Forest Clearing Among Farm Households in the Maya Biosphere Reserve*

David L. Carr
University of California, Santa Barbara

Central America's tropical forests have been felled more rapidly than those of any other world region during the latter half of the twentieth century. During this time, nearly half of Guatemala's forests were eliminated. Most of this deforestation has been concentrated in the northern department of Petén. The remaining forests in Petén are now mainly concentrated in the Maya Biosphere Reserve (MBR), the heart of the largest lowland tropical forest in Central America. The pace, magnitude, and geography of this trend is of critical importance to forest conservation and rural development efforts. This article examines socioeconomic, political, demographic, and ecological factors behind settler land use and forest clearing among 241 farm households in the Sierra de Lacandón National Park (SLNP), a core conservation zone of the MBR. Some of the factors positively related to forest clearing were household size, Q'eqchí Maya ethnicity, land owned in the previous residence, farm size, land title, and the cropping of velvet bean as a soil amendment. Education, off-farm employment, and farm distance to a road were negatively related to farm-level deforestation. **Key Words: Guatemala, Latin America, deforestation, land use and land cover change (LUCC), agricultural frontier.**

Introduction

Latin America boasts the greatest extent of tropical forests in the world, yet no region lost more tropical forest during the past two decades (FAO 2001). Research on the topic has gained interest in recent years for its importance in environmental change and rural development. Although Central America's forests were eliminated at double the rate of any world region despite a small, and in many cases declining, rural population (FAO 2001), many of these research studies have focused on the Amazon basin countries. An astounding 38 percent of Guatemala's forests were removed between 1966 and 1994, mainly due to the opening of the vast northern department, Petén, to agricultural settlement (Bilsborrow and Carr 2001). Since the southern half of the department has been settled for several decades, the main colonization frontiers available to new land-hungry colonists are found in the Maya Biosphere Reserve (MBR)—the heart of *La Selva Maya* and the largest lowland tropical forest north of the Amazon (see Figure 1).

Millions of dollars were poured into the conservation of these forests annually under the U.S. Agency for International Development (USAID) sponsored Mayarema Project during the 1990s, and over fifty nongovernment organizations (NGOs) participated in a host of projects on sustainable development and forest conservation. Unfortunately, such projects were based on limited information, mainly on existing anecdotal evidence and modest qualitative pilot studies in select communities. The research presented here takes advantage of the first detailed survey—and the largest one to date in Central America—on population and frontier forest clearing in the MBR.

The purpose of this article is to determine the relative strength of relations among socioeconomic, political, demographic, and ecological factors behind settler land use and forest clearing in a core conservation zone of Guatemala's MBR. These factors are examined in the context

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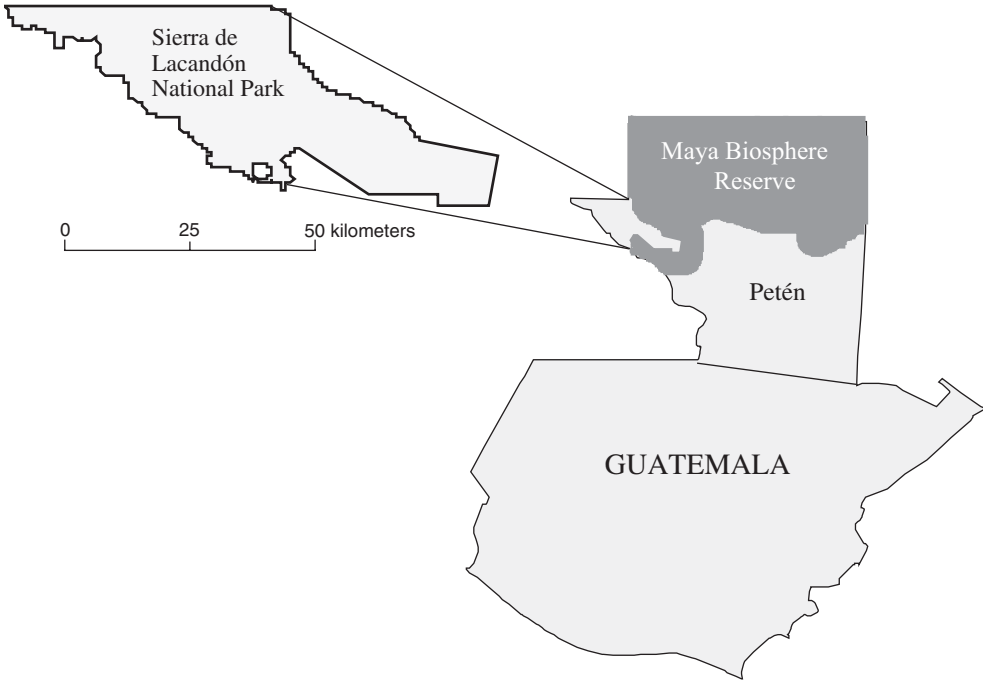

Figure 1 *Reserva de la Biosfera Maya and Sierra de Lacandón National Park.*

of northern Guatemala, where the socioeconomic, ecological, and policy environment differs from regions of previous frontier land use, particularly the Amazon. Since most settlement occurred during the 1990s, this offers a unique opportunity to examine deforestation patterns on a recently emerging frontier. Such an environment differs from most studies on the topic, which were conducted in long-settled agricultural regions, few of which can any longer appropriately be called frontiers. Variability among farmland use is less pronounced in the Sierra de Lacandón National Park (SLNP) than in a longer-settled region because it remains in an incipient stage of settlement. Regression analyses can offer valuable insight into which initial conditions may be leading to inequities among farm households and accompanying trajectories of forest conversion.

The article begins with a discussion of land-use and land-cover change (LUCC) in tropical agricultural frontiers. I then describe the survey site, sample design, and data and provide a description of the sample households, including political, economic, ecological, and demographic characteristics and patterns of land use. The selection of predictor variables is discussed, followed by hypotheses regarding the relations between the selected predictors and land-use outcomes, model specification, and analysis, including an explanation of some of the diagnostics used to assess potential violations of model assumptions and a presentation and interpretation of model results. The article concludes with a discussion of the larger study on frontier migration and land use, of which this analysis is a part, and on the implications of the study for theory, future empirical research, and policy.

A Conceptual Approach to LUCC in Tropical Agricultural Frontiers

Frontier LUCC is not an inevitable outcome. It results from complex processes that require a consideration of proximate and underlying dynamics (Carr 2004c). The expansion of farmland along agricultural frontiers represents the proximate cause of most deforestation in the

Latin American tropics (Geist and Lambdin 2001; United Nations 2001; Achard et al. 2002).[1] Settler farmers are a key part of this process. Some scholars assert that they are responsible for most of the forest conversion on the planet since they are usually the agents of the first wave of forest clearing of primary forests in frontier "hot spots" before lands are consolidated in the hands of large plantation and ranch owners (Myers 1991; Houghton 1994). Although there is considerable variability in initial conditions and in farmer characteristics across Latin America, frontier settlers tend to share several characteristics crucial to understanding proximate drivers of forest conversion. Settler farmers in remote, population-scarce regions invest intensively in labor and extensively in natural resources. Ample land, but scarce labor and capital assets, form conditions favoring swidden, or slash-and-burn, agriculture (Pichón 1997). Remote access to markets and technology and scant assistance from development agencies mire frontier households in an environment of marginality in regard to access to produce, capital, labor markets, and secure land titling. Farmers under such conditions simply do what is logical for maximizing the resources at their disposition. They intensively use what they have—abundant natural resources—while making do with modest capital, labor, and technology inputs. This leads directly to a slash-and-burn farming system where crop production is maintained over time by safeguarding soil fertility through frequent forest felling and burning to add rich ash nutrients to impoverished soils.

The contemporary LUCC literature features several models of tropical deforestation, none crafted in detail for the specific phenomenon of LUCC following frontier agricultural settlement in the Latin American tropics. Given the disproportionate share of the world's forest clearing attributed to this phenomenon, I have built on previous frameworks (e.g., Turner, Moss, and Skole 1993; Ojima, Galvin, and Turner 1994; Kaimowitz and Angelsen 1998; Contreras-Hermosillo 2000), and, more recently, Geist and Lambdin's (2001) model, to conceptualize the proximate determinants of settler-farmer LUCC in Latin American agricultural frontier environments.

Households migrate to the frontier following the exhaustion of other available alternatives. Frontier farming is therefore not a fait accompli; households make decisions based on available options that enable or constrain their decisions. Once a farm household has settled on the frontier, variables affecting forest conversion on frontier farms can be subsumed under four major categories: demographic, political-economic, socioeconomic, and ecological (for a more in-depth discussion, see Carr 2002). The suite of variables within these categories enables and constrains household decision making regarding economic and demographic outcomes. Economic decisions include land, capital, and labor investment allocation, including land-use allocation, investment in technologies and agricultural inputs, and on-and-off farm labor investments. Demographic decisions may include regulation of household size as well as temporary and permanent migration (Amelung and Diehl 1992; Barbieri and Carr forthcoming). The relative influence of these variables on household responses will vary from place to place, depending on natural resource endowments and characteristics and on variation in social and economic geographies, including proximity to market and vicissitudes in market prices, access to health care, education, and cultural mores.

Based on farm level evidence collected in the MBR, this article explores differences in land-use and forest conversion patterns across households, given farm natural resource characteristics, the policy environment, and household demographic and socioeconomic factors. Land-use decisions are made within the contexts of (1) other available economic, demographic choices for maximizing household well-being and (2) the distinct political-economic, social, demographic, and ecological realities influencing household decisions from multiple scales. The results of this analysis are crucial not only for improving understanding the determinants of deforestation in most of Latin America; they also indicate remedies to improve farmers' livelihoods.

Research Site, Sample Design, and Data

The Sierra de Lacandón National Park (SLNP) was established in 1990 as one of four core zones (areas of strict conservation) within the MBR.

The SLNP boasts the richest biodiversity in the *Selva Maya* (The Nature Conservancy 1997), yet suffers from rapid population growth and agricultural expansion. In the 1990s, more than 3,000 farm families settled the region, resulting in destruction of over 10 percent of its forest canopy (Carr 2000; Sader et al. 2000). Throughout the MBR, scant technical assistance, credit, or market-oriented strategies did little to promote conservationist agricultural management among farmers. In order to relieve human pressures on the reserve's forests during the 1990s, the Guatemalan government, USAID, and European donor agencies collaborated on sustainable development projects, mainly in the buffer zones of the Reserve. By that time, the buffer zone had largely been altered by human intervention. Meanwhile, the Reserve's core conservation zones were being impacted by recent agricultural settlements. Efforts to minimize human impacts in the core zones of protected areas were modest, and illegal squatter settlements, ineligible for government development aid, sprung up pell-mell.

The farmers of the MBR frontier suffer from unfavorable market conditions, a dearth of technology, lack of labor and alternative farm management strategies, and few employment possibilities. The most desired resource available to these farmers is an abundance of land (Carr forthcoming a). How households make decisions on land use will result from a consideration of resource allocation based on labor availability, land quality, and the security of farm ownership (see, e.g., Pichón 1996).

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 studies. These are usually conducted at the macro scale, where complex causal operating processes are concealed by data aggregation, or at the micro scale, where true frontier research is rare and is commonly a misnomer for postfrontier environments.

The core zone of the SLNP was the study site for a survey conducted in 1998 (Carr 2000, 2003), and a follow-up in the fall of 1999 provided supplementary information. A detailed description of the survey is explicated in Carr (2002 and 2003). I will briefly mention several central aspects of the survey. With the exception of cooperative farmers in two communities and a cluster of farmers with private land in one community, the farmers with agricultural fields in the twenty-eight communities within the park are squatters who followed newly opened roads to settle the vast public lands of the Reserve. A probability sample of approximately 10 percent of the SLNP settler households was achieved. For the purpose of this analysis, a community of returned refugees—an anomaly in the park—is excluded, paring the original sample of 279 to 241 heads of household.

Description of the Sample

Colonists came from diverse rural regions of Guatemala; the southeast region and Petén represent the regions of highest out-migration. Rapid migration followed the completion of a road from Flores to El Naranjo in the mid-1980s. Virtually all settlers hailed from rural environments, yet only a third enjoyed access to land for farming in their previous residence. Household size ranged widely, from two to sixteen members. Given the young age of the household heads, the large number of children suggests that fertility is notably higher than in other rural regions of Guatemala, the nation with the highest rural fertility in Latin America (DHS 1998). The mean household size of 6.5 persons per household exceeded the national mean (5.3), the national rural mean (5.6), and Petén's average of 5.7 (Instituto Nacional de Estadistica 1999; Sutherland, Carr, and Curtis 2004). At almost nine persons per *caballeria* (45 ha), the household population density (measured as household members per caballeria of land occupied by the household) exceeds what local farmers would consider the region's carrying capacity. The male-weighted sex ratio in the SLNP (129 men per 100 women) is reminiscent of the early colonization of the Brazilian Amazon in the 1960s and 1970s (Martine 1981). As in the Brazilian case, men often settle first in the SLNP, followed by their spouses and young children after secure settlement has been established.

Nearly 70 percent of the sample were homesteaders squatting illegally on parkland or households renting land (usually on a squatter's farm). Only a handful (5 percent) had received credit from a lending agency, mostly for purchasing cattle. Fewer than half the respondents

claimed to have had contact with a conservation or development agent.

Three-quarters of the household heads were Ladinos. Of the remaining households, slightly more than half were Q'eqchí Maya, the rest pertaining to various Maya groups. Most households had remained poor following settlement in the region. The average household had little more than a room, a palm leaf roof, walls of sticks, and dirt floors. In a measure of some basic assets (including radio, automobile, chainsaw, horse/burro, and automobile), the average number of assets per family was one. Usually a radio was the sole item owned. Another source of income, in addition to selling maize or renting out chainsaws or animals, was working on neighboring farms for a modest daily wage. Almost half of the household heads had worked as wage laborers at least once during the year previous to data collection, usually during times of great labor demand such as harvest season. Educational achievement was another socioeconomic indicator where the sample was at a clear disadvantage relative to other regions of the country. None of the household members had an education beyond primary school. This education level was below the national average, where almost half the population had finished primary school (Instituto Nacional de Estadistica 1999).

Farm plots generally shared a chemically viable karstic base with erratic drainage on flat to slightly hilly slopes. Forty percent of the informants claimed that their soil was highly fertile; only a quarter complained that they endured poor soils, the remainder having average soils.

Most households have large farms, usually 30–45 ha, that were cleared for sowing maize and, in some cases, pasture grass. Approximately one-quarter of the households in the region consisted of small farms of several hectares. Such households generally rented land near the road in order to have access to the market and services.

Most farms had 4–8 ha of maize—which was sometimes supplemented by *frijól* (black beans) or *pepitoria* (a type of squash)—and approximately the same amount in fallow land. One-quarter of the households (all nonrenters and many with some degree of legal claim to their farm) owned some cattle, typically no more than a few head. Most farmers, save for the small plots of renters, had yet to complete their crop rotations since they had only settled their farm plot during the past several years.

Some inexpensive forms of intensification have emerged here. Approximately half the households cropped maize with velvet bean or used some type of herbicide. The use of velvet bean allows the compression of fallow rotations, and the application of herbicides facilitates cropping in successive years (see, e.g., Mausolff and Ferber 1995; Shriar 2001); therefore, these forms of intensification are expected to be negatively related to land in fallow. However, it is possible that agricultural intensification may ultimately promote extensification since producing more on less land can free up land for cattle expansion (Zweifler, Gold, and Thomas 1994).

Following this introduction of social, demographic, and ecological characteristics of the sample and the natural resource base, the following section examines interrelations between farmland use allocations and some of the household and farm characteristics described above. First, the selection of variables and hypotheses are developed. Second, the model design is explained for the regression model. Following the model design, results are discussed.

Selection of Variables and Hypotheses

The hypothesized relations between the predictor variables and forest conversion by settler households are summarized in Table 1. A plus or minus sign is assigned to indicate the anticipated direction of the relation between the predictors and farm-level forest clearing. Each suite of factors is described in this section. Given the relatively great level of homogeneity in land use among settlers, there are two primary land uses in which farmers' impact on forest clearing may vary: (1) through the cropping of velvet bean (*Mucuna Pruriens*) and (2) through the adoption of cattle. Swidden maize farming in the region usually consists of a four-field system, with two years of cropping one field and six years of fallow on the other three fields. This rotation can be extended to six or more fields if land is sufficient and farmers wish to expand cleared land for introducing pasture. It can also be shortened

Table 1 *Expected Associations of Predictors to Land Use*

Predictors	Forest Cleared	Crops and Fallow
Demographics factors		
Household size	+	+
Political-economic factors		
Contact with an NGO	–	–
No land title	+	+
Socioeconomic factors		
Household socio-economic characteristics		
Ethnicity	?	?
Educational Achievement	?	?
Land in Previous Residence	+	+
Chainsaw Ownership	+	+
Off-farm Labor	–	–
Rents Land	–	–
Farm and farming characteristics		
Farm Size	+	+
Farm Distance to Road	–	+
Duration on the Farm	+	+
Additional Agricultural Fields	+	+
Ecological factors		
Flat Land	–	–
Soil Quality	+	+

to a three-field rotation if available forest becomes scarce. The alternative practice is the use of a two-field rotation for the first harvest crop of maize enabled by cropping velvet bean, which enhances soil nitrogen content. The other primary way farmers could variably impact forest clearing is through the adoption of cattle. Cattle demand 1 ha of grazing land per head. Thus, even a small number of cattle will greatly increase the amount of land put in production.

The outcome variables used in this analysis (total cleared land and land used for crop production) capture the variance in these different farming systems. Differences in crop intensification are examined in the model showing land cleared for crops and fallow. With duration on the farm as a control variable, the analysis should adequately differentiate among levels of fallow intensification, irrespective of how long the land has been farmed. Any differences in the model between crop production and total land cleared can be attributed to cattle, the only land use other than crops. An extended discussion of the hypotheses relating independent variables to land use outcomes is found in Carr (2002). Following a review of the literature and based on knowledge of the study site, the hypotheses are summarized in Table 1.

Model Design and Results

The models of forest clearing and crop/fallow land use presented are standard multiple regressions (MR). The results of MR yield an equation that represents the best prediction for a dependent variable (DV) from a set of continuous or dichotomous independent variables (IVs). The equation takes the general form:

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

where Y is the DV, A is the intercept, the Xs are the IVs, and the Bs are the coefficients assigned to each predictor during the regression. The purpose of regression analysis is to demonstrate relations among variables, but such relations do not indicate causality. For the specific DVs analyzed, the equation takes the forms:

$$Y_{forest\_cleared} = A + B_1X_1 + B_1X_1 + \cdots B_kX_k$$

and

$$Y_{crops\_fallow} = A + B_1X_1 + B_1X_1 + \cdots B_kX_k,$$

where each Y is the number of hectares of forest cleared at the farm level in Model 1 and the land dedicated to crops and fallow in Model 2, A is the intercept for each dependent variable, the Xs are the IVs for each DV, and the Bs are the coefficients assigned to each IV.

Each IV was evaluated relative to its contribution to the models after all the other IVs were entered. Thus, each IV is assessed by what it adds to the prediction of the DVs, that is, different from, or "over and above," the predictability provided by all other IVs. It is therefore possible for a variable to appear unimportant in the model when it is actually highly correlated with the DV. The sample size of 241 households exceeds the minimum requirements for testing relations between the seventeen predictors and the outcome variable of cleared land (Green 1991).

The final models are shown in Table 2. The final adjusted R^2 values of 0.56 for forest cleared on the farm and 0.49 for land in crops and fallow indicate a good association between the dependent variables and the predictor variables. I will now summarize results for the model and consider the relations between predictors and forest conversion for (a) fallow and crops and for (b) fallow, crops, and pasture.

Table 2 *Regression Results for Hectares of Forest Cleared and Land in Crops and Fallow*

Independent Variables	Cleared Forest on the Farm			Land in Crops and Fallow		
	Adjusted R^2 0.56			Adjusted R^2 0.49		
	Unstandardized Beta	St. Beta	Sig.	Unstandardized Beta	St. Beta	Sig.
(Constant)	4.50		0.25	3.96		0.17
Demographics factors						
Household size	0.48	0.12	0.01**	0.48	0.13	0.01**
Political-economic factors						
Contact with NGO or GO	−1.07	−0.04	0.37	−0.77	−0.03	0.49
No Land Title	−3.01	−0.11	0.05*	0.44	0.02	0.76
Socioeconomic factors						
Household socio-economic characteristics						
Ethnicity	2.99	0.10	0.03*	3.10	0.12	0.01*
Educational Achievement	−2.47	−0.10	0.04*	−2.58	−0.12	0.02*
Land in Previous Residence	0.21	0.12	0.01**	0.23	0.16	0.00**
Chainsaw Ownership	−4.77	−0.10	0.04*	−6.16	−0.15	0.00**
Off-farm Labor	−3.02	−0.12	0.01**	−2.35	−0.11	0.03*
Rents Land	−4.46	−0.15	0.01**	−5.55	−0.21	0.00**
Farm and farming characteristics						
Farm Size	0.26	0.47	0.00**	0.21	0.42	0.00**
Farm Distance to Road	−0.45	−0.18	0.01**	−0.46	−0.21	0.00**
Duration on the Farm	1.91	0.08	0.11	2.14	0.10	0.06
Additional Agricultural Fields	4.00	0.12	0.01**	4.80	0.16	0.00**
Velvet Bean	3.03	0.12	0.01**	2.96	0.13	0.01**
Ecological factors						
Flat Land	−0.83	−0.03	0.51	−0.27	−0.01	0.82
Soil Quality	−1.41	−0.06	0.25	−0.96	−0.04	0.40
	n = 241					

** Significant at the .05 level*
*** Significant at the .01 level*

Demographic Factors

Demographic processes are exceptionally dynamic in frontier settings and are intimately linked to land use and forest conversion patterns (Carr 2004b). While migration is responsible for most of the population growth in expanding frontiers, in this survey of frontier settlers, the impact of migration on land use is not measurable in a regression model; that they are in the sample at all represents a 100 percent correlation between migration and land use! Nevertheless, as is typical of other recently settled frontiers in Latin America, fertility remains extremely high in the PNSL, and family size has been linked to extensive land use in other similar environments in Central and South America (Pichón 1997; Rosero-Bixby and Palloni 1998).

Household size had a significant positive association, as hypothesized, with land extensification. The addition of one household member was associated with nearly one-half hectare more land cleared for agricultural purposes. This offers support for the argument that more household members stimulate greater demand for crops for household consumption and/or for sale to market.

Political-Economic Factors

Institutional and macroeconomic factors have been cited widely in the literature as key processes driving tropical deforestation or, conversely, forest conservation (Geist and Lambdin 2001; Barbier 2004). Yet, few studies have measured how these processes affect farmer land use at the household level where farmland-use decisions are made. Contact with an NGO or other development organization was expected to be associated with less forest cleared, less land in fallow, less land in crops, and more land in forest—assuming such contact was with conservation organizations. However, this variable was insignificant in both models. This is not a sanguine result for the effects of conservation efforts in the region. I speculate, instead, that this relation could be capturing the effect that a greater proportion of farmers with cattle have visited credit-lending agencies (often to receive

loans for purchasing cattle). In addition, this contact may have involved other nonconservation organizations, such as agricultural development agencies.[2]

Much of the rural land-use literature agrees that land titling leads to a more sustainable land management, while lack of land title encourages a more myopic "land mining" of forest and soil resources (Southgate 1990; Barbier 2004). Yet in the SLNP, lacking legal claim to the farm was associated with less land cleared (more than 3 ha less) and less land in crops (more than 2 ha less). Some legal claim to the farm, however tenuous, meant a much greater likelihood of having pasture (Carr 2004a).[3] Land title enables credit for purchasing cattle and is associated with more established, wealthier households. These links are unsurprising, having emerged in the case study literature on South American LUCC (Fujisaka et al. 1996; Jokisch and Lair 2002) where the vast majority of agricultural land is in pasture (Carr and Bilsborrow 2001).

It was unexpected that the relation would be negative in relation to land in crops since squatter farmers were considered more likely to have a greater proportion of land in crops relative to pasture. Apparently, this variable is capturing some of the effect of renters, none of whom have land titles and most of whom have very little land to extensify holdings.

Socioeconomic Factors

Household socioeconomic characteristics Research in agricultural frontiers in South America suggests that socioeconomic and individual characteristics are important variables relating to land use, deforestation, and economic well-being (Brondizio et al. 2002; Pan et al. forthcoming). Few studies, however, have examined the role of different ethnic groups in relation to land use (for some exceptions see, e.g., Atran 1993; Steinberg 1998). Ethnicity was positively associated with forest clearing. Farmers of Maya ethnicity cleared nearly 3 ha more forest than others. This offers tentative support for the notion that indigenous peoples are more expansive farmers than their Ladino neighbors. However, prior work indicated only slight differences between Q'eqchí and Ladino land use when duration on the farm was taken into account (Carr 2004a). This implies that non-Q'eqchí Maya may be the most land extensive of the three dominant groups in the SLNP (Ladino, Q'eqchí, and other Maya) and suggests the importance of examining differences in land use among indigenous groups rather than combining them into one category.

The educational achievement of the head of household was negatively related to agricultural extensification (total land cleared and percent land cleared). Households whose head had attended school at some point had approximately 2.5 ha less land cleared for crop production and total land cleared on the farm. This means there was no difference in land in pasture between these two groups, but rather that there was quite a large difference in crop production intensification. This contradicts the argument that education stimulates consumption aspirations and the motivation and ability to increase production (Moran 1984; Pichón 1997; Godoy, Groff, and O'Neill 1998). It supports the notion that some minimum level of education promotes agricultural intensification, perhaps by way of sufficient literacy to increase the likelihood of adoption of intensification techniques. While this association could be thought to reflect that those with more education are more likely to engage in off-farm activities, this is already controlled by the inclusion of off-farm work in the model. Moreover, it is unlikely since 97 percent of the farmers worked primarily in agriculture.

Having access to land to farm in the previous residence was associated with greater levels of extensification, corroborating the importance of land-use experience prior to migration (e.g., Almeida 1992). The positive association of access to land to farm in the previous residence with fallow land may be suggestive of farmers that came from previous frontier environments where land was sufficiently abundant for a "bush fallow" crop rotation. Future research could include this as a dummy variable in the model.

Chainsaw ownership, counterintuitively, was related to less land cleared on the farm, and even less land cleared in crops. With approximately six fewer hectares in crops, chainsaw owners had approximately half the amount of land in crop production as the sample mean. Evidently, with only eighteen of the farmers in the sample owning a chainsaw, a great demand existed for their services. These household heads were investing much of their time renting their services to clear forest on others' farms, taking away time they would spend farming their own cropland. This finding illustrates the importance of place and

the need to couple survey research with in-depth, exploratory qualitative research in order to understand statistically significant relations emerging in quantitative analyses.

As hypothesized, off-farm labor was negatively associated with forest clearing and land in crop production. Only two variables in the cleared-land model had higher Beta values: (1) renting land and (2) farm distance to road. Households with heads participating in off-farm labor at some time during the year (usually a couple of weeks, total) reduced the amount of land cleared on the farm by 3 ha. This supports the theory that household heads that work off the farm have less time to invest labor in agricultural production on their own farms (e.g., Murphy, Bilsborrow, and Pichón 1997).

Renting land was negatively associated with cleared land and land cleared for crop production. Renters used 5.5 ha less land in their crop production rotation. In the case of a small farmer, often an itinerant renter, fallow land was superfluous if the farmer intended to work a plot for only a year or two.

Farm characteristics Size of total holdings was, as expected, the strongest predictor of land use. This finding corroborates previous studies in frontier regions where land is a relatively abundant resource (e.g., Pichón 1997). Size of total holdings had approximately three times the effect of any other variable in the cleared land and percent cleared models, based on the Beta coefficients, which reflect the actual variance across each variable. The larger the farm, the more land that may be cleared for crops and that may be maintained in fallow and in forest, but the lower the percentage of the farm that is cleared. Thus, for each additional hectare of farmland, farmers cleared one-quarter hectare of forest.

Farm distance to road was negatively associated with cleared land and land cleared for crop production. Farmers cleared nearly one-half hectare less per kilometer of distance to the road. Farm distance to road had the second largest effect after size of total holdings on farmland cleared, although in opposing effects (size of total holdings was positive; farm distance to road was negative). This is consistent with results found in frontier environments in South America (e.g., Pan et al. forthcoming). The association is also negative with land in fallow, which was expected. Farmers located further from the road may be less market oriented and may have been on the farm less time than farmers closer to the road. Hence, they have had less time to clear the forest on their farm.

Additional agricultural fields were positively related to cleared land and land cleared for crop production. Occupying additional agricultural fields increased cleared land by more than 4 ha (with most being in crops). This supports the theory that ownership of an additional field implies a desire to expand crop production.

Unexpectedly, duration on the farm was insignificantly related to the land-use outcomes. While there was clearly a direct positive association between duration and land clearing in a bivariate relation, it appears that other variables, notably distance to road, reduced the significance of the association.

The use of velvet bean was positively associated with agricultural extensification. These results contradict expectations. However, as mentioned previously, agricultural intensification may ultimately promote extensification by allowing more land to be sown in pasture while minimizing the contraction of grain production below a minimally desired threshold for household consumption. The possibility that longer farming duration led to soil decline and thus increased the use of velvet bean cannot be determined from the data.

Ecological Factors

While environmental change has been modeled as an outcome variable in scores of studies from frontier environments, fewer studies have examined the effect of ecological change on land use and land cover outcomes. The two measures of ecological conditions measured here were insignificant in the models. Flat land and soil fertility were not significantly related to either outcome variables at the 0.05 level and therefore failed to meet the expectation that they would be associated with agricultural extensification. The lack of variability (yet) in ecological conditions among the farms in the sample precludes the emergence of statistically significant associations. With abundant forestland remaining on most farms, soil depletion is not yet an issue either since good yields can usually be obtained on new plots of recently cleared land. Similarly, land abundance allowed farmers to avoid crop-

ping on slopes that were so steep as to cause substantial erosion.

Conclusion

This examination of frontier land use addressed demographic, political, social, economic, and ecological factors associated with farm-level land use and agricultural expansion along a forest frontier in a core conservation zone of the MBR. Data were collected from 241 heads of household in eight communities in the SLNP. Farmers cleared forest primarily for subsistence maize farming and, increasingly, for pasture creation and expansion. Demographic, political-economic, socioeconomic, and ecological factors were examined in relation to land use and forest conversion on these frontier farms.

Cleared land on the farm was positively related to household size, ethnicity, having land in the previous residence, size of farm holdings, having additional agricultural fields, and use of velvet bean and/or herbicides. Cleared land was negatively associated with lack of land title, having any formal education, off-farm labor, renting land, and distance to road. For land in crops and fallow, the direction and significance level of the relations remained the same except for the associations with land title. While owning land title enabled the purchase of cattle, it did not appear to affect how farmers managed their crop production.

This research is part of a larger project examining the proximate and underlying causes of deforestation in the MBR. Preliminary research from origin areas of migrants to the MBR indicates that larger households, Q'eqchí Maya, land-poor and landless households, households with unsustainably small or environmentally degraded farms, households with penurious access to markets, the least educated, and the extraordinarily poor are at the greatest risk for migration to the MBR (Carr 2002). The factors involved in farmer land use on the frontier consist of proximate causes of frontier deforestation. To understand a necessary underlying cause of frontier deforestation, research must also probe the basic reasons for settlers to migrate to the frontier. In addition to conducting research on migration to the frontier—a key understudied driver of global deforestation—future analyses on proximate causes could be enhanced by incorporating a statistical methodology that explicitly takes the interrelations between forms of land as trade-offs into account, as well as the effect of community context on farmer land use within a multilevel model. Such research has rich rural development and conservation policy implications. Better-informed investigations on this topic are crucial for improving our still modest understanding of small farmer agricultural expansion along newly settled forest frontiers, a key process implicated in most of the deforestation in the humid tropics of Latin America, and possibly the world. ■

Notes

[1] Estimates of the share of global deforestation attributed to shifting cultivators range from 45 percent (United Nations Environment Program 1992) and 60 percent (World Bank 1991; Myers 1992) to 79 percent (Amelung and Diehl 1992).

[2] In retrospect it would have been valuable to disaggregate conservation and other development organizations in the survey instrument.

[3] Nevertheless, Carr (forthcoming b) finds that farmers in the region belonging to agricultural cooperatives had less land in pasture than farmers with private landholdings.

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DAVID CARR is an Assistant Professor in the Department of Geography at the University of California, Santa Barbara, CA 93106. E-mail: carr@geog.ucsb.edu. His research interests include population-environment interactions, fertility, migration, and deforestation in Latin America.