# PEOPLE AND THE ENVIRONMENT

## *Approaches for Linking Household and Community Surveys to Remote Sensing and GIS*

*edited by*

**Jefferson Fox**
*East-West Center - Honolulu*

**Ronald R. Rindfuss**
*University of North Carolina - Chapel Hill*

**Stephen J. Walsh**
*University of North Carolina - Chapel Hill*

**Vinod Mishra**
*East-West Center - Honolulu*

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Chapter 3

# HOUSEHOLD DEMOGRAPHIC STRUCTURE AND ITS RELATIONSHIP TO DEFORESTATION IN THE AMAZON BASIN


Emilio F. Moran
*Anthropological Center for Training and Research on Global Environmental Change, Indiana University*
*moran@indiana.edu*
Andréa Siqueira
*Anthropological Center for Training and Research on Global Environmental Change, Indiana University*
Eduardo Brondizio
*Anthropological Center for Training and Research on Global Environmental Change, Indiana University*



**Abstract** The greatest challenge to theory in human ecology has been how to define the unit of study so that it can be reasonably well studied, while at the same time not losing sight of the larger whole or ecosystem within which human beings interact with their biophysical surroundings. Some relevant theoretical approaches used to address particular questions include those aiming at explaining patterns of agriculture intensification (e.g., Boserupian and Von-Thunenian models), and household development cycles (e.g., Chaianovian models). In this project we ask what the role of household demographic structure on observed rates of deforestation might be. The study of human impacts on land cover can follow any number of approaches. What we have found most useful is to take a multi-scaled approach that examines at each level of aggregation both biophysical and socioeconomic variables. We have used a variety of methods of data collection and mined a variety of data sources: time-series Landsat satellite data; survey research; stratified random sampling of properties; registering property boundaries onto satellite image time series in a geographic information system; carried out soil and vegetation stand sampling with precise coordinates using GPS; examined the reproductive histories of women and their decisions using survey research at the household level; and obtained time series price data and other economic statistical time-series. A key goal of this study was to understand whether trajectories of deforestation could be better understood knowing the age and general structure of households through time, rather than just in aggregate number.

We think that our study does show the technical feasibility of examining land use and land cover change at the level of households and properties—and that the insights are worth the effort and investment required to achieve it.

**Keywords:** Population and environment, Amazon, household demographic structure, deforestation, land use, land cover

## 1. INTRODUCTION

Our research on population and the environment evolved from earlier interests some of us have had in government-directed colonization into the Amazon Basin, the process of adaptation by migrants to a new biophysical and social environment, and on trajectories of deforestation (Moran 1976, 1981, 1987, 1990, 1993). Theoretically we have been guided by a set of theories generally referred to as human ecology (Moran 1979, 2000; Moran and Brondizio 2001), and more recently as environmental social science (Moran in preparation). Its antecedents are the work of geographers and anthropologists such as Julian Steward (1955), Robert Netting (1968, 1981), Carl Sauer (1958), William Denevan (1976), Karl Butzer (1980), Roy Rappaport (1967), and others. The greatest challenge to theory in human ecology has been how to define the unit of study so that it can be reasonably well studied, while at the same time not losing sight of the larger whole or ecosystem within which human beings interact with their biophysical surroundings. Several solutions have been offered in the past: the use of a cultural area as the equivalent of a biogeographical area (Kroeber 1939); the use of social organization for subsistence as a core set of variables (Steward 1955); and the ecosystem as a unit of analysis (Rappaport 1967; Moran 1990, for a review of the ecosystem literature). From the onset we realized that no "monolithic" theory could account for human decisions and land use change in the region. However, some relevant theoretical approaches used to address particular questions include those aiming at explaining patterns of agriculture intensification (e.g., Boserupian and Von-Thunenian models), and household development cycles (e.g., Chajanovian models).

In this particular project we were driven to ask what the role of household demographic structure on observed rates of deforestation might be. This question was suggested by earlier work in the region (Moran 1976, 1981) in which it was observed that younger households pursued very different land use strategies than middle aged and aging households. In a frontier region, where labor is generally scarce, the number of working age members might reasonably be inferred to play a key role in how much labor a household can muster for farm work and thus which strategies are likely to be chosen. Yet, it was also observed that households pursued a more intense process of deforestation at the outset, when they had least labor. The result of these observations in the field, in the course of studying issues of adaptation and trajectories of secondary succession, led to our current project on population and environment.



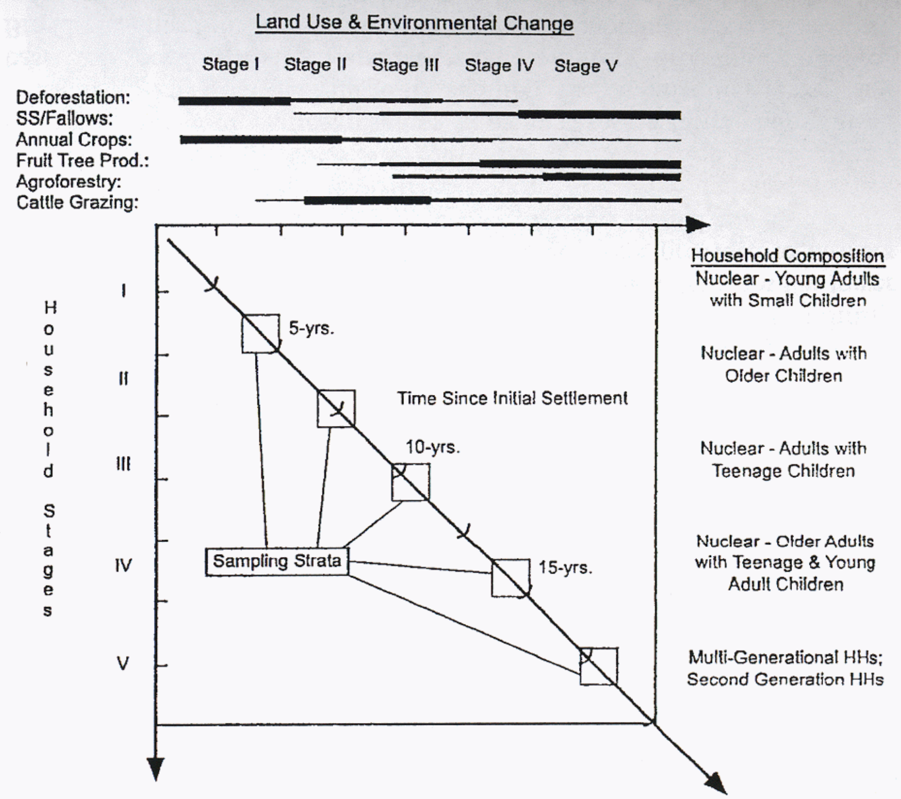


*Figure 1.* Conceptual model of demographic and environmental change (Brondizio et al. In press)

Figure 1 illustrates the conceptual model that guided this research linking household demographic structure to the deforestation and land use behavior of households. The model posits that there is a developmental cycle (Goody 1962, 1976) resulting from the changing age and gender composition of the household over time. The timing and magnitude of these reproductive decisions are expected to affect how households relate to environment and economy. The model proposes that younger households, with very young children and low supplies of capital, will focus on annual crops in the frontier as a way of building up their capital stock, and as a way to transform the biomass of the forest into fertilizer for fast growing crops. Over time, we expected these households to shift from annual crops to pasture and more cash and labor demanding activities such as cash crops and permanent tree crops, such as mahogany, cocoa, pepper, and sugar cane. As the young people in the household reach marriageable age, we expect the household heads to shift again towards less labor demanding crops, and to crops, which ensure them of regular cash flow. We expect with another generation taking over the farm that the process will be repeated, but limited by the much smaller supply of forest and the presence of permanent crops and pastures as initial conditions.

The study of human impacts on land cover can follow any number of approaches. What we have found most useful is to take a multi-scaled approach that examines at each level of aggregation both biophysical and socioeconomic variables. We have used a variety of methods of data collection and mined a variety of data sources: time-series satellite data such as Landsat; survey research; stratified random sampling of properties; registering property boundaries onto satellite image time series in a geographic information system; carried out soil and vegetation stand sampling with precise coordinates using GPS; examined the reproductive histories of women and their decisions using survey research at the household level; and obtained time series price data and other economic statistical time-series. We will examine these design questions in the pages that follow.

## 2. RESEARCH DESIGN

The project began with one great advantage in that the PI and co-PIs had years of experience in the region, and had already collected substantial biophysical and social data over a period of several years. We developed detailed measurements to characterize land cover structure and composition to inform spectral data analysis. We emphasized the most dynamic land cover classes -- stages of secondary succession and pasture. These are key land cover classes that inform the analysis of land use trajectories associated with agropastoral cycles. Detail vegetation inventories of 25 areas representing land cover classes in the area were undertaken. In each vegetation area, we used nested plots (n=10) of 150 square meters, with subplots (n=10) of ten square meters randomly distributed. These plots were used to measure (height, DBH, number of individuals) and identify trees, and saplings and seedlings, respectively. Using these inventoried areas to provide structural parameters defining types of land cover, more than 300



training samples were collected to be used during image classification (see Moran and Brondizio 1998).

Thus, we already had a reasonably good idea of the trajectories of deforestation at the landscape level between 1985 and 1991. We had good survey data on histories of land use in the regions where vegetation and soil sampling had been carried out. This work gave us substantial insights into the role of soils and land use on the rate of secondary succession or regrowth following deforestation, and we were able to demonstrate the feasibility of monitoring stages of secondary succession in the Amazon using a combination of field studies and satellite remote sensing (Mausel et al. 1993; Moran et al. 1994; Brondizio et al. 1994; Moran and Brondizio 1998, 2001). This work was at the landscape level and provided important insights. However, we felt that to understand decisions about deforestation we had to focus more on household structure and household decision-making and thus our project grew to incorporate this dimension.

### 2.1 Study Area

The original government colonization scheme proposed to build a road across the Amazon Basin, the Transamazon Highway, and it also included building planned communities/villages (agrovilas) every 10 kilometers along the main road, and also 10 km inside the feeder roads. The initial plan was to have in each village, a community center where basic services (a primary school, a health post staffed by a nurse, an ecumenical church, a water tower to ensure supply, and some agricultural storage) were provided to farmers and their families. Ideally, the farm plots were to be located at a distance no greater than 4 km from the village within which the farmers resided. However, this idea's scheme was subverted by the decision to let farmers choose their own properties, resulting in many cases, in farms ending up as much as 20 km from the village. In addition, the communities lacked any basis for social cohesion: families came from very different regions of Brazil, belonged to very different religious denominations which were unfriendly to each other and unwilling to be ecumenical or planned for, the health and education posts often went unfilled, and the water towers failed to guarantee a supply of potable water. Over time, families began to abandon these poorly-serviced villages and began to settle on the farm properties to make their commute easier.

The conception of community in any frontier site must by its very nature be fluid. Church membership and region of origin can help define a sense of community. But in an area with so many people from different regions and religions, the sense of community emerged slowly. Few things acted to bring members of the villages together into a "community." Over time, most of these villages have been abandoned as farm communities and they have been occupied by single workers or landless relatives. They are, in fact, dorm communities with very little social cohesion. Many of them have been entirely abandoned, especially those in the side roads.

A key element in our research strategy was an early methodological decision. We had obtained in the past a property grid used by the colonization agency in keeping track of the land allotments to settlers. Since in this colonization project the colonization agency gave each household one property in the settlement scheme, there was a one-to-one relationship between households and properties, so that by observing changes in a property using satellite images, we could begin to observe the outcome of household decisions over time in a spatially explicit fashion. So one important first step in our research was figuring out a way to overlay the property grid onto the satellite images (see Figure 2a, b) (which themselves were overlaid on each other in a time series) with sufficient accuracy that we could examine change in land cover at both the landscape and the property level. The property grid added an entirely new capability to the understanding of land cover changes over time. Observation of the Landsat image provides a good idea of changes but these cannot be tied to any particular household. With the overlay of the grid, and of an ID for each property, it becomes possible to query land cover change on any particular property.

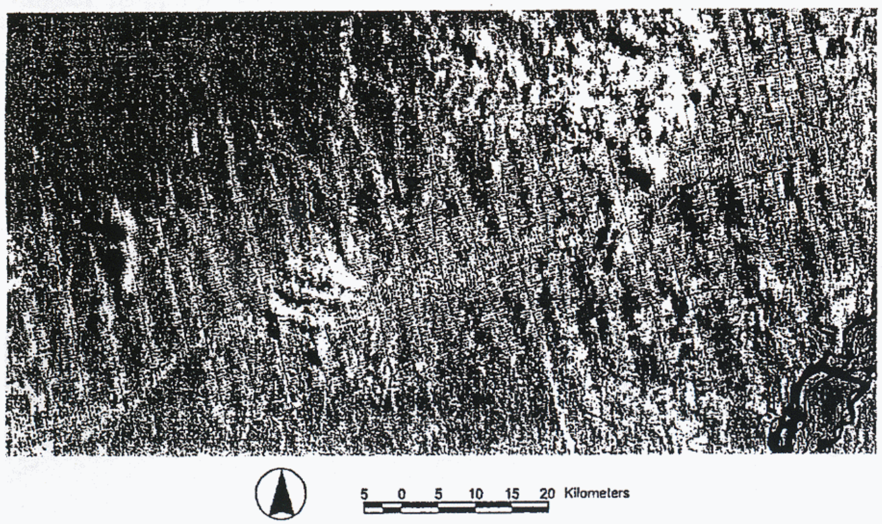


*Figure 2a.* Property grid and landscape (after McCracken et al. In press [b])



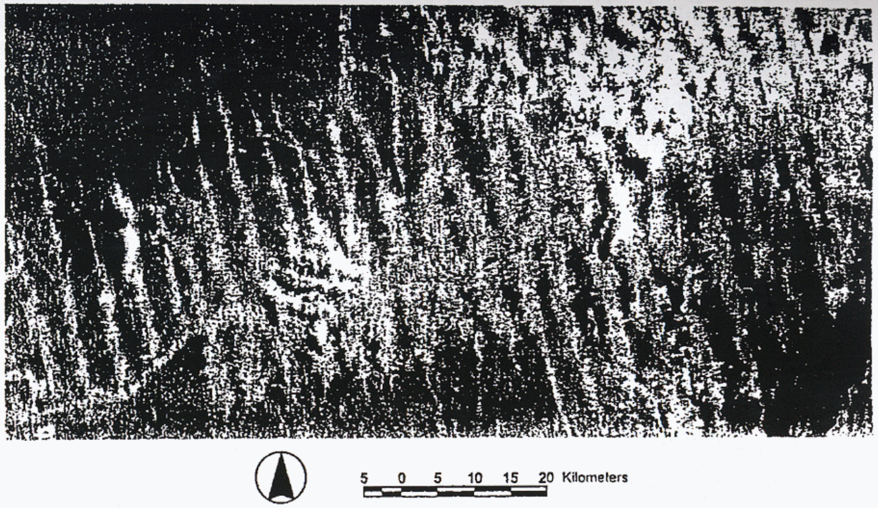


*Figure 2b.* Landscape (1996 Landsat TM Image, Bands 5, 4, 3) (after Boucek and Moran In press)

This process proved to be far more time consuming than we originally imagined, but this was not the result of technical failures, or of taking the wrong direction in the work. The property grid we had obtained proved to be an "ideal" view of the landscape and the properties. It did not take into account topographic features, rivers, and other natural features. In reality, as land was occupied, owners and neighbors negotiated changes in the precise boundaries of many properties when this made sense for their farm production. The "ideal" properties, imagined to be exactly 100 hectares, have, over time, become variable in size from 84 to 123 hectares, and their perfect rectangular shape has experienced realistic rounding (see Figure 3). Thus we were trying to fit a grid that was not the real grid. We solved this problem through very large investments of GPS work and visual on-screen modifications based on how land use evolved in the time series to bring out the real boundaries between properties, so that the final grid we have at present is well over 90% accurate. This is no mean feat, considering that this is an area of 3,784 properties or a total of 3,800 square kilometers. We have detailed the technical details followed in another paper (McCracken et al. 1999 and McCracken et al. in press [a]).

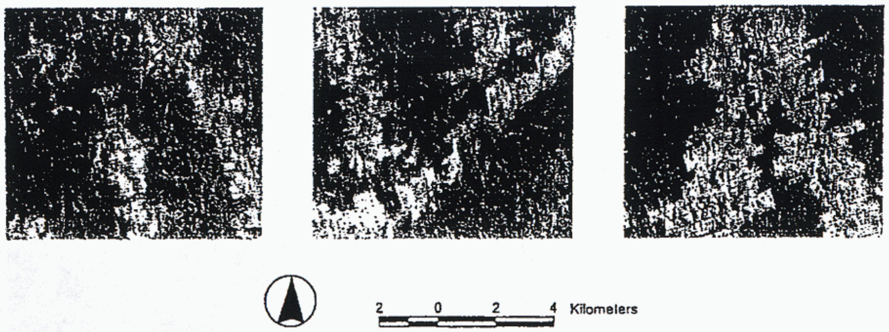


*Figure 3.* Examples of atypical properties

The approach we took can not be used in places that lack a one-to-one relationship between household and property, given the all too common reality of people living in villages and walking to their fields, the uneven size and commonly fragmented nature of landholdings in many other cases with a household having many very small holdings, and the presence of very diverse systems of land tenure in the same area. In our study area we benefited from a system based on individual private land tenure (although titling is a problem), of most households having only one property and living right on the property. But our study area is hardly unique. We have used the same methods to study a two settlement region in western Amazonia in Rondônia (Batistella 2001), a traditional peasant region that has combined common and private property (Futemma 2000), and in a region of south Central Brazil at Alta Floresta, Mato Grosso (Oliveira Filho 2001). The lessons learned in Altamira were applied and speeded up the work in these other regions.

Ideally, a time series should (a) cover the duration of the settlement; (b) cover consistent intervals to observe dominant land use systems; and, (c) capture inter-annual agropastoral cycles to allow observation of crop decisions following deforestation events.

The temporal scope of the study was extended backwards to 1970 before the land settlement scheme began to bring colonists, and forward to 1996 (covering therefore a period of 25 years). We were unable to obtain cloud-free images of the study area for 1997 or 1998 when field research took place. Similarly, the deterioration of Landsat MSS image archives has limited the availability of digital data covering the period of 1972 to 1984. Fortunately, photographic print outs of Landsat MSS products were available at the regional development agency (SUDAM).

Aerial photos for 1970 and 1978, together with Landsat MSS images for 1973, 1975,1976, and 1979, and Landsat TM images for 1985, 1988, 1991



and 1996 provided a dramatic time series of the trajectory of deforestation (see Figure 4).

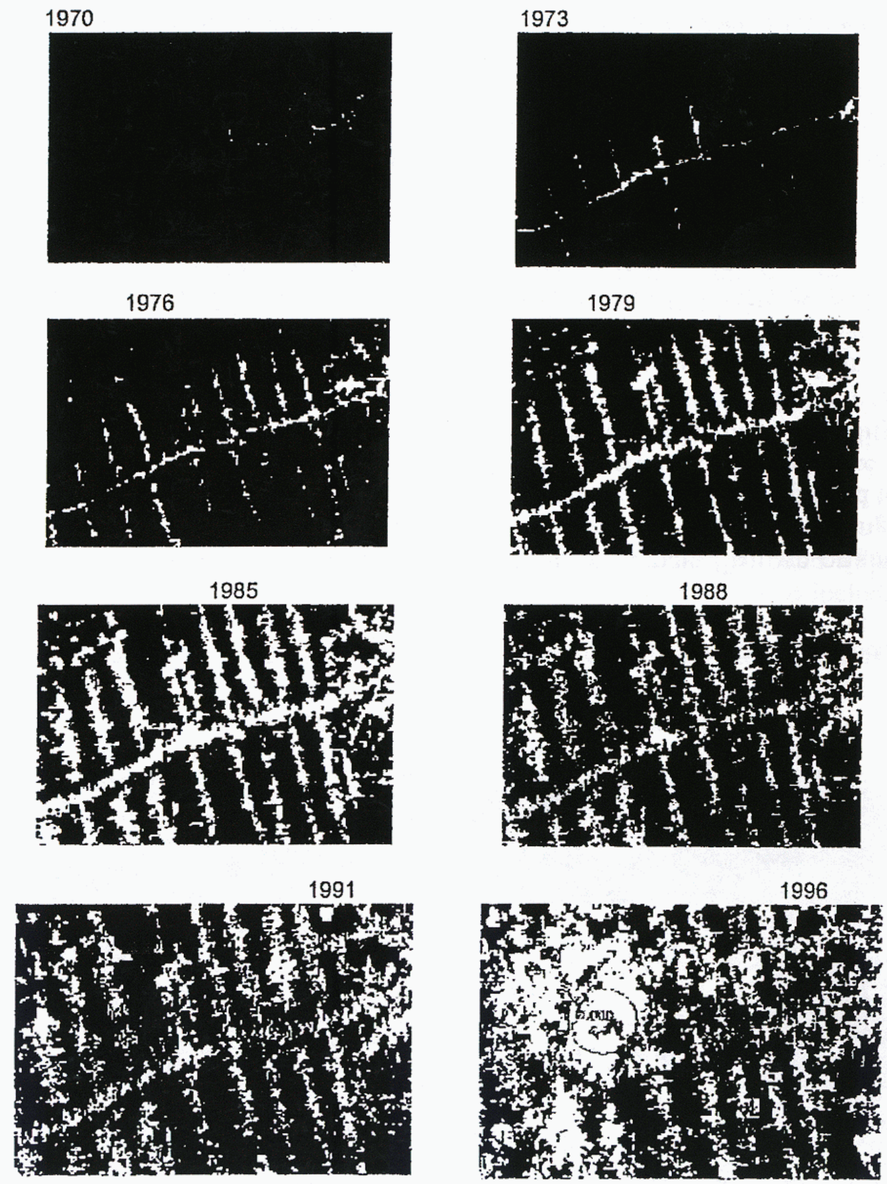


*Figure 4.* Time series of the trajectory of deforestation in Altamira (from Moran and McCracken, submitted manuscript)

Training samples representing land cover classes were evaluated using statistical and spectral analysis (e.g., separability analysis) to ensure proper aggregation of samples and accuracy during classification. Image classification was based on a hybrid approach including pre-field unsupervised classifications and incorporation of training samples and unsupervised spectral signatures. We relied on a spatial-spectral classifier ECHO and Maximum Likelihood algorithms (see Mausel et al. 1993, Moran et al. 1994, Brondizio et al. 1996, McCracken et al. 1999). It was possible to distinguish among three stages of secondary succession representing initial, intermediate, and advanced phases of regrowth. Initial classification aiming at distinguishing early stages (e.g., one-two year-old regrowth from three-five year-old regrowth) and advanced stages from mature forest proved difficult. To ensure a minimum classification accuracy of 85% across all classes we merged five classes of secondary succession into the three classes presented here. We used standard Kappa accuracy measures based on test fields. Test fields are areas initially collected as training samples, but not used during classification. Overall image classification accuracy is around 88% for the images of 1996 and 1991 and 85% for the images of 1988 and 1985. However, classification accuracy varied from 92% to 85% among land cover classes. Classification accuracy for our Landsat MSS (1973, 1975, 1976, and 1979) and aerial photography (1970, 1978) was not possible to calculate using test field procedures. For these dates, we defined four land-cover classes (forest, non-forest, roads, and water), which allowed us a higher mapping accuracy than otherwise possible with the inclusion of secondary succession stages. Accuracy was further assured during the development of transition matrices across dates. Inconsistent transitions (for instance from non-forest to forest in few years) were re-coded properly to correct for spatial mismatch.

The accuracy of our property grid varies within the region, with an overall rate of 90%. Accuracy was lower (around 80%) in areas of variable topography as well as in areas where the definition of lots was not closely followed by INCRA. In this area, lots and the road network tend to assume various shapes making if difficult to guarantee a perfect match between our vector layer and field reality. Property grid accuracy is higher ~95% for the farm lots where households members were interviewed (n=402).

Another key methodological decision made early on, which shaped the entire study was to try to distinguish between period and cohort effects. Period effects are those effects resulting from events that all actors experience equally, such as hyperinflation in the national economy or a major shift in world commodity prices relevant to a population. Cohort effects are those specific to a cohort but not necessarily experienced by other cohorts. Since the population migrating to the Amazon came and is still arriving, it is possible to distinguish cohorts of arriving settlers. Those



arriving in 1971 experienced a very different set of conditions than those who came in 1985 or in 1996.

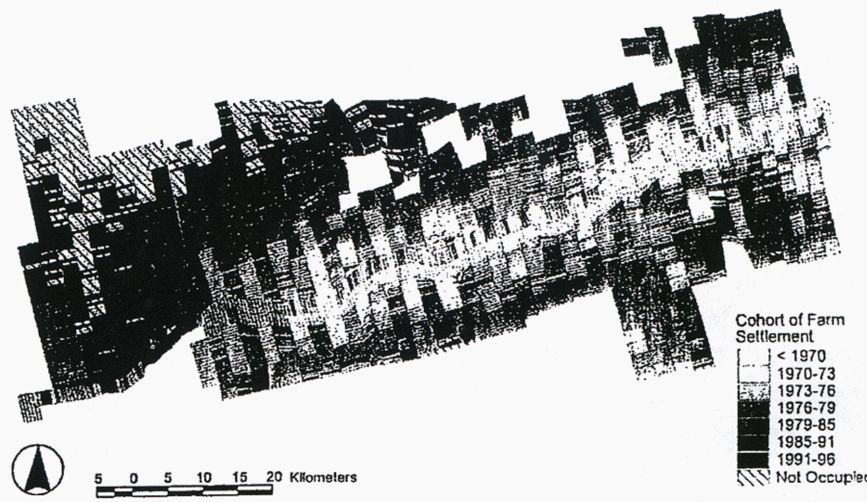


*Figure 5.* Farm property cohort of settlement (after McCracken et al. In press [b])

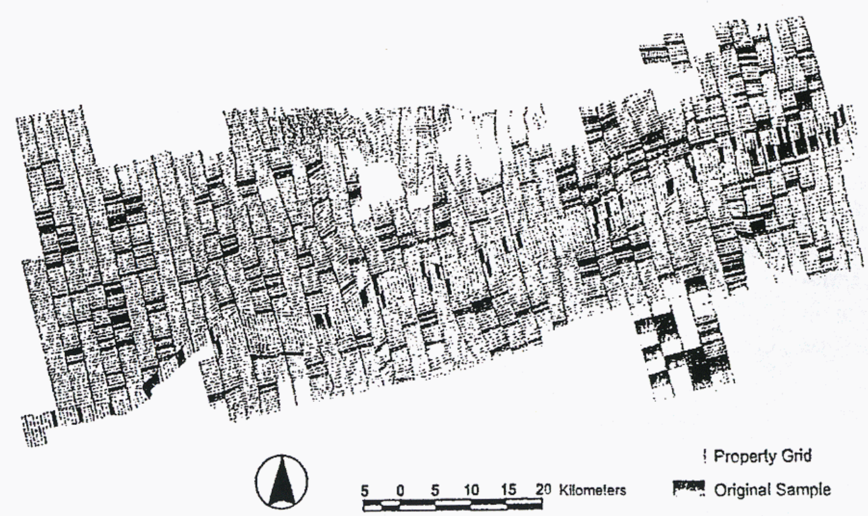


*Figure 6.* Property sampling strategy

For the purposes of our study, we decided to determine the membership of a household in a particular cohort by when we were able to observe on the satellite image the clearing of at least 5 hectares of mature forest. This was based on our earlier work in the Amazon wherein we had noted that most households cleared a minimum of 3 hectares per year. Since our satellite time series was roughly spaced in three year intervals, 5 hectares would indeed be a minimum that a household could be expected to clear, thereby announcing their arrival on the property—and membership in a given cohort. In this fashion, we were able to define 8 cohorts. Our stratified sample was based on the analysis of five land cover classifications and their respective land cover transitions (1970, 1978, 1985, 1988, 1991). This allowed for the development of a stratified sampling frame for selecting properties and households based on (a) timing of settlement based on period of initial forest clearing, and (b) extent of deforestation as of 1991. This method proved useful to allow a sampling frame compatible with our conceptual model of life cycle of households, agriculture strategies, and deforestation levels. The size of each cohort was quite variable because of the heavy involvement of government in the 1971-76 period in bringing colonists to the area at an accelerated rate, and due to shifts in the economy and in the presence of alternative areas for migrants to go to. Because some of the cohorts were small, we chose to draw a disproportionate sample to ensure a sufficient number of households from each cohort in the final sample (Figures 5 and 6).

A potential problem was the inclusion of "replacement households" where families that originally opened the lot sold the lot and moved away. To overcome this problem, we developed an alternate sampling frame consistent with the goals of our sampling design. The use of an "alternate" sampling frame proved very important to guarantee work continuity during the day (that is, to find neighboring farms that could be used for replacement during a interview trip).

Households in the study area are comprised of those sharing the same roof. We considered households as joint economic units and our survey did not attempt to grasp possible conflicts between household members related to access and allocation of resources and processes of decision-making. However, we included questions in our survey referring to outside members (usually grown up children and relatives) and their contribution in remittances, work, food, and gifts, if any, to the focus household in order to understand possible flows of labor, goods and resources among households. Keeping track of changes on household composition through time was possible with retrospective histories of household membership. One problem we faced while reconstructing household/family history was to match it with the farm's land use history. Besides being a region with already a significant settled population, property turnovers occur with relative frequency.

The size of our sample was based on our past experience in the region, and on the past work of Pichon and Bilsborrow (1992) in the Ecuadorian Amazon. From long experience working in the Amazon, we know the best we can hope for is one or two interviews per day per team of interviewers



given distances and transportation difficulties in the region. We used 6 teams of interviewers and completed interviews of 402 households in the Altamira region using a survey instrument of some 27 pages that inquired from the male head of household about land use and economics of the farm, and a women's questionnaire that examined household structure and composition, reproductive histories and decisions made by women. We focused our sample on the settlement scheme and we did not interview urban households except in those cases where the sampled household happened to live in town rather than on the farm. We are currently conducting a study in this region and another region which focuses on the question of whether there are discernable differences in the land use decisions of urban and rural dwellers. Our sample covers the landscape and allows us to examine other important variables such as distance to road and markets, to towns and other features. With the development of a digital elevation model we are moving towards addressing the role of topography in land use and improving our soil mapping (Figure 7).

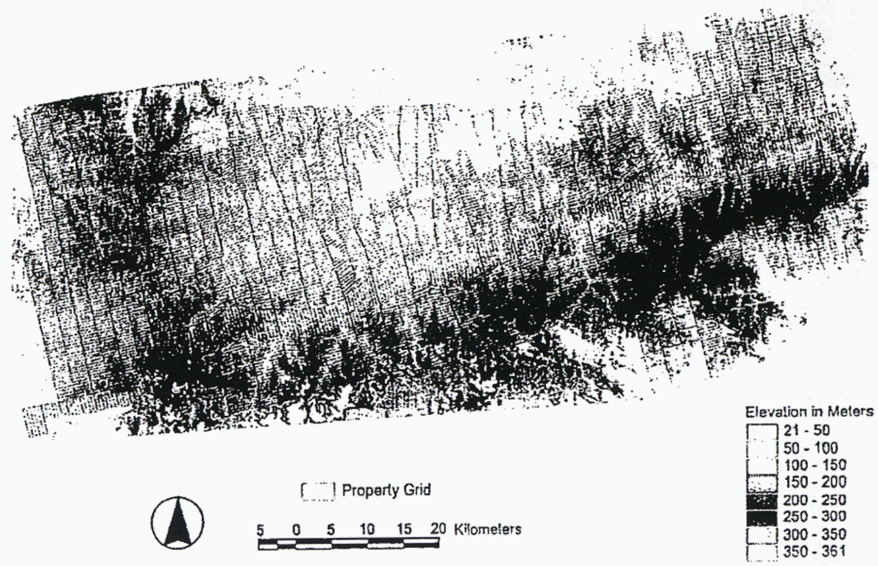


*Figure 7.* Digital elevation model with property grid overlay

Households in the region were on the whole very cooperative to the study and welcomed us. They answered our very long questionnaires with remarkable patience and interest. There was some suspicion that our team might be from the environmental protection agency (IBAMA) and thus discover some violation of regulations about deforestation and the use of fire. But in general we were able to convince them that our information was largely academic, and would be kept confidential, and that it would not be passed on to IBAMA or other enforcement agencies. We focused on the history of land use in the farm and highlighted the importance of understanding the farmer's experience, successes and failures during the life in the frontier; also, we ensure the academic nature of our research. Contrasting with the receptiveness of farmers was the reluctance of absentee landowners living in Altamira, usually professionals and wholesale merchants, to meet us for interviews. Interesting to note, however, is that absentee landowners, usually merchants, living in smaller urban centers, such as Brasil Novo and Medicilandia, were willing to answer our survey questions when requested. The satellite images were a source of continuous amazement to the population and recognizing that, we printed a copy of a time series of the property in question, and a couple of adjacent ones on which we made markings along with them on their land use through time. This was helpful in aiding memory of past events in land use. We left a clean copy of this same image with each household interview as a gift. This was deeply appreciated, and in some cases where return visits have taken place, households still had the image after a couple of years, and they had obviously discussed it at some length after we left. We think this is a very useful tool in promoting thoughtful discussion by households of their land use strategies and the outcome of their decisions (Figure 8).

Despite this participative use of satellite images, households varied a good deal in their ability to recall land uses several years in the past. The images were helpful in capturing the larger changes, but we have found that smaller management decisions may be lost until better resolution such as IKONOS images are widely used (Figure 9). We encouraged our teams of interviewers to not only conduct a careful interview in the home of the farmers, but also to go out and walk around the property to better understand the spatial distribution of the maps created and the location of major types of land cover. This led in many cases to modifications of the maps to better reflect what was there at present. Remarkably, a very large percentage of farmers have a keen understanding of the spatial location of their plantations and are able to provide if not a perfectly scaled map, at least one that is reasonably accurate about the position of their various crops. Careful use of the reflectance data can help distinguish the different crops, should the images be concurrent with the field work. Of course, in the humid tropics this is not always possible due to a high frequency of cloud cover.



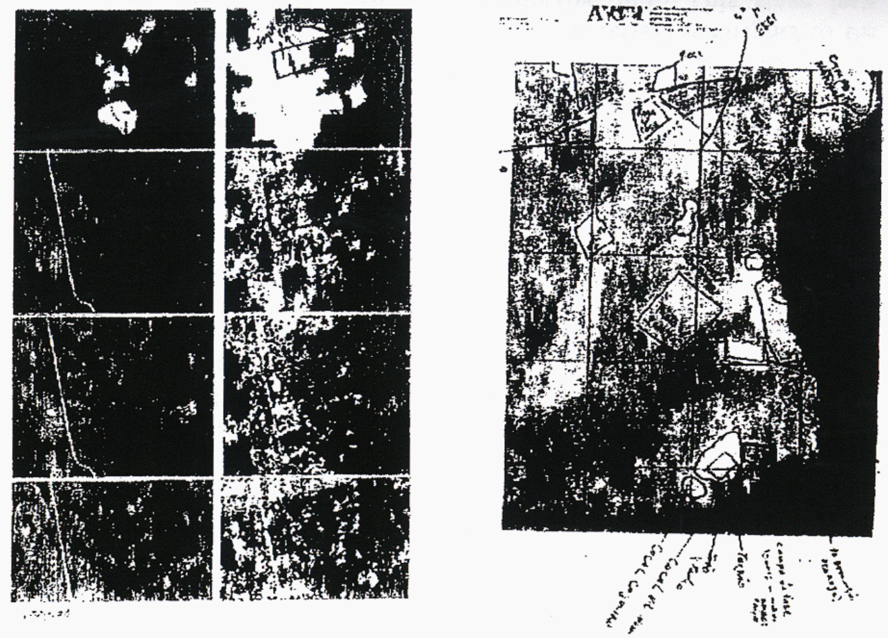

*Figure 8.* Using images in the field: farm and community level interview

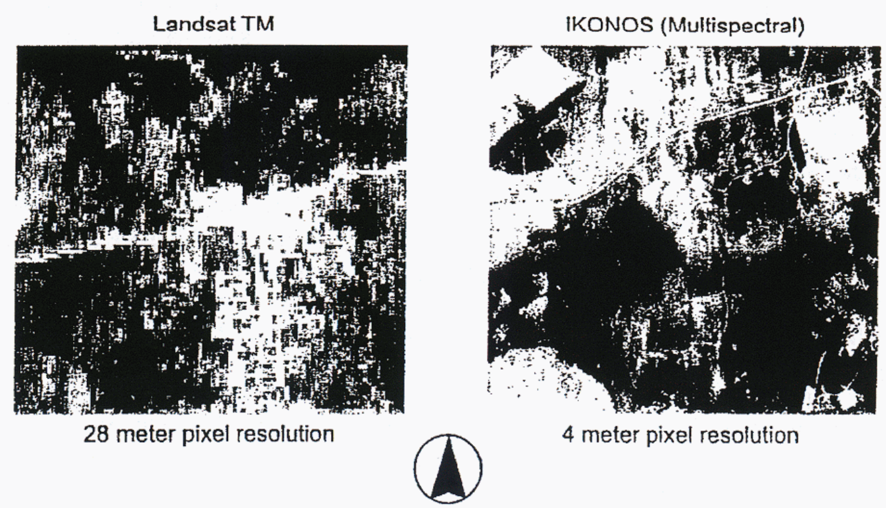


*Figure 9.* Comparison of Landsat TM and IKONOS Multispectral Data (The images provided are of two different locations within Altamira and are intended only to illustrate the differences in resolution.)

In this particular study, we did not face the difficult choices faced by others over frequent joint ownership of parcels, fragmentation of properties over time, and the reconstitution of properties through inheritance and land portioning. In this area, to date, land has been largely maintained as a unit, and commonly one heir takes over the property. More common has been the aggregation of multiple neighboring lots into large land holdings owned by absentee landowners. In a few cases more than one heir lives in the property if there are rich resources such as cocoa plantations, in which case they divide the number of trees that each owns and takes care of. Some households acquire additional properties so that their children will each be able to have one full one hundred hectare property. However, many children choose to live in the city and to leave the rural way of life.

The greatest source of frustration in this regard was the poor quality of government records on land titles and who owned what piece of land. In most cases the records were out of date and inaccurate. Thus we relied largely on our survey research but could not have much assurance that all the properties in the landscape studied were adequately recorded. The agencies seemed to be working with poor maps and records of ownership. According to Brazilian law, those receiving land from government colonization programs should return the land to the colonization agencies and are not allowed to sell it to third parties. As expected, this law is not enforced, but does not permit the government agencies to keep track of the changes in ownership. Given that, a remarkable number of farmers did not have a fully recorded title to their land, although they had some sort of document that proved ownership.

For the survey research, we relied on a combination of our USA-based team members and a largely local population (often children of settlers) who had pursued a high school education and some technical education. Each team was made up of a man and a woman, with the man usually asking the male head of household the land use and farm production questions, and a woman asking the female head of household and other women about demographic and other reproductive and child raising questions. Our research team includes anthropologists, geographers, sociologists, demographers, GIS/remote sensing specialists, and ecologists. The presence on almost each team of at least one child of the region, as they are called, facilitated rapport with the population who recognized them and who could converse on events with them in familiar terms. Even our USA-based team consisted of fluent and experienced Brazilian researchers, such as the co-authors, Andrea Siqueira and Eduardo Brondizio.

Teams were trained before beginning the interviews. Regular meetings to go over entries in the forms that were not clear to the supervisors took place regularly. This has always proven to be one of the most challenging aspects of this work, because the



requires that several knowledgeable staff be on hand to check each questionnaire and correct errors found within a day of the interview. This means having at least two people who are not going to the field to interview but who are just devoted to checking the surveys. Since most people prefer to be in the field, than in an uncomfortable office with minimum infrastructure, it is a thankless job from their point of view. We did not allocate that much personnel in previous studies, an error that we have corrected in our current study in the region, and this proved to increase the yield and reliability of the answers. We tried to rotate who stayed behind so that the spirit of the team was better and everyone had a chance to appreciate both the difficulty of the fieldwork, and the difficulty of ensuring accuracy from a large group of enumerators.

Each team also had to be trained to use a GPS and how to interpret a satellite image so that they could answer questions from farmers and use the image to help the interviewees recall past events. This is a very important step and we did not at first fully appreciate the amount of time required to train the enumerators. This is a fundamental step, otherwise the spatial data may be compromised and a great opportunity to link households to landscape can be missed.

Data entry, data clean up, and data analysis is, as we all know and recognize, an arduous and time-consuming processes. Because of the very large number of questions asked, it took a long time to go from the survey data to the writing of papers. The spatial analyses came first, with examination of the insights gained from having a property level analysis vis-à-vis one based purely at the landscape level (McCracken et al.1999). Then came a series of papers examining the role of soil fertility in farmers' choices of crops [1](Moran et al. in press, 2000, Figure 10); examination of trajectories of land use and deforestation at both household and landscape levels (Brondizio et al. in press and Figures 11 and 12); and examination of the role of time on the farm on the trajectory of deforestation[2] (Brondizio et al. in press, Figure 13).

A key goal of this study was to understand whether trajectories of deforestation could be better understood knowing the age and gender structure of households through time, rather than just their aggregate number. In a paper presented at Population Association of America 2001, and currently under review, we find that indeed the model proposed at the outset of the study is consistent with the empirical results of the study (Moran et al., submitted). Each cohort begins occupation of the land with an exponential rate of deforestation necessary to establish their rights to the land, and to establish the farm as a productive unit. This stage lasts approximately 5 years. After this period, there is a steady decline in the rate of deforestation as the household begins to manage the areas already cleared, Households begin to shift from largely annual crops to pasture and perennial crops. This requires more labor, now available to them through the aging of their children into teenagers. Each cohort experiences a less steep but still noticeable second rapid increase in deforestation that is more short-lived. This we refer to as a consolidation stage of the farm when the now aging household tries to put their property in order before either passing it on to their children or selling it (Brondizio et al. In press). Over this 20-year period, the deforestation has declined from 5 - 6% per year, to 3%, and settled around 1.2% per year. Projecting out to 2020, we expect that in the study area, 24 to 32% of forest will remain.

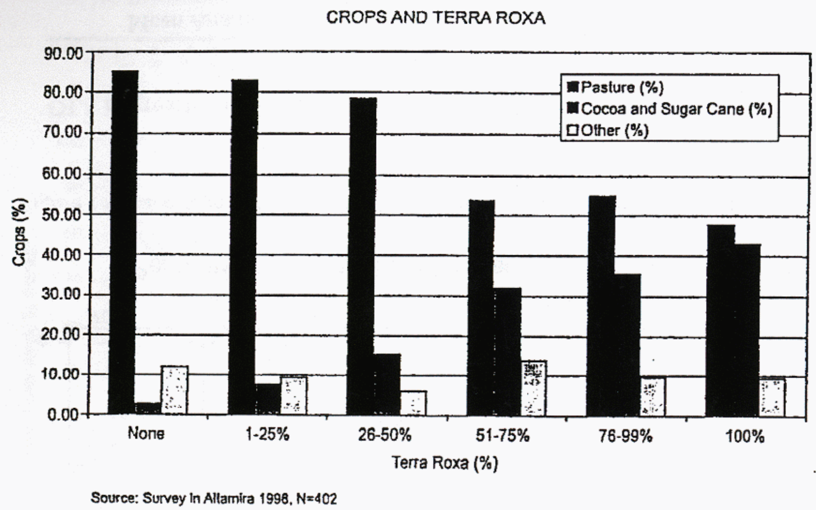


*Figure 10.* Crops and terra roxa (Moran et al. In press)

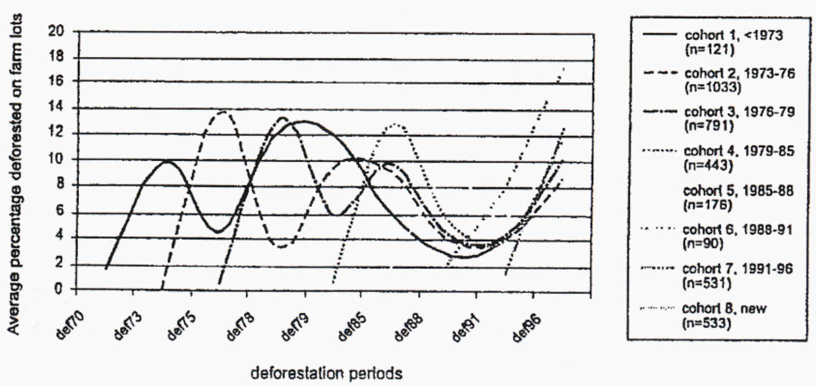


*Figure 11.* The colonist footprint: average deforestation trajectories across cohorts (Brondizio et al. In press)



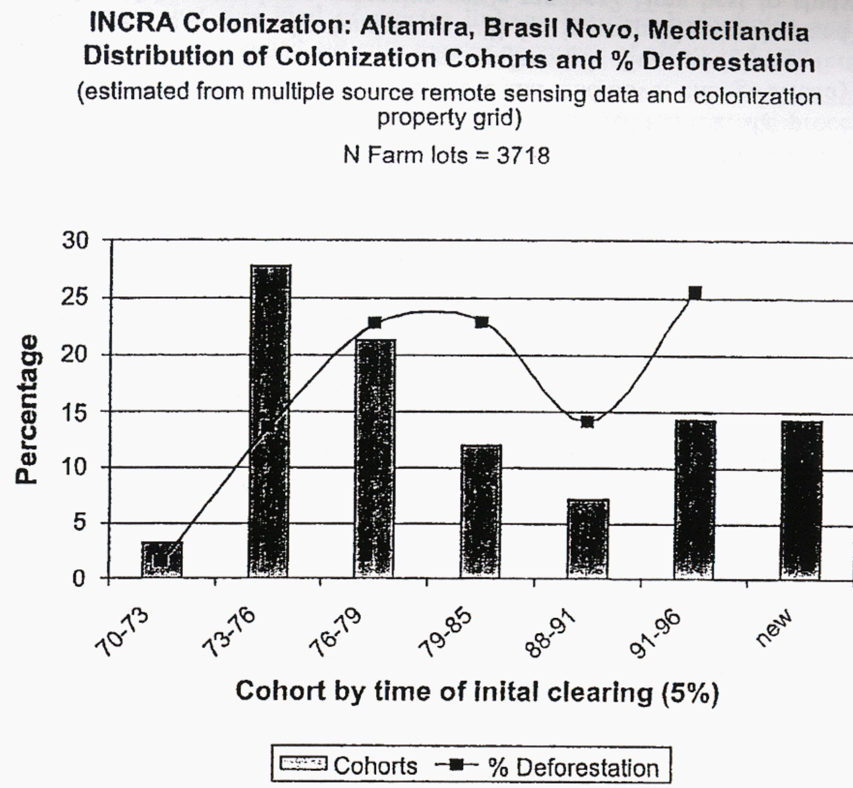


*Figure 12.* INCRA colonization: Altamira, Brasil Novo, and Medicilandia; distribution of colonization cohorts and percent deforestation (Brondizio et al. In press)

In a paper currently in press (McCracken et al. in press [b]), we suggest that there are at least three plausible scenarios depending on which set of variables is selected. To obtain the age-dependent pattern of deforestation at the farm level we fitted our mean annual rates of farm area deforested with ordinary least-squared regression (OLS) with a simple linear model based on age, and curvilinear models with the inclusion of age-squared and a quadratic equation with an age-cubed term. The results are presented in Table 1. In Figure 14 the observations for each interval between remotely classified images are presented by approximate age of the farm, and a line from the quadratic equation is used to illustrate the general age pattern associated with deforestation on the farms. We found considerable variation about the regression line. The simple linear regression suggests that farms begin by clearing about 4.8% of the forest during the first year, based on the y-intercept. In each subsequent year the area deforested declines by 0.1724. By the 12th year, the percent of the farm deforested fall to less than 3%, and to 1.5% per year by year 20. Applying these rates to a 100 hectare typical farm suggests that approximately 32% of the farm would remain in forest by 2020.

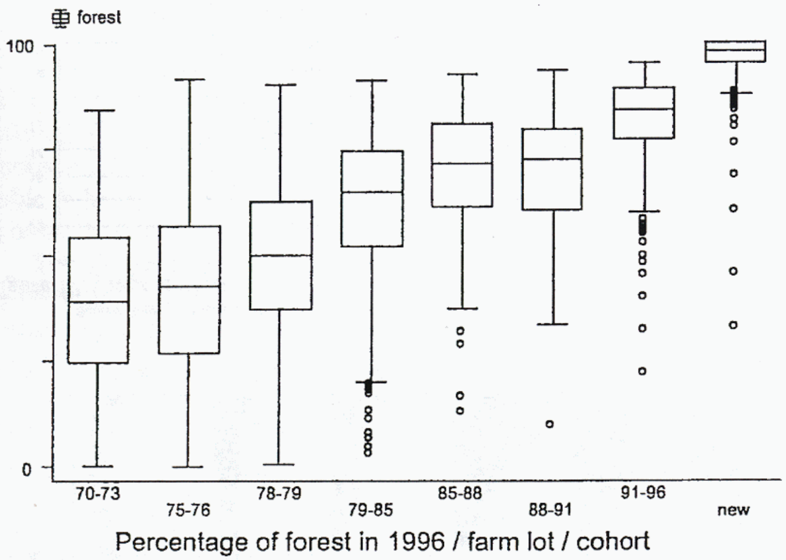


*Figure 13.* Percentage of forest in 1996 / farm lot / cohort (Brondizio et al. In press)

**Table 1**

**OLS Regression on Mean Annual Percent of Farm Area Deforested**

| Mean Annual Percent of Farm Area Deforested | Linear | Curvilear-Sq. | Quadratic |
|---|---|---|---|
| Independent Vars | | | |
| Years on Lot | -0.1724 | -0.4667 | -0.7200 |
| Years-Squared | | 0.0125 | 0.0374 |
| Years-Cubed | | | -0.0007 |
| Constant | 4.7712 | 5.8458 | 6.3826 |
| Number of Obs. | 13383 | 13383 | 13383 |
| F | 2007.24 | 1269.45 | 870.43 |
| Prob > F | 0.0000 | 0.0000 | 0.0000 |
| Adj. R-squared | 0.1304 | 0.1594 | 0.1631 |

All results were significant at the 0.01 level

*Table 1.* OLS regression on mean annual percent of farm area deforested (McCracken et al. In press [b])



The use of age-squared and age-cubed models results in curvilinear patterns with very different consequences for the amounts of forest remaining. Both suggest that deforestation is greater in the beginning and declines to about 2 percent by the 13th year and begins to level off in year 20. After year 20 the simpler model using age and age-squared suggests that deforestation will increase by year 25 and then accelerate—resulting in no more original forest remaining on the farm by year 36. The use of a quadratic equation provides a very different portrayal: it begins with high rates of farm clearing, levels off by year 20 at about 2 percent, and then declines slowly after 30 years with no more deforestation after year 36. Applying these rates to a typical farm would result in 24 percent of the forest remaining on the property.

The linear regression in our view understates the amount of deforestation associated with initial farm creation, and overstates the amount of forest remaining in future years. The curvilinear resulting from use of a squared term for age results in complete deforestation. The quadratic model results are more in line with field observations and knowledge of the area. We have found frequent concern among settlers with preserving some portion of their farm as forest, and a preference to shift to clearing secondary vegetation rather than primary forest over time.

Our project is now entering its more productive phase as the data both spatial and survey is fully available for analysis, and allows us to ask many questions of relevance to population and environment. The region still presents a demographic pattern typical of a frontier[3], where there are more men than women in all age groups (McCracken et al. in press [b]). Women leave their parents' households at an earlier age than their brothers in order to marry, work or pursue education in nearby urban centers, while there seems to be a men's "farm labor retention" (Siqueira et al. in press). One notable question, which bears close examination, is the role of the precipitous decline in female fertility in Brazil, and even in the Amazon frontier. In our study, 43% of women aged 25-29 are already sterilized, with a sizable number using contraception (see Table 2) (McCracken and Siqueira, in preparation). Very few younger women are having more than one or two children, and are using sterilization to ensure that this is a permanent choice. What does this say about the future of land use and land cover in the Amazon frontier? Is this another indication that the process of urbanization is a major driver of land use and land cover change already, and will be more so in the future? As labor in farms declines with lower fertility, does this mean that the landscape will be inescapably mechanized? Or dominated by very large extensive cattle ranches? How best to study and capture these changes now and in the future?

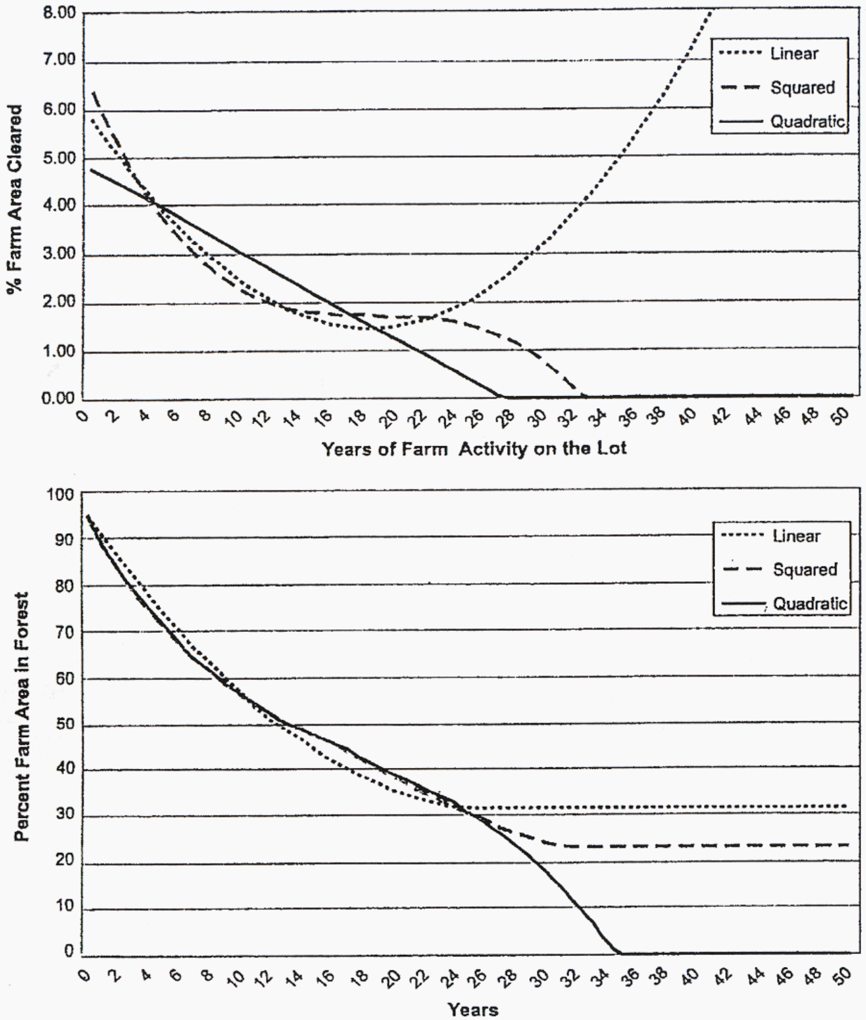


*Figure 14.* General age pattern associated with deforestation on farms

We think that our study does show the technical feasibility of examining land use and land cover change at the level of households and properties -- and that the insights are worth the effort and investment required to achieve it. We have been able to do it in Rondonia in a fraction of the time and effort it took in Altamira because the grid for Machadinho in Rondonia was almost perfect. It was developed 12 years later, with greater sophistication and resources, and made our work fairly easy by comparison. As more government agencies make use of GPS technology to survey and map, we



can expect that this kind of precise linkage between households and land use/cover can be carried out with greater economy of effort and cost.

| Age Group | Method Used Currently | | | Past Contraceptive Use | | |
|---|---|---|---|---|---|---|
| | Pill | Other | Steriliz. | Past Use | Never | Total |
| 15–19 | 15 | 1 | 3 | 18 | 3 | 40 |
| | 37.50 | 2.50 | 7.50 | 45.00 | 7.50 | 100.00 |
| 20–24 | 14 | 3 | 5 | 37 | 7 | 66 |
| | 21.21 | 4.55 | 7.58 | 56.06 | 10.61 | 100.00 |
| 25–29 | 6 | 0 | 27 | 28 | 1 | 62 |
| | 9.68 | 0.00 | 43.55 | 45.16 | 1.61 | 100.00 |
| 30–34 | 2 | 3 | 29 | 7 | 3 | 44 |
| | 4.55 | 6.82 | 65.91 | 15.91 | 6.82 | 100.00 |
| 35–39 | 0 | 1 | 43 | 10 | 3 | 57 |
| | 0.00 | 1.75 | 75.44 | 17.54 | 5.26 | 100.00 |
| 40–44 | 2 | 1 | 37 | 4 | 2 | 46 |
| | 4.35 | 2.17 | 80.43 | 8.70 | 4.35 | 100.00 |
| 45–49 | 0 | 0 | 30 | 6 | 5 | 41 |
| | 0.00 | 0.00 | 73.17 | 14.63 | 12.20 | 100.00 |
| 50–54 | 0 | 1 | 29 | 12 | 4 | 46 |
| | 0.00 | 2.17 | 63.04 | 26.09 | 8.70 | 100.00 |
| 55–59 | 0 | 0 | 20 | 11 | 13 | 44 |
| | 0.00 | 0.00 | 45.45 | 25.00 | 29.55 | 100.00 |
| 60–64 | 0 | 0 | 16 | 30 | 16 | 62 |
| | 0.00 | 0.00 | 25.81 | 48.39 | 25.81 | 100.00 |
| **Total** | **39** | **10** | **239** | **163** | **57** | **508** |
| | **7.68** | **1.97** | **47.05** | **32.09** | **11.22** | **100.00** |

*Table 2.* Contraceptive use among married women by age group, colonization area, Altamira (Moran and McCracken, submitted manuscript)

Our team has been nurtured in an interdisciplinary fashion and we have not experienced major difficulties working together. We have encouraged our team members to become reasonably familiar with GIS, GPS, and other spatial approaches so we can all communicate easily. There is a division of labor, wherein the demographers on the team focus more on those issues, while others focus on credit and the economy, soils and vegetation, or labor allocation and work effort in the farm by age and gender. However, we emphasized the role of "unifying questions" in fostering interaction across fields and disciplines. We encourage papers to be written across these boundaries of topics and disciplines. We try to encourage our younger team members to publish in their disciplinary journals, and not just in interdisciplinary ones, to ensure that they are credible in their own disciplines. This is sometimes a challenge given that many key disciplinary journals still resist papers that are interdisciplinary in nature and that are framed in ways that may be unfamiliar to narrowly trained reviewers in the disciplines.

## 3. FINAL REMARKS

We would not make any major changes in how we went about our study. We were challenged by the poor quality of the property grid, and this cost us years of man-labor to improve to the point we could trust the boundaries and thus the statistical output of land cover changes at the level of properties. An error of 100 meters could cause an error of some 25% in the changes in land cover obtained, and thus swamp any real differences resulting from decisions taken by households. In other study areas, we have obtained better property grids and the work has been much less time consuming and more rewarding. The use of satellite images and the beginning of deforestation to create cohorts and then to use these cohorts to draw a sample was very useful and we would encourage others to use this approach to sampling whenever possible. The results of our work suggest that we need to more closely examine the role of household structure on any number of changes taking place in the environment. Deforestation was just one clear example, but there are surely others. One of the greatest challenges to researchers is how we are to change our methods to capture the increasingly urban-driven nature of land use and land cover change.

## ACKNOWLEDGMENTS

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## NOTES

[1] Our research has found that soil fertility differences account for a significant proportion of the variance in observed rates of secondary successional regrowth (Moran and Brondizio 1998; Tucker et al. 1998) and even in the portfolio composition of crops cultivated by farmers (Moran et al. in press; 2001). In the more fertile sites we have studied, we find at least a two-fold 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 (Tucker et al. 1998; Moran et al. in press). We have also found that households with above average soils (specifically, households with terra roxa estruturada eutrofica, or alfisols) are consistently more able to hold on to their land than households who lack these soils (see Table 3). In Table 3 one can see that households who arrived early were able to choose the best soils and that farms with these soils have not entered the real estate turnover pool, otherwise one would see a greater number of farmers who came later having access to the better soils. Farmers prefer to buy properties that are already developed or partially deforested to virgin plots. There is a very high turnover rate in land holding, but these are disproportionally on the poor soils. Crop choice is affected as well. Households with poor soils had more than 80% of their cleared area in pastures. There is a steady decline in the proportion of the cleared land in pasture as the percentage of good soils increases (see Figure 10). For those households who have their entire property in good soils, there is a balanced portfolio of pasture and cash crops evident in Figure 10.

CHOOSING TERRA ROXA BY COHORT*

| % terra roxa | Before 1971 | 1971-75 | 1976-80 | 1981-85 | After 1985 | Total |
|---|---|---|---|---|---|---|
| None | 6.25 | 38.82 | **62.69** | **62.12** | **72.62** | 59.45 |
| 1-25% | 6.25 | 10.59 | 14.93 | 19.7 | 13.1 | 13.68 |
| 26-50% | **62.5** | 10.59 | 7.46 | 12.12 | 1.79 | 8.71 |
| 51-75% | 18.75 | 7.06 | 4.48 | 3.03 | 5.95 | 5.97 |
| 76-99% | 6.25 | 12.94 | 2.99 | 1.52 | 5.36 | 5.97 |
| 100% | 0.00 | 20.00 | 7.46 | 1.52 | 1.19 | 6.22 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

*cohort is based on the year of arrival in the lot
Source: Survey in Altamira 1998, N=402 households
(Moran et al In press, 2002)

*Table 3.* Choosing Terra Roxa by Cohort (Moran et al. In press)

[2] The combination of time series remote sensing data, property grid maps, and field surveys has provided us the opportunity to look at land use and cover change at several levels, such as the colonization landscape, groups of farm lots, and individual lots; this way, it provides tools to capture the arrival of colonization cohorts and the simultaneous process of farm consolidation and expansion.

Colonization landscape level: Despite of the high rates of deforestation during the period of settlement, 61% of the total colonization area remain in forest by 1996, whereas total deforestation adds up to 37%, and non-classified area represent about 2%. By taking into account areas of bare soil, pasture, and cocoa plantations (as estimated by Comisão Executiva do Plano da Lavorura Cacaueira - CEPLAC), our estimate shows that about a half of the deforested area from 1970 to 1996 remains in production by 1996, whereas half of it has been taken over by different stages of secondary vegetation.

Fluctuation in deforestation rates can be observed during this period. Frontier occupation is an on-going dynamic process where "old settlers" co-exist 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. Fluctuation of deforestation rates after 1985 coincides with the arrival of colonist farmers and with national-level economic indicators. Economic depression and inflation during the second half of the 1980's and withdrawal of cattle ranching incentives are potential explanations for the sharp decrease in deforestation rate seen between 1985 and 1991. (See Figure 12)

Cohort level: There is a close relationship 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% conf. interval), however with strong internal variation. Three main groups can be distinguished according to forest cover and time of arrival. Cohort farm lots of the 1970's present similar average in forest cover, about 40% of forest in the farm, but with strong variation within cohort, that is from 0% to 90% of forest. Cohort farm lots of the 1980's show on average about 60% of forest cover in their lots, but ranging from about 30% to 90% forest cover in average. Cohort farm lots of the 1990's show in average more than 75% of forest cover by 1996, but ranging from about 60% to 95% of the farm lot.

The area in secondary succession and production, however, present less significant correlation with time of settlement. Whereas secondary succession (Adj. r 2 = 0.27, significant at 95% conf. Interval) and production (Adj. r 2 = 0.31, significant at 95% conf. Interval) increases with time of settlement, differences among cohorts are less notable. Older cohorts have larger variation of secondary succession and production areas. Cohorts of the 1970's have in average about 8% to 10% of the farm area in secondary succession, varying between 0% and 50% of the total property in fallow. Cohorts of the 1980's have in average 5% in secondary succession, varying within cohorts from 0% to 20% of the total property in fallow. Similar distribution is perceived in production areas. The 1970's cohorts have 6% of their farm lots in production, with variation among farm lots ranging from 0 to 25% of the property. Cohorts of the 1980's present on average 4% of the farm lot in production, however, they show smaller variation within cohorts, with production areas ranging from 0% to 8% of the farm lot. (See Figure 14)

Whereas positive significant correlation exists between time of settlement and deforestation, this 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, composition, and in farm production potential.

The data suggest that deforestation trajectories across cohorts are marked by cycles of farm lot formation characterized by deforestation pulses of different magnitudes--termed by Brondizio et al. (in press) as the colonist footprint (Figure 11). Independent of cohort group, frontier farms consistently present cycles of deforestation and agro-pastoral activities development associated with periods of establishment, expansion, and consolidation. These cycles are marked by pulses of deforestation followed by strategies of crop and pasture development, and secondary succession management. Whereas these cycles represent an "age effect," the magnitude of each pulse of deforestation is influenced by factors such as national economic conditions (e.g., inflation rates) and the availability of credit support programs.
In this sense, "the colonist footprint" is characterized by the co-existence of extensification and intensification of production strategies marked by cycles of expansion and consolidation of the farm operation. These processes, 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 (e.g., cohort effect), cohort and household dynamics (e.g., aging, household labor composition, experience, origin), and period effects (e.g., credit, inflation), underlined by environmental, market, and infrastructural conditions.

[3] The observed pattern of family size is much closer to the current Brazilian urban pattern, that is, it is nuclear and relatively small. The current household size is about 4.6 individuals. Marriage is the most common reason (about 67%) to leave a parents' household for both sexes, followed by search of off-farm jobs (~11%), schooling (~10%) and other reasons (11%). On the other hand, most of the incorporation into the household is through birth (about 72%), marriage representing only 10%. Usually, the young women between the ages of 15-24 are the individuals being incorporated into the household (McCracken et al. in press [a], Siqueira et al. in press). Figure 15 (on the CD-ROM) shows the current age and sex distribution of the study population. Overall, this figure illustrates two main processes taking place in the area, the general aging process of households in this by now 30 year agricultural frontier, and the general loss of labor from children as these become young adults and leave the households, especially women (McCracken et al. in press [a]). In all five-year age intervals there are more males than females. Women are more likely to leave their family household in earlier ages than men, and usually due to marriage and schooling. Young men are more likely to stay in the farm longer, which seems to be a household "labor retention" strategy. Nevertheless, the current sex ratio is more balanced than the initial migration flows to the region. Figure 16 (on the CD-ROM) illustrates what could be called the "gender selectivity process" at arrival. When arriving on the frontier, households are composed of predominantly young members, and slightly more males than females. This pattern of male dominated sex rations, even among infants and children and through the early 20s suggests selectivity in favor of male labor as families migrate to the frontier (ibid).

Perhaps the most important demographic change taking place at the level of household is related to women's reproductive behavior. For the past twenty years we observed a rapid fertility decline among the women in this frontier area. For the late 1960s and early 1970s, fertility for women was very high, on the order of 10-11 children per women. By 1980s fertility declined to about 4.3 children, and we observed that by age 29 more than 40% of women have been sterilized by tying their tubes, which is a common procedure elsewhere in Brazil but unexpected on a frontier area due to the reported scarcity of labor. The current fertility rate is still between 0.5 and 0.8 children above the rest of rural Brazil, but the observed decline in fertility is as important as the rapid fertility decline occurred in the country as a whole (McCracken and Siqueira, in preparation; Siqueira et al. in press).

The possible explanatory reasons for this behavior and the consequences for family labor availability still require further investigation, but it seems fair to point the role of institutional and economic changes taking place in Brazil since late 1950s. Rapid urbanization, the expansion of consumer society and social security coverage, increase in mass communication and better access to health care are possible causes/incentives to the changes observed on the reproductive behavior of these frontier women.

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