Property Size and Land Cover Change in the Brazilian Amazon

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Abstract   This paper considers the size of a farmer's property as a key variable influencing land cover and land cover change in rural areas of developing countries. Data from 126 rural familial properties in the region around the city of Santarém, Pará, in the Brazilian Amazon, indicate that property size is important for understanding the trajectories of land cover change. Past research has focused on the distinction between small family farms and large capitalized farms, arguing that family farmers have a higher deforestation intensity, or on estimating the strength of the effect of property size relative to economic or demographic factors. This paper shows that larger *familial properties* are able both to retain a larger area in forest and to have long enough cycles of use and fallow to allow previously used land to become forested again. Based on these analyses and discussion, we argue that land use and land cover research must consider property size as an organizing principle in order to better comprehend the reciprocal relationship between population and environment in frontier areas of the Brazilian Amazon and other rural landscapes.

Keywords   Brazil · Amazon · Land cover change · Property size · Deforestation

Introduction

During the 1970's and 1980's, deforestation and colonization in the Brazilian Amazon become an emerging environmental issue (Almeida, 1992; Moran, 1981; Wood & Schmink, 1979). The decade mean rate of gross deforestation in the Brazilian Amazon from 1978 to 1988 was estimated at 21,130 km^2 per year (Instituto

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Nacional de Pesquisas Espaciais [INPE], 2006). Government directed colonization and development projects motivated high immigration rates into the frontier region of the Amazon, making immigration the most important component in regional population growth since the 1970s. The settlements and other federal projects to colonize the region had a considerable impact on the Amazon landscape (Browder & Godfrey, 1997). Overall causes of deforestation were therefore related to the characteristics of human land use systems that replaced (or preserved) the forest (Fearnside, 1987). Deforestation and land use and land cover change in the Amazon continue to be important issues. Deforestation is now at its highest level ever,[1] despite the efforts to control it, and the accumulated knowledge about the relationship of the Amazon forest with global environmental dynamics shows that deforestation and related loss of biodiversity and release of carbon constitute global problems (Fearnside, 2005; Houghton et al., 2000; Laurance, Albernaz, & Costa, 2002a).

We address one aspect of the process of land use and land cover change in the Brazilian Amazon by considering the role of property size in determining land use and land cover at the property level. Though past research has largely overlooked property size (other than as a scaling variable) or simply considered a dichotomy between large and small farmers, we argue that there are three reasons why property size is important to the study of household processes of land use and land cover change. First, the size of the property delimits the direct impact of households on land use and land cover change. This is particularly important when we seek to scale up from household level studies to landscape changes. Second, property size is dynamic. Rural familial properties vary in size and their sizes can change over time due to intergenerational processes (e.g., property fragmentation through inheritance) and socioeconomic changes (e.g., land consolidation caused by capitalization by some small owners, the expansion of cattle ranching and mechanized agriculture). Third, if property size—and changes in property size—are related to larger scale land use and land cover changes (e.g., the conversion of small rural properties into urbanized villages or the mechanization and more extensive deforestation of consolidated farms), property size should be used to move from the micro level analysis to the municipal/regional level to understand or predict land use and land cover change.

This paper follows a tradition, developed in the 1990's, of linking social survey data to satellite data using Geographic Information System (GIS) technology (Evans, VanWey, & Moran, 2005; Fox, 2003; Liverman, Moran, Rindfuss, & Stern, 1998; Walsh, & Crews-Meyer, 2002). Micro-level analyses, linking households' social data to biophysical aspects (land cover, for example) inside their rural properties, allow us to link social scientific theories of household decision-making to changes occurring on the landscape. This approach has been successfully applied and combined with important theoretical developments in a variety of research projects in the Amazon and elsewhere (Brondízio et al., 2002; Entwisle, Walsh, Rindfuss, & Chamratrithirong, 1998; McCracken et al., 1999; Moran, Brondízio, Mausel, & Wu,

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[1] According to PRODES/INPE the total deforestation since 1978 totals 528,005 square kilometers. Annual totals since 1989 show the increases over the 1990s and 2000s: 1989: 17,985; 1990: 13,810; 1991: 11,130; 1992: 13,786; 1993: 15,410; 1994: 14,896; 1995: 29,059; 1996: 18,160; 1997: 13,040; 1998: 16,840; 1999: 17,259; 2000: 19,836; 2001: 18,130; 2002: 25,500; 2003: 24,605; 2004: 26,129.

1994a; Perz & Walker, 2002; Pichón & Bilsborrow, 1994; Walker & Homma, 1996; Walker, Perz, Caldas, & Guilherme Teixeira Silva, 2002).

Background

Past research tells us a great deal about the ways in which land use and land cover change as families occupy properties in various types of settlements in the Amazon, and as these families change over time. However, past research has often focused on areas of government-sponsored settlement in which property size varies very little from family to family. Families are assigned to properties, which have standard sizes and shapes. For example, Walker's (2003) model uses data from a settlement area in Uruará, Pará to predict deforestation per family varying between 20 and 90 ha (including 30 ha of secondary succession) of a 100 ha property. But what happens if a family does not have 90 or even 20 ha available? In some areas of more spontaneous settlement properties are less regular, and in either type of settlement area properties will change over time. Thus, property size will grow increasingly more important for understanding land use and land cover change in the Amazon.

Among the results of previous studies about land use and land cover change in settlement areas, three are important to guide the present paper. First, households in the frontier region follow a predictable trajectory of land clearing over time with the absolute magnitude of clearing reflecting their social, political, economic and biophysical environment (McCracken et al., 1999; McCracken, Boucek, & Moran, 2002). Deforestation trajectories among properties are related to temporal and spatial aspects of settlement of farm families, timing of arrival, cohort and household dynamics, biophysical characteristics of the farm lot, and period effects (for example, credit and inflation) underlain by environmental, market, and infrastructural conditions (Brondízio et al., 2002). In the present paper, size of properties reflects family changes (e.g. inheritance and associated land fragmentation) and household strategies (e.g. owner selling part of the property); it is also a spatial constraint that affects land use decisions. The pattern of land ownership in our Santarém study area reflects the long history of spontaneous settlement, fragmentation over time, and consolidation. Family properties range from very small to very large, with small properties much like an area of the Ecuadorian Amazon studied by Bilsborrow, Barbieri, and Pan (2004), where subdivision of properties and intensification of agriculture over time were argued to be due to population increase and scarcity of land for new families.

Second, different types of land uses occur depending on occupation histories (for example: traditional systems of diversified land use (Brondízio, Moran, Mausel, & Wu, 1996) versus colonization projects (Brondízio, 2004). These histories imply distinct land management practices (agroforestry, slash-and-burn agriculture, pasture, mechanization) influencing soil fertility, land cover (forest and deforestation) and the potential for forest regrowth. Some deforested areas can revert to secondary successional vegetation but continued reclearing (in more intensive use situations) causes progressive floristic impoverishment (Moran, Brondízio, & Mausel, 1994b; Nepstad & Uhl, 1991; Perz & Skole, 2003; Smith, 2000). By analyzing vegetation cover, such as the stages of secondary succession, the researcher can gain a better understanding of the different types of land use patterns and the implications of

distinct activities (Brondízio et al., 2002; Moran & Brondízio, 1998). We build on this line of research by showing that, among family farmers with relatively homogenous production systems, the size of familial properties affects the amount of used land and the amount of fallow land (which has the potential to regrow into new forest).

Third, distinct settlement designs result in different spatial patterns of land use/ land cover. Considering the settlement as a whole, its composition and configuration affect forest fragmentation—patterns of forest–non forest in the Amazon. For example, Batistella, Robeson, and Moran (2003) show that a settlement following a grid road network in Anari, Rondônia causes a higher level of forest fragmentation than a nearby settlement in Machadinho, Rondônia that was designed to follow the topography and access to water, and to include forest reserves. At a regional level, deforestation in the Amazon is also not random but follows road networks related to development and settlement plans (Alves, 2002; Laurance et al., 2002b; Neptstad et al., 2002; Soares-Filho et al., 2004). This paper considers a yet different type of settlement, an older settlement area with episodic periods of spontaneous settlement, later planned settlement, irregular property sizes and shapes, and properties following both road and river networks. The current pattern of settlement reflects both the initial pattern of settlement and the processes of fragmentation, consolidation and land use change over time.

Some past research focuses on the effect of farm size. Farm size is an important factor in "land cover change" in the Ecuadorian Amazon (Pichón & Bilsborrow, 1994; Pichón, 1997). Pichón (1997) shows that larger properties are able to clear a smaller proportion of their area. Carr (2004) shows that farm size is the strongest predictor of land use in Guatemala's Maya Biosphere Reserve, and is positively related to forest clearing. Turner and colleagues (Turner & Geoghegan, 2004; Sader, Chowdhury, Schneider, & Turner, 2004) also show the importance of property size in understanding land cover change in the Yucatán, Mexico. However, property size effects have generally not been the focus of past micro-level analyses in the Amazon. In cases where they prove to be significant and substantial, they are generally interpreted as a scaling factor (more land means the possibility of more deforestation) and not treated as theoretically interesting.

Other past research that has studied property size has tended to aggregate properties into large classes ("small farms" and "large farms"), with cattle ranching often differentiating between types of farmers ("small farmers," who usually received plots up to 100 ha versus "cattle ranchers" with larger holdings) (Walker, Moran, & Anselin, 2000). Earlier research shows the positive relationship between size of property and herd size and the importance of cattle ranching in explaining deforestation (Downing, Hecht, Pearson, & Downing, 1992; Faminow and Vosti, 1998; Kaimowitz, 1996). Though cattle ranching has been identified as an important factor in deforestation in the Brazilian Amazon (Fearnside, 2005), researchers disagree about how much of the deforestation is attributable to large and to small farmers. Fearnside (1993) argues that medium and large size ranches (greater than 100 ha) are responsible for about 70% of clearing activity, while Faminow (1998) attributes less impact (around 25%) to the larger properties. Although we see some contradictory results, this literature suggests a relationship between land cover and land distribution. Some researchers argue that there is a tendency toward land turnover and concentration of landholdings (Hecht, 1993). This literature also shows that farm land in pasture increases with farm size, but that "larger plots are less likely to have large

proportions of their land cleared'' (Pichón, 1997: 78). In other words, ''deforestation intensity... declines with increasing property size'' (Fearnside, 1993: 9).

We build on these past studies by examining the process of land cover change within properties of various sizes, in order to better understand how deforestation intensity comes to be higher in smaller properties. Our approach is based on the premise that a change in property size is not linearly (or even non-linearly) related to areas in various land covers, but that a change in property size brings about a systemic change. This not to say that other variables (socioeconomic, demographic, biophysical) are unimportant for an understanding of land use and land cover. Rather, a traditional regression model including these and property size as independent variables assumes the same relationship between property size and land use/land cover for all farms, missing the way in which property size can change the land use/land cover system. Our analyses below control for some factors by including only farms that share similar technology (slash-and-burn), production objectives (familial consumption and sale in local markets) and source of labor (mainly household members).

We examine the effect of property size by considering size differences beyond simply comparing two groups. We seek to go further and to look at patterns within more detailed groups defined by property size, all of whom are family farmers. The methodology we use allows us to combine satellite imagery and survey data. The key linkage between these data sources is at the property level, with household survey information from surveying owners' households linked to the satellite data in a Geographic Information System (GIS) (McCracken et al., 2002). We use social survey data and satellite data from two points in time to examine changes in land cover on properties that were consistently owned by the same owners over 15 years. Though our data do not allow the examination of properties being sold from one family to another or passed through inheritance, our data do provide a window into the dynamic process of land use and land cover change on properties of varying sizes.

These analyses show that larger properties are able to retain a larger proportion of their area in forest by managing fallow and regrowth cycles. Larger farmers can allow used areas to grow into forest before clearing again for use, while smaller farmers must clear younger secondary growth before it grows to be labeled as forest. These differences that we find in the ways that land cover changes over time in the different sizes of properties suggest that future research should explore how key social, economic and demographic variables have different effects for properties of different sizes. Methodologically, this means that the effects of these variables are likely to be different across different property sizes and that samples should be split by property size for regression analyses.

The Santarém Area

In the North of Brazil, Santarém is the most important city in the western portion of Pará State. Located 850 km from Belém (the state capital), Santarém is strategically positioned at the confluence of the Tapajós and Amazon rivers; it is an important port connecting the two largest cities in the Brazilian Amazon, Manaus on the western side and Belém at the mouth of the Amazon and estuary. Located on the Federal Highway BR163 (Cuiabá-Santarém), it also has a privileged interregional connection to the Center-West of Brazil, although the current condition of the road is not good. Figure 1 shows the study area, which includes parts of the rural areas of
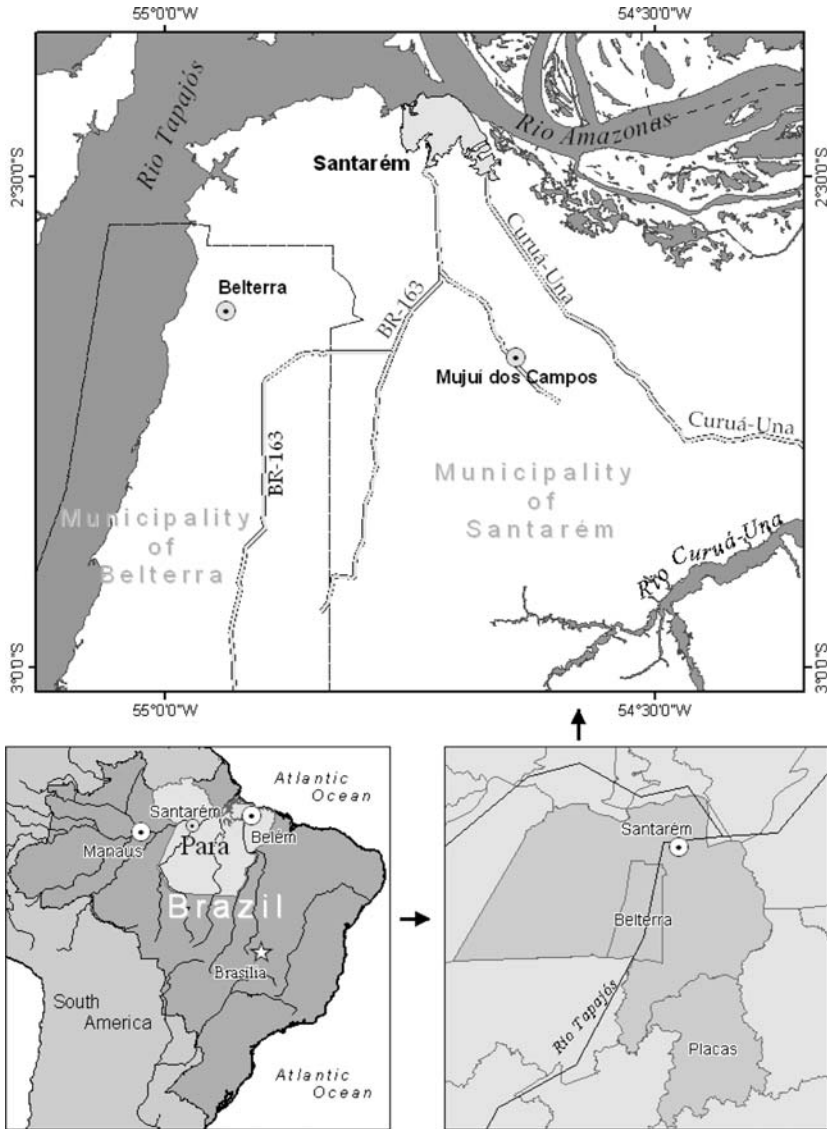
Fig. 1 Santarém area. Produced by Scott S. Hetrick

the municipalities of Santarém and Belterra. The figure also shows the municipality of Placas, emancipated from Santarém in the 1990's.[2]

Santarém (city) has existed since the colonial period (Reis, 1979). The area has a long history of immigration and settlement following economic boom and bust cycles – including cocoa, sugar cane, rubber, jute, timber, gold and fish. Through the 20th

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[2] Belterra and Placas are municipalities created in 1997, from area previously contained in the municipio of Santarém. Although no portion of our study area is located in there, Placas is shown here and included in census data presented below to allow over time comparisons.

century, small farming, cattle ranching and logging have developed and co-existed (Futemma & Brondízio, 2003: 373). The study area includes portions spontaneously occupied (with or without later regularization), and portions with government-sponsored occupation (colonization projects) since the 1970s. The study area now is experiencing a soy boom, with associated land consolidation and social and environmental changes. Soybean mechanized agriculture has become a viable and expanding cash crop in the region, following multiple technical, political, and economic changes, and related to improvements in infrastructure (the Cargill port [Flaskerud, 2003] and the project to pave the federal highway BR163) that attract producers from the South and Center-West of Brazil. The soybean production and mechanization are affecting agrarian structure, including changes in land distribution, technology, products and objectives of production, and population mobility and distribution (Steward, 2004). Our study considers small family farmers, who still represent a majority of producers and area in this region, and focuses on their decisions in the period before large-scale soy production began.

   Santarém shows a mosaic of land use and land cover as a result of different waves of occupation and subsequent land use changes. There is a heterogeneous pattern of properties and settlements, combined with conservation areas, larger farms, rural villages, small and large towns connected by a precarious road and river network. Figure 2 is a false color representation of a Landsat satellite image of the study area, in which darker colors indicate larger amounts of vegetation, with the darkest gray
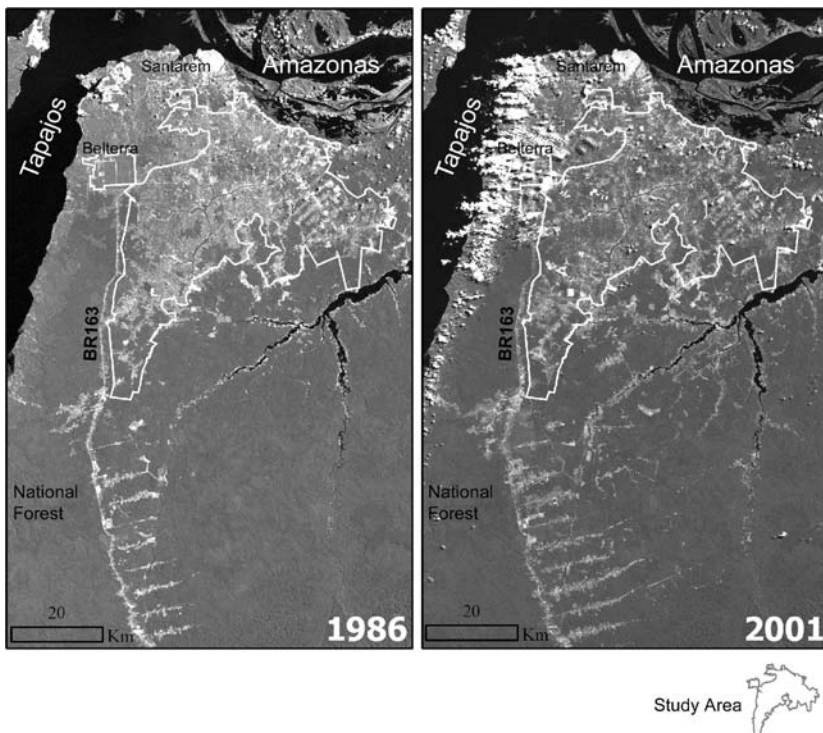

Fig. 2 Land cover, 1986 and 2001, Santarém area. Source: Landsat TM 1986, 2001. Scene: Path 227 Row 062

being forest and the lightest being fields (medium gray areas are largely secondary growth). This figure shows that much of the study area was already in use (and in secondary growth) in 1986, and by 2001 that use had expanded near and inside the National Forest (FLONA) and in the southern portion of the study area.

Secondary data about land distribution, production and population, combined with fieldwork observations, show that the region is experiencing land concentration into larger market-oriented farms, usually more capital-intensive, as well as reduction in the population growth rate and increases in urbanization—which means not only changes in fertility patterns but also changes in population's spatial organization. The annual population growth rate for Santarém has been lower than that for the North as a whole since the 1970's (Instituto Brasileiro de Geografia e Estatística [IBGE], 2000) reflecting less settlement in recent decades, a more urban fertility pattern and more recently, emigration. Urbanization in Santarém followed the general pattern seen in all of Brazil, with increasing proportions of the population living in urban areas, from 45% in the 1970's to 67% in 2000. This indicates that Santarém is not simply a rural landscape of agriculture and cattle ranching. Though Santarém remains less urban than either Brazil or the North Region in 2000 (urbanization in Brazil was 81% and in the North was 70%), it is moving in the same direction as the rest of the country (IBGE, 2000). These data in fact underestimate the extent of urbanization by missing human concentration in new villages (which are still classified as rural in census data) that was evident during our fieldwork. The movement to the villages keeps population in historically rural areas that are progressively urbanizing, and is an alternative to the exodus to the seat of the municipality, to other cities, or to a new agricultural frontier.

Table 1 compares the land distribution in Santarém to that of the North Region and of the whole country, according to the 1996 Census of Agriculture (IBGE, 1996). Santarém reflects the larger property sizes of the Amazon (and North region), but also includes a larger proportion of properties that are small to medium (and fewer very large properties), leading to a much larger proportion

Table 1 Land distribution in 1996—number and area of establishments (%). Brazil, North Region and Municipality of Santarém, Pará, Brazil

Area	Brazil		North		Santarém	
	Number (%)	Area (%)	Number (%)	Area (%)	Number (%)	Area (%)
Up to 1 ha	10.54	0.09	4.43	0.01	8.62	0.05
1 to less than 5 ha	26.09	0.98	16.67	0.34	16.15	0.78
5 to less than 10 ha	12.81	1.36	9.11	0.48	11.79	1.50
10 to less than 50 ha	31.19	10.81	31.80	6.27	25.70	11.15
50 to less than 100 ha	8.24	8.41	16.86	8.63	12.10	14.75
100 to less than 200 ha	5.07	10.02	11.67	10.73	22.66	43.92
200 to less than 500 ha	3.40	14.96	5.26	12.02	2.31	11.33
500 to less than 1.000 ha	1.20	11.45	1.82	9.57	0.49	5.58
1.000 ha or more	1.02	41.92	1.79	51.95	0.18	10.94
Not Reported	0.44	0.00	0.59	0.00	–	0.00
Total	100.00	100.00	100.00	100.00	100.00	100.00

Source: IBGE – Censo Agropecuário 1996

of the total area accounted for by medium farms (70% of the area is in farms between 10 and 200 ha). This distribution is a snapshot of a region in transition. By comparing lots surveyed or assigned by the Instituto Nacional de Reforma Agrária (INCRA) beginning in the 1970's to the updated property grid constructed after fieldwork in 2003, we found that the agrarian structure in Santarém is changing through time (results not shown). In 2003, there is a higher proportion of very small properties (less than 5 ha) and large properties (more than 100 ha), and a correspondingly lower proportion of intermediate sized properties (between 5 ha and 100 ha).

These changes in the agrarian structure have intensified since the end of the 1990's, through two related processes: land consolidation and land fragmentation. On the one hand, land aggregation (or consolidation) is motivated by owners from the Center-West and South of Brazil who have purchased large areas in Santarém for mechanized agriculture (cropping rice first and now rice and soybeans). Some of the local large owners, who often had large areas in pasture in the past, are now practicing mechanized agriculture and buying new land to expand their holdings. As part of this process, some current small farmers are selling their land to large owners as a result of increasing land prices and land scarcity. Some of these small farmers then use the money to buy small non-agricultural properties near villages, while others are searching for land in forested areas away from the city in order to open new farms. Still others are using this opportunity to leave farming and move to the city. On the other hand, land fragmentation is occurring on small lots. The successive division of original lots through inheritance leads to fragmentation, as does the sale by inheritors of portions (excluding the portion with houses) of inherited land to land speculators or large farmers. Fragmentation is also occurring through current owners selling small parcels only suitable for residences along the road frontage in their property.

The changes in land distribution mirror changes in rural production at the municipal level. Secondary data indicates changes in production objectives (from subsistence and local market to external markets) and changes in production technology, visible in the increase in productivity of annual crops (IBGE, 1996). However, the prevalent cropping pattern throughout has been the production of annuals. Between 1990 and 2002 in the Santarém area (Santarém, Placas and Belterra municípios) there was a slight increase in the area used for perennial crops and a large (80%) increase in the area used for annual crops. In addition to these changes in area, the relative importance of various crops changed. There was a substantial increase in the area devoted to rice, beans, soy and coffee while there was a substantial decrease in the area devoted to black pepper and a stabilization of manioc areas. These changes reflect responses to market forces (changing prices for pepper and the increasing viability of rice and soy as cash crops) rather than to increasing needs for personal and family consumption. The early phases of agricultural mechanization and modernization are visible in these figures. For example, the area planted in rice increased by 200% but rice production increased by 800%, indicating rapid increases in productivity. We see a similar though smaller increase in the productivity of corn, with the area in corn actually declining while the production increases by more than 50% (IBGE 2006).

Data

Property Grid, Sample Selection and Survey Data

In order to analyze the effects of property level characteristics (and characteristics of the owners of properties) on land cover, we collected survey data from households owning (and living on) a sample of properties in our study area. The sampling frame was the properties based on digitized INCRA property maps (scale 1:50,000) validated with visible features from Landsat TM (1997 and 1999) images and topographical maps from IBGE (scale 1:100,000). The resulting property grid contained 6,084 rural properties registered by INCRA (most of them more than 20 years ago). The properties were divided into four survey regions defined by four main terrestrial roads of access, representing distinct axes of influence and occupation. In each region, properties were randomly selected for interviewing using a two-stage selection process (more details are available in Moran, Brondízio, & VanWey, 2005).

During fieldwork in the summer of 2003, we collected survey data from 401 households living on 244 familial properties in this sample. The surveys covered the past and present economic and demographic characteristics of farm households, as well as current and past land use. In addition to these surveys focused on small farmers, data on ownership, age of property, current land use and land cover data were collected on 216 non-familial properties also in the sample which either were not used for farming or were used by non-resident owners. These include large farms (cattle ranches and mechanized areas), small lots located in villages and abandoned lots with no inhabitants or use. The boundaries and configuration of properties were updated during fieldwork using GPS points, sketch maps, and remotely sensed imagery. The resulting spatially explicit property grid was then linked to a time series of remotely sensed data and to temporally deep retrospective survey data. The combination of these diverse sources of information and data collection instruments enables the association of social and biophysical variables, and multi-temporal analysis.

Satellite Data

Two Landsat TM satellite images (1986 and 2001) were used for the land cover analysis presented in this paper. The 1986 satellite image captures the region after the period of increased deforestation from the 1970's until the middle of 1980's (Futemma & Brondízio, 2003; Moran, 1993). The 2001 satellite image illustrates land cover just before the soybean boom, making it possible to see the process of land use and landscape change without most of the changes influenced by mechanization and soy production.

Images were classified using a hybrid approach (unsupervised and supervised classification) and using training samples collected during 2002 and 2003. Image classes used in this paper include: bare soil (B), secondary succession (S), forest (F), water (W) and cloud (C). Bare soil includes areas with little or no agricultural use; it also includes areas with agriculture and pasture. Secondary succession represents fallow land, including a gradient from pioneer species that grow quickly when an opening in the canopy occurs, to the gradual turnover of species and replacement

with slower-to-mature forest tree species. Forests can be defined as areas with high density of trees, plants and other vegetation representing a closed canopy system. Water stands for rivers, streams, estuaries, lakes, ponds, flooded areas and other bodies of water. The cloud class includes clouds and their shadows, areas with unidentifiable land cover in either image. Once both images were classified and edited, analysis was conducted using a transition matrix approach. A transition image was created with a set of 10 classes: clouds (cloud or cloud shadows in either 1986 or 2001), water (in 1986 or 2001), forest at both times (F → F), forest to secondary succession (F → S), forest to bare soil (F → B), secondary succession to forest (S → F) secondary succession at both times (S → S), secondary succession to bare soil (S → B), bare soil to secondary succession (B → S) and bare soil at both times (B → B). From this image (Fig. 3), we calculated the area in each of these transition classes in each property in our sample.

Table 2 shows the percent of the entire study area in each of the classes in the transition image. The land cover transition data extracted for the whole study area (183,058 ha) shows a decrease in forested areas, and an increase in both secondary succession and bare soil. Of the total area, 27.8% was forest at both time points, while 18.4% was deforested during the period: forest in 1986, but secondary succession (12.5%) or bare soil (5.9%) in 2001. On the other hand, we identified forest regeneration in 9.5% of the study area (area classified as secondary succession in 1986 and forest in 2001). Thus, the net loss of forest was 8.9% of the study area between 1986 and 2001. The aggregate figures for the study area also show agricultural rotation within areas of secondary growth, with 8.2% of the area being converted from secondary succession to bare soil and 7.9% of the area being converted from bare soil to secondary succession.

Sub Sample Selection: Familial Properties

Based on availability of satellite land cover data for the property, time of occupation by the present owner, and characteristics of the owners, a subset of the 244 interviewed properties was selected for the analysis presented in this paper. In order to avoid land cover changes caused by changes in ownership (and possibly variations in boundaries), 111 properties whose owner arrived after 1986 were discarded. Another 6 properties covered by clouds were also discarded, leaving 127 properties with a continuous land owner and valid land cover data. One additional property, a cattle ranch with 569 ha was discarded as an outlier on property size. The selected 126 properties constitute a coherent group here called *familial properties*.[3]

Table 3 shows the distribution of these properties by size. Most of the properties (59.5%) are from 10 to 50 ha; most of the total area (38.7%) is also in this group of properties. On the other hand, properties from 100 to 242 ha form the smallest group of properties (9.5%) but include a large percentage of the total area (37.8%). The data indicate that even among familial properties an uneven land distribution is found: 77.8% of the properties have less than 50 ha, but correspond to only 40.7% of the total area; 22.2% of the properties have more than 50 ha, but correspond to 59.3% of the total area.

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[3] We define the familial property based on the characteristics of the owners and the type of production system. It is important to note that this differs from the legal definition of a ''familial property,'' which is based solely on size (within a given region in Brazil).
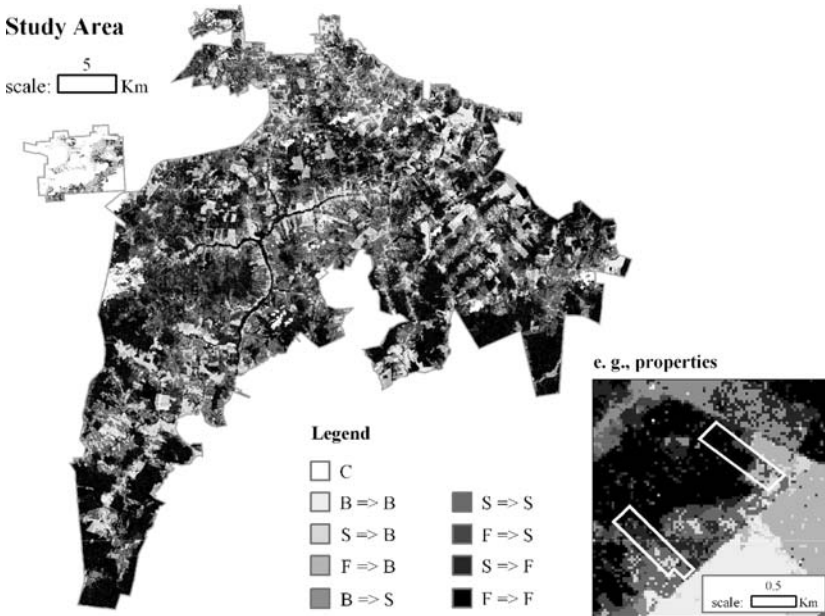
Fig. 3 Land cover transition (1986 → 2001) Note: C: clouds; B → B: bare soil in 1986 and 2001; S → B: secondary succession (1986) to bare soil (2001); F → B: forest (1986) to bare soil (2001); B → S: bare soil (1986) to secondary succession (2001); S → S: secondary succession in 1986 and 2001; F → S: forest (1986) to secondary succession (2001); S → F: secondary succession (1986) to forest (2001); F → F: forest in 1986 and 2001

Table 2 Land cover transition 1986–2001 for entire study area, Santarém, Pará, Brazil

Classes		2001					Total 1986 (%)
		F (%)	S (%)	B (%)	C (%)	W (%)	
1986	Forest (F)	27.75	12.50	5.91	0.00	0.00	46.15
	Secondary Succession (S)	9.53	17.43	8.21	0.00	0.00	35.18
	Bare Soil (B)	0.00	7.87	6.38	0.00	0.00	14.26
	Cloud (C)	0.00	0.00	0.00	4.34	0.00	4.34
	Water (W)	0.00	0.00	0.00	0.00	0.07	0.07
	Total 2001	37.28	37.80	20.51	4.34	0.07	100.00

In the households owning or managing the properties, 125 of the 126 owners/managers interviewed declared themselves to be owners of the properties. This includes a wide variety of actual documents or arrangements. Only 55.2% of the 125 owners have the property title in their names or their husband/wives' names. The remaining 40.8% of the self declared owners have a receipt from the previous owner or other kind of document (17.6%), the property title in another's name (7.2%), are in the process of regularizing their situation with respect to the property (5.6%), or do not have any document to prove ownership (10.4%). Statistics on how the lot was acquired show the longer settlement history in Santarém than in some other areas of the Amazon, as well as the dynamic nature of the population. There are high levels of turnover and low levels of acquiring lots from INCRA, as well as a moderate

Table 3 Distribution of familial properties by size (N = 126)	Group	Properties		Area	
		Number	%	Hectares	%
	<10 ha	23	18.30	98.60	2.00
	10 to < 50 ha	75	59.50	1836.70	38.70
	50 to < 100 ha	16	12.70	1022.00	21.50
	100 to 242 ha	12	9.50	1786.30	37.80
	Total	126	100.00%	4743.60	100.00%

amount of inheritance. Almost 65% of owners bought their lots while only 8% of owners received lots from INCRA (or from another governmental institution). Just over 23% of owners received their properties by inheritance and 4% received the property by other means (marriage, donation, possession).

Properties are commonly occupied by multiple households, usually members of the same family. In 59.5% of the 126 properties, only one household existed while 27.8% contained two or three households and 12.7% contained four or more households. A total of 1171 individuals were living in 247 households on the 126 properties (mean = 4.7; median = 4 individuals per household). Population and household distributions indicate human concentration in some properties, but there is no strong evidence of a relationship between size of property and number of households.

These sample properties reflect the production patterns in the larger region and the familial nature of the production. Only 16.0% of the properties did not produce any annuals (or products derived from annuals crops, e.g. manioc flour), while the numbers of properties without perennials (46.8%) or cattle (58.7%) were much higher. Most household production was for subsistence and sale of surplus in local markets. Among properties that produced annuals, only 4.8% produced for sale exclusively. Among properties that produced perennials, 20.9% produced them for sale exclusively. Among the relatively small number of properties with cattle, 23.8% produced them for sale exclusively, showing again the low levels of ranching activity relative to production of annuals in this region. Related to these low levels of production for sale and rarity of cattle ranching, households primarily use familial labor in the production of annuals and perennials; only 1.7% of property-owning households use permanent labor, while 82.6% of them complement familial labor with temporary labor during planting and harvest. Similarly, the production involves primarily very basic technologies, with 62.4% of owners using only manual technologies. This low level of technology points to the importance of forest regrowth as a strategy to manage productive areas and maintain soil fertility.

Land Use/Land Cover Analysis

Spatial Organization of the Familial Property

Although there are differences based on property size and other factors, the spatial organization of sample properties shows some generalities. The average familial property includes the areas of the house or houses (houses are usually located together near the road at the front of the property), a nearby orchard, and an area

Table 4 Average areas in agriculture and pasture, by property size, familial properties ($N = 126$)

Area	Agriculture			Pasture		
	Mean area (hectares)	SD of area	Mean % of property	Mean area (hectares)	SD of area	Mean % of property
<10 ha	1.72	1.76	49.84	1.00	2.02	25.68
10 to <50 ha	3.90	3.59	17.57	2.52	4.11	10.13
50 to <100 ha	3.92	3.65	6.56	8.69	20.47	12.04
100 to 242 ha	9.02	10.27	6.22	15.67	23.40	11.52

for growing annual crops for household consumption (and/or sale if a surplus exists). Sometimes, the property also includes an area for growing perennial crops (such as pepper or coffee) and pasture area. The property also includes areas of distinct ages of *capoeira* (secondary succession) and a contiguous area of forest, usually located at the back of the farm. The secondary succession and the forest are reserved for future production. Secondary succession areas have been used in the past and will be used again in the future, as part of a systematic rotation of cultivated areas.

Table 4 shows that the used area (number of hectares, based on survey data) increases if the property is larger. In smaller properties the area dedicated to agriculture is larger than the area in pasture, while in larger properties the area in pasture is much larger than the agricultural areas. This difference corresponds to the predominance of larger herds in larger properties. Area in pasture and area with agriculture are positively correlated with size of property (both correlations are significant at 0.01 level[4]), but the correlation between percent of area in agriculture and property size is negative and significant. No significant correlation was found between percent of area in pasture and property size. Number of households living in a property is not correlated with size of the property but it is positively (and significantly) correlated with area in agriculture.

Land Use and Land Cover Schemas

Characteristics of the labor, technology, type and objectives of the production, as well as resources available, orient the management of the familial properties through a similar routine, although sociodemographic (e.g. household composition), biophysical (e.g. soils) and circumstantial (e.g. economic incentives to produce a specific kind of crop) aspects can affect land use decisions. According to interviewees and fieldwork observations, we delineate a simplified schema of land use/cover over time, as follows:

(1)   Conversion of a forested area into a cropped area—or more rarely into pasture. The simple/direct conversion from forest to pasture (or at least the reporting of this kind of action) is generally avoided due to legal implications, but also due to the fact that the producers use the cleaned area at least once to crop annuals before the complete formation of the pasture.

(2)   Use (management) of the agricultural area according to the kind of crops—perennials, annuals—over some years. Land availability, soil conditions

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[4]   All correlations reported are based on Pearson correlation coefficients, and all tests of significance are two-tailed tests. Unless otherwise indicated, tests used the .01 level to assess significance.
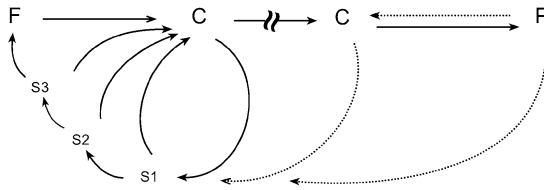
Fig. 4 Land use schema for Santarém familial properties. Note: F: forest; C: crops; P: pasture; S: secondary succession (higher numbers mean higher/more dense vegetation). Arrows: land use/land cover change

and productivity determine the combination/succession of crops and how many years the area can be used, but the producers prefer to rotate the annual crops rather than using the same area from one year to the next.

(3) Conversion of cropped area to non-crop use. Based on its previous use (more or less intensive), ecological conditions (e.g. adjacent forest), place in the property (e.g. close to the front side of the property), and owner strategy (e.g. preference for cattle), it might be abandoned to secondary growth, converted into pasture, or kept as cleared land. Through time, the non-use of secondary succession areas leads to higher levels of vegetation, moving the land toward forest again. In contrast, the year-by-year maintenance of cleaned areas reduces the probability of their conversion into secondary succession, and consequently into forest in the future.

(4) Conversion of forested or secondary succession areas into cropping areas. Forested areas have ''better'' soil but require more work to clear the land. Secondary succession, although the soil is not so rich as that existing in forested areas, is easier to clean, and, of course, is preferable to continuously used cropping areas. Thus, the central decision, every year, is: which portion of the property is best to be used for productive activities, based on desired production and the availability of labor. Following the reported preferences and constraints of interviewees, it appears that all forest area in small properties will be converted to some use at some point in the future. Most of the owners in smaller properties declared that the soil is weak, meaning that fallow areas are not productive anymore and they have no alternative other than to incorporate forested areas (if available) into production or to work in property belonging to someone else.

Figure 4 represents this schema of how familial properties manage their land. The arrows indicate the transitions among Forest (F), Secondary Succession (S), Crops (C) and Pasture (P). The dashed arrow indicates that the continuous use of cropped area tends to impede its reforestation, and that it is more likely to be converted into pasture or other uses without vegetation. The dotted arrows indicate less common transitions: the low possibility of areas used for a long time being converted to secondary succession. Figure 5 then shows the simplified system of conversions that is visible in the satellite imagery and the transition matrix generated from the 1986 and 2001 images. The darker lines in Fig. 5 indicate transitions from one class to another. The gray lines indicate the portion of each class that did not change in the period.

The reduced form schema in Fig. 5 shows two cycles through which a given piece of land might go. What we term a ''complete cycle'' is a complete regeneration of

Fig. 5 Land cover schema (3
classes). Note: F: forest; B:
bare soil; S: secondary
succession. Arrows mean land
cover change
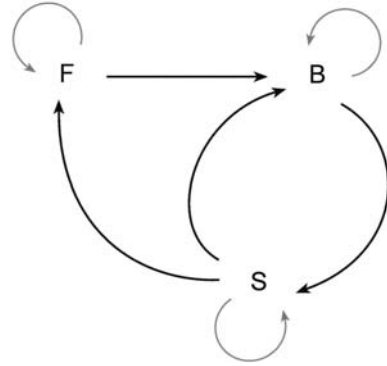
forest on a previously used piece of land—not regeneration to exactly the same
structure and functioning, but regeneration to a recognizable forest. This cycle takes
the land from forest, to bare soil, to secondary succession, and then to forest again
(F → B → S → F). This complete cycle is indicated by the outermost dark
arrows in Fig. 5. What we term an ''internal cycle'' is a rotation of cleared land
between use and fallow, evident in transitions from bare soil to secondary succession
(B → S) and from secondary succession to bare soil (S → B).[5] We argue here
that different proportions of familial properties follow the internal and complete
cycles depending on property size. As we saw during our fieldwork, a small property
can not provide products for household consumption without clearing increasing
amounts of forest area, bringing that area into the internal cycle or putting it in a
permanently cleared state.

Land Use and Land Cover Change

Figure 6 shows the land cover distribution in 1986 and in 2001 by size class of
properties. At both times, a cross-sectional relationship between property size and
land cover is evident; larger properties have a higher proportion of their area in
forest (significant positive correlation between continuous measures of property size
and proportion of area in forest in both years) and smaller proportions bare (sig-
nificant negative correlation in 1986, but not in 2001) or in secondary succession
(significant negative correlation, $P < .05$ in 1986, $P < .01$ in 2001). By comparing the
two graphs, we can see a deforestation trend and an increase in secondary succession
over time. However, this deforestation trend is not correlated with property size; the
loss of forest (decline in proportion of area in forest) between 1986 and 2001 is not
higher in smaller properties. Thus it is unclear from these statistics whether the
cross-sectional relationship between property size and proportion in forest is
explained by differential changes over time in forest cover by property size. We turn

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[5] Using two satellite images as we did in this paper, with an interval of 15 years from each other,
gives us only two points to capture cycles or sub cycles. For example, a pixel identified as forest in
1986 and as secondary succession in 2001 is represented as F → S, when in fact it is F → B → S.
Using two points it is not possible determine if in 15 years this pixel was converted to bare one or
more times. However, we can get a good sense of the proportions of properties that are making the
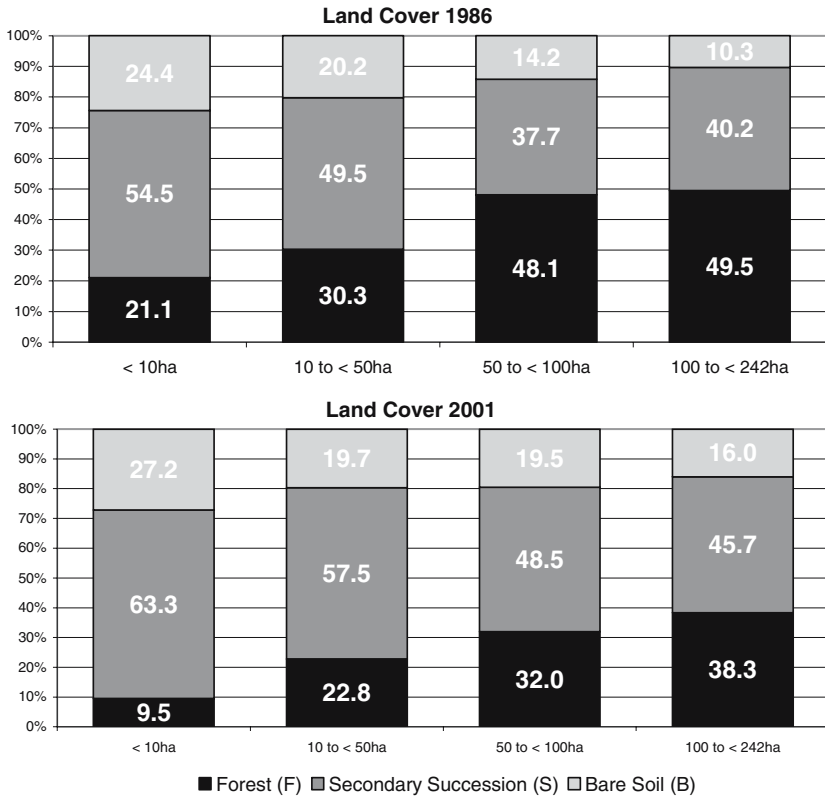internal cycle and the complete cycle.

Fig. 6 Land cover in 1986 and 2001 (N = 126 familial properties)

now to an analysis of the more detailed transitions to determine differences by property size in land cover changes over time.

Figure 7 shows the average proportion of the area of properties in each of the size classes experiencing each of the transitions in our transition matrix. Panels a-c reiterate the finding that larger properties can retain a larger proportion of their area in forest over these 15 years (positive and significant correlation between continuous measures), but larger properties have a smaller proportion of their area continuously in secondary succession or continuously in bare soil (negative and significant, $P < .05$, correlations between continuous measures). Panel d shows that larger farms are able to use previously forested land and then have it already experiencing regrowth during the 15 year window provided by these two images. Finally, panels g and h show that smaller farms have higher proportions of their area in the transitions that represent the internal cycle—S → B and B → S (negative and significant correlations between continuous measures).

Looking at the numbers using the logic of the land cover schema (Fig. 8) we find evidence in smaller properties of a more intense internal cycle (B → S → B → S...) and a less intense complete cycle (F → B → S → F). In the average property under 10 ha, 15.3% of the area is converted from bare to secondary succession and 13.5% is converted from secondary succession to bare, while a total of 16.9% (4.6 + 12.3%) is converted from forest to some use and only
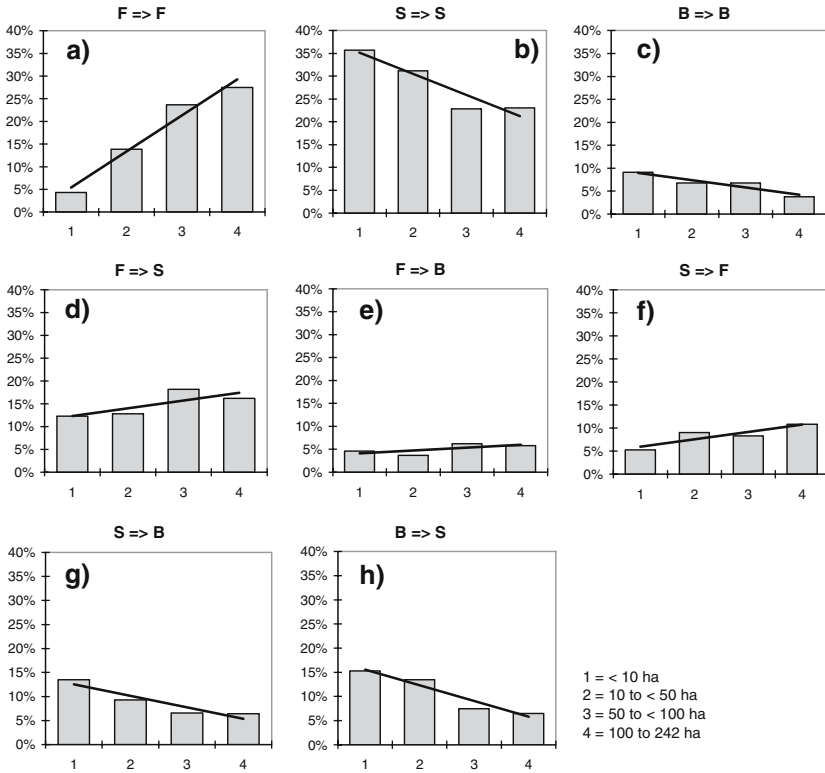
Fig. 7 Land cover change 1986–2001 (N = 126 familial properties). Note: F $\rightarrow$ F: forest in 1986 and 2001; S $\rightarrow$ S: secondary succession in 1986 and 2001; B $\rightarrow$ B: bare soil in 1986 and 2001; F $\rightarrow$ S: forest (1986) to secondary succession (2001); F $\rightarrow$ B: forest (1986) to bare soil (2001); S $\rightarrow$ F: secondary succession (1986) to forest (2001); S $\rightarrow$ B: secondary succession (1986) to bare soil (2001); B $\rightarrow$ S: bare soil (1986) to secondary succession (2001)

5.2% changes from secondary succession to forest. With larger properties, the complete cycle is more prevalent. In properties over 100 ha, only 12.9% (6.4 + 6.5%) is cycling between secondary succession and bare, while 22% (5.8 + 16.2%) is converted from forest to some use with 16.2% of that going to secondary succession within the 15 year window. An additional 10.8% goes from secondary succession to forest in these largest properties. The intermediate groups present some contradictory results in some legs of the cycles, but the main tendencies confirm the pattern: (a) deforestation and reforestation are more intense in larger properties; (b) smaller properties tend to follow the internal cycle.

These results show that higher deforestation combined with lower levels of reuse of land in fallow make possible higher rates of reforestation; lower deforestation followed by more reuse of land in fallow reduce the reforestation. These illustrative but apparently paradoxical elements show the decisive role of secondary succession in the deforestation–reforestation processes. In an old frontier area, with many previous cycles of land clearing and regeneration, the changes in forest are determined by regrowth. The data show that this regrowth is happening on the larger
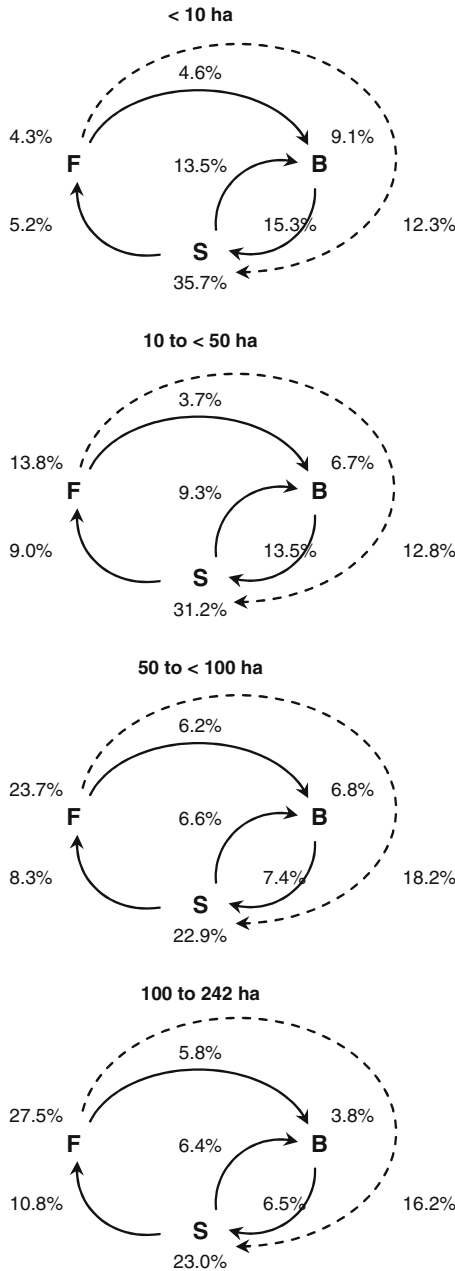
< 10 ha

10 to < 50 ha

50 to < 100 ha

100 to 242 ha

Fig. 8 Land cover cycles (1986–2001) by property size (N = 126 familial properties). Note: F: forest; B: bare soil; S: secondary succession. Arrows mean land cover change. The percentages indicate the land cover change among two land cover classes in the period 1986–2001

properties (Fig. 9). The larger the property, the higher the proportion of secondary succession in 1986 that was converted to forest by 2001 (positive significant, P < .05, correlation between continuous measures).

Fig. 9 Percentage of
secondary succession in 1986
regenerated to forest in 2001
(*N* = 126 familial properties)

1 = < 10 ha
2 = 10 to < 50 ha
3 = 50 to < 100 ha
4 = 100 to 242 ha
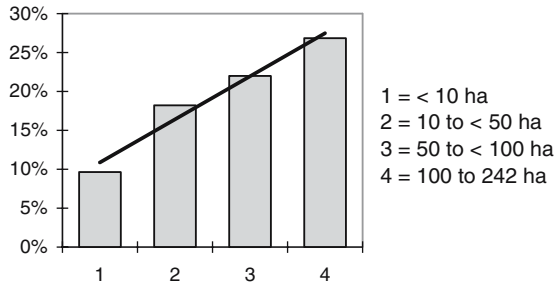
The results are consistent with the land use schema represented in Fig. 4. In small properties, the number of hectares of forest is small; the scarcity of forested areas induces a more recurrent use of fallow land in order to have the necessary area to crop every year without cleaning all the forest. The repeated use of those areas with secondary succession speeds up the impoverishment of the soil and hinders the vegetation regrowth and the forest regeneration. Poor soils reduce a farm's productivity and force the farmers to keep converting at least part of the small portion of forested area in order to keep the familial production at a satisfactory level. At the other extreme, larger properties have more forest available (in hectares and proportion) so the farmers are more inclined to convert it into productive areas every year. The regular deforestation makes it possible for areas in fallow to rest, which means a more consistent vegetation regrowth towards forest.

Conclusions

Using an analysis of the correlations between property size and land cover change, and an analysis of the land cover transitions in the context of our stylized land use change schema, we find a relationship between property size and land cover change. Larger familial properties are able to put more of their land through a "complete cycle," allowing it to regenerate through secondary succession and often back to forest before using it again. In contrast, small family farmers cycle their land between secondary succession and active use, not allowing it to regenerate into forest and eventually retaining a higher proportion of their properties in permanently cleared area. Based on our interviews with farmers, the motivation for the small farmers to clear a larger proportion of their land and to have shorter cycles of regeneration is a scarcity of forests and the depletion of soil fertility on previously used lands. The farmers report that they would prefer to keep a reserve of forests, against a future unexpected need for money or to leave to their children, but that the weakness of soils in other areas means that they must clear the forested land to sustain adequate production for their families.

The study area is characterized by low levels of ranching in comparison to other Amazonian regions. Manioc, rice, and soy are economically much more important in the region. This is in part due to the variation in property sizes and the relatively small average size of properties, as it takes a considerable area to make ranching economically viable. Thus it is important to note that our findings might not apply to areas in which ranching is more common. Pasture takes land completely out of the

cycles that we are studying, and indeed we find even with a small number of farmers having substantial areas of pasture that pasture in 1986 is related to land cover change between 1986 and 2001. There is a positive correlation between area of the property in pasture and the area changing from forest to bare soil, a positive correlation ($P < .05$) between pasture and the proportion remaining in bare at both time points, and a negative correlation ($P < .05$) between pasture and the proportion remaining in secondary succession at both time points.

These results build on previous work arguing that deforestation intensity is higher on smaller properties (Fearnside, 2005) to investigate the transitions between forest and other land covers on different sizes of properties. These analyses show that larger *familial properties* not only have lower levels of deforestation in a point in time analysis, they also are able to keep land out of production for long enough that it regenerates into forest (though clearly not into the same forest that existed before). Our sample controls for many large-scale variations in agricultural technology and practices by focusing on small family farmers in a region characterized by low levels of ranching. The long settlement history in Santarém gives us variation in size across familial properties, a group which has generally been considered to have higher levels of deforestation intensity than large capitalized farmers. Our results show that property size is important to consider even in studies of only small farmers. It remains to be seen whether property size differences among large farmers have a similar impact on their actions. It is also important to note that the results shown here are about the process of land cover change *among* familial farmers and not about the absolute impact on the landscape of such farmers with varying sizes of properties. The total area represented by our 12 farmers with 100 or more hectares is 1,786 ha while the total area represented by our 23 farmers with less than 10 ha is 99 ha. Thus, the 90.5% deforested on the smaller farms in 2001 represents only 90 ha of cleared land while the 61.7% deforested on the larger farms in 2001 represents 1,102 ha of cleared land.

Future research is needed to explore the role of property size in determining the effects of other variables on land use and land cover. Specifically, because of the prevalence of internal cycles among small farmers, we might expect that small farmers are more constrained in their decision-making. Because of the need to clear more areas with secondary growth rather than forest, they can expect less return on investment and there may be certain crops that are eliminated as options. This almost goes without saying, as those who are better off always have more choices. However, this also implies a lower labor need on these small farms, as secondary growth is easier to clear. This suggests that the relative value of off-farm employment might be higher for family members on small farms, leading them to diversify into other sectors of the economy and potentially improve their position. Issues such as these need to be explored both theoretically and empirically in future research.

We conclude here with a few notes about the particularities of our study area and thoughts about the future of the people and the landscape there. Santarém is an old settlement area by Amazonian standards, with recent waves of settlement since the early 20th century. Thus, the variation in sizes of properties, which allows us to see the effects of property size, results from a generations-long process of spontaneous settlement and land fragmentation through inheritance. The situation in Santarém now might well be the future of other settlement areas in the Amazon, as they experience changes over time in the sizes and organization of properties due to intergenerational

processes and to increasing levels of knowledge about the biophysical constraints of the land. However, the future of Santarém is likely to look very different. The region is currently undergoing a process of land consolidation and the expansion of large fields of annual crops, corresponding to the entry of mechanized agriculture into the region. Currently the landscape is a mosaic of small farming, large farming, and growing villages, including areas in forest, in new and old secondary growth and in a variety of crops. However, it remains to be seen whether the current soy boom in the region leads to a depopulated landscape of large farms combined with former farmers making a living in cities and small villages. It also remains to be seen whether the corresponding increases in production and productivity spur adequate economic growth to employ those leaving agriculture in other sectors.

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