DRAFT: DO NOT CITE WITHOUT PERMISSION OF THE AUTHORS

Household Life Cycle and Land Use in Santarém and Altamira, Pará, Brasil

Leah K. VanWey
Álvaro de O. D'Antona
Eduardo S. Brondízio

Direct Correspondence to:
Leah K. VanWey
Department of Sociology
Indiana University
1020 E. Kirkwood Ave.
Bloomington, IN 47405
Email: Lvanwey@indiana.edu
Phone: 812-855-7432

Debates have raged for centuries on the importance of human demography in environmental change (Boserup 1981; Carr 2004; Ehrlich and Holdren 1971; Malthus 1989 [1803]; Rindfuss et al. 2004; VanWey, Ostrom and Meretsky 2005). This issue has seemed pressing at various points in history because of positive (and often high) population growth rates and various negative environmental trends (e.g. increasing air and water pollution, desertification, global climate change, and local food shortages). However, the analysis of the relationship between population change and environmental change has often focused on macro-level trends and correlations and not on the actions or characteristics of individuals and households (Dietz and Rosa 1997; Ehrhardt-Martinez, Crenshaw and Jenkins 2002; Lambin et al. 2001; O'Neill, MacKellar and Lutz 2001; Pebley 1998; Perz and Skole 2003). More recently, the focus of much research on population and environment has been on the actions of individuals and households (An et al. 2001; Liu et al. 1999; Marquette 1998; McCracken et al. 1999; McCracken et al. 2002; Walker et al. 2002; Walker and Homma 1996).

A large body of recent research on individual or household level population and environment relationships has also focused on land use and land cover change on parcels of land associated with households (Brondizio et al. 2002; McCracken et al. 1999; Pan et al. 2004; Perz 2001b, 2002; Pichón 1996; Walker, Moran and Anselin 2000; Walker et al. 2002; Walker and Homma 1996). Most of this research has examined the changing household demographic composition over the household life cycle and its effects on land use or land cover change. This research is on the forefront of new advances combining the efforts of social scientists and natural scientists, and thus includes scientists approaching the problem from the land use perspective and scientists approaching the problem from the land cover perspective. Land use is the division of the landscape into areas with socially or economically meaningful uses – for example, pasture, coffee trees, forest with useful timber, forest without useful timber – while land cover is the division of the landscape into ecological meaningful areas – for example, low secondary succession, old secondary succession, scrubby brush. At times, these categories overlap but at other times they cannot be meaningfully compared.

This paper advances the theoretical and methodological frontiers of this research on household demographic effects on land use and land cover by examining the relationships between household demographic composition and land use and between household demographic composition and land cover for two study areas in the Brazilian Amazon. We construct roughly comparable social survey based measures of land use and satellite based measures of land cover for properties associated with households in these two regions, and then examine the relationship between household characteristics and these two outcome variables. The comparison between our two study regions, around the cities of Altamira and Santarém in the state of Pará in Brazil, allows us to assess the robustness of results to differences in topography and settlement history.

To preview, our results show there is no consistent effect of household demographic composition on used area or forested area, either within or across study areas. The measures of land use and land cover are only moderately correlated and produce different results when used as dependent variables in regression models. We conclude by arguing that the pattern of differences and similarities across models suggests that the congruence between remotely sensed measures of land cover and survey based measures of land use is greater earlier in time and in more recently settled areas.

Household Life Cycle Models

The household life cycle approach to frontier household land use is based theoretically on the Chayanovian peasant economy model (Chayanov 1966; Walker et al. 2004; Walker et al. 2002; Walker and Homma 1996). When households enter a frontier, in which land is abundant and labor and capital are scarce, their land use decisions are determined by household demography. Household demography influences the decisions in three ways. First, it represents the consumption needs of the household. In Chayanov's original formulation, peasants exist outside of a monetary or exchange economy and therefore produce primarily to meet consumption needs. This argues for an effect of children and elderly dependents as well as an overall effect of household size. Second, household demography determines the amount of labor available for farming which, in the absence of capital and labor-saving technology, determines the amount of land that can be used. This argues for an effect of the number of working age members of the household, particularly males in a setting where men do the majority of the farm work. Third, as the owners of land and their children age and as their children move to other properties or to urban areas, the time horizon of the owners changes. Households with many small children have a short time horizon, seeing only the need to feed and care for the family for the next few years. As these children become able to help with farm work, and available labor increases beyond the minimum necessary to support the family, households begin make investments in perennial crops or pasture. These are activities that require many years of investment before generating a return, but which provide a higher return in the long run. This argues for changes over time, but those changes over time are largely determined by the demographic composition of the household and can be modeled by examining the effects of children of various ages on land use or land cover.

This approach has been used by many researchers studying household land use decision-making in the Amazon (Brondizio et al. 2002; McCracken et al. 1999; McCracken et al. 2002; Pan et al. 2001; Pan et al. 2004; Perz 2001b, 2002; Pichon 1996b; Walker et al. 2002). Walker (Walker 2003; Walker and Homma 1996) develops the theoretical principles underlying the modeling of household demographic and other effects by combining the Chayanovian approach with a household production model (and recognizing the changing institutional context of the frontier). Walker, Perz and colleagues have used this approach in their study area around Uruará in the state of Pará in the Brazilian Amazon (located between our two study areas). They find mixed evidence for household life cycle effects using a variety of data and methods. Walker et al. (2002) review the extensive relevant literature, which also shows mixed effects of household demographic composition on land use, and conduct an empirical analysis using survey data for a sample of farm households. Results show that the dependency ratio (ratio of consumers to producers) and male family workers each significantly predict only one of six farming systems (combinations of land uses). These effects are consistent with the theoretical approach, as the male family members predict annuals with perennials and the dependency ratio negative affects perennials with annuals, but the evidence is not overwhelming for these household life cycle effects. Using the same approach and the same data, Perz (2001) finds that the number of adults in the household has a positive effect on the area in perennials and pasture and on cattle production. The number of children has no significant effect in these models.

Walker and colleagues (Walker 2003; Walker et al. 2004) combine these survey data with remotely sensed measures of forest cover and a modeling approach to examine the development of farm properties in the region in a spatially explicit manner. They use their theoretical development to motivate a behavioral model that parameterizes an agent based model in a geographic information system (GIS). This agent based model predicts the spatial pattern and amount of deforestation in all properties in the property grid for their study area. They conclude that the model is a good predictive model by comparing results to a forest cover surface based on remotely sensed data, and they argue that an agent-based model based on a behavioral model (which is itself based on both theory and past empirical results) is preferable to the types of agent-based models most commonly seen in the literature.

In most of these articles and other work by this team predicting related outcomes (e.g. Perz 2001a, 2003, 2004, 2005), the time on the property has a significant effect on the farm system or extent of various land uses. The authors interpret this as a household life cycle effect. However, in our work we argue against this interpretation because households settle their properties at different ages, and the average settler is beyond the earliest stage of his household life cycle. We argue instead that this represents a process of learning and evolution on the property rather than by a household.

McCracken, Brondízio and colleagues have also used the approach in their study area in Altamira, one of the areas included in our analyses in this paper (Brondizio et al. 2002; McCracken et al. 1999; McCracken et al. 2002). They find evidence for changing deforestation rates (based on remotely sensed data) over the household life cycle (Brondizio et al. 2002; McCracken et al. 1999), with initially low rates of deforestation after settlement, followed by a peak in deforestation within five years after settlement and another peak 10-15 years after settlement (Brondizio et al. 2002). They use a cohort based approach, examining each settlement cohort separately and finding the same pattern for each. However, they also point out that there is more variation within cohorts than across cohorts, reflecting differences in household characteristics. This research used remotely sensed measures of forest cover, and also used the time since settlement (opening of a property) as a proxy for household life cycle.

Bilsborrow, Pichón and colleagues have also used the approach in studying land use among farm colonist households in the Northern Ecuadorian Amazon. They initially used their field observations to argue for a refinement of traditional models of rural livelihoods which assumed land scarcity and labor abundance, the reverse of what is found in Amazonian frontiers (Pichón 1996). In empirical analysis using only survey data from their sample of farms in the Northern Ecuadorian Amazon settlement area, they find that women with children under 12 are more likely to participate in farmwork (Thapa, Bilsborrow and Murphy 1996). They also find that area in perennials and pasture increases as a function of household size but that the area in food crops in not significantly related to household size (Pichon 1996a). They similarly find household life cycle effects on forest clearing (Marquette 1998). However, they find that no measures of household size or composition significantly predict farm income, participation in off-farm work or income from cattle (Murphy 2001).

In more recent work, this team has both linked remotely sensed data to their survey data and used more complicated statistical methods to estimate household and community effects on land use / land cover (Pan et al. 2001; Pan and Bilsborrow 2005; Pan et al. 2004). This recent work uses the area in a variety of land covers or land uses (summing to 100% of the property) as dependent variables in statistical models that simultaneously predict all of the outcomes (dealing with the correlations between choices about, e.g., perennials and pasture). These models do not show perfect support for the household life cycle or household production approaches, but they do show some of the expected effects of household labor supply and children on area in annuals, perennials, pasture or forest.

Research Questions and Analytical Strategy

In the context of this research tradition, this paper asks two questions: how does household demographic composition affect land use and land cover in two study areas in the state of Pará in the Brazilian Amazon, and how do the effects on land use differ from the effects on land cover? Thus there are two key comparisons that we make in the analyses presented below. First, we compare the effects of household demography in our Altamira study area to those in our Santarém study area (the study areas are described in more detail below). Second, we examine correlations between used area and forested area (measures described below) from survey and remotely sensed data and compare the results of regression models using these variables from the two data sources as dependent variables.

The first comparison examines the effects of household demographic composition with an eye towards both estimating an effect of household demography and testing the robustness of that effect to changes in settlement history and topography (among other factors). The household life cycle model has most often been applied in recent frontiers among first generation settler households, while the theory should be general enough to apply in earlier settled regions or among second or higher generation settlers. Thus, we compare our Altamira study area, a recent frontier with primarily first generation settlers represented in the sample, to our Santarém study area, with a longer settlement history and more variation among households in length of residence.

The second comparison allows us to address methodological concerns that arise in considering the results of work using only a single source of data (social surveys or remotely sensed imagery). Past research has often interpreted land cover measures to be representative of land use or vice versa. While the defensibility of this practice depends on the quality of ground truthing of classifications, there remains some difference between the measures even in the highest quality measures of both land use and land cover. Some differences in results between studies from different research teams or regions might be attributable to these differences. We seek to understand how important these measurement differences are by examining only two categories of land use / land cover – used area and forested area – which should be more comparable than more detailed categories.

To make the first and second comparisons, we utilize simple linear regression models. Analyzing three years for Altamira and two years for Santarém (years for which good satellite imagery is available), we estimate the effects of household demography on used area and on forested area, controlling for time on property and other basic characteristics of the property. We estimate separate models for the survey based measures and the measures based on remotely sensed data, for forest area and for used area, and for each year, resulting in 12 regression models for Altamira and eight regression models for Santarém. We then interpret the pattern of results that we find across models rather than specifically focusing on the results of one or two models.

Study Areas

Figure 1 shows the locations of our two study areas within the state of Pará in Brazil. The area around Altamira is shown in more detail in Figures 2 and 3. Altamira is a region of rolling topography, including frequent steep slopes that are unsuitable for most crops. It is characterized by relatively fertile soils (terra roxa) and available water. The main rural economic activities are cattle ranching and cocoa production, along with subsistence cropping. Figure 2 shows the outline of the study region in red over a false color presentation of a 2003 Landsat satellite image. In this image, the darker greens are more vegetation while the lighter greens and pinks are areas with little or no vegetation. This image shows that Altamira exhibits the traditional fishbone pattern of deforestation radiating out from planned roads. The TransAmazon Highway runs east-west in the center of the study area, with north-south feeder roads intersecting it at roughly four kilometer intervals. Settlement in this region was planned by the Instituto Nacional de Colonização e Reforma Agrária (INCRA) of the Brazilian government. INCRA laid out a grid of 100 hectare properties with 500 meters of road frontage on side roads (or 400 on the highway) and gave these properties to settlers for little or no investment beginning in the early 1970s (Moran 1981).

Figure 3 shows how the clearing of old growth forest progressed from that point. This figure indicates the earliest time in which clearing was evident in remotely sensed data. Very little clearing was evident before 1970 (shown in white), while the rapid clearing by colonists in the 1970s and 1980s is evident in the yellow (cleared by 1975) and orange (cleared by 1985). Previous research on this region has shown the cycles of deforestation undertaken by colonists, both as a function of the time since a lot was first settled (was “opened”) and as a function of macroeconomic and political forces (Brondizio et al. 2002; McCracken et al. 1999). As described above, this research analyzed the rate of deforestation between successive satellite images for properties grouped by “cohort,” the time of first clearing and settlement on the lot. It was found that properties follow a standard trajectory of high deforestation rates at approximately five and then 10-15 years after settlement. However, the magnitude of the deforestation rate (as opposed to the pattern over time) was determined more by the particular economic and political circumstances in a particular time period.

The area around Santarém is shown in more detail in Figures 4 and 5. Santarém's position at the confluence of the Amazon and Tapajós Rivers has made it an important commercial center for centuries. It has experienced earlier recent waves of settlement, in the 1930s, 1950s, and 1970s-1980s. These waves of settlement are evident in Figure 4, showing the clearing of old growth forest by dates for which we have remotely sensed data. A large portion of the study area was cleared before the early 1970s, and the vast majority of the area had been cleared at some point before 2001.

Figure 5 shows a false color representation of a Landsat image for 2001, illustrating other key differences between Santarém and Altamira. Despite the majority of the area having been cleared by the 1990s, there is a lot more greenness in the image of Santarém. This reflects the lower prevalence of pasture and the larger proportion of the area in some sort of secondary growth (from small scrubby growth to areas that are indistinguishable from forest in satellite imagery). Figure 5 also shows the higher level of disorganization in the landscape, with large contiguous farms relatively rare and with clearing following both road networks and river networks. This in turn is the result of the longer and unplanned settlement history of Santarém.

The biophysical characteristics of the Santarém study area are also distinct from those of the Altamira study area. The topography is flatter in Santarém with the exception of a narrow band of steep slopes near the Amazon River. The soils are worse in Santarém, with a relative paucity of the fertile terra roxa that is more common in Altamira. Santarém also experiences more frequent water shortages. Wells must be deep and water is hard to come by. As a result, Altamira is more suited to the raising of cattle and permits more effective production of perennial crops. This is not to say that production of perennials is not possible in Santarém, or that farmers cannot raise cattle, but both are harder. This tendency away from cattle production and perennials is exacerbated by the recent introduction of soybeans into the Santarém area, with the multinational Cargill constructing a deep water port on the Amazon River in the city accompanied by land consolidation and large scale mechanized soy production (VanWey, D'Antona and Adams 2004).

These differences between Altamira and Santarém mean that the comparison between the two regions provides a good test of the generality of relationships between household demography and land use. We find some differences in results between the two areas and can not distinguish between topography, climate, and settlement history as explanations for these differences, but the key results (and non-results) that we see are common across these two very different study areas. Thus these results are robust to the variety of differences between the study areas.

Data – Sampling and Household Surveys

The samples for the social survey data collection are based on INCRA property grids for each study area. In Altamira, the grid represents the settlement plan for the region, while in Santarém the grid is for planned settlement in a small portion of the region and is a regularization of existing land tenure in the remainder of the region. In each case, the grid represents the reality of land ownership at the point at which the area was surveyed (times vary by location, but generally this is prior to the 1990s). For Altamira, the boundaries of properties were relatively unchanged from the creation of the grid until the time of our data collection. However, in Santarém there are substantial differences between the original grid and the current land ownership patterns across the landscape. We describe below how this was dealt with in our data collection in Santarém.

In Altamira, we selected a stratified random sample of properties from the property grid. Each property in the grid was assigned to a settlement cohort, based on the year in which a cleared area of five hectares was visible in a satellite image. Figure 6 shows the property grid and the assignment of properties to cohorts. Within each cohort, we then selected a random sample of properties, with the goal of an equal representation of cohorts in the final sample, despite the larger number of properties in the earlier cohorts in the population.

We then visited each of these properties in either 1997 or 1998 and interviewed the household of the property owner, conducting interviews usually with the male and female heads of household about land use and production and about household demography and economy, respectively. In some cases, we substituted an alternate property for the originally sampled property when the sampled property was vacant or the owners were impossible to locate to interview.[1] The interview with the male head of household included information on the various land uses on the property at the time of acquisition and at the time of the survey, and included a land use history showing the changes in area in certain land uses over the ownership of the property. The conversations about current and past land use were facilitated by sketch maps that the interviewers drew with the farmers and by satellite images from four dates showing the property, which the interviewers interpreted with the farmer. This information allows us to estimate the area in various uses in any year that the household owned the property. The interview with the female head of household included information about the current and past composition of the household, allowing us to construct measures of the household size and composition in any year since the household arrived on the property. All of the properties in this sample (subject to some restrictions described below) are included in our analyses for this paper.

[1] Sampled properties were replaced with alternates only when owners were impossible to locate and not because of owners refusing to participate. In this wave of data collection we had no farmers refuse to participate in our study.

In Santarém, we also sampled from an existing property grid with the goal of an equal representation of properties occupied at different times. Because of the longer settlement history, we were not able to stratify the population of properties in the study area by time of first clearing. Instead, we stratified by region within the study area. Figure 7 shows these regions in yellow, pink, green and blue. Each region follows a major road – from West to East, the Cuiabá-Santarém Highway (BR-163), smaller roads to Jabuti and Mojui dos Campos, and the Curuá-Una Highway (linking the region to the hydroelectric power generated by the Curuá-Una dam) – which was opened in a different era, leading to settlement of the region at a different time. Within each region, we overlaid a grid of 3km by 3km cells and selected a sample of these cells to achieve a spatially clustered sample to reduce transportation costs. Within each of these cells, we selected five target properties and four alternates (or fewer if there were fewer than nine properties in the cell).

We visited these target properties in the summer of 2003 and attempted to interview both the household of the owner of the property and any other households on the property. Because of the long settlement history and a more active land market in Santarém, we encountered three situations that made the achievement of interviews in all sampled properties difficult. First, many properties had been divided and the area covered by the sampled property was occupied by multiple properties or by parts of multiple properties. In this case, we attempted to interview all the properties that were wholly or partially in the area covered by the sampled property. Second, many other properties had been aggregated with others into large farms, often managed by absentee owners or used for commercial farming with no households resident onsite. In this case, we interviewed the owning household if that household lived on some portion of the aggregated land and managed it themselves. If the farm owner was absent and/or the farm was managed completely as a commercial endeavor, we collected a limited set of data about the current owner and land use transformations on the property from neighbors and workers. Third, we encountered areas in which the property grid bore no resemblance to the actual division of land and no informants could remember a time in which land had been partitioned in that way. In this case, we again attempted to conduct interviews in all properties wholly or partially in the area covered by the sampled property.

The sample of properties from the original property grid was designed to be representative of the landscape, allowing us to generalize our results to the population of properties and therefore to the landscape. By interviewing properties that are in the same physical area as the sampled properties from the original property grid, we preserve this ability to generalize to the landscape. By interviewing all households resident on the property, we also have a multistage cluster sample that is representative of all the households living in the study area. For the analysis below, we restrict the sample to the households of property owners on the properties that are still owned and managed as family properties (as opposed to as commercial farms).

In both study areas, we further restrict our sample in three ways for the analyses for this paper. First, we include only households who have owned their properties for approximately 10 years prior to the survey. The exact dates of ownership differ between study areas because of different availability of remotely sensed data. We use images from 1988, 1991, and 1996 for Altamira and from 1991 and 2001 for Santarém. We use survey data from 1986 through 1996 for Altamira and from 1989 through 2001 for Santarém, giving us two years of data prior to the first image for measuring household characteristics (see below). We limit the sample to households who have owned their properties in all these years. Second, we limit the sample to properties that have less than 10% cloud or cloud shadow in any given remotely sensed image. For example, if a property has 15% cloud in 1988 but no cloud in 1991, that property is included in the analyses for 1991 but not for 1988. For this reason, the sample sizes vary somewhat between years in the analyses below. Third, we limit the sample to properties that are larger than five hectares. This is only a consideration in Santarém as all of the properties in Altamira are substantially larger than that (see Table 1).

We create four sets of variables from the survey data for the analyses for this paper. First, we create measures of the area on the property in forest and the area used, measured in hectares. The area in forest is calculated as the area in forest when the household acquired the property minus any areas that have been cleared between arrival and a given year. The used area is similarly calculated based on initial conditions and changes over time. The used area includes area reported to be used for annuals, perennials, or pasture. This definition is broad and misses some important distinctions between the economic and demographic motivations for cultivation of annuals or perennials or raising of cattle. However, the secondary goal of this paper, to compare measures based on surveys to those based on remotely sensed data necessitates the use of very general categories. It is difficult or impossible to distinguish more detailed categories in both the remotely sensed and survey data. Each data source alone allows us to distinguish more detailed categories, but these categories are not compatible across data sources.

Second, we create a measure of the time since the acquisition of the lot by the household. The date of acquisition is the year in which the current owner purchased or began making decisions about the property; this covers situations in which owners had (or have) insecure title or in which they cared for the property in anticipation of inheriting it. This allows us to distinguish a "lot life cycle," the pattern of changes that a lot goes through over the course of management by a single household from changes over time that are the result of household demographic changes.

Third, we create a set of variables to measure the household demographic composition in any given year. These are: the number of children (0-11), the number of female adolescents (12-18), the number of male adolescents (12-18), the number of female adults (19-54), the number of male adults (19-54), the number of older females (55+) and the number of older males (55+). These numbers are created by taking the demographic composition of the household at the time of the survey, removing any current members who were not yet in the household in the year (for example, children who had yet to be born), adding any past members who had left by the time of the survey (for example, children who were in the household but had left by the time of the survey), and then computing the number of members in each sex-age group from the sexes and dates of birth of all of the members. These count variables allow us to distinguish between the effects of dependents (children and older members) and working age household members, and allow us to examine the gendered nature of demographic effects. The household life cycle theory argues for increases in production as a function of dependents and as a function of members who are able to contribute labor to production. Because of the nature of farming in these regions, the majority of the labor is supplied by men, suggesting that the number of females, children and older members should have a positive effect on production, but that the number of working age males should have a stronger effect.

Fourth is a set of control variables reflecting the characteristics of the property. The total area of the property is measured in hectares and is the respondent's report of the size the property. Because of the more complex organization of properties in Santarém, we collected information about the timing of purchases and sales of parcels of land contiguous with the interviewed property. Thus, the area of the property in the Santarém analyses can vary from year to year. We also include as controls in regression models measures of the area in pasture and perennials when the household acquired the property. These are uses of land that tend to persist over time and might form the basis for the household purchasing the property, in contrast to area in annuals which must be decided anew each year.

The descriptive statistics on these variables for each year are shown in Tables 1a and 2a. Table 1a shows descriptive statistics for the Altamira analysis samples using survey-based dependent variables, while Table 2a shows the same for Santarém. Table 1a shows that the average property in Altamira was just over the planned size of 100 hectares, with approximately half (depending on year) in forest and almost all of the remainder in used area. In contrast, the average property in Santarém is only just over 40 hectares, with only about one quarter in forest and half that in used area. This reflects the prevalence of unused (fallow or abandoned) areas of secondary growth in Santarém. The time trends in these measures are shown in Figure 8. The recent settlement of Altamira leads to a steady decline in forested area and increase in used area, while the relative stability of land use in the longer-settled Santarém properties leads to little change in either forest or used area between the two dates. The differences in land use across the study areas are also evident in the area in pasture and perennials when the property was acquired; Altamira shows a higher average area in pasture or perennials when acquired, reflecting the larger number of households acquiring land that already contained pasture and the larger average property size.

The measures of household demographic composition vary little between the two areas. Both reflect settled households past their childbearing years at the time of the survey (because of the sample restriction requiring them to have owned the property for more than 10 years), showing both aging and declines in size. The declining household size and changing composition is shown graphically in Figure 9. The households have few children immediately before the survey date (1996 sample for Altamira and 2001 sample for Santarém), but had an average of two children in the earliest analysis sample. They have averages of more than one working age member of each gender and slightly over one adolescent member at all time points. The average number of older members increases over time as these households age. In each gender-differentiated age group, the average number of males is higher than the average number of females, reflecting the tendency for daughters to leave their natal household at higher rates than sons in this area and the tendency for older women to move off the farm for the amenities of living in the city.

Data – Remotely Sensed Measures

We also use measures of land cover based on remotely sensed data. These measures are the area in a property that is in forest or in a group of categories that together represent used area in classifications of satellite data. The satellite images are all Landsat images, taken in July of 1988 and 1991, and June of 1996 over the Altamira study area and in July of 1991 and 2001 over the Santarém study area. We used a combination of supervised and unsupervised classification techniques to classify each pixel in these images into a specific land cover (or into cloud or cloud shadow). These classifications produced a continuous surface of land cover for each study area for each time point. We then partitioned the portion of the landscape associated with each surveyed property using the boundaries of the property in the property grid. These boundaries were updated during fieldwork based on the information provided by farmers and on GPS (Global Positioning System) points taken at the corners of properties.

The GIS produced the area in each of the following categories: forest, secondary succession 3 (SS3), secondary succession 2 (SS2), secondary succession 1 (SS1), bare, pasture, water, cloud and cloud shadow for Altamira;[2] forest (two types), forest/SS3, SS2/SS3, SS2, SS1/SS2, SS1, bare/SS1, bare, cloud, and cloud shadow for the first Santarém image; and bare (divided into high and low reflectance), agriculture, pasture, SS1, SS2, forest, and water for the second image from Santarém.[3] Because these categories reflect primarily the amount of vegetation on the landscape and not the type of vegetation on the landscape, making measures that are comparable to the survey-based measures is difficult. We started from the land use categories (annuals, perennials and pasture) and designed the land cover measures to capture those as closely as possible. The measure of forest cover in the analyses below uses the area classified as forest or SS3 in Altamira and the area classified as forest/SS3 in Santarém. SS3 is not old growth forest, but it is densely vegetated area that can be considered similar to old growth forest (evidenced by our inability to distinguish SS3 from forest in our Santarém classification). The measure of used area in Altamira includes area classified as bare, pasture or SS1[4]. The measure of used area in Santarém includes the area classified as bare, bare/SS1, SS1, or SS1/SS2. Because our images come from the summer months, the bare category combines recently cleared land with dry pasture or lawn areas around houses. The SS1 or SS2 land cover combines wetter pasture with young perennials (bananas, pepper, young cocoa), but misses older

[2] In 1991, the classification also included a category for sugar cane, capturing a short-lived explosion of sugar cane cultivation during the operation of a factory for converting sugar cane to alcohol. We do not use this category in our analyses.
[3] The differences among the classifications reflect both differences in the ability of the research team to distinguish categories and differences in the initial uses of the classified imagery. In each case, the categories collapse into the used and forested area in which we are interested in comparable ways.
[4] We tested alternate combinations of categories, particularly adding the SS2 and SS2/SS3 categories into our measure of used area. The specification that we describe here showed the highest correlation with the survey-based measures.

cocoa which is an perennial important crop in Altamira. Older cocoa is indistinguishable from SS3 in the imagery because the full grown trees create area with dense leaf cover.

The descriptive statistics on these measures of land cover are shown in Tables 1b and 2b, with the time trend shown graphically in Figure 10. These measures estimate more average forested area and less average used area than the farmers estimate in Altamira. The lower estimate of used area suggests that our remotely sensed measure is missing the cocoa and potentially other perennial crops. In Santarém, in contrast, the averages are closer to each other in absolute terms – averages of five hectares vs. six and 11 hectares vs. seven used area and 18 vs. 13 and 10 vs. 11 of forest. However, these smaller absolute differences in means mask a lower correlation between the remotely sensed and survey based measures in Santarém than in Altamira. Table 3 shows these correlations for Altamira while Table 4 shows them for Santarém. In Altamira, the correlations between the two types of measure of used area are above .6 and the correlations between the two types of measure of forested area are above .7. In Santarém, the corresponding correlations are below .5 and below .4. These differences suggest that differences between data sources in Altamira are systematic (i.e. surveys consistently estimate less forest and more used area) but that both are estimating basically the same thing. However, in Santarém the different data sources do not appear to estimating the same thing.

If this interpretation is correct, we would expect to see a particular pattern of differences between regression models. We would expect the regression models in Altamira to show the same effects of covariates, differing only in the intercept term. We would expect the regression models in Santarém to show one of two things. If the differences between the remotely sensed and survey based measures are primarily due to greater error in estimating forest area or used area in both data sources (as we might expect with relatively similar means but low correlations), the effects of covariates should be the same across models. If the differences between the two types of measures is not solely due to measurement error (or other random error), for example it reflects real differences in what it is measuring that vary substantially across households, we would expect the effects of covariates to differ across models.

Results

Tables 5-8 show the results of the regression models predicting used area and forested area. Tables 5 and 6 show the results from Altamira, while Tables 7 and 8 show the results from Santarém. Each set contains first the analysis of used area (Tables 5 and 7) and then the analysis of forested area (Tables 6 and 8). Tables by and large show expected effects for control variables. The area of the property has a positive effect on the used area and on the forested area (significant in all but two models), while the area in pasture when the property was acquired has a positive effect on the used area and a negative effect on the forested area (significant in the majority of models). The time since the household acquired the property has only a marginally significant effect in one model for Santarém, but has significant effects in the majority of the models for Altamira. The longer that a household has owned a property, the more area used and the less area forested. The size of this effect increases over time for the survey based dependent variables and decreases over time for the remotely sensed dependent variables (we will return to this point).

With respect to the effects of household demographic composition results are mixed and largely non-significant. Out of 140 coefficients measuring the effect of demographic variables, 22 are significant at the .10 level, only a few more than would be expected by chance. Only 13 are significant at the .05 level. Instead of focusing on any one or few of these coefficients, we examine the results for patterns that are consistent across years, across data sources and / or across study sites. Within the Altamira analyses, the only such consistent effects are of older women in the household. Households with more women 55 or older have substantially less used area and more forested area, according to the survey based measures of used and forested area. This is consistent with the household life cycle model that argues that as households age they consolidate into lower labor activities. The marginally significant negative effects of children on the used area (from the survey) and significant positive effects on the forested area (from the remotely sensed data) together suggest that households early in their life cycle are using less area, consistent with the arguments of the household life cycle model.

There are no such consistent effects across models in the Santarém analyses shown in Tables 7 and 8. While there are a few significant effects that might be interpreted in single models, there is no effect that is consistent across time or data source. Only the number of female adolescents has an expected positive effect on used area in one model (survey based measure, 1991) and negative effect on forested area in one model (remotely sensed measure, 1991). From the combination of results across all models, we conclude that there is no consistent effect of household demographic composition on land use or land cover.[5]

Turning to our second research question, on the differences between using survey based and remotely sensed measures of land use or land cover, we examine the similarities between coefficients across the two data sources. In both study areas, the effects of household demography vary between the two sets of dependent variables. The only variable that has a consistent effect (in significance, direction, and approximate size) for the Altamira models is the area of the property, which we include as a scaling variable. The effect of this variable provides

[5] In other work, we are exploring whether the lack of significant effects on used area masks significant opposite direction effects on different types of land use, but preliminary results suggest that is not the case.

important information about the average proportion of each property that is used or in forest. The coefficient represents the increase in used (forested) area for a one hectare increase in property size. Of particular interest in these models are the increase in the size of the coefficient in the models of used area from the earliest to the latest date, and the lower coefficient estimated in the models with the remotely sensed dependent variable. These reflect the increasing extent of used area over time (as would be expected in a relatively young frontier) and the fact that the remotely sensed data does not capture some uses (such as cocoa).

The models of forested area show even more consistency across data source in Altamira. Property size has effects of similar magnitude (indicating that approximately 50-60% of the property is forested) that decline over time for both dependent variables. In contrast, in Santarém property size has very small but significant positive effects on used area measured from remotely sensed data, but no significant effects on used area measured from the survey. Again, the effects are more consistent on forested area, with the size of the property having positive and significant effects on forested area in all models. As in Altamira, the size of these coefficients declines from the earlier to the later model, indicating a decrease in the proportion of the property in forest over time.

Models with remotely sensed and survey based dependent variables are in direct conflict (rather than showing different significance patterns or coefficients in the same direction but of different magnitudes) in examining the effect of the time since acquisition of the property. The models in Santarém show no significant effect of time since acquisition, but the models in Altamira show significant effects of different magnitude that are moving in different directions over time. Specifically, the effect of time since acquiring the property on used area measured from the survey is large and positive and increases in the later models while the same effect on used area measured from the remotely sensed data is smaller (though still positive) and declines over time (losing significance in the second time point). Similarly, the negative effect of time since acquiring the property on forested area increases over time for the survey based dependent variable but declines and even becomes positive (but non-significant) over time for the remotely sensed dependent variable. This result suggests that the congruence between how people think about their property and what is happening on the landscape bear less and less resemblance over time.

The other important difference to note between the models using remotely sensed dependent variables and those using survey based dependent variables is in the effect of the area in pasture when the property was acquired. In Altamira, area in pasture when acquired has significant positive effects on used area and negative effects on forested area, but only when using the *survey based* measures of used and forested area. In Santarém, the area in pasture when acquired has significant positive effects on used area and negative effects on forested area, but only when using the *remotely sensed* measures of used and forested area. We are not sure what to make of this difference, but it again highlights the differences between the data sources and the differences in their congruence between the two study sites.

Conclusions

Based on the results presented in this paper, we conclude that the household life cycle model does not adequately capture the reality of the relationship between smallholder households and land use / land cover. This result is in contrast to previous results based on our Altamira study area (Brondizio et al. 2002; McCracken et al. 1999) and other study areas in the Amazon (Perz 2001b; Walker et al. 2002), but is consistent with the arguments of Walker (Walker 2004;

Walker et al. 2002) that the main determinants of deforestation and land use for smallholders are available hired labor and road networks. In both of our study areas, local labor markets are well-developed and we find a considerable amount of off-farm agricultural employment among members of our surveyed households. This points then to the primacy of the economic characteristics of the household and the availability of credit for hiring labor to clear land.

Our second conclusion is that measures derived from survey data and from remotely sensed data can not be used interchangeably. In contrast to Walker, Moran and Anselin (2000), who conclude that the survey respondents are underestimating forest cover to avoid government sanctions, we argue that the two measures are simply capturing different realities. It is important to note that the differences between the effects in regression models were greater in the later dates, reflecting a divergence between remotely sensed and survey based measures over the time that the property has been occupied. The differences were also more evident in the Santarém region, an area characterized by a longer settlement history. The implication for the larger research community is that, in order to understand and model the effects of smallholders on land cover change, we need to explicitly model the relationship between land use and land cover. This modeling needs to use data from a variety of study areas, representing the range from new frontiers to older settlement areas to regions including a mix of agricultural and non-agricultural land uses (such as much of rural America).

REFERENCES

An, L., J. Liu, Z.Y. Ouyang, M. Linderman, S.Q. Zhou, and H.M. Zhang. 2001. "Simulating Demographic and Socioeconomic Processes on Household Level and Implications For Giant Panda Habitats." *Ecological Modelling* 140(1-2):31-49.

Boserup, E. 1981. *Population and Technological Change: A Study of Long-Term Trends*. Chicago: University of Chicago Press.

Brondizio, E.S., S. McCracken, E.F. Moran, A.D. Siqueira, D. Nelson, and C. Rodriguez-Pedraza. 2002. "The Colonist Footprint: Toward a Conceptual Framework of Land Use and Deforestation Trajectories among Small Farmers in the Amazonian Frontier." Pp. 162-192 in *Deforestation and Land Use in the Amazon*, edited by C.H. Wood and R. Porro. Gainsville, FL: University Press of Florida.

Carr, D.L. 2004. "Proximate population factors and deforestation in tropical agricultural frontiers." *Population and Environment* 25(6):585-612.

Chayanov, A.V. 1966. *The Theory of Peasant Economy*. Homewood, IL: Richard D. Irwin.

Dietz, T.and E.A. Rosa. 1997. "Effects of Population and Affluence on CO_2 Emissions." *Proceedings of the National Academy of Sciences of the United States* 94(1):175-179.

Ehrhardt-Martinez, K., E.M. Crenshaw, and J.C. Jenkins. 2002. "Deforestation and the environmental Kuznets curve: A cross- national investigation of intervening mechanisms." *Social Science Quarterly* 83(1):226-243.

Ehrlich, P.R.and J.P. Holdren. 1971. "Impact of Population Growth." *Science* 171:1212-1217.

Lambin, E.F., B.L. Turner, H.J. Geist, S.B. Agbola, A. Angelsen, J.W. Bruce, O.T. Coomes, R. Dirzo, G. Fischer, C. Folke, P.S. George, K. Homewood, J. Imbernon, R. Leemans, X.B. Li, E.F. Moran, M. Mortimore, P.S. Ramakrishnan, J.F. Richards, H. Skanes, W. Steffen, G.D. Stone, U. Svedin, T.A. Veldkamp, C. Vogel, and J.C. Xu. 2001. "The causes of land-use and land-cover change: moving beyond the myths." *Global Environmental Change-Human and Policy Dimensions* 11(4):261-269.

Liu, J.G., Z.Y. Ouyang, Y.C. Tan, J. Yang, and H.M. Zhang. 1999. "Changes in human population structure: Implications for biodiversity conservation " *Population and Environment* 21:45-58.

Malthus, T.R. 1989 [1803]. *An Essay on the Principle of Population*. Cambridge: Cambridge University Press.

Marquette, C.M. 1998. "Land use patterns among small farmer settlers in the Northeastern Ecuadorian Amazon." *Human Ecology* 26(4):573-598.

McCracken, S., E.S. Brondizio, D. Nelson, E.F. Moran, A. Siqueira, and C. Rodriguez-Pedraza. 1999. "Remote Sensing and GIS at the Farm Property Level: Demography and Deforestation in the Brazilian Amazon." *Photogrammetric Engineering and Remote Sensing* 65:1311-1320.

McCracken, S., A. Siqueira, E.F. Moran, and E.S. Brondizio. 2002. "Land-Use Patterns on an Agricultural Frontier in Brazil: Insights and Examples from a Demographic Perspective." in *Deforestation and Land Use in the Amazon*, edited by C.H. Wood and R. Porro. Gainsville, FL: University Press of Florida.

Moran, E.F. 1981. *Developing the Amazon*. Bloomington, IN: Indiana University Press.

Murphy, L.L. 2001. "Colonist farm income, off-farm work, cattle, and differentiation in Ecuador's northern Amazon." *Human Organization* 60(1):67-79.

O'Neill, B.C., F.L. MacKellar, and W. Lutz. 2001. *Population and Climate Change*. Cambridge, UK: Cambridge University Press.
Pan, W., L. Murphy, B. Sullivan, and R.E. Bilsborrow. 2001. "Population and Land Use in Ecuador's Northern Amazon in 1999: Intensification and Growth in the Frontier." Presented at Population Association of America Annual Meetings, Washington, DC.
Pan, W.K.Y.and R.E. Bilsborrow. 2005. "The Use of a Multilevel Statistical Model to Analyze Factors Influencing Land Use: A Study of the Ecuadorian Amazon." *Global and Planetary Change* 47:232-252.
Pan, W.K.Y., S.J. Walsh, R.E. Bilsborrow, B.G. Frizzelle, C.M. Erlien, and F. Baquero. 2004. "Farm-level models of spatial patterns of land use and land cover dynamics in the Ecuadorian Amazon." *Agriculture Ecosystems & Environment* 101(2-3):117-134.
Pebley, A.R. 1998. "Demography and the Environment." *Demography* 35(4):377-389.
Perz, S.G. 2001a. "From sustainable development to "productive conservation": Forest conservation options and agricultural income and assets in the Brazilian Amazon." *Rural Sociology* 66(1):93-112.
—. 2001b. "Household demographic factors as life cycle determinants of land use in the Amazon." *Population Research and Policy Review* 20(3):159-186.
—. 2002. "Household life cycles and secondary forest cover among small farm colonists in the Amazon." *World Development* 30(6):1009-1027.
—. 2003. "Social determinants and land use correlates of agricultural technology adoption in a forest frontier: A case study in the Brazilian Amazon." *Human Ecology* 31(1):133-165.
—. 2004. "Are agricultural production and forest conservation compatible? Agricultural diversity, agricultural incomes and primary forest cover among small farm colonists in the Amazon." *World Development* 32(6):957-977.
—. 2005. "The effects of household asset endowments on agricultural diversity among frontier colonists in the Amazon." *Agroforestry Systems* 63(3):263-279.
Perz, S.G.and D.L. Skole. 2003. "Social determinants of secondary forests in the Brazilian Amazon." *Social Science Research* 32(1):25-60.
Pichon, F.J. 1996a. "Land-use strategies in the Amazon frontier: Farm-level evidence from Ecuador." *Human Organization* 55(4):416-424.
—. 1996b. "Settler agriculture and the dynamics of resource allocation in frontier environments." *Human Ecology* 24(3):341-371.
Pichón, F.J. 1996. "Settler Agriculture and the Dynamics of Resource Allocation in Frontier Environments." *Human Ecology* 24(3):341-371.
Rindfuss, R.R., B.L. Turner II, B. Entwisle, and S.J. Walsh. 2004. "Land Cover/Use and Population." in *Land Change Science: Observing, Monitoring, and Understanding Trajectories of Change on the Earth's Surface*, edited by G. Gutman, T. Janetos, C. Justice, E.F. Moran, J. Mustard, R.R. Rindfuss, D. Skole, and B.L. Turner II. Boston: Kluwer Academic Publishers.
Thapa, K.K., R.E. Bilsborrow, and L. Murphy. 1996. "Deforestation, land use, and women's agricultural activities in the Ecuadorian Amazon." *World Development* 24(8):1317-1332.
VanWey, L.K., A.O. D'Antona, and R.T. Adams. 2004. "Land Consolidation in Santarém, Pará, Brazil." presented at Michigan State University Center for Systems Integration and Sustainability.
VanWey, L.K., E. Ostrom, and V. Meretsky. 2005. "Theories Underlying the Study of Human-Environment Interactions." Pp. 23-56 in *Seeing the Forest and the Trees: Human-*

Environment Interactions in Forest Ecosystems, edited by E.F. Moran and E. Ostrom. Cambridge, MA: MIT Press.

Walker, R. 2003. "Mapping process to pattern in the landscape change of the Amazonian frontier." *Annals of the Association of American Geographers* 93(2):376-398.

—. 2004. "Theorizing land-cover and land-use change: The case of tropical deforestation." *International Regional Science Review* 27(3):247-270.

Walker, R., S.A. Drzyzga, Y.L. Li, J.G. Qi, M. Caldas, E. Arima, and D. Vergara. 2004. "A behavioral model of landscape change in the Amazon Basin: The colonist case." *Ecological Applications* 14(4):S299-S312.

Walker, R., E. Moran, and L. Anselin. 2000. "Deforestation and cattle ranching in the Brazilian Amazon: External capital and household processes." *World Development* 28(4):683-699.

Walker, R., S. Perz, M. Caldas, and L.G.T. Silva. 2002. "Land use and land cover change in forest frontiers: The role of household life cycles." *International Regional Science Review* 25(2):169-199.

Walker, R.T.and A.K.O. Homma. 1996. "Land Use and Land Cover Dynamics in the Brazilian Amazon: An Overview." *Ecological Economics* 18:67-80.

Table 1. Descriptive Statistics for Altamira

	Sample with Survey Based Dependent Variables								
	1988 N = 189			1991 N = 192			1996 N = 160		
Variable	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Used Area	40.63	0	404.50	44.65	0	424.50	55.71	0	504.50
Forest Area	64.76	0	409	59.40	0	369	51.44	0	324
Log (time since acquiring property)	2.29	1.10	3.18	2.58	1.79	3.30	2.90	2.40	3.47
Number of Kids (0-11)	2.01	0	7	1.55	0	7.33	0.92	0	6
Number of Females (12-18)	0.58	0	3.33	0.65	0	3.67	0.51	0	4
Number of Males (12-18)	0.84	0	4.33	0.84	0	4.33	0.65	0	3.33
Number of Females (19-54)	1.30	0	8	1.22	0	8	1.10	0	8
Number of Males (19-54)	1.53	0	6	1.60	0	6.33	1.61	0	7.67
Number of Females (55+)	0.28	0	1	0.37	0	1	0.54	0	1
Number of Males (55+)	0.42	0	1	0.53	0	1	0.69	0	2
Size of Property (hectares)	110.48	35	501	110.24	35	501	111.16	35	501
Area in Pasture when Began Working (hectares)	0.88	0	50	0.98	0	50	1.11	0	50
Area in Perennials when Began Working (hectares)	0.09	0	4	0.09	0	4	0.11	0	4

	Sample with Remotely Sensed Dependent Variables								
	1988 N = 182			1991 N = 185			1996 N = 154		
Variable	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Used Area 1988 (RS)	21.38	0	164.79	---	---	---	---	---	---
Forest Area 1988 (RS)	72.82	14.22	417.69	---	---	---	---	---	---
Used Area 1991 (RS)	---	---	---	23.31	0	224.55	---	---	---
Forest Area 1991 (RS)	---	---	---	67.25	13.68	394.65	---	---	---
Used Area 1996 (RS)	---	---	---	---	---	---	27.11	0	246.87
Forest Area 1996 (RS)	---	---	---	---	---	---	69.20	2.34	402.66
Log (time since acquiring property)	2.31	1.10	3.18	2.60	1.79	3.30	2.92	2.40	3.47
Number of Kids (0-11)	1.97	0	7	1.50	0	7.33	0.88	0	6
Number of Females (12-18)	0.57	0	3.33	0.63	0	3.67	0.50	0	4
Number of Males (12-18)	0.83	0	4.33	0.83	0	4.33	0.63	0	3.33
Number of Females (19-54)	1.30	0	8	1.21	0	8	1.08	0	8
Number of Males (19-54)	1.53	0	6	1.60	0	6.33	1.60	0	7.67
Number of Females (55+)	0.29	0	1	0.37	0	1	0.54	0	1
Number of Males (55+)	0.43	0	1	0.53	0	1	0.70	0	2
Size of Property (hectares)	111.88	35.73	521	111.77	35.73	521	114.20	35.73	521
Area in Pasture when Began Working (hectares)	0.92	0	50	1.02	0	50	1.15	0	50
Area in Perennials when Began Working (hectares)	0.08	0	4	0.08	0	4	0.09	0	4

Table 2. Descriptive Statistics for Santarem

	Sample with Survey Based Dependent Variables					
	1991			2001		
	N = 88			N = 94		
Variable	Mean	Min	Max	Mean	Min	Max
Used Area	6.25	0	53	6.76	0	30
Forest Area	12.73	0	80	10.90	0	80
Log (time since acquiring property)	2.66	1.10	3.93	3.25	2.56	4.11
Number of Kids (0-11)	1.96	0	6.33	0.86	0	5.67
Number of Females (12-18)	0.55	0	2.67	0.43	0	2.67
Number of Males (12-18)	0.86	0	4	0.62	0	3.33
Number of Females (19-54)	0.98	0	3	0.73	0	3
Number of Males (19-54)	1.05	0	4	1.13	0	5.67
Number of Females (55+)	0.28	0	1	0.61	0	1
Number of Males (55+)	0.42	0	1	0.79	0	2
Size of Property (hectares)	42.83	5.5	284	40.36	5.5	284
Area in Pasture when Began Working (hectares)	0.43	0	31	0.42	0	31
Area in Perennials when Began Working (hectares)	0.02	0	1	0.04	0	1

	Sample with Remotely Sensed Dependent Variables					
	1991			2001		
	N = 80			N = 88		
Variable	Mean	Min	Max	Mean	Min	Max
Used Area 1991 (RS)	5.166	0.18	25.83	---	---	---
Forest Area 1991 (RS)	17.68	0	93.51	---	---	---
Used Area 2001 (RS)	---	---	---	10.85	1.26	61.65
Forest Area 2001 (RS)	---	---	---	9.95	0	66.15
Log (time since acquiring property)	2.65	1.10	3.93	3.25	2.56	4.11
Number of Kids (0-11)	1.94	0	6.33	0.82	0	4.33
Number of Females (12-18)	0.55	0	2.67	0.42	0	2.67
Number of Males (12-18)	0.90	0	4	0.64	0	3
Number of Females (19-54)	1.02	0	3	0.75	0	3
Number of Males (19-54)	1.05	0	4	1.19	0	6
Number of Females (55+)	0.28	0	1	0.64	0	1
Number of Males (55+)	0.43	0	1	0.82	0	2
Size of Property (hectares)	38.60	5	161	36.37	6	161
Area in Pasture when Began Working (hectares)	0.48	0	31	0.45	0	31
Area in Perennials when Began Working (hectares)	0.03	0	1	0.04	0	1

Table 3. Correlations between Remotely Sensed and Survey Based Measures: Altamira

	Used Area 1988 (RS)	Forest Area 1988 (RS)	Used Area 1991 (RS)	Forest Area 1991 (RS)	Used Area 1996 (RS)	Forest Area 1996 (RS)	Used Area (survey)	Forest Area (survey)	Size (GIS)	Size (survey)
Used Area 1988 (RS)	1									
Forest Area 1988 (RS)	0.438	1								
Used Area 1991 (RS)	---	---	1							
Forest Area 1991 (RS)	---	---	0.432	1						
Used Area 1996 (RS)	---	---	---	---	1					
Forest Area 1996 (RS)	---	---	---	---	0.323	1				
Used Area (survey)	0.656	0.331	0.735	0.328	0.786	0.393	1			
Forest Area (survey)	0.391	0.814	0.375	0.787	0.244	0.744	0.054	1		
Size (GIS)	0.629	0.871	0.674	0.839	0.627	0.831	0.525	0.674	1	
Size (survey)	0.690	0.880	0.727	0.844	0.691	0.845	0.603	0.773	0.870	1

NOTE: all correlations significant ($p < .01$) except for Forest Area (survey) with Used Area (survey)

Table 4. Correlations between Remotely Sensed and Survey Based Measures: Santarem

	Used Area 1991 (RS)	Forest Area 1991 (RS)	Used Area 2001 (RS)	Forest Area 2001 (RS)	Used Area (survey)	Forest Area (survey)	Area (GIS)	Current Size (survey)
Used Area 1991 (RS)	1							
Forest Area 1991 (RS)	0.241*	1						
Used Area 2001 (RS)	---	---	1					
Forest Area 2001 (RS)	---	---	0.194+	1				
Used Area (survey)	0.342*	0.1759	0.414*	0.252*	1			
Forest Area (survey)	0.363*	0.321*	0.128	0.380*	0.343*	1		
Size (GIS)	0.523*	0.875*	0.684*	0.759*	0.308*	0.355*	1	
Current Size (survey)	0.376*	0.664*	0.450*	0.667*	0.354*	0.396*	0.744*	1

NOTE: + $p < .10$ * $p < .05$

Table 5. Regression Models Predicting Used Area: Altamira

	Remotely Sensed Measure of Used Area					
	Used Area 1988		Used Area 1991		Used Area 1996	
	b	se(b)	b	se(b)	b	se(b)
Log (time since acquiring property)	7.807 *	2.327	4.728	3.536	0.129	7.072
Number of Kids (0-11)	-0.839	0.820	-1.924 +	1.075	-1.886	1.930
Number of Females (12-18)	0.112	1.809	1.460	1.745	2.515	2.816
Number of Males (12-18)	1.668	1.443	1.009	1.522	-2.023	2.612
Number of Females (19-54)	-0.540	1.271	-0.691	1.363	-0.357	1.801
Number of Males (19-54)	-0.493	1.145	0.132	1.201	0.781	1.483
Number of Females (55+)	-0.020	3.747	-2.223	3.827	-3.218	4.904
Number of Males (55+)	-1.778	3.453	-3.423	3.534	3.313	4.853
Size of Property (hectares)	0.191 *	0.018	0.231 *	0.019	0.234 *	0.025
Area in Pasture when Began Working (hectares)	0.339	0.287	0.447	0.295	0.424	0.399
Area in Perennials when Began Working (hectares)	-2.217	2.983	-1.244	3.183	-0.189	4.197
Intercept	-15.754 *	6.467	-10.745	10.222	-0.191	21.341
R-squared	0.4474		0.4844		0.4123	
N	182		185		154	

	Survey Based Measure of Used Area					
	Used Area 1988		Used Area 1991		Used Area 1996	
	b	se(b)	b	se(b)	b	se(b)
Log (time since acquiring property)	14.901 *	3.911	17.352 *	5.456	20.427 *	10.008
Number of Kids (0-11)	-2.438 +	1.362	-2.924 +	1.648	-4.485	2.723
Number of Females (12-18)	0.942	3.024	0.197	2.702	2.275	4.001
Number of Males (12-18)	0.818	2.433	-0.306	2.395	-3.368	3.697
Number of Females (19-54)	-0.594	2.143	-1.093	2.111	-1.553	2.530
Number of Males (19-54)	1.078	1.956	0.049	1.884	-1.160	2.122
Number of Females (55+)	-15.229 *	6.435	-14.571 *	5.951	-18.182 *	7.032
Number of Males (55+)	-3.581	5.876	0.684	5.581	5.936	6.923
Size of Property (hectares)	0.305 *	0.034	0.362 *	0.033	0.482 *	0.042
Area in Pasture when Began Working (hectares)	1.536 *	0.487	1.692 *	0.463	1.667 *	0.568
Area in Perennials when Began Working (hectares)	-2.501	4.578	-0.014	4.500	-0.299	5.391
Intercept	-19.700 +	10.892	-30.838 +	15.806	-44.670	30.234
R-squared	0.3921		0.4561		0.5299	
N	189		192		160	

NOTE: * p < .05

Table 6. Regression Models Predicting Forested Area: Altamira

	Remotely Sensed Measure of Forested Area					
	Forested Area 1988 (RS		Forested Area 1991 (RS		Forested Area 1996 (RS	
	b	se(b)	b	se(b)	b	se(b)
Log (time since acquiring property)	-10.528 *	3.421	-9.734 *	4.851	3.633	9.177
Number of Kids (0-11)	2.846 *	1.206	4.457 *	1.475	2.335	2.504
Number of Females (12-18)	-2.690	2.659	-0.304	2.394	-2.088	3.654
Number of Males (12-18)	-0.574	2.122	-0.392	2.088	1.257	3.389
Number of Females (19-54)	-1.521	1.869	-0.450	1.870	1.795	2.337
Number of Males (19-54)	1.018	1.683	2.548	1.647	0.149	1.924
Number of Females (55+)	4.034	5.509	9.811 +	5.250	0.900	6.363
Number of Males (55+)	9.020 +	5.076	-1.746	4.848	-2.432	6.297
Size of Property (hectares)	0.632 *	0.027	0.559 *	0.027	0.583 *	0.033
Area in Pasture when Began Working (hectares)	-0.085	0.422	-0.059	0.405	-0.222	0.517
Area in Perennials when Began Working (hectares)	-0.647	4.386	-1.567	4.366	-0.157	5.446
Intercept	18.288	9.508	17.753	14.022	-10.451	27.693
R-squared	0.7834		0.7331		0.697	
N	182		185		154	

	Survey Based Measure of Forested Area					
	Forested Area 1988		Forested Area 1991		Forested Area 1996	
	b	se(b)	b	se(b)	b	se(b)
Log (time since acquiring property)	-17.519 *	3.635	-22.065 *	5.053	-24.149 *	8.960
Number of Kids (0-11)	1.568	1.266	1.981	1.526	2.430	2.438
Number of Females (12-18)	-2.091	2.811	-2.086	2.503	-2.569	3.582
Number of Males (12-18)	-1.565	2.262	-0.605	2.218	1.358	3.310
Number of Females (19-54)	1.968	1.992	2.352	1.955	3.907 +	2.265
Number of Males (19-54)	-1.377	1.818	-0.265	1.745	-0.573	1.899
Number of Females (55+)	13.153 *	5.982	16.083 *	5.512	17.792 *	6.296
Number of Males (55+)	2.745	5.462	-2.899	5.169	-2.560	6.197
Size of Property (hectares)	0.668 *	0.032	0.600 *	0.031	0.484 *	0.037
Area in Pasture when Began Working (hectares)	-1.032 *	0.453	-1.167 *	0.428	-1.495 *	0.509
Area in Perennials when Began Working (hectares)	1.794	4.256	0.555	4.168	2.379	4.826
Intercept	25.937 *	10.125	43.314 *	14.640	56.216 *	27.067
R-squared	0.7485		0.7116		0.5818	
N	189		192		160	

NOTE: * $p < .05$

Table 7. Regression Models Predicting Used Area: Santarem

	Remotely Sensed Measure of Used Area			
	Used Area 1991		Used Area 2001	
	b	se(b)	b	se(b)
Log (time since acquiring property)	-0.606	0.791	-2.649	2.094
Number of Kids (0-11)	-0.114	0.333	-0.763	0.916
Number of Females (12-18)	0.429	0.787	-0.352	1.421
Number of Males (12-18)	0.784	0.610	-0.206	1.133
Number of Females (19-54)	-0.486	0.864	-1.124	1.240
Number of Males (19-54)	1.162 +	0.624	0.076	0.723
Number of Females (55+)	1.358	1.883	-1.463	2.543
Number of Males (55+)	-0.407	1.553	2.245	2.527
Size of Property (hectares)	0.069 *	0.017	0.190 *	0.027
Area in Pasture when Began Working (hectares)	0.285 +	0.163	1.124 *	0.261
Area in Perennials when Began Working (hectares)	-0.866	3.499	0.686	4.143
Intercept	2.310	2.524	12.771 +	7.023
R-squared	0.3686		0.5986	
N	80		88	

	Survey Based Measure of Used Area			
	Used Area 1991		Used Area 2001	
	b	se(b)	b	se(b)
Log (time since acquiring property)	0.913	1.220	0.524	1.821
Number of Kids (0-11)	-0.779	0.505	-0.379	0.735
Number of Females (12-18)	3.749 *	1.171	0.361	1.200
Number of Males (12-18)	-0.715	0.934	0.210	1.003
Number of Females (19-54)	-0.318	1.309	-1.442	1.065
Number of Males (19-54)	0.365	0.967	0.711	0.629
Number of Females (55+)	2.119	2.984	-3.089	2.257
Number of Males (55+)	-1.634	2.485	4.691 *	2.191
Size of Property (hectares)	0.031	0.019	0.029 +	0.016
Area in Pasture when Began Working (hectares)	0.119	0.251	0.031	0.226
Area in Perennials when Began Working (hectares)	-5.483	5.539	0.301	3.685
Intercept	2.675	3.905	2.316	6.207
R-squared	0.1945		0.1392	
N	88		94	

NOTE: * p < .05

Table 8. Regression Models Predicting Forested Area: Santarem

	Remotely Sensed Measure of Forested Area					
	Forested Area 1991 (RS			Forested Area 2001 (RS		
	b		se(b)	b		se(b)
Log (time since acquiring property)	2.175		1.409	1.064		2.246
Number of Kids (0-11)	-0.702		0.594	1.885	+	0.983
Number of Females (12-18)	-2.954	*	1.401	0.154		1.524
Number of Males (12-18)	-1.142		1.086	-0.466		1.215
Number of Females (19-54)	-0.211		1.538	0.114		1.330
Number of Males (19-54)	0.817		1.111	1.705	*	0.776
Number of Females (55+)	-7.800	*	3.353	2.211		2.727
Number of Males (55+)	3.544		2.765	1.848		2.710
Size of Property (hectares)	0.524	*	0.031	0.350	*	0.028
Area in Pasture when Began Working (hectares)	-0.681	*	0.290	-0.581	*	0.280
Area in Perennials when Began Working (hectares)	1.671		6.231	0.357		4.443
Intercept	-3.936		4.495	-12.348		7.532
R-squared	0.8355			0.7077		
N	80			88		

	Survey Based Measure of Forested Area					
	Forested Area 1991			Forested Area 2001		
	b		se(b)	b		se(b)
Log (time since acquiring property)	2.145		2.327	7.116	+	3.968
Number of Kids (0-11)	0.598		0.965	-0.583		1.603
Number of Females (12-18)	-0.789		2.234	-2.535		2.614
Number of Males (12-18)	3.253		1.782	-0.539		2.185
Number of Females (19-54)	-4.058		2.497	-1.624		2.320
Number of Males (19-54)	1.628		1.845	0.107		1.370
Number of Females (55+)	1.284		5.694	-9.703	+	4.919
Number of Males (55+)	-0.317		4.741	4.385		4.774
Size of Property (hectares)	0.254	*	0.036	0.214	*	0.035
Area in Pasture when Began Working (hectares)	-0.664		0.478	-0.264		0.493
Area in Perennials when Began Working (hectares)	-2.919		10.569	-0.908		8.030
Intercept	-5.020		7.451	-15.373		13.526
R-squared	0.4535			0.4236		
N	88			94		

NOTE: * p < .05

Figure 1. Locations of Study Areas

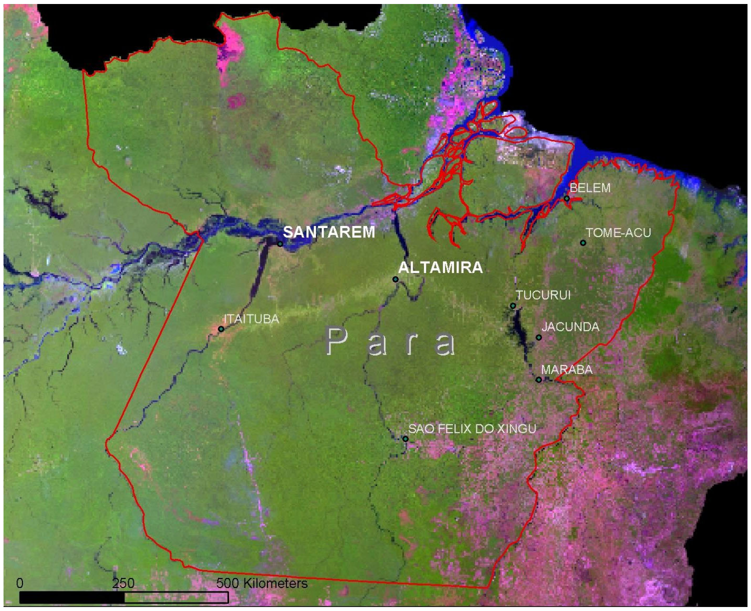


Figure 2. Altamira Study Area

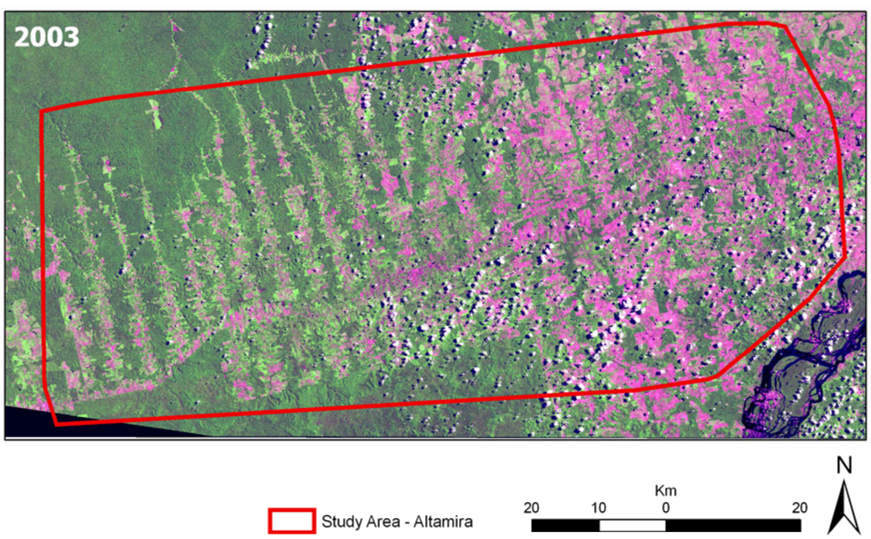
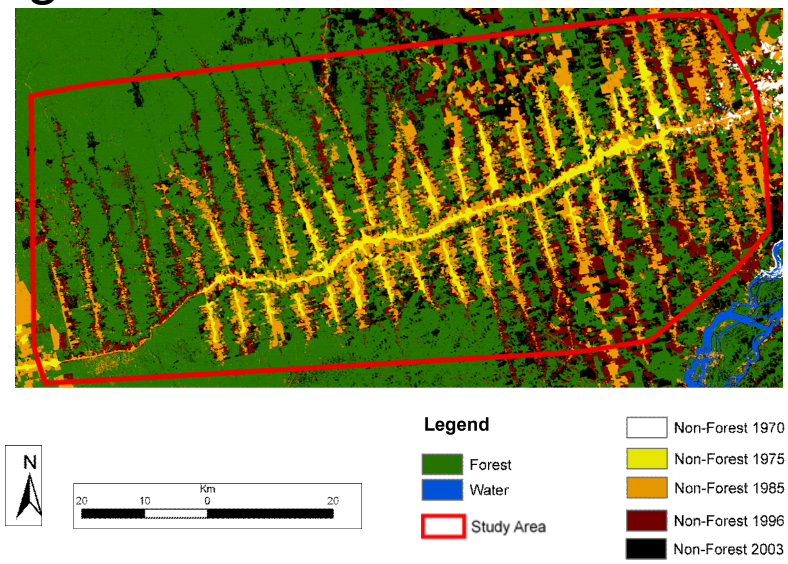


Figure 3. Settlement of Altamira



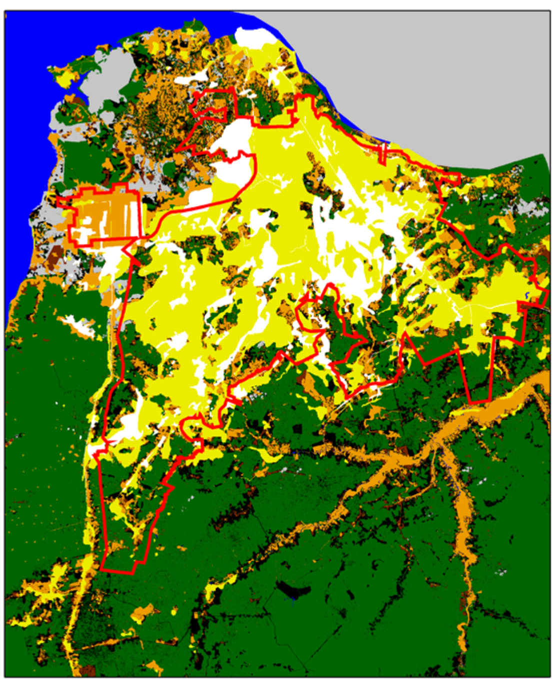


Figure 4. Settlement of Santarem

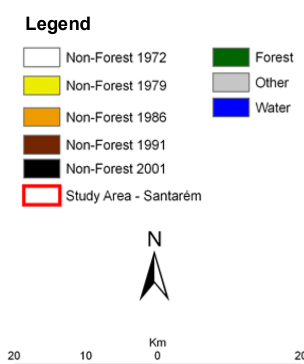


Figure 5: Santarem Study Area

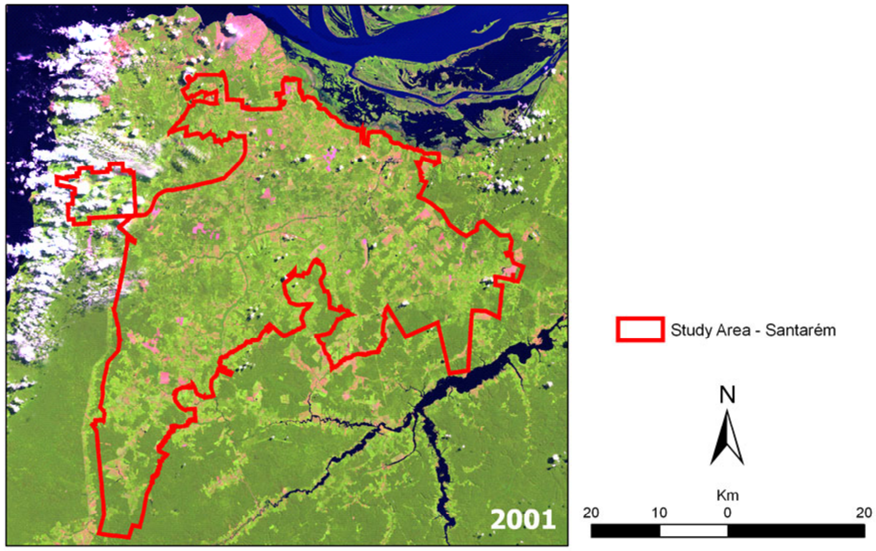


Figure 6. Sampling Frame - Altamira

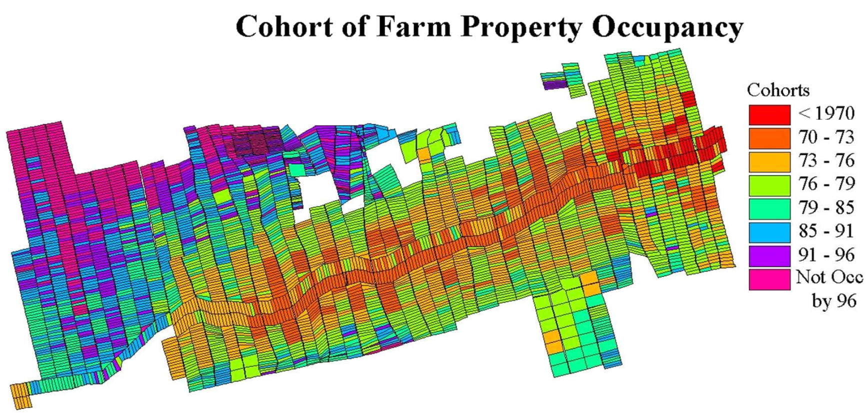


Figure 7. Sampling Procedure - Santarém

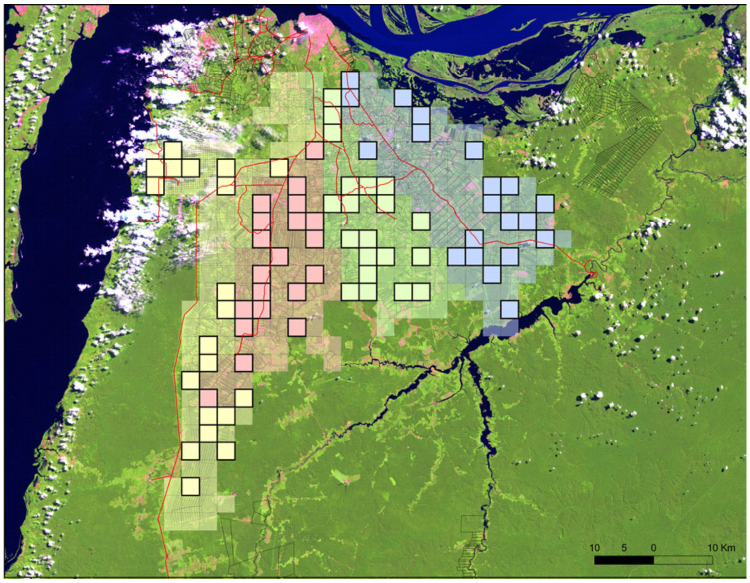


Figure 8: Averages for Survey-Based Measures of Land Use

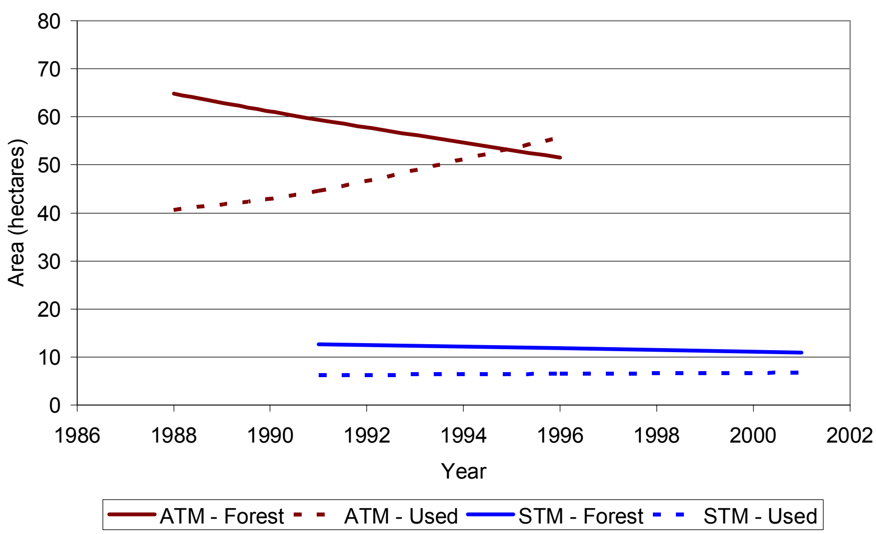


Figure 9: Averages for Measures of Household Demography

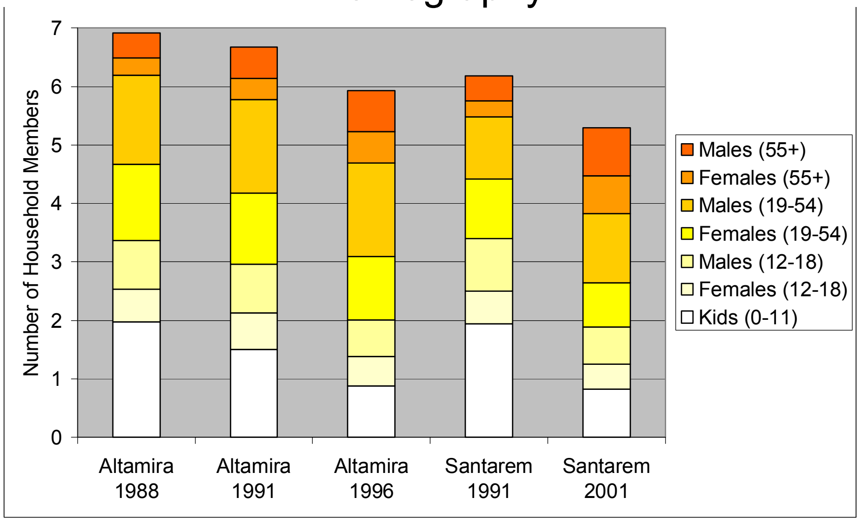


Figure 10: Averages for Remotely Sensed Measures of Land Cover