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Farm Households and Land Use in a Core Conservation Zone of the Maya Biosphere Reserve, Guatemala

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Abstract This paper employs cross-tabular analysis, and multivariate and logistic regression to explore demographic, political-economic, socioeconomic, and ecological patterns of farm households and land use outcomes in an emergent agricultural frontier: the Sierra de Lacandón National Park (SLNP)-a core conservation zone of the Maya Biosphere Reserve (MBR), Petén, Guatemala. Data were obtained from a 1998 probability sample of 241 farm households, the first large detailed household land use survey in Guatemala's *Selva Maya*-the largest lowland tropical forest in Central America. Virtually all settler households were poor maize farmers who colonized the SLNP in search of land for subsistence. While they faced similar ecological and economic conditions, land use strategies and patterns of forest clearing varied with demographic, household, and farm characteristics. Findings support and refute elements from previous frontier land use theory and offer policy implications for conservation and development initiatives in the Maya Forest specifically, and in tropical agricultural frontiers in general.

Keywords Maya Biosphere Reserve · Guatemala · Land use · Deforestation · Latin America

Introduction

The long history of forest conversion to agriculture represents the most expansive footprint of human habitation on the earth's surface (Myers 1991; Parsons 1994). The planet's intact forests have dwindled to one-fifth their original cover (World Resources Institute 1997). During recent decades, deforestation has accelerated and is now almost totally concentrated in the tropics. If rates continue as they have during the last decade, the most biologically rich forests on the planet will be erased within fifty years (FAO 2001). In recent years, 90% of species extinctions—27,000 species annually—are estimated to have occurred in a biome that covers only 7% of the earth's terrestrial surface—tropical forests (Myers 1991).

This trend has several human and environmental consequences. The diminution of the planet's gene pool through tropical deforestation threatens future advances in science, medicine, and food production (Smith and Schultes 1990; Wilson 1992). Forest elimination has also led to (a) soil erosion and increased sedimentation of waterways (Southgate and Whitaker 1992), (b) hydrological and nutrient cycle perturbation (Fearnside and Barbosa 1998), and (c) soil impoverishment (Ehui and Hertel 1992; Weischet and Caviedes 1993; Lal 1996; Saikh *et al.* 1998). Tropical deforestation has global consequences as well, threatening to exacerbate climate change at local (O'Brien 1995; Fearnside 1996; Tinker *et al.* 1996) and global scales (Naughton-Treves 2004), where it has been estimated that 25–30% of climate warming is caused by the elimination of forests in the tropics (Adger and Brown 1994).

Latin America harbors the greatest area of closed tropical forests in the world and over half of all fresh water on the Earth. During the 1990s, 446,200 km^2 of forest were felled in Latin America, more than any other world region (FAO 2001). While most of the net forest cleared in Latin America opened agricultural land in the Amazon region of South America, Central America's forests were eliminated at double the rate of any world region (FAO 2001). Latin

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American forests have been destroyed hastily despite a relatively small (and, in many cases, declining) rural population inhabiting the region. This is because Latin Americans deforested five times more forest per rural person than Africans and 40 times more than Asians (Bilsborrow and Carr 2001). This results from the great forest clearing per household accomplished by the small proportion of migrants who colonize remote frontiers (Bilsborrow and Carr 2001).

Nowhere is this trend more evident than in Guatemala. Farming, logging, and urban expansion claimed an astounding 38% of Guatemala's forest cover between 1966 and 1994 (Bilsborrow and Carr 2001). At the end of the 1990s, no other country in Latin America—and only seven countries worldwide—possessed as much forest as Guatemala (over 28 thousand square km.) while having cleared its forests at 1.7% (or greater) per annum during the 1990s (FAO 2001). Most of the forest clearing in Guatemala during the last decade of the 20th century was to open agricultural land in the vast northern departamento (similar to a U.S. state) of Petén (Fig. 1). As most of the southern half of the *departamentos*' forestland was cleared by the 1970s, migration in recent years has threatened the *departamento*'s northern forests, most of which are located within the Maya Biosphere Reserve (MBR). The MBR forms the heart of *La Selva Maya*-the largest lowland tropical forest north of the Amazon. Mass colonization by land-poor corn farmers during the past decade has spurred dramatic forest clearing in the MBR (Grunberg 2000).

Compared to South America, research on frontier land use in Central America has been scant and narrowly focused. The complex suite of socioeconomic, political, demographic, and ecological factors behind farmers' land use and variability from one context to another have hampered research endeavors and policy interventions. Studies have been replicated in diverse environments without the aid of a unified theory. A dearth of representative data on the broad spectrum of factors influencing frontier farmers' land use in the form of detailed household surveys limits studies to privileging certain factors over others with unfaithful representation of the full set of variables related to farmers' land use. Progress has been achieved in integrating remote sensing data with survey research, though all markedly different from the context of the MBR except in a select few environments, and few if any, in emergent frontiers. Inevitably, scholars and policy makers have committed the ecological fallacy, imputing causes from one scale of analysis or region to explaining patterns at another scale or another geographical area.

The purpose of this article is to enhance understanding of the role of socioeconomic, political, demographic, and ecological factors behind farmers' land use and forest clearing in Guatemala's MBR. The analysis here contends

Fig. 1 The SLNP, RBM, and Petén, Guatemala

that these factors must be examined in the context of the *Selva Maya*, where these roles differ from regions of previous frontier land use, particularly the Amazon. This exploration, therefore, introduces a case study from a region that has received relatively scant attention relative to the preponderance of case studies from South America. The analysis explores rich data which are unique in constituting the only detailed statistically representative human-environment survey of settler households in a Central American agricultural frontier. The study site is also important from an ecological perspective; the MBR is a global hot spot of biodiversity (Myers *et al.* 2000).

The article begins with a discussion of the state of knowledge on frontier land use in the Latin American tropics and proposes a conceptual framework for examining the proximate determinants of frontier farmers' land use within the context of household demographics and socioeconomic characteristics, the natural resource base, and the institutional context within which farmers make land use decisions. The next section presents the research site and describes the survey sample design and data collection. This is followed by a descriptive overview of the sample households and farms relative to demographic, socioeconomic, political, and ecological characteristics, and examines the primary land use outcomes among the sample farm households[1]. Building on the proposed conceptual framework, and informed from previous literature and the descriptive analysis, the penultimate section employs cross-tabular and multivariate regression to investigate the distinct patterns of land use and forest conversion among smallholders based on household and farm variation in size, population density, land tenure, assets, duration on the farm, and soil quality. The paper concludes with a discussion

[1] Although farmers in the region use *manzanas* (0.7 ha), measurements for these three variables and cleared land were converted to hectares for purposes of broader comparison.

of the implications for future research and policy interventions both in the MBR and elsewhere.

Frontier Land Use in the Latin American Tropics

The proximate causes of deforestation in the humid tropics vary significantly across and within countries, but it is generally agreed that rural-rural migrant farmers are the primary *direct* agents (Myers 1991; Houghton 1994; Geist and Lambin 2001, 2002; United Nations 2001).[2] Protected areas, especially throughout the tropics, face increasing threats from internal migration (Harmon and Brechin 1994; Mc Neely and Ness 1996). This is particularly the case in Latin America, where the vast majority of the region's forest loss in recent decades—increasingly in biodiversity-rich "protected" areas—has been linked to agricultural expansion along colonization frontiers (Rudel and Roper 1996; Carr and Bilsborrow 2001; Barbier 2004; Laurance *et al.* 2004).

However, how the direct agents of land use and land cover change (LUCC) decide to manage their farm is a result of complex processes that are not easily explained by monotopic theoretical models (Lambin *et al.* 2001; Geist and Lambin 2001, 2002; Turner *et al.* 2004; Wood 2003). Malthusian, behaviorist, frontier pioneer cycle theories, and more recently, demographic transition theories help our understanding but insufficiently apprehend the full suite of processes underlying frontier farmer land use. As alarm over the physical and human consequences of tropical deforestation has gained attention in the media and policy arenas, the empirical literature has grown and draws on a host of disciplines in the human and natural sciences. Though a review of the literature imbues an appreciation of the variable political economic and physical contexts of settler environments, some important characteristics are shared. Frontier settlers tend to invest intensively in labor and extensively in their resource base relative to farmers in areas of greater population density. Given plentiful land and scarce labor and capital resources, swidden or slash and burn agriculture is a logical way for settler farmers to maximize available resources (Pichón 1997a; Carr 2004a, b, c).

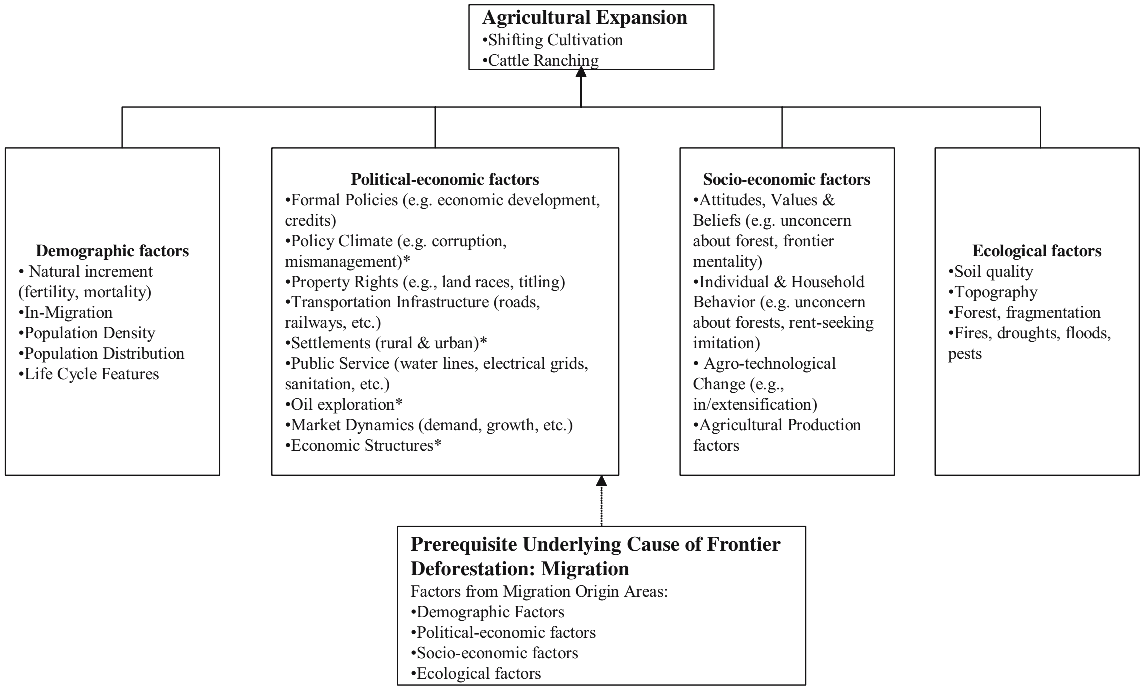
Pathways to forest conversion interact in complex ways and across multiple temporal and spatial scales. A large literature documents these as described above. Some of the more salient factors found to be associated with tropical deforestation include (a) distance to the nearest road or market and duration of residence on the farm (Rudel and Horowitz 1993; Nelson and Hellerstein 1997; Sader *et al.* 1997; Pan *et al.* 2004; Pichón and Bilsborrow 1999); (b) land tenure security (Southgate *et al.* 1990; Schneider 1993; Mahar and Schneider 1994); (c) soil quality and topography (Hecht 1985a; Moran *et al.* 1994; Pichón 1997b); (d) household demographic characteristics, including household size and family life cycle (Marquette 1995; Rosero-Bixby and Palloni 1998; Mc Cracken *et al.* 1999; Pichón and Bilsborrow 1999; Carr 2004a, b, c, 2005), (e) adoption of land, labor, and capital intensive farming (Perz 2003; Shriar 2001; Krautkraemer 1994) and (f) educational achievement (e.g., Moran 1984; Godoy *et al.* 1998). Others have noted the effects of fiscal and political structures, the expansion of export agriculture, cattle ranching, land speculation, and agricultural output prices (Southgate 1990; Rudel and Horowitz 1993; Stonich 1993; Stewart 1994; Walker *et al.* 2000). Based on cross-country data, Bilsborrow and Carr (2001) found deforestation linked to land availability and cattle adoption in Latin America, corroborating previous work on the region (Heckandon 1983; De Walt 1985; Hecht 1985b; Jones 1990; Nations 1992; Hecht 1993; Rudel and Roper 1997). For a more in depth review of drivers of deforestation, see Geist and Lambin 2001; Carr 2002, 2004a, b.

Place-based effects, however, have yielded quite different results in different places (Carr 2002). Despite the recognition of the importance of context and spatial scale, the literature on frontier LUCC largely ignores the effects of contextual factors at the community and subregional level. Further, most studies come from Amazonian developed, or even post-frontier, environments where there is more variability, different political and economic contexts, and relatively little forest remaining to be cleared (Rudel *et al.* 2002).

A conceptual model is needed that allows for patterns recurrent in the literature, but flexible enough to take into account the diverse local conditions of a given case study. Some recent LUCC literature describes the determinants of tropical deforestation as pertaining to underlying and proximate causes (e.g., Turner *et al.* 1993; Ojima *et al.* 1994; Geist and Lambin 2001, 2002). From the research on tropical deforestation explicitly modeling proximate causes, three essential types of land use emerge: agricultural expansion, timber extraction, and infrastructure development (Ledec 1985; Kaimowitz and Angelsen 1998; Contreras-Hermosillo 2000; Geist and Lambin 2001, 2002). The first, often facilitated by the latter two, is the number one cause of deforestation, particularly in Latin America.

Conceptual LUCC models framed in proximate and underlying causes require modification for addressing the more specific phenomenon of LUCC caused by frontier agricultural settlement. Figure 2 represents a conceptualizing of the proximate determinants of small farmer frontier forest conversion in an agricultural frontier. Variables affecting forest conversion on frontier farms can be subsumed under four major causal categories: demographic, political-economic, socioeconomic, and ecological. The suite of

[2] Estimates of the share of global deforestation attributed to shifting cultivators range from 45% (UNEP 1992) and 60% (World Bank 1991; Myers 1992) to 79% (Amelung and Diehl 1992).



*Macro-economic or institutional factors measurable at the community level or greater.

Fig. 2 Factors affecting the proximate cause of deforestation in the agricultural colonization frontier: Colonist farmer land use

variables within these categories enable and constrain household decision-making regarding economic and demographic outcomes. The relative influence of these factors on household responses will vary from place to place depending on natural resource endowments and characteristics, and variation in social and economic geographies, including proximity to market and vicissitudes in market prices, access to health care, education, and cultural mores.

Survey Site and Methods

Petén and the Maya Biosphere Reserve (MBR)

Since the 1960s, Petén's population has exploded from a few chicle extractors to 600,000 farmers and laborers (Instituto Nacional de Estadistica 1999) while half of the departamento's forests were extirpated (Valenzuela 1996). This dramatic forest conversion has been investigated by a number of scholars (e.g., Jones 1990; Colchester 1991; Schwartz 1990; Sader *et al.* 1994; Grunberg 2000). Several factors have been examined. A number of researchers have noted the dearth of land tenure as one of the main hurdles to forest conservation in Guatemala's Petén (Kaimowitz 1995; Clark 2000; Carr 1999). Lack of capital and institutional support has also resulted in extensive swidden cultivation that may be efficient relative to labor investment but highly demanding of continued forest conversion (Shriar 2001). To the extent farmers are intensifying production, often through the adoption of the nitrogen-fixing legume, *Mucuna pruriens* or frijol abono, as opposed to more extensive land uses such as cattle ranching, farmers reduce pressures on forest resources (Shriar 2001; Carr 2004c). Authors have also examined whether Q'eqchí Maya exert a greater impact on forest conversion than do other ethnic groups (Atran *et al.* 1999; Corzo-Márquez and Obando 2000; Carr 2004c; see also Steinberg 1998 for an example from western Belize). To protect the last vestiges of forest in the region, UNESCO and the Guatemalan government established the Maya Biosphere Reserve (MBR) in 1989. The MBR lies at the center of the *Selva Maya* (the largest lowland tropical forest in Central America) and comprises nearly 60% of Petén.

The Sierra de Lacandón National Park

The SLNP, established in 1990 as one of four *core* zones (area of strict conservation) of the MBR, is the second largest national park in Guatemala (The Nature Conservancy [TNC] 1997). The SLNP boasts the greatest biodiversity in the *Selva Maya* yet also suffers from some of the fastest population growth and largest agricultural expansion in Petén (TNC 1997). Since most of the park's 3,000 families settled there from 1990 to 1999 (Carr 2008), an analysis of time series satellite imagery indicates that approximately 10% of the park was converted to agriculture (Fig. 3).

While ineffectually protecting the park's natural resources through underfunded government agencies, the govern-

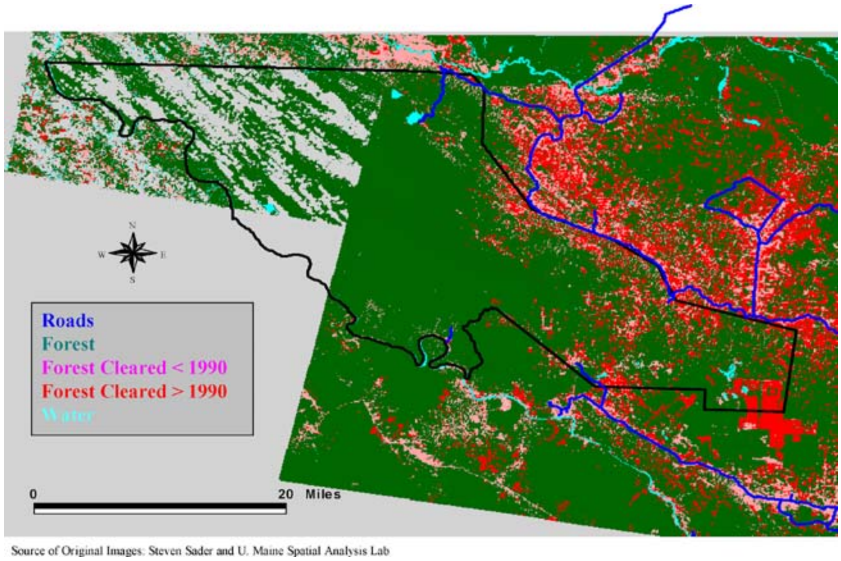


Fig. 3 Composite satellite image of the SLNP indicating deforestation prior to 1990 and from 1990 to 1999

ment has facilitated further settlement by paving much of the major access road to the park. Little has been provided to the farmers in the way of technical assistance, credit, or market strategies to promote sustainable agricultural management (Carr 2006). Currently the Guatemalan government, in collaboration with the U.S. Agency for International Development (USAID) and other donor agencies, has invested in sustainable farming practices in the buffer zones of the MBR. But data are scant on farm-level decisions for resource use, hampering policy efforts to temper the environmental impacts of local farmers. Further, the buffer zone areas have already been significantly altered by human intervention and stand little chance of reverting to forest. It is the core zones that are the most ecologically precious and imminently threatened forests in the MBR.

Sample Design and Data

The SLNP is an exceptional study site for conducting research on small farmer colonization and tropical deforestation because of its rich biological diversity coupled with the rapidity of population growth and forest clearing in recent years. Such a study contrasts with the vast majority of LUCC research which is either conducted at the macro scale-where complex causal processes operating at the local scale are concealed by data aggregation—or at the micro scale-where research in emerging frontiers is rare, and is more commonly conducted in post-frontier environments.

The data presented here are from a survey collected in 1998 and from qualitative research conducted from 1997 to 2000. A two-stage probability sample representing approximately 10% of the settler population households was achieved by focusing on the 241 heads of household interviewed in 8 of the 28 communities that farm in the SLNP. Only one person, of over 500 total interviewed (including community leaders, heads of households, and heads' wives) declined to participate in the study. Before conducting the survey I lived among various SLNP communities for several months in order to improve questionnaire content, improve language design, and to gain the trust of locals. The fieldwork was physically challenging. Access to villages consisted of hikes of 10 km or more through mountainous jungle paths, food was comprised almost entirely of maize tortillas, and political violence and forest fires were common impediments to field research (See Carr 2003 for more information on the survey design).

Analytical Methods

Cross tabular analysis among variables of interest are examined along with multivariate regression. Standard multiple regression (MR) yields an equation that produces the best prediction for a dependent variable (DV) given continuous or dichotomous independent variables (IVs). The MR takes the following general form:

$$Y = A + B_1X_1 + B_2X_2 + \ldots B_kX_k$$

where Y is the DV, A is the intercept, the Xs represent the IVs, and the Bs are the coefficients related to each predictor variable. When outcome variables are dichotomous, a logistic regression model is employed. Logistic regression (LR) predicts group membership among a set of independent variables. Logistic regression is related to multiple regression but makes no assumptions of normality relative to the distribution of the independent variables (Tabachnick and Fidell 1996).

The general equation for logistic regression takes the form:

$$\ln\left(\frac{Y}{1-Y}\right) = A + \Sigma B_j X_{ij}$$

so that the equation equals the natural log of the probability of membership in one group divided by the probability of membership in the comparison group (Tabachnick and Fidell 1996).

Description of the Sample

Demographic Characteristics

The homogeneity of settler socioeconomic and land use characteristics belies the diversity of migrant origins. Migrants came from all regions of Guatemala, with the southeast the most represented area. Most colonists arrived in the park during the 1990s, following a road built by oil interests adjacent to the park in the mid-1980s. Virtually all households left their origin communities in search of farmland; political violence was a catalyst for a number of the settlers, though acquiring land was cited by the vast majority as the primary determinant. The mean household size was 6.5 persons, notably higher than Petén's average of 5.7 (INE 1999). The adult sex ratio of the sample (129 men per 100 women) mirrored early-stage Amazonian frontiers (Martine 1981); men settled first, followed by the nuclear family after the farmstead was safely established. The Child Dependency Ratio of approximately one and one-half children under 12 relative to adults twelve years or older indicated a surplus of producers to consumers.

Socioeconomic Characteristics

Three-quarters of the household heads were Ladino, of mixed European and Indigenous ancestry, 13% were Q'eqchí Maya, and the remainder other Maya groups. Settlers remained poor following migration to the SLNP. The typical home was comprised of one room covered by a palm leaf roof, enclosed by walls of sticks, on a dirt floor base. Few households had assets extending beyond a machete and basic cooking utensils. Nearly half of the household heads had worked as a day laborer the year prior to data collection. None of the settlers had studied beyond primary school, a level well below the national average (INE 1999). The first settlers typically claimed farms of one *caballeria* (45 ha) adjacent to the road. By 1998, the average farm size had declined by approximately 10 ha from farm fragmentation due to children entering adulthood, continued in-migration, and the average distance of farms to the road—now 6 km.

Political-economic Characteristics

Nearly 70% of the households squatted illegally on park land or rented land and nearly a third of the farmers enjoyed some legal claim to their farm. These farms are located adjacent to the road in the narrow "multiple use zone". Partially due to the low percentage of landowners, only 5% of farm households had received credit to develop agricultural activities. Conversely, many households remained indebted to middlemen engaged in the storage and transportation of crops. Conservation and development efforts in the park had yet to be successful. Fewer than half the heads of household had made contact with a conservation or development extensionist, while a third claimed to be ignorant of the park's existence.

Ecological Characteristics

Farms in the region were on flat to slightly hilly karstic soils of irregular drainage. Nearly half the farmers claimed their farm soil was highly fertile, and only a quarter complained they sowed crops on poor soils. Because of the relatively low population density of the park, less than half of the farmers reported having hilly land on their farm, despite the fact that the SLNP is covered in jagged, fractured terrain. However, among the most recent settlements nestled between the Lacandón mountain chains, agricultural expansion on hillsides had become more frequent.

Relations Between Land Cover and Household and Farm Characteristics

This section examines relations between household and farm characteristics and farm land use allocations described above. First, farm land allocations and the use of agricultural inputs are described. The second part examines relations between farm land use, forest clearing for farm extensification, and agricultural intensification on the one hand and the following hypothesized associated factors: (a) household size and composition, (b) population density, (c) farm size, duration on the farm, (d) household assets, (e) land tenure, and (f) soil quality. Each of these variables are derived from household surveys. Where associated factors are theoretically related to land management or associated variables—such as age of household head with household size or farm topography with soil quality—they are included in the analysis.

Land Use

With few assets other than land and labor, prospects for present and future security of the household depend directly on what farmers can produce from the land. Despite diverse agricultural experiences in origin areas, SLNP colonists uniformly practiced swidden maize production with modest allocations to beans. Farmers differed in the use of agricultural inputs and in complementary land allocations to cattle, in other words the extent to which they chose to extensify or intensify production. These decisions were affected in turn by some key variables examined here.

Table 1 reports some descriptive characteristics of farm land management patterns. Roughly half the land on the typical plot was cleared, with half remaining in forest. Of the cleared land, most was allocated to crops and fallow. The crop-to-fallow ratio was approximately one-to-one. However, one third of the sample had no fallow land (yet). Consistent with Boserup's designation for a bush-fallow rotation for rural populations of low technology and moderately low population density, farms with fallow land in the sample had a crop-to-fallow ratio of nearly one-to-two. Nearly two-thirds of SLNP maize farmers cropped a field for two or three years before letting the cropped field lay fallow and rotating to a new field.

The majority cultivated maize exclusively, with a mean of 5 ha, only slightly less than the average amount of land dedicated to all crops (5.9 ha). Less than a third cultivated frijol and less than a fifth grew other crops, such as *pepitoria* (a member of the squash family, sold largely to Mexican markets for its seeds popular in snacks), peanuts, or tomatoes. A quarter of the respondents grazed cattle on farmland cleared for pasture—mostly one or several head of cattle occupying a few hectares of land. The intent of virtually all households was to develop their plot, with most wishing to adopt livestock. The desire of farmers to expand cropland by 100% and pastureland five-fold presages the potential for significant deforestation on the internal frontier.

Table 1 Land Use (in ha)

Land allocations	Percentage affirmative (%)	Mean ha	Percent of Farm
Farm size	100	34.8	
Maize	95	5.0	14
Frijol	29	0.4	1
Other crops	18	0.5	1
Total crops	98	5.9	17
Fallow	68	7.3	21
Pasture	24	1.3	4
Unusable land	11	0.5	1
Forest	78	19.8	57
Cleared land	100	15.0	43
Land use ambitions (in ha)			
Crops in 2008	89	12.7	36
Pasture in 2008	56	6.3	18
Agricultural Production		Quintales	
Corn production (quintales) per hectare (first harvest)	92	32.1	
Agricultural intensification			
Velvet Bean	38		
Herbicides	13		
Other Inputs	11		

Source: Interviews with 241 household heads in eight communities in the SLNP

The average farmer produced approximately 30 quintales (100 lb. sack) of maize per hectare in the first harvest, known as *la primera*, which he typically sold for 20–60 *Quetzales* (Q) per *quintal* with an average of Q40. This amount was equivalent to just under U.S. $1,000 of revenue from the first harvest of corn on an average farm with 5 hectares in maize. The second harvest usually produced half this amount and was sown (on half again as much land in some cases) on the same land used for the first harvest. When the cost of hiring labor and own labor costs were calculated (both valued at the average daily salary in the area of Q25), in addition to the cost of clearing and transporting the product (paid in labor or in cash for chainsaw, horse, or truck rental), most farmers either lost money, broke even, or scratched out a marginal capital gain.

The cropping of the nitrogen-fixing legume, velvet bean (*mucuna pruriens*), and the application of herbicides were the most common means of enhancing crop production; still, approximately half of the survey sample cultivated crops with no additional inputs whatsoever. Nearly 40% of the sample reported cropping velvet bean to enhance production of their second maize crop. Only 10% reported using pesticides or fertilizers of any kind, including manure, or purchased fertilizers.

Demographic Factors

Household Size and Composition

The Neomalthusian and Boserupian debate can be investigated at the farm-level. Do more people on the farm mean more pressure on the forest, leading to agricultural extensification? Or does it promote forest-conserving, production-enhancing intensification? With a focus on household size and composition, the demand side means more mouths to feed may promote the expansion of cropland, while the supply side means more hands to work the land and more labor available for clearing land (or for intensifying production).

As indicated in Table 2, the related factors, duration on the farm and age of household head, remained significant at the 0.05 level. Asterisks on the left hand side of the variable names represent statistical significance in model one, which includes only related factors. Asterisks on the right hand side of variable names signify statistical significance in

Table 2 Demographic Factors

Household Size	1 to 3			4 to 5			6 to 7			8 to 9			10+		
	Mean	N	%	Mean	N	%	Mean	N	%	Mean	N	%	Mean	N	%
Related factors															
Duration on the farm (years)	7.9	44		9.5	63		7.6	56		9.7	38		12.2	40	
***Age of household head (years)**	33.8	44		38.2	63		39.1	56		44.8	38		46.6	40	
Land use outcomes															
Farm size (ha)**	32.8	44		31.4	63		28.9	56		40.6	38		45.1	40	
Forest (ha)	23.2	44	71	15.5	63	50	16.5	56	57	23.9	38	59	23.3	40	52
Cleared land (ha)***	9.5	44	29	15.8	63	50	12.3	56	43	16.8	38	41	21.7	40	48
Cropland (ha)	4.8	44	15	5.3	63	17	5.9	56	21	7.1	38	17	6.9	40	15
Fallow (ha)***	4.3	44	13	7.8	63	25	5.2	56	18	7.5	38	18	12.3	40	27
Pasture (ha)	0.1	44	0	2.1	63	7	0.8	56	3	2.0	38	5	1.6	40	4
Pct of people**			5			35			13			34			38
Agricultural inputs[a]	0.6	44		0.9	63		0.8	56		0.8	38		0.8	40	

[a] Agriculural inputs: *0* No usage, *1* crops velvet bean or applies herbicides, *2* crops velvet bean and applies herbicides
*Significant at 0.01 level
**Significant at 0.05 level
***Significant at 0.01 level

secondary models, in which related variables are modeled with each land use outcome entered separately. Model 1 of related factors yielded an R^2 of 0.14. Farm size, cleared land, fallow land, and cattle ownership were significant at the 0.05 level or better when combined with the related factors of duration on the farm and age of household head. Adding land use outcomes increased the percentage of the residuals explained in the model to within a range of 0.15 to 0.17.

The cross-tabular table assists in interpreting the regression results. For example, it is evident that as the household matures, larger families, with their augmented labor pool and increased food demands, were indeed associated with more land cleared. Although this cross-sectional analysis is insufficient to identify whether the effect of consumption or production was more significant, for both supply and demand it is reasonable to expect a larger household to clear more land. In support of both supply and demand effects, separate tabulations unreported here of farm labor supply (males over 12) and consumption (family consumption units) demonstrated a similar relation.

Household size is notably related to farm size in the positive direction. Thus, when examining the relation between size of household and *percentage* of the farm cleared (which controls for differences in farm size), the relation between population and deforestation was attenuated. Households ranging from four to nine members cleared, on average, 40 to 50% of their farms. Only among the smallest households, did an evident relationship exist when considering both total amount and percent of farm cleared. Although the smallest households (those under three members) had much smaller plots than the largest households (those over ten members) in support of a relation between household size and agricultural extensification, the small households still cleared less than a third of their holdings, compared to almost half of the holdings cleared among the largest families.

Despite notable differences in total land cleared, the percent of land in crops did not increase with household size. This finding is consonant with a marked difference between the smallest and largest households in two land uses: fallow and pasture (Sutherland *et al.* 2004). Very large households had three times more fallow land and were almost eight times more likely to have cattle than very small households. However, it is evident that these differences were also closely related to household duration on the farm and household life cycle effects, captured by the age of the household head. Households of longer duration on the farm tended to have older heads of households. These, in turn, were more likely to be further along in the demographic evolution of the household (more children). Lastly, a threshold is evident whereby the smallest household group was noticeably less intensive in their use of velvet bean and herbicides than the rest of the sample, supporting evidence for population-induced intensification in the region.

Household Density

Though household size in itself may influence land management, land use was also influenced by incentives to intensify or extensify agriculture, based on population pressure on available land (Table 3). When combined with land use outcome variables only the intention to have cattle in 2008 and distance to a road remained statistically significant in the regression models. Combined with these two predictors, only hectares in pasture and cattle owner-

Table 3 Household Population Density[a]

Parameter	1 to 3.9			4 to 5.9			6 to 7.9			8 to 14.9			15 to 39.9			40+		
	Mean	N	Percent of Total Sum	Mean	N	Percent of Total Sum	Mean	N	Percent of Total Sum	Mean	N	Percent of Total Sum	Mean	N	Percent of Total Sum	Mean	N	Percent of Total Sum
Related factors																		
Age of household head (years)	35.5	42		41.4	46		42.66	35		42.74	50		35.29	28		40.88	40	
*Off-farm labor[b]	29%	42		46	46		43%	35		42	50		43%	28		58	40	
*Renter[c]	2%	42		7	46		9%	35		10	50		25%	28		90	40	
***Percent who want cattle in 2008**	86%	42		67	46		54%	35		52	50		36%	28		30	40	
***No land title[d]	64%	42		59	46		69%	35		58	50		75%	28		95	40	
Duration on the farm (years)	7.9	42		11.8	46		8.7	35		10.1	50		8.2	28		7.8	40	
Distance to road (km)	7.3	42		6.8	46		6.3	35		5.6	50		5.6	28		3.9	40	
Land Use outcomes																		
Farm size (ha)***	48.5	42		52.9	46		45.5	35		37.1	50		12.4	28		3.0	40	
Forest (ha)***	31.8	42	66	32.3	46	61	26.8	35	59	18.4	50	50	2.7	28	22	0.2	40	8
Cleared land (ha)***	16.6	42	34	20.6	46	39	18.7	35	41	18.6	50	50	9.7	28	79	2.8	40	92
Cropland (ha)***	5.9	42	12	7.4	46	14	7.7	35	17	6.2	50	17	5.4	28	43	2.6	40	85
Fallow (ha)***	8.0	42	16	9.7	46	18	9.5	35	21	10.4	50	28	4.0	28	32	0.2	40	6
Pasture (ha)	2.3	42	5	2.3	46	4	1.0	35	2	1.5	50	4	0.18	28	1	0.0	40	1
Pct of people			26			41			26			32			11			3
Agricultural Inputs***	0.6	42		0.9	46		1.0	35		0.9	50		1.0	28		0.5	40	

[a] Household population density is the number of members of the household per caballeria (45 ha of land)

[b] Off-farm labor is dichotomous; *1* The respondent worked for wages during the previous 12 months, *0* no wage labor during the previous 12 months

[c] Renter is a household that rents its principle farm plot

[d] No land title represents the proportion of respondents who have no legal claim to their farm

ship were insignificant in the second models. All other land use outcomes remained significant at the 0.01 level. Farm size, cleared land, fallow land, and cattle ownership were significant at the 0.05 level or better when combined with the related factors of duration on the farm and age of household head. The related variables explained 11% of the residuals relative to household population density. However, when incorporating cleared land (R^2=0.21), forest (R^2= 0.25), and farm size (R^2=0.33), the percentage of residuals explained increases dramatically in the second models.

Variation in population density appears more constrained by the numerator (number of people) than by the denominator (amount of land) so that the most salient difference between households of high- and low-population density was not the number of members in the household, but rather the size of the farm. Therefore, while the smallest group was largely comprised of small households on large farms, the remaining groups had relatively similar household sizes, but differing land sizes. The first four groups of ascending population density had roughly one *caballeria* of land (give or take several hectares) while the majority of the farmers in the two groups of highest population density worked small rental subsistence plots of only several hectares.

As anticipated, a negative relation existed between household population density and total land in forest and percentage of landholdings in forest. Higher density households devoted virtually all their land to crop production with little or no land in forest, fallow, or other land uses. The difference between the percentage of the farm devoted to crops in the high density households relative to the low density households was much greater than the difference in the absolute number of hectares in crops between the two groups. Indeed, of the forty households of highest density, only a fraction had *any* land *not* in crops. This offers tentative support for two important notions: (1) the existence of a hierarchy of land use needs, as follows: (a) short-term subsistence in the form of crop production, (b) long-term maintenance of subsistence (fallow land), and, (c) enhanced household security through asset diversification—and ultimately, capital accumulation—in the form of cattle and (2), the threshold of (short-term) subsistence for rudimentary, maize farming appeared to be 2–3 ha of land.

Although the measure of agricultural intensification lacks a statistically significant association with population density, it is noteworthy that the groups of lowest and highest density were the least intensive farmers, as measured by their use of the nitrogen-fixing legume, (velvet bean) and herbicides. High-density households farming only 2–3 ha cropped all of the land for short-term subsistence despite having to abandon the plot following two years of harvests due to declining soil fertility. These households tended to rent land in different places each year or two, in many cases serving as free labor for large farmers to clear forest and sow pasture in exchange for using the land for two to four maize harvests. Since they move to another plot the following year, there is no incentive for them to invest in conservation techniques. The lowest density households also had little incentive to intensify, but for quite different reasons. They were comprised of young households with little labor supply or consumption demand on comfortably large farms. This understanding of the local context helps explain why population density relations to agricultural intensification do not follow expectations from Boserupian theory. It also underscores the importance of closely examining data in cross-tabular form before dismissing as meaningless insignificant variables in regression analyses.

Socioeconomic Factors

Farm Size

By examining land use by farm size, it is possible to investigate distinctions between population density and farm size effects on land use outcomes (Table 4). Farm size was significantly related to all the variables clustered together in model 1: duration on the farm, expected hectares in crops and in pasture, land tenure, and distance to a road. Moreover each of these variables remained significant when combined with land use outcome variables. Insignificant were hectares in pasture and cattle adoption. However, when hectares of cattle anticipated in 2008 is removed from the model both these variables are statistically significant. All land cover measures were significant at the 0.01 level and the use of agricultural inputs was significant at the .05 level.

As observed with household population density, the smallest farms dedicated virtually all of their land to crop production, suggesting that at least several hectares are necessary even for short-term subsistence in this ecological and socioeconomic frontier context. Land consolidation for cattle ranching, as observed in much Amazon frontier development appeared to be commencing in the SLNP, with many farms now below 45 h, the size of the plots initially claimed. Land conversion to pasture is a key land use positively related to farm size (which is positively related to relative wealth and duration on the farm), apparently independent of population density. For example, not one farm smaller than 7 ha had pasture. With at least 1 ha needed per head of cattle, and several hectares needed for subsistence agriculture, cattle adoption on small farms was simply not viable, regardless of population density. Cattle ranching is labor extensive, demanding less labor inputs per unit area than growing crops. Because of the great impact of cattle ranching on deforestation and its low labor

Table 4 Farm Size (ha)

Parameter	0–6.9			7–29.9			30–44.9			44–45.9			46+		
	Mean	*N*	Percent of Total Sum	Mean	*N*	Percent of Total Sum	Mean	*N*	Percent of Total Sum	Mean	*N*	Percent of Total Sum	Mean	*N*	Percent of Total Sum
Related factors															
Duration on the Farm	7.9	47		8.3	40		9.9	45		8.6	75		12.8	34	
Crops expected in 2008	6.7	47		9.4	40		11.0	45		16.3	75		19.1	34	
Pasture expected in 2008	1.5	47		2.7	40		7.2	45		9.7	75		8.5	34	
Land Tenure	0.9	47		0.8	40		0.6	45		0.6	75		0.4	34	
Distance to Road	3.6	47		5.8	40		5.2	45		8.2	75		5.1	34	
Land Use outcomes															
Farm Size (ha)	3.0	47		18.75	40		38.37	45		45.06	75		70.13	34	
Forest (ha)***	0.24	47	8	6.73	40	36	19.12	45	50	30.01	75	67	40.54	34	58
Cleared land (ha)***	2.77	47	92	12.02	40	64	19.25	45	50	15.05	75	33	29.60	34	42
Cropland (ha)***	2.6	47	85	5.7	40	30	6.6	45	17	5.9	75	13	9.8	34	14
Fallow (ha)***	0.19	47	6	5.92	40	32	9.55	45	25	7.15	75	16	16.01	34	23
Pasture (ha)	0.00	47	0	0.18	40	1	1.96	45	5	1.69	75	4	2.78	34	4
Pct of people			0			13			36			29			47
Agricultural inputs**	0.6	47		1.1	40		0.8	45		0.7	75		1.0	34	

requirements, the small absolute number of households with cattle will have a disproportionately great impact on forest conversion.

Duration on the Farm

Consistent with frontier land use evolution throughout Latin America, it appears that duration on the farm is another key predictor of cattle adoption (Table 5). Among the factors related to duration on the farm, only lack of legal title to the farm remained significant when modeled with other land use factors. Nevertheless, among the land use factors, hectares in fallow is significant at the .01 level while farm size, hectares in forest, in cleared land, and the use of agricultural inputs were significant at the 0.05 level. Longer-settled farms had much more land in fallow and cleared land, which was to be expected, since earlier arrivals had yet to complete their intended crop rotations. On the other hand, some of the difference in fallow land may be attributed to earlier arrivals not having adopted velvet bean initially, since only in recent years has it been promoted by local NGO agricultural extensionists. As we have seen above, and similar to the literature on frontier regions in South America, settlement duration appeared to be positively associated with proximity to the road and land tenure (Walker *et al.* 2002).

Assets

If we examine the wealth-tenure relation from the perspective of asset differentials, it is evident that at the extremes, the wealthiest households tended to enjoy land title while the reverse was true for the "poorest" households (Table 6). Duration on farm remains significant when included in the secondary models related to assets. Among these, only hectares in forest is insignificantly related to asset accumu-

Table 5 Duration on the Farm (years)

Parameter	<Median			≥Median		
	Mean	*N*	Percent of Total Sum	Mean	*N*	Percent of Total Sum
Related factors						
Household population density	35.4	104		24.2	137	
Child dependency ratio*	1.1	104		0.9	137	
No land title	81%	104		60%	137	
**Distance to road (km.)	6.9	104		5.1	137	
Land Use outcomes						
Farm Size (ha)**	29.9	104		38.5	137	
Forest (ha)**	18.4	104	62	20.8	137	54
Cleared land (ha)**	11.5	104	38	17.6	137	46
Cropland (ha)	5.5	104	18	6.2	137	16
Fallow (ha)***	4.8	104	16	9.1	137	24
Pasture (ha)	1.0	104	3	1.5	137	4
Pct of people			17			30
Agricultural inputs**	0.7	104		0.9	137	

lation, while hectares in pasture is modestly significant. The remaining land use variables are significantly associated with asset levels at the 0.05 level or better. Assets appeared to be quite strongly and consistently (across sub-groups) related to farm size, cropland, agricultural intensification with velvet bean and herbicides, and the probability of having cattle. A threshold between assets and land in forest and land in pasture emerged at the level of possessing three key household assets; the nine wealthiest farmers in the sample have substantially more forest and pasture than do their neighbors. As we have seen above, and similar to the literature on frontier regions in South America, settlement duration appeared to be positively associated with the acquisition of assets (or having them before migrating). As elsewhere, asset accumulation simultaneously enables greater agricultural intensification and extensification (Walker *et al.* 2002).

Political-economic Factors

Land Tenure

Land title has emerged as a key determinant of land use in South American frontier contexts (Tucker 1999; Cattaneo 2001; Fearnside 2001). Table 7 examines potential relations between land tenure and land use outcomes in the SLNP. It is

Table 6 Assets[a]

Parameter	0			1			2			3		
	Mean	*N*	Percent of Total Sum	Mean	*N*	Percent of Total Sum	Mean	*N*	Percent of Total Sum	Mean	*N*	Percent of Total Sum
Related factors												
No land title	70%	54		73%	89		69%	89		22%	9	
***Duration on the farm (years)**												
Land Use outcomes	7.7	54		9.2	89		9.6	89		14.9	9	
Farm Size (ha)***	27.9	54		32.9	89		39.3	89		50.0	9	
Forest (ha)	18.0	54	65	18.8	89	57	21.0	89	54	30.2	9	60
Cleared land (ha)***	9.9	54	35	14.1	89	43	18.3	89	46	22.2	9	44
Cropland (ha)***	4.6	54	17	5.2	89	16	6.9	89	17	10.8	9	22
Fallow (ha)**	4.0	54	14	7.5	89	23	9.5	89	24	3.6	9	7
Pasture (ha)*	1.1	54	4	1.0	89	3	1.1	89	3	7.2	9	14
Pct of people***			13			19			31			75
Agricultural Inputs***	0.5			0.8			0.9			1.1 9		

[a] Assets are measured such that one point each is assigned to the following items: radio, automobile, chainsaw, and horse

Table 7 Land Tenure

Parameter	Legal Claim to Farm			No Legal Claim		
	Mean	*N*	Percent of Total Sum	Mean	*N*	Percent of Total Sum
Related factors						
Household size	7.1	75		6.2	166	
**Household population density	15.1	75		35.3	166	
Received credit(a)	13%	75		2%	166	
Duration on the farm (years)	12.1	75		7.9	166	
Distance to road (km.)	3.3	75		7.1	166	
Renter	11%	75		28%	166	
***Corn production(b)**	26.88	75		32.1	166	
***Percent who want cattle in 2008**	72%	75		48%	166	
Percent with mostly flat land	65%	75		36%	166	
Land Use outcomes						
Farm Size (ha)***	45.5	75		29.9	166	
Forest (ha)	23.7	75	52%	18.0	166	60%
Cleared land (ha)***	21.8	75	48%	11.9	166	40%
Cropland (ha)***	8.2	75	18%	4.9	166	16%
Fallow (ha)	9.1	75	20%	6.5	166	22%
Pasture (ha)***	3.90	75	9%	0.15	166	1%
Pct of people***			64%			7%
Agricultural Inputs	0.8			0.8		

[a] Received credit is dichotomous; *1* Received credit during the previous 12 months, *0* did not
[b] Corn production equals quintales of corn in previous first harvest per hectare

usually anticipated that farmers with land tenure will have a greater incentive to invest in intensification for sustainable farm production. However, farmers with some level of land title security cleared a greater percentage of their farm and cleared nearly double the total amount of forest than squatter farmers. Results here suggest a host of variables significantly associated with land title to the farm, including household population density, duration on the farm, distance to a road, agricultural production (of maize), and desire for acquiring cattle in the near future. These variables explain approximately half of the relation between the independent variables and whether or not a household has some legal claim to their land or, alternatively, are squatter farmers. With the exception of land in forest and in fallow, all land use variables were significant at the 0.01 level when included in the model with the significant related variables.

As in other frontier environments in Latin America, land tenure greatly facilitated the adoption of cattle (e.g., Almeida 1990; Pichón 1992). Although land title could be leveraged to invest in machinery and chemical inputs to intensify production, it was used more commonly in the SLNP to purchase cattle. Indeed, farmers with land tenure invested in cattle despite the fact that their farms were the most appropriate for developing market crops. Farm families with legal tenure tended to have large farms that were acquired when the frontier was in its infancy. These farmers had the advantage of choosing the best land, and they selected wisely, seizing the plots closest to the road that had good farming characteristics in the form of level land. These processes underscore the importance of understanding the local context of farmer land use decisions and policy implications regarding farm household development and forest conservation.

Ecological Factors

Soil Quality

Soil conditions form the canvas on which farmers will inscribe land use patterns. Modest variations in the natural resource base meant that the independent variables employed here poorly predicted soil quality (Table 8). Household population density and whether or not a household rented land were only modestly significant. Only predominantly flat land on the farm was significant at the 0.05 level. Among land use outcomes only forest cover on the farm was significant at the 0.10 level in relation to soil quality on the farm.

Farmers' perception of a relation between forest abundance and soil fertility (which is true for farming purposes since forests are converted to ash fertilizer, though such a perception says little of the underlying physical and

Table 8 Soil Quality

Parameter	Poor soil			Mediocre soil			Very fertile soil		
	Mean	*N*	%	Mean	*N*	%	Mean	*N*	%
Related factors									
*Household population density	43.0	59		20.4	85		28.1	97	
No land title	80%	59		60%	85		70%	97	
***Percent with mostly flat land**	31%	59		47%	85		52%	97	
Renter	32%	59		24%	85		16%	97	
Land Use outcomes									
Farm Size (ha)	29.0	59		37.5	85		35.9	97	
Forest (ha)*	15.9	59	55	19.1	85	51	22.7	97	63
Cleared land (ha)	13.1	59	45	18.4	85	49	13.1	97	37
Cropland (ha)	5.2	59	18	6.6	85	18	5.7	97	16
Fallow (ha)	6.3	59	22	9.7	85	26	5.8	97	16
Pasture (ha)	0.7	59	2	1.6	85	4	1.5	97	4
Pct of people			17			32			23
Agricultural Inputs	0.7	59		0.9	85		0.8	97	

chemical viability of the soil) is reflected in the data with the highest soil fertility group having nearly 50% more forest cover than the lowest soil fertility group. Some evidence suggests a non-linear association between population density and soil degradation on the farm; the population density on poor soils was almost double that for the mediocre and good soil groups. This relation has been discussed by a host of authors, but few have found a direct relation (Barbier 1990; Zimmerer 1993; Krautkraemer 1994). However, another explanation for this relation is that the group of highest population density was predominantly comprised of renters farming land undesirable to the actual land owners. Indeed, smaller average farm size and less secure land tenure corroborated that many of the farms with poor soil were farmed by land renters (32% compared to 24% for the sample as a whole). Similarly, the data suggest that perhaps some farmers claimed to have good soils, not because they were naturally superior, but because they had improved them through cropping velvet bean.

Lastly, the farms with poor soil were also much less likely to have pasture. This is counterintuitive on the one hand since a sound farm management strategy would have the best soil reserved for crops, the worst for pasture (pasture grass has a higher tolerance for degraded soil than does maize). But, as described above, the farmers who were able to afford cattle appeared to be those who benefited from selecting the best, most accessible (and larger) farms.

Conclusion

It is important for development agencies making policy aimed at conservation and sustainable development in ecologically and economically fragile frontier regions to understand how land use decisions are made and how they interact with the forest ecosystem and farm sustainability. Scores of development agencies have poured billions of dollars into sustainable rural development. Yet on the frontier, where farmer land use has a disproportionately great impact on natural ecosystems and where households are among the poorest of all rural households, relatively few detailed statistically representative samples inform such investments.

Policies to date have focused on intensification techniques, perennial cultivation, and forest harvesting. But labor availability, land tenure, lack of off-farm employment, and poor public education are acute problems in marginalized frontiers. These conditions feed into land use decisions. Sustainable development projects foisted deductively from above on distinct local places may or may not work depending on contextual factors; it is crucial to study each place with a critical lens.

In a perfect world, if farmers had ample land or other resources and alternative options in origin areas, they would never migrate to the MBR in the first place. But in the real world, farmers have already settled en masse inside core conservation zones of the MBR as in other protected areas throughout the tropics. Governments and NGOs need to plan to maximize farmers' well being and minimize farmer impacts on the forest ecology of the reserve. Current land use systems, therefore, must be understood to make them more economically viable and ecologically benign. This research is the first attempt to systematically examine such farming systems with the first large detailed survey of land use and its social, political, demographic, and ecological associated factors in Central America.

Returning to the theoretical discussion and conceptual model (Fig. 2), political, economic, social, demographic, and ecological dynamics shaped farm household decision-making, including land allocation and land use, which in turn led to variable forest conversion patterns. With low labor, capital, and technology available, SLNP farmer land use was extensive, yet even modest variability in these and associated factors led to distinct land use and land cover patterns.

Despite diverse agricultural experiences in origin areas, SLNP colonists uniformly practiced bush fallow, swidden maize production. Farmers differed in land use trajectories through the extent to which they chose to extensify or intensify production vis a vis the use of agricultural inputs, or conversely through land allocation to cattle. Results suggest that even in this emerging frontier, variability in land use could be explained by differences among households in these and other related factors.

Some observations corroborated expectations from the literature on frontier land use; others reflected the importance of understanding the local context to explain apparent theoretical anomalies. For example, larger families with ample labor and greater food demands were associated with extensive land use and deforestation. The largest households managed a more extensive crop rotation and were eight times more likely to have cattle than the smallest households. This relation remained strong despite intervening positive relations among household size, farm size, and duration on the farm. However, age of a household head (a proxy measure for demographic household cycle) was strongly related to household size, supporting the importance of household life cycle effects (McCracken *et al.* 2002; Walker *et al.* 2002). The data support Boserupian population-induced intensification among farms with scarce forest remaining and high population pressure. A strong negative relation emerged between household population density and total land in forest and percentage of land in forest, with farm size emerging as the key predictor (relative to household size). Households of highest population density had shortened fallow rotations, allocating nearly all their land to crops. Households with fewer than several hectares had no fallow land, suggesting that short-term subsistence in the form of crop production was clearly a first priority in the hierarchy of household needs. Households met this need even if it meant spending all the soil nutrient capital of their farms within two years.

Nevertheless, in contradiction to Boserupian expectations, because the densest households were the poorest farmers with little land and insecure land title, population density was negatively related to agricultural intensification in the form of cropping velvet bean or applying herbicides. This highlights the importance of understanding the local context. Farmers most in need of intensifying production were the ones least able to do so. Many of these families were squatters or short-term renters and thus had little incentive to invest in long-term land improvements. Policies should target these farmers first. Policies encouraging and supplying family planning services could quickly reduce fertility in the region given the great latent demand for such services, thus reducing pressures on the forest. But when a farmer has only several hectares of land, and is producing only maize, he will likely clear his whole plot regardless of how many children he has or his labor availability. Technical assistance with the means to viably produce and market perennials and more intensive annual crops would be a welcome intervention. Land titling could encourage more sustainable land use, so long as cattle adoption is discouraged and high-yield market crops are encouraged.

Farmers' desire to convert forest and cropland to pasture is currently enabled by land title, used as collateral for bank loans. Following the lesson of South America, such conditions are ripe for land consolidation among cattle ranchers, increasing the gap between those with large farms and poorer subsistence farmers pushed onto ever-dwindling plots of land of diminished soil quality. These trends have emerged as incipient patterns, even on this recently settled frontier. Such a development augurs poorly for equitable and sustainable rural development and forest conservation, making it imperative that technical land use training designed at increasing yields with modest labor and capital inputs while discouraging cattle adoption accompany land-titling efforts.

Based on the preceding analysis, a limitation on farm size would be featured in an informed policy formulation for sustainable land use in the region. Larger farms were much more likely to have cattle and to manage extensive crop rotations. The impact of cattle ranching on deforestation was enormous, with the small number of cattle ranchers exerting a disproportionate impact on the elimination of the park's forest canopy. If cattle ownership retains migrants, as found in the Ecuadorian Amazon (despite requiring little labor), near-term out-migration from the SLNP may be less than in other frontier regions (Laurian *et al.* 1998; Barbieri and Carr 2005). That most of the SLNP farms remained largely in forest and that fewer than half the respondents claimed to have had contact with a conservation or development agent portend great possibilities for improving the economic yield and sustainability of farming efforts and the conservation of forests on presently settled farms.

Despite an increasing number of studies, mainly in the Amazon, little is known about how human populations interact with the environment along the dynamic penumbra of forest and agriculture, ecology and society. More research is needed to better understand how human processes affect frontier deforestation. Three needs are particularly acute. First, trends need to be examined over time (a great dearth in present knowledge) in order to begin to make reliable causal inferences. Secondly, micro-scale processes need to be linked to meso- and macro-scale trends in order to elucidate nested scales of reciprocal processes in the human-environment frontier. Third, research and subsequent policies must be particularly sensitive to social systems underlying land use decisions, particularly the roles of gender and ethnicity (Carr 2004c).

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