labor composition, experience, origin, and expectations), and period effects (for example, credit, inflation), underlain by environmental, market, and infrastructural conditions.

In order to inform better land use policies and to provide better support to colonist farmers, attention should be paid not only to regional dynamics, but also to intraregional variability and differential conditions among colonists’ cohorts and farms. This study aimed to contribute to a better understanding of the variability of deforestation rate and pattern, stocks and maintenance of forest, secondary succession, and production areas across cohorts and households in different time periods, all of which are key elements in characterizing deforestation and land use as processes in frontier areas. Understanding these processes will help improve existing infrastructure and value local experiences that help existing farmers to maintain forest in their lots, to increase agro-pastoral production, and to improve the quality of life of their families—all key elements of better policies that seek to decrease deforestation rates in the Brazilian Amazon.
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Land Use Patterns on an Agricultural Frontier in Brazil

Insights and Examples from a Demographic Perspective

Stephen D. McCracken, Andrea D. Siqueira, Emilio F. Moran, and Eduardo S. Brondízio

This chapter is part of an ongoing research endeavor on trajectories of land use change associated with frontier settlement at the household/property level in the Altamira region of Pará State, Brazil. The research is being carried out by a multidisciplinary team at the Anthropological Center for Training and Research on Global Environmental Change at Indiana University with funding from the National Institute of Child Health and Human Development (NICHD). A central concern of the project is to link landscape change to demographic dynamics of frontier settlement through the use of remotely-sensed imagery and household/property surveys. It is a micro-level approach with a view to uncovering specific mechanisms of land use change that, in the medium to long run, shape landscape change. Much current remote sensing analysis deals with broad-based landscape change and focuses on “hot spots” of deforestation. These changes are often associated with macro- and aggregate-level processes (for example, road construction, migration flows, economic trends, and government policies). In contrast, a micro-level approach can evaluate and enlighten our understanding of how households and communities, embedded in these macro-level processes, transform the landscape during a generation-long process of frontier occupation, settlement, and consolidation. This micro-level demographic approach, focusing on the process of transformation, provides an alternative, yet complementary, perspective on landscape changes taking place in frontier regions of the Amazon and possibly in other agricultural frontiers.
The chapter progresses as follows. First, we outline some of the conceptual and methodological issues in linking demographic and remotely-sensed image analysis. We then illustrate the potential of a demographic perspective through a discussion on period, cohort, and age effects for understanding and disentangling causal mechanisms underlying processes of landscape transformation. Next, we discuss a conceptual framework for linking the demography of families to agricultural strategies as well as to levels and patterns of deforestation and afforestation. Briefly we outline a research strategy we developed (property grid development and sampling) in order to link household/farm data to remotely-sensed data. Finally, we provide a discussion of our results on demographic changes over the course of frontier occupation and settlement among our sample of 402 households in the Altamira region.

**Issues in Linking Sociodemographic and Remotely-Sensed Analyses**

In recent years there has been increasing interest in promoting multidisciplinary research on environmental change that integrates social and natural sciences. Land use/land cover change has served as a unifying theme for this integration that combines remotely-sensed data and analysis with social science perspectives and methods. The recent volume *People and Pixels*, edited by Liverman and others (1998), highlights the promise of this kind of research. Many articles discuss the rationale, possibilities, and limitations of this work as well as provide excellent examples of particular research strategies. At the risk of oversimplification and omission of the range of research possibilities, it is useful to outline some of the conceptual and methodological issues that emerge in this process of bringing different research communities and perspectives together in research on land use/land cover change. Table 6.1 and the following discussion provide a schematization of these issues as they relate to incorporating quantitative socioeconomic and demographic research strategies and data into this research agenda.

Recent technological innovations in software and hardware facilitate the collection, organization, manipulation, and analysis of spatially-distributed data (Michalak 1993). The methodological toolboxes of Global Positioning System (GPS) and Geographical Information Systems (GIS) greatly facilitate the integration of social science research into the land use/land cover research agenda. Nevertheless a series of conceptual and methodological issues must be addressed to make this research more fruitful. While overall interest in landscape conditions and changes is the focus of
Table 6.1. Conceptual and methodological issues in linking demographic and remote sensing analysis

<table>
<thead>
<tr>
<th>Focus</th>
<th>Socioeconomic/Demographic</th>
<th>Remote Sensing</th>
</tr>
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<tbody>
<tr>
<td>Methodological concerns</td>
<td>Units of observation and units of analysis (events, individuals, households, social groups, communities, social organization/mode of production, regions, nations)</td>
<td>scale</td>
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<td></td>
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<td>Resolution</td>
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<td>Spatial boundaries</td>
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<td>Emergent implications</td>
<td>Who are the social actors of interest and what are their spatial dimensions?</td>
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<tr>
<td>Data sources</td>
<td>Censuses and sample surveys</td>
<td>Remotely sensed imagery</td>
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<td>Spatial dimensions</td>
<td>Political/administrative boundaries (census blocks, tracks, counties . . .)</td>
<td>Pixels (with varying resolution)</td>
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<tr>
<td>Census:</td>
<td>Possible point or boundary definition with GPS equipment</td>
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<tr>
<td>Surveys:</td>
<td>Periodic complete coverage</td>
<td>Complete temporal and spatial coverage</td>
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<td>Coverage</td>
<td>Incomplete coverage</td>
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<tr>
<td>Potential problems</td>
<td>Problem of ecological correlation, spatial units with urban bias (urbanized areas are small and rural areas are large) Heterogeneity within large spatial units may be greater than heterogeneity among units</td>
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<td>Census:</td>
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the research, approaches to these questions vary substantively across disciplinary lines. We can say that environmental scientists working with remotely-sensed data focus primarily on land cover and typically think about landscape changes. Their smallest unit of observation is the pixel. The different bands of reflectance of pixels can be analyzed as continuous variables over space or be grouped into patterns and classes of land cover. Resolution, scale, and amount of information gathered (for instance, different bands of reflectance) of remotely-sensed data vary by types of sensors carried by satellites and result in pixels of different sizes.

One distinct feature of satellite image analysis is that these data represent complete coverage for an area. Frequent passes by satellites can provide multiple images for analysis over time. These characteristics of remotely-sensed data provide great flexibility for spatial and temporal data reorganization and analysis. Geographers, ecologists, and other environmental scientists working with spatial analysis and satellite imagery are particularly sensitive to issues of scale, resolution, boundaries, and areal units in their investigation of biophysical phenomena.

In contrast, social scientists involved in this research agenda are interested in land use. Often we infer “use” implicitly from analyses of land cover, but land use and land cover are distinct concepts. Land use is concerned with social, cultural, and economic behavior; it involves human actors and actions as they affect, shape, and organize the environment. Quantitatively oriented social scientists, who work primarily with census and sample surveys, are sensitive to another set of conceptual and methodological issues in their analysis of social actors. Important to this discussion is the distinction between units of observation, units of analysis, and levels of analysis. Units of analysis are events, individuals, families, households, social groups, communities, and other forms of social organization, while data for these analyses are primarily from census and sample surveys of individuals and households, or aggregations of these. Mismatch between units of observation and units of analysis can lead researchers to make heroic assumptions and misleading inferences when we try to infer community-level processes from individual-level data, or conversely, make inferences about individuals or households from community-level data or population aggregates. A pivotal concern emerges from this brief comparison of approaches: Who are the social actors of interest and what are their spatial dimensions?

Standard approaches involving census data or sample surveys have different potentials and limitations for research on land use/land cover change. Individual- and household-level socioeconomic and demographic
data from censuses are typically only available for samples (data from U.S. Public Use Microdata Samples [PUMS], for example). These individual- and household-level data generally lack any spatial reference other than “rural,” “urban,” and possibly “suburban,” as characteristics of these social actors, groups, or communities. Given the general lack of spatial references and incomplete coverage, these census samples are not useful for making the spatial links with land cover data.

Census tabulations by various areal units (blocks, block group, tracks, counties, clusters of counties) provide other possibilities but are not without additional challenges. Unlike individual data formats, census tabulations provide aggregate measures of population characteristics for areal units; the difficulty emerges in establishing relationships among variables within the population. A common approach is to infer relationships through the comparison of spatial units. In doing so we run the risk of inferring relationships at the individual level that may be considerably different from, or even contradict, observed correlation at the aggregate level. This potential problem is commonly known as “ecological correlation” (Robinson 1950).

Linking these standard sources of population data also presents other hurdles when we consider the analysis of land use/land cover. First, small areal units devised for administrative and political purposes and used in census tabulations, such as block or census track data, have a decidedly urban bias. Areal units are small in urbanized areas and increase in size in rural and remote areas. The size of areal units for administrative and census purposes is typically associated with population density. These characteristics of data organization limit the possibilities for dealing with many aspects of the human dimensions of land use/land cover change.

GIS is important for overlaying and extracting aggregated data between various layers of information at the level of the larger areal units. This aggregation of information (derived at the level of the pixel) increases the heterogeneity within our units of analysis. In addition to the potential problems of ecological correlation and comparability among differently-sized areal units, these studies have to contend with how well spatial units match spatial boundaries or clusters of land cover types. If heterogeneity is greater *within* areal units vis-à-vis heterogeneity *between* areal units, analytical potential is reduced. The possibilities of these studies will depend on the extent of overlay between the various areal units and the degree of heterogeneity within and between them. Studies that make use of census data and satellite information will certainly increase as these data sources become more readily available, but may be relegated to macro-
scale analysis of municipalities and provinces as a result. There are already several noteworthy examples that illustrate possible directions of this kind of research (Rosero-Bixby and Palloni 1998; Wood and Skole, 1998). We raise these issues as concerns and potential pitfalls that must guide research strategies and clarify the range of possible research endeavors. These studies will no doubt be important for understanding the human dimensions of environmental change on a very broad scale but will be limited for understanding and making inferences about land use/land cover change at meso- and micro-levels where individuals, families, and communities directly influence and change their environments.

Another set of questions arises when we consider the use of social science surveys for research on environmental change: What are the spatial dimensions of human actions, actors, or social groups? How do we construct spatial boundaries for our units of analysis? In some social contexts these questions may be more readily discernable than in others. Where the use of land by individuals and households (or even communities) varies across large areas, defining areal units of observation and analysis may prove very difficult. We raise these observations as a result of past work by ourselves and colleagues on households, nutrition, and land use in the traditional maize region of central Yucatan (Gurri 1997; Sohn et al. 1998). In this region, land is held collectively among ejido community members and a rotational agriculture of slash-and-burn is practiced. In this context, where use rights are not fixed spatially by clear boundaries, linking households to land use/land cover is difficult. Similar difficulties may apply when defining spatial boundaries for areas that have multiple uses and multiple user groups. Entwisle and her colleagues (1998) similarly note the difficulty of linking land cover data in contexts where land use is fragmented and dispersed and local populations live in nuclear settlements. In research situations such as these it may be inappropriate and/or impractical for research endeavors to link spatially defined land use/land cover change to individuals, families, and households. For practical and theoretical reasons, analysis may more appropriately proceed at the community level with comparisons of many communities and their surrounding areas. Indeed many of the research questions about land cover change in these contexts may be more appropriately addressed at the community level, where individuals share opportunities and constraints on land use together. (See Entwisle et al. [1998] for further discussion on conceptual and methodological issues in linking data for analysis of land use/land cover change.)

In addition to these more conceptual issues related to units and levels of
analysis, it is important to ask how to incorporate information from sample surveys with satellite image analysis. Unlike censuses, remotely-sensed data, or other commonly used GIS data layers, sample surveys typically provide incomplete coverage of the population of interest. As such they are of limited value in standard approaches to GIS-based research and analysis. The gains to be made in this kind of endeavor are best accomplished by the back-and-forth sharing of information between sample surveys and remotely-sensed data through the use of GIS methods. The project presented in the remainder of this chapter is an example of some of the possible avenues of this kind of research. With regard to many of the difficulties of integrating social and environmental research on land use/land cover discussed above, our study area is ideal: it is characterized by a grid-like distribution of farm properties where land use takes place within clearly defined boundaries and households live on their farms. Our primary units of observation and analysis are households and their farm property. In particular, we are interested in how the demography of families affects the adoption of different agricultural strategies, and how these, in turn, affect the rates and patterns of deforestation on a family farm.

In the following section we outline the need for more intensive work on micro-level processes to better understand the process of frontier occupation, settlement, and consolidation as it affects landscape changes.

Landscape Transformation and Frontiers: Insights from a Demographic Perspective on Change

Much of the current research with remotely-sensed data (such as Multi-Spectral Scanner [MSS] and Thematic Mapper [TM] imagery) deals with broad landscape change. Linking these changes to specific socioeconomic, political, and demographic processes is at the heart of our research agenda, yet frequently we speculate on the causal nature of these changes by making loose references to macro-level processes such as annual variation in climatic conditions, changes in credit policy, economic trends, and migration. Much of this speculation does not explain the spatial variation and intensities of transformation observed in the satellite imagery. One useful avenue of research, suggested here, is to distinguish between patterns of change in different stages of frontier occupation, settlement, and consolidation as opposed to focusing on “hot spots” of recent deforestation. A useful conceptual tool is the demographic perspective of cohort, age, and period effects in the analysis of agricultural frontier communities.

To illustrate the point, consider changes in areas associated with land
cover classes for a subsection of the Altamira region (Mausel et al. 1993) in figure 6.1. For this small area, centered on kilometer 23 of the Transamazon Highway and settled in the early 1970s, approximately 55 percent had been deforested by 1985 and a large proportion of this area was covered by bare ground (presumably being prepared for cultivation) or was in pasture. Less than 20 percent of the area was covered in some stage of secondary vegetation, primarily less than twelve years old. After three years, in July 1988, an additional 4 percent of the area had been deforested, the area in pasture and bare earth was much smaller, and secondary succession had grown to nearly 40 percent of the area. This dramatic shift from pasture and bare soils to secondary succession signals important changes in activities in the area.

In ascribing causal factors to these changes, it is easy to speculate on the changing role of credit policies during the period, the importance of cocoa in the mid-1980s, and its decline in subsequent years. An alternative ex-
planation, without knowledge of the area, might include generalized field or farm abandonment. All of the explanations noted above are what demographers refer to as *period effects*. Alternative hypotheses might include the investigation of possible *age* and *cohort effects* in our inquiries about these changes. A pure age effect would reflect similar patterns of farm development among households by length of time on the farm property irrespective of when they arrived or what types of policies were being carried out. A cohort effect is one in which some event or process common to a group of households results in a distinctive pattern of behavior. Timing of arrival on the frontier is a clear marker for defining cohorts and exploring the idea of possible cohort effects. Individuals and households settling during the same period experience many similar opportunities and constraints of the frontier that are markedly different for others arriving later (for example, off-farm employment opportunities, road conditions, market possibilities). These shared experiences within a cohort vis-à-vis other cohorts may result in quite different agricultural strategies from those suggested by either age or period effects.

In the above illustration, might the increase in secondary succession represent a cyclical fallow management strategy of these farm families? Is this observed process a secular trend possibly reflecting length-of-time trajectories of land use associated with the development of family farms? Could the shift be associated with the aging of these farm families fifteen to twenty years after initial settlement? Or, might these changes be specific to a particular cohort of occupation and settlement? Incorporating this demographic perspective in research may aid in disentangling many of the specific causal mechanisms involved in land cover change as well as provide us with a better understanding of processes of frontier expansion and consolidation.

Figure 6.2 illustrates some of the methodological concerns for carrying out this kind of inquiry. The first, upper diagram (A) exemplifies inferences from cross-sectional approaches. Information on current characteristics of households and farms is collected at one point in time. Typical comparisons among these households/farms involve inferences related to length of residence on the property (age effects) and farm formation. The question that arises is whether initial differences between cohorts (capital, and origin, or timing of arrival, for instance) may explain many of the variations in land use. Similarly, we face difficulties in understanding the relative roles of age effects and period effects if we study only one cohort of settlement (diagram B) in that all the households/farms experienced the same period effects (credit change, market conditions) at
A) Cross-sectional Approach

B) Rates of Land-Cover Change of Different Farms Started during the Same Period

C) Use of Retrospective Data Collection Approaches for Comparing Different Groups at Different Points in Time

Notes:  ••••• Refers to events affecting everyone in the community.
- - - - Refers to information at different lengths of residence for household/farm.

Fig. 6.2. Examples of the use of demographic concepts of cohort, age, and period effects to understand the processes of landscape transformation
similar stages of farm formation and length of residence. Does, for example, an increase in deforestation on these farms indicate a change in market conditions or credit policy (period effect), or does it merely reflect a time or age effect associated with farm development? In order to disentangle cohort/age and period effects, we have to compare different groups at different points in time (diagram C).

Implicit in this approach is the view that households and farms have trajectories of development related to length of settlement. We also assume that land use is shaped, but not determined, by changing public policies, market conditions, and economic trends. The landscape can be seen as a mosaic of farm properties at different stages of formation. Farm development on an agricultural frontier is a process often spanning a generation or two. Research at the household and farm level has been the focus of attention of much fieldwork in the Amazon over the past two decades. Econometric and ethnographic studies have detailed the complex ways in which land use decisions are made. Factors commonly mentioned include environmental characteristics such as topography and soils, public policies affecting credit and market conditions, and an array of household characteristics such as origin, initial capital at time of settlement, and agricultural experience in the region. What is less known is how farm development takes place over the long term. Are there trajectories of land use associated with different agricultural strategies or, as we suggest in the following section, with the labor composition of households and their domestic life cycle? Sensitivity to the conceptual issues of cohort, age, and period effects may help to disentangle this complex web of relationships at the individual farm level while also enlightening our understanding of landscape change.

Development of a Conceptual Framework

During the course of previous fieldwork, Emilio Moran observed that neighboring farms often had quite dissimilar patterns of land use. Some of these differences could be explained by variations in initial capital of incoming migrant families, their origin, and their experience with agriculture and with the region (Moran 1977, 1981). Access to water, distribution of soils, and distance to markets typically are shared among neighbors and provide less insight into these different patterns of land use (among neighbors), while they appear to be important at the broader landscape level. Household labor appears to play a significant role in the different agricultural strategies (Moran 1977). Households with abun-
dant labor often became involved in perennial crop activities such as fruit trees, coffee, cocoa, and black-pepper. Smaller families focused their activities on creating pasture and raising cattle. Reflections on this process suggest that land use, while strongly affected by environmental and economic considerations, is influenced by the labor supply of households over the course of the domestic life cycle of these families. Recent settler families in a frontier are predominantly composed of small young nuclear households, with a head couple in their mid-20s to early 30s and a few young children. Their initial agricultural activities involve clearing a small area of forest (three to five hectares) to cultivate annual crops such as rice, beans, and manioc for consumption and for sale in local markets. Each year additional forest areas are cleared and previous plots are either left in fallow, formed into pasture, or planted in perennial crops. The shift to cattle and perennial crops is typically a slow process that involves high initial capital and labor cost, and the gains from these activities will only be reaped in later years. Typically, perennial crops will not provide any returns to the family for three to five years, while acquiring cattle may be an important capital-saving strategy. Cattle can be quickly purchased or sold depending on household needs. While the initial labor and capital costs for raising cattle and planting perennial crops may be similar, the medium-run labor needs appear to be quite different. Perennial crops require continual maintenance to obtain high yields, and the periods of harvesting and market preparations are long and labor intensive. Most well-established farms rely on sharecropping arrangements involving as many as two to five other families, depending on the area and number of trees. In contrast, raising cattle on established pasture typically involves only one or two adult male household members supplemented by temporary laborers for periodic cleaning of pastures. On larger ranches a handful of permanent laborers may be employed. Pasture maintenance is not a trivial issue in the Amazon given the rapid regrowth of secondary succession (Moran et al. 1994, 1996). Weeding and burning fields is typically carried out during the dry season rather than year round, and these maintenance cycles vary from one to three years. Replanting pastures with new grass seeds has a much longer cycle. The availability of certain soils and water sources, capital, and/or credit, and the amount of household labor affect the shift to either perennial crops or raising cattle, or remaining in annual cash crop activities. With the exception of soils and water there may be varying degrees of substitutability between capital, credit, and labor. In the early stages of farm development most farm families exhaust their initial capital reserves (Moran 1981), and incorporating the labor of ado-
Fig. 6.3. Possible scenarios of farm-level and land use trajectories

lescents and teenage children may be a determining factor along with credit possibilities for furthering farm investments.

This discussion suggests two possible scenarios for land use trajectories, illustrated in figure 6.3. The first (scenario 1) suggests an overall trajectory in which households use cattle raising as a capital-accumulating strategy for subsequent shifts to perennial crop activities. The second scenario (scenario 2) proposes that households begin a process of differentiation following the initial period of occupation, toward an emphasis on either cattle grazing or perennial crop production. In reality families typically practice combined strategies with varying concentrations on an-
annual crops, perennial crops, and cattle-raising activities. The question that emerges is whether these shifts in land use reflect ad hoc decisions based on credit availability and market prices, are constrained by soil distribution and water sources, or form part of a long-run land use trajectory.

As noted earlier in this section, household labor composition appears to have an important influence on these strategies and outcomes. In figure 6.4 we present a conceptual framework that highlights the role of household labor over the domestic life course of households as these relate to land use/land cover trajectories for an agricultural frontier. The approach is seen as a complement, rather than an alternative, to approaches focusing on environmental and economic factors, and is linked to the earlier discussions on cohort, age, and period effects. It does emphasize the role of household labor in the short- and long-term patterns of land use/land cover change. In the upper section of the diagram, we suggest a pattern of land use over the course of farm occupation and development. The thickness of each line represents the level of activity in each of five primary land use activities. These stages of land use (upper x-axis) are linked to different stages of a domestic life cycle of households (left-side y-axis) as young nuclear families migrate to the frontier, age over time, and then dissolve into multigenerational and second-generation households as children reach adulthood. The diagonal from the upper left to the lower right corners represents our general expectation of farm formation and the domestic life course of households. Initial activities of these migrant families involve clearing forest and planting annual cash crops for consumption and for local markets. As they establish perennial crops and pastures (stages II and III), rates of deforestation decline, fallow management increases with the growth of secondary succession, and families increasingly focus their energies on perennial crop production and raising cattle. In stages II and III, some families are expected to continue their investments in perennials while others emphasize development of pasturelands and raising cattle. The former group maintains cattle as a risk management strategy but focuses primarily on expanding their long-term crop activities. The decision to shift to one or the other of these activities, we hypothesize, is related to composition of household labor. In contrast to cattle raising, perennial crop activities provide few potential short-term gains; initial returns to this investment will begin in three to five years, and the investment does not provide the liquidity associated with owning cattle. Shifts to perennial crops are, in the short run, a risky endeavor. The presence of adolescent and teenage children may be important for this shift to perennial crops.
Fig. 6.4. Conceptual framework of household transformations, land use, and environmental change
In this conceptual framework other factors such as initial capital, credit, and large supplies of labor are expected to increase the pace at which households are able to consolidate their farm activities in perennial crop production and raising cattle. This consolidation, we suggest, implies a slowing of deforestation on the farm and an increase in the growth of secondary succession. We anticipate that this tendency will be strongest among households focusing their attention on perennial crop activities. In contrast, other households that have had difficulty in initiating cattle raising and/or perennial crops as a result of restricted supply of labor, less initial capital, or limited access to credit will concentrate on continued annual crop activities to meet their immediate household needs. These households are expected to continue deforesting larger areas of their farm as they shift plots every couple of years. The long-run implication of a dominant emphasis on annual crops is that a larger area is deforested in much less time and secondary vegetation may cover a much larger area of the farm property.

This discussion of our conceptual framework is cast at the individual household and farm level. In a much broader view it is a description of what might be considered demographic and environmental transitions that accompany frontier occupation, settlement, and consolidation. The following series of questions addresses specific elements of our research propositions.

(1) What is the demographic composition of colonist families at the time of settlement over the course of frontier occupation? Are the gender and age compositions of incoming migrant families similar or do they change at different stages of frontier expansion?
(2) How does the age and gender composition of household labor change over the domestic life cycle as a result of fertility, mortality, marriage, and migration? More specifically, are fertility and marriage important for incorporating additional labor? What happens with adult children? Do they remain on the farm, migrate to new agricultural frontiers, or seek wage employment in nearby towns?
(3) How do changes in the labor composition of households, interacting with capital and credit and environmental variables (for instance, soil quality, topography), affect the particular strategies of forest clearing, fallow management, and agricultural activities? For example: Do small families tend to favor cattle grazing over time? Do large families slowly invest in agroforestry, rubber, coffee, black-pepper, and cocoa? How does the timing of credit (during the course
of farm development) affect land use decisions among these families with different amounts of labor?

(4) What are the implications of these farm strategies for the patterns and levels of deforestation, secondary succession, and forest regeneration? In other words, does the farming strategy based primarily on cattle grazing lead to greater levels of deforestation? Does a shift to agroforestry and perennial crop production lead to slower rates of deforestation and foster forest regrowth of other areas once cleared? What are the implications of continued rotating of annual cash crop production for the pattern and overall level of deforestation?

Succinctly stated, the research agenda is to evaluate how the demography of families affects the agricultural strategies pursued on family farms and how, in turn, these strategies differentially affect patterns and levels of deforestation and secondary succession.

Research Strategy, Activities, and Sampling

With a view to this research agenda, our work over the past two years has been devoted to three realms of activity: (1) remotely-sensed data analysis; (2) development and implementation of a sample survey with farm families; and (3) integration of remotely-sensed and survey data through the use of GIS. Much of our work is based on previous activities carried out at the Anthropological Center for Training and Research on Global Environmental Change (ACT) with vegetation inventories, ground-truth fieldwork, and MSS and TM Landsat satellite image analysis (see Moran and Brondízio 1998). During the last two years additional land coverages have been incorporated (see Brondízio et al., chapter 5 in this volume) to create a time series of land cover for our study region dating back to 1970 with ten points in time. In shifting our attention to the level of households, spatially identifying farms and households has been a primary concern in the current project. A property grid with 3,800 properties has been developed for overlaying remotely-sensed imagery and for other GIS layers (such as topography, drainage systems, distribution of soils, and cost-distance surfaces relating farms to local markets and road networks). This grid of farm properties serves to demarcate spatial boundaries for our household units of observation and analysis, and for developing a sampling frame for survey fieldwork. Data can be extracted from remotely-sensed imagery at the property level for cross-sectional and longitudinal analysis of land cover change. A description of the property grid develop-
ment and the potential for analysis at the farm property level can be found in McCracken and others (1999). Brondízio and colleagues present an analysis of these types of data in chapter 5 with a view to disentangling cohort/age effects from period effects and developing general patterns of land cover change at the farm level.

Given our research focus on cohort, age, and period effects at the household/farm level, the use of a property grid with remotely-sensed imagery proved a useful strategy for temporally stratifying our sampling frame. In this colonization area a disproportional number of farm properties were settled in the early to mid-1970s. Data on the area deforested between each land cover classification allowed us to temporally ascribe a period of initial settlement to each farm lot, resulting in five strata or cohorts of settlement. We used an area of five hectares cleared between satellite images as a signal of the period of initial settlement. Equal numbers of household/farms were randomly selected from each cohort of settlement for inclusion in our sample survey. The purpose of this stratification was to ensure that we interviewed families who arrived at different times over the course of frontier settlement. Figure 6.5 illustrates the distribution of cohorts of settlement for the grid of properties. Figure 6.6 shows the distribution of households interviewed by their time of arrival on the farm property. During the course of fieldwork, teams of interviewers used Garmin GPS equipment to reach the sampled farm property and its family to carry out in-depth retrospective demographic histories of
households and their members and land use histories. In December 1998 we completed our surveys with 402 households in this region.

In the following section we focus on general aspects of demographic change found with the sample survey data to illustrate the importance of household labor for agricultural strategies and to highlight the dramatic demographic processes that have accompanied frontier settlement over the course of thirty years in the study area.

**Demographic Change on an Agricultural Frontier: Evidence from Altamira**

Gathering socioeconomic and demographic information on households and their members, coupled with detailed retrospective data on entries and exits of household members, permits the reconstruction of the evolution of household composition since these families arrived on the frontier. Analyses can be carried out at the individual level on fertility, mortality, marriage, and leaving the household. In later analyses we will link these data to information gathered in land use histories to evaluate if and how
agricultural strategies vary with the changing composition of households. The use of these data with retrospective data on different types of labor involved in farm activities illustrates the important role of household labor to farm investments and development. A simple calculation of the number of persons multiplied by the number of years each person worked on the farm for different types of labor—household, permanent, and sharecropping—provides a dramatic illustration of the labor that goes into developing these frontier farms. These calculations of person-years worked are presented by cohort of arrival on the farm in figure 6.7. As the figure illustrates, household labor, on average, accounts for a large share of labor on these farms. Unfortunately we are at present unable to present estimates of temporary day labor for previous years given problems of interview recall. Preliminary analysis of current uses, and field observation, indicate that use of day labor is quite common but varies substantially by household composition, agricultural activities, and length of time on the farm. Of the labor sources considered here, family labor represents 84 percent of labor inputs for the oldest cohort of settlers and over 93 percent for the most recent settlers. On the oldest farms, settled before 1976, family labor represents a household investment of more than 90 person-years of work. In no case does either sharecrop or permanent labor

![Fig. 6.7. Person/years worked by type of labor and period of arrival](image-url)
represent more than 10 percent of labor inputs, and each is associated with households and farms that have been established for a longer period of time.

If the role of household labor is as important as these figures suggest, then the size, age, and gender composition of households can be expected to play a role in the amount and types of agricultural activities pursued. In the land use histories we also gathered information on the types of activities (domestic, child care, gardening, care for animals and cattle, milking, felling trees, burning, planting, weeding, harvesting, and processing of agricultural products) each member of the household had been involved

Fig. 6.8. Age-specific rates of participation in domestic and agricultural activities on the farm by gender. Current household members, sample survey, Altamira. (a) Female.
in, on a regular basis, during the last twelve months. Examination of these age and gender rates of participation (fig. 6.8) suggests that agricultural activities are not strictly segregated. Rather, there is a general flexibility in the activities that different members of a household can be involved in. These rates do show a general pattern of involvement in certain activities by age and gender, which can be expected to vary in households of different composition and/or socioeconomic conditions and over the course of farm development.

In general, young adolescents take on domestic duties early and are involved with caring for younger children and tending to animals (for example, chickens, ducks, and other yard animals). The gender composition of these activities is disproportionately female and increases as teen-
age boys are incorporated into caring for cattle and milking, where they are twice as likely to be involved as their female counterparts. Gender differences are most pronounced throughout adulthood for activities such as felling trees, burning, and weeding, where men are three to four times more likely to be involved. The gender differences are less marked in harvesting and processing agricultural products, in which a larger share of women are involved. The pattern of participation in these agricultural activities typically declines for women in their 20s as they begin childbearing, increases again, and then declines after age 45. For men, participation in these activities reaches a high level by their early 20s, remains high through their early 50s, and then steadily declines. There are no clear gender differences in the making of manioc flour or in gardening near the house although gardening activities tend to increase with age.

Given the importance of household labor to farm investments, and the general patterns of activities associated with age and gender, household composition over time is expected to affect the types of investments and direction of agricultural strategies. An analysis of the population composition of our sample illustrates the demographic transformations taking place on the frontier and the changing composition of labor among farm families over the course of the domestic life cycle. Figure 6.9 presents three population pyramids that highlight the processes of entries, exits, and aging among these households. The first two pyramids show the age and sex composition of household members at the time of arrival while the third presents the current age composition of both former and current household members. In all three pyramids the inner pyramid indicates the number of individuals who currently remain in the households. The first pyramid indicates that as families arrive on the frontier their households are composed of predominantly young members, and slightly more males than females. This pattern of male-dominated sex ratios, even among infants and children and through the early 20s, suggests selectivity in favor of male labor as families migrate to the frontier. This pyramid also illustrates the important role of household dissolution as children age and begin leaving the domestic unit.

In the second (middle) pyramid, the outer bars indicate the arrival age of members joining these families and suggest some unexpected household labor strategies. Children born into the household after arrival on the lot, not included in this figure, comprise the largest group of new household members (72 percent of joiners) as might be expected. Excluding these children, the majority of new members in these households are women between the ages of 15 and 24. Combined with insights from other analy-
Fig. 6.9. Age and sex pyramids of current household members, joining members, and leaving members.
ses, we interpret this as a pattern in-marriage of women associated with a male labor retention strategy. The third pyramid illustrates both the male selectivity in initial family migration as well as this male retention strategy. A comparison of the ratio of males and females between the ages of 10 and 24 illustrates the disproportionate number of young males in these farm households. Moreover, a much larger share of female children between the ages of 10 and 19 has already left the household. Further examination of the survey information indicates that young women are more likely to leave their households of origin for schooling as well as for marriage. Often, better-off households will establish a second residence in a nearby town so that children can continue their education. This pattern typically favors higher education among girls over boys in our sample. Out-migration of young women through marriage is also quite common and typically involves moving to another farm household, setting up a new farm as part of marriage, or, more often, leaving to live in a nearby town with a husband. Young men are more likely to stay on the family farm, eventually taking over responsibilities from their parents, or, in conjunction with their original household, purchasing another farm property.

The comparison of the first and third pyramids, showing ages at the time of arrival and interview respectively, illustrates the overall loss of labor from children as these become young adults and shows the general aging process of households on the frontier over time. In figure 6.10 we present a cross-sectional approach to these data to further illustrate demographic dynamics on the frontier: current age and sex composition is presented by the period of arrival of these households on the farm property. This cross-sectional comparison suggests a general aging process among households over time. The age and sex composition of families arriving within the last eight years (first pyramid) exhibits a similar pattern to that noted above when looking at the age of arrival of all households surveyed; it is young with a broad base. The second pyramid shows the age and sex composition of families who settled on their farm lot 9 to 14 years before the survey. It, and subsequent pyramids, illustrates a general aging process, with an increasingly larger share of elderly members and older children and teenagers, and shows a general reduction in fertility with few children under the age of five. The third pyramid suggests a growing share of older households with greater shares of adolescent and teenage children, while the fourth and fifth pyramids, for households arriving prior to 1979, illustrate the increasing importance of multigenerational and second-generation households with a growing share of young adults. The fifth pyramid is composed of a large share of members over the age of
sixty, a large share of young married couples and single male adult children, and an initial third generation of children now under the age of five.

Demographic processes of frontier occupation and settlement are dynamic and complex, yet these processes are often neglected in understanding frontier settlement or the resultant transformations of the landscape. As households age on the frontier, and as farms are consolidated and passed on to children, we can expect to see different patterns of land use.

Fig. 6.10. Age and sex pyramids by period of arrival of the households. Sample survey, Altamira region, 1998.
Family Labor, Agricultural Strategies, and Deforestation: A Discussion of Preliminary Results

In the preceding pages we laid out some general responses to the first two sets of research questions presented above. The overall goals of the previous section were to highlight the role of family labor on these frontier colonist farms as well as to illustrate the dynamic demographic processes that accompany frontier expansion and consolidation at the local level. In this section we briefly discuss preliminary results from the land use survey collected with each farm family. Farming strategies among our sample of farm families indicate a wide range and diverse set of combined activities in annual and perennial crops and pasture for raising cattle. Preliminary analyses show that environmental, economic, and household labor composition are important to agricultural strategies as measured as the percent of agricultural operational area devoted to each of the three broad categories of activities (annual crops, perennial crops, and pasture formation and cattle grazing) on these farms. Emphasis on pasture and cattle, for example, is significantly related to poorer quality soils, access to water, and having had agricultural credit. Percent of productive, or operational, area devoted to pasture is also significantly positively associated with the number of previous owners of the lot, and significantly negatively associated with mean annual family labor. In contrast, percent of operational area in perennial crop activities is significantly and positively related to area with terra roxa soil and with the amount of family labor (also see Moran et al., chapter 7 in this volume), but is negatively associated with number of previous owners of the lot. These results support our general propositions about the relationship between family labor and agricultural strategies. Furthermore, preliminary analysis with the household sample data reveals that the percent of farm lot deforested since arrival on the lot is significantly associated with percent of operational area devoted to pasture, having had credit, and, most importantly, with the number of years on the farm lot. The same measurement of deforestation at the farm level was also negatively and significantly associated with having other farm lots and other off-farm activities. When we analyzed percent of farm area deforested since arrival using dummy variables for each of the agricultural emphases (annual, perennial, and pasture) based on percent of the operational area in each, controlling for these other variables (credit, previous owners, other properties, and off-farm activities), we find that farms with an emphasis on pasture and cattle grazing have between 8 and 10 percent more of their farm lot deforested. Farms
with an emphasis on annual crops were not significantly different from those with an emphasis on cocoa, coffee, and black-pepper. Similar conclusions were reached in an analysis of remotely-sensed data at the farm level (McCracken et al. 1999).

These results, based on a cross-sectional approach, provide strong yet preliminary support for our general propositions outlined earlier. Further analysis of the retrospective data, we anticipate, will provide evidence on how the changing composition of household labor leads to particular combinations of agricultural activities, and how these, in turn, lead to different patterns and intensities of deforestation at the farm level. A particular aim of this more detailed questioning of the retrospective data is the understanding of how period, cohort, and age effects shape land use on individual farms and how these, in turn, play out in the patterns of deforestation at the landscape level. In chapter 5, Brondízio and colleagues provide further insights into and evidence on the relative roles of period, age, and cohort effects on patterns of deforestation in their analysis of remotely-sensed data at the property level.

Conclusions

In the initial section of this chapter we summarized several of our concerns about linking quantitative social science, demographic approaches, and census data with analysis of remotely-sensed data. Common constraints have to do with the problem of ecological correlation, spatial units with urban bias, and great heterogeneity within these typically large spatial units vis-à-vis the heterogeneity among units. Of particular concern are the issues of (1) identifying who the social and economic actors of interest are, and (2) identifying the spatial extent of their actions. Sample surveys, particularly with the innovations in GPS and GIS, offer additional opportunities but are not without shortcomings. Sample surveys typically involve incomplete coverage of the actors of interest, but data and findings can be shared back and forth between analyses of survey data and that of remotely-sensed data. Following this overview and discussion, the chapter focused on the analysis of frontier landscapes.

In the context of analyzing land use/land cover change on agricultural frontiers we suggest a new approach that draws on the demographic concepts of period, cohort, and age effects. Typical land cover change analyses, which incorporate demographic data and processes, focus on the important roles of migration and natural growth. These are often cast at the aggregate level. In the particular context of frontier settlement, the con-
cepts of period, cohort, and age effects may provide additional insights for investigating the complex processes of transformation in these agricultural frontiers as individual families migrate to, occupy, and transform plots of forest into family farms. The landscape is a mosaic of farms initiated during different periods, and farm formation and development is a long process often taking place over a couple of generations. Environmental factors, economic trends, and government policies shape the agricultural strategies that individual families pursue at different stages of farm development. We suggest that, in addition to these factors, households and farms are shaped by their labor composition over the course of their domestic life cycle and result in a range of land use trajectories with direct long-term consequences for frontier landscapes.

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References


Interest in the causes of land use change at local and regional scale is longstanding in the social sciences (Glacken 1973; Sauer 1962; Steward 1955; Thomas 1954; Turner et al. 1990). Population growth, migratory currents, landlessness, developmentalist policies, road building, and climate change are among the many causes suggested for large-scale changes in the Amazon (Denich 1991; Fearnside 1986; Gash et al. 1996; Moran 1981; Skole et al. 1994; Smith 1982; Wood and Skole 1998). Whereas land cover describes the land’s physical attributes (for example, forest, grassland), land use expresses the way such attributes have been transformed by human action. To understand land use, it is critical that we take into account resource perception (and reality); the structure of opportunity costs; the range of management practices known and historically practiced; how they may be constrained by available labor, land, or capital; and the levels of risk a population may be willing to entertain.

Studies of human perception of environment have contributed important findings to our understanding of changing landscapes. How a farmer understands or classifies a soil plays a role in shaping his pattern of land clearing, land use, and land abandonment (Behrens 1989; Conklin 1954; Moran 1977; Tucker et al. 1998). If a soil is “good for bananas” it is likely that a population will implement land use consistent with this cultural knowledge when such a soil is available to the individual who possesses this information (Behrens 1989). In the same manner, some soils are commonly classified as being inappropriate for agricultural use and are never cultivated, leading to a pattern of land use for those patches different from that of adjacent areas. Likewise, understanding how a local population classifies or distinguishes between different types of land cover embodies
a set of cultural criteria that shape vegetation use and land use trajectories (Brondízio 1996; Brondízio et al. 1994, 1996). Among populations with long residence in a location and precise knowledge of forest land and soils, the use of vegetative criteria for selecting soils for different uses is common and highly accurate (Behrens 1989; Conklin 1954; Moran 1975 and 1977). This use of criteria is less true among frontier migrants since they lack site-specific cultural knowledge relevant to their new biophysical environment.

In this chapter we show that soil fertility differences account for a significant proportion of the variance in observed rates of secondary succession regrowth and therefore in the rate of carbon sequestration following deforestation of primary forests in the Amazon, and in the land use trajectories of farmers. In the more fertile sites we have studied, we find at least a twofold difference in biomass over nutrient-poor sites, a difference that amplifies in the second and third decade of regrowth. We have also found significant differences in species composition, with the more fertile sites having greater tree species diversity because of greater canopy development, but lesser total plant species diversity because of lesser understory development (Moran et al. 2000; Tucker et al. 1998). In other words, the spectacular gains in biomass and carbon in the above average fertility sites should not be taken to mean that they are more rapidly restored in terms of biodiversity, but only that they gain biomass more quickly. More study is required to determine whether the greater total diversity in poor areas persists over time as the canopy closes overhead.

In this chapter we find in addition that households with above average soils (terra roxa estruturada eutrófica, or alfisols) are consistently more able to hold onto their land than households who lack these soils, and that they are more likely to have a diverse land use strategy than those with poor soils. In short, the proportion of the land characterized by high-fertility soils is a major component in explaining the land use trajectory of households in a colonization front that we have tracked for the past twenty-eight years. Current and past models of land use have only rarely paid much attention to the difference that soils can make in shaping the land use trajectory of households, and in the resilience of the landscape to a range of land uses.

Study Area and Methods

This chapter begins with an overview of the results of our studies in five regions of the Amazon (see map 7.1). The five study areas represent char-
characteristic differences in soil fertility and a range of land uses typical of the region. One of these areas, Altamira, is characterized by above average soils because of the presence of patches of alfisols—soils with above average pH and nutrients and excellent texture. The other four areas are more typical of the 75 percent of the Amazon that is characterized by oxisols and ultisols, with well-drained but low pH and low levels of nutrients (Cochrane and Sanchez 1982; Nicholaides et al. 1983). Ponta de Pedras in Marajó Island, located in the estuary, is composed of upland oxisols and floodplain alluvial soils. Igarapé-Açu in the Bragantina region is characterized by both nutrient-poor spodosols and oxisols. Tomé-Açu, south of Igarapé-Açu, represents a mosaic of oxisols and ultisols. Yapú, in the Colombian Vaupés, is composed of patches of spodosols and oxisols. Three of the areas are colonization regions at various degrees of development: Altamira is a colonization front that opened up in 1971, whereas Tomé-Açu was settled by a Japanese population in the 1930s, and Bragantina was settled in the early part of the twentieth century. Marajó is the home of caboclos, whereas Yapú is home to Tukanoan Native American populations. In these study areas we find slash-and-burn cultivation as well as plantation agriculture and mechanized agriculture. Lengths of fallows vary in these communities. The two indigenous areas leave their land in longer fallow than do the three colonization areas, and the proportion of land prepared from secondary forests increases with length of settlement as the stock of mature forest declines over time.

At each site, soil samples were collected with a dutch bipartite soil auger at 20-centimeter intervals down to a depth of 1 meter. Soil color was determined by use of Munsell color charts, and chemical and textural analyses were carried out by the soil laboratories of the Cocoa Research Center (CEPLAC) and the Brazilian Agropastoral Research Center for the Humid Tropics (EMBRAPA/CPATU) in Belém, Pará, Brazil. Soil samples were taken in association with vegetation inventories in secondary succession areas at various stages of regrowth, and in adjacent mature forests as a control over initial forest and soil conditions.

In association with the vegetation and soil sampling, household interviews were carried out to examine the age/gender composition of households, their history of land use, and the changing trajectory of economic activity on the property. At the more fertile site, a study was carried out by the first author in 1972–74 that involved long-term residence in the area, a detailed household and demographic survey of 136 households, and soil sampling (Moran 1975 and 1981). Secondary succession was the focus of studies in 1991–93. A more detailed household-level study began in 1997,
Map 7.1. Study areas

1 Altamira, Xingú Basin, Pará, Brazil
2 Ponta de Pedras, Marajó Island, Pará, Brazil
3 Igarapé-Açú, Bragantina, Pará, Brazil
4 Tome-Açú, Pará, Brazil
5 Yapú, Vaupés Basin, Colombia
with 402 of the interviewed households included in our final sample, and use of aerial photos and Landsat satellite data covering every three years since the beginning of settlement (Brondízio et al., chapter 5 in this volume; McCracken et al. 1998; McCracken et al. 1999; McCracken et al., chapter 6 in this volume). The overlay of the property grid on this satellite time-series permits extraction of land cover at both the property level and the landscape level, facilitating aggregation and disaggregation of land cover and its association with land use trajectories verified by household-level interviews.

**Soils and Succession**

Studies of secondary succession have been steadily increasing (Alves et al. 1997; Brown and Lugo 1990; Dantas 1988; Mausel et al. 1993; Moran et al. 1994; Nepstad et al. 1991; Saldarriaga 1985; Uhl 1987), but rarely have their findings been connected to differences in soil fertility or texture (among the exceptions are Moran and Brondízio 1998; Moran et al. 2000; Tucker et al. 1998). Ecologists have long noted the tendency of plant communities to change through time—a process that is referred to as *succession* (Clements 1916; Luken 1990). The way we use the term in this chapter, “succession” represents a gradient from pioneer species that grow quickly when an opening in the canopy occurs, to the gradual turnover of species as these pioneers are replaced by slower-to-mature forest tree species.

Human populations participate in this process of creation of openings through their land use activities. Much of the work on succession points out that different degrees of disturbance result in differential rates of secondary growth (Uhl et al. 1988), and in cases of very intense pasture use points to impoverishment of the seed bank and to very slow rates of regrowth (Nepstad et al. 1991). Given the poverty of many of the soils of the Amazon, cultivation periods have tended to be short, and successional fallows have played an important role in soil restoration through accumulation of biomass, buildup of organic matter and litter, and reduction in weed species. Among traditional populations, so-called fallows have been actively managed to provide food, fiber, and pharmacologically important plant substances (Denevan and Padoch 1988; Posey and Balée 1989).

Regrowth dynamics are closely correlated to factors such as the way the forest was cut and burnt; the land used in different crops and/or pasture; the length of use; the technology used; the presence or absence of surrounding forest vegetation; the size and shape of the area; the soil’s fertil-
ity; and the presence or absence of species whose dispersion pattern relies on wind and/or animals that frequent fallows (Howe and Smallwood 1982; Salomão 1994; Uhl 1987; Vieira et al. 1996).

To begin our assessment of differences in soil fertility among our study sites, we constructed a soil fertility index based on the suggestions of Paulo Alvim (1974). The index uses pH, organic matter, phosphorus, potassium, calcium, and magnesium, and aluminum. This method for expressing relative soil fertility graphically is useful in understanding the proportions of major elements in tropical soils. The index was prepared for each depth at 20-centimeter intervals, and an average index was prepared across depths. In figure 7.1 we present the soil fertility index developed to illustrate the differences in overall fertility of these sites. Altamira’s superior soils can be visually observed in this index, particularly its higher pH, phosphorus,

Fig. 7.1. Soil fertility index. The index represents fertility as defined by pH, organic matter, phosphorus, potassium, calcium, and magnesium levels and relative lack of aluminum saturation (based on Alvim 1974).
Fig. 7.2. Carbon content in successional forests of eastern Pará, Brazil
calcium and magnesium, and organic matter, and lower aluminum saturation.

Soil fertility proved to be the key element that discriminated among rates of secondary succession when comparing our five study regions. The poorer the soil, the more developed the root biomass component tends to be, as the vegetation searches for nutrients and attempts to capture available substances before they escape from the catchment area. In extremely

![Graph A](image1)

![Graph B](image2)

Fig. 7.3. Soil carbon in Altamira (7.3a) and Bragantina (7.3b) sites. Mature and successional forests at three soil depths (0–20, 20–40, 40–60 cm).
nutrient-poor areas of the Rio Negro, Herrera and others (1978) have noted that the water entering streams is of nearly distilled water quality. Up to 67 percent of total biomass was below ground in the poorest site studied (see fig. 7.2), whereas the amount of below-ground biomass at the most fertile site was 20 percent. Middling sites fall in between these two extremes. On the more fertile soils, the root biomass is significantly lower, and more of the nutrients are found in the soil rather than primarily in the vegetation itself as is the case in the poor soils. Note the higher amounts of soil carbon in the Altamira site as compared with the Bragantina sites in figure 7.3.

Soil structure and texture, as represented by percentage of fine sand, coarse sand, silt, and clay, were analyzed. Coarse sand and clay are the elements most able to provide discrimination across regions (see fig. 7.4). Altamira soils have low content of fine and coarse sand at all depths (averaging around 10 percent) and clay content above 45 percent at all depths. Although the Yapú region presents a similar textural pattern, it differs in the presence of a spodic B-horizon with low permeability and penetrability. Marajó and Bragantina soils are rather similar in terms of sand and clay content at all depths. In both cases, average fine and coarse sand content are above 25 percent and average clay is below 20 percent at all depths. Tomé-Açu soils have lower content of fine sand (below 25 percent) and higher clay content (30–40 percent) at all depths.

Differences in soil fertility are small but significant. Altamira stands alone in terms of soil fertility, with differences among the four other sites more subtle, as shown in figure 7.5. The average pH above 5 in Altamira contrasts with a pH below 5 in the other regions. However, the pH is lower in Yapú and Marajó than in Bragantina and Tomé-Açu. Yapú has the highest aluminum saturation and the lowest concentrations of calcium and magnesium. This nutrient-poor and acidic profile is reinforced by the low availability of phosphorus. Phosphorus is considered the most limiting nutrient in the Amazon (Cochrane and Sanchez 1982), frequently found only as a trace (less than 1 part per million). Phosphorus is low in all study regions, but it is slightly higher in Altamira. Organic matter did not differentiate among regions.

Analysis of variance shows that soil fertility is associated with differences in rates of regrowth, using height increments as a measure of biomass gains (adj. $r^2 = 0.69$, $p = .05$). Similar regrowth rates between Marajó, Bragantina, Tomé-Açu, and Yapú are consistent with their similar soil endowments. Altamira is the only region with above average rates of regrowth (see fig. 7.6). During the first five years, Altamira fallows are 2
Fig. 7.4. Soil texture by depth (Altamira, Marajó, Bragantina, Tomé-Açú, Yapú)
Fig. 7.5. Levels of pH, aluminum, and calcium and magnesium by soil depth at five study regions. Source: Moran et al. 2000, 142.
meters higher on average, and 5 meters taller on average by year 15 of succession. When considering maximum tree height, Altamira fallows are three times taller than those in the poor-soil regions. Taking another measure, a 15-year fallow in the poor regions has reached only 17 percent of the tree basal area of the adjacent mature forest, whereas in that same period of time an Altamira fallow will have reached 45 percent of the tree basal area of mature forest (see fig. 7.7 and Tucker et al. 1998).

Land Use in Altamira

Land use is not simply a product of the natural endowments of a place, whether soil, moisture, or temperature. These biophysical endowments interact with individual, household, and community characteristics of the human population that lives in that place. The Altamira site in the Xingu Basin of the Brazilian Amazon will be used in this section to examine the
trajectories of land use through time as they shift with changing social, economic, and demographic processes. The city of Altamira was an old trading post in the rubber trade, and its fortunes rose and fell with the trade. In the 1950s an effort was made to attract colonists from northeast Brazil, mostly from Piauí, who came and settled along streams as far out as 20 kilometers from the city center. With the construction of the Transamazon Highway in 1970, this population and older caboclo settlers from earlier rubber eras claimed land along the new highway and legalized their land claims. One of the findings from the first author’s original study in the early 1970s was that the caboclos used vegetative criteria for selecting soils good for agriculture, and that their criteria were accurate and resulted in higher yields per hectare than the criteria used by the arriving colonists (Moran 1975 and 1981).

Our restudy of the area (see fig. 7.8), using a combination of Landsat time-series digital data and a much larger household survey, supports this early finding. Substantial areas of terra roxa are still occupied by the pre-1971 colonization cohort. Only 6.25 percent of the pre-1971 cohort had no terra roxa on their current properties, whereas 62.5 percent of that cohort had half of their land with terra roxa, and 25 percent had more
than half of their land with *terra roxa*. In contrast, 38.82 percent of the migrants that came between 1971 and 1975 (the largest single cohort in the study area) did not select land with *terra roxa*, 21.18 percent had lots with up to half of the area in *terra roxa*, and 40 percent were fortunate to find lots with more than half of the area in *terra roxa*. Nearly 63 to 73 percent of settlers after 1975 were unable to locate themselves on lots with *terra roxa* (see table 7.1). This suggests that land turnover is much less in lots having *terra roxa*, as post-1975 settlers should have been able to have more *terra roxa* properties if they had been for sale. Figure 7.9 illustrates the spatial distribution of *terra roxa*, using the distribution of properties planted in cocoa as a proxy for the presence of *terra roxa* and its areal extent. While some farmers planted cocoa in the 1970s on non-*terra roxa* soils, this tree crop did poorly on those soils, and today the presence of
Table 7.1. Percentage choosing *terra roxa* by cohort

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>None</td>
<td>6.25</td>
<td>38.82</td>
<td>62.69</td>
<td>62.12</td>
<td>72.62</td>
<td>59.45</td>
</tr>
<tr>
<td>1–25</td>
<td>6.25</td>
<td>10.59</td>
<td>14.93</td>
<td>19.70</td>
<td>13.10</td>
<td>13.68</td>
</tr>
<tr>
<td>26–50</td>
<td>62.50</td>
<td>10.59</td>
<td>7.46</td>
<td>12.12</td>
<td>1.79</td>
<td>8.71</td>
</tr>
<tr>
<td>51–75</td>
<td>18.75</td>
<td>7.06</td>
<td>4.48</td>
<td>3.03</td>
<td>5.95</td>
<td>5.97</td>
</tr>
<tr>
<td>76–99</td>
<td>6.25</td>
<td>12.94</td>
<td>2.99</td>
<td>1.52</td>
<td>5.36</td>
<td>5.97</td>
</tr>
<tr>
<td>100</td>
<td>0.00</td>
<td>20.00</td>
<td>7.46</td>
<td>1.52</td>
<td>1.19</td>
<td>6.22</td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>


a. Cohort is based on the year of arrival in the lot.

cocoa is closely associated with *terra roxa*, although it may not perfectly represent its areal extent.

This relationship is further confirmed by verifying how many of the post-1975 settlers obtained new plots vis-à-vis purchased land from early settlers. Seventy-six to 90 percent of the properties of settlers coming after 1975 had previous owners, as compared with less than 20 percent of the settlers before 1975. Given the small proportions of *terra roxa* in post-1975 cohorts, it appears that the land that is on the land market is differentially non-*terra roxa* properties. In short, land turnover is not random, but is a product of farmer decisions as to their initial choice of soil quality.
and subsequent production outcomes related in part, but not totally, to their soil endowments. Those who arrived early and selected *terra roxa* plots have been able to perform well enough to be able to stay on their farm holdings more frequently than those who came later or who failed to select the more favorable soils. In an earlier paper (Moran 1987), the first author found in another colonization area characterized by fertile soils (Tucumã) that farmers with poor soils experienced yields ranging from 432 to 1,002 kilograms per hectare, whereas farmers with *terra roxa* had yields from 570 to 1,880 kilograms per hectare. Thus, while outstanding management skills permit farmers on even poor soils to raise their production above levels achieved by poor managers on excellent soils, the achievable yields on excellent soils with good management are nearly twice those achievable even by excellent managers on the poor soils. Soil quality and management skill both matter, but the soil endowment caps what is achievable by even superior skills and can make a difference in the ability of households to hold onto their land when problems arise in the conditions for production.

There are no significant differences among cohorts arriving in Altamira in the proportion of owners who acquire more than one property. For all arriving cohorts, 64 to 70 percent have only a single 100-hectare property, and 30 to 36 percent have more than one property. In the proximity of Altamira there is evidence of land consolidation undertaken by Altamira ranchers, bankers, and merchants who acquire several properties near the city. This process has particularly taken off since the currency was stabilized in 1994. We have also observed a significant increase in deforestation in the mid-1990s, a process that Eduardo Brondízio et al. discuss in chapter 5.

As students of change, we expected more dramatic changes than we found in the composition of the population since 1973. Those who arrived early but with little capital did well at the outset of settlement in the early 1970s (1975) and are still doing considerably better today in terms of accumulated durable goods than many other settlers who arrived later with more capital (see fig. 7.10). This was an unexpected finding that reflects the difference between the aggregate analysis of all households and our observations of particular families, where the wealth of some individuals gave the impression that later arriving households were doing much better than earlier cohorts that arrived with little capital at the beginning of settlement of the region. As was the case in 1972–74 when the first author began studies in the region, the total population today has only 21 to 26 percent of households with prior business experience and
farm property before coming to the frontier, and only 21 percent who had urban property before coming to the frontier. Most intriguing, and important to note, is the fact that having capital before coming to the frontier did not assure settlers of obtaining the best land in the area. Early arrival was more predictive of having terra roxa than initial capital. However, having some capital and arriving early is most predictive of obtaining terra roxa—although the amounts of initial capital of the earliest cohorts were modest indeed (approximately U.S.$500).

Nearly 30 percent of the cohort that arrived in the heyday of new settlement in Altamira (1972–75) were of urban origin with little agricultural experience, in contrast to the agriculturally experienced pre-1971 cohort of caboclos in the area, and the 1975 to 1985 cohorts of nonsubsidized settlers characteristic of so-called spontaneously settled frontiers. However, our survey suggests that the cohort settling after 1985 has more than 20 percent of its members with little agricultural experience and more
capital than other cohorts. How well they perform in this frontier remains to be seen, although the results to date are not encouraging.

If any frontier offers choice of crop it is the Altamira region, with its patchwork of alfisols and oxisols, well-drained and well-structured soils, a strong dry season of four months, and abundant but well-distributed precipitation. Nevertheless, here as elsewhere in the Amazon, the predominant choice is pasture (Hecht et al. 1988). If we group the farm properties by percentage of terra roxa we observe a modest decline in the percent of land in pasture where more than 50 percent of the land is in terra roxa, and there is a larger area in cocoa and sugarcane (table 7.2). There is a marked decline in land use for pasture from land with no terra roxa (85.18 percent) to land entirely with terra roxa (47.74 percent) (table 7.2). In contrast, in the classes with more than 50 percent of terra roxa, the proportion of the land in cocoa and sugarcane rises significantly. Blackpepper, acerola, coffee, corn, beans, and other staple and cash crops are grown, but overall they account for less than 14 percent of the cleared land throughout the twenty-five years we have monitored the study area of Altamira.

One strong reason for favoring pasture over other land uses is the favorable treatment it continues to receive from banks for credit. More than half (55 percent) of the population seeks out formal credit (table 7.3). In 37 percent of the cases the credit obtained is applied to pasture-related operations and 20 percent is applied to perennial crops, primarily cocoa or sugarcane. The remaining credit is used for a variety of agricultural activities (table 7.4). The amount of credit provided for cattle and pasture tends to be larger than for crops, and length of time to payment of the loan longer and thus less risky to the borrower given the wild oscillation of the Brazilian economy. Cattle is also a particularly liquid asset that permits quick conversion to cash to meet needs of households: it can walk itself to

### Table 7.2. Crops and terra roxa

<table>
<thead>
<tr>
<th>Terra roxa (%)</th>
<th>Pasture (%)</th>
<th>Cocoa and Sugarcane (%)</th>
<th>Other (%)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>85.18</td>
<td>2.68</td>
<td>12.15</td>
<td>100.00</td>
</tr>
<tr>
<td>1–25</td>
<td>82.99</td>
<td>7.50</td>
<td>9.51</td>
<td>100.00</td>
</tr>
<tr>
<td>26–50</td>
<td>78.79</td>
<td>15.42</td>
<td>5.79</td>
<td>100.00</td>
</tr>
<tr>
<td>51–75</td>
<td>53.81</td>
<td>32.09</td>
<td>14.10</td>
<td>100.00</td>
</tr>
<tr>
<td>76–99</td>
<td>55.02</td>
<td>35.56</td>
<td>9.43</td>
<td>100.00</td>
</tr>
<tr>
<td>100</td>
<td>47.74</td>
<td>43.00</td>
<td>9.26</td>
<td>100.00</td>
</tr>
</tbody>
</table>

*Source: Survey in Altamira 1998, N = 402 households.*
market (thereby overcoming the limitations of poor roads in the region), and the pastureland makes it more attractive to buyers with cash than intensively cultivated cropland.

Our current study of the Altamira region is particularly focused on trying to disentangle period effects from cohort effects, and particularly the role of the developmental cycle of domestic groups (in other words, their changing age and gender composition through time) on the population’s land use trajectories. Although our survey data were still being collected at the very end of 1998, and only recently was data entering completed, preliminary results suggest that indeed, as households age and begin to lose members, their land use strategy switches from annual crops to pasture, and then to a mixture of pasture, cocoa, and sugarcane. The choice of cocoa and sugarcane is, moreover, constrained by the soil quality present on the property. We are currently working on separating these demographic determinants from the role of capital in these households, since it is also possible that as households age, they accumulate capital,

<table>
<thead>
<tr>
<th>Crops</th>
<th>No Credit (%)</th>
<th>Credit Once (%)</th>
<th>More than Once (%)</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasture</td>
<td>80.73</td>
<td>77.40</td>
<td>72.99</td>
<td>77.62</td>
</tr>
<tr>
<td>Cocoa and Sugarcane</td>
<td>7.43</td>
<td>12.65</td>
<td>16.96</td>
<td>11.60</td>
</tr>
<tr>
<td>Other(^\text{a})</td>
<td>11.84</td>
<td>9.95</td>
<td>10.05</td>
<td>10.78</td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
</tr>
<tr>
<td>Observations</td>
<td>179</td>
<td>122</td>
<td>101</td>
<td>402</td>
</tr>
<tr>
<td>Percent</td>
<td>44.5</td>
<td>30.4</td>
<td>25.1</td>
<td>100.0</td>
</tr>
</tbody>
</table>


\(^{a}\) “Other” includes areas in annual crops, manioc, garden horticulture, coffee, black-pepper, fruit trees, planted trees, and other minor crops.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Number of Cases</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td>120</td>
<td>32.09</td>
</tr>
<tr>
<td>Agriculture/cattle ranching</td>
<td>23</td>
<td>6.15</td>
</tr>
<tr>
<td>Cattle ranching</td>
<td>139</td>
<td>37.17</td>
</tr>
<tr>
<td>Perennials</td>
<td>75</td>
<td>20.05</td>
</tr>
<tr>
<td>Equipment</td>
<td>17</td>
<td>4.55</td>
</tr>
<tr>
<td>Total acts of credit</td>
<td>374</td>
<td>100.00</td>
</tr>
</tbody>
</table>

and they are able to make a switch from staple crops to a more diversified strategy.

**Trajectories of Land Use**

The above discussion helps us begin to develop trajectories of land use that take into account the combined effect of soils, deforestation trajectory, successional forest dynamics, and crop choices. It has been suggested by classic studies of the frontier that the early settlers are replaced by later-arriving settlers with more capital and know-how, and that land consolidation proceeds inexorably in a capitalist frontier (Turner 1920). Our analysis, like those of many other colleagues, finds that indeed there is steady land turnover, but we find that turnover is not random but differentially more frequent on properties with fewer soil endowments. We find that arriving early in the frontier was most predictive of locating the best soils in the area, and that once these were located, most households have been able to hold onto their land and to accumulate substantial amounts of durable goods over time. In contrast, settlers who arrive late are less frequently able to obtain the best soils in the region, despite larger amounts of initial capital, and their turnover rate is much higher; they accumulate fewer durable goods; and they even experience substantial net losses in capital from their Amazonian adventure.

Our analysis confirms the work of many other Amazonian scholars who have documented the dominance of pasture as a land use strategy without regard for cohort or period effects (Hecht et al. 1988; Walker et al. 2000). Remarkably, pasture developers even disregard the soil endowments present, except for a modest reduction in pasture areal extent in properties characterized by more than 50 percent of *terra roxa*, where one finds an increase in cocoa and sugarcane area. In our view, allocation of alfisols to pasture represents misuse of one of the scarcest resources in the Amazon.

The Altamira region, unlike other regions of the Amazon, has had a relatively peaceful history of settlement. Early settlement was driven by geopolitical goals and political economic policies that transferred production of staples like rice, corn, and beans from the southernmost Brazilian states to the north region. The region has had a gradual shift to a more diverse set of land uses: pasture, cocoa, sugarcane, black-pepper, and staple crops. Mahogany is beginning to be planted in cocoa groves as a diversification strategy and can be expected to benefit landowners who have the best soils in the area. In the past, and in the future, it makes a
difference what soils a property has. The early-arriving caboclos and experienced small farmers with modest capital have had very positive results over time because of their choice of soil and subsequent stewardship. The value of these properties will continue to increase because they represent relatively scarce high-quality areas in the Amazon.

Public policy should take an interest to ensure that small farmers, who have historically been the group most able to intensify production and make diverse use of their land and labor, continue to benefit from their intensive use of high-quality soil resources—rather than favor policies that lead to the capinização or “savannization” of even the most fertile soils of the Amazon to provide convenient tax writeoffs for absentee owners. Land use diversification on the most fertile soils of the Amazon should continue to grow even more than it has to date, if a balance between use and conservation of resources in this rich realm of nature is to be achieved.

Acknowledgments

The authors wish to thank the organizers of the Gainesville Conference on Patterns and Processes of Land Use and Forest Change in the Amazon for their kind invitation to share our ideas with colleagues at the meeting, and for the stimulating setting they provided for scholarly debate. We wish to thank the National Institute for Child Health and Human Development, Social Sciences and Population Study Section (9701386A), which has provided grant support for the land use and demographic portions of the study. Previous support by the National Science Foundation, through grants 9100526 and 9310049, made it possible to carry out the research on soils and succession. We acknowledge support from the National Institute for Global Environmental Change (NIGEC) and colleague J. C. Randolph, who participated in the collection of the carbon data reported herein. Illustrations were prepared for publication by Bruce Boucek. We acknowledge the support of EMBRAPA/CPATU in Belém, particularly of Adilson Serrão and Italo Claudio Falesi throughout our years in the Amazon and especially in this recent study. We could not have done it without them. A wonderful team of local people in Altamira, many of them members of colonist households, helped us collect the survey data. We thank the more than four hundred household heads in the Altamira region who bore patiently with us during our long interviews. Their struggle in the frontier for the past twenty-eight years is of epic proportions. The views expressed herein are the sole responsibility of the authors and do not represent those of the funding agencies, nor of other persons or institutions.
References


Despite the importance of small farmers as agents of landscape change in the Amazon, surprisingly little is known about their land use decision-making processes. The nascent research literature on this subject, which includes only a handful of empirical studies, is largely informed by two underlying frameworks: the normative economic tradition and a structuralist capitalist incorporation perspective. Both frameworks tend to view land use change deterministically, reflecting the underlying logic of economic expansion that each framework interprets differently. Yet, both frameworks tend to view those land use changes as occurring in a sequence of identifiable and predictable linear stages.

The basic argument of this chapter is that both of these frameworks make poor starting points for the analysis of rural household land use decision-making. If we continue to adhere to the underlying assumptions of these frameworks, we will not move any closer to a more accurate and complete understanding of the highly heterogeneous and complex forces at work in shaping colonist landscapes. I do not propose any substitute framework; indeed I would caution against efforts to achieve any kind of unified conceptual hegemony. Rather, I urge healthy doses of both conceptual and methodological pluralism.

This chapter reviews the research literature on the dynamics of landscape change among small farmers in the Brazilian Amazon from both normative economic and capitalist incorporation perspectives. The findings of a recent comparative survey of 240 small farmers in Rondônia are presented to demonstrate the diversity of land use patterns found in this agrarian population. Finally, the household and land use histories of three
farmers during their initial settlement period are described to illustrate the range of land use strategies that farm households pursue in response to changing internal and external conditions. These findings suggest that no single theoretical framework adequately explains the variations in land use patterns observed in this population. Rather, farmers operate on the basis of a “situational rationality” in regard to land use decisions. A list of factors that probably influence those decisions is appended for future research.

The Normative Economic Tradition

Arguably the most influential movement in the analysis of land use in the Amazon arises from neoclassical economics. With its emphasis on the concepts of “rationality” and “utility maximization,” the normative economic tradition (NET) asserts that farmers manage the landscape as they would any other useful resource to maximize utility constrained by exogenous (market and environmental) and endogenous (household labor) characteristics.

In its simplest form, the NET model posits that increasing capitalization of agriculture is accompanied by a generalized shift, through a series of progressive linear stages, from subsistence-oriented polycultures, based on labor-intensive temporary ground/food cropping systems, to increasingly more commercial-crop-oriented monocultures, dependent on capital-intensive mechanical and chemical inputs. In the subsistence stage, farmers are seen as risk-averse, emphasizing food security over cash income in the short term. In the commercial stage, priority is given to net financial returns on investment (profit), with a view toward long-term capital accumulation that might be invested in more lucrative activities outside of agriculture.

Predicting land use transition in Amazonian colonist communities has proven to be a tricky proposition. Jones and others (1995), using cross-sectional data from a 1991 survey of eighty-three multiproduct farms in the municipality of Ouro Preto of Rondônia, estimate the production functions of several agricultural land use activities. Their aim was not to predict specific land use sequences over time, but rather to examine the determinants of gross farm income and deforestation. The authors found evidence of increasing returns to scale in cattle. However, cattle income appears to be a “hedge” that permits more extensive cultivation of subsistence food crops rather than providing a springboard for investing in more risky perennial crops, suggesting a possible “target income” response by
farmers (183). This finding would appear to challenge the profit-maximization assumption of the NET. Moreover, the authors found that deforestation appears to be driven more strongly by crop profitability than by profitability of cattle production. While the authors affirm that “Rondonian farmers appear to be making economically thought-out land use choices” (183), consistent with NET, they concede that income maximization and capital accumulation by themselves are not the sole criteria used by farmers in making land use decisions. Once farmers earn a “target income” from one activity (for example, cattle), they diversify into other activities (for example, plant annual crops) to reduce the risk of household food scarcity.

In a study prepared under the Alternatives to Slash and Burn Program, Vosti and his colleagues (1998) sought, in part, to identify the socioeconomic and biophysical factors influencing land use patterns among small farm households in Rondônia. This cross-sectional study, drawing upon a 1995 survey of 150 households in Theobroma and Pedro Peixoto colonization projects, correlated land use, especially the trend toward pasture, with the set of household characteristics summarized in table 8.1. The study presents some surprising findings and highlights the important point that the factors driving deforestation decisions are not always related to those that determine subsequent land use decisions. For example, the authors found that while households owning urban properties (“urban link”) tended to clear more forest than those without such links, urban landownership had no significant effect on type of land use, a finding that conflicts with my own research (Browder and Godfrey 1997, 315). Educational attainment positively correlates with both deforestation and land use, favoring the transition to pasture. Farm distance from market negatively correlates with deforestation and has a predictable effect on land use in which farms closer to market specialize in perishable annual food crops while those more remote specialize in cattle. Secure land tenure positively correlates with both deforestation and land use, favoring the transition to pasture. Social participation (in farmer groups, church, and so forth) negatively correlates with deforestation.

Vosti and his colleagues (1998) also developed a linear programming model to evaluate the impacts of biophysical and economic factors on land use decisions over a twenty-five-year period, assuming the optimization of income. Although the authors do not explain how they specified a dynamic model from a cross-sectional database, they predict (in their baseline scenario) a progressive increase in areas in pasture and secondary growth, and a corresponding decrease in primary forest cover, while an-
annual and perennial crop areas remain constant. The configuration of activities that maximizes income over this time period, following their analysis, is pasture combined with annual cropping and “sustainable timber extraction.” Alternative farming systems that include agroforestry as a component are dismissed by the authors as too risky, even though other survey research in Rondônia suggests that the majority of Rondônia’s farmers would integrate agroforestry into their farms if certain impediments to doing so were alleviated. Income generation is an important variable in land use decisions, but income maximization is not necessarily so.

Another utility maximization approach in the NET was developed by Caviglia and Kahn (n.d.) in which a discrete choice (Heckman) model is used to estimate the probability that small farmers will adopt “sustainable agriculture” in Rondônia (defined as intercropping perennials, annuals, or beekeeping versus slash-and burn). Based on a survey of 171 farmers in Ouro Preto municipality, the authors’ analysis posits the decision to adopt sustainable agriculture as a dichotomous choice, based on utility (combined family income and leisure). The most significant variable determining the farmer’s probability of adopting sustainable agriculture is the farmer’s knowledge that sustainable agriculture exists. Social participation was also positively linked to adoption probability as was the number of years in residence on the current farm. The authors’ analysis does not explicitly indicate a particular land use sequence leading to “sustainable agriculture,” but it does confirm the importance of specific variables.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Deforestation Effect</th>
<th>Land Use Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban link</td>
<td>positive</td>
<td>none</td>
</tr>
<tr>
<td>Consumer durable goods</td>
<td>negative</td>
<td>none</td>
</tr>
<tr>
<td>Household labor</td>
<td>positive</td>
<td>none</td>
</tr>
<tr>
<td>Educational level</td>
<td>positive</td>
<td>more pasture</td>
</tr>
<tr>
<td>Off-farm income</td>
<td>none</td>
<td>fewer annuals</td>
</tr>
<tr>
<td>Forest product extraction</td>
<td>negative</td>
<td>more fallow</td>
</tr>
<tr>
<td>Distance from market</td>
<td>negative</td>
<td>positive</td>
</tr>
<tr>
<td>Secure land tenure</td>
<td>positive</td>
<td>pasture</td>
</tr>
<tr>
<td>Soil quality</td>
<td>negative</td>
<td>less pasture</td>
</tr>
<tr>
<td>Social participation</td>
<td>negative</td>
<td>—</td>
</tr>
<tr>
<td>Years in residence</td>
<td>positive</td>
<td>—</td>
</tr>
<tr>
<td>Age of farm</td>
<td>none</td>
<td>—</td>
</tr>
</tbody>
</table>

Source: Vosti et al. 1998.
Scatena and his coauthors (1996) come the closest to developing a schematic model of the factors that influence crop and fallow sequences on small farms in the Brazilian Amazon from a NET perspective. In their 1992 survey of sixty-five landholdings near Santarém, Pará, the authors examine different general strategies that farmers have followed to maximize production and household utility. Presumably based on respondent recall, the authors diagrammatically reconstruct the sequence of land uses (in this case specific crop choices) over time from four predominant vegetation starting points: mature forest, short fallow (1–3 years), mid-length fallow (3–6 years), and long fallow (8–12 years). From these original conditions, the authors estimate the “conditional probabilities” (percentage of their sample) that farmers will elect a specific crop pathway following clearing. Examining the authors’ data suggests that temporary crops (rice, beans, corn, manioc) and pasture are the most probable postfallow cropping choices. Although the number of planting cycles is not specified for each crop, it is clear that cropping choices vary somewhat depending on the existing vegetation type. Rice, the most prevalent crop in all scenarios, was planted on 88 percent of the fields cleared from mature forest, on 58 percent of the fields cleared from older fallow, on 50 percent of the mid-aged fallows, and on 45 percent of the young fallows. Manioc is usually the last crop planted before a field is retired back into fallow (Scatena et al. 1996, 35–36). Acknowledging that no single variable determines fallow length and crop selection, the authors hypothesize that several general economic and ecological factors come into play: the productivity of the landscape (soil, water, climate), costs of site preparation and agricultural treatments, land availability, labor availability, age structure of families and their subsistence requirements, and various local economic conditions (for instance, land values, credit, off-farm income, commodity markets) (37).

On the whole, researchers in the NET tend to privilege the utility maximization assumption about farmer land use behavior. One issue here is how “utility” is defined, that is, from the farmer’s perspective or that of the outside economist who is likely to think in terms of gross income or some other monetary measure of productivity. Given this assumption, farmers are viewed as uniformly selecting land uses (crop choices) that will result in the highest income/productivity, and the only variability in this pattern is introduced by the differential capacity of farmers to overcome a series of exogenous and internal constraints to income maximization.
Controlling for the constraints, then, would enable the economist to predict the land use sequence. But, when asked “what is useful?” farmers often reply with a range of responses not intuitively derivable from strict economic calculus (see the appendix at the end of this chapter for a list of factors that hypothetically influence colonist land use). A comprehensive model of land use change, if one is indeed possible, must go beyond basic assumptions of the normative economic tradition.

**The Capitalist Incorporation Model**

Drawn largely from neo-Marxist interpretations of the global division of labor, unequal exchange, and surplus extraction, the capitalist incorporation model (CIM)—also called the “capitalist penetration model”—situates the transition from peasant forms of subsistence farming to modern, mechanized agribusiness in the milieu of labor exploitation. In the Brazilian frontier context, landless farmers are pushed into the Amazon, applying their labor value to the land by clearing forest and planting short-term subsistence crops. This initial stage of frontier settlement paves the way for subsequent “incorporation/penetration” by agribusiness and other social elites, who appropriate the labor value “congealed” in the landscape and push the peasantry off the land once again in a repeating cycle of forest destruction and social expulsion and itinerancy.

Out of this doctrine emerges a conceptual scheme of landscape transition that is based on the progressive impoverishment and victimization of the peasantry. Faced with monopolistic crop marketing agents, declining soil nutrients and crop yields, falling prices, mounting farmer debt, and household labor losses due to sickness and out-migration, peasant impoverishment induces a sequence of landscape successions that further impoverishes and weakens both social and ecological systems. All of this is seen as facilitating the spread of capitalism.

Ozorio de Almeida (1992) adopts the CIM framework, but avoids explaining exactly how market expansion induces specific land use changes on peasant farms and in so doing does not situate her analysis squarely in a Marxist interpretation. Rather, based on field surveys of colonists in both private and government settlement projects in Mato Grosso, she observes four land use options following clearing of forest and planting of annual crops: intensification of annual crop production through technical inputs, or shifts to perennials, pasture, or fallow. In addition, the author employs an econometric analysis to ascertain the factors that might influence farm income, capital accumulation, and farmer mobility (“itiner-
The author finds that “local economic and institutional” factors (nonfarm income, size of cultivated area, land title, and extension of technical assistance) explain most of the variation in household income, while “individual variables” (farm household age structure and startup costs) most strongly correlate with long-term investment and savings. Perhaps the most interesting finding concerns the role of itinerancy in promoting accumulation. Contrary to the assumption of many NET models, that farmers arrive on the land with the expectation of maximizing income from production, Ozorio de Almeida’s study suggests the logic of itinerancy. For some farmers, occupying the land, clearing forest, selling out, and moving on in the short term enhances their own capital accumulation. While this reason for itinerancy is conceptually consistent with utility-oriented NET approaches, it is not a scenario that is frequently hypothesized in NET analyses. Again, while “economic rationality” clearly plays an important role in influencing farmer land use decisions, such rationality is often embedded in a more specific “situational rationality” that mediates the relative influence of economic and noneconomic forces.

Work by political ecologists Jane Collins (1986) and Susan Stonich (1995) points to the structural determinants of small farmland use change in efforts to explain the high rates of small farm failure. Although not specifying a typology of farm-level land use pathways, Collins (1986) proposes a synergistic model relating colonist differentiation (toward poverty) with processes of ecological degradation in the Brazilian Transamazon, northeast Ecuadorian Amazon, and the Tambopata Valley region of the Peruvian Amazon. Drawing upon secondary sources, namely Moran (1976, 1981), Smith (1982), and Wood and Schmink (1979), Collins notes that colonists participating in the government’s Transamazon colonization program did not enter the region with comparable skills, experience, and capital, but were initially segmented into two groups, “brokers and clients,” according to Moran. “Brokers were entrepreneurs or independent farmers who were able to generate their own capital and to reinvest in their enterprises. Clients depended on brokers for their access to cash and produced mainly for subsistence rather than reinvestment. Clients were subdivided by Moran into laborers and artisans depending on their antecedent economic activities” (Collins 1986, 3).

From the onset of their Amazonian experience, then, smallholders were differentiated in their capacities and access to resources, and presumably reached land use decisions on the basis of different situationally specific criteria. One would not expect to find, therefore, a single land use deci-
sion-making function applicable to most households that might be discernable from the uniforming optic of NET.

Collins’s models of social and ecological cycles provide a convincing outline of a general trajectory of land use transition. She situates the driving force of these cycles in the context of the political economy of Brazilian agricultural modernization ideology, with its emphasis on cash crops (in this case an ecologically inappropriate variety of rice), induced into colonist communities of the Transamazon through short-term government loans. The challenge that Collins and others present is in accurately characterizing the migrant population as diverse from the onset and understanding that different logics of land use decision-making associated with different colonist subgroups set in motion an often unpredictable dynamic in landscape change.

So, given such diversity, how do we read colonist landscapes in the Amazon? How do we explain the dynamics of landscape change? I suggest we critically examine what deeply entrenched paradigms have to offer, carry forward what seems to work in specific local situations, and shrug off the excess theoretical baggage. But, it would behoove us to begin from a perspective of openness toward diverse possibilities—toward pluralism.

Diversity and Differentiation: Farmers of Rondônia

In this section I report selected findings of my 1992 survey of 240 farm households in three municipalities of Rondônia (Rolim de Moura [RM], Ouro Preto [OP], and Alto Paraiso [AP]), all settled about the same time (between 1981 and 1982), to illustrate the range of land use strategies followed by this seemingly homogeneous agrarian population. On the surface, these farmers appear to be homogeneous in regard to lot size (average = 80.6 hectares, standard deviation [std. dev.] = 8.0), the proportion of the sample in which owner resides full time on the farm (average = 90.7 percent, std. dev. = 1.79), the proportion of the sample that acquired their lots free through the government (average = 37.6 percent, std. dev. = 16.1), and the proportion of the sample holding definitive land titles (average = 49.6 percent, std. dev. = 9.65). In other words, the baseline survey revealed that absentee rural landownership was uncommon; most farm owners dwelled on their farms. Moreover, most farms were purchased from private landowners and speculators, not acquired through the Brazilian National Institute for Colonization and Agrarian Reform (INCRA). And, finally, half of the farmers were legal owners of their land. Beyond
these apparent similarities, significant differences in land use, income generation, job creation, capital investment, and natural resource use emerge between these three study sites.

**Land Use**

Although dozens of distinctive planting regimes of various sizes and species were encountered in our 1992 field surveys, the presentation here is confined to three broad land use categories—temporary crops (maize, manioc, beans, rice), permanent crops (coffee, cocoa, rubber), and pasture (*panicum, brachiaria*). In 1992 significant differences in the areas planted in permanent crops and pasture existed among the three study sites. For example, farmers in Rolim de Moura had twice the area in pasture (26.7 hectares) as did farmers in Alto Paraiso (13.9 hectares), but less than one-third of the area in permanent crops, suggesting the prevalence of much more extensive low-input farming systems in Rolim de Moura than in Alto Paraiso. The areas planted in temporary crops were not significantly different among the three study sites (average = 6.0 hectares) (table 8.2). Simply stated, Rondônia’s agricultural population has developed heterogeneous land use strategies.

**Gross Income**

The value of agricultural production in the three study sites clearly reflects the local differences in land use. The average annual farm income for 1991 was U.S.$3,172 for the sample overall. Farmers in Alto Paraiso earned slightly more than those in either Rolim de Moura or Ouro Preto, and 74 percent of that income derived from permanent crops. In Rolim de Moura, not surprisingly, 74 percent of farm income arose from cattle and milk sales and pasture rental (that is, pasture use). Gross incomes from mar-

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**Table 8.2. Land use patterns (hectares)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>RM</th>
<th>OP</th>
<th>AP</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average farm size</td>
<td>79.6</td>
<td>73.5</td>
<td>88.7</td>
<td>80.2</td>
</tr>
<tr>
<td>Mean area in temporary crops</td>
<td>5.4</td>
<td>6.4</td>
<td>6.1</td>
<td>6.0</td>
</tr>
<tr>
<td>Mean area in permanent crops</td>
<td>3.7</td>
<td>6.0</td>
<td>12.9</td>
<td>8.2</td>
</tr>
<tr>
<td>Mean area in pasture</td>
<td>26.7</td>
<td>23.0</td>
<td>13.9</td>
<td>20.8</td>
</tr>
<tr>
<td>Sample size</td>
<td>61</td>
<td>97</td>
<td>82</td>
<td>240</td>
</tr>
</tbody>
</table>

Source: John O. Browder 1992 field survey.

a. RM = Rolim de Moura  
b. OP = Ouro Preto  
c. AP = Alto Paraiso
Market output in 1991 were roughly proportional to land use differences, reflecting diverse strategies pursued by a seemingly similar population (table 8.3).

### Capital Investment and Assets

The majority (average = 56.4 percent, std. dev. = 12.7) of farmers surveyed reported earning no surplus income in 1991, no surplus income being reported by 70 percent of the farmers surveyed in Rolim de Moura versus 44.7 percent in Ouro Preto. Of those farmers obtaining a surplus, the most commonly cited investment out of eleven mentioned by farmers was to “buy cattle” (to build up the household’s herd). But these low levels of reported surplus income do not mean that farmers are without capital assets. Multiple rural property ownership ranged from 13.5 percent of households in Ouro Preto to 20.7 percent in Alto Paraiso. Urban property ownership ranged from 15.0 percent of households in Ouro Preto to 46.7 percent in Rolim de Moura. Commercial savings accounts ranged from 13.8 percent in Ouro Preto to 29.3 percent in Rolim de Moura (table 8.4).

#### Table 8.3. Gross income for marketed output (1991 U.S.$)

<table>
<thead>
<tr>
<th>Variable</th>
<th>RM(^a)</th>
<th>OP(^b)</th>
<th>AP(^c)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average annual income</td>
<td>3,206</td>
<td>2,909</td>
<td>3,422</td>
<td>3,172</td>
</tr>
<tr>
<td>Income from temporary crops</td>
<td>299</td>
<td>1,079</td>
<td>282</td>
<td>589</td>
</tr>
<tr>
<td>Income from permanent crops</td>
<td>527</td>
<td>615</td>
<td>2,527</td>
<td>1,283</td>
</tr>
<tr>
<td>Income from pasture (cattle)</td>
<td>2,380</td>
<td>1,206</td>
<td>612</td>
<td>1,296</td>
</tr>
<tr>
<td>Sample size</td>
<td>59</td>
<td>86</td>
<td>82</td>
<td>227</td>
</tr>
</tbody>
</table>

Source: John O. Browder 1992 field survey.

\(a\). RM = Rolim de Moura
\(b\). OP = Ouro Preto
\(c\). AP = Alto Paraiso

#### Table 8.4. Capital investment and assets

<table>
<thead>
<tr>
<th>Variable</th>
<th>RM(^a)</th>
<th>OP(^b)</th>
<th>AP(^c)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent of households owning more than one rural property</td>
<td>16.4</td>
<td>13.5</td>
<td>20.7</td>
<td>16.7</td>
</tr>
<tr>
<td>Percent of households owning one or more urban properties</td>
<td>46.7</td>
<td>15.0</td>
<td>31.7</td>
<td>28.9</td>
</tr>
<tr>
<td>Percent of households holding active commercial savings account</td>
<td>29.3</td>
<td>13.8</td>
<td>15.8</td>
<td>18.4</td>
</tr>
<tr>
<td>Percent of households buying new cattle in 1991</td>
<td>16.7</td>
<td>38.3</td>
<td>24.3</td>
<td>28.0</td>
</tr>
<tr>
<td>Sample size</td>
<td>61</td>
<td>97</td>
<td>82</td>
<td>240</td>
</tr>
</tbody>
</table>

Source: John O. Browder 1992 field survey.

\(a\). RM = Rolim de Moura
\(b\). OP = Ouro Preto
\(c\). AP = Alto Paraiso
Diversity prevails in the investment behavior and asset portfolios found among this agrarian population.

**Rural Temporary Labor Employment**

The vast majority of farm operations are labor self-sufficient; the household provides all labor requirements (table 8.5). However, one-fifth (21.7 percent) of the farms in the sample overall hired workers on a daily basis (at a daily wage of about U.S.$1.50), typically at harvest or in forest clearing and crop planting activities. Not surprisingly, due to the local emphasis on relatively labor-intensive permanent crop production, the proportion of households employing others for on-farm activities was higher (at 25.6 percent) in Alto Paraiso than in other study sites. The average number of workdays per year (1991) was also considerably higher (124.3 days) than in either of the other study sites. Different farming strategies entail different labor requirements, and Rondônia’s agrarian population displays a wide range of both.

**Natural Forest Resource Use**

Finally, there are significant differences in forest resource use and interest in planting native tree species among farmers in the three study sites. Although the forests in all three study sites share a common classification, much higher proportions of the farmers in Alto Paraiso both extract and market timber and nontimber forest products than their counterparts in either Rolim de Moura or Ouro Preto (table 8.6). Social rather than environmental factors may better explain this difference in resource utilization. Interest in planting native tree species mirrors forest resource use, as a higher proportion of farmers in Alto Paraiso actually plant trees and expressed interest in agroforestry than those in either other site. Explaining the variations in these patterns would be a worthy, but separate, under-
taking. For present purposes, suffice to say the variations suggest a heterogeneous agrarian population who respond differently to resource (income) opportunities.

The Amazon’s agrarian population is highly diverse in the landscapes they create, suggesting differences in land use decision-making processes. If reliability of prediction of land use change in the Amazon is affected by the social differentiation within the farming population, as many of the CIM researchers suggest, then understanding the forces driving such differentiation would be a necessary prerequisite to characterizing the process of land use change accurately.

The Dynamics of Land Use Transition: Three Case Studies from Rondônia

In an earlier study (Browder 1994), I hypothesized that three broad classes of factors influence small-farmer land use decisions: environmental factors (agro-ecological constraints, human epidemiology, and crop pathologies); institutional/structural factors (labor, land, credit, extension, and marketing constraints); and household-level factors (demographics and capital constraints). In this study, drawn from my 1984 survey of seventy farmers in Rolim de Moura municipality, I describe the “survival strategies” (in other words, land use decisions aggregated over time) of three colonist farmers over a five-year period (1980 through 1984) to illustrate the wide, and sometimes unexpected, range of factors that determine strategic land use decisions (that is, decisions that set in motion nearly irreversible courses of action). All three farmers began with roughly compa-

<table>
<thead>
<tr>
<th>Variable</th>
<th>RM</th>
<th>OP</th>
<th>AP</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of farmers extracting wood products</td>
<td>26.2</td>
<td>62.9</td>
<td>84.1</td>
<td>60.8</td>
</tr>
<tr>
<td>Percentage of farmers marketing wood products</td>
<td>6.5</td>
<td>5.8</td>
<td>40.2</td>
<td>15.8</td>
</tr>
<tr>
<td>Percentage of farmers extracting non-wood forest products</td>
<td>36.1</td>
<td>69.1</td>
<td>96.3</td>
<td>70.0</td>
</tr>
<tr>
<td>Percentage of farmers marketing non-wood forest products</td>
<td>4.9</td>
<td>10.3</td>
<td>18.3</td>
<td>11.7</td>
</tr>
<tr>
<td>Percentage of farmers already planting native tree species</td>
<td>10.3</td>
<td>21.0</td>
<td>48.8</td>
<td>28.1</td>
</tr>
<tr>
<td>Percentage of farmers wishing to plant native tree species in agroforestry systems</td>
<td>4.0</td>
<td>48.9</td>
<td>50.0</td>
<td>39.3</td>
</tr>
</tbody>
</table>

Source: John O. Browder 1992 field survey.
a. RM = Rolim de Moura
b. OP = Ouro Preto
c. AP = Alto Paraiso
rable land uses, but possessed different household capacities and faced varied environmental constraints. Their divergent land use strategies reveal the interesting range of spontaneous responses to unexpected contingencies.

**Case 1: José’s Annual Cash Cropping Strategy**

Virtually all small farmers plant annual food crops for household consumption, animal feed, and sale, and the majority derive some cash income from annual crops, especially during the formative four to five years immediately following settlement before perennial crops come to fruition. Yet few farmers intentionally adopt a long-term survival strategy based entirely on annual crops. Frequently, the failure of coffee seedlings to reach a productive stage locks farmers into annual cash cropping. This was the situation facing José, who accidentally burned his relatively small 1.25-hectare coffee grove planted in 1981 while preparing adjoining land for cultivation the following year. The effects of this unfortunate event were magnified by household-level characteristics. José had no initial start-up capital and no formal education, and although he held legal title to his land he never secured external financing for production. Significantly, José had four young dependent children to support with only the additional labor of his spouse. Without either family labor or cash to hire day workers, José’s options were limited in the short term. Having accidentally destroyed his coffee planting, not an uncommon occurrence in Rondônia, José’s long-term options were also bleak.

Environmental factors also worked against José, whose farm possessed relatively poor soils for annual cropping, the strategy into which José was pushed by virtue of his coffee failure. During the first five years José had not planted annual crops on the same plot for two consecutive years, a land management practice reflecting unsuitable soil conditions given his crop choices. Consequently, José spent more time clearing more forest himself than did his neighbors who successfully established coffee groves, an activity that put him at greater risk of contracting malaria. Indeed, José reported contracting malaria in each year since arriving on his farm. Although it was unclear what specific effect this disease had on his farming productivity, it undoubtedly cost him both lost workdays and money for medication.

To supplement a meager subsistence income based on upland rice, never planted on more than 2.5 hectares, José, who owned a chain saw, hired himself out to other farmers as a day laborer clearing forest. In 1984 José came upon a relative windfall, selling 35 cubic meters of a locally
marketed hardwood found on his lot. This modest income supplement of about U.S.$120 enabled José to buy new coffee seedlings, which he planted on a fresh 2.5-hectare clearing.

José’s situation illustrates the interplay of environmental and household-level factors in constraining a farmer’s land use options to a strategy based on ecologically inappropriate annual cropping. José’s circumstances are reflected by the financial return to his labor: In none of his five years of farming in Rondônia did José obtain a financial return to labor in excess of 54 percent of Rondônia’s minimum wage (table 8.7). Without any cash reserves for future emergencies or additional labor to expand production, José would either eke out a subsistence living from annual crops in the hope that his new coffee planting would mature, take on rent-paying tenants (an increasingly common practice in Rondônia), or sell off all or a portion of his lot and move on. Not surprisingly, José was among those that had left their farms between 1985 and 1990, when I returned to the study site to revisit these farmers.

Case 2: Milton’s Successful Transition from Annual to Perennial Crops

Unlike José, Milton successfully planted a relatively large area (10 hectares) in coffee within two years of settlement. Milton also cultivated rice and beans, always selling 75–80 percent of each year’s crop while waiting for the coffee planting to mature. Milton invested his surplus income in cattle, rather than in a commercial savings account, and by 1985 he owned a mixed herd of thirty-five head of Nellore cattle. He was proud that he had not had to sell even one animal during the five years he had lived on the farm, although he reported giving away several heifers and young steers as gifts to kin elsewhere in the Rolim de Moura settlement area.

Milton exemplifies a relatively successful farmer in Rondônia. Unlike José, Milton, having a larger family labor force (six teenagers), was able to bring a much larger land area into production quickly. Whereas José, with only his spouse as coworker, invested 472 workdays on their farm during the first three years, Milton’s family invested 2,000 workdays in forest clearing, planting, weeding, and harvesting during the same period. With about U.S.$950 in initial startup capital, Milton was also able to hire day workers in four of his first five years. Significantly, Milton’s farm lot is located on a large patch of relatively fertile terra roxa soil, an environmental factor further distinguishing him from José. Like José, Milton’s family planted coffee and annuals in the first year. With more labor, Milton could afford to be a better manager: no plantings were accidentally destroyed by
## Table 8.7. Percentage of total farm labor input and farm income by activity and daily return to labor (1980 Cr$)

<table>
<thead>
<tr>
<th></th>
<th>An</th>
<th>Per</th>
<th>Pas</th>
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<th>Per</th>
<th>Pas</th>
<th>An</th>
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<th>Pas</th>
<th>An</th>
<th>Per</th>
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<tbody>
<tr>
<td><strong>José (annuals)</strong></td>
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<tr>
<td>% of farm labor input</td>
<td>57</td>
<td>39</td>
<td>4</td>
<td>100</td>
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<td>47</td>
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<tr>
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<tr>
<td>Daily return to labor&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>63</td>
<td>260</td>
<td>303</td>
<td>764</td>
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<tr>
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<td>.54</td>
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<td>.23</td>
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<td><strong>Milton (annuals to coffee)</strong></td>
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<tr>
<td>% of farm labor input</td>
<td>57</td>
<td>41</td>
<td>2</td>
<td>62</td>
<td>37</td>
<td>1</td>
<td>87</td>
<td>11</td>
<td>2</td>
<td>75</td>
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<td>1.56</td>
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<tr>
<td><strong>Rogério (annuals to cattle)</strong></td>
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<td>338</td>
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<tr>
<td>Cr$ (% of min. wage)</td>
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<td>.36</td>
<td>.70</td>
<td>—</td>
<td>5.17</td>
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**Nonagricultural Income Alternatives**

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<tr>
<td>Min. wage rate Cr$</td>
<td>115</td>
<td>238</td>
<td>480</td>
<td>1,020</td>
<td>3,239</td>
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<tr>
<td>Urban wage rate Cr$</td>
<td>432</td>
<td>913</td>
<td>1,551</td>
<td>3,418</td>
<td>9,166</td>
</tr>
</tbody>
</table>

a. An = annual; Per = perennial cropping; Pas = pasture
b. Minimum wage rate: Porto Velho (IBGE, various years); and urban wage rate: prevailing composite wage for twelve semiskilled worker categories (IBGE, various years).
fire, regular weeding occurred, and harvest was punctual. Not surprisingly, Milton’s household income surpassed José’s. Milton obtained financial returns to his labor that consistently exceeded the legal minimum wage (table 8.7). With substantial assets in cattle that could be sold at will, Milton could consider various other land use options.

Providentially, Milton faced no overwhelming environmental (agro-ecological) constraints on his cropping strategy. He contracted no debilitating illness and enjoyed favorable household characteristics (for instance, numerous adult members, some startup capital). In spite of confronting adverse institutional/structural conditions (he purchased his lot on a fraudulent market from a speculator and did not receive a legal title), the interplay of environmental and household factors created net positive opportunities for survival.

Case 3: Rogério’s Shift from Annual Crops to Cattle

Like most of Rondônia’s settlers, Rogério arrived (in 1980) with no money to start a farm, only his labor and tools. With three young children and spouse, he cleared a small area of forest in each of their first three years, planting rice, beans, and coffee (in the first year). Yields were low and Rogério’s income was well below the legal minimum wage in each year. No pasture grass was planted during this time. Then, in 1983, Rogério secured a subsidized government loan to expand rice production, but contracted malaria and was incapacitated during the subsequent planting season. Only 1 hectare of maize was planted by Rogério’s spouse during his illness and the rest of his fields (some 5 hectares), now in fallow, were casually planted in *panicum* pasture grass. No new forest was cleared. In 1983 Rogério’s family survived entirely off the cash he had borrowed plus revenues from the sale of a small amount of timber.

Rogério’s fortunes changed in 1984 and so did his farming strategy. Late in 1983 his brother-in-law’s family (including four adult males) moved to the farm, bringing with them a herd of thirty-one cattle from a nearby farm. With the significant addition of labor and the cattle herd as collateral, Rogério secured a second (commercial) loan to plant 10 hectares of rice. Although Rogério had not repaid the first loan at the time of the survey, the fresh capital from the second loan (borrowed from a different bank), combined with new extended family labor, enabled Rogério to clear 20 hectares of forest, about half of which was planted in rice and half in pasture. By the end of 1984, Rogério’s farm had marketed 18 metric tons of rice, 8 fattened steers, and 720 kilograms of coffee beans from his 1980 planting. The 1984 financial return to labor on Rogério’s farm ex-
ceeded the prevailing urban wage rate in Rondônia, due mainly to the sale of cattle.

Although Rogério had not initially intended to specialize in cattle production, one year of debilitating illness (human epidemiological constraints) and the opportunity presented by extended family assets and labor (household-level characteristics), combined with his success in securing external financing (institutional/structural factor) and selling timber (environmental factor), enabled Rogério to effectuate a survival-enhancing shift in farming strategy. Rice production, initially the mainstay of Rogério’s farming strategy, became a “backstop” to cattle production in the fifth year.

Table 8.7 compares the percentage of farm input (labor) and output (income) for each case study and estimates the financial returns to labor of each strategy compared to alternative off-farm wage rates. These data show that there was little differentiation in the basic strategy of these three farmers in their first year (1980). Each farmer invested roughly the same proportion of workdays in annual crops (57–60 percent), perennial crops (39–41 percent), and pasture (0–4 percent). In the first four years of farming all three farms earned 100 percent of their farm income from annual crops. By the fifth year (1984), three distinct farming strategies had emerged. Only José obtained 100 percent of his income from annuals in that year. Milton earned 59 percent of his income from perennials, and Rogério derived 55 percent of his income from pasture (cattle) in the fifth year.

Not surprisingly the landscapes of these farms appear very different from the ground level. However, reading these landscapes from their spectral signatures via satellite could not tell the story of how these farms evolved. Nor, for that matter, would either NET or CIM frameworks have accurately predicted these landscape outcomes.

The interplay of environmental factors, many seemingly random, with household variables (personal attributes, social history, and cultural identity), set in motion divergent land use trajectories. Here, perhaps we find new meaning to Peirce Lewis’s poignant observation that “landscapes are our unwitting cultural autobiographies” (Lewis 1979).

The mosaic of land uses revealed by satellite images of the Rondonian landscape are the composites of these divergent situational rationalities at work, rationalities that cannot be conveniently compressed into the necessarily limited analytical categories of existing hegemonic theories (NET, CIM) and that, moreover, cannot be reliably discerned from orbital platforms (see Browder 1996a).
Conclusions and Recommendations

Small farmers in the Amazon are a complex, heterogeneous population. They arrive in the region with diverse backgrounds and capacities for survival. They respond to similar exogenous forces in different ways. The landscapes they create are physical manifestations of the interplay of numerous internal and external factors, reflecting varied situational rationalities. Often there is no predictable sequence of land uses on small Amazonian farms. Unexpected circumstances often arise that induce fundamental shifts in land use strategies, confounding efforts to predict. Such efforts, nonetheless, have been initiated. Informed by the underlying assumptions of normative economic theory and capitalist incorporation theory, these efforts, while informative in many ways, have not been particularly successful in explaining land use succession.

This chapter has endeavored to explore some of the nuances of land use change among small farmers in the Brazilian Amazon. Drawing upon survey research undertaken in Rondônia, the agrarian population is depicted as heterogeneous. The process of land use transition is highly contingent and pluralistic. Multiple forces operating at various spatial levels (household, locality, region, nation) enter into the determination of how resources are used. Five recommendations for future research are offered.

1. **The need for comparative time-series research.** The empirical research to date on this subject largely has been confined to isolated case studies, generating cross-sectional data of limited usefulness to understanding the temporal dynamics of landscape change. A concerted donor-driven effort to sponsor comparative follow-up studies of several colonist communities across the region would increase the likelihood of new and more accurate knowledge of the land use succession and the factors influencing land use change.

2. **The need to move beyond conventional meta-theories.** NET and CIP have structured the perception of researchers for decades. While theory is important, the risks of reducing the highly complex reality of this subject to sterile, anachronistic conceptual categories are too great to continue in the conventional theoretical mold. What is needed is not a new meta-theory, but a methodological approach to the subject that is open to the possibility of multiple and even conflicting explanations simultaneously.

3. **The need for methodological pluralism.** Following from item 2, the importance of survey research (the application of well-designed questionnaires) is not challenged here. Surveys produce useful, com-
parable, and verifiable data. But other more qualitative and participatory modes of investigation should supplement the traditional survey instrument. Historical reconstruction of land use in “an over-the-lunch-table” interview is not very reliable. My own field research, full of trial and error and numerous mistakes, suggests rich possibilities in a peripatetic approach. Walk with each farmer and other indicated household members over the entire farm, stopping at each clearing to review the history of the land. Map the farm as you go. Ask how each field has been treated since it was cleared, and how much it produced. Reconstruct the memory of each field by standing in it, talking about it for a time. Look around for physical artifacts of previous land uses that jog memory. Recognize that even this approach has reliability limits, and it may not be advisable to go back much more than five to six years. Ask why the farmer changed the planting regime along the way. This approach takes time (count on one farm per day, two at best, per researcher). But, for the patient, seasoned principal investigator, this strategy can produce rich rewards.

4. *The fecundity of explanatory factors.* Field research should begin with a recognition that land use decisions are influenced by a much wider range of variables than most researchers have been willing to test (see appendix for a preliminary list). Future research on this subject should strive to integrate these variables into the analysis. Especially interesting is the range of variables that emerge from the regional trend toward the “urbanization of rainforest land ownership” (see Browder and Godfrey 1997).

5. *The limitations of satellite data.* The desire to link ground-level data to satellite imagery is seemingly irresistible for some researchers. There are limitations and drawbacks of a satellite-driven research agenda. First, the civilian remote sensing technologies used over the last thirty years are not sufficiently refined to reliably distinguish enough important land use classes, for example, coffee from bush fallow, ten-year-old versus twenty-year-old secondary forest, pasture from corn. Second, even if refined so that a time series of accurate spectral signatures could be arrayed in a sequence of identifiable land uses, this information would still reveal nothing about the farmer’s reasons for shifting from one use to another over time. The situational rationality of the farmer goes unrecognized. Third, to do such research successfully is extraordinarily expensive, entailing high opportunity costs for other research. Finally, there are po-
litical and ethical implications for people making land use decisions based on satellite-driven research agendas. The idea that a regional-level database could be compiled using satellite imagery implies a top-down, command and control-oriented planning model. Such knowledge undoubtedly would be the property of powerful research or government institutions and a few elite scientists. The application of such knowledge likely would be focused on policies that seek to induce changes in colonist land use from the top down, rather than the bottom up.

Appendix: Land Use Sequence Model

What is the underlying logic driving the sequence from one use to another? Whereas two conventional NET and CIM frameworks presuppose a consistent, unchanging logic, in reality the very logic may change in response to the new circumstances.

Plot

<table>
<thead>
<tr>
<th>Forest</th>
<th>t1</th>
<th>t2</th>
<th>t3</th>
<th>t4</th>
<th>t5</th>
<th>t6</th>
<th>t7</th>
<th>t8</th>
<th>t9</th>
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<tbody>
<tr>
<td>1a</td>
<td>a</td>
<td>g</td>
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<td>2p</td>
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<tr>
<td>3g</td>
<td>F</td>
<td>F</td>
<td>g</td>
<td>g</td>
<td>bF</td>
<td>sf</td>
<td>sf</td>
<td>sf</td>
<td>sf</td>
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<tr>
<td>4F</td>
<td>F</td>
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<td>a</td>
<td>a</td>
<td>g</td>
<td>g</td>
<td>g</td>
<td>g</td>
<td>g</td>
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<tr>
<td>5F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>ap</td>
<td>ap</td>
<td>ap</td>
<td>p</td>
</tr>
</tbody>
</table>

a. Decision function: \( D1 = f (I1 .. n, E1.. n, D2 - n) \). Where \( I \) = internal factors; \( E \) = external factors; \( D \) = all the other plot decisions, and \( a \) = annual crops; \( g \) = grass; \( p \) = perennial crops; \( bf \) = bush fallow; \( sf \) = secondary forest; \( F \) = primary forest

Based on interviews with 240 farmers in Rondônia, described in this chapter, the following factors probably influence small-farmer land use decisions. It is recommended that future research in land use transition endeavor to integrate these factors as analytical variables in models that seek to simulate or predict land use sequences.

Internal Factors (demographic, economic, social, political)

1. Household composition, labor force (by age, gender, and form of remuneration)
2. Initial household capital stock (fixed and liquid)
3. Household debt/capital ratio (degree of indebtedness)
4. Off-farm income
5. Urban links (for example, urban fixed capital equity)
6. Multiple rural properties
7. Extended filial network resources (income remittances, labor/asset sharing)
(8) Farm distance to nearest urban center
(9) Educational level of household decision-makers
(10) Religious affiliation
(11) Political party affiliation
(12) Associational affiliation
(13) Farmer technical knowledge of natural resource management
(14) Household human health condition
(15) Intact remnant forest area
(16) Household land tenure status
(17) Type of production technologies available to households
(18) Lot size
(19) Years in residence on lot
(20) Land burning history

External Factors—Local

(21) Soil resource base (soil quality/suitability for nonforest uses)
(22) Irrigable water supply
(23) Aquatic resources (fisheries, game)
(24) Forest resources (timber and nontimber)
(25) Local real estate market (land prices)
(26) Supply of local day labor
(27) Land use rents (pasture)
(28) Public social overhead and social services (roads, bridges, hospitals, schools)
(29) Public land use policies/programs (municipality-level land use incentives)
(30) Existence of farmer support organizations (cooperatives, credit associations, workers’ unions, and so forth)
(31) Existence of affordable crop-marketing infrastructure and services (transport, storage, processing, packaging services)
(32) Existence of viable technical extension services

External Factors—Regional

(33) Access/distance to regional wholesale markets
(34) Regional and inter-regional transport infrastructure
(35) Regional development program inputs (incentives)
(36) Regional-level credit programs (if distinct from the above)
(37) Regional-level laws/regulations restricting land use options
External Factors-National/Transnational

(38) National debt service ratio
(39) National factor price policies (including wages)
(40) National minimum crop price supports
(41) National export promotion incentives (subsidized credits)
(42) National market prices
(43) Environmental policy and restrictions on land use
(44) Transnational capital investment in agriculture, forestry

Notes

1. In a 1992 survey of 240 farmers in three different municipalities of Rondônia, I found that 54.5 percent of the sample expressed a desire to plant trees on their farms, and 39.3 percent would do so in association with temporary ground cultivars if the following obstacles were eliminated: lack of knowledge of useful tree species, lack of knowledge of how to manage agroforest plots, and lack of knowledge about markets (Browder 1996b).

2. The forest type of three study sites is classified as Transitional Tropical Seasonal Moist Forest (Floresta Ombrófila Aberta).

References


Jones, Donald W., Virginia H. Dale, John J. Beauchamp, Marcos A. Pedlowski,


Endogenous Patterns and Processes of Settler Land Use and Forest Change in the Ecuadorian Amazon

Francisco Pichón, Catherine Marquette, Laura Murphy, and Richard Bilsborrow

Three questions must be asked about technology for sustainable agriculture in the Amazon frontier: Is it available? If not, is it likely to be generated? If yes, is it likely to be adopted? The answer to the first question is, on the whole, no. Other than slash-and-burn, there is no system of agriculture that satisfies the requisites for sustainability in the Amazon. With regard to the other two questions, the prevailing resource endowments of the frontier, characterized by the abundance of land and relative scarcity of human labor and capital, increases the odds that the answers will also be negative as such a situation makes development and adoption of natural resource-saving technologies unattractive.

Cunha and Sawyer 1997, 183

Since relatively uninhabited land still exists in many Latin American countries, governments in the region are increasingly struggling to develop policies that reflect the difficult tradeoffs involved in fostering an economically productive yet environmentally sustainable farm sector capable of reconciling the concerns for resource productivity and forest conservation in the Amazon. This tradeoff needs to be explicitly dealt with in policymaking: Will policies that promote improved agricultural productivity in the Amazon also limit expansion, or do policymakers face a tradeoff between the different policy objectives?

In the search for ways to improve frontier agricultural systems, low agricultural productivity is generally presumed to be a key factor leading to continual land clearing among small settler farmers on the Amazon frontier. Many would-be developers of “more sustainable” farming systems thus assume that alternative systems that may increase agricultural productivity (in terms of production per unit of area or per person-hour)
will reduce farmers’ need to keep clearing new lands to ensure a good total harvest undiminished by loss of agricultural productivity, and thereby limit forest loss (Sanchez and Bents 1987; World Bank 1992).

Evidence from our study of frontier settlers in the northeastern Ecuadorian Amazon, however, suggests that it might not be the case that higher agricultural productivity due to farming on more fertile soils or aided by productivity-enhancing technologies and systems reduces deforestation among small farmers on the frontier. In fact, the opposite appears to be the case. In considering the benefits and disadvantages of improving agricultural productivity, the impact on deforestation is likely to be a negative rather than a positive factor, largely because of the nonsubsistence motivation of most clearing in the Amazon region. Explanations for the observed positive links between technological change, agricultural productivity, and forest clearing are linked to the fact that small-farmer settlers rely on their agricultural activity to satisfy their material and nonmaterial aspirations, which extend far beyond meeting mere food requirements. On this basis, profits from more productive farming may be readily reinvested in other land uses that involve even more rapid deforestation (for example, cattle raising), yet provide higher material payoffs that can better meet the household’s complex and often increasing consumption needs. As such, a dilemma may emerge in that technological change and increased agricultural productivity among small farmers may, contrary to common assumptions, work to increase rather than decrease forest loss (Fearnside 1987).

To gain a better understanding of the nature of the dilemma that may exist between technological change, agricultural productivity, and forest clearing among small farmers on the frontier, as well as of the complex economic decision-making in which they may be involved, this chapter examines information from 420 settler households in the northeastern Ecuadorian Amazon during the 1990s. In previous work, we have investigated the heterogeneous nature of settler households in terms of their socioeconomic characteristics and other policy factors determining their access to capital, labor, and land inputs, and we have accounted for the differential outcomes in terms of land use and forest conservation (Marquette 1995 and 1998; Murphy 1998; Murphy et al. 1999; Pichón 1993, 1996a, b, c, 1997a, b). In this chapter we consider households’ production strategies and their implications for the material and nonmaterial aspirations of settlers. We discuss important policy, socioeconomic, and ecological factors that shape settlers’ land use decision-making and the links between technological change, agricultural productivity, and for-
est conservation on the frontier. We conclude by considering the implications of our findings for frontier settlement agricultural and development policy.

Technological Change and Settler Adaptation in the Frontier

Technological Change in the Land-Surplus and Labor-Scarce Environment of the Frontier

Farm households in the rainforest frontier, while similar in many ways to other rural agricultural households, exist in environments characterized by an abundance of land relative to the other factors of production, namely labor, capital, and regional infrastructure. These households strive to improve their material conditions through resource technologies that take advantage of these conditions, utilizing land-extensive and labor-saving production strategies such as raising cattle (Pichón 1996a). Given the remote location of farmer plots and low population density, family labor supply is a limiting factor, however. The frontier also lacks basic services and infrastructure, such as agricultural extension, credit, roads, and health care, each of which increases the cost of technological innovation and thus constrains farmers’ production strategies (Vosti and Reardon 1997).

The fundamental paradox surrounding frontier settlement in the Amazon today is that although the need for technological innovation in natural resource management is greater, the means with which to innovate are lacking (Blaikie and Brookfield 1987). Frontier settlement often involves farmers who have been largely displaced from long-settled regions elsewhere by poverty, land scarcity, natural disasters, and political conflict. Thus settlement often means that much of the new and frequently fragile land resources of the Amazon are in the hands of those with the fewest resources to devote to their management. Driven by environmental constraints and survival needs, and by the absence of affordable and/or alternative forms of agricultural technology that better sustain soil fertility, farmers have little choice but to encroach more and more on forested land. Declining productivity is thus compensated for primarily through the now infamous overuse of slash-and-burn agriculture and a strong drive for labor-saving and land-using resource utilization systems (such as cattle ranching), which continually bring more land into production rather than maintain productivity of the same area over the long term.

Since technological innovations always tend to reflect relative factor
scarcity rather than change, settler agriculture expands primarily through the continuous incorporation of new land and, ironically, the destruction of its own resource base. Frontier agriculture is thus a rational approach to natural resource use in a land-surplus and land-accessible economy (Cunha and Sawyer 1997; Locascio 1995; Marquette 1998; Murphy et al. 1997; Southgate and Whitaker 1992, 1994; Walker et al. 1993, 1994). The economics of cheap, easily accessible land combined with low population densities and lack of capital inputs encourage unsustainable use of the agricultural resource base, such as land-using/labor-saving cattle ranching. With the perception of limitless land resources and the low cost of land that this implies, it is simply cheaper for the farmer to exploit the agricultural resource base indiscriminately and move on than to adopt more costly sustainable techniques. The perpetuation of this system depends on the continued expansion of the road system into new frontier lands, although, as previous analyses have shown, the process varies from farm to farm, depending on the quality of soils, ease of forest access, availability of labor, off-farm employment, credit, and the land tenure situation.

Preservation of the resource base is a form of investment that requires technical knowledge, financial resources, a low discount rate, and a long-term outlook—conditions associated with abundance of capital, not of land, which are just the opposite of conditions prevailing in the Amazon frontier (Cunha and Sawyer 1997; Southgate and Whitaker 1994). Fortunately, resource endowments are not only accidents of geography but also products of the market and institutions (Cunha and Sawyer 1997). The conditions that make innovations profitable can be changed: Capital and labor are mobile; land can be enclosed or otherwise regulated; road construction can be more strategically planned; and the legal and institutional framework can be re-evaluated to promote more intensive, land-saving agricultural practices in the region (Schneider 1995).¹

Explaining the prevalence of extensive land use systems such as slash-and-burn agriculture or cattle raising as a function of frontier conditions is, however, only half the picture. Frontier farming activities and goals are shaped by a larger matrix of economic choices that involves balancing profits, losses, time allocations, and investments gained from off-farm employment and other nonagricultural activities as well (Perz 1998; Schmink 1984, 1996; Wood and Walker 1998). As frontier farmers play out their economic strategies, their production decisions are shaped by their specific political environment and the formal and informal policies affecting land tenure, credit availability, infrastructure development (such
as road building), and government and nongovernment support for all the agricultural and nonagricultural activities in which they may be engaged. It is also important to consider how the perceptions that settlers themselves have of the frontier may shape their ability both to react to frontier conditions and to transform these conditions proactively—or rather to “adapt.”

As discussed by Murphy and her coauthors (1997), our understanding of settlers’ behavior and their agricultural strategies would benefit greatly from drawing on existing concepts and frameworks of human adaptation, adaptive strategies, and adaptive processes as found in the human ecology and ecological and economic anthropology literature. In recent years, conceptual frameworks for analyzing human adaptation, influenced by practice theory, have placed greater emphasis on the importance of contextualized action and the role of environmental perceptions within adaptive processes (Croll and Parkin 1992; Descola and Pálsson 1996; Ellen and Fukui 1996; Ingold 1987). In line with these trends, in the discussion below we more closely consider settler perceptions of the frontier environment, particularly with regard to the risk of failure and how this risk may shape how colonist settlers adapt.

Settlers’ Perceptions of Risk and Adaptation to Frontier Conditions

Colonists’ perceptions of risks have been extensively mythologized in many frontier settlement settings (for example, the American West). In northeastern Ecuador and elsewhere in the Amazon frontier, settler households also perceive the frontier environment as high-risk. This perception may firstly derive from the risk entailed by migration itself, which may involve the stress and uncertainty of disconnecting social and economic ties at least to some extent from existing socioeconomic networks in their areas of origin. Also, as in-migrants, settlers come to the frontier with diverse agricultural backgrounds (from highland and coastal areas) that may leave them with varying degrees of preparation to cope with the Amazon region’s different agroecological conditions. Many settlers in our study area had in fact not been landholders prior to settlement, indicating that moving to the Amazon represented perhaps a first venture into household farming. Additionally, the settler household’s marginal economic status; the need to adjust to what are more or less new socioeconomic, cultural and political conditions; and perhaps a new experience of geographic isolation may create perceptions of insecurity, tension, and stress within the settler households towards the settlement process, and subsequently towards the frontier environment itself. These perceptions may particu-
larly be the case during early duration of settlement, but they are likely to persist over time even as the frontier environment becomes more familiar. External factors particular to the Ecuadorian Amazon frontier (for instance, lack of infrastructure and basic services such as agricultural extension, roads, credit, and health care; conflicts between settlers and indigenous groups; and weak penetration of legal and judicial structures) may clearly create a continual sense of risk on the frontier.

In response to this perceived risk, settlers may tend towards “tried and true” land use patterns and resource use techniques grounded either in their own previous experience outside the Amazon or observed as being successfully used among other settlers already within the region. In terms of the larger adaptive processes that may be at work, using what is “tried and true” is probably a mixture of both replication and relying on practices from areas of origin and innovation based on the adaptation of new behaviors observed among other settlers in the region. Given the heightened perceived risk of failing in their agricultural activities, frontier settlers, in contrast to the standard neoclassical agricultural household model in which income maximization is an important force, tend to adopt agricultural strategies that make risk minimization—not income maximization—a priority. As a result, settlers may adopt agricultural strategies that merely generate an acceptable but secure level of income for the household over the long run rather than those that necessarily maximize income each year (Pichón 1996a). Farmers thus consider the possible welfare and economic consequences of all available land use options. They focus on whether or not there is an overlap between the ranges of competing outcomes and on the likelihood of having to face disaster or great satisfaction, given the constraints under which they produce, sell, and consume in the frontier context.

Under the risky conditions of the frontier (fragile and easily degradable soils, poorly developed market mechanisms and physical infrastructure, and so forth), farmers’ decisions need to be flexible and leave room for a number of contingency strategies (Netting 1993). Thus a small farmer may be reluctant to shift from a traditional technology of cultivation or crop pattern (such as one that has had the benefit of several years of trial-and-error adaptations by earlier settlers on neighboring farms) to a new one that promises higher yields but may entail greater risks of crop failure. Instead, of all the familiar outcomes, farmers choose the option that offers them the most security. As we will see below, many settlers in the northeastern Ecuadorian Amazon rely on a polyculture production system involving diverse food and cash crops yet centering on a proven perennial
cash crop—coffee—which, despite its low prices and the long-term investment required, provides steady income. When household security is at stake, it would seem more important for the farmer to avoid a “bad” year (that is, total crop failure) than to maximize output in “better” years. Still, the potential conflict between the goals of minimization of risk and maximization of profits should not be overstressed, as within the same high-risk environment of the frontier some households do clearly undertake land use patterns based on extensive cattle ranching, which generate relatively greater income as well.

To illuminate this general discussion, we now draw on findings from our research in the northeastern Ecuadorian Amazon to consider patterns of land use among frontier settlers emerging in this area of frontier settlement.

Frontier Settlement in the Northeastern Ecuadorian Amazon

The Setting

The information on Amazon settler households discussed below derives from a cross-sectional survey of approximately 420 settler households in the northeastern Ecuadorian Amazon (specifically in the provinces of Napo and Sucumbios; see map 9.1) carried out in the early 1990s by Francisco Pichón and Richard Bilsborrow from the University of North Carolina with the assistance of five teams of Ecuadorian interviewers. To date, this survey continues to be one of the few representative samples of settler households from Ecuador and any extensive Amazon area. Detailed information on survey design, methodology, and sample selection for the 1990 survey is given by Pichón (1997b). At present Laura Murphy and Bilsborrow are heading a follow-up survey in the region whose data are not yet available; this survey will provide some longitudinal information on the 1990 households. In the absence of these more recent data, the shortcomings of using such cross-sectional data on settlers, particularly to analyze longitudinal trends or what they may do over time on the frontier, have been discussed elsewhere (Marquette 1998).

The upper basin of the Amazon in Ecuador, bordering on the eastern slopes of the Andes, is of major global significance in terms of biological diversity and has been designated as one of the world’s ten major biodiversity hot spots (Myers 1988). At the same time, over half of the Ecuadorian government revenues and foreign exchange earnings are derived from petroleum extracted precisely from the part of the Ecuadorian Ama-
Map 9.1. Ecuador and study area (Amazon settlement frontier)
zon that is undergoing massive spontaneous settlement and deforestation (Hicks 1990; World Bank 1995). Most forest intervention in the region has come at the hands of the spontaneous colonist farmers attempting to establish land claims and agricultural livelihoods along transport routes originally constructed to aid in petroleum exploration and exploitation (Landazuri 1988; Pichón 1993).

These are farmers who have formerly made a living in long-established farmlands and who, for various reasons (population pressures, pervasive poverty, maldistribution of farmland, lack of inputs for intensive cultivation, lack of nonagrarian livelihood opportunities, and generally inadequate rural development), have been increasingly squeezed out of their homelands (Bromley 1972, 1981; CLIRSEN 1986; Eastwood and Pollard 1992; Pichón 1993). As a result of this process, the population in this part of the Amazon is growing rapidly, with several of its counties recording double-digit annual growth rates primarily from in-migration (INEC 1992). Correspondingly, rates of deforestation in the Ecuadorian Amazon are also high and are most closely linked to agricultural expansion by small farmers (FAO 1993).

Table 9.1 provides some key characteristics on the study sample. More detailed information may be found in Pichón (1997a and 1997b), Murphy (1998), and Marquette (1998). It is important to note that half of all settlers were not landholders prior to settlement; most were either agricultural workers or sharecroppers. The average household head reflects some primary education, and he and his spouse are in their middle to late thirties. Once on the frontier, households generally occupy plots of approximately 50 hectares in size. With an average household size of approximately six, there are generally three adult males available and involved in

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of households</td>
<td>404</td>
</tr>
<tr>
<td>Mean household size (sd)</td>
<td>6.6 persons (3.8)</td>
</tr>
<tr>
<td>Mean plot size</td>
<td>46.4 hectares (14.2)</td>
</tr>
<tr>
<td>Mean duration of residence in Amazon</td>
<td>8.7 years (5.2)</td>
</tr>
<tr>
<td>Median household income per annum</td>
<td>680.00 US$</td>
</tr>
<tr>
<td>% households using hired labor</td>
<td>60.0%</td>
</tr>
<tr>
<td>Off-farm labor</td>
<td>30.0%</td>
</tr>
<tr>
<td>% households using any fertilizer</td>
<td>56.0%</td>
</tr>
</tbody>
</table>
forest clearing or agricultural labor. Only a third or fewer of women or children are involved in agricultural labor on the farm. The median overall annual household income was U.S.$680. Given the larger average household size in the frontier (6.6 persons), the average per capita income was thus much lower than the 1990 national per capita average income of U.S.$1,200 (World Bank 1995).

Over half of the settler households use about one to three months of hired or exchange agricultural labor at some point during the year, mainly during planting and harvesting periods. About a third of the settler households also have one member (primarily the household head) working off-farm for one or two months during the year, generally helping on a neighboring settler farm. Levels of technological input (such as use of improved seeds, fertilizer, and chain saws) and access to credit as well as general technical assistance are low. Farm technology is simple, based largely on hand tools and the occasional application of chemical herbicides (mainly to coffee crops) by about 56 percent of the households. The extraction of timber or nontimber forest products for either household use or sale is limited.

The study area presents several characteristics that may limit the generalized insights that may be drawn from the region. First, soil quality is on average higher than in other areas of the Amazon (Sánchez and Bents 1987). The presence of large areas of volcanic and alluvial soils in the study area perhaps makes northeastern Ecuador comparable to areas colonized in the Brazilian state of Rondônia, which also exhibit somewhat more fertile soils than those found in the majority of the Brazilian Amazon. However, the soils in the study area, as everywhere else, are very “patchy,” with radical differences occurring over short distances, and it is not uncommon for colonists to have wide variations in soil quality within their usual 40- to 50-hectare plots. The superior quality of the natural resource base, however, can mean a greater resistance capacity and longer cultivation time before soil fertility corrective measures need to be undertaken.

Second, the high and seasonally uniform precipitation in this part of the Ecuadorian Amazon results in the use of a slash-and-mulch rather than slash-and-burn system of forest clearing and planting, and a continual growing season. This situation contrasts with the extreme variability in rainfall (including both excessive rainfall and drought) and seasonal cropping that characterizes many other Amazon frontiers, including those in Brazil. Also, in contrast with other frontier areas where monocultivation of annual crops may dominate, settlers’ production strategies in Ecuador
involve polyculture mixed farming of food crops, cash crops, and raising of cattle and other small livestock (pigs and chickens).

Third, the fact that virtually all agricultural settlements in the Ecuadorian Amazon are spontaneous, rather than directed and semidirected as in the Brazilian Amazon, also makes the area atypical. Settlers in the northeastern Ecuadorian Amazon are almost all small farmers. There have been no significant government settlement programs, nor the promotion of single cash agricultural crops or major cattle-raising subsidies and credit schemes as in Brazil. There is only some limited capital-intensive oil-palm plantation activity, no extensive timber and mineral extraction, and little presence of large multinational corporations apart from the oil companies. Additionally, the uniform 40–50-hectare farm size of this colonization area is different from most settlement patterns elsewhere in the Amazon region, particularly in Brazil. And, also unlike the Brazilian Amazon, the Ecuadorian Amazon is generally far enough from major urban centers to escape any special effects of marketing and employment opportunities (Browder and Godfrey 1997), although some off-farm income-earning opportunities are available to settlers through the oil companies and service activities in the local towns.

The study region settlers on the whole, however, reflect many of the key characteristics of the contemporary Amazon frontier, so that conclusions based on them are generalizable. Settlers undertake farming that relies mainly on family labor and simple (manual) agricultural technologies with little or no use of modern agricultural inputs. Household labor is an important and relatively scarce resource given low technology and low population density. In addition, households are subject to severe socioeconomic and political constraints that are common throughout Amazon frontier environments. The region’s limited services, institutions, agricultural extension, and insecurity of land tenure are typical of most colonization areas throughout the Amazon. Settler families in Ecuador as in other Amazon frontier areas also rely on some off-farm employment, out-migration of members of the household, and occasionally remittances from previous members who have moved away. Finally, participation of Ecuadorian settlers in the cash economy of the region through the production of cash crops is also a common feature in the Amazon.

Settler Land Use Patterns

Unlike many other parts of the Amazon frontier, settlers in the northeastern Ecuadorian Amazon practice a true “polyculture” cultivation system (Pichón 1997a). As table 9.2 indicates, settlers engage in mixed agricul-
tural and livestock-raising activities that involve a range of annual food crops (yucca, corn, plantains) and perennial and tree cash crops (coffee, cocoa, citrus trees) (Pichón 1997a). In order of importance, the main crops cultivated are coffee, a perennial crop grown by almost all (95 percent), and food crops (plantains, yucca, corn), grown by 50 to 80 percent. Cocoa, another perennial crop, is grown by over a third of households but on a smaller scale than coffee. The crop data and variation in share of gross cropped area show that, despite general similarities, substantial variation in agricultural production may also exist among households. Still, a distinctive general feature of the study households is that most grow coffee as their main cash crop. In addition, despite generally low levels of technology among a third of the households, intensive land uses such as intercropping of annuals (including corn and rice), semiannuals (such as plantains, bananas, and manioc [yucca]), and perennials (such as coffee, cocoa, guaba, achiote, and citrus trees) are practiced by virtually all settlers in the region.

Table 9.3 presents information on the percentage of households growing crops or with pasture by duration of settlement. As table 9.3 indicates, for most colonists coffee is the main cash crop, while bananas, yucca, and corn are the main food crops, and most settlers at early duration of settlement generally plant both cash and food crops. Cocoa is the only crop that may be increasingly cultivated by some households over time in any significant proportion. Food crops are grown mainly for household subsistence purposes as are most livestock. Pasture and fallow areas (known in the region as rastrojo) are created through the conversion of previously cultivated fields to extensive grasslands and increase with time on the frontier (table 9.3). Among recently settled households rastrojo may comprise only a small proportion of the total farm area, while households that have been settled for five to ten years may have a third or more of their plots in pasture and fallow. Despite the pervasiveness of pasture and fallow, numbers of cattle owned are on average small—under two head—regardless of duration of settlement. The percentage owning at least some cattle does increase over time (table 9.3). Some large-scale ranching does occur, representing an important deviation from the general pattern.

We have described elsewhere how the quality of the natural resource base may act as a “natural resource straitjacket,” given the low technology level, on settler land use options (Pichón 1997a and 1997b). Similarly, we have explored how various “blocks” of factors centering on a household’s natural resource base (soil quality, topography, change over time), institutional and technology environment (road access, availability
<table>
<thead>
<tr>
<th>Perennial Crops</th>
<th>Annual Food Crops</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Perennial Crops</td>
<td>Annual Food Crops</td>
</tr>
<tr>
<td></td>
<td>Mean proportion</td>
<td>of cropped area</td>
</tr>
<tr>
<td></td>
<td>(std. dev.)</td>
<td>(std. dev.)</td>
</tr>
<tr>
<td>Coffee</td>
<td>0.70</td>
<td>0.10</td>
</tr>
<tr>
<td>Cocoa</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>African Palm</td>
<td>0.01</td>
<td>0.11</td>
</tr>
<tr>
<td>Fruits</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>Range</td>
</tr>
<tr>
<td>Coffee</td>
<td>0–1.0</td>
<td>0–1.0</td>
</tr>
<tr>
<td>Cocoa</td>
<td>0–0.77</td>
<td>0–0.5</td>
</tr>
<tr>
<td>African Palm</td>
<td>0–0.35</td>
<td>0–0.73</td>
</tr>
<tr>
<td>Fruits</td>
<td>0–0.6</td>
<td>0–0.4</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>Range</td>
</tr>
<tr>
<td>No. of producers</td>
<td>393</td>
<td>201</td>
</tr>
<tr>
<td>% of farms</td>
<td>95</td>
<td>49</td>
</tr>
</tbody>
</table>


a. Excludes pasture and fallow area.
Table 9.3. Crops grown by settlers and pasture and cattle-owning by duration of settlement

<table>
<thead>
<tr>
<th>Duration of Settlement</th>
<th>% Growing Cash Crop</th>
<th>% Growing Food Crops</th>
<th>% with Some Pasture</th>
<th>% with Some Cattle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>coffee</td>
<td>cocoa</td>
<td>bananas</td>
<td>yucca</td>
</tr>
<tr>
<td>Recent 0–3 years (n = 74)</td>
<td>87.8</td>
<td>18.9</td>
<td>79.7</td>
<td>54.1</td>
</tr>
<tr>
<td>Longer 4–10 years (n = 186)</td>
<td>97.3</td>
<td>32.3</td>
<td>86.6</td>
<td>60.2</td>
</tr>
<tr>
<td>Longest 10–20 years (n = 141)</td>
<td>97.5</td>
<td>47.5</td>
<td>88.7</td>
<td>62.7</td>
</tr>
<tr>
<td>All (n = 401)</td>
<td>93.7</td>
<td>35.1</td>
<td>82.3</td>
<td>58.1</td>
</tr>
</tbody>
</table>

<sup>a</sup> Assuming forest area starts out at 100.0% or entire plot is forested. Probably an overestimate since some settlers purchase plots from other settlers and some portion of plot may already be in pasture upon settlement.
of agricultural technology and assistance, access to labor markets, land tenure policies), and household and farm characteristics (farm size, agro-economic background, and household demographic composition and labor) may tighten or loosen the household resource straitjacket to shape land use outcomes (Marquette 1998; Pichón 1997a and 1997b). In the context of the present discussion, we consider how the perceptions that settlers themselves have of the frontier environment shape their ability not only to react to the conditions of the frontier but also to adapt their land use strategies proactively to such conditions.

As suggested above, the perceived risks involved in frontier farming lead settlers in the study area to adopt “tried and true” practices that may draw on both their own past experience in their areas of origin and observed practice among other settlers on the frontier. For example, all households use the slash-and-mulch technique of forest clearing prevalent in the area due to continual rainfall. This practice is likely to be one that settlers are not familiar with before coming to the frontier but rather learn by observing what other established settlers do.

Table 9.4 compares crops grown by settler households in their area of origin (coastal and sierra regions) with crops grown by the same settler households on the frontier. This table suggests that the mixed agricultural pattern characteristic of the region appears to be extensively learned or adopted by households once on the frontier. Intercropping of food crops and tree crops may also be a technique adopted once in the region by observing other settlers. However, variations may exist depending on area of origin. Coastal farmers, for example, were more likely to be familiar with cocoa growing prior to settlement—for them, growing cocoa is more often an extension of previous practices.

Land Use Strategies and Implications for Forest Clearing

Since each part of the amalgam of land use decisions a farmer makes has implications for the other parts, understanding production strategies involves considering the combined uses of land on their plot. We have used a series of cluster analyses to explore the most frequently occurring land use combinations among settlers, based upon the percentage of a given household plot allocated to (a) forest, (b) food crops, (c) perennial crops (mainly coffee), and (d) pasture and fallow (rastrojo). In order to get an overall sense of the impacts that the most frequently identified land use combinations had on the forest environment, we also classify the identified land use patterns according to the relative degree of forest clearing.
Table 9.4. Comparison of crops grown before and after settlement among settler households who owned land in area of origin (n = 175)

<table>
<thead>
<tr>
<th>Time</th>
<th>Region of origin</th>
<th>Coffee</th>
<th>Cocoa</th>
<th>Bananas</th>
<th>Yucca</th>
<th>Corn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before settlement</td>
<td>Sierra (n = 125)</td>
<td>28.8</td>
<td>4.0</td>
<td>7.9</td>
<td>4.0</td>
<td>17.6</td>
</tr>
<tr>
<td></td>
<td>Costa (n = 50)</td>
<td>38.0</td>
<td>24.0</td>
<td>10.0</td>
<td>2.0</td>
<td>2.7</td>
</tr>
<tr>
<td>After settlement</td>
<td>Sierra</td>
<td>98.4</td>
<td>38.4</td>
<td>88.0</td>
<td>59.2</td>
<td>52.0</td>
</tr>
<tr>
<td></td>
<td>Costa</td>
<td>96.0</td>
<td>32.0</td>
<td>80.0</td>
<td>54.0</td>
<td>36.0</td>
</tr>
</tbody>
</table>

they involve (low, medium, or high). We also consider the identified clusters by relative duration of settlement—that is, whether households are recently settled (0–3 years in the Amazon), longer settled (4–10 years settled), or longest settled (10–20 years settled). Table 9.5 presents the results of the cluster analyses by duration of settlement group (parts a–c) and for all households overall (part d). Only the main results are summarized here.

Beginning with all households, four land use patterns emerge, as illustrated in figure 9.1: a low-cleared-area pattern that is most prevalent (61.1 percent of all households), a medium-cleared-area pattern (24.2 percent of all households), and two high-cleared-area patterns focusing on specialization in either cattle raising (8.5 percent of all households) or coffee growing (3.2 percent of all households). Figure 9.2 illustrates households by land use pattern while controlling for duration of settlement. As this figure reflects, the largest proportion of settlers at each duration of settlement (84 percent recently, 50 percent longer, and 64 percent longest settled) also reflects the low-cleared-area pattern. Reading longitudinally across the stages of settlement groups to infer what any individual household might do over time, the results suggest that most settlers start out and continue with a low-cleared-area pattern even as duration of settlement increases. Three alternative patterns (medium-cleared-area based on cattle, high-cleared-area based on cattle, and high-cleared-area based on coffee), involving larger cleared areas, emerge among just over a third of all households and only at later duration of settlement. The number of longest settled households with the low-cleared pattern (64 percent) is actually greater than in the longer settled households (50 percent), while the number of longest and longer settled households with high-cleared-area patterns is similar. If settlers did move progressively towards more cleared areas and specialized patterns after ten years of settlement we
Table 9.5. Land use patterns among settler households in northeastern Ecuadorian Amazon based on cluster analysis

a. Recently settled households (0–3 years in Amazon) n = 74

<table>
<thead>
<tr>
<th>Land use pattern</th>
<th>LCA Pattern</th>
<th>Predetermined Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster center:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% plot in forest</td>
<td>83.2</td>
<td>19.0</td>
</tr>
<tr>
<td>% plot in food</td>
<td>3.4</td>
<td>25.0</td>
</tr>
<tr>
<td>% plot in coffee</td>
<td>7.2</td>
<td>27.0</td>
</tr>
<tr>
<td>% plot in pasture/fallow</td>
<td>6.2</td>
<td>29.0</td>
</tr>
<tr>
<td>Totals</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Median number of cows owned

No. and % of all recently settled households in cluster (n = 74 = 100.0%)

<table>
<thead>
<tr>
<th>Average distance of individual households from cluster centers (sd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
</tr>
<tr>
<td>62</td>
</tr>
<tr>
<td>(9.7)</td>
</tr>
</tbody>
</table>

b. Longer settled households (4–10 years in Amazon) n = 186

<table>
<thead>
<tr>
<th>Land use pattern</th>
<th>LCA Pattern</th>
<th>MCA Pattern</th>
<th>HCA-cattle Pattern</th>
<th>HCA-coffee Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster centers:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% plot in forest</td>
<td>79.7</td>
<td>45.5</td>
<td>9.0</td>
<td>5.9</td>
</tr>
<tr>
<td>% plot in food</td>
<td>2.7</td>
<td>7.0</td>
<td>9.0</td>
<td>14.9</td>
</tr>
<tr>
<td>% plot in coffee</td>
<td>10.3</td>
<td>18.8</td>
<td>13.0</td>
<td>68.3</td>
</tr>
<tr>
<td>% plot in pasture/fallow</td>
<td>7.3</td>
<td>28.7</td>
<td>69.0</td>
<td>10.9</td>
</tr>
<tr>
<td>Totals</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Median number of cows owned

No. and % of all longer settled households in cluster

Average distance of individual households from cluster centers (sd)

(continued)
### c. Longest settled households (10–20 years in Amazon) \( n = 141 \)

<table>
<thead>
<tr>
<th>Land use pattern</th>
<th>LCA Pattern</th>
<th>MCA Pattern</th>
<th>HCA-cattle Pattern</th>
<th>HCA-coffee Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster centers:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% plot in forest</td>
<td>67.0</td>
<td>25.0</td>
<td>10.9</td>
<td>20.1</td>
</tr>
<tr>
<td>% plot in food</td>
<td>5.0</td>
<td>9.0</td>
<td>2.0</td>
<td>5.4</td>
</tr>
<tr>
<td>% plot in coffee</td>
<td>13.0</td>
<td>24.0</td>
<td>6.9</td>
<td>66.4</td>
</tr>
<tr>
<td>% plot in pasture/fallow</td>
<td>15.0</td>
<td>42.0</td>
<td>80.2</td>
<td>8.1</td>
</tr>
<tr>
<td>Totals</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Median number of cows owned</td>
<td>5</td>
<td>12</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>No. and % of all longest settled households in cluster</td>
<td>90</td>
<td>33</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>Average distance of individual households from cluster centers (sd)</td>
<td>18.9</td>
<td>27.7</td>
<td>15.0</td>
<td>20.4</td>
</tr>
<tr>
<td>(8.9)</td>
<td>(9.3)</td>
<td>(6.6)</td>
<td>(16.0)</td>
<td></td>
</tr>
</tbody>
</table>

### d. All households \( N = 401 \)

<table>
<thead>
<tr>
<th>Land use pattern</th>
<th>LCA Pattern</th>
<th>Predetermined Pattern</th>
<th>MCA Pattern</th>
<th>HCA-cattle Pattern</th>
<th>HCA-coffee Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster centers:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% plot in forest</td>
<td>72.0</td>
<td>19.0</td>
<td>28.3</td>
<td>6.0</td>
<td>11.4</td>
</tr>
<tr>
<td>% plot in food</td>
<td>3.0</td>
<td>25.0</td>
<td>10.2</td>
<td>4.0</td>
<td>11.0</td>
</tr>
<tr>
<td>% plot in coffee</td>
<td>13.0</td>
<td>27.0</td>
<td>23.2</td>
<td>12.0</td>
<td>67.8</td>
</tr>
<tr>
<td>% plot in pasture/fallow</td>
<td>12.0</td>
<td>29.0</td>
<td>38.3</td>
<td>78.0</td>
<td>9.8</td>
</tr>
<tr>
<td>Totals</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Median number of cows owned</td>
<td>3</td>
<td>2</td>
<td>8</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>No. and % of all households in cluster</td>
<td>245</td>
<td>12</td>
<td>97</td>
<td>34</td>
<td>13</td>
</tr>
<tr>
<td>Average distance of individual households from cluster centers (sd)</td>
<td>15.9</td>
<td>54.9</td>
<td>24.2</td>
<td>16.6</td>
<td>27.3</td>
</tr>
<tr>
<td>(7.8)</td>
<td>(20.1)</td>
<td>(8.5)</td>
<td>(8.9)</td>
<td>(16.2)</td>
<td></td>
</tr>
</tbody>
</table>

**Source:** Marquette 1988, table 2.

a. LCA = low-cleared-area pattern.
b. MCA = medium-cleared-area pattern.
c. HCA = high-cleared-area pattern.
would expect the longest settled group to have more households with high-cleared-area patterns and fewer with low-cleared-area patterns.

As table 9.5 indicates, an additional predetermined pattern was identified among twelve of the recently settled households. Invariably these households had purchased their plot from other settlers, and most of their plots likely bear more the imprint of the previous occupant’s land use activity rather than that of the current household. For example, most of their plots have on average larger cultivated and pasture areas (25 percent or more of the plot) but few cattle (two head). This group points to the important recognition that as land turnover increases on the frontier, the

Fig. 9.1. Land use patterns of sample households
The type of cluster analysis undertaken here will become increasingly complicated, because land use patterns on a plot at any given moment in time will reflect the history of several occupants. The predetermined group represents an important subset but is excluded from the analysis here due to the complexity it represents. Subsequent discussion, therefore, focuses on those households (n = 389) that reflect the low-, medium-, or high-cleared-area patterns. Because this majority of households did not purchase their plot from other settlers, the confounding effects of previous owners are assumed to be minimal, and their land use patterns are interpreted as a result of the activity of the current household.

Figures 9.3 to 9.6 draw on the information provided in Table 9.5 to further illustrate the relative proportions of land use activity that characterize each of the four main patterns identified. As Figure 9.3 illustrates, the most prevalent low-cleared-area pattern is based on a polyculture farming strategy involving annual and perennial crop growing and pasture for small-scale cattle raising. The median number of cattle owned is small (under five) (Table 9.5). Notably, most of the plot (50 percent or more) remains in forest. This pattern thus has the most limited impact on forest resources, since most of the plot remains uncleared. Table 9.6 summarizes the key land use, duration of settlement, and labor and other
characteristics associated with the four land use patterns identified as well as some potential policy consequences and responses. As table 9.6 indicates, the low-cleared-area pattern is associated with limited adult male household labor, the use of some external labor, and lower average income.

As figure 9.4 indicates, the medium-cleared-area pattern (reflected by 34 percent of households at longer duration and 23 percent of households at longest duration of settlement) still involves polyculture activity and mixed farming with cattle raising, but on a somewhat larger scale and thus with more clearing of the plot (20 to 50 percent of plot on average remains in forest). As figures 9.5 and 9.6 show, the high-cleared-area cattle and coffee patterns (reflected by 11.3 percent and 4.8 percent of households at longer duration and 9.2 percent and 3.6 percent at longest duration of settlement, respectively) reflect the largest cleared areas (less than 20 percent of plot remains in forest) and specialization in cattle raising or coffee growing. For households reflecting the high-cleared-area cattle pattern, the number of cattle is at herd level (greater than 15 head) (table 9.5). As

![Fig. 9.3. Mean percentage plot in different land uses by duration of settlement group for low-cleared-area-pattern households (n = 245)](image-url)
Table 9.6. Characteristics of settler land use patterns identified through cluster analysis (n = 389)

<table>
<thead>
<tr>
<th></th>
<th>Low-Cleared-Area Pattern (63.0% of all households)</th>
<th>Medium-Cleared-Area Pattern (25.0% of all households)</th>
<th>High-Cleared-Area Cattle (8.4% of all households)</th>
<th>High-Cleared-Area Coffee (3.0% of all households)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Land use</strong></td>
<td>• smaller scale mixed agricultural production (coffee and food)</td>
<td>• larger scale mixed agricultural production (coffee and food)</td>
<td>• primarily cattle raising (15+ head)</td>
<td>• primarily coffee growing</td>
</tr>
<tr>
<td></td>
<td>• small scale cattle raising (&lt; 5 head)</td>
<td>• greater cattle raising (5–10 head)</td>
<td>• smaller scale mixed cattle raising</td>
<td>• larger cattle raising (&lt; 5 head)</td>
</tr>
<tr>
<td><strong>Duration of settlement</strong></td>
<td>• most prevalent</td>
<td>• major alternative</td>
<td>• less common alternative</td>
<td>• least common alternative</td>
</tr>
<tr>
<td></td>
<td>• major alternative</td>
<td>• emerges only after 4+ years of settlement</td>
<td>• emerges only after 4+ years of settlement</td>
<td>• emerges only after 4+ years of settlement</td>
</tr>
<tr>
<td></td>
<td>• older cohorts may clear more</td>
<td>• older cohorts may clear more</td>
<td>• older cohorts may clear more</td>
<td>• older cohorts may clear more</td>
</tr>
<tr>
<td><strong>Labor</strong></td>
<td>• fewer household workers</td>
<td>• more household workers</td>
<td>• more household workers</td>
<td>• more household workers</td>
</tr>
<tr>
<td></td>
<td>• high participation by adult men</td>
<td>• high participation by adult men</td>
<td>• highest participation by adult men</td>
<td>• high participation by adult men</td>
</tr>
<tr>
<td></td>
<td>• low participation by women and children</td>
<td>• highest participation by women and children</td>
<td>• lowest participation by adult men, women, and children</td>
<td>• low participation by women and children</td>
</tr>
<tr>
<td></td>
<td>• less hired labor</td>
<td>• more hired labor</td>
<td>• more hired labor</td>
<td>• more hired labor</td>
</tr>
<tr>
<td><strong>Household Characteristics</strong></td>
<td>• smaller household size</td>
<td>• larger household size</td>
<td>• larger household size</td>
<td>• larger household size</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• household head more likely from coast</td>
<td>• smaller plot size</td>
<td>• smaller plot size</td>
</tr>
<tr>
<td>Natural Resource and Ecological Setting</td>
<td>Institutional and Infrastructural</td>
<td>Consequences</td>
<td>Policy responses</td>
<td></td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>----------------------------------</td>
<td>--------------</td>
<td>-----------------</td>
<td></td>
</tr>
<tr>
<td>* poorer quality natural resource base</td>
<td>* closer to roads and markets</td>
<td>* smaller cleared areas</td>
<td>* reinforce prevalence by making more profitable</td>
<td></td>
</tr>
<tr>
<td></td>
<td>* closer to roads and markets</td>
<td>* larger cleared areas</td>
<td>* reinforce coffee production to reduce clearing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>* better quality natural resource base</td>
<td>* larger cleared areas</td>
<td>* efforts to reduce labor burdens</td>
<td></td>
</tr>
<tr>
<td></td>
<td>* closer to roads and markets</td>
<td>* larger cleared areas</td>
<td>* off-farm employment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>* better quality natural resource base</td>
<td>* larger cleared areas</td>
<td>* reinforce coffee production to reduce clearing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>* closer to roads and markets</td>
<td>* larger cleared areas</td>
<td>* efforts to reduce labor burdens</td>
<td></td>
</tr>
<tr>
<td></td>
<td>* better quality natural resource base</td>
<td>* larger cleared areas</td>
<td>* efforts to reduce labor burdens</td>
<td></td>
</tr>
<tr>
<td></td>
<td>* closer to roads and markets</td>
<td>* larger cleared areas</td>
<td>* encourage conversion of cleared areas rather than new clearing to expand agricultural or pastoral activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>* better quality natural resource base</td>
<td>* larger cleared areas</td>
<td>* efforts to reduce labor burdens</td>
<td></td>
</tr>
<tr>
<td></td>
<td>* closer to roads and markets</td>
<td>* larger cleared areas</td>
<td>* encourage conversion of cleared areas rather than new clearing to expand agricultural or pastoral activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>* better quality natural resource base</td>
<td>* larger cleared areas</td>
<td>* efforts to reduce labor burdens</td>
<td></td>
</tr>
<tr>
<td></td>
<td>* closer to roads and markets</td>
<td>* larger cleared areas</td>
<td>* encourage conversion of cleared areas rather than new clearing to expand agricultural or pastoral activity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>* better quality natural resource base</td>
<td>* larger cleared areas</td>
<td>* efforts to reduce labor burdens</td>
<td></td>
</tr>
</tbody>
</table>

**Source:** Marquette 1998, table 5.
Table 9.6 indicates, other important characteristics associated with both the medium- and high-cleared-area patterns are greater on-farm labor resources (in terms of household workers and hired labor), larger household size, smaller plot size in the case of coffee specialization, and larger plot size and coastal origins of the heads of household in the case of cattle-raising specialization. Ecological factors associated with combinations involving medium- or high-cleared-area patterns include better soil quality and flatter terrain, as well as greater access to credit, roads, and markets.

The land use combinations identified present several implications in terms of the links between agricultural technology, agricultural productivity, and forest clearing. More productive soils, which may be naturally more prevalent in the region, are not associated with less cultivation or clearing among the settlers but rather with more (the medium- and high-cleared-area patterns). This finding contradicts the assumption that “poor” soils are associated with higher rates of farm deforestation than “good” soils. As such, it challenges the notion that the introduction of

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Fig. 9.4. Mean percentage plot in different land uses by duration of settlement group for medium-cleared-area-pattern households (n = 97)
Fig. 9.5. Mean percentage plot in different land uses by duration of settlement group for high-cleared-area cattle-pattern households (n = 34)

Fig. 9.6. Mean percentage plot in different land uses by duration of settlement group for high-cleared-area coffee-pattern households (n = 13)
agricultural technologies for increasing agricultural productivity on settler farms will be sufficient for reducing forest clearing.

The land use patterns in the study area also suggest that even though technology levels are low and agricultural technologies for increasing land or labor productivity are generally not available to the average farmer, this situation may not lead inevitably to land extensification (that is, constant clearing for agriculture or cattle raising). Most of the study settlers regardless of duration of settlement reflect a land use strategy centering on coffee production, which may minimize forest clearing. Indeed, their cropping patterns even reflect the use of low-technology intensification practices such as intercropping.

The question arises as to how coffee production may promote less extensive production systems despite low technology levels or agricultural inputs. At the same time, some households at later duration of settlement do reflect more extensive land use combinations with a minority even specializing in cattle raising (or coffee production) and clearing most of their plot. The question also arises as to how this minority of households may differ from the majority and what implications their situation may have for the links between agricultural technology, productivity, and forest clearing. To explore these questions we consider in more detail the role of coffee and cattle raising in settler production strategies.

The Role of Coffee

Detailed analysis of income among the study settlers (Murphy et al. 1997) indicates that even though cattle was the largest source of income for the richest households in the sample, coffee was the most important source of income overall. At first glance, coffee growing represents a surprising economic and productive cornerstone for settler production strategies in the Ecuadorian Amazon. In the labor-scarce environment of the frontier, household coffee production may require much higher labor inputs at all stages in terms of the clearing, soil preparation, planting, weeding, and harvesting. Moreover, given the soil characteristics of the northeastern Ecuadorian Amazon, labor requirements for weeding coffee plants may be greater there than in other areas of settlement (Estrada et al. 1988)—coffee may place continual and high labor demands on the settler household’s limited labor force. Coffee trees also take several years to mature, requiring a four- to five-year waiting period after planting before a major crop is harvested. Coffee therefore reflects a long-term investment that
does not offer the immediate returns the cash-short frontier households may demand.

Offsetting the drawbacks of coffee growing, however, there is evidence that there may be agroecological advantages to growing coffee in the Amazon as opposed to other cash or food crops. Many of the cash crops (rice and sugarcane) as well as annual food crops (grains, beans, vegetables) traditionally grown in the settlers’ areas of origin are not suited to Amazon ecology and generally low-input situation. The *robusta* varieties of coffee that prevail among settlers, however, may do quite well in the region’s soil and low-input (limited fertilizer) conditions (Estrada et al. 1988). There is also some indication that coffee may be more resistant to disease and have a longer productive lifespan in the Amazon than other tree crops such as cocoa. This may at least partly explain the preference for coffee over cocoa as a cash crop among settlers in the region.

Coffee may also offer certain economic advantages over other cash crop options. Settlers start with limited economic resources, so the most logical choices to begin capital formation in the frontier may be items produced with limited initial investment, a ready market, and low bulk to allow shipment from remote areas. Coffee production fulfils these criteria. Coffee may also better stand up to the precariousness of transport in the region than do other food or fruit tree crops. Coffee has a generally higher price and better ratio of price to transport costs than other food and cash crops in the northeastern Ecuadorian Amazon (Barral 1987, 103; Estrada et al. 1988, 62–63). Conversations with farmers imply that transporting coffee to market consumes only 10 percent of its value, compared to 50 percent for plantains, 19 percent for corn, and 37 percent for rice. An additional economic incentive for coffee growing may be that its long productive cycle increases the value of land more than other cash crops such as cocoa (Gonard et al. 1988).

An important factor to consider with regard to the prevalence of coffee growing in the region is the role of this perennial crop in addressing settlers’ concerns for maximizing security in the high-risk environment of the frontier. Drawing on qualitative data collected from settler farmers on their attitudes towards different crops and expected returns, we can better understand the role of coffee production in settlers’ economic strategies and the importance of farmers’ perceptions of risk in the decision to invest in this perennial crop. Settlers indicate that coffee provides some stability and certainty in terms of labor demands and the allocation of labor, since the growing season in the region is continual and since coffee requires
fairly continual labor inputs throughout the year. Coffee trees indeed take several years to mature, but they bear for a long time thereafter. Settlers therefore perceive that, once planted, an area of coffee trees will yield income for many years. In the words of one settler, “It is hard to lose a crop of coffee; other crops are very risky.” Also, settlers’ perceptions of the long-term security offered by coffee even seem to compensate for the variability of short-term returns from the crop due to its variability in price. Settlers are aware of much variation in harvest, price, and relative profits from coffee production, but are reluctant to question in strictly economic terms the rationality and benefits of their decision to invest in coffee production.

Although calculations about yields and prices are made numerically by farmers, most frequently past yields and prices are assimilated into qualitative judgments about expected returns. The market availability of coffee is obviously important, as there are other crops that cannot be sold at any price in the region (manioc and other roots, for example), but the unpredictability of market prices does not seem to significantly change colonists’ minds about the decision to invest in coffee production. Instead, the “negotiability” of the product is frequently mentioned as a point of favor for the crop (such as the advantage of raising pigs or chickens that can be sold whenever a colonist needs cash), as contrasted with other annual or semiannual crops that only produce money at fixed times once or twice a year. Thus, the decision to grow coffee is clearly part of an active process of weighing its advantages and returns compared to alternative crops in terms of long-term secure income.

Farmers’ perceptions indicate that the decision to commit resources to a plot of coffee is therefore considered very carefully based on the crop’s characteristics (for instance, its comparative advantage in the region) rather than on purely short-term economic returns. The farmer knows he is investing in a long-term income source and makes his calculations accordingly, since he cannot simply replace coffee trees with other crops whenever prevailing market conditions seem more favorable. The fact that coffee prices fluctuate unpredictably from year to year, moreover, may only reinforce the long-term nature of the decision. Thus coffee may form a central part of settler production strategies not necessarily because it offers the most productive short-term use of land for immediate returns but rather because it provides secure and steady returns in the long run.

Of key importance in terms of forest impacts is the fact that the coffee-centered production is associated with the prevalence of a land use combination (low-cleared-area pattern) that may result in less forest clearing or
less extensive land use despite the low technology levels prevalent among farmers in the region. As others have previously suggested (Estrada et al. 1988; Marquette 1998), coffee-centered production may place a limit on cleared areas due to the labor it requires. In the face of restricted household labor and limited access to hired labor, the labor inputs required by coffee production may place a “brake” on the areas that settlers may plant and thus ultimately clear. Given the labor-intensive nature of coffee cultivation, most settler households may have insufficient labor necessary to expand agricultural production beyond a certain point. Other study in the region has estimated that the average settler household of about six persons can feasibly work about 7 hectares of coffee plants, or 14 percent of a 50-hectare plot (Estrada et al. 1988). Our research similarly indicates that most settlers grow a similar proportion of coffee on their plots (7 to 13 percent on average), confirming that some kind of brake may exist on coffee production and ultimately forest clearing (Marquette 1998).

From the perspective of settler welfare, the coffee-based strategy prevalent among settlers may provide secure if not improved incomes for many households. Table 9.7 provides information on the income status of settlers before and after settlement. The poorest households prior to settlement tend to be better off on the frontier, the moderately well and well off mainly the same or better. The rough estimates for median incomes in table 9.6 also indicate that there may be important income variation. Households with the low-cleared-area pattern may do somewhat worse than those with the medium- and in particular the high-cleared-area pattern specializing in cattle. We therefore consider more closely the role of cattle raising among households, which is positively associated with income in the region.

<table>
<thead>
<tr>
<th>Economic status before settlement</th>
<th>Low</th>
<th>Middle</th>
<th>Upper</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>15</td>
<td>92</td>
<td>5</td>
<td>112</td>
</tr>
<tr>
<td>Moderate</td>
<td>23</td>
<td>191</td>
<td>22</td>
<td>236</td>
</tr>
<tr>
<td>Well off</td>
<td>1</td>
<td>56</td>
<td>13</td>
<td>70</td>
</tr>
<tr>
<td>Total</td>
<td>39</td>
<td>339</td>
<td>40</td>
<td>418</td>
</tr>
</tbody>
</table>

*Source: Murphy et al. 1997, table 7.*
The Drive to Raise Cattle

The appeal of cattle raising, which has lower labor requirements than coffee growing, seems a likely option for frontier settlers given their limited labor supplies. Additionally, the uniformly high temperatures of the area, the absence of a dry season, the high average annual rainfall, and the relatively level topography encourage the growth of pasture grasses throughout the year, making the region ideal for cattle raising. The price prospects for beef are also better than for most agricultural crops, including coffee. Beef prices are more stable, and, even when adverse changes occur, cattle do not present the same storage problem as do crops. Without proper storage facilities, which are often beyond the economic means of settlers, coffee beans can deteriorate rapidly, whereas livestock can be retained with limited care and cost. Cattle’s high productivity to labor ratio and generally lower labor demands also offer critical advantages to labor-scarce frontier households.

Cattle may also fulfill multiple objectives within the farmers’ strategy of ensuring the basic elements of their food supply as a source of cash flow. Cattle provide milk, a highly versatile product, which may be consumed or sold for cash. Cattle also provide a convenient means of storing and accumulating wealth, especially in years of low crop prices, and represent a readily marketed, high-value good (Loker 1993). Cattle raising also frequently makes it possible to obtain credit and related technical assistance that would not otherwise be available, since cattle can be used as collateral. Not surprisingly, close to half of all settlers surveyed in the study area indicated that, given the chance, they undoubtedly would switch to some kind of specialized cattle raising to improve their welfare. Pasture is also valued in its own right, independent of cattle ownership, since it provides physical proof of land possession.

Given settler aspirations and the advantages of cattle raising on the frontier, it is important to consider why larger-scale cattle raising is not more prevalent and why it does not seem to release the braking effects that the interaction of labor factors and coffee production may exert on cleared areas. As table 9.6 indicates, the factors that may allow some households to move toward more extensive land uses include more productive baseline agroeconomic conditions on their plots, namely better soils and flatter plots. Those who specialize in large-scale cattle raising (over 15 head) generally have much larger plots than average as well. The estimates in table 9.6 suggest that settlers who do adopt the more extensive land use patterns also have higher average annual incomes (U.S.$1,170 for the
medium-cleared-area pattern and U.S.$2,483 for the high-cleared-area pattern) than the majority who opt for the low-cleared-area strategy (U.S.$658). A much more detailed study of settler income and welfare (Murphy et al. 1997) has demonstrated that areas in pasture, an indicator for involvement in cattle-raising activity, are significantly associated with higher income. This result implies that the economic returns of the more extensive land use patterns involving cattle raising are indeed likely higher. Table 9.8 confirms this positive relationship between income level and percentage of plot in pasture. Households with 21 percent or more of their plot in pasture are likely to fall into the higher income percentiles.

The positive association between a better natural resource base (higher soil quality, flatter and larger plots), more extensive land use patterns including cattle-raising, and higher income among settlers again suggests that having land with higher potential productivity or higher economic returns does not necessarily result in less forest clearing. The higher economic returns gained by households with better resources and with higher incomes from expanded agricultural activity or cattle raising may be reinvested in activities that lead to even more forest clearing or extensive land use, such as the purchasing of more cattle. Households that specialize more in cattle raising on much larger plots than average were also more likely to have access to credit for investment, further suggesting that settler investments built on returns from higher production or credit may be directed towards more extensive land use activities such as cattle raising.

Settlers perceive cattle raising as an ideal form of land use and most indicate an aspiration to shift from coffee cropping to cattle ranching. Some may try to convert their annual and perennial cropping fields to pastures even before sufficient capital has been accumulated to start cattle raising, often leaving them with insufficient land for other crops. No

Table 9.8. Distribution of settler households by income level and proportion of plot in pasture, Ecuadorian Amazon, 1990

<table>
<thead>
<tr>
<th>Income bracket</th>
<th>Percentage of plot in pasture</th>
<th>Total households</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0–10</td>
<td>11–20</td>
</tr>
<tr>
<td>Bottom (lowest) income quartile</td>
<td>66</td>
<td>25</td>
</tr>
<tr>
<td>Third income quartile</td>
<td>60</td>
<td>24</td>
</tr>
<tr>
<td>Second income quartile</td>
<td>57</td>
<td>23</td>
</tr>
<tr>
<td>Highest (top) income quartile</td>
<td>33</td>
<td>21</td>
</tr>
<tr>
<td>Total</td>
<td>216</td>
<td>93</td>
</tr>
</tbody>
</table>

doubt pressure for transition to cattle is driven by frustration with the relatively slower pace of capital accumulation from coffee cultivation, including the high labor and capital investments needed to install and maintain this perennial crop compared with the requirements of cattle. The considerable delay between investment in planting and anticipated returns may also create pressure to move into cattle raising (Pichón 1997b). However, as the high prevalence of the low-cleared-area pattern relative to the medium- and high-cleared-area patterns indicates, few can make this transition. Positive links between a poorer natural resource base (poorer soil quality, hilly or smaller size plots), lower income, lack of access to credit, and less extensive land use are some of the reasons explaining why this transition does not occur more frequently.

**Some Conclusions and Policy Implications**

The discussion above supports the notion that the relationships between agricultural productivity, land use, and land clearing on the Amazon frontier may be more complex than any one existing viewpoint may capture. Even under low technology conditions, most settlers in the northeastern Ecuadorian Amazon have developed a low-cleared-area land use strategy centering on coffee production, which, due to the high labor demands involved, generates less forest clearing regardless of duration of settlement. In the face of restricted household labor and limited access to hired labor, the labor inputs required by coffee production place a “brake” on the areas that settlers clear and plant. However, specialization in cattle raising among a third of the sample households, in contrast to the low-cleared-area land use pattern, is associated with better household welfare (in terms of both higher payoffs for agricultural activity and lower labor burdens) but less forest cover. These more affluent settler households tend to convert more forest than average to pasture for raising cattle, as settlers perceive cattle ranching as the primary avenue to a better life, a view also observed elsewhere in the Amazon frontier. Households with more productive resource bases simply use their higher economic returns to invest in more extensive land use forms such as cattle raising, while those who cannot do the same maintain a shift into cattle-raising as an ideal to strive for.

Another important characteristic of the coffee-based endogenous technology arising among Amazon settlers in Ecuador is that its widespread practice in the region contradicts the assumption that high subjective discount rates and credit constraints preclude poor farmers’ adoption of
technologies that require long-term investments. Despite their risk aversion and credit constraints, the importance of coffee among settlers (as a crop that takes several years to produce) and the extensive adoption of the coffee-centered cultivation system suggest that settlers in the region do exhibit the potential for long-term investments. This behavior is especially critical in a tropical frontier environment, where concern for maintaining productivity in the long term (rather than an exclusive focus on the maximization of output) may be an important factor in reducing need for development of new lands.

Turning to specific policy implications, our analysis suggests that, given the low technology and high risk levels pervasive on the frontier, more emphasis needs to be placed on considering alternative lower technology systems that are evolving among settlers as they employ “tried and true” methods involving stable if not the most productive returns and possibly even less clearing. If lower cleared area on settler plots is presumed to be more desirable and sustainable from a forest conservation standpoint than higher cleared areas, improving settlers’ land use activities may mean reinforcing what most are already doing and what most do to begin with. As has been suggested elsewhere (Boese 1992; Proano 1993), rather than focusing on introducing or developing new technologies for use by settlers, a greater amount of agricultural research might be directed at exploring the potential advantages of improving the existing multicrop systems that settlers may already be using, as evidenced by the perennial and food crop combinations observed in Ecuador.6

It is important to recognize that many new or introduced innovative land use systems have done little to accommodate or address farmer constraints such as labor scarcity, tenure insecurity, lack of alternative sources of off-farm employment, and other factors that have been shown in the literature to more fully account for the inability of settlers to establish sustainable forms of land use on the frontier. New systems are of little use if households lack the labor to implement recommendations, or if tenure insecurity makes investing in land-improving inputs too risky to be practical. Also, even if successful, small-scale experimental systems should not be presumed to be easily expandable to widespread forms of land use in frontier regions. Preoccupation with experimental or model systems reflects a long-standing bias toward technological solutions, which cannot substitute for confronting the need for broader structural and policy changes (Fearnside 1987).

It is important to note, at the same time, that the low-cleared-area coffee-centered land use pattern prevalent among most settlers in the
northeastern Ecuadorian Amazon reflects some serious drawbacks that also need to be addressed. The pattern may have poorer economic returns, put intensive labor demands on households, and subject them to the vagaries of coffee prices and problems of a long-term investment. The current low-cleared-area pattern prevalent among settlers in Ecuador should not be overidealized, since it may be associated also with important and possibly increasing differentials in income and welfare. The range of incomes among the settlers is wide, with total gross household income varying from zero to a maximum of about U.S.$22,000 (Murphy et al. 1997). The richest 5 percent earn more than seven times the median income. This top 5 percent probably possess, in addition to a herd of cattle and other livestock, large wooden houses with cement floors and tin roofs and numerous durable goods (electric appliances, a gun, several horses, chain saw, canoe, or motorized vehicle). Meanwhile a family at the bottom 5 percent of the income ladder may possess no cattle or livestock, live in a bamboo house with an earthen floor, have a couple of benches and a table and few durables beyond hand tools. In between these two extremes of prosperity and poverty, settlers may experience a diverse range of living conditions (Murphy et al. 1997). It is therefore important that, in considering existing land use systems, adverse impacts be carefully evaluated in any future research.

Although it may not be a feasible option for most settlers, their widespread aspirations to engage in more profitable activities such as expanded agricultural activity or cattle raising despite the ecological drawbacks need to be seriously considered as well. From a policy perspective, it is important to identify the factors that may potentially release the brake exerted by the combination of household labor availability and coffee production on cleared areas, allowing settlers to realize their aspirations. Because of the association between household labor supply and more extensive land use systems, changing household demographic characteristics over the household life cycle (particularly increasing household size due either to larger family size or in-migration) may increase the number of household workers, causing further agricultural expansion on existing settler plots.

Also, greater access to hired labor due to increased in-migration or landlessness in the frontier might trigger the same process if hired labor were used to expand rather than merely substitute for the work of household members. Increased availability of labor-saving farm technologies (for example, chain saws and pesticides to reduce weeds and thus weeding needs of coffee fields) might have the same expansive effect on coffee areas
by reducing the necessary human labor requirements. Perhaps the major factor that might release the brake placed on forest clearing by coffee production would be increased access to credit for cattle. If opportunities for cattle ownership were to increase, for example, because of greater access to credit for this purpose, the brake on forest clearing exerted by coffee growing might be removed for an increasing number of households.

As apparent from the above discussion of policy implications, no single intervention in the area of technology offers a simple way to help settlers pursue economic goals beyond purely subsistence while protecting the forest environment. A package of policy changes, infrastructure, incentives, services, and technical assistance is thus necessary. Given that the most ecologically damaging farming systems (extensive agriculture and cattle raising) are precisely those that provide better economic return to settlers, it is likely that promoting the use of low-clearing strategies will need to involve stimulating the profitability of complementary or alternative economic activities that do not depend on additional forest clearing. One way to do this may be to create incentives for integrating more off-farm employment and diversification into nonfarm activities alongside the use of low-cleared-area land use strategies.

An important finding in our previous work is that most settlers participating in off-farm employment activities are improving their material circumstances and effectively diversifying income sources beyond farming, thus alleviating economic pressures to clear large areas of forest to support their families. The income-earning effects and potential for off-farm employment are large. Among households earning any off-farm income, about 60 percent earned at least half of their income from off-farm wages (Murphy et al. 1997). Over time, these more successful and experienced frontier households are expected to accumulate wealth and increase resource productivity through investments in their natural resource base. Nevertheless, in the absence of parallel incentives and disincentives, better access to services and markets is not always a guarantee that farmers will make the required long-term ecologically sustainable capital investments on their plots, since settler households are economically rational and would aim to boost family income any way they can.

There is no easy answer to the problem imposed by the profitability of agricultural expansion that may entail important trade-offs between human welfare and forest conservation. Because settlers’ livelihoods depend highly on the land, concern for their welfare cannot be easily separated from the attempt to find solutions to mitigate deforestation in the Amazon. Future policy needs to be sensitive to the quality of life for settler
households as well as to the well-being of forest resources. Our research in Ecuador suggests that looking at the potential advantages of what most settler households are actually doing is as important in meeting these multiple objectives as exploring the potential impacts of introduced agricultural technologies. This recognition presents a strong argument for building upon endogenous and existing systems that may already encapsulate successful responses and adaptations not only to ecological conditions but also to the wider socioeconomic constraints and political situation of the frontier environment.

Notes

1. Although seldom empirically documented, the extensive literature on the forest conversion process also emphasizes the variability in settler land use strategies that result from differences in land access and tenure, labor availability, local infrastructure, soil quality, and other environmental features of the settled region (see, for example, Henriques 1988; Moran 1989; Ozorio de Almeida 1992; Porro 1998; Schmink and Wood 1984 and 1992; Sydenstricker and Vosti 1993 in Brazil; Pichón 1997b; Rudel 1993; Uquillas 1984 in Ecuador; Aramburu 1984 in Peru; Eastwood 1990; Henkel 1982; Painter 1987; Stearman 1984; Thiele 1995; Weil 1989 in Bolivia; Findley 1988 in the Latin American humid tropics; and Moran 1984a, b; Oberai 1988 in frontier environments in general).

2. The neoclassical agricultural household model suggests that given a set of initial resources—namely land, labor, capital, and technology—the household farm rationally allocates resources to maximize both production and the consumption of total income (both leisure time and consumer goods) (Ellis 1993; Singh et al. 1986).

3. Soils in the study area include brown-black flat volcanic (organic, high fertility) soils (23.7 percent); red-hill (acid, low fertility) soils, which are mainly ultisols (47.5 percent); and black floodplain alluvial (moderately fertile) soils, primarily inceptisols (17.7 percent). Amazonian soils elsewhere are generally more infertile. Nearly 75 percent of the Amazon basin is occupied by acid, infertile soils, classified as oxisols and ultisols. These soils are deep, usually well drained, of red or yellow color, with generally favorable physical properties, but very acidic and deficient in nutrients. In contrast, only 8.4 percent of Amazon soils are said to have no major deficits for crop production (Moran 1981), though other sources suggest a more encouraging picture. According to the World Bank, quoting estimates from RADAMBRASIL, the FAO, and UNESCO, 7.1 percent of the soil is classified as “good,” 44.4 percent “moderately good,” and only 28.5 percent as “unsuitable” for agriculture (World Bank 1992). For more details on the controversial question of Amazon soil quality, see Sánchez et al. (1982) and Herrera et al. (1978).

4. Slash-and-mulch involves several stages of activity. First there is the socola
(clearing) of undergrowth such as vines, bushes, and small trees, which may be started at any time. Then seeds and cuttings are planted under the shade of larger trees within five to fifteen days after the *socola*. The planting is known as the *plantio*. When sprouts appear, the remaining vegetation, excepting economically useful trees, is turned down (*tumba*). In the process of *tumba*, some percentage of the seedlings are covered or crushed by the felled vegetation, but sufficient plantings survive to provide subsequent harvests. The felled vegetation is not burned, but instead serves as mulch for the cultivated plants through its decomposition and release of minerals. After two months the trunks and larger branches are cut into pieces for better contact with the ground and more rapid decay; two months later the process is repeated. Depending on the intensity of weed growth, there may be one or two *chapeos*, or weedings, before the harvest of annuals. Thereafter certain cleanings (*limpias*) take place on a continuing basis, two a year for plantains and one or two per crop for corn, which often yields two harvests per year.

5. Preconceived notions about land use that focus on only one or two dimensions (for example, area deforested or cleared area used as pasture) may lead to an inadequate understanding of the amalgam of land use choices available to farmers. More land may be put into pasture, for example, by converting land from its use in perennial crops, annual crops, or forest. These conversions have different ramifications for the settler family’s food security, its production and income, and the sustainability of its agricultural resource base.

6. Perennial crops may present a good alternative in the Amazon since they may be less susceptible to pest problems, may maintain yields over a longer period of time, and may be more protective against erosion and soil exhaustion than annual and semiannual farm crops (World Bank 1992). However, even though it may be physically possible and perhaps advantageous to grow perennial crops in the Amazon, it has been more difficult to grow them profitably. The outlook for coffee in the northeastern Ecuadorian region, for example, is uncertain because cultivation is conducted presently with little technical guidance and because the price prospects for the crop are generally poor. A major challenge for policymakers as well as agricultural researchers is to use existing systems as a basis for developing improved land use options that are not only more agriculturally sustainable but also feasible in the context of the restricted commodity markets of the frontier.

References


Part III

Fires, Pastures, and Deforestation
Recognized as a historic if infrequent element of the Amazonian disturbance regime (Meggers 1994; Saldarriaga and West 1986; Sanford et al. 1985; Turcq et al. 1998), fire as it currently exists in the Amazon is far more frequent and anthropogenic in nature (Cochrane and Schulze 1999; Holdsworth and Uhl 1997; Kauffman 1991; Uhl and Buschbacher 1985; Uhl et al. 1988). Annual composite satellite images (AVHRR [Advanced Very High Resolution Radiometers], GOES [Geostationary Operational Environmental Satellite]) of fire incidence in the Amazon basin show fires clustering around roads and other areas of human habitation (Prins and Menzel 1996; Setzer and Pereira 1991). Although deforestation has been the primary focus of land use and carbon release studies (Fearnside 1997; Hall and Uhlig 1991; Houghton 1997), selective logging (Uhl et al. 1991; Veríssimo et al. 1992) and fire (Cochrane and Schulze 1999) substantially reduce forest biomass as well (Nepstad et al. 1999). Selectively logged (Uhl et al. 1988) and undisturbed forests (Nepstad et al. 1995) that burn generally lose less than 10 percent of their living biomass, but recurrent fires in previously burned forests can kill 80 percent or more of the living biomass (Cochrane and Schulze 1999). The fire dynamic, as it currently exists in Amazonian forests, must be understood in order to ascertain whether these fires will become an important source of atmospheric carbon and land cover change.

Methods

The fire dynamic in forests of the Brazilian Amazon was investigated through a combination of field studies, landowner interviews, and multi-
temporal analyses of satellite imagery. Field studies were concentrated in the Tailândia region (map 10.1). Ten 0.5-hectare plots (eight fire-impacted and two control), spread over 100 square kilometers, were established in 1996 to study fire impacts on forest structure, biomass, and species composition (Cochrane and Schulze 1999). These same plots were re-censused after the dry season of 1997, during which eight of the plots burned to varying degrees. Fire recurrence, tree mortality, and biomass combustion levels within forests of different burn histories were quantified. In addition, combustible fuel mass was assessed using the planar intersect method (Brown 1974) as adapted by Uhl and Kauffman (1990). Fuel load quantities, divided into standard time-lag size classes (1-h, 10-h, 100-h, and 1000-h for <0.6, >0.6–2.5, >2.5–7.6, and >7.6 centimeter diameter, respectively), fuel height, and leaf litter depth were measured along randomly directed 10-meter transects at three points within each
plot (125, 250, and 375 meters). Additional fuel load measurements were made in the vicinity of all observed fires.

Fire characteristics were quantified in four forest types (unburned, once-burned, twice-burned, more than two previous burns) during a fire complex that occurred during December 1997. Direct observations of fires were made at widely scattered locations within a 150-square-kilometer area south of Tailândia. For each observed fire, flame heights and depths were measured or estimated. At each observation site (n = 44), roughly 10 meters of fireline was observed for several minutes (average observation time, 7.4 minutes), and the average minimum and maximum of each flame characteristic were recorded. Flareups of short duration or small area were noted separately. The time the fireline took to move across a known distance was used to calculate the rate of spread and combined with flame depth data to calculate the average range of flame residence times at a point. Flame height was used as a conservative estimate of total flame length for the calculation of fireline intensity (Agee 1993), as there were minimal wind and slope (Rothermel 1983).

A linear mixture modeling methodology (Cochrane and Souza 1998) was used to separate forest from nonforest and to classify burned forests in a series of images for 1,280 square kilometers near Paragominas (1984, 1991, 1993, 1995) and 2,640 square kilometers around Tailândia (1984, 1991, 1993, 1995, 1997). Specifically, bands 1–5 and 7 of several Landsat Thematic Mapper (TM) images with sensor radiometric corrections were acquired from INPE (Brazilian Space Agency). Nearest neighbor resampling was used to register the subsets of the images used in this research. The images were geometrically corrected using differentially corrected Global Positioning System (GPS) points stratified throughout the imaged region. Atmospheric effects were ignored since no atmospheric calibration data are available for this region.

Spectral endmembers were extracted from the image and selected using principal component axes 1 and 2 (Smith et al. 1985), corresponding to 98 percent of the multispectral data variance. A three-endmember mixing model was then run to separate the proportion of landscape materials (vegetation and soil) and illumination variability (shade) found within the image pixels in the study area. The mixing model was solved by applying a least-square estimator (Shimabukuro and Smith 1991) with an unconstrained solution (Schanzer 1993).

Previously deforested areas were then masked from the imagery (Cochrane and Souza 1998), and a second mixing model was created using a
band 4/band 5 scatter plot of the forest-masked image to select forest endmembers (vegetation, shade, and nonphotosynthetic vegetation [NPV] [Roberts, Adams, and Smith 1993]) and unmix the forested pixels. The individual imagery from each year was then classified to separate unburned forest from recently (one to two years) burned forest using the derived NPV fraction image.

Multitemporal analysis of satellite imagery (Landsat TM) was used to extend our study of fire in space and time in the Tailândia and Paragominas regions (map 10.1). Both regions have similar forests, pronounced dry seasons, and average annual rainfall of 1,500 to 1,800 millimeters (Silva 1996). The forest location and area affected by fire were determined for the images of each region. Cross tabulation of the classified images provided a history of deforestation, second growth, and forest burning throughout the study regions. The fire rotation, which is the amount of time required to burn an area equivalent to the entire forested area (Van Wagner 1978), was calculated for each region.

Imagery-derived results were compared with data from five regions along a 2,900-kilometer transect through the states of Pará, Mato Grosso, Rondônia, and Acre (map 10.1). A total of 202 randomly chosen landowners were asked to mark deforested and burned forest areas on TM image prints for 1994 and 1995 (map 10.1; table 10.1). The accuracy of these landholder maps was tested by comparing them, in one study region, with a classified 1995 Landsat TM image (Nepstad et al. 1999).

Much of the deforestation and hence fire in the Brazilian Amazon occurs in an arc along the eastern and southern edges of the forest, the so-called “arc of deforestation.” In order to be able to calculate estimates of the forest area potentially threatened by fire, we used a 260-kilometer-wide swath to encompass this area of active deforestation (map 10.1). Forest cover remaining in this area as of 1996 (300,000 square kilometers) was estimated by using Stone and colleagues’ (1994) forest cover map as a base and then adjusting the forested area for each state through published deforestation rates (INPE 1992, 1996, 1997). Since the necessary fire data exist for only Pará and Mato Grosso, the fire rotation analysis was limited to the area intersecting these states (475,000 square kilometers). Biomass contained in the remaining forests was estimated using Fearnside’s (1997) data on average forest biomass by state. Potential standing biomass for recurrently fire-visited forests was estimated using projected regrowth values for deforested areas (Fearnside 1997).
Table 10.1. Deforestation and forest burning in several study regions determined using two different methodologies

<table>
<thead>
<tr>
<th>Study Region</th>
<th>Imagery Analyses(^a)</th>
<th>Interview-Based Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tailândia</td>
<td>Paragominas</td>
</tr>
<tr>
<td><strong>Area (km(^2))</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1984</td>
<td>2,640</td>
<td>1,281</td>
</tr>
<tr>
<td>1991</td>
<td>2,640</td>
<td>1,281</td>
</tr>
<tr>
<td>1993</td>
<td>2,640</td>
<td>1,281</td>
</tr>
<tr>
<td>1994</td>
<td>2,640</td>
<td>1,281</td>
</tr>
<tr>
<td>1995</td>
<td>2,640</td>
<td>1,281</td>
</tr>
<tr>
<td>1997</td>
<td>2,640</td>
<td>1,281</td>
</tr>
<tr>
<td><strong>Total % Deforested</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1984</td>
<td>9.8</td>
<td>38.1</td>
</tr>
<tr>
<td>1991</td>
<td>27.4</td>
<td>48.7</td>
</tr>
<tr>
<td>1993</td>
<td>32.9</td>
<td>55.0</td>
</tr>
<tr>
<td>1994</td>
<td>44.3</td>
<td>64.0</td>
</tr>
<tr>
<td>1995</td>
<td>40.9</td>
<td>64.0</td>
</tr>
<tr>
<td><strong>Average Annual Rate</strong></td>
<td>2.3</td>
<td>1.8</td>
</tr>
<tr>
<td><strong>Annual Percentage of Forest Burning</strong>(^c)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1984</td>
<td>9.6</td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>1.0</td>
<td>4.7</td>
</tr>
<tr>
<td>1993</td>
<td>23.1</td>
<td>45.9</td>
</tr>
<tr>
<td>1994</td>
<td>0.4</td>
<td>5.6</td>
</tr>
<tr>
<td>1995</td>
<td>2.9</td>
<td>1.3</td>
</tr>
<tr>
<td>1997</td>
<td>31.2</td>
<td></td>
</tr>
<tr>
<td><strong>Fire Rotation</strong>(^f)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Years</td>
<td>7–14</td>
<td>7–13</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Information based on multitemporal analyses of Landsat TM imagery.
\(^b\) Information based on 1996 landowner interview study of fire and deforestation. Comparison of these data with satellite imagery has shown them to be very conservative with regard to fire and deforestation (Nepstad et al. 1999). Ariquemes experienced fire but fire rotations weren’t calculated due to the study region’s having less than 500 km\(^2\) of remaining forest area (Fahnestock and Agee 1983). Rio Branco had no recorded occurrence of accidental forest fire and is apparently wetter and less seasonal.
\(^c\) Additional area of Paragominas County, 51% overlap with the imagery study region.
\(^d\) Numbers give the percentage of the study region deforested for the given year. For the imagery analyzed areas, the long-term deforestation rate is the average annual percentage cleared since incorporation (Tailândia, 1978 and Paragominas, 1960).
\(^e\) Numbers show the percentage of the standing forest that burned in a given year. Cochrane and Souza Jr.’s (1998) technique detects fires greater than one year old but less than two. 1983, 1992, and 1997 were El Niño years and the resultant fires were detected in the 1984, 1993, and 1997 images.
\(^f\) Time necessary to burn an area equal to the total forested area based on the average annual percentage of forest burning. Tailândia and Paragominas fire rotations are presented as ranges since the methodology used detects fire of 1 to 2 years of age.
\(^g\) Interview data were systematically underestimated in Paragominas; the number in parentheses shows fire rotation if this underestimate is corrected.
Results and Discussion

Initial forest fires generally move slowly along the ground (table 10.2) and are similar to a prescribed burn (less than 50 kilowatts per meter [kWm\(^{-1}\)]) in intensity (Cochrane and Schulze 1998). These fires consume little besides the dry leaf litter, but due to the characteristically thin tree bark (7.3±3.7 millimeters [mm] for greater than or equal to 20-centimeter [cm] diameter at breast height [dbh] [Uhl and Kauffman 1990]) still kill roughly 95 percent of the contacted stems greater than 1 cm dbh. Large thick-barked trees survive. After the fire, a rain of combustible fuels in all sizes falls from the standing dead trees (table 10.2; Cochrane et al. 1999). Fire damage and wind throw in these thinned forests continue to cause mortality for at least two years (Holdsworth and Uhl 1997). Mortality of trees (greater than or equal to 10 cm dbh) in previously unburned forests that burned in 1995 was 38 percent one year after the fire and 68 percent at the end of the second year. Annual mortality in unburned forest during this time period was lower than 1 percent (Cochrane et al. 1999). Fuel levels rise substantially, while the open canopy (50 to 70 percent cover) allows greater solar heating and air movement to dry out the forest fuels. Previously burned forests become susceptible to fire during common dry season weather conditions (Cochrane and Schulze 1999).

In 1997, previously burned forests were much more likely to burn than unburned forest (table 10.2). Burned forests are often adjacent to fire-maintained pasture and agricultural plots and therefore frequently exposed to sources of ignition. Second fires are faster moving and much more intense (table 10.2). We estimate heat release (Rothermel 1983) of less than 7,500 kWm\(^{-2}\) in first burns and 75,000 kWm\(^{-2}\) or more in subsequent burns. Due to the increased flame depth, the residence time increases despite faster rates of spread, resulting in greater tree mortality. Large trees have little survival advantage during these more intense fires.

Fire-induced tree mortality can be modeled as a function of bark thickness and fire residence time (Peterson and Ryan 1986). For the observed fire characteristics and bark thickness distribution (Uhl and Kauffman 1990), no more than 45 percent of trees over 20 cm dbh are susceptible to fire-induced mortality in the initial fires. However, in recurrent fires, up to 98 percent of these same trees become susceptible to fire-induced mortality (Cochrane et al. 1999).

The impacts of recurrent fires are much worse than initial fires (Cochrane and Schulze 1998). Higher mortality results in a very open canopy (10 to 40 percent cover), large inputs of combustible fuels, and faster
Table 10.2. Forest, fuel, and fire characteristics for four different forest types within the Tailândia study region

<table>
<thead>
<tr>
<th>Forest Type</th>
<th>Unburned</th>
<th>First Burn</th>
<th>Second Burn</th>
<th>Third Burn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Canopy Cover (%)</td>
<td>87.1</td>
<td>61.0</td>
<td>33.9</td>
<td>13.8</td>
</tr>
<tr>
<td>Standing Biomass (Cochrane and Schulze 1999)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Live (Mg·ha⁻¹)</td>
<td>242</td>
<td>220</td>
<td>129</td>
<td>47</td>
</tr>
<tr>
<td>Dead (Mg·ha⁻¹)</td>
<td>53</td>
<td>50</td>
<td>71</td>
<td>116</td>
</tr>
<tr>
<td>Total (Mg·ha⁻¹)</td>
<td>295</td>
<td>270</td>
<td>200</td>
<td>163</td>
</tr>
<tr>
<td>Fuel Load</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-hr (Mg·ha⁻¹)</td>
<td>1.3</td>
<td>3.3ᵃ</td>
<td>6.6ᵈ</td>
<td></td>
</tr>
<tr>
<td>10-hr (Mg·ha⁻¹)</td>
<td>5.2</td>
<td>11.8ᵃ</td>
<td>16.9ᵈ</td>
<td></td>
</tr>
<tr>
<td>100-hr (Mg·ha⁻¹)</td>
<td>16.8</td>
<td>36.8ᵃ</td>
<td>40.1ᶜ</td>
<td></td>
</tr>
<tr>
<td>1000-hr (Mg·ha⁻¹)</td>
<td>15.5</td>
<td>124.9</td>
<td>106.1ᵈ</td>
<td></td>
</tr>
<tr>
<td>Fuel Height (cm)</td>
<td>15.8</td>
<td>47.8ᵃ</td>
<td>60.2ᵈ</td>
<td></td>
</tr>
<tr>
<td>Leaf Litter Depth (cm)</td>
<td>2.94</td>
<td>2.55</td>
<td>3.15ᵃ</td>
<td></td>
</tr>
<tr>
<td>Fire Characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flame heights (m)</td>
<td>—</td>
<td>0.13–0.46</td>
<td>0.32–0.88ᵃ</td>
<td>0.46ᵈ–1.33ᵈ</td>
</tr>
<tr>
<td>Flame depths (m)</td>
<td>—</td>
<td>0.08–0.20</td>
<td>0.18–0.49</td>
<td>0.29ᵈ–0.99ᵈ</td>
</tr>
<tr>
<td>Rate of spread (m·min⁻¹)</td>
<td>—</td>
<td>0.25</td>
<td>0.33</td>
<td>0.52ᵈ</td>
</tr>
<tr>
<td>Residence time (min)</td>
<td>—</td>
<td>0.32–0.80</td>
<td>0.49ᵇ–1.39ᵃ</td>
<td>0.66ᵈ–2.27ᵈ</td>
</tr>
<tr>
<td>Fireline intensity (kW·m⁻¹)ᵉ</td>
<td>—</td>
<td>4.4–55.0</td>
<td>82.5–412.2ᵃ</td>
<td>94.2ᵈ–728.3ᵈ</td>
</tr>
<tr>
<td>Height of crown scorch (m)ᶠ</td>
<td>—</td>
<td>0.3–1.9</td>
<td>2.4–8.2ᵃ</td>
<td>4.6ᵈ–17.2ᵈ</td>
</tr>
<tr>
<td>Distribution of 1997 Fire⁸</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area burned (ha)</td>
<td>30964</td>
<td>33441</td>
<td>3196</td>
<td>30</td>
</tr>
<tr>
<td>Percentage of existing forest type that burned</td>
<td>22.7%</td>
<td>39.2%</td>
<td>47.8%</td>
<td>68.8%</td>
</tr>
</tbody>
</table>

a. Indicate significant difference from unburned forest at ≤0.1 (Mann-Whitney test).
b. Indicate significant difference from unburned forest at ≤0.05 (Mann-Whitney test).
c. Indicate significant difference from unburned forest at ≤0.01 (Mann-Whitney test).
d. Indicate significant difference from unburned forest at ≤0.001 (Mann-Whitney test).
e. Fireline intensity calculated as \( I = 258 F L^{2.17} \) with flame height used to estimate flame length (FL) (Agee 1993).
f. Height of crown scorch calculated as \( h_s = 4.46 P^{2/3} (60 – T) \); \( T \) = ambient temperature (Van Wagner 1973).
g. Only covers fires in Tailândia occurring before the October 1997 TM image. Additional fires burned large areas of both previously unburned and burned forests within the study region between December 4 and 10. Percentage burned signifies the amount of the remaining unburned, previously once-burned, twice-burned and thrice-burned forests that burned (e.g., 39.2% of all forests already once-burned, burned again in 1997).
drying. During the 1997 fires, substantial amounts of carbon were released to the atmosphere, with combustion reducing onsite biomass by approximately 15, 90, and 140 metric tons per hectare (Mgha⁻¹) in first, second, and recurrent burns, respectively (Cochrane et al. 1999). Invading grasses and weedy vines add highly combustible live fuels to the already fuel-laden forest. Fires in highly degraded areas are significantly more severe in all respects (flame height, intensity, depth, residence time, and rate of spread). Recurrent fires have the potential to eradicate trees from the landscape. Field studies of forests in 1996 revealed plots with as few as eighteen live trees per hectare (302 standing dead per hectare) (Cochrane and Schulze 1999). The fires of 1997 had left only three live trees, threatened by an oncoming fire, when recensused.

Areas that are minimally forested due to recurrence of fire are likely to appear deforested in satellite (such as Landsat TM, SPOT, AVHRR) imagery analyses. Visual inspection of paper Landsat TM images, as used to monitor deforestation in the Brazilian Amazon (Skole and Tucker 1993; INPE 1997), is also expected to misclassify many burned forests as deforested areas. In this study, cross-tabulation showed that, in comparison to unburned forest, once-burned forests were twice as likely to be classified as having been deforested, while twice- and thrice-burned forests were eleven and fifteen times as likely to appear deforested.

We conducted a detailed study of deforestation in burned forests. Imagery of Paragominas for the 1993 to 1995 period was used to test whether deforestation of forests that had burned in 1992 was intentional (for example, slash-and-burn for cattle pasture and crops) or accidentally induced by fire (that is, extremely thinned). Areas of forest that burned in 1992 that became either new slash or pasture were classified as intentional deforestation. These areas were generally adjacent to existing forest edges and had regular shapes. Forests that became “degraded pasture” (in other words, second growth), an unlikely transition in just two years, were classified as accidental fire-induced deforestation. Fire-induced deforestation was generally irregular in shape and often occurred far from forest edges (fig. 10.1).

In the Paragominas region we estimate that accidental fire-induced deforestation increased deforestation estimates by 129 percent between 1993 and 1995. Correcting the deforestation estimate for this factor yields an intentional (slash-and-burn) deforestation rate of 1.7 percent for 1993–95, which is in accord with the average (1.8 percent) deforestation rate prior to the El Niño–induced fires of 1992–93 (table 10.1). This surprising result implies that the basinwide jump in estimated deforestation
rates from 1993–95 (INPE 1996, 1997) may have occurred largely due to the widespread forest fires of 1992 and 1993.

Second-growth forest was insignificant in the relatively new frontier region of Tailândia, but averaged 0.5 percent per year in the older Paragominas region. However, this regeneration rate is misleading since the majority of it was either deforested or accidentally destroyed by fire within three years of its appearance in the imagery. In the eleven-year period encompassed by this study, 91 percent of the new growth was either deforested or burned.

There have been no known analyses of the natural fire rotation in lowland tropical rainforests, but the limited data from charcoal studies (Meggars 1994; Saldarriaga and West 1986; Sanford et al. 1985; Turcq et al. 1998) imply a fire rotation of hundreds or thousands of years. Fire-return intervals of less than ninety years can eliminate rainforest tree species, while intervals of less than twenty years may eradicate trees entirely (Jackson 1968). Based on our time series analysis of imagery, we calculate that Paragominas’s and Tailândia’s primary and secondary forests are currently experiencing fire rotations of between seven and fourteen years. Previously burned forests are even more prone to burning, with calculated fire rotations of less than five years.
To determine if the observed fire dynamic is widespread across the Brazilian Amazon, we used landowner interview data from five regions along a 2,900-kilometer transect through the states of Pará, Mato Grosso, Rondônia, and Acre to estimate regional fire rotations (map 10.1). To assess the accuracy of the interviews, a comparison of methodologies was made in Paragominas. The burns detected in the imagery were compared with data from landowner questionnaires (n = 75) that described fire history from 1982 to 1995 (Nepstad et al. 1999). Questionnaire data included 51.4 percent of the imagery study region and showed 100 percent detection of reported fires that occurred within one year of the image date. Comparisons of the area reported burned by landowners with data from the imagery classifications showed that area burned was systematically underreported by an average of 43 percent (p < 0.001; sign test), and only small fires (less than 50 hectares) were overestimated by landowners. Calculated fire rotations for the regions (table 10.1) indicate that Acre may be wetter, with no reported forest fires, but the entire region between Mato Grosso and northeastern Pará may be experiencing the same fire regime. The Rondônia site experienced fire in 1994 but not in 1995; however, the forested area is too small to calculate a meaningful fire rotation value (Fahnestock and Agee 1983). Though interview-based rotation times were longer than those determined by analysis of TM images, the landowner estimates of forest area burned were for non–El Niño years (1994 and 1995). The resultant fire rotation calculations are therefore very conservative, since this study’s multitemporal imagery analyses show that 90 percent of forest burning has occurred during El Niño years.

Conclusion

The average rate and intensity of forest burning and deforestation can be expected to increase as previously burned forest area expands. A positive feedback exists between forest fires, future fire susceptibility, fuel loading, and fire severity. In the last several years, roughly 50 percent of the remaining forests in the study regions around Paragominas and Tailândia have burned, 20 percent having burned more than once. First-time burns can be controlled and put out manually with minimal equipment, but more than 30 percent of the observed fires in previously burned forest had fireline intensities beyond the limits of manual control (Pyne 1984). Left unchecked, the current fire regime will result in an inexorable transition of the entire affected area to either scrub or grassland (Jackson 1968). Effects
on the regional climate, biodiversity, and economy are likely to be extreme.

Solutions to the fire problem in the Amazon will not be easy, likely requiring a combination of educational, legislative, monitoring, enforcement, and economic initiatives in addition to community organization and better overall fire management (Nepstad, Moreira, and Alencar 1999). Solutions must be found, though, and soon, because unless changes are made in current land management practices, the entire 300,000 square kilometers (1996 estimate) of forest remaining within a 260-kilometer-wide band (map 10.1) of Pará and Mato Grosso is at risk of being lost. Accounting for differences in forest biomass by state and the projected future land cover of deforested areas (Fearnside 1997), this effectively equates to a net committed emission of 6.0 billion tonnes of carbon. This emission is on the order of the annual global emissions of carbon from fossil fuels and is equivalent to over eighty years’ worth of Brazil’s current fossil fuel emissions (Marland et al. 1998a, 1998b). This estimate is conservative too since conditions in Tocantins and Maranhão are likely the same or worse, and even Rondônia may be currently experiencing this fire dynamic. These fire-induced changes will take several years to occur but are likely to be irreversible (Mueller-Dombois 1981; Shukla et al. 1990) under current climatic conditions. Furthermore, it should be realized that, without intervention, this same undesired interaction of land use and fire will continue to advance in lock step with the advancing frontier.

Acknowledgments

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References


Can Pasture Intensification Discourage Deforestation in the Amazon and Pantanal Regions of Brazil?

Philip M. Fearnside

Cattle pasture is the predominant land use in deforested areas in the Brazilian Amazon (Fearnside 1990, 1996). Any policy changes that affect the motivations to expand this land use would therefore have a key role in shaping the future course of deforestation. Intensification of pasture management, especially through application of phosphate fertilizers, has been subsidized by the Brazilian government as a means of reducing deforestation. The assumptions underlying this strategy require careful examination.

The Rationale for Intensification

The logic of subsidizing intensification is summarized by Serrão and Homma (1993, 319–20) of the Brazilian Enterprise for Agriculture and Cattle Ranching Research (EMBRAPA): “With technological intensification and consequent improvement in the sustainability of forest-replacing pastures, . . . productivity from cattle raising operations in the Amazon can be doubled or tripled. Therefore, from a technical point of view, no more than 50 percent of the area already used for cattle raising is actually necessary to meet the regional demand for beef. . . . If this is correct, . . . a considerable amount of already degraded pastureland can be reclaimed or regenerated toward forest formation and biomass accumulation.”

Pasture intensification is done through applications of fertilizers and herbicides, replanting with better grass varieties, genetic improvement of cattle herds, and better regulation of stocking densities and rotation schedules. Intensification is promoted both in ranches cut from Amazon forest and those in the Pantanal wetlands of Mato Grosso and Mato Grosso do Sul (map 11.1). In the case of the Pantanal, EMBRAPA has
recommended that properties plant 10 percent of their area in improved
pasture, even though some forest on high nonflooded ground within each
property must be sacrificed to do this. This clearing is in “encordilleiras,”
or unflooded areas on rises within the Pantanal; these topographic fea-
tures occupy a greater proportion of the landscape in the area nearest the
“planalto” (upland areas outside of the Pantanal) on the eastern edge of
the region.

Proposals to create new subsidies or to “redirect” old ones (see Serrão
and Toledo 1990, 210) will always find enthusiastic support among ben-
eficiaries. Beneficiaries represent an interest group that can be expected to
work to perpetuate and expand any subsidy program, regardless of its
agronomic, social, or environmental results. Amazonian ranchers ben-
efited from generous government subsidies in the form of fiscal incentives
and subsidized credit in the 1970s and 1980s (Yokomizo 1989). Contrary
to popular belief, many of these ranchers still receive fiscal incentives be-
cause the June 25, 1991, decree (no. 153) on incentives only suspended
granting new incentives, rather than revoking old (already approved)
one. Ranchers represent a political force with influence far beyond their
small numbers. Great care must therefore be taken in initiating new sub-
sidies.

Reasons to Doubt the Official Scenario

The Full-Stomach Hypothesis

A variety of indications suggests a lack of reality in the imagined scenario
whereby ranchers who profit from successful intensification will refrain
from further clearing. First, this scenario runs contrary to what is known
of human economic behavior generally. When people make money from a
given activity, the virtually universal response is to expand that activity
rather than to limit it. If pasture intensification were really an economic
success, then not only would individual ranchers increase the proportion
of their land devoted to the system, but additional investors would be
attracted to the region to take advantage of the opportunity.

As Kaimowitz (1996, 56) has observed in the context of Central
America, “A plausible argument can even be made that improved live-
stock technology applicable to areas with poor soils in the humid tropics
is likely to increase deforestation, as it would make cattle raising in these
areas more profitable.” In the Amazonian context, likely effects would
include further stimulation of land sales and expulsion of small farmers to
more distant deforestation frontiers, because Amazonian ranchers, who have a higher shadow price for the land, buy out small farmers with offers of attractive sums (Schneider 1994). This difference in shadow price would increase even more if improved technologies were available, to which ranchers would be likely to have better access (Kaimowitz 1996, 56). When small farmers are bought out, deforestation rates on the purchased properties approximately double (Fearnside 1984).

An alternative response to income gained from intensification is to invest the profits in other promising activities (such as expanding extensive ranching)—but these activities usually involve cutting down more forest. An example is the investment of income from successful cocoa harvests in Rondônia in expanding extensive cattle pastures, rather than putting the money back into the environmentally more desirable perennial crop (see
Another is the use of profits from timber to keep the ranching industry going in Paragominas, Pará (Mattos and Uhl 1994).

The argument that increasing the productivity of pastures will “limit future use of forest for new pasture” has recently been made by Faminow (1998, 232). The assumption is that, with higher productivity, either ranchers would be satisfied with their profits or the market for beef would be saturated such that further clearing is unprofitable. I have often questioned the notion that Amazonian small farmers would stop clearing if only their stomachs could be filled by improved yields (for instance, Fearnside 1987a, 1998a). The idea of ranchers limiting their expansion because they are satisfied with their level of material existence would be even more far-fetched. Markets, on the other hand, can eventually become saturated, but pasture is likely to be able to expand tremendously, and at great environmental cost, before market forces would restrain this process. The beef demand in the Amazon that was assumed by Serrão and Homma (1993, 319–20) to set the upper limit on the extent of Amazonian ranching is hardly the ceiling imagined. Beef can be consumed in the rest of Brazil and beyond, despite restrictions on the export of frozen beef to many countries due to aphthosis (hoof-and-mouth disease) in South America. More importantly, ranchers base their deforestation decisions on many motives other than beef sale.

Pasture Is Not for Beef Alone

The logic of intensification as a strategy for slowing deforestation rests on the assumption that the primary motive for expanding pasture is to produce beef. Various indications point to other motives as critical in the behavior of Amazonian ranchers. Perhaps the clearest indication is the case of the Agriculture and Ranching district of the Manaus Free Trade Zone (SUFRAMA). In the state of Amazonas, which is dominated by the state capital at Manaus (1999 population approximately 1.6 million), only 25 percent of the beef consumed is produced in the state (Faminow 1998, 132). The SUFRAMA agriculture and ranching district, located on the outskirts of Manaus and protected from competition by vast distances to competing producer areas, is notorious for having become a sea of secondary forest when government subsidies dried up beginning in 1984. If beef production were so profitable, why haven’t these ranches remained active over the period since 1984, during which time the population of Manaus has approximately doubled, along with its attendant beef demand? The case of Manaus fits a picture that includes deforestation motives other than the beef market: Motivation for maintaining the
SUFRAMA ranches would have depended almost solely on beef profits because the timber value of these forests is relatively low, because pasture is not needed to maintain possession of the land since the ranches are part of a government-organized scheme with proper surveying and documentation (unlike the legal free-for-all of southern Pará), and because the threat of invasion by landless migrants has (until very recently) been quite remote.

Land speculation and government financial incentives add to the profitability of felling for pasture, even in the face of negligible production of beef (Browder 1988; Fearnside 1980, 1987b; Hecht 1993; Hecht et al. 1988). Faminow (1998) has presented a contrary view (for a rebuttal, see Fearnside 1999a). Faminow (1998, 125 and 131) believes instead that demand for beef and milk in Amazonian cities is the key factor motivating pasture conversion. The case of Manaus belies the generality of such an interpretation.

Perhaps the clearest sign that land speculation has been a significant force in deforestation is the pattern of deforestation since Brazil’s July 1994 Plano Real economic package was instituted, greatly reducing the rate of inflation. Landsat imagery indicates a tremendous initial jump in the deforestation rate in 1995, to $29 \times 10^3$ square kilometers per year, versus $15 \times 10^3$ square kilometers per year in 1994 (Brazil, INPE 1998); the jump is best explained as the result of a much larger volume of money becoming available for investment following institution of the Plano Real. The 1995 peak was followed by a substantial decline, to $14 \times 10^3$ square kilometers per year in 1996 and $13 \times 10^3$ square kilometers in 1997; according to a preliminary estimate, the decline was followed by an increase to $17 \times 10^3$ square kilometers per year in 1998 (Brazil, INPE 1999). The 1995–97 decline in deforestation rates accompanied a drop in land prices of over 50 percent during the same period—a price decrease that is best explained as the result of the greatly reduced rate of inflation having eliminated the role of land as an inflation hedge. The association of falling land prices with reduced deforestation rates suggests that a significant part of the deforestation that was taking place in prior years was motivated by speculation.

It is important to remember that speculation takes place on the basis of whole properties rather than just the portion of each one that has been converted to pasture. The forested portions of the properties, including the timber stocks they contain, represent a significant value. The pasture provides an effective guarantee of continued possession of the entire property, therefore providing an important motivation in addition to beef pro-
duction. If a property were offered for sale without a portion of it being under pasture, even if degraded, the remaining forest would have a lower sale value because of the need for a prospective buyer to either make heavy expenditures in clearing part of the forest or risk losing possession of the property.

Money laundering offers another potential motivation for investment in expanding Amazonian cattle pasture. “Dirty” money gained through drugs, corruption, and many other illegal sources can be converted into “clean” money by investing in Amazonian business ventures, such as gold mining dredges and cattle ranches, even if they are unprofitable based on the face value of return on investment. The logic is illustrated by the case of former federal deputy (congressperson) João Alves, who gained notoriety in Brazil’s 1993 federal budget scandal (ISTOÉ 1993). João Alves won approximately fifty-five times in Brazil’s national lottery because he had bought many thousands of tickets in order to convert an estimated U.S.$50 million in illegally gained cash into legally recognized winnings. The small percentage of money invested in lottery tickets that will, on average, return to a bettor as winnings would make investments in financially unpromising Amazonian ranching schemes seem like excellent deals.

**Cattle Density, Pasture Productivity, and Clearing**

In an analysis of 191 municipalities (municípios) in the Brazilian Amazon, Reis and Margulis (1991, 358) found a strong positive relationship between cattle density per square kilometer and rate of deforestation. However, this econometric analysis indicated that annual cropping had a greater elasticity than the size of the cattle herd, both when the analysis was done using areas of annual crops (Reis and Margulis 1991) and using their production in tons (Reis and Margulis 1994, 186). Cline (1991) believes that collinearity among the various variables is the likely explanation for Reis and Margulis’s 1991 finding of a relatively low contribution from the cattle herd (explaining only 10 percent of the deforestation in simulations for 1980–85).

One would expect a close association between cattle and deforestation because of the known association between property size and deforestation, and because of the obvious fact that large ranches tend to plant more pasture than small farms (although small farmers also plant pasture). Evidence that most clearing is done by medium and large ranches includes regressions of the deforestation rate on the area of private land in different property sizes in the Amazonian states, adjusted for the differences in the
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sizes of the states. Such regressions explain 74 percent of the variance in deforestation rates for 1990 and 1991, and indicate that small farmers account for only 30.5 percent of the total deforestation (Fearnside 1993). Another explanation is revealed in interviews conducted by Nepstad et al. (1999) on 202 properties in the “arc of deforestation” from Paragominas to Rio Branco, which indicated that only 25 percent of the clearing was in properties of 100 hectares or less. An indirect indication is provided by the sizes of clearings measured on Landsat imagery for 1995–97 (Brazil, INPE 1998, 1999). These measurements indicate that the percentage of clearings smaller than 15 hectares in area was 21 percent in 1995, 18 percent in 1996, and 10 percent in 1997. The 15-hectare cutoff is well above the approximately 3 hectares per year that small farmer families can clear using family labor. These values offer only an indirect indication of the role of small farmers because the values omit small clearings—the limit of detection is 6.25 hectares at the 1:250,000 scale used for image interpretation. Note that the areas refer to the size of clearings, not to the size of the properties in which they are located.

In a study of farming in Rondônia, Jones and his colleagues (1995) found that “productivity of land in cattle appears to be essentially unaffected by clearance rates.” One can deduce from this finding that the opposite also applies, that is, that changes in cattle productivity do not affect farmers’ land-clearing behavior. Dale and coauthors (1993, 1002) found that good soils have the largest number of beef cattle in Ouro Preto do Oeste, Rondônia, but Jones et al. (1995) have found that soil quality is unrelated to deforestation rate at the site.

Future Prospects of Intensification

Economic Competitiveness

One sign that bodes poorly for intensification is the minimal extent of unsubsidized pasture using higher-input systems. Hecht (1992) points out the lack of response to technology improvement in the Paragominas area. A dramatic demonstration of this occurred in 1995, when the Plano Real economic package (inaugurated in July 1994) suddenly made much larger amounts of money available for investment. Rather than a boom in adoption of improved pasture management, the response of Amazonian ranchers was a tremendous increase in deforestation rates. The annual deforestation rate more than doubled, from \(14 \times 10^3\) square kilometers per year in 1994 to \(29 \times 10^3\) square kilometers in 1995 (Brazil, INPE 1998).
In the Altamira area of Pará, Castellanet and colleagues (1994) found that the predictions of Boserup (1965) regarding population density and intensification were borne out in the case of pasture management. In other words, landowners in Altamira are not intensifying their pastures. Boserup (1965) provides the classic presentation of the relationship of population density changes to land use intensities, where producers in sparsely populated regions such as the Amazon tend to adopt extensive rather than intensive technologies, only shifting to more intensive methods when the density of settlement increases.

**Phosphate Limits**

EMBRAPA has recognized that added phosphorus is necessary to maintain pasture productivity, and in 1977 changed its previous position that pasture improves soil, recommending instead that productivity be maintained by applying 200 to 300 kilograms per hectare of phosphate fertilizer (50 percent simple superphosphate, 50 percent hyperphosphate) (Serrão and Falesi 1977, 55), to supply 50 kilograms per hectare of diphosphorus pentoxide (P$_2$O$_5$) (Serrão et al. 1978, 28). This recommendation was subsequently modified to 25 to 50 kilograms per hectare of P$_2$O$_5$ (Serrão et al. 1979, 220), but more recent recommendations have been for the original 50 kilograms per hectare (Correa and Reichardt 1995).

Low levels of available phosphorus in the soil have been found to limit growth of pasture grasses in Paragominas (Serrão et al. 1978, 1979). Problems limiting reliance on phosphate fertilizers are the cost of supplying phosphate and the absolute limits to minable stocks of this mineral. A report on Brazil’s phosphate deposits published by the Ministry of Mines and Energy indicates that only one small deposit exists in the Amazon (actually two close together, Serra de Pirocaua and Ilha Trauira), located on the Atlantic coast near the border of Pará and Maranhão (de Lima 1976; see also Fenster and León 1979). In addition to the deposit’s small size, it has the disadvantage of being made up of aluminum compounds that render its agricultural use suboptimal, but not impossible if new technologies were developed for fertilizer manufacture (Santos 1981, 178). An additional deposit has been found on the Maecuru River, near Monte Alegre, Pará (Beisiegel and de Souza 1986), but estimation of its size is still incomplete. Almost all of Brazil’s phosphates are in Minas Gerais, a site very distant from most of the Amazon.

Brazil as a whole is not blessed with a particularly large stock of phosphates—the United States, for example, has deposits about twenty times
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larger—and Brazil’s reserves total only 1.6 percent of the global total (de Lima 1976, 26). Continuation of post–World War II trends in phosphate use would exhaust the world’s stocks by the middle of the twenty-first century (U.S. CEQ and Department of State 1980). Although simple extrapolation of these trends is questionable because of limits to continued human population increase at past rates, the conversion of a substantial portion of the Amazon to fertilized pasture would greatly hasten the day when phosphate stocks are exhausted in Brazil and the world. Brazil would be wise to ponder carefully whether its remaining stocks of this limited resource should be allocated to Amazonian pastures (Fearnside 1997).

A rough calculation can be made of the adequacy of Brazilian phosphate reserves to sustain pastures in the Amazon. Brazilian reserves of phosphate rock total 780.6 × 10^6 tonnes, with an average P_2O_5 content of 12 percent (de Lima 1976, 24), not counting the Maecuru deposit still being assessed. Discounting the loss of 8 percent of P_2O_5 in transforming rock to phosphate fertilizer (de Lima 1976, 10), this amount represents 86.2 × 10^6 tonnes of P_2O_5. The five largest companies have reserves totaling 67.1 × 10^6 tonnes of P_2O_5 (after corrections for losses), which current extraction rates would exhaust in only thirty years in a projection that includes no expectation of phosphate use for pasture fertilization (Albuquerque 1996, 56 and 99). The 54.7 × 10^6 hectares of forest cleared by 1998 in the Legal Amazon (Brazil, INPE 1998) would consume 1.1 × 10^6 tonnes of P_2O_5 annually if maintained in pasture. This amount assumes that pastures are fertilized once every 2.5 years (Serrão et al. 1979, 220) at the 50-kilogram-per-hectare dose of P_2O_5 per fertilization, considering a minimum critical level of 5 parts per million P_2O_5 in the soil rather than the traditional critical level of 10 parts per million, which would require annual doses of fertilizer to maintain. If the entire 400 × 10^6 hectares of originally forested area in the Legal Amazon were fertilized at the rate recommended for pasture, it would require 8.0 × 10^6 tonnes of P_2O_5 annually. If all of Brazil’s phosphate reserves were devoted to this purpose, they would last seventy-nine years in maintaining the currently deforested area (an area the size of France) under pasture, and only eleven years if the remainder of the originally forested area were also converted to pasture (table 11.1). However, Brazil’s fertilizer deposits are already almost totally committed to maintaining agricultural production outside the Legal Amazon (Fearnside 1998b).

Nothing obliges Brazil to rely solely on domestic phosphate supplies, although global supplies are also finite. For high-priority uses, phosphates
are already imported to the Amazon from abroad. The Jari project now uses phosphates from North Carolina, United States. In the case of the soybean and irrigated rice project in Humaitá that became a top political priority in the state of Amazonas prior to the 1998 gubernatorial elections, nitrogen-phosphorus-potassium (NPK) fertilizer was imported from Israel for distribution to the farmers.

Global Warming Mitigation

Could intensification of pasture management be subsidized with the objective of sequestering carbon in the soil as a global warming mitigation measure? This would give subsidization programs access to much greater volumes of money; for example, the United States is expecting to spend U.S.$8 billion annually on “flexibility mechanisms” such as the Clean Development Mechanism (CDM) in order to meet its commitments under the Kyoto Protocol (see Fearnside 1998b). Intensification of Amazonian pasture management has been proposed for its carbon benefits in surface soils (Batjes and Sombroek 1997; Cerri et al. 1996), but the effectiveness of such measures depends greatly on assumptions regarding previous land use and subsequent management (Fearnside and Barbosa 1998). Most importantly, funds intended to avert global warming would be much bet-
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ter spent on measures to slow the rate of deforestation. Slowing the rate of deforestation would not only be the most cost-effective use of funds for mitigating climate change, but would also bring many additional benefits in maintaining forests intact (Fearnside 1995).

Understanding Deforestation

Understanding of the causes of Amazonian deforestation is still in an embryonic state, in part because of the lack of concerted research efforts on the causes of deforestation on a scale commensurate with the importance of the problem. I have always been impressed by the disparity between modeling efforts in the field of climate change and those for tropical deforestation. The half-dozen major global circulation models (GCMs) used for estimates of climatic changes consist of approximately 300,000 lines each of computer code, run on a “super computer,” and have a full-time team of programmers maintained over several decades to continually test and improve the model. By contrast, efforts to model tropical deforestation are usually the efforts of individuals or small groups working with minimal resources. Despite these limitations, progress continues to be made on modeling deforestation (see reviews by Kaimowitz and Angelsen 1998, and Lambin 1994). Perhaps if understanding the dynamics of deforestation were given a priority on a par with that accorded climate change, we would be closer to having predictive models. We would need functional (in other words, causal) models that are spatially explicit and include location-specific representation of the behavior of different social groups. Only when such models provide adequately reliable scenarios under a range of alternative policy regimes would it be possible to tap the major financial resources that could become available should, for example, policy changes to slow deforestation be accepted as a means of avoiding greenhouse gas emissions under the terms of the Kyoto Protocol (that is, with “verifiability” of “additionality”).

A danger exists that controversy among researchers over the causes of deforestation will be seized upon as an excuse to postpone doing anything about the problem. Ample precedents exist, such as the tobacco industry lobby’s delaying for decades action by any government to discourage smoking on the strength of an alleged “controversy” over whether smoking causes cancer, or similar successes by fossil fuel lobbies to delay and weaken action on global warming. In the case of Amazonian deforestation, we already know enough to identify some of the critical drivers that should be the targets of immediate government action. These drivers in-
clude policies governing land-tenure establishment, levying and collecting of taxes to remove the profits from land speculation, strengthening of environmental impact assessment requirements for proposed development projects, and limiting the construction of highways (Fearnside 1989). Subsidizing pasture intensification is not recommended as a strategy to slow deforestation.

Conclusions

Subsidizing the intensification of pasture management in the Brazilian Amazon is not likely to result in the deforestation rate reductions foreseen by proponents. In addition, limits on financial resources and on physical inputs such as phosphates are unlikely to permit maintenance of vast areas of pasture under these systems. The search for effective measures to discourage deforestation should focus on the suite of motivations that lead ranchers to invest in forest clearing, including factors unrelated to producing beef. Factors such as land speculation and land tenure security can override expected effects of subsidizing pasture intensification.

Acknowledgments

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References


Can Pasture Intensification Discourage Deforestation?


Land Use, Cattle Ranching, and the Concentration of Landownership in Maranhão, Brazil

Roberto Porro

The changing pattern of land use, deforestation, and secondary forest succession since the eighteenth century in the Brazilian state of Maranhão provides useful insights into the interplay of socioeconomic, political, and ecological factors that constructed the social and natural landscapes we observe today. The analysis in this chapter focuses on the history of peasant producers and cattle ranchers in areas of secondary succession where babassu palms have largely come to replace the species-rich mature forests that once characterized the region. The transformations that took place in the “babassu zone” were mainly driven by the expansion of croplands and pastures through a process that was strongly influenced by the actions of state agencies, as well as by the mobilization of agro-extractive peasants whose collective actions partially reversed the high concentration of landownership that had come about. Because Maranhão is one of the oldest settlement regions in the eastern Brazilian Amazon, its troubled history may herald some of the events that may occur elsewhere in the region.

Maranhão: Background

The state of Maranhão consistently ranks among the poorer states in Brazil. It has the lowest rate of urbanization in the country, and the highest rural demographic density in Brazil’s Legal Amazon. Within the Amazon region, the peasant population in Maranhão is highly diversified in terms of ethnic identity, geographic origins, and economic performance. The more than two million rural people of Maranhão include the largest group of squatters in Brazil: 140,000 households, or 20 percent of the country’s total (Fundação IBGE 1998b). Today’s rural population also includes market-oriented ranchers, some of whom trace their origins to the eco-
economic differentiation of peasant producers, while others are recently arrived capitalist entrepreneurs. Ecologically, Maranhão presents transitional features between the ecosystems of Brazil’s Amazon rainforest on the one hand, and dry northeast on the other hand. Although Brazil’s National Institute for Spatial Research (INPE) estimates that deforestation in Maranhão reached 100,590 square kilometers by mid-1998, it is likely that this figure is underestimated due to frequent cloud cover and the limitations of remote sensing platforms in distinguishing mature from secondary palm forests. Today, mature forests comprise a small portion of the state’s surface, mostly in the west, in areas increasingly threatened by demographic expansion and growing markets for timber and charcoal that encroach on indigenous lands, protected areas, and lands for settlement projects carried out by state and federal governments. In addition, the rural population of Maranhão supplied a large number of the colonists and landless families that migrated to other parts of the Amazon, mainly during the 1970s and 1980s.

The pattern of secondary succession characterized by the dominance of babassu-palm forests is the most significant ecological feature of the state, with profound implications for the economic strategies adopted by land users (Anderson, May, and Balick 1990; May 1986). Initially disseminated by rivers and later by indigenous peoples (Anderson, May, and Balick 1990; Balée 1988), secondary forests of high-density babassu palm (*Attalea speciosa*, previously known as *Orbignya phalerata*) are associated with human intervention in the natural environment. As babassu is the dominant species after slash-and-burn agriculture carried out by peasants, agro-extractive cultivators benefit from a variety of products obtained from the babassu palm, of which the kernels and charcoal are the most important. The sale of babassu kernels is a year-round source of monetary income to peasant households. Competing in the market for copra, palm kernels, and palm oil, the oil extracted from these kernels is used by soap and food industries. Another important product to local households is the charcoal produced from the shells of babassu nuts and still used for cooking by the vast majority of peasant households in Maranhão. It is therefore unsurprising that ecological processes leading to predominant land cover types in Maranhão are related to social processes taking place since the end of the eighteenth century, when changes in natural resource use intensified. The next section will discuss the relationship between social processes, land use, and land cover in Maranhão. Map 12.1 shows the location of the state and identifies the five meso-regions and twenty-one
Map 12.1. Meso- and micro-regions in the state of Maranhão
micro-regions according to the Brazilian Geography and Statistics Bureau, IBGE (Instituto Brasileiro de Geografia e Estatística).

Land Occupation and Land Use in Maranhão

Table 12.1 summarizes historical developments relevant to resource use and land cover change in Maranhão, starting in the mid-eighteenth century. Despite initial colonization attempts by the Portuguese, and later incursions by the French (1612–16) and the Dutch (1642), the population of European origin in Maranhão by the early eighteenth century was less than 1,500 people. Included among them were Azorean settlers who established farms at the Itapecuru River valley in 1621 and who first introduced cattle and draft animals. Subsequent occupation of Maranhão’s lands by nonindigenous, white populations between 1750 and 1850 took place through the expansion of two main activities. One was related to the growth of livestock—the “pastoralist front”—consisting of the arrival of cattlemen (*vaqueiros*), most of whom drove cattle herds up from the state of Bahia in search of the natural pastures that lay to the north of them. Several towns were established during this period in southern Maranhão, such as Pastos Bons (1754), Grajaú (1811), and Carolina (1816). The regional economy of the day was based on products and services derived from cattle ranching, mainly beef and leather (Viveiros 1970).

The other mode of occupation of lands in Maranhão was associated with the agricultural activities in the coastal areas, as well as in the lower stretches of the Itapecuru, Mearim, Grajaú, and Pindaré Rivers. These lands were mostly inhabited by descendants of African slaves, indigenous populations, and a minority of settlers of European origin who engaged in the cultivation of sugarcane and cotton. The establishment in 1756 of the Grão-Pará and Maranhão General Trade Company stimulated the plantations and led to the most significant human intervention on the local environment until termination of slave traffic in 1850. By the end of the nineteenth century, Maranhão’s population totaled about a half million people. During the boom of the cotton trade, the state’s annual production reached over 8,000 metric tons of cotton (*algodão em pluma*), cultivated on approximately 50,000 hectares. Sugarcane cultivation was also noteworthy up to the end of that century, when about 500,000 sacks of sugar were exported annually. The end of slavery, and the consequent need to hire and pay for labor, exposed the inefficiencies of sugar and cotton production and processing, resulting in the decline of the plantation-based economy.
Table 12.1. Major social processes associated with land use/land cover change in Maranhão, 1750–2000

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Major social processes</td>
<td>'Slavery'</td>
<td>'Northeastern migrants'</td>
<td>'Government subsidies'</td>
<td>'Collective action'</td>
</tr>
<tr>
<td></td>
<td>'Grão-Pará &amp; Maranhão Gen. Trade Company'</td>
<td>'Settlement as squatters'</td>
<td>'Road opening'</td>
<td>'Land struggles'</td>
</tr>
<tr>
<td></td>
<td>'Pastoralist occupation'</td>
<td>'Capital accumulation by middlemen'</td>
<td>'Land concentration'</td>
<td>'Settlement projects'</td>
</tr>
<tr>
<td></td>
<td></td>
<td>'Freed slaves'</td>
<td>'Elimination of babassu'</td>
<td>'Economic stratification'</td>
</tr>
<tr>
<td>Main primary products</td>
<td>Cotton, sugarcane</td>
<td>Cotton, rice Babassu kernels Animal skins Cattle (South, North, East) Timber</td>
<td>Rice, manioc Babassu kernels, charcoal Cattle (Center, West) Timber (Center, West)</td>
<td>Cattle (West, Center) Soybeans (South) Rice, manioc Babassu kernels, charcoal Timber (West)</td>
</tr>
<tr>
<td>Predominant land uses</td>
<td>Forest use by native people Plantation agriculture Hunting + fishing Pastoralism</td>
<td>Shifting cultivation Babassu extraction Forest use by native people Hunting + fishing Cattle raising</td>
<td>Shifting cultivation Babassu extraction Cattle ranching Land speculation</td>
<td>Cattle ranching Shifting cultivation Modern agriculture Babassu extraction Land speculation</td>
</tr>
<tr>
<td>Predominant land-cover types</td>
<td>Primary-mature forest Cropland Native grassland</td>
<td>Primary-mature forest Babassu secondary forest Cropland, fallow Native grassland Planted pastures (1950s)</td>
<td>Babassu secondary forest Planted pasture (jaraguá) Pasture + babassu Cropland, fallow (“roça”) Planted pasture (brachiária) Pasture + babassu Cropland, fallow (“roça”) Cropland (soybean—South)</td>
<td></td>
</tr>
</tbody>
</table>
The failure of the plantation system led to two important developments. On the one hand, it generated attractive conditions for the adoption of cattle ranching on the natural pastures and fields within properties that were hitherto engaged in commercial agriculture. On the other hand, the demise of the plantations facilitated the expansion of a peasant social system based on the common use of resources and a highly cooperative system of exchange among rural households (Andrade 1980; Gayoso 1970; Gomes 1981; Viveiros 1970).

Starting in the late nineteenth century, and mainly by the 1910s, the Itapecuru and Mearim River valleys were the destinations of thousands of migrant families originally from the semiarid northeastern states, mostly Ceará and Piauí. Their arrival increased demographic pressures on already settled lands, prompting the movement of peasants into unsettled and forested areas in the west. Tenant farming and rental agreements became increasingly common in the newly settled areas. These arrangements, while promoting the consolidation of the peasant society, resulted in the commercial exploitation of their agricultural crops as the main mechanism for capital accumulation. Rice and babassu kernels, produced through an agro-extractive system that combined slash-and-burn technology and shifting cultivation, replaced cotton and sugarcane as the main products of Maranhão’s primary sector. From the industry investor’s standpoint, compared to the standards of the cotton and sugar industries, babassu extraction was an easier and more rewarding investment opportunity, requiring lower inputs of capital and labor. By the 1940s, babassu extraction was the main economic activity in Maranhão, shifting the state’s financial basis from the cotton trade to the processing and sale of kernels.

Although most babassu extraction in Maranhão took place in the eastern part of the state until the 1940s (63 percent of the total), figure 12.1a shows that, from then on, the activity became more pronounced in the central and western regions. The shift was related to the process of conversion of primary forests to agriculture, and then to secondary growth or pastures. By 1960, the state of Maranhão annually produced over 100,000 tons of babassu kernels, an activity almost entirely based on the female and child labor found within peasant households. Given capitalist appropriation of the results of their agro-extractive system of production, and the subsequent context of land scarcity, peasant households became the main agents of a drastic environmental transformation, as annual crops and secondary growth in the form of babassu stands increasingly replaced the mature and diversified forests in the region.
Fig. 12.1. Production of babassu kernels (A), rice (B), and cattle herd (C) by Maranhão’s meso-regions, 1940–96. Sources: Fundação IBGE 1969, 1991, 1998b; IBGE 1952.
High biomass production on areas covered by babassu and the palm’s resilience to fire allow the recovery of soil fertility after fallow periods of only five to six years. The author’s field observations indicate that such a short fallow is about half the time required on plots with similar soils but with no babassu. Still, up to the 1970s, land availability in most locations meant that land plots would seldom be used for at least a decade.

The influx of northeasterners between 1940 and 1960 led to a fourfold increase in the production of rice. In 1960, more than 550,000 tons of rice were harvested on 400,000 hectares in Maranhão, and these numbers nearly doubled in the 1970s. Like the harvesting of babassu, rice production is almost entirely based on peasant labor. In the period from 1940 to 1960, Maranhão’s population experienced a twofold increase, from 1.2 to 2.5 million. Figure 12.1b shows that although rice cultivation initially predominated at the eastern region of the state (50 percent of the total in 1940), it gradually shifted towards the central and western regions in conjunction with peasant occupation (58 percent of the total in 1960).

Cattle ranching was not yet widespread in Maranhão, and the state’s cattle herd expanded at a slower rate, from 800,000 in 1940 to 1.38 million in 1960. As seen in figures 12.1c and 12.2, the quantity of land that was transformed from forest to pasture was relatively small, mainly because until 1960 livestock production was concentrated in the natural grasslands in the north, east, and south regions of the state. Some 88 percent of Maranhão’s cattle herd in 1940, and 77 percent in 1960, were raised in those three areas. Although the expansion of ranching had been limited up to then, new circumstances that favored capital accumulation resulted in the entrance of market-oriented actors, greater economic differentiation in the countryside, and the formation of a wealthier stratum of landholders. The latter came to depend on the creation of pasture to accumulate wealth and to expand their holdings (Almeida 1981a, 1981b; Andrade 1980; Musumeci 1988; Valverde 1957; Velho 1972).

Thereafter a distinct pattern of land cover change came to predominate in Maranhão. By the mid-1960s, as in other Amazonian frontiers, government development policies and colonization projects promoted the illegal appropriation of lands held by squatters or indigenous peoples. Fiscal incentives, tax breaks, and subsidized rural credit were among the policies and programs that introduced and imposed capitalist relations of production in the region. As peasant farmers continued to occupy the Grajaú, Pindaré, and Turi River valleys, land increasingly became a marketable commodity, a trend that was bolstered by the passing of “Maranhão’s State Law of the Land” in 1969. The incorporation of land into the market
was accompanied by the concentration of wealth and of landownership, by growing violence and land struggles, by the displacement of hundreds of peasant communities, and by the conversion of large tracts of forest and secondary growth to pasture.

As state-led colonization projects targeting smallholders began to fail, regional development agencies were able to subsidize dozens of large projects that promoted the conversion of land to pasture and the expansion of cattle ranching. The area converted to planted (as opposed to natural) pastures increased from just over 150,000 hectares in 1960 to 2.8 million hectares by 1985, representing more than twice the area cropped with grains (fig. 12.2). Maranhão’s cattle herd grew 135 percent between 1960 and 1985, reaching over 3.2 million. In the same period, rice and babassu production increased by just 40 and 43 percent, respectively. The construction of roads and the paving of major highways in the central and western regions of the state increased the value of rural land and reorganized the marketing system for cattle. By 1985, more than 55 percent of Maranhão’s cattle herd was raised in those two regions.
The privatization and enclosure of land, in conjunction with the expansion of pastures, led to the steady decline in the density of babassu stands and to increased restrictions placed on peasant producers. When peasants contested their reduced access to the babassu stands, ranchers came to see the maintenance of palms within pastures as a threat to their questionably acquired property rights. Their solution was to begin the process of systematically eliminating babassu from the lands that they claimed. The concentration of landownership further intensified the pressure on remaining agricultural lands, undermining the conditions required for shifting cultivation by shortening fallow periods (Almeida 1981a, 1981b; Almeida and Mourão 1976; Amaral Filho 1990; May 1986).

After suffering decades of oppression and expropriation, and in the face of increasing obstacles to westward out-migration, peasants began to engage in new and more intensive forms of collective action and social organization. The result over the last fifteen years or so has been a conflictive process, often with violent reactions, through which peasant groups managed to regain some of their rights to property that they had lost. Many of these collective movements were organized by Rural Workers’ Unions (Sindicatos de Trabalhadores Rurais) and more recently by the Landless Rural Workers’ Movement (Movimento dos Trabalhadores Rurais Sem-Terra). Many such movements were also supported by the Catholic Church and other nongovernmental organizations. Confronted by the intense political pressure exerted by the mobilization of grassroots organizations, state agencies were compelled to distribute 2.3 million hectares to some 64,000 families between 1985 and 1999. Although not massive in scale, these events nonetheless reconfigured production and management strategies among local resource users in ways that had significant social, ecological, and economic implications.

Although land users continued to rely on subsistence crops, in most cases the land that they managed to recover was unable to sustain a system of shifting cultivation. As a result, peasants were compelled to experiment with other economic alternatives, such as semi-perennial crops and cattle ranching. In a number of the government-led land-reform projects (termed projetos de assentamento, or settlement projects), peasants gained access to credit and to extension services, resulting in greater economic differentiation within and between communities. In communities better organized towards this end, peasants engaged in cooperative processing and trading of babassu products. In addition, peasants not only reduced the rate at which babassu palms were being felled, but also effectively contested private claims to babassu stands. Through their collective
actions, peasant communities demanded, and were sometimes able to obtain, unrestricted access to palms on nearby ranches. Moreover, gender relations changed as women began to assume positions of leadership in the struggle to save the babassu palm stands. In a striking transformation from their traditional gender roles, women’s social action pitted them not only against cattle ranchers who were felling the palms, but against members of their own community who also engaged in this activity. In some instances, these women were even set against their own husbands as women struggled to maintain access to this important source of economic sustenance (Miyasaka-Porro 1997; Porro 1997, n.d.). Collective actions such as these were among the factors that influenced changes in the ecosystem as well as in the standards of living experienced by people living in rural Maranhão. Moreover, peasant collective action was the primary form for effectively reducing the concentration of landownership in Maranhão.

**Land Use and the Concentration of Landownership in Maranhão**

One of the most telling indicators of agrarian structure and rural well-being is the degree to which landownership is concentrated in the hands of a rural elite, which can be measured by using census data on land distribution by municipality to calculate Gini coefficients. This section will discuss the association between concentration of landownership and the patterns of land use in Maranhão by analyzing the 1960, 1985, and 1996 Brazilian agricultural censuses.

Before turning to the results, it is important to note the significant decrease in the number and area of landholdings in Maranhão from 1985 to 1996. Whereas in 1985 IBGE data computed 531,413 landholdings for 15.5 million hectares (approximately 45 percent of the state’s total area), these totals for 1996 were 368,191 and 12.5 million, respectively. The figures represent a 30 percent decrease in the number of rural establishments and a 20 percent decrease in the area of landholdings. Of the “missing” landholdings in 1996, 96 percent are smaller than five hectares, whereas the decrease in area of landholdings is pronounced for both extremes of the distribution: The area of landholdings smaller than 10 hectares fell by 42 percent, and the area of landholdings larger than 200 hectares fell by 24 percent. The area and number of landholdings in the range of 10 to 200 hectares remained virtually unchanged during this period, partially as a result of land settlement projects.

The data presented in table 12.2 seem to indicate decreasing concentra-
tion of landownership between the two censuses, as shown by the decrease in number and smaller average areas for landholdings larger than 5,000 hectares. Yet, given the significance of the above numbers, further investigation is necessary to understand whether the decrease in number of smallholdings is due to methodological adjustments for IBGE survey protocols, or possibly to a massive rural exodus that is not captured by analyses based on Gini coefficients. In addition, by 1996 the majority of smallholders in Maranhão had no tenure security: According to the 1996 agricultural census, two-thirds of the landholdings in the state consisted of either squatters or tenants (FIBGE 1998b).

In the analysis of concentration of landownership in Maranhão, I will first present the change that occurred between 1960 and 1985 and then discuss the variation in the period 1985–96. Using Gini coefficients to compare 1960 and 1985, the data show that the concentration of landownership increased in all five of Maranhão’s meso-regions, and in twenty of the twenty-one micro-regions of the state (table 12.3 and fig. 12.3). Larger increments occurred in the western and central portions of the

Table 12.2. Distribution of number and area of landholdings in Maranhão, 1985 and 1996

<table>
<thead>
<tr>
<th>Size of Landholding (ha)</th>
<th>1985 Landholdings</th>
<th>1996 Landholdings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Area (ha)</td>
</tr>
<tr>
<td>&lt; 1</td>
<td>203,027</td>
<td>127,376</td>
</tr>
<tr>
<td>1–2</td>
<td>144,283</td>
<td>202,238</td>
</tr>
<tr>
<td>2–5</td>
<td>82,033</td>
<td>239,352</td>
</tr>
<tr>
<td>5–10</td>
<td>15,721</td>
<td>106,766</td>
</tr>
<tr>
<td>10–20</td>
<td>10,606</td>
<td>146,597</td>
</tr>
<tr>
<td>20–50</td>
<td>25,116</td>
<td>843,312</td>
</tr>
<tr>
<td>50–100</td>
<td>21,483</td>
<td>1,371,491</td>
</tr>
<tr>
<td>100–200</td>
<td>11,885</td>
<td>1,570,653</td>
</tr>
<tr>
<td>200–500</td>
<td>8,298</td>
<td>2,472,978</td>
</tr>
<tr>
<td>500–1,000</td>
<td>2,885</td>
<td>1,959,307</td>
</tr>
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<td>1,000–2,000</td>
<td>1,393</td>
<td>1,887,439</td>
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<tr>
<td>2,000–5,000</td>
<td>716</td>
<td>2,089,341</td>
</tr>
<tr>
<td>5,000–10,000</td>
<td>157</td>
<td>1,068,467</td>
</tr>
<tr>
<td>10,000–100,000</td>
<td>75</td>
<td>1,352,337</td>
</tr>
<tr>
<td>&gt; 100,000</td>
<td>1</td>
<td>110,000</td>
</tr>
<tr>
<td>Total</td>
<td>527,679</td>
<td>15,547,654</td>
</tr>
</tbody>
</table>

state, areas primarily characterized by the emergence of land markets and the expansion of cattle ranching. Micro-regions showing greater increases from 1960 to 1985 are the Pindaré (Gini coefficient rising from 0.45 to 0.89), Presidente Dutra (0.43 to 0.84), and Médio Mearim (0.61 to 0.90). By 1985, the overall Gini coefficient for the entire state was 0.921.

The comparison of 1985 with 1996 shows that although the concentration of landownership in Maranhão was still extremely high (an aggregated 1996 Gini coefficient of 0.901), a slight reversal began to occur in much of the state. Gini coefficients decreased in 81 of the 132 existing municipalities in 1985. A similar change was observed in thirteen of the twenty-one micro-regions, and in all but one of the state’s meso-regions. Improvements in this regard were greater in the western, central, and southern areas of the state, coinciding with the establishment of settlement projects, mostly in the west. Conversely, the more consolidated eastern meso-region is the only one that maintained the highly concentrated pattern of the previous quarter century.

Notwithstanding slight improvement in the concentration of landownership, 1996 IBGE statistics show little increase in the area devoted to annual crops or the production of subsistence foods. To the contrary, figure 12.4 shows a decline between 1985 and 1996 for areas devoted to rice, manioc, and the production of babassu kernels. A similar decline is evi-
dent in the size of swine herds, also central to the survival of peasant households. Conversely, large-scale commercial agriculture increased in southern Maranhão. By 1995 more than 60,000 hectares were under soybean cultivation, reaching 150,000 hectares by the end of the decade, mostly by market-oriented farmers arrived from the Brazilian south. Production of some 300,000 tons of soybeans by the year 2000 means that in less than two decades this crop became one of the most significant agricultural products in the state, second in revenue only to rice.

Table 12.3. Gini coefficient for concentration of landownership in Maranhão’s meso- and micro-regions, 1940–96

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<tbody>
<tr>
<td>North</td>
<td>0.885</td>
<td>0.921</td>
<td>0.817</td>
<td>0.909</td>
<td>0.909</td>
</tr>
<tr>
<td>Litoral Ocidental Maranhense</td>
<td>0.937</td>
<td>0.925</td>
<td>0.890</td>
<td>0.868</td>
<td>0.892</td>
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<tr>
<td>Aglomeração Urbana S. Luís</td>
<td>0.490</td>
<td>0.466</td>
<td>0.625</td>
<td>0.875</td>
<td>0.815</td>
</tr>
<tr>
<td>Rosário</td>
<td>0.927</td>
<td>0.821</td>
<td>0.635</td>
<td>0.823</td>
<td>0.877</td>
</tr>
<tr>
<td>Lençóis Maranhenses</td>
<td>0.776</td>
<td>0.929</td>
<td>0.832</td>
<td>0.854</td>
<td>0.788</td>
</tr>
<tr>
<td>Baixada Maranhense</td>
<td>0.682</td>
<td>0.901</td>
<td>0.739</td>
<td>0.903</td>
<td>0.900</td>
</tr>
<tr>
<td>Itapecuru Mirim</td>
<td>0.841</td>
<td>0.919</td>
<td>0.859</td>
<td>0.941</td>
<td>0.943</td>
</tr>
<tr>
<td>West</td>
<td>0.854</td>
<td>0.935</td>
<td>0.708</td>
<td>0.886</td>
<td>0.806</td>
</tr>
<tr>
<td>Gurupi</td>
<td>0.935</td>
<td>0.969</td>
<td>0.792</td>
<td>0.875</td>
<td>0.809</td>
</tr>
<tr>
<td>Pindaré</td>
<td>0.121</td>
<td>0.331</td>
<td>0.445</td>
<td>0.889</td>
<td>0.772</td>
</tr>
<tr>
<td>Imperatriz</td>
<td>0.179</td>
<td>0.661</td>
<td>0.749</td>
<td>0.881</td>
<td>0.805</td>
</tr>
<tr>
<td>Center</td>
<td>0.482</td>
<td>0.925</td>
<td>0.735</td>
<td>0.889</td>
<td>0.845</td>
</tr>
<tr>
<td>Médio Mearim</td>
<td>0.338</td>
<td>0.610</td>
<td>0.610</td>
<td>0.897</td>
<td>0.876</td>
</tr>
<tr>
<td>Alto Mearim e Grajaú</td>
<td>0.667</td>
<td>0.876</td>
<td>0.871</td>
<td>0.878</td>
<td>0.799</td>
</tr>
<tr>
<td>Presidente Dutra</td>
<td>—</td>
<td>0.410</td>
<td>0.428</td>
<td>0.836</td>
<td>0.839</td>
</tr>
<tr>
<td>East</td>
<td>0.914</td>
<td>0.865</td>
<td>0.907</td>
<td>0.927</td>
<td>0.929</td>
</tr>
<tr>
<td>Baixo Parnaiba</td>
<td>0.697</td>
<td>0.753</td>
<td>0.739</td>
<td>0.920</td>
<td>0.937</td>
</tr>
<tr>
<td>Chapadinha</td>
<td>0.841</td>
<td>0.750</td>
<td>0.908</td>
<td>0.914</td>
<td>0.929</td>
</tr>
<tr>
<td>Codó</td>
<td>0.778</td>
<td>0.959</td>
<td>0.866</td>
<td>0.941</td>
<td>0.935</td>
</tr>
<tr>
<td>Coelho Neto</td>
<td>0.877</td>
<td>0.594</td>
<td>0.916</td>
<td>0.935</td>
<td>0.952</td>
</tr>
<tr>
<td>Caxias</td>
<td>0.922</td>
<td>0.849</td>
<td>0.901</td>
<td>0.923</td>
<td>0.929</td>
</tr>
<tr>
<td>Chapadas do Alto Itapecuru</td>
<td>0.885</td>
<td>0.769</td>
<td>0.729</td>
<td>0.909</td>
<td>0.893</td>
</tr>
<tr>
<td>South</td>
<td>0.796</td>
<td>0.704</td>
<td>0.756</td>
<td>0.872</td>
<td>0.814</td>
</tr>
<tr>
<td>Porto Franco</td>
<td>0.519</td>
<td>0.495</td>
<td>0.596</td>
<td>0.793</td>
<td>0.702</td>
</tr>
<tr>
<td>Gerais de Balsas</td>
<td>0.859</td>
<td>0.635</td>
<td>0.791</td>
<td>0.879</td>
<td>0.818</td>
</tr>
<tr>
<td>Chapadas das Mangabeiras</td>
<td>0.649</td>
<td>0.733</td>
<td>0.710</td>
<td>0.901</td>
<td>0.869</td>
</tr>
<tr>
<td>State total</td>
<td>0.908</td>
<td>0.930</td>
<td>0.917</td>
<td>0.921</td>
<td>0.901</td>
</tr>
</tbody>
</table>
The decline of traditional peasant production was partially caused by the worsening of social and natural conditions including unstable weather and soil depletion, both of which undermined traditional agricultural systems. Other factors included the market-based comparative advantages of capitalist farms producing rice and palm-oil elsewhere in Brazil and overseas, and the lack of technical assistance and support from government agencies. Moreover, market incentives and the expansion of pastures prompted peasants, and smallholders in general, to engage in cattle ranching. In the next section I will focus on the expansion of cattle ranching as an economic alternative to peasant households in Maranhão and particularly the interaction of pastures and palms in the landscapes surrounding peasant communities.

Cattle Ranching and Land Use/Land Cover Change in Maranhão

The expansion of cattle ranching in Maranhão has occurred at a steady pace since the 1960s. Today, Maranhão’s cattle herd has reached around four million head. Given the relatively large percentage of cattle raised on
small and mid-size landholdings, it is evident that small landholders have integrated cattle ranching into their production systems. While this strategy is a way of securing their livelihood, the expansion of cattle ranching has also contributed to increased socioeconomic stratification within peasant communities (Porro n.d.). As table 12.4 shows, by 1996, 45 percent of Maranhão’s cattle were raised in landholdings smaller than 200 hectares, and 20 percent of these were in areas not larger than 50 hectares. The latter stands in sharp contrast to the significantly lower percentages recorded in Rondônia (14 percent), Pará (9 percent), Mato Grosso (4.5 percent), and Tocantins (4 percent). These states, together with Maranhão, contain 95 percent of the cattle herd in the Legal Amazon. Table 12.4 also shows that, although Maranhão’s herd represents only 11 percent of the regional total, the state contained 24 percent of the cattle raised on landholdings smaller than 50 hectares in the Amazon.

Further observations concerning the distribution of cattle ranching by size of rural establishment reveal additional aspects of Maranhão’s changing agricultural base. Although 85 percent of the state’s 370,000 landholdings have less than 50 hectares, only a small portion of those are currently engaged in ranching. As noted in table 12.5, the proportion engaged in cattle ranching was only 30 percent among landholders with 5 to 10 hectares. The proportion increases to 40 percent among those with 10 to 50 hectares, rising to 80 percent among landholders with over 200 hectares. Table 12.5 also indicates that the average cattle herd rose between 1985 and 1996 for small and mid-size landholders with over 5 hectares of land. The average herd of landholdings between 5 and 10 hectares rose from 13 to 22 cattle. Increases from 17 to 25 cattle, and from 33 to 49, were observed for landholdings between 10 and 50 hectares, and for those between 50 and 200 hectares, respectively.

Ecological features of secondary growth in Maranhão make the expansion of ranching significantly more important in light of the affinities between pastures and palm trees. As illustrated by map 12.2, there seems to be a strong correlation between cattle density and the production of babassu kernels. Ongoing research by the author is focusing on this correlation. Babassu palms not only coexist with cattle pastures, but actually have their productivity enhanced by their association with pastures. Hence, municipalities that showed a high density of cattle are also those with high levels of babassu production. Moreover, babassu continues to provide the greatest share of both monetary and nonmonetary income, at
Table 12.4. Total and percentages of 1996 cattle herd in states of the Brazilian Amazon by groups of landholdings according to their size

<table>
<thead>
<tr>
<th>Size of Landholdings (ha)</th>
<th>Acre</th>
<th>Amapá</th>
<th>Amazonas</th>
<th>Maranhão</th>
<th>M. Grosso</th>
<th>Pará</th>
<th>Rondônia</th>
<th>Roraima</th>
<th>Tocantins</th>
<th>Total Amazon</th>
<th>Percentage of Amazon’s total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 10 ha</td>
<td>4,609</td>
<td>587</td>
<td>53,016</td>
<td>379,997</td>
<td>53,886</td>
<td>84,779</td>
<td>56,774</td>
<td>9,214</td>
<td>9,766</td>
<td>652,628</td>
<td>2.4%</td>
</tr>
<tr>
<td>11–50 ha</td>
<td>54,625</td>
<td>1,459</td>
<td>161,238</td>
<td>403,030</td>
<td>583,078</td>
<td>459,043</td>
<td>496,380</td>
<td>3,631</td>
<td>192,266</td>
<td>2,354,750</td>
<td>1.8%</td>
</tr>
<tr>
<td>51–200 ha</td>
<td>264,668</td>
<td>10,719</td>
<td>225,522</td>
<td>1,492,770</td>
<td>1,378,250</td>
<td>1,509,006</td>
<td>664,597</td>
<td>727,449</td>
<td>6,624,552</td>
<td>8,840,864</td>
<td>18.6%</td>
</tr>
<tr>
<td>201–1,000 ha</td>
<td>185,271</td>
<td>25,085</td>
<td>167,960</td>
<td>1,176,478</td>
<td>2,965,503</td>
<td>965,648</td>
<td>99,440</td>
<td>1,768,881</td>
<td>12,552,669</td>
<td>4,578,140</td>
<td>35.2%</td>
</tr>
<tr>
<td>&gt; 10,000 ha</td>
<td>75,084</td>
<td>121</td>
<td>26,204</td>
<td>142,681</td>
<td>3,111,929</td>
<td>671,361</td>
<td>208,529</td>
<td>41,939</td>
<td>300,292</td>
<td>4,578,140</td>
<td>12.9%</td>
</tr>
<tr>
<td>not classified</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8,154</td>
<td>0</td>
<td>1,714</td>
<td>0</td>
<td>159</td>
<td>3,735</td>
<td>13,762</td>
<td>0.1%</td>
</tr>
<tr>
<td>Total by state</td>
<td>847,208</td>
<td>59,700</td>
<td>733,910</td>
<td>3,902,609</td>
<td>14,438,135</td>
<td>6,080,431</td>
<td>3,937,291</td>
<td>399,939</td>
<td>5,218,142</td>
<td>35,617,365</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Table 12.5. Landholdings engaged in cattle ranching: total and average cattle herd by groups of landholdings according to their size

<table>
<thead>
<tr>
<th>Size of Landholdings (hectares)</th>
<th>Landholdings Engaged in Cattle Ranching and Percentage in Relation to Total Landholdings</th>
<th>Cattle Herd: Total and Average Herd by Group of Landholding Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>number</td>
<td>%</td>
</tr>
<tr>
<td>&lt; 5</td>
<td>29,745</td>
<td>(13.9)</td>
</tr>
<tr>
<td>5–10</td>
<td>4,532</td>
<td>(28.0)</td>
</tr>
<tr>
<td>10–50</td>
<td>6,217</td>
<td>(38.9)</td>
</tr>
<tr>
<td>50–200</td>
<td>5,031</td>
<td>(57.4)</td>
</tr>
<tr>
<td>200–1,000</td>
<td>4,547</td>
<td>(71.9)</td>
</tr>
<tr>
<td>1,000–10,000</td>
<td>1,211</td>
<td>(81.6)</td>
</tr>
<tr>
<td>&gt; 10,000</td>
<td>38</td>
<td>(95.0)</td>
</tr>
<tr>
<td>not classified</td>
<td>430</td>
<td>(65.1)</td>
</tr>
<tr>
<td>Total</td>
<td>51,751</td>
<td>(19.8)</td>
</tr>
</tbody>
</table>

Map 12.2. Cattle density and babassu density by municipalities in the state of Maranhão, 1998. 
Source: IBGE <http://www.sidra.ibge.gov.br/>
least among the poorest households in Maranhão, which struggle to survive on landholdings of less than 5 hectares.

**Conclusion**

Cattle ranching, although still the purview of large landholders, has come to play an important role in the livelihood strategies of small landholders in the region, a significant proportion of whom are new to this kind of economic activity. State-sponsored initiatives to redistribute land, which were largely prompted by political pressure from the grassroots mobilization of the peasantry, have led to a slight improvement in the concentration of landownership in a state that continues to have one of the highest Gini coefficients in the country. While land redistribution has yet to reach a larger share of the peasantry, the maintenance of babassu palms within pastures and the access of peasants to these palm stands are imperative to attenuate the effects of socioeconomic stratification and to accrue the benefits provided by cattle ranching to some landholders so that they are not overcome by the worsening of livelihood of the poorest households.

More generally, the social and environmental histories of Maranhão have been defined by shifts in the relative importance of agriculture, ranching, and extractive activities. The changing profile of these forms of land use—and the environmental implications in terms of land cover—have been closely tied to the forms of access to resources and property rights that prevailed in the region, to the character of domestic production in the countryside, to the mobilization of peasant groups, to the response by state agencies and institutions, and to the unique gender relations that emerged as a consequence of the struggle for land and livelihood. Ultimately, it was the interplay of such factors that influenced the choice of land use and management strategies, with significant implications for the sustainability of resource use and for the quality of life among people living in rural Maranhão.

**Notes**

1. Babassu palms occur in nearly 200,000 square kilometers of Brazil’s national territory. The “babassu zone” refers to an area of palm stands that lies from 2° to 7° S, and between 42° and 48° W.
2. For the characterization of agro-extractive peasants in the “babassu zone,” see Porro 1997.
3. The Legal Amazon is a 5-million-hectare federal planning region created in
Land Use, Ranching, and Landownership in Maranhão

1966. It comprises the Brazilian states of Acre, Amapá, Amazonas, Mato Grosso, Pará, Rondônia, Roraima, Tocantins, and the portion of Maranhão west of 44° W. Maranhão had an area of 328,665 square kilometers and a population of 5.63 million in the year 2000, resulting in a human population density of 17 inhabitants per square kilometer. In 2000, over 40 percent of this population resided in rural areas.

4. Goals of the Alto Turi Colonization Project, administered by Companhia de Colonização do Nordeste (COLONE), included the occupation of 3 million hectares by 40,000 households. The Companhia Maranhense de Colonização (COMARCO) intended to settle 10,000 families on 30-hectare plots at the Grajaú and Pindaré valleys. And the Brazilian National Institute for Colonization and Agrarian Reform’s (INCRA’s) Barra do Corda colonization scheme targeted the settlement of 3,000 families on 340,000 hectares.

5. Several new municipalities were created in Maranhão after 1960, when larger municipalities were subdivided into smaller ones. For this reason, in addition to the municipality, units of analysis for this assessment include IBGE’s 1996 micro-region boundaries, aggregating data from their constituent municipalities. Micro-regions for 1960 were standardized to the same geographic coverage (homogenized) according to 1996 and 1985 classifications. Municipality-level data for number of landholdings and area of landholdings were summed, generating Gini coefficients at the micro-region level and allowing comparisons over time.

Census data show the distribution of landholdings according to the size of the rural establishment and the associated area encompassed by each size class. Cumulative percentages of both variables are calculated, and the cumulative percentage of number of landholdings (dependent variable) is plotted against the cumulative percentage of area occupied by these landholdings (independent variable), resulting in the Lorenz Curve. The “Gini Concentration Ratio,” or “Gini coefficient,” measures the proportion of the total area between a diagonal line indicating a condition of equal distribution and the Lorenz Curve (Shryock et al. 1971). The calculation of the Gini coefficient (GI) is based on the formula

\[
GI = ( \sum_{i} X_i Y_{i+1} ) - ( \sum_{i} X_{i+1} Y_i )
\]

where “\(X_i\)” is the cumulative percentage of area occupied by landholdings, “\(Y_i\)” is the cumulative percentage of number of landholdings, and “\(i\)” is the respective class interval.

6. Landholding is the translation used in this text for “estabelecimento agropecuário,” the concept employed in Brazilian agricultural censuses. It is important to note, however, that the number of “estabelecimentos agropecuários” does not exactly correspond to the number of families, or households, that live and work in rural areas. The term is conceptualized by IBGE as “every continuous land area—regardless of size, location, and number of parcels—that is used by an individual landholder for agricultural purposes” (IBGE 1998: 21). The concept includes land parcels used by landowners, squatters, sharecroppers, and renters. The compara-
tive analysis of number and area of “estabelecimentos agropecuários,” however, is still the best proxis to account for land distribution in Brazil.

7. One factor that is likely to have contributed to such a discrepancy was data collection at different times. Data for the 1996 census began to be gathered in August 1996, at the end of the 1995–1996 agricultural year, while data for all previous censuses were collected after December, at the end of the civil year. IBGE acknowledges that such discrepancy, although having improved data collection protocols, has also affected the number of landholders surveyed. The problem of collecting data after the harvest is that a number of (mainly) renters and sharecroppers that hold the smaller, temporary, and more precarious land parcels are no longer identifiable in the field, as these landholders moved to other locations. This problem is aggravated at remote sites, where even landowners only occasionally visit their property in times when there is no agricultural activity (IBGE 1998: 27–29).

References


———. 1981b. *Autonomia e Mobilização Política dos Camponeses no Maranhão*. São Luís, Brazil: CPT.


Part IV

Community Participation
and Resource Management
Lessons Learned from Participatory Land Use Planning in the Brazilian Amazon

Virgílio M. Viana and Renata Freire

Land use planning has traditionally been viewed as a technical exercise that strives to impose cartographic order on information coming from various disciplines so as to guide policy design. All too often the products of such exercises amount to little more than attractive colored maps and thick technical reports. The problems with such products are numerous. Because they are descriptive by nature, maps offer scant insight into the factors that drive land use change and tell us little about the associated economic, environmental, and social implications.

The Brazilian Amazon, like many other parts of the world, presents numerous unsuccessful examples of conventional land use planning. Federal and state governments have invested considerable resources in these initiatives, many of which were funded by international donors and multilateral organizations (Mahar and Ducrot 1998). There is nonetheless a growing perception that conventional technocratic and top-down planning can only play a limited role in assisting the design of policies that address the broad goals of sustainable development. At the same time, there is increasing evidence that demonstrates the efficacy of participatory methods (Borrini-Feyerabend 1996).

Fortunately, a growing number of experiences of land use planning in the Brazilian Amazon are based on intensive participation of key stakeholders (Alechandre et al. 1998). These experiences often come from non-governmental-organization-led initiatives. The objective of this chapter is to extract lessons learned from some of these experiences, drawing on two case studies of community projects carried out by the Institute of Forest and Agriculture Certification and Management (IMAFLORA), a nongovernmental organization (NGO) based in Piracicaba, Brazil. Although all
examples come from the Brazilian Amazon, many of the lessons derived from these cases are relevant to other regions of the world.

Case Studies

Tapajós National Forest

The Tapajós National Forest is located in central Amazon, near Santarém, along the Tapajós River. There are eighteen riverine communities located within the national forest, some of which trace their origins back to the nineteenth century. Since the creation of the national forest in 1974, there has been a history of conflicts between these communities and IBAMA (Brazilian Institute for the Environment and Renewable Natural Resources), the federal agency in charge of managing national forests. From 1995 onward, as a part of a pilot program to protect the Brazilian rain-forest, these communities have been involved in a participatory planning initiative.

The project was based on a participatory approach that sought to empower social groups who were traditionally excluded from the decision-making process (Nelson and Wright 1995). The approach established an open process that allowed a balanced representation of the views held by various stakeholders, and formulated information and an appropriate meeting format that encouraged community participation (IMAFLORA 1997). The results were approved in a public assembly, with the participation of elected representatives of all of the communities. Other participants included grassroots organizations, IBAMA, and observers from various institutions, including local NGOs, social movements, international donor organizations, and government agencies. Empowering local people produced a change in the relationship between the communities involved and IBAMA, an institution that was historically seen by local communities as an invader of the national forest (IMAFLORA 1997).

Only through the planning process did it become evident that the occupation of local communities in this area dated back at least 150 years, possibly encompassing the period of the Cabanagem movement in the 1830s. The community-generated map not only recognized the legitimacy of community claims to land, but also their rights to an area larger than what had been demanded by the communities themselves (a strip of 10 kilometers along the river) and what had been proposed by IBAMA. Positive gains from the planning process included (a) the preparation of a land use zone, named Management Plan of the Tapajós National Forest; (b) an
educational process that resulted in the production of educational materials, the training of leaders, and the empowerment of local communities; and (c) increased interinstitutional collaboration that ultimately resulted in the creation of a board of directors (Grupo Gestor) of the national forest.

Municipality of Boa Vista do Ramos

The municipality of Boa Vista do Ramos is located in central Amazon, near Manaus, along the Amazon River. There are forty-three riverine communities in the municipality. Beginning in 1998, when a new administration took office, local officials implemented a new policy aimed at increasing community participation. In 1998–99, IMAFLORA used funding from the National Lottery Charity Board of the United Kingdom to carry out a participatory land use planning effort with all forty-three communities.

The participatory process included the training of environmental defense agents. The training relied on small workshops using educational materials that dealt with mapping techniques and that introduced concepts relevant to sustainable development. Several reasons account for the interest taken by the municipality of Boa Vista do Ramos in the development of the mapping process. For one thing, their participation resulted in an important planning tool that involved several governmental agencies responsible for health care, education, and rural development. Second, the planning effort was seen as a way to “regularize” land titles in the area, and as a way to formulate economic development strategies based on the use of natural resources.

The product of the mapping initiative was made available to all agencies of the municipal government and was incorporated into a geographic information system. The goal is to produce an atlas, to be used in schools and as a tool for resource planning. Maps will be reproduced and given back to the communities so that the communities themselves can carry out their own initiatives. Maps will also be part of a land tenure regularization program, forming the basis of a community forestry project.

Lessons Learned

Political Support

Conventional land use planning does not incorporate dialogue among stakeholders as a methodological procedure. As a consequence of this
oversight, there is often little political support from many interest groups that are involved. In most cases the products of such planning efforts are destined to wind up as little more than colored posters hung in agency offices, and as reports stored in unopened file cabinets.

The most important difference between these two cases was the level of political support from governmental agencies. In the Tapajós case, there was strong support from the worker’s unions (Sindicato de Trabalhadores Rurais de Belterra e Santarém) and from community organizations (Associações de Moradores e Associações Inter-comunitárias). IBAMA on the other hand was not comfortable with some results of the planning process, especially because they created difficulties for a forest management experiment. Of particular relevance was a conventional logging experiment, financed by the International Tropical Timber Organization (ITTO). Part of the area that was claimed by the communities—and which was recognized in the participatory mapping exercise—overlapped with the ITTO project. The new map that IBAMA produced and was to turn over to the communities excluded the areas that were assigned to the ITTO project, and did not incorporate historical claims and rights to land. The zoning aspect of the planning process was thus only partially successful. The zoning of the national forest as a whole was adopted, but the areas assigned to the communities were not.

The Boa Vista do Ramos case benefited from strong support from the municipality, although there was opposition from city council members who were against the municipal administration. There was also initial distrust on the part of some religious leaders, but these problems were overcome during the process of project implementation.

A key lesson derived from the Boa Vista do Ramos experience is the need to build political support for the land use planning process. Support should include not only the governmental institutions involved, but also key stakeholders such as community organizations, local NGOs, and religious leaders. The question is how to build this political support. The two case studies suggest the need to (a) strengthen community organizations themselves so that they can have effective and empowered participation in the process; (b) establish a clearly defined forum and transparent procedures for engaging in political dialogue; and (c) build a consensus while, at the same time, respecting the legitimacy of different perceptions and views, especially among community organizations that often find it difficult to oppose strongly held views by government officials.
Land Tenure

Conventional land use planning does not include activities that address the establishment of secure land tenure. Land tenure security needs to be considered as a central element in land use planning initiatives that aim to achieve sustainable forms of development. Clear land ownership, whether individual or collective, public or private, is a necessary component of sustainable resource use. In the absence of tenure security, the ability to reap the long-term benefits from sustainable resource planning cannot be counted on.

In both cases, participatory mapping was a very useful method of understanding present land use patterns and for discussing appropriate models for land tenure regularization, ranging from individual lots to community areas. Because land tenure is an issue that can generate strong community participation, it can help strengthen community organization, especially in terms of identifying protected areas and finding economic alternatives to existing forms of land use.

The precision required of the mapping process depends on the purpose at hand. If mapping is to be used to establish legal rights to land, the coordinates must be sufficiently precise to meet legal standards. Precision is less important when maps are to be used for community planning purposes. The availability of simple mapping techniques can yield substantial savings. These include using satellite imagery, global positioning systems (GPS), and interpretation of images and design of maps by trained local community members.

Valuing Local Knowledge

In the conventional approach, land use planning is based solely on technical information, which combines social, economic, and ecologic information into the planning exercise. The problem is that the process of generating this kind of information is expensive, and existing information is usually of poor quality and insufficiently detailed to be of much use. Moreover, land use decision-making is often carried out at the household or community levels, a scale of analysis that is often overlooked.

Conventional approaches also neglect the wealth of information that exists in rural communities, especially among Amerindian and other traditional groups who have accumulated empirical information over generations. When participatory mapping is a strategic component of land use planning, the process values local knowledge that is rapidly disappearing as a consequence of cultural erosion. By giving value and recognition
to local knowledge, the process helps to preserve information that might otherwise be lost, as well as shift the balance of power in the decision-making process. Participatory mapping thus improves the quality of information, and does so at a relatively low cost.

Valuing local knowledge is thus a key element in successful land use planning and in the establishment of sustainable development strategies. In valuing local knowledge, it is necessary to recognize that communities are not homogeneous entities, but rather are structured into formal and informal groups, divided by such factors as gender, age, religion, and origin. These groups possess different levels of information with respect to various elements of the landscape, and with respect to the distribution and use of natural resources.

A key lesson from both case studies is the need to invest in the education of children and adults based on the use of maps and associated information. This education should include information on territorial boundaries, the distribution and uses of resources throughout the landscape, and the history of community development. Education is therefore an important step in establishing a clearer understanding of the potential for community-based resource management.

Training Technical Staff

Although participatory methods need to be implemented in land use planning as a means of incorporating local knowledge and interests, technical personnel are rarely trained to carry out effective participatory initiatives. What is written on paper in terms of participation is often not what is implemented in the field. Universities and technical schools are usually poorly equipped to introduce professionals to the concepts and methods of participatory programs. Educational institutions that train rural extension agents usually focus on agricultural and forestry aspects of resource management, rarely providing training on anthropology, ethnobiology, and participatory methods. As a result, the education of technicians is left to on-the-job training, which is erratic and often inefficient. In addition, extension agents are usually unprepared to deal with social and political issues related to land use and land tenure, such as those in the case studies presented here. Explicit attention to acquainting technical personnel with the assumptions of participatory approaches, and training them in methods of carrying them out, is therefore a key component of land use planning and sustainable development initiatives.
Encouraging Balanced Participation

Participation is a broad concept that allows room for significant confusion. Community-based participation is often seen as a necessary component simply because it is fashionable, and because it is often required by donor agencies. However, due to lack of adequate staff training and/or the lack of tradition by local communities themselves, participation is neither balanced nor effective. Women, for example, are often under-represented. Similarly, religious leaders are often not explicitly incorporated into the planning process, even though they are often important stakeholders at the local level.

A balanced representation of the views and interests of key stakeholders is critical not only with respect to incorporating local knowledge and perception into the process, but also to give the exercise a greater degree of credibility and political support. To accomplish this goal, the participatory process must be tailored to the habits and to the availability of the stakeholders involved.

The participatory approach also needs to be sensitive to the different interests and forms of organization that characterize various subgroups of the community, which can be divided in terms of gender, age, religion, and economic activity. Maps are important tools for analyzing such differences, especially with respect to land tenure and resource use. Maps can be usefully presented in different formats, and consultations should not be limited to large meetings or to gatherings that only include community leaders.

Providing Access to Information

Conventional land use planning often produces reports and presentations that are not accessible to key stakeholders. The format used to disseminate information during and after the conclusion of the various phases of the planning process is frequently inappropriate to the capabilities of individuals who may not be able to read or who are unfamiliar with the form in which information is presented. There are a number of examples where government institutions claimed to have carried out a participatory process, yet did so by convening a meeting at the wrong time, or by using a presentation format that was poorly adapted to local capabilities. In some cases, community members were called together and expected to discuss technical reports that ran several hundred pages long.

Participation is only possible if key information is made available to stakeholders in an appropriate format, which requires major changes in the conventional approach. Information needs to be provided in simple
text, specially prepared for particular stakeholder groups (for example, booklets, posters, and other forms of visual representation). Meetings should incorporate an educational component to help people understand key concepts and information, and the presentational formats should be informal and visually accessible.

Key lessons derived from the two case studies include the need to (1) provide clear information about the process in which communities are participating by specifying the roles, responsibilities, and timing of various activities involved; (2) document information in appropriate formats; and (3) make information available at all levels, including the household level.

**Institutional Partnerships**

Regional institutions are often untapped resources in the process of land use planning. They can play a critical role in strengthening local institutions, lowering planning costs, and promoting long-term support for sustainable development. Institutional partnerships are tricky, however. If not properly handled, they can be a source of problems that drain scarce resources.

It is important to emphasize the need to share responsibilities in community-based resource management initiatives (Renard 1997). It is often not possible for a community to handle all aspects of resource management. Partnerships with government and nongovernmental agencies and with the private sector are fundamental to promoting sustainable production systems.

A lesson that emerges from this analysis is the need to develop methods to forge partnerships between community organizations and other institutions and agencies that may be operating in the region, or that have a stake in local outcomes. Making visits and establishing personal contacts between communities and the relevant institutions can facilitate achieving this goal.

**Holistic Approach**

A key lesson that emerges from both cases is that mapping provides an opportunity for a holistic view of resource use. Technical personnel should therefore be trained to appreciate the relationships between natural, social, and economic factors, regardless of their particular area of expertise. In addition, the planning process should avoid the temptation to narrow the focus to issues that are mainly the areas of interest and expertise on the
part of the technical staff. Pitfalls such as these are commonplace in the conventional approach to planning.

The scope of land use planning should not be limited to a concern for resource use and conservation. Attention should be given to key issues that affect sustainable development initiatives, such as health and education. Broadening the scope of land use planning exercises can help increase participation since many of these issues attract the interest of key stakeholders. It should be remembered that local communities often make use of an array of resources, and that local representatives have a range of talents and knowledge that can be drawn upon. The goal is therefore to create an effective team that endorses a truly interdisciplinary point of view rather than a multidisciplinary group comprised of different specializations.

Economic Instruments to Implement Land Use Planning

Land use planning needs to cope with the fact that local people have very concrete agendas for short-term survival. This means that participation will depend on people's perception of how land use planning can affect their welfare. It is important to combine simple and short-term activities with those that are more long term, complex, and costly. This allows communities to give greater value to the planning effort and to feel more confident in defending their short-term needs. The consequence is greater commitment and motivation to engage in and implement participatory planning.

Forest conservation, for example, depends on how people perceive the derived benefits of such initiatives. Revenues that accrue from forest management or from payments in exchange for environmental services are thus critical in promoting forest conservation in designated areas. There is a need to combine planning with incentives for sustainable forest management. There are many challenges for forest management, including management itself. The latter involves the processing and quality of timber and nontimber products, and challenges associated with logistics, transport, and marketing. Nor is estimating the net incomes of forest-dependent peoples an easy enterprise (Anderson and Ioris 1992; Wollenberg and Ingles 1998; Wollenberg and Nawir 1998).

A lesson that emerges from the cases reviewed here is that planning new activities should take into account the existing activities that create seasonal constraints on resources and labor. In addition, planning should have a double focus. First, it should focus on traditional activities for
subsistence or commercialization. Secondly, it should focus on new activities, especially those that favor existing assets, both in terms of resources and local knowledge. Such initiatives should be based on a coherent business plan and should strive to bring together different communities in order to achieve economies of scale.

Conclusions

The road to sustainability is a long one. Land use planning can be seen as a continuous process by which a vision of the future is translated in terms of an ever-changing reality. As new information becomes available, perceptions of resource use change, as does the reality on which planning is based.

The participation of local stakeholders should not be treated as a simple facade, but as a central element in land use planning. Although there are several promising examples of participatory land use planning in the Amazon, there remains the need for formal scholarly work to generate findings that can improve on existing methods. The task of advancing participatory methods of land use and natural resource planning is an intellectual challenge with strategic importance to the effective field implementation of sustainable development projects.

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An Experiment in Participatory Mapping in Brazil’s Jaú National Park

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Between 1995 and 1998, the Vitória Amazonica Foundation (Fundação Vitória Amazônica, FVA) engaged in a participatory mapping effort with communities living within the boundaries of the Jaú National Park, located in the Amazon region of Brazil. Key players in this initiative included social and biological scientists, technical personnel from various government agencies and nongovernmental organizations (NGOs), and the people living in the area. The result of this collective effort was a zoning plan for the park that was agreed to by all of the stakeholders involved. The techniques that were used to create the maps of natural resources use, and the strategies employed to negotiate the conflicts of interests between the interest groups in the area, describe the conceptual and methodological basis for the Jaú project. By analyzing the participatory methods that were used to arrive at the consensus that was achieved, and by identifying the questions that still remain at this stage in the project, this chapter provides insights into the social, physical, and political factors involved in mapping and zoning resource use within a national park.

Introduction to the Project

The FVA is a Brazilian nonprofit NGO created in 1990 and headquartered in Manaus. The FVA’s objective is to integrate environmental conservation and improvement in human welfare in the Amazon region, particularly in the Rio Negro basin. Sustainable use of natural resources and respect for cultural and ethnic diversity are among FVA’s guiding principles. FVA’s team has been involved in the design and implementation of Jaú’s Na-
tional Park Management Plan since 1991. These activities have been carried out through partnerships (convênios) with IBAMA (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis), the Brazilian Institute for the Environment and Renewable Natural Resources.

Jaú Park (JNP), at 22,720 square kilometers, is the largest national park in Brazil and second largest in the humid tropics (map 14.1). In contrast to other parks in the Amazon, and to most protected areas and conservation units in Brazil, the JNP encompasses almost an entire river basin. The boundaries of the JNP are circumscribed by the Unini and Paunini Rivers to the north, and to the south by the Carabinani, a tributary of the Jaú River. Headwaters of the Paunini, Jaú, and Carabinani Rivers demarcate the park’s western boundaries, whereas the Rio Negro is the eastern boundary.

As in most parks in Brazil, people inhabit the Jaú area, although population density in Jaú is low. As of 1996, there were 143 families living within the park boundaries, mostly located in peripheral zones. Local residents understand that the park’s natural resources were, and continue to
be, affected by extractive activities carried out by outsiders (such as loggers, fishermen, and hunters) and by the residents themselves. However, these changes have not had an appreciable effect on the park’s forest cover.

In the early stages of establishing the Jaú management plan, background information was provided by historical narratives from the eighteenth and nineteenth centuries and by travel reports by Schubbart and his students (1977). In addition, FVA used thematic maps of the Radar da Amazonia (RADAM) Project, and two Landsat satellite scenes covering the area of the park. In assembling all of this information, the FVA team hoped to turn the JNP research project into a conservation model that could be applied elsewhere.

FVA led discussion sessions with the stakeholders deemed important to the future of the project. FVA, IBAMA, and local entrepreneurs jointly designed a set of guidelines for an assessment of the area. The FVA’s first in-depth contact with the park and its people began in 1992 when it carried out a socioeconomic survey and census of local residents. As the FVA group began to appreciate the social and biological complexity of the area, it became increasingly clear that the local residents were to play a key role, not only in understanding the park’s natural resources, but also in protecting the resources in the future. The information gathered during the early stages of the project also led the research team to conclude that the inhabitants had a fundamental right to remain in the area, and that the presence of people in the park could be rendered compatible with conservation objectives.

From then on, FVA began to include local residents in discussions concerning the park’s management plan. Survey results showed that the population had low levels of education and that illiteracy was common. These social characteristics, and the fact that people were geographically spread out across great distances, called for the development of a methodology that was adapted to local conditions and that could include the local population in the formulation of the management plan.

The Management Plan

The primary objective of a national park’s management plan is to preserve biodiversity and, at the same time, to identify areas that could be designated for public educational and recreational purposes. The plan was drafted using the methodological guidelines that IBAMA proposed in 1996, which were adapted in accordance with the results of the studies that the FVA had carried out in the park.
The FVA-sponsored research and related activities were carried out by a team of fifty-one researchers, not counting support and administrative personnel. Specific studies included inventories of the park’s flora and fauna, analyses of the watershed and flooding patterns, and a social component designed to document the socioeconomic characteristics of the population, their degree of social organization, and their use of natural resources in the area. Working in collaboration with a number of institutions, the FVA created a data bank using Geographic Information Systems (GIS) and became continually involved in public policies related to the park.

The strategy envisioned a management plan that would be “participatory, continuous, gradual, and flexible.” Despite resistance from some parties, the method called for the involvement of local residents in the discussion, elaboration, and implementation of the plan. The goal was not only to invite residents to meetings and to the various forums that were held, but also to provide them with information that the FVA had collected and to encourage them to voice their opinions, preferences, and needs.

**Stakeholders’ Analysis**

At the outset of the project, the views held by relevant stakeholders in the area could be summarized as follows.

(1) IBAMA. This organization is the constitutional authority in charge of protected and conservation areas in Brazil. Although many individuals within IBAMA consider the preservation of flora and fauna as the most important priority, it is fortunate that the agency is not monolithic in this respect. Indeed, the perspective that has come to prevail within the institution is one that advocates a balance between the conservation of nature and human development. Nonetheless, Brazilian law regards the human presence in protected areas as illegal, and, as an institution, IBAMA’s mandate is to remove them. IBAMA initial intent was to resolve the issue by either moving local residents to another location or by compensating them for the value of their investments and then removing them from the park.

(2) Park residents. At the outset local residents had no clear understanding of what was meant by a national park, nor did they fully understand what it meant to be living within one. Because violence was used to evict people from the neighboring Anavilhanas Ecologi-
caled Station, people associated the idea with a series of restrictions and threats to their livelihood. Understandably local residents feared and distrusted IBAMA. In the early stages of the project, before FVA’s role became clear, residents had a hard time telling the difference between FVA and IBAMA. Due to the lack of community organization, and because there was no institutionalized form of representation, the residents could be described as a group of individual actors rather than a unified interest group. The positions that emerged fell into three principal categories: Some wished to stay put at all costs, even if they had to negotiate and abide by rules about what activities they could and could not carry out; others viewed the situation as an opportunity to maximize the amount of compensation they could receive, after which they would willingly leave the area; and a third group adopted a wait-and-see attitude.

(3) The FVA. The FVA’s original intent was to carry out a scientific research project that was designed to assess the park’s natural features, and that included a social component as well. However, once the researchers came face to face with the situation that the park residents confronted, and in light of the commitment to integrate them into the management plan, the FVA ended up taking a more active role in organizing the community. The FVA assumed the additional responsibility of disseminating information and promoting group discussions, in some instances becoming an advocate for community interests, even though the FVA had no mandate or clear basis for doing so.

(4) Local elites. In the municipalities (municípios) that border on the park there is an overlap between the political and economic elites. In many instances, those who hold public office are also merchants and middlemen engaged in the marketing of products that are extracted from the surrounding area. As a result, the mayors (prefeitos) and city councillors (vereadores) in the neighboring municipalities of Novo Airão and Barcelos viewed the park as an infringement on their power to exploit the natural and human resources in the area. Despite a public discourse that endorsed environmental concerns, local politicians urged people to oppose the creation of the park and supported their right to unhindered access to the park’s natural resources. Both IBAMA and the FVA were viewed with distrust, especially in light of the initiatives undertaken by both organizations to educate and organize the population. Yet, in the final analysis, poli-
ticians in both municipalities collaborated in the construction of schools as a means of appealing to voters.

(5) The FVA researchers. Like the residents of the park, the researchers involved in the project did not initially think of themselves as being players in a collective process. With a few notable exceptions, the researchers mainly thought of their mission as having the exclusively academic objective of accumulating information rather than explicitly taking a political stand. At most, the researchers thought that the findings that they produced could be used by other actors involved.

(6) Local businesses. The business enterprises with a stake in the park were associated with two major sectors—the export of products extracted from the area (such as timber, turtles, and commercial and ornamental fish), and those involved in organized tourism who brought sport fishermen into the area, despite the fact that this activity was illegal. Although some of these groups belonged to organized institutions, such as the Ornamental Fish Association, few of the actors openly lobbied on behalf of their interests. For the most part, they tended to see IBAMA and FVA as a threat to their enterprises and were prone to spreading damaging rumors about the organizations.

(7) Other actors. Additional stakeholders included the state of Amazonas and its various agencies such as the Institute for the Environmental Protection of the Amazon (Instituto de Proteção Ambiental do Amazonas, IPAAM), the Land Institute of Amazonas (Instituto Fundiário do Amazonas), and the Public Counselor (Ministério Público). Federal institutions also played a role, including the National Institute for Historical Patrimony (Instituto Nacional do Patrimônio Histórico), although the presence of this organization was limited. Agencies such as the Ministério Público mainly served as mediators in public hearings, or negotiated divergent political interests, as in the case of the state government.

For the management plan to be truly participatory it was necessary that all stakeholders be organized, and that they have full access to the gathered information. By the same token, it was necessary to provide forums for them to voice their interests at each point in the process of consolidating the plan. The FVA focused its attention on park residents and devoted its efforts to carrying out the analyses that the project required. The method
that the FVA devised called for an action-research approach in order to execute a participatory mapping effort of the park area. In the process of doing so, the objective was also to achieve the more intangible goal of increasing the level of organization of the local population.

**Methodology**

According to the management plan developed by the FVA (1998a), “Action-based research is a scientific practice that promotes the integration of researchers and their subjects in the concrete process of executing a study. That interaction produces outcomes that influence the very social processes that are the object of analysis by overcoming the initial limitations of social organization and exclusion, yet at the same time enhancing scientific understanding. The research activities, and the implementation of community education and organization initiatives, involved the articulation of popular and scientific knowledge and were based on the principles of equality, freedom of expression, and respect for diversity.” In keeping with these principles, the participatory mapping of natural resources that was carried out by the park residents was an excellent example of how, in the process of collecting information essential to the management plan, it was possible to incorporate the knowledge and involvement of the local population in order to produce the zoning map for the park.

Between 1992 and 1994, the participatory mapping exercise began with visits to each residence. Individuals within each household were identified in order to demarcate the area used for their livelihood and to identify the types of activities that were carried out in different places. Along with georeferenced maps of the rivers and streams in the area, the results of the participatory initiative provided knowledge about the distribution of natural resources, as well as about the social, cultural, and economic characteristics of the population. Beginning in 1996, a number of strategically located meetings were held. In addition to discussing the map itself, the meetings were an opportunity to address the concepts underlying the management plan, as well as broader issues such as the tenure status of landholders located in the park. The gatherings also provided the occasion for bringing together people who lived along distant stretches of the river. The researchers who attended the meetings were always an interdisciplinary group that included specialists in both the social and natural sciences.

The community meetings often started with attempts to break down the barriers that often arise in encounters between city-based academics (referred to as “doctors” by the locals) and members of the community
(who described themselves as “without knowledge” or “without education”). The objective was to establish a degree of understanding and empathy among the participants in the discussion. The approach used humor and jokes as a means to overcome social, economic, age, and gender divisions that may have existed. It was a style of interaction that the community members themselves came to adopt in their own meetings. In places where religion played a strong role, the meetings were often introduced with prayers led by community leaders. Follow-up meetings took place in order to share and discuss the findings obtained during previous visits, to present new issues to the various groups, and to clarify any remaining doubts or misunderstandings.

Training sessions were held to explain the satellite images that would become the basis for the maps to be produced. Because the maps were two-dimensional representations of the three-dimensional physical context in which the people lived, it was necessary to educate people in the interpretation of the images. The colors and icons that appeared on the map were decoded by making reference to actual surroundings and by carrying out simple exercises. Using images and large-scale maps representing only the hydrological system that made up the watershed, the participants were asked to identify and name rivers, lakes, and tributaries. They were then asked to overlay their own maps, and to use colored flags and icons to spatially locate the house they lived in as well as the various livelihood activities that had been identified during the early round of interviews and discussions. These locations included agricultural plots, fishing sites, and most distant points where extractive activities had taken place, such as rubber tapping. Each family was designated by a different color, and each activity by a different symbol. The map-making exercises were organized so that the occasions could also be used to accomplish other objectives. For example, when one family was working on the map, parallel meetings were held between other families and technical personnel, including lawyers, agricultural extension agents, and researchers.

The distribution of flags generated a map that depicted not only the territory that was exploited by each family, but also the spatial distribution of natural resources in the area. These data were later introduced into a GIS in order to produce georeferenced maps of the location and social uses of the natural resources located within the park. The process, which was carried out in 1997 and 1998, accounted for nearly 100 percent of the families. The maps generated through these methods were consistent with other sources of information, such as land cover classifications derived from the independent analyses of satellite images.
The procedures described here were systematically carried out through a continuous process that incorporated and gave equal voice to the people involved. The various methods comprised a set of activities that promoted the participation of individuals and the social organization of communities. In addition to establishing the basis for the participatory mapping, the techniques generated suggestions and solutions important to the elaboration of the management plan for the park.

The collaborative effort to construct tangible outcomes, and the strategy of continually returning to the communities for further discussions and interactions, were fundamentally important to the process of creating what the FVA referred to as “resident” social actors. In this way, the knowledge held by individual members of the community was legitimized and incorporated into the process of generating information pertinent to the objectives of the project.

Zoning the Park

Once the resource use maps were completed, the information was presented in meetings held with community representatives, who proceeded to formulate a zoning plan for the park. The latter was discussed among people that they represented and was considered in light of the plan that the researchers proposed. Playing the role of mediator in the process, the FVA suggested ways that the two maps could be rendered compatible. Understandably, the version put forth by the residents focused mainly on the riverine areas that they either occupied or used (map 14.2). The map constructed by the researchers encompassed the entire park (map 14.3). Despite some differences between them, the FVA was able to integrate both versions into a single representation of the area (map 14.4).

The map that resulted from this process provided the basis for demarcating those areas of the park that the residents could use. Known landmarks were represented, along with the rivers and tributaries located in the park. The resources designated for use included timber, Brazil nuts, rubber trees, hunting grounds, fishing spots, and turtle harvesting areas. Using the map of the watershed as reference, a 1.5-kilometer band along the river banks was defined as the occupation zone. This distance was selected because it represented the average of the estimated width of the areas used by park residents, visiting tourists, and fishermen as they pursued their various activities. Smaller polygons were aggregated to form a continuous band and adjustments were made by overlaying the use zones with soil maps of the park. The final map, which excluded low-lying areas
Map 14.2. Zoning of the Jaú National Park according to residents’ perspective

Map 14.3. Zoning of the Jaú National Park according to researchers’ perspective
subject to seasonal inundation, identified “zones of extensive use,” “zones of intensive use,” and a third category called “zones of special use.”

**Negotiations with IBAMA**

The map produced by the participatory method, and which was revised in subsequent discussions with the researchers, was then the basis for negotiations with IBAMA. The talks with IBAMA included delegates from the communities living in the park and representatives of the various stakeholders, including businessmen in the area.

The talks were extremely tense due to the situation in which IBAMA found itself. If the agency accepted the maps that were produced by the communities, the acceptance would signify an implicit recognition of their right to live within the park—an outcome that would be counter to IBAMA’s legal mandate. After a week of intensive negotiations, there emerged a five-year truce during which the residents were included in the “special use zone.” The size of the zone was intentionally overestimated to encompass nearly 14 percent of the park’s total area. During the five-year period covered by the arrangement, the special area would be subject to much more detailed zoning. Additional features of the agreement included
a number of activities that directly involved residents in the protection of the park itself.

The final negotiations with individuals elected by the communities in Jaú took place in the IBAMA offices in Brasília. Although the participants from IBAMA later included a number of people who represented the strong preservationist faction within the organization, the meetings led to an agreement that was accepted by all parties. The successful outcome of the discussions was largely made possible by the favorable stance adopted by individuals highly placed in IBAMA’s organizational structure.

Despite this success, it is clear that the consensus that was achieved is a fragile one. Many of the terms of the agreement still must overcome resistance within IBAMA. Moreover, to protect themselves in the future, it will be necessary for the park residents to organize themselves into officially recognized entities rather than relying on the FVA or counting on favors from IBAMA. Part of the challenge that they face is the need to devise mechanisms to keep people better informed, and to endorse the idea that representing community interests is more a question of accepting responsibilities than enjoying privileges.

As for the researchers involved, the next step is to advance the management plan in ways that incorporate biological and social factors and that build on the participatory method that was developed. The micro-zoning of the special use area, to be carried out with park residents, is the most immediate task. As in earlier stages of the project, the zoning effort calls into play the need to join scientific and traditional knowledge, and faces the challenge of enhancing the degree of community participation in the process of learning more about the park’s natural resources and biodiversity.

The FVA, for its part, faces the challenge of accompanying the process by which the community organizations mature and become more independent. An important factor is for the FVA to have greater confidence in the ability of the community organizations to defend themselves, yet, at the same time, to continue to help them collect and analyze data. Finally, the FVA will be engaged in an effort to find and promote low-impact economic activities that can improve the residents’ quality of life and thereby improve their chances of remaining in the park.

Conclusions and Disquiets

The effort to map and zone the Jaú National Park was successful on a number of counts. The high degree of community participation and the effectiveness of that involvement in the formulation of the management
plan were among the project’s accomplishments. Similarly, the research and community development initiatives served to clarify the roles played by the various stakeholders, including the FVA itself. Still, advances such as these are not sufficient to ensure the long-run success of the effort.

If all points of view are to be openly expressed and recognized, the various stakeholders, acting independently of one another, must have full access to information. In addition, there must be an institutionalized forum in which divergent opinions can be expressed and conflicts of interests negotiated. A related issue concerns the need to change Brazilian law in order to recognize the rights of area residents to remain within the national park. Living under the constant threat of expulsion, as they now do, is likely to promote attitudes and behaviors that undermine the integrity of the area that so many have an interest in protecting.

The participatory mapping experience is undoubtedly an important tool in the formulation of a management plan to conserve biodiversity. Although the Jaú case indicates that the approach is viable, at this point in the process the participatory method still remains a goal to strive for. Its ultimate success will depend on the stakeholders themselves, and their ability to continue a constructive dialogue among the various actors. A full evaluation of the strengths and weaknesses of the methods and procedures of the action-based research and planning strategy will only come later, when the Jaú experience is assessed in light of similar initiatives elsewhere.

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