Deforestation and Land Use in the Amazon

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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

1992); and infrastructure (urbanization, access/roads and markets, for instance, Alves, chap. 3 in this volume; Browder and Godfrey 1997). 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 Medicilândia, 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-

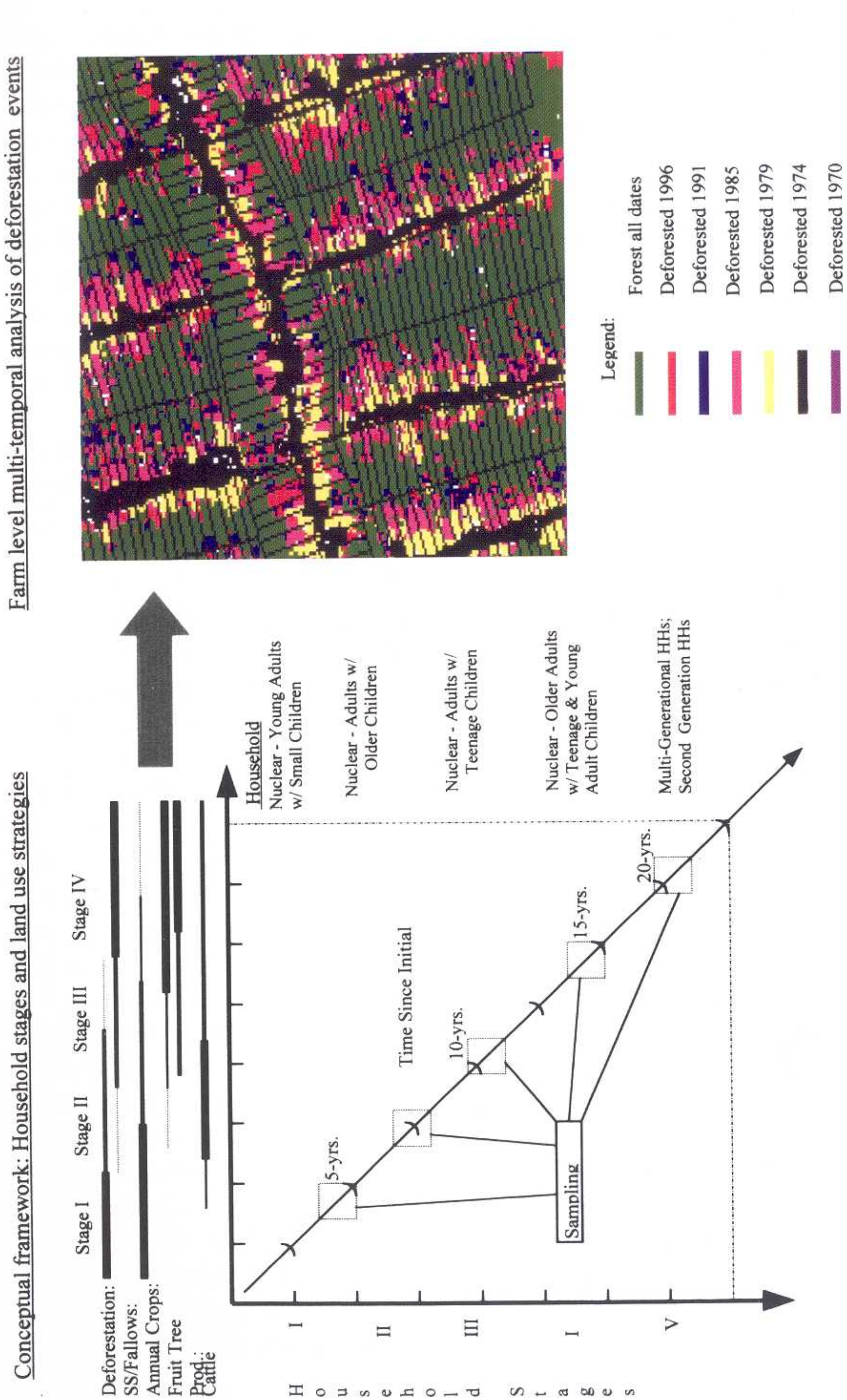


Fig. 5.1. Linking a conceptual framework of household stages and land use trajectories to a remotely-sensed-based assessment of farm-level multitemporal analysis of deforestation events

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 Amazônia, 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

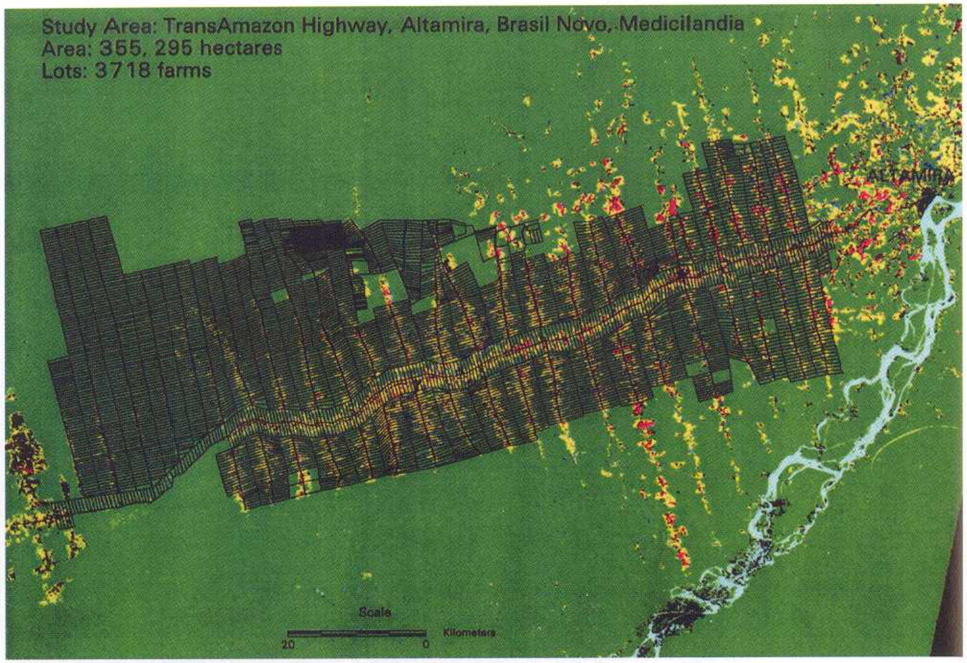


Fig. 5.2. Study area: Transamazon Highway, Altamira, Brasil Novo, Medicilândia, Pará State

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 Aerolevantamentos 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.

Landsat TM (1985, 1988, 1991, and 1996). Digital data were classified using a hybrid approach and taking advantage of a large field-based data set comprised of training samples and detailed vegetation inventories collected during 1992, 1993, 1997, and 1998. Images were classified into classes of water, forest, initial secondary succession (SS 1), intermediate secondary succession (SS 2), advanced secondary succession (SS 3), pasture, bare soil, and, for 1985 and 1991, sugarcane plantations. Detailed descriptions of classification methods and accuracy assessment can be found in Mausel et al. 1993; Moran et al. 1994; and McCracken et al. 1999.

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

Table 5.1. Distribution of farm lots into cohort groups and definition of cohort groups

Cohorts[a]	Freq.	Percent	Cum.
1970–73	121	3.25	3.25
1975–76	1,033	27.78	31.04
1978–79	791	21.27	52.31
1979–85	443	11.92	64.23
1985–88	176	4.73	68.96
1988–91	90	2.42	71.38
1991–96	531	14.28	85.66
new	533	14.34	100.00
Total	3,718	100.00	

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.

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

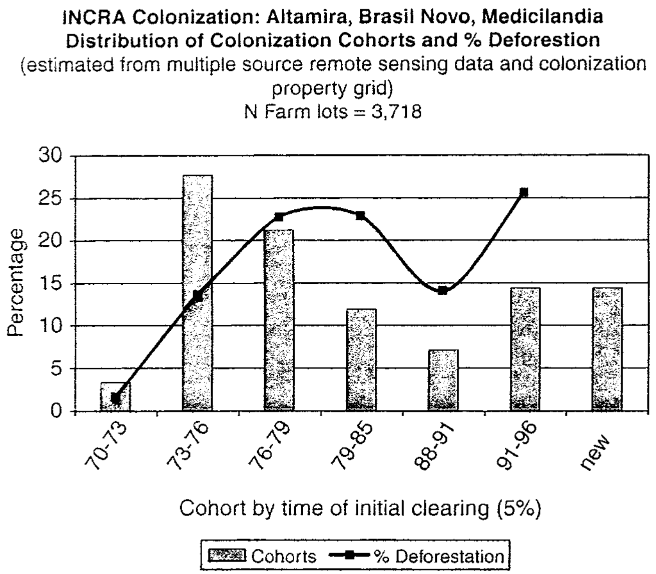


Fig. 5.3. The colonization area: deforestation trajectory and cohort arrival

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.

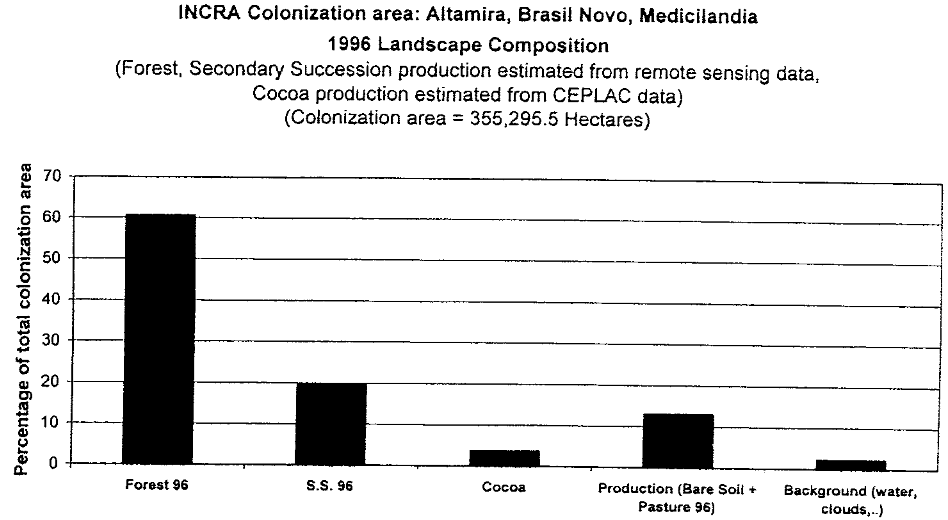


Fig. 5.4. Land cover composition of the 1996 colonization landscape

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.

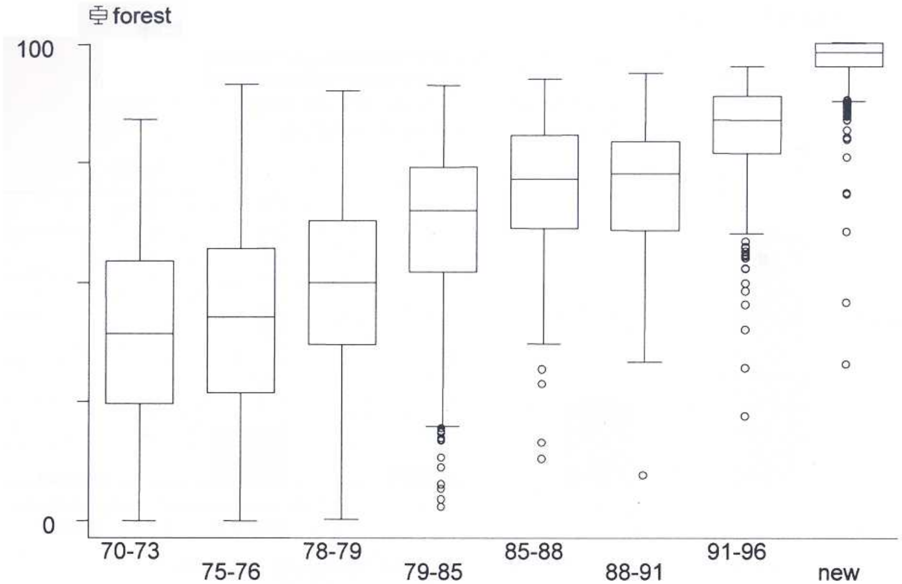


Fig. 5.5a. Total forest cover (%) in 1996 by farm cohorts

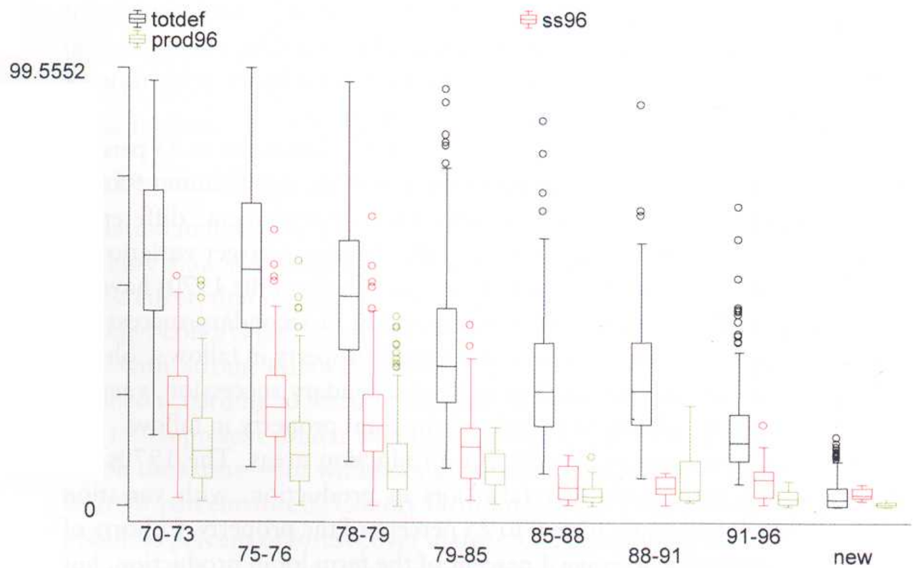
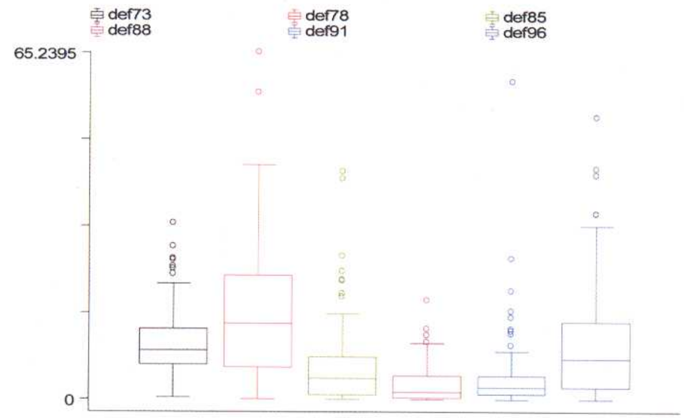


Fig. 5.5b. Total deforestation, secondary succession, and area in production (%) in 1970–96 by farm cohorts

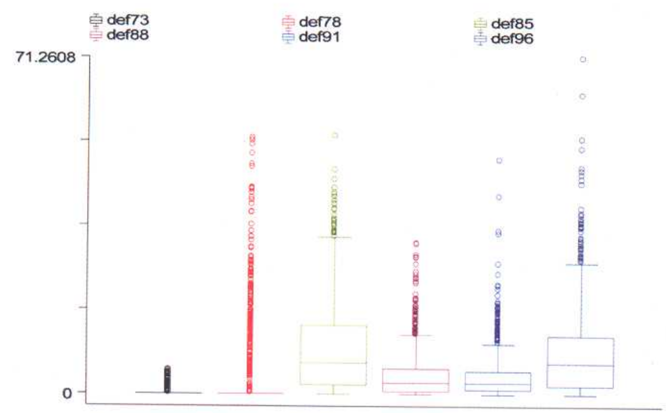
Farm-Level Deforestation Trajectory Across Cohorts

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-

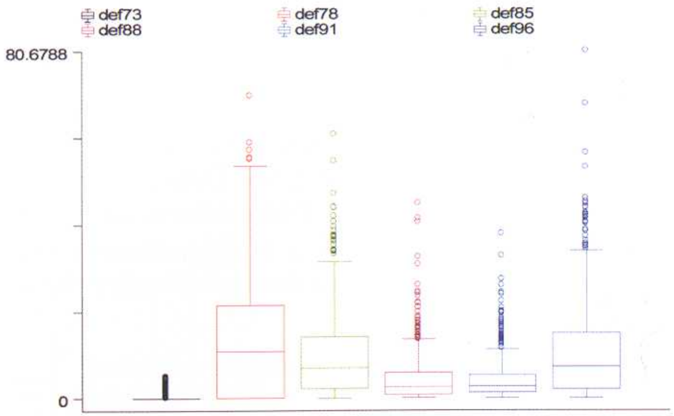
Figs. 5.6a–h. Deforestation trajectories (quartiles) for each cohort



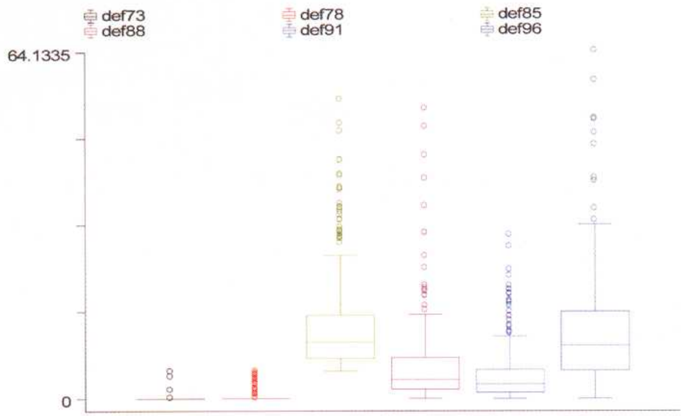
5.6a. Deforestation trajectory [73-96] of Cohort [1] 1970–73



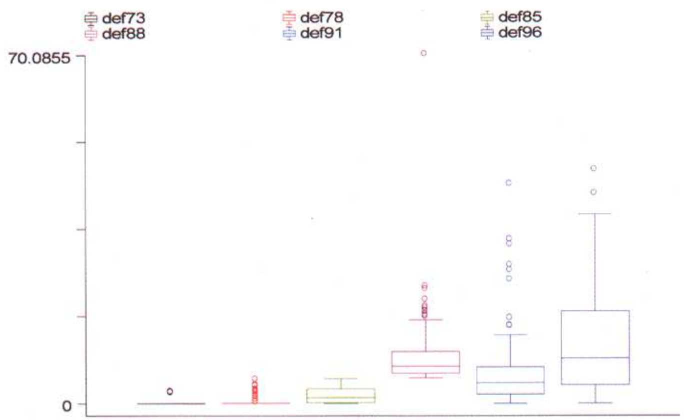
5.6b. Deforestation trajectory [73-96] of Cohort [2] 1975–76



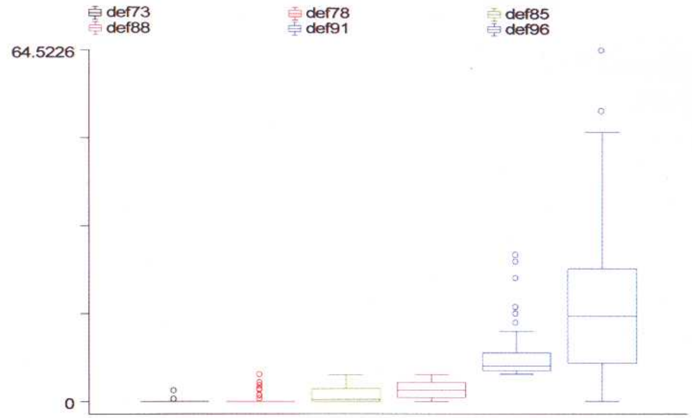
5.6c. Deforestation trajectory [73-96] of Cohort [3] 1978–79



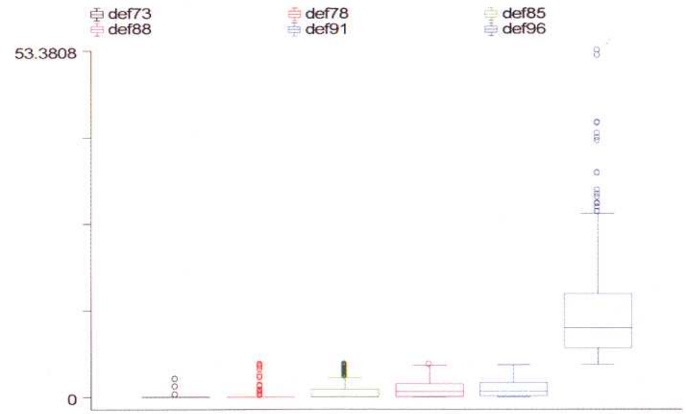
5.6d. Deforestation trajectory [73-96] of Cohort [4] 1979–85



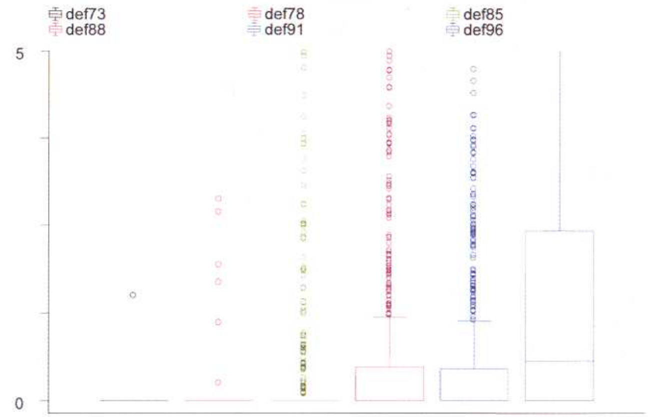
5.6e. Deforestation trajectory [73-96] of Cohort [5] 1985–88



5.6f. Deforestation trajectory [73-96] of Cohort [6] 1988–91



5.6g. Deforestation trajectory [73-96] of Cohort [7] 1991–96



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

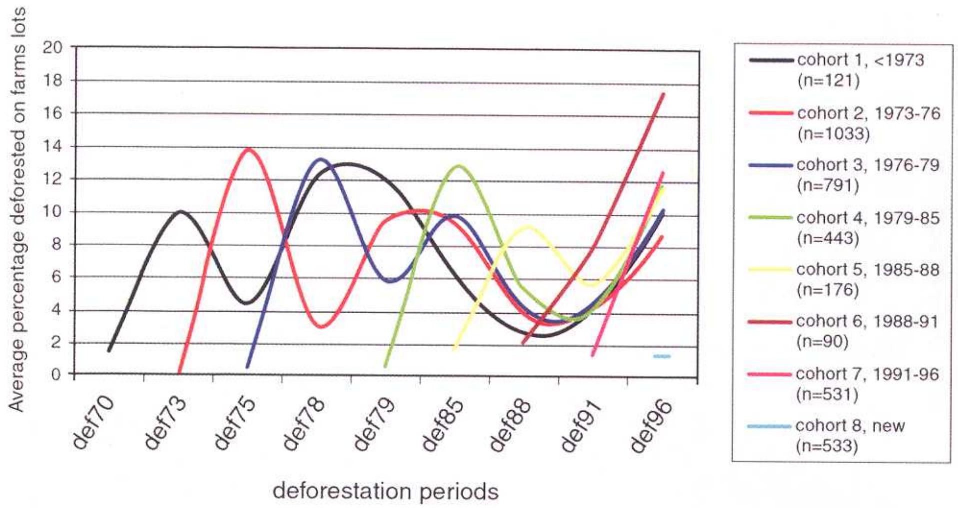


Fig. 5.7. The colonist footprint: Average deforestation trajectories by colonization cohorts

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

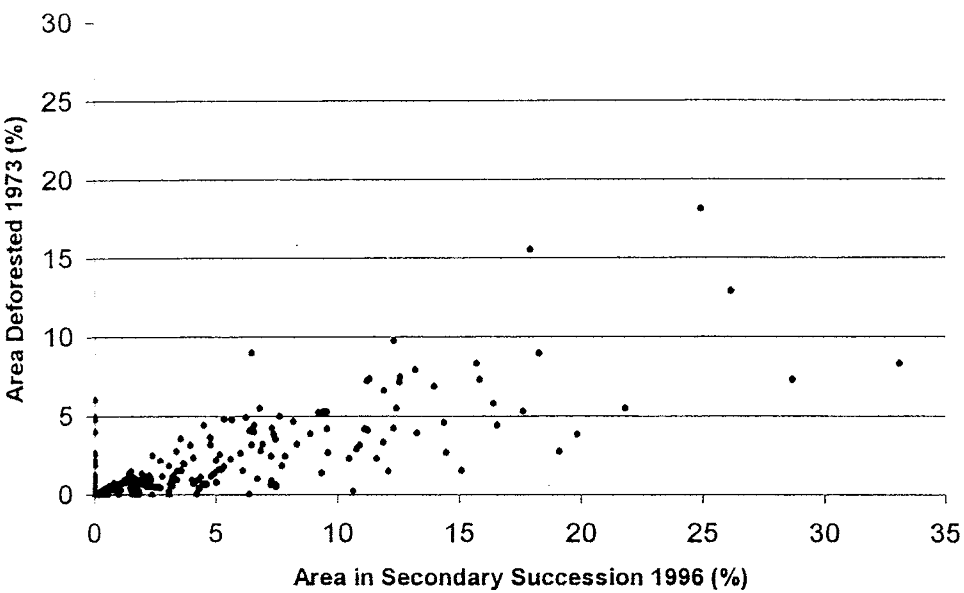


Fig. 5.8a. Deforested area in 1973 turning into secondary succession in 1996; farm level (n = 802)

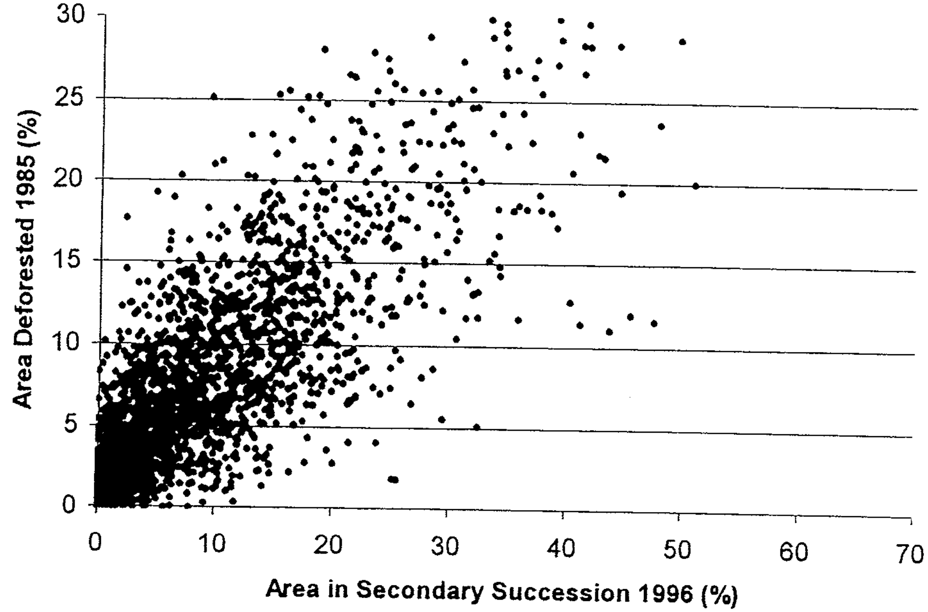


Fig. 5.9a. Deforested area in 1985 turning into secondary succession in 1996; farm level (n = 3288)

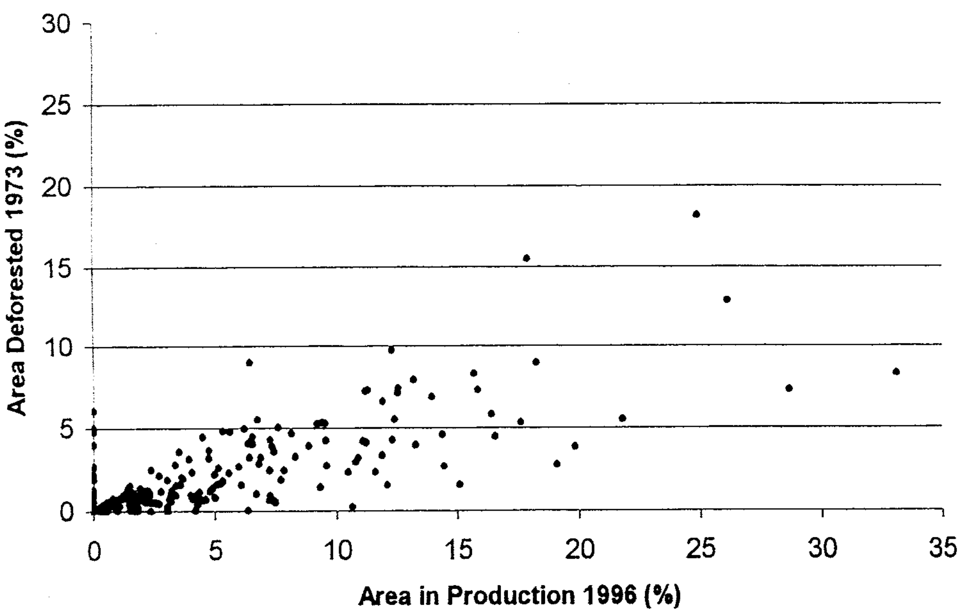


Fig. 5.8b. Deforested area in 1973 turning into production in 1996; farm level (n = 802)

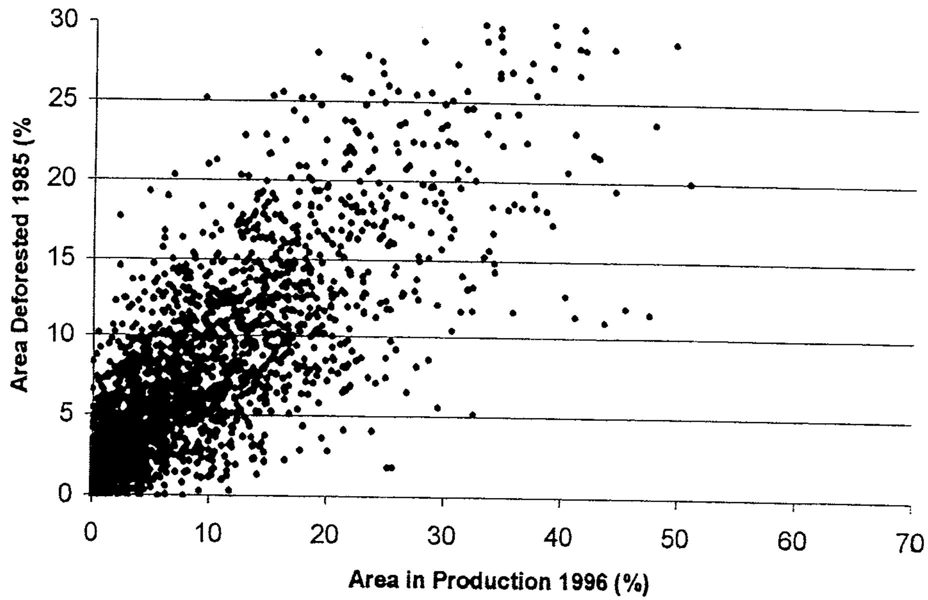


Fig. 5.9b. Deforested area in 1985 turning into production in 1996; farm level (n = 3288)

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 subregions 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 socioeconomic conditions that interact with period effect. Field observations in 1997 and 1998 show that the introduction of a new grass (locally called *braquiarão* [*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 scantly 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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References

Alves, Diógenes. 1999. An Analysis of the Spatial Patterns of Deforestation in Brazilian Amazon in the 1991–1996 Period. Paper presented at the conference Patterns and Processes of Land Use and Forest Change in the Amazon, March 23–26. Gainesville: Center for Latin American Studies, University of Florida.

Brondízio, E. S., and A. D. Siqueira. 1997. From Extractivists to Forest Farmers: Changing Concepts of Caboclo Agroforestry in the Amazon Estuary. *Research in Economic Anthropology* 18: 234–79.

Brondízio, E., E. Moran, P. Mausel, and Y. Wu. 1994. Land Use Change in the Amazon Estuary: Patterns of Caboclo Settlement and Landscape Management. *Human Ecology* 22, no. 3: 249–78.

Browder, John O. 1988. Public Policy and Deforestation in the Brazilian Amazon. In *Public Policies and the Misuse of Forest Resources*, edited by R. Repetto and M. Gillis, 247–97. New York: Cambridge University Press.

Browder, J. O., and B. Godfrey. 1997. *Rainforest Cities: Urbanization, Development, and Globalization of the Brazilian Amazon*. New York: Columbia University Press.

Hecht, Susanna. 1985. Environment, Development and Politics: Capital Accumulation and the Livestock Sector in the Eastern Amazon. *World Development* 13, no. 6: 663–84.

Kaimowitz, David, and Arild Angelsen. 1998. *Economic Models of Tropical Deforestation: A Review*. Bogor, Indonesia: Center for International Forestry Research (CIFOR).

Mahar, Dennis J. 1989. *Government Policies and Deforestation in the Brazilian Amazon Region*. Washington, D.C.: World Bank.

———. 1979. *Frontier Development in the Brazilian Amazon: A Study of Amazonia*. New York: Praeger.

Mausel, P., Y. Wu, E. Moran, and E. Brondízio. 1993. Spectral Identification of Succession Stages Following Deforestation in the Amazon. *Geocarto International* 8, no. 4: 61–71.

McCracken, S., E. Brondízio, D. Nelson, E. F. Moran, A. Siqueira, and C. Rodriguez-Pedraza. 1999. Remote Sensing and GIS at Farm Property Level: Demography and Deforestation in the Brazilian Amazon. *Photogrammetric Engineering and Remote Sensing* 65, no. 11: 1311–20.

Moran, E. F., E. Brondízio, P. Mausel, and Y. Wu. 1994. Integrating Amazonian Vegetation, Land Use and Satellite Data. *BioScience* 44, no. 5: 329–39.

Ozorio de Almeida, A. L. 1992. *The Colonization of the Amazon*. Austin: University of Texas Press.

Pichón, Francisco. 1997. Settler Households and Land-Use Strategies in the Amazon Frontier: Farm-Level Evidence from Ecuador. *World Development* 25, no. 1: 67–91.

Pichón, F., and R. Bilsborrow. 1992. Land Use Systems, Deforestation and Associated Demographic Factors in the Humid Tropics. Paper presented at the International Union for the Scientific Study of Population (IUSSP) Seminar on Population and Deforestation in the Humid Tropics. Campinas, São Paulo, Brazil.

Schmink, M., and C. H. Wood. 1992. *Contested Frontiers in Amazonia*. New York: Columbia University Press.

Wood, C. H., and D. Skole. 1998. Linking Satellite, Census, and Survey Data to Study Deforestation in the Brazilian Amazon. In *People and Pixels: Linking Remote Sensing and Social Science*, edited by D. Liverman, E. Moran, R. Rindfuss, and P. Stern, 70–93. Washington, D.C.: National Academy Press.