Land succession and intensification in the agricultural frontier: Sierra del Lacandón National Park, Guatemala

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Introduction

Figure 1: Map of the study area

Humans have long been implicated in causing deforestation, with agency ascribed to a variety of sources. In the frontier forests of the tropics deforestation is of particular concern because of high biodiversity and ecosystem services contained in these areas, the elimination of which may have dramatic effects across a wide range of physical systems (e.g. local to global climate change) as well as social systems (e.g. elimination of a natural resource base for productive use). In these frontier environments migrant farmers seeking cultivable plots are often viewed as the primary proximate agents of deforestation (Rudel & Roper 1996; Geist & Lambin 2001).

Although population growth is positively associated with agricultural expansion in Latin America (e.g., Bilsborrow & Geores 1994; Perz & Walker 2002; Barbier 2004) the scale of analysis at which the phenomena is examined can conceal or be revelatory of the mechanism by which population increase does (or does not) lead to deforestation. Brute population growth alone does not necessarily lead to increased deforestation, for the interaction of these populations with their environment is mediated by technology, markets, physical and structural constraints, and agricultural policies, among other influences. Examinations from the national-level in many Latin American countries typically reveal that overall rural populations have declined while, counter-intuitively, deforestation has persisted and even in some instances accelerated (Carr et al. 2006). Most household farm-level deforestation, however, is taking place in the regions' frontier areas, the destination of only a small subset of migrants, often the poorest and most marginal.

This study takes both a household and a land parcel perspective, employing a multiphasic model perspective for a household level analysis of *in situ* land use. As Shriar (2002) points out, the rational for focusing conservation research on the level of the land user comes from the experience gained demonstrating that the most effective method for identifying the least uncertain policy leverage points comes from research conducted at the level of the land user. Understanding at the level of the households and their land management decisions, therefore, carries both the possibilities of ameliorating rural poverty as well as promoting conservation (Pan et al. 2007).

We propose a land use case study of frontier farmers in the Sierra del Lacandón National Park (SLNP), in the northernmost *departamento* (similar to a state) of Petén in Guatemala. This is an area where the agricultural frontier has expanded progressively into lowland tropical forest (Sader et al. 1997). In-migration of small-scale agriculturalists and cropping done by the same are the direct agents of deforestation in this area of high biodiversity.

This case study was conducted in the same frontier communities within which López-Carr collected his 1998 community and household datasets for his dissertation work creating household models of land use/cover change (LUCC) (Carr 2002). As such, this research adds value to that conducted by López-Carr in creating a panel survey in the agricultural frontier (instances of which remain rare, especially in Mesoamerica), and in its examination of the changes in land management that take place in an agricultural area as mounting population pressure limits the possibilities for both new, would-be colonists and the offspring of already established colonists to encounter sufficient agricultural lands.

In the intervening 10 year period since López-Carr's study, high levels of continued in-migration and natural increase have continued to be associated with deforestation (Suter & López-Carr 2010) and the frontier has effectively become closed (i.e., without potential for further expansion in the immediate area). Most communities abut one another, while those communities which do find themselves surrounded by forests are not permitted to expand their footprint further by the co-administration of the protected area, the non-governmental organization (NGO) *Fundación de los Defensores de la Naturaleza* (hereinto referred to as Defensores) and the Guatemalan Council of Protected Areas (CONAP, *Consejo Nacional de Areas Protegidas in Spanish*).

Where will new households settle, and how will their presence impact land cover in the area? More specifically: given mounting population pressure on the finite resource of cultivable land, what will be the succession of land "ownership" between 1998 and 2008; what changes in land cover will we witness in comparison to the baseline year of 1998; what do these land covers say about the intensity of land use by farming populations (i.e. do they show an increase in the intensity of land use and thus exhibit a Boserupian-type response to population pressure); and how do the possible responses to population pressure combine with contextual factors to influence land use outcomes? These questions will be examined by drawing upon the multiphasic response theory (Bilsborrow 1987; Bilsborrow & Okoth-Ogendo 1992; Carr et al. 2009; Davis & Lopez-Carr 2010).

Theoretical framework: the multiphasic model

We borrow on Bilsborrow's "multiphasic response" conceptual model treating the rural response to increased population pressure, itself derived from an earlier, exclusively demographic, response proposed by the Berkeley demographer Kingsley Davis (1963). Davis problematized the tendency towards oversimplification in studying rural responses to threats to their living standards via population increase, and the tendency to investigate only a single hypothesis at a time, such as only contraceptive use or only a delay in marriage (Davis 1963). Davis called for a more complex conceptualization of the responses to demographic change since they are, he argued, both reflexive and behavioral. In this way Davis situates any one response within a suite of possible responses, and recognizes that the contextual circumstances would alter the nature of the responses exhibited.

Bilsborrow (1987) augmented this theory from the purely demographic framework, which assumed fixed land area and technology, and expanded it to include economic responses as well. In addition to the possibility of allowing an increase in the cultivated area, he challenged the Ricardian-Malthusian assumption of constant technology to include a more Boserupian response of increasing intensiveness of farming (Boserup 1965). In her turn, however, Boserup had left out the possibility of a demographic response, so this new, more integrative conceptualization of the response to rising population density was comprised of three possibilities: (1) demographic (decreases in fertility arising from whatever source, such as increased celibacy or use of contraception, (2) economic (such as increases in land under cultivation or substitution of more productive crops in already cultivated areas), and (3) demographic-economic (migration, whether it be permanent or seasonal, or rural-rural, rural-urban, or rural-international) (Bilsborrow 1987). Bilsborrow and Okoth Ogendo (1992) furthered the approach for application to population driven land use in developing countries by elaborating concurrent or cumulative phases of response to population growth in the following order: 1. Tenurial, 2. Extensification, 3. Technological (intensification), and 4. Demographic. More on the application of these to the SLNP case study is described in (Suter & López-Carr 2010).

We use the multiphasic response conceptual framework because of its aptness to the situation (i.e. population density in the area has increased since the 1998 interviews). We felt that the four phases it examines are of critical importance in this frontier environment and could have strong impact on changes seen in the area over time. Further, it allows for an emphasis on land use change, while different human-environment frameworks such as the livelihood framework do not explicitly address this. Lastly, we wanted to have data comparable to that gathered in the Northern Ecuadorian Amazon (NEA) by research teams from the Caroline Population Center in 1990 and 1999 (Pan et al. 2004; Barbieri et al. 2005). We modeled our own research after that conducted in the NEA since it is an agricultural frontier similar to our site in the SLNP. The suite of variables they gathered from interviewees derives from the multiphasic response framework. In the future we would like to draw comparisons between the patterns and processes of population growth and land cover change taking place in theses two areas.

The substantive findings of this paper will focus primarily on conclusions gathered from examining two aspects of the multiphasic model, the technological phase and the tenurial phase. We modeled these outcomes as a function of other possible multiphasic responses, as well as other household variables with theoretical importance for influencing change in land cover and/or ownership, such as the household lifecycle theory (Perz 2001; Walker et al. 2002; Barbieri et al. 2005) . Full model details can be found in Suter (2012).

The technological model is addressed with land use models capturing change between 1998 and 2009 in the categories of land covers in the households which have remained in the park since their 1998 interview and who Dr. Suter interviewed again in 2009. The changes in these categories of land covers are modeled as a function of the demographic, political-economic, socio-economic, and geographical/ecological factors of the 1998 household, plus alternative responses germane to the multiphasic framework, such as the use of agricultural inputs. The change in each category of land use is interpreted for its implications in terms of intensity of farm use. These changes are modeled as a function of baseline characteristics and as a function of salient characteristics taken in 2009.

We modeled the tenurial response using model predicting farm sales, that is whether or not a non-rental farm belonging to a household sampled in 1998 sold none or some/all of their land by 2009, based primarily on the characteristics captured in the surveys administered in 1998. This allows a modeling of which farms were “at risk” for land sales based on the land and household characteristics collected in 1998. For example, an original colonizer who claimed a *caballería* of land (45 Ha., the standard claim back when land was free or practically free for the taking) may have sold half of his land to two incoming families before the original household was re-interviewed in 1998, perhaps to pay medical bills or cover some other debt. Therefore the parcels identified in 1998 in many cases now support more households instead of the one household it supported in 1998. We hypothesize that baseline characteristics of the farm and farmer from the 1998 sample will influence land sales, which in turn will influence land use and cover (Pan et al. 2004).

Background of the study site

Land use and migration in Guatemala

If one were to take a snap-shot of the locations of frontier deforestation in Guatemala (mostly in the buffer zones of the mega-conservation complex, the Maya Biosphere Reserve), one would see the majority of this deforestation taking place at the hands of small-scale subsistence farmers. This is in contrast to frontier areas of the Amazon, where one witnesses both the small-scale subsistence producer and the large-scale agro-business as agents of frontier land conversion (Fearnside 2001; Hecht 2005).

For this reason, the most facile explanation for frontier deforestation in Guatemala is the slash and burn agriculture of peasant farmers, characterized as an ecologically inappropriate farming technique which soon exhausts the marginal soils, leading to a repeated cycle of frontier deforestation and degradation (Sundberg 1998). However, if one were to take the snap-shot view of all the agricultural areas in Guatemala, one would not see the arable land-surface dominated by subsistence production, but instead by large-scale pasture and export fruit and vegetable production. According to the Guatemalan Agricultural Census, in 2003 90% of the farms in Guatemala shared just 20% of the total land area, while the remaining 10% of the farms comprise 80% of the land (INE 2004). This inequality perhaps would not be so dire in a non-agrarian society, but as of 2010, 51% of the Guatemalan population is rural (Central Intelligence Agency 2010).

Migration to the Petén began in earnest during the civil war, as a government encouraged escape-valve for the lack of land reform, but also spontaneously to escape the violence and to take advantage of the available land. Migration continues to this day, though there is little land technically still considered available for grabbing (Margoluis 2004). The cheapness and abundance of land in the region attracted subsistence migrants, but likewise these characteristics (in combination with their high biodiversity) also attracted the attention of internationally backed conservation organizations, who provide an estimated 90% of the funding for these conservation programs (Zimmerer & Carter 2002).

Within Latin America and the Caribbean, the vast number of conservation zones have been located within the existing human footprint (that is, areas which have already been highly impacted by human activities), while the vast areal extent of conservation zones have been located outside of the human footprint, in the same frontier areas which attract landless farmers (Naughton-Treves et al. 2005). The setting aside of conservation areas to stave off deforestation smacks of colonial arguments for excluding traditional land managers from “degraded” areas (Fairhead & Leach 1995), with blame for the deforestation in the area being primarily placed on the shoulders of landless migrants who are characterized as using inappropriate technologies for the environment. Competing interests for park resources, such as the many large-scale cattle ranches found within the reserve, have been left out of the conservation plan (Sundberg 1998).

Guatemala's Maya Biosphere Reserve

To stave off further migration into these areas, international and Guatemalan conservationists worked in the early 1990s to establish a vast network of protected areas across the country. Guatemala now has more than ninety protected areas, covering 28% of Guatemala's territory (three million hectares); approximately half of Guatemala's protected areas by area are located within Petén.

The 1.6 million hectare Maya Biosphere Reserve forms a conservation corridor with protected areas of Belize as well as Chiapas and the Yucatan in Mexico, with the whole tri-national conservation area called the "Maya Forest" (La Selva Maya). The MBR is comprised of many different protected areas with varying levels of access, such as core areas in which no human habitation or extractive activity is permitted, surrounded by "multiple use" zones and/or buffer zones, where land-use is permitted but ostensibly restricted. The population of the MBR when established in 1992 is unknown, but by 1998 it was estimated there were at least 90,000 people living inside this protected area, with most living in the multiple-use and buffer zones (Grandia 2006).

Within the MBR, the SLNP comprises one of the four core biological and Mayan cultural heritage conservation zones in the Maya Biosphere Reserve (CONAP 2005). The state has difficulties keeping pace with further encroachment into conservation areas, with the ironic result that this conservation area, like many in the world, is vulnerable to land conversion (Brandon & Wells 1992). Since the late 1980s, arriving waves of colonists are estimated to have reached 20,000 individuals in the park by 1999 (Carr 1999). Concomitantly, approximately 11% of the park's forest canopy was eliminated (Carr 2002). We estimate that the population in the park reached almost 25,000 by 2008, an increase of 25% over the 1998 estimate (Suter & López-Carr 2010).

The coadministrators of the park, Defensores and CONAP, have to varying degrees reached accords with many of the communities occupying areas of the park, negotiating their continued settlement in the area. Each community finds itself in a delimited area within the park, either constrained by a footprint drawn by the co-administration or, more often, by abutting communities. For this reason the multiphasic framework is relevant for this situation, which posits the possible responses of a growing population within a fixed area of agricultural production. This leads to the main questions driving this research: as population density increases in the area due to continued in-migration and high rates of natural increase, how will these new households be accommodated (where will see these tenurial and technological shifts predicted in the multiphasic theory)? Population density will most likely increase on the majority of farms, which may precipitate a change in household patterns of land use, a change that will affect land cover and conservation possibilities in the area.

However, assuming that population increase is the only change in the area since the previous sampling in 1998 is not a valid assumption. Since that time the local, national, and international transportation networks have improved, the urban centers within a few hours' distance have grown, the national park the communities fringe (or in some cases, are wholly contained within) has been in existence longer, the management of the park has changed, NGOs have come and gone, trade liberalization is taking place between Central and North America, and both legal and illegal markets have changed. These are but a few of the confounding factors in the study area.

Many of these changes, such as improvements in local transportation, are taken to be part and parcel to frontier development, just as a growing population is, so knowledge of their impact on farm ownership and land change is also of interest. Others, such as the intensification of drug smuggling through the area, are more idiosyncratic. Though probably not generalizable (that is, negatively impacting external validity), these types of idiosyncratic occurrences still contribute to interesting land use outcomes. Therefore, how are these possible responses enabled or constrained by the context in which they are made? Employing a multiphasic framework acknowledges that there are multiple possible responses and that a household can undertake any possible combination of them. Likewise, it acknowledges that the responses exhibited are also a function of the environment in which they are made.

Data

In 1998, Dr. López-Carr selected eight communities as a clustered probability sample of the communities with households located within the park boundaries. In these eight communities, Dr. López-Carr interviewed 247 randomly chosen households using survey instruments comprised of questions on migration and land use that incorporated demographic (e.g., household size and composition, fertility, and migration), political-economic (e.g., government subsidies, road-building, land titling practices), socio-economic (e.g., household *Assets*, household characteristics previous to migrating, ethnicity, knowledge and attitudes about conservation, farm location, size of farm, land management, and off-farm employment) and ecological (e.g., farm topography and soil) factors. Household surveys were fixed-format with a few short open-ended questions per subsection. Of these 247 households, 241 qualified for inclusion in his land use modeling efforts (Carr 2002), with six households not included in the land use modeling because they neither "owned," rented, nor borrowed land for farming purposes.

In 2009, Dr. Suter attempted to reinterview those 247 households interviewed in 1998. To this end, she spent several weeks piecing together the presence or absence of households previously interviewed in 1998 with community leaders. If a household was no longer to be found in the same community, she sought someone familiar with the household to interview about the departed household, preferably a relative. In several cases she arranged interviews with departed 1998 subjects in their new location. Of the 247 household heads interviewed in 1998, repeat interviews were conducted with 244 households, either with the subjects themselves or someone familiar with the household if the household was no longer present. Full interviews were not administered in all cases if a friend or family member stood in as a proxy for the unavailable household.

Meanwhile, Dr. Suter also randomly selected additional households within those currently residing in the eight subject communities so as to construct a sample representative of the current population. This sample included 213 households, 203 of which had access to owned, rented, or borrowed agricultural land. Comparisons between the 1998 and the 2009 random samples with land illustrate changes in the agricultural frontier over time.

Results

Frontier changes over time

An agricultural frontier such as the SLNP is an area undergoing rapid growth and change. In addition to maturation of the area and population living there, the region has experienced substantial structural changes. How has the frontier changed between the initial interviews in 1998 and subsequent interviews in 2009? This question is examined by examining change in the park population, and by comparing the changes in household agricultural characteristics of the cross-sectional random populations of the two dates, 241 households in eight communities in 1998, 203 households in the same eight communities in 2009.

The overall population of all 28 communities within or adjacent to the park grew an estimated 25% between 1998 and 2008, at which time it reached an estimated 25,000 people. The eight communities of interest overall show an estimated growth of 55% between 1998 and 2009. However, this growth was not consistent across all communities: several communities such as El Retalteco and Poza Azul showed growth which far exceeded the average, while others such as El Manantial saw a marked decrease in population. Browder, Pedlowski et al. (2008), in their comparison of three frontier communities in the Amazon over time, remarked upon the different development trends seen in each community. However, one consistent trend in all three communities was de-population as the frontier became the post-frontier. Our eight communities of interest are not consistent in that respect, suggesting that they are still at dramatically different stages and perhaps on different trajectories in their developmental arc.

Some of the most striking changes to agriculture (Table 1) are that the area on average that a household farms has gone down significantly between the two dates, as has the area devoted to maize, though the percentage of total land in maize has remained nearly the same. The number of households with pasture has increased substantially, along with the number of households with cattle. Herbicide use, the most frequently employed agricultural input in 1998, has doubled since then, and the number of households with a chainsaw has also increased. The number of households cultivating higher value crops has increased substantially, though trails behind increases in pasture. Many more households now cultivate black beans; nonetheless the area in black beans per household has shown only a marginally significant increase. The randomly selected 2009 households are cropping less land area, though the proportion of their overall land holdings cropped has increased. The area in fallow, however, and the proportion of land in fallow have both increased significantly, as have the area of land cleared and the proportion of land cleared. All in all, fewer households have forest on their land, and forests comprise a smaller area and smaller proportion of land for a household on average in 2009 than they did in 1998. Chemical fertilizer use has increased significantly, while the prevalence of green manure plots has declined substantially. There is more crop diversity in the area, but also a higher prevalence of pasture and less land in forest, suggesting households are not adopting land conservation practices in order to preserve forest.

Table 1: Changes in household farming characteristics between 1998 and 2009

Household farming characteristics	Year	N	Mean	Std. Deviation	Min.	Max.
Total land (Ha.)	1998	241	34.7	23.3	.7	135.2
	2009*	203	28.5	33.5	.7	179.0
Area of Maize (Ha.)	1998	241	5.0	4.3	.0	33.1
	2009**	203	3.3	3.6	.0	31.5
% land in maize	1998	241	.30	.33	.0	1.0
	2009*	203	.36	.36	.0	1.0
Pasture (0=no, 1=yes)	1998	241	.24	.43	.0	1.0
	2009*	203	.34	.48	.0	1.0
Cattle (0=no, 1=yes)	1998	241	.12	.32	.0	1.0
	2009**	203	.26	.44	.0	1.0
Herbicide (0=no, 1=yes)	1998	241	.43	.50	.0	1.0
	2009**	203	.88	.32	.0	1.0
Own chainsaw (0=no, 1=yes)	1998	241	.07	.26	.0	1.0
	2009**	203	.27	.45	.0	1.0
Higher value crops (0=no, 1=yes)	1998	241	.18	.39	.0	1.0
	2009*	203	.27	.45	.0	1.0
Black bean (0=no, 1=yes)	1998	241	.29	.46	.0	1.0
	2009**	203	.64	.48	.0	1.0
Area of black bean (Ha.)	1998	241	.4	.8	.0	6.3
	2009§	203	.5	.7	.0	3.5
Total cropped land (Ha.)	1998	241	5.9	4.9	.0	33.1
	2009*	203	4.7	5.6	.0	49.0
% land cropped	1998	241	.33	.34	.0	1.0
	2009**	203	.48	.41	.0	1.0
Area of fallow (Ha.)	1998	241	7.5	9.8	.0	49.3
	2009**	203	12.2	19.0	.0	100.7
% land fallow	1998	241	.20	.23	.0	1.0
	2009**	203	.30	.33	.0	1.0
Total cleared land (Ha.)	1998	241	15.2	13.1	.0	67.6
	2009**	203	22.4	26.3	.0	139.2
% land cleared	1998	241	.56	.32	.0	1.0
	2009**	203	.89	.21	.0	1.0
Forest (0=no, 1=yes)	1998	241	.77	.42	.0	1.0
	2009**	203	.35	.48	.0	1.0
Area of forest (Ha.)	1998	241	19.5	18.2	.0	90.1
	2009**	203	6.1	14.2	.0	118.2
% land forest	1998	241	.44	.32	.0	1.0
	2009**	203	.11	.21	.0	1.0
Chemical fertilizer (0=no, 1=yes)	1998	241	.07	.26	.0	1.0
	2009**	203	.19	.39	.0	1.0
Green manure (0=no, 1=yes)	1998	241	.38	.49	.0	1.0
	2009**	203	.09	.29	.0	1.0

** = $p < 0.01$, * = $p < 0.05$, § = $p < 0.1$

Changes over time in land area and in land cover categories

This section seeks to examine Phase III of the multiphasic framework, which posits the potential for technological changes related to farming in the face of rising population density. Technological changes can refer to methods and inputs used to farm more intensively on a given area, and it can also refer to changing land use, with less intensive land uses giving way to uses which produce more calories or cash per given unit of area (Bilsborrow 1987; Bilsborrow & Okoth-Ogendo 1992).

Although there is evidence that in densely populated, market-integrated areas, land use intensification can offset households' needs for more land, there is little evidence that intensification in the agricultural frontier is a means employed by households to preserve forest cover on the land they manage (Perz 2003). So the questions here is, are there signs of intensification in the sampled communities of the SLNP? How do these intensification measures possibly impact changes in forest cover over time for households who were interviewed in both 1998 and again in 2009? What is the relationship between land cover changes and variables deemed important within the multiphasic framework, or with variables deemed important within alternative frameworks such as the household lifecycle, the farm lifecycle, and other economic and ecological variables?

One way of examining intensification is to model changes in different land cover categories and gauge their impact on clearing forested areas. We examined absolute and proportional changes between 1998 and 2009 in three categories: the total area under the management of a household, the amount of land cleared, and the amount of land forested. We modeled these outcomes as a function of variables meant to represent the various multiphasic phases, such as intensification and disentensification variables related to Phase III, as well as variables meant to represent other phases such as a parent sharing land with members of the next generation (Phase I), out-migration from the parental household to seek opportunity elsewhere (Phase II), and couples seeking to control their fertility because of current or anticipated land shortages (Phase IV). We also included variables from other theories relevant to land use in the agricultural frontier, such as the household lifecycle theory, the farm lifecycle theory, and assorted ecological, economic, and geographical variables often examined in the frontier context (e.g., Walker et al. 2002; Perz 2003; Carr 2005; Pan et al. 2007; VanWey et al. 2007). These results are summarized from findings reported in Suter (2012).

The *Age of household head*, which serves as a variable representing the household lifecycle, is insignificant in predicting changes in total area or proportion of land managed by a household or in any of the land categories modeled. Although this variable is often included as a predictor within household lifecycle theory, it has rarely emerged as a significant predictor (VanWey et al. 2007). The age of the household head at the time of the interview negatively predicted the number of hectares of primary forest cut in a study conducted by Godoy, Jacobson, et al. (1998). However, according to the review article on the household lifecycle hypothesis by Walker, Perz et al. (2002), the example provided by Godoy, Jacobson, et al. (1998) was the only one in which the age of the household head proved to be significant in predicting a land cover. My findings, therefore, that the age of the household head does not predict changes in land area or land categories managed by a household between 1998 and 2009 is consistent with most findings.

Total household count, the companion predictor to *Age of household head*, likewise does not contribute towards predicting the outcome variables. This is the most common household lifecycle variable included as a predictor in land use studies (Walker et al. 2002). Total household size has in some contexts evinced association with positively predicting the percentage of land in annuals and in perennials, while negatively predicting the percentage in forest (Pichón 1996; Marquette 1998), and was shown by Carr (2002) to be positively related to the total amount of cleared land, percentage of cleared land, and negatively related to total amount of forestland in 1998. However, unlike the significance garnered by other variables in predicting change based upon their association with the percentage of land already cleared in 1998, household size in 1998 did not seem to impact land change between then and 2009.

More nuanced variables attempting to represent household demographic structure such as *Count males ≥ 12 years* and *Child dependency ratio* were also candidates for inclusion in the model, but never proved to be statistically significant. My conclusion therefore is that the household lifecycle does not seem to influence total or relative changes in land area or the land categories examined. There are still a few different ways to represent the household demographic structure, however, such as the total number of adults, total number of females, etc. Thus, a future paper dealing specifically with the household lifecycle could test a larger suite of household demographic structure variables for significance. Likewise, a more detailed examination of the household lifecycle could employ variables capturing the household demographic structure at different points in time other than just 1998, such as at the mid-point, 2004, or at the time of the second interview in 2009.

The farm lifecycle variable *Years on farm* remained insignificant in the majority of models. It was modestly and negatively related to the change in proportion of land cleared and positively to the change in proportion of land in forest. This is similar to the findings related by Pichón (1997), which linked duration of a household on a farm with a greater percentage of land in pasture and a lesser percentage of land in forest, and Brondizio, McCracken et al. (2002), who linked deforestation with years since settlement of a property in the Amazon. However, in the case of the SLNP, this effect may have been the influence of just a few outliers, as their omission from the model nullified their significance. Perhaps there is a threshold number of years up to which the number of years in residence makes a significant difference in the proportional area of different land coverages, but beyond which there is little discernable effect. A future paper examining the household lifecycle and farm lifecycle in more depth would incorporate variables seeking to tease out what this theorized threshold in number of years of residence may be.

Distance to road of primary plot (Km.) is a geographic variable, which significantly predicts a gain in total land by 2009, as well as a positive change in amount of cleared land. It does not predict a change in forest area, the natural log of the proportional change in amount of land, proportional change in forest, or proportional change in cleared land. Similar to other studies undertaken in Latin America (Fujisaka et al. 1996; Pichón 1997; Sader et al. 1997), Carr (2002) found that farms farther from the road in 1998 had a larger area of land in forest back in 1998, thus more remaining to deforest by 2009. Households were also perhaps able to expand the area of land at their disposal because of cheaper prices farther from the road.

One of the household variables representing intensification for the multiphasic framework employed in this model, *Either green manure OR herbicide (0/1=n/y)*, did not prove significant in any model. We bundled these labor intensive and capital intensive methods together as they both have potential for allowing continued cultivation of the same plot. Intensification may offset the need for clearing additional forest by extending the life of a given farm plot already under cultivation, referred to as productive conservation (Perz 2003). The non-significance of this variable influencing either total area or percentage of land cleared, however, fails to support the productive conservation hypothesis. However, these intensification methods of employing green manure or herbicides, when allowed separate entry, did have some success in predicting the outcomes of some models.

Green manure (0/1=n/y) predicts a positive change in the total amount of land at the disposal of a household between 1998 and 2009, but it does not predict absolute or relative changes in either cleared land or forested land. Shriar's (2001) study of intensification methods in or near the study area of the SLNP revealed that along the Ruta Naranjo (the north-eastern border of the SLNP), the proportion of cultivated land covered by established velvet bean had a significant, negative relationship with the proportion of mature forest belonging to a household In the greater MBR buffer zone, the same proportional coverage of velvet bean has a negative, borderline significant relationship with the household's proportion of land in fallow. In these cases, therefore, the households may have turned to velvet bean cultivation out of a real need to extract extended use out of an already employed area, as they have limited surplus fallow or forest land as recourse. Perhaps households with the money and labor to invest in velvet bean were able over time to purchase more land, but they did not show a marked preference for purchasing forested over cleared land and therefore those areas did not show a significant change.

Herbicide (0/1=n/y) use in 1998, when individually examined on the other hand, does not predict an overall gain in land but it does predict an increase in forested land, which could only come about through increasing or swapping the land at the household's disposal by 2009. Herbicide use is more prevalent among households with higher initial wealth in the Amazon (Perz 2003). If higher initial wealth associating with herbicide use were also the case in our study area, these households might parley their wealth into an increase in land, with a preference for forested land. Herbicide use also predicts a decrease in the change in the proportion of land cleared, but only before the inclusion of the variable capturing how much of a household's land was already cleared back in 1998. Inclusion of *% of land cleared in 1998*, however, rendered the effect of *Herbicide (0/1=n/y)* not significant in predicting the proportional decrease in amount of land cleared. Households which used green manure and/or herbicides in 1998 had a higher proportion of their land already deforested (Carr 2002), thus the association of herbicide with less change in cleared land. This echoes Shriar's (2001) findings in the area, which showed that households employing herbicides cultivated a greater area per adult-equivalent in the household, owing to herbicide's labor-amplifying effect, and Perz's (2003) findings in the Amazon, where households which employed herbicides had a smaller proportion of their land in primary forest and a higher proportion in pasture.

Another intensification variable of interest to the multiphasic framework, *Higher value crops (0/1=n/y)*, has a borderline, positive relationship predicting a household's change in total land between 1998 and 2009, and a positive relationship with the natural log of a household's land holdings in 2009 relative to their land holdings in 1998. Wealthier households are more likely to engage in more capital intensive, higher value crop production (Immink & Alarcon 1992), meaning the household would have the means for purchasing additional, possibly forested, land. This could help explain why it has a positive, significant relationship with a household's gain in forested area between 1998 and 2009. Purchasing additional or replacement land by 2009 is the primary means by which a household could increase the amount of primary forest it owns, as secondary forest regrowth does not enter into this land cover category. Interestingly, it does not have a significant effect on the absolute change in area of cleared land, though it does have a negative relationship with the change in proportion of land cleared and a positive relationship with change in proportion of land in forest. Cultivating higher value market-crops therefore, does not seem to encourage additional clearing (although these crops may be cultivated on land by households who already cleared all or most of their land), but it does seem to relate to the purchase of additional land, and preferentially additional land with remaining tracts of primary forest. Further examination of the characteristics and practices of those households with the largest amounts of forest in 2009 could reveal the implications for future clearing of the forested land acquired during the interim. The fact that households with a larger number head of cattle in 1998 also had a positive relationship to an increase in the forested land, however, may mean that the land is ultimately destined for pasture.

The opposite of intensification is extensification or disintensification, and cattle ownership is one such form of extensification Ranching instead of cropping represents a disintensification of land use, since cattle require less labor and agricultural inputs per hectare than crops, while also yielding a lower economic return per unit area (Perz 2003). The multiphasic theory predicts that as a rural area increases in population density, the amount of land devoted to pasture should decrease (Bilsborrow 1987). However, more households in the study area own cattle in 2009 than in 1998, making it more prevalent over time. Despite their high land requirements, cattle are highly desirable given their versatility in providing not only meat and milk, but also as a repository of cash, insurance, or collateral for the household, all with a low labor investment (Loker 1993). The extensification variables relating to cattle in 1998 (either *Number of Cattle* or *Cattle (0=no, 1=yes)*) were significant in a fair number of the models. The *Number of Cattle* belonging to a household related positively to a household's increase in total land holdings between 1998 and 2009, perhaps due to the high land demand of cattle (Hecht 1983; Loker 1993; Fujisaka et al. 1996). Seemingly, when acquiring additional land cattle-owning households showed a preference for forested land, since the independent variable had a positive relationship to the household's change in forest area, and its change in proportion of land in forest. It related negatively to the change in proportion of land cleared. Whether or not a household had cattle (*Cattle (0=no, 1=yes)*) related positively to the household's change in cleared land, perhaps to accommodate an enlarging herd. However, the amount of forested land amassed post-1998 must have been sufficient to offset a proportional loss in forest, since cattle were associated with a decrease in the proportion of land cleared. It also related positively, though marginally so, with the natural log of the relative increase in total landholdings in 2009 vs. 1998. Cattle, therefore, can have a dramatic impact on land holdings and land cover over time.

A multiphasic variable capturing one aspect of Phase II (out-migration) is the variable *Household receives/d remittances from USA (0/1=n/y)*. Unlike some studies in which remittances were used to expand farm holdings (Jokisch 2002; de Haas 2006) or to diversify into ranching (Eakin 2006; Taylor et al. 2006), in this study remittances did not (at least, not as of yet) have a significant effect on predicting an absolute or relative change in the amount of land under the management of a household, nor in predicting an absolute or relative change in the amount of land cleared or in the amount of land forested. Perhaps this income stream is still too young to see changes on the order of a land purchase, and investment in agriculture will come later as in the case of Durand and Massey (1992), Jones (1995), and Basok (2003). The majority of remittances earners were still living in the USA at the time of the 2009 interview, so perhaps migrant-sending households await the return of the migrant to invest their earnings in land, or some alternative investment. In the meantime, remittance recipients seem to spend the early remittances on home improvements and small household purchases, as observed elsewhere in Guatemala (Davis & Lopez-Carr 2010).

A variable meant to capture Phase I of the multiphasic model, a tenurial shift in population impacted areas, is whether or not the original, parental household *Shares land with next generation (0/1=n/y)*. This variable showed a significant, positive relationship with an increase in the area of forest, and a borderline positive relationship with the natural log of a household's total amount of land in 2009 relative to their 1998 amount. It also showed a borderline significant relationship with the change in the proportion of land cleared, but in the negative direction. However, all of these relationships become non-significant with the omission of outliers, casting doubt in the overall trend of *Shares land with next generation (0/1=n/y)* in affecting land area or land cover in absolute or relative terms. The number of households who share land with members of the next generation living apart from the parental household is relatively small in 2009 (18% among those interviewed in both 1998 and 2009), though perhaps it will grow with time as more offspring come of age and form new households.

The fourth and final phase in the multiphasic framework is fertility reduction. This was captured by whether or not the couple used contraception in 1998 (*Couple uses contraception (0/1=n/y)*), though the few household with a female partner 49 years if age or younger which did report using a method (20%) primarily used natural methods. Like the household lifecycle variable related to fertility, *Total household count*, whether or not a household used contraception in 1998 shows no impact on any of the changes in amounts or proportions of land or land categories by 2009. Any children conceived in 1998 as a result of not using contraception would still be too young in 2009 to contribute substantially to household labor. Their potential impact on household production as an additional consumer does not make a substantial difference to the outcomes. But the prevalence of contraception use, primarily the rhythm method, may have been too rare or too ineffectual among the population included in this model for it to make a substantive impact. Future work exploring this aspect of the framework could seek to capture fertility reduction via other means other than a household reporting using a contraception method in 1998, such as an actual reduction in the number of births between 1998 and 2009.

To conclude, only a few of the variables chosen to represent the multiphasic framework, household lifecycle, farm lifecycle, or other economic and ecological variables commonly explored in land change modeling proved to have a significant relationship to the modeled outcomes. None of the included household lifecycle or farm lifecycle variables (age of household head, total count of household members, or years on farm) showed a significant relationship to the outcomes modeled when we omitted outliers. The environmental variable *distance to road of primary plot* relates positively to the total change in land managed by a household between 1998 and 2009, as well as a positive change in the amount of cleared land. Of the multiphasic variables employed, only those which related to intensification or extensification had a significant relationship to any of the outcomes. In terms of intensification variables the use of inputs such as green manure in 1998 predicted a positive change in total landholdings, while the use of herbicides in 1998 predicted a positive change in forested land by 2009. Cultivating higher value crops in 1998, however, predicted a positive change in: total landholdings, the natural log of the proportion of landholdings in 2009 relative to 1998, the change in forested land, and the change in proportion of forested land. Cultivating higher value crops in 1998 negatively predicted the change in proportion of land cleared. In terms of extensification, the ownership of cattle in 1998 positively predicted the change in the amount of cleared land and the change in the natural log of a household's landholdings in 2009 vs. 1998. The number of head cattle in 1998 positively related to the change in total landholdings, the change in the area of forest, and the change in the proportion of forest. The remaining multiphasic variables, however, capturing the receipt of remittances, land sharing with the next generation, or fertility control did not relate significantly to any of the outcomes examined.

Of the variables typically examined for predicting land use/cover change, therefore, few ultimately held much power for explicating the changes seen in these frontier households over time. Variables which represented the relative household affluence in 1998 seemed to be the strongest predictors of changes in landholdings and changes in cleared and forested land over time; the direction of these changes, however, was not necessarily in the direction predicted by the multiphasic theory, however, supporting Perz's notion (2003) that intensification measures undertaken in the frontier do not typically lead to forest conservation.

Land owners and land sales

This section examines the redistribution of rural lands in the agricultural frontier, one of the responses to rising population density theorized by Bilsborrow and Okoth-Ogendo (1992). Why a household sells their land, to how many households, and who these households are play an important roll in shaping the type and pace of changes seen over time in the agricultural frontier. Additionally, understanding longer-term pattern of land use in the frontier requires examination of intergenerational processes such as land bequeathals (de Sherbinin et al. 2008).

For these reasons, we decided to investigate which household characteristics were more likely to associate with a 1998 land owner selling all or part of their land versus retaining their entire original parcel. We explored variables derived from the multiphasic theory, as well as variables derived from the household lifecycle theory, the farm lifecycle theory, and geographical variables. The variables selected for inclusion are those which have made frequent appearances in prior land use models, such as models seeking to explore whether or not the household lifecycle theory does in fact have implications for frontier land use patterns (e.g., McCracken et al. 1999; Perz 2001; Walker et al. 2002; Pan & Bilsborrow 2005). They are not, therefore, variables often selected for examining a household's likelihood of selling its land holding because few examples of such models exist (one exception is Pan, Carr et al. (2004), however this deals primarily with land subdivision and not land sales; Browder, Pedlowski et al. (2008) makes some examination of parcel subdivision, but it is not modeled as an outcome). Some of the variables selected for theoretically compelling reasons proved to associate with land sales, while others did not.

Age of household head is a household lifecycle covariate that did not prove significant in predicting whether or not a household had sold land before 2009 in almost all models run. The household lifecycle hypothesis may lead one to believe that an older household head would be more likely to subdivide his plot to accommodate grown children (Pan et al. 2004). This hypothesized effect may be somewhat refuted by the fact that *Age of household head* showed a borderline significance in negatively predicting a land sale in the case of households which remained in the park up to at least 2009 when accounting for a higher number of out-migrants from the household. This suggests that a younger household head with a higher number of out-migrants from the household is more likely to have engaged in a land transaction. In this scenario, householders who remained in the area may have shared all or a portion of their land with their departing offspring, or may have sold their land to finance their offsprings' ventures, such as emigrating.

Another household lifecycle variable, *Total household count*, does not prove to be significant in any of the models predicting land sales, contrasting with the findings shown in Pan, Carr et al. (2004). It does show some borderline significance with the models which include female partner data related to her field labor contribution or to her use of contraception, but we believe that is more of a function of sample biasing in sub-selecting those households with female responses.

The property lifecycle variable *Years on farm* did not prove to be significant in any of the models created, suggesting it has no bearing on influencing whether or not a household sold their land by 2009. A newer household in 1998 was as likely to have sold their land before 2009 as an older household in 1998. This contrasts with the findings from Pan, Carr et al. (2004), which found that farms with a greater number of head-of-household years (since farms were sometimes already subdivided at the time of the initial interview in 1990) were more likely to have further subdivided by 2009.

The geographical variable *Distance to road of primary plot (Km.)* was not significant in the majority of models, although it showed a marginally negative relationship with the outcome in the model dealing with only households who had remained in the area through 2009, perhaps for the reasons discussed above. When examining all landowning households in 1998, however, the variable did not prove to impact whether a household sold their land. Since that group included households which left the area before 2009, perhaps a household's decision to leave was irrespective of their land's distance to the road, while those that remained were more likely to sell if their land was closer to the road. This could perhaps be because of increased value due to proximity to transportation routes. This corroborates the findings by Pan, Carr et al. (2004), who noted that farm parcels farther from the nearby urban centers were less likely to subdivide.

The intensification variable *Either green manure OR herbicide (0/1=n/y)* was marginally, negatively significant in the model containing only households who had remained in the park through 2009, perhaps for the reasons mentioned above. This variable did not show a relationship with the model containing all landowning households in 1998, suggesting that, as above, a household leaving the area did so irrespective of intensifying production on their land via these inputs. Households which remained, however, were less likely to sell their land if they had intensified upon it. The implication for this is that households who sold their land and left the area did so out of a desire to leave the area. Perhaps the SNLP area was not to their liking and they wanted to return to their origin area, or move on to a new destination. Possibly, they wanted to cash in on their land and attempt to repeat the cycle of land speculation elsewhere. They made these decisions irrespective of their household affluence level, as indicated by proxy by their use of intensification measures (Shriar 2001; Perz 2003). Those that remained in the area, however, were more likely to maintain their original landholding if they were more affluent. These households did not have to sell their land in the face of a household crisis, as so many did.

The other intensification variable, *% land higher value crops*, was significant in all models, relating negatively to the probability that a household would sell all or some of its land. Households with a higher percentage of their land devoted to higher value crops, therefore, were less likely to sell their land by 2009 regardless of whether they left or remained in the area.

Although the logical flow of the multiphasic model would be land splintering followed by intensification, Pan, Carr et al. (2004) found that households with more land in perennials at the time of the first interview were more likely to have bequeathed part of their land to their offspring by the time of the second interview. However, so few of the land transactions in the SLNP scenario go from parent to child, and there is no evidence of this sort of preparation of the land via intensification prior to selling it to a third party. These higher value crops in the SLNP are mostly annuals anyway, meaning that they are not a long term land improvement (with the possible exception of stump removal) and would perhaps only attract a buyer by demonstrating that growing the higher value crops is possible upon that land, given adequate resources.

Most work discussing intensification via a change in crops planted by frontier farmers discusses the shift from annuals to perennials (Pichón 1996; Marquette 1998; Pan & Bilsborrow 2005), a long-term investment which may require years before yielding benefits. Although some households of the SLNP had planted a few perennials for household consumption, such as citrus trees, households have not as yet made the shift to planting commercial perennials. The shift from planting exclusively maize and black beans to also planting higher value annuals is still a dramatic change for those households which have done so. However, aside from possible stump removal, the change does not represent a real long-term land investment like planting perennials does.

The variable *% land higher value crops*, therefore, seems mostly indicative of a household of means, providing them a cushion from perturbations which may prompt a more vulnerable family to sell their most valuable asset. Unlike the previous intensification variable which may have served as a proxy for capital, *Either green manure OR herbicide (0/1=n/y)*, *% land higher value crops* is significant whether analyzing the whole sample of landowners in 1998 or just the subset of landowners who remained in the area up into 2009. This suggest that unlike households who used inputs such as green manure or herbicide, households with land in higher value crops were also more likely to remain in the area and thus not sell the land they had acquired. This is interesting, give that the higher value crops are primarily annuals and thus typically do not represent a long-term investment in the land.

The extensification variable, *Number of head cattle*, has a negative relationship to whether or not a household sells their land in the case of all landowning households in 1998. The *Number of head cattle* on its own is negatively significant in predicting whether a household remaining in the area sold their land or not, but when combined with the other variables included in the model it is only marginally significant in predicting a land sale. The contrast between these two models suggests that the number of head cattle have retention power for keeping a household in the area, but among those who stay perhaps it does not have as strong an influence on whether a household will sell their land or not beyond the importance of the other variables indicating wealth. Perhaps the retention power pertains to the capital improvements to the land necessary for keeping a herd of cattle, and thus is less common in a household planning to move. The households which stay, however, may not be relying exclusively upon the insurance function provided by cattle in the frontier (Loker 1993; Perz 2003).

Number of next generation out-migrants, the multiphasic variable capturing out-migration from the parental household, is included only in the models dealing with the households which remained through 2009. When it is entered in the model prior to adding the rest of the theoretical variables, it shows no significant relationship with the outcome variable; however, when the rest of the theoretical variables are added, the addition of *Age of household head* makes it significant and positive, suggesting that if a younger household head has a high number of out-migrants from the household, he is more likely to have sold all or some of his land. Unlike Davis (2010) who found no impact of the number of out-migrants on land sales, this scenario seems to reflect more closely that of Pan, Carr et al. (2004), in which more out-migrants means land is more likely to have subdivided.

Amount of land purchased since 1998 (Ha.) is another variable which was entered in the model containing only households who had remained in the park through 2009, since it details the amount of land they had purchased since the original 1998 interview. This did not turn out to be a significant variable, meaning that the decision to purchase additional or different land did not overall have an influence on a household selling their 1998 parcel. Thus there was not a strong trend of upgrading or downgrading owned land in the area; most households who sold their 1998 parcel and remained to farm in the area did so by renting land.

The final theoretical multiphasic variable, which captures a household's attempt at fertility reduction, *Couple uses contraception (0/1=n/y)*, evinced no significant relationship with the outcome variable among households with female partners 49 years or younger interviewed in 1998. Although this variable may be an inadequate means for measuring the influence of additional household members on land-sale decisions, it does not support the notion that a fertility reduction in the household will lead to more land turnover as suggested by the multiphasic model (Bilsborrow & Okoth-Ogendo 1992).

The models created for predicting the land sales for households originally interviewed in 1998 focused primarily on independent variables chosen to represent theories often applied to land use in the agricultural frontier. In these models, some of the household lifecycle variables showed no apparent relationship to a household's propensity towards selling their land by 2009, such as *Total household count* and *Years* *on farm* (alternatively counted as a property lifecycle variable). One variable did show a marginal relationship with the probability of a household selling land (*Age of household head*), but only when combined with the multiphasic variable *Number of next-generation out-migrants*. The geographical variable *Distance to road of primary plot (Km.)* was significant when examining only the households who remained, as was the multiphasic variable *Either green manure OR herbicide (0/1=n/y)*. Overall, the multiphasic variables had some success in predicting land sales (i.e. *Either green manure OR herbicide (0/1=n/y)*, *% land higher value crops*, *Number of head cattle*, and *Number of next generation out-migrants*). However, they did not always predict land sales in the direction one might have expected according to the multiphasic theory, suggesting that economic principles are perhaps more at work here in determining a household's long-term relationship with its land than the labor-allotments provided by household members.

This section sought to characterize land turnover in the frontier, examining under what circumstances landowners from an earlier interview date in 1998 divested themselves of all or part of their land by the time of the second interview in 2009. This provides an opportunity for understanding how the frontier changes over time, vis-à-vis land turnover. The hollow frontier theory, for example, expects a repeating cycle of wealthy landowners consolidating the land cleared by peasant smallholders upon in-migration (Rudel et al. 2002; Browder et al. 2008). Theories such as these can be more thoroughly examined by understanding how land changes hands and how the cast of characters changes over time in the dynamic frontier (Pan et al. 2004). Similar to Chapter 6, multiphasic variables related to intensification (*% land higher value crops* in 1998) and extensification (*number of head cattle* in 1998) did have some success in predicting whether or not a household sold land by 2009, but the direction of influence was negative in both cases despite their dramatically different land vs. labor requirements. Their significance, therefore, did not seem to derive from the necessity to make due with more or less land as expected from the multiphasic framework. Rather, their significance appeared to relate more to what the variables represented in terms of the household's material wealth and its dedication of the same to farming and ranching. Household economy, not including household provided labor, may trump the influences deemed important by the multiphasic model, household lifecycle model, or property lifecycle model in determining land turnover.

Conclusion

How has this agricultural frontier changed over time? Comparisons between the two dates reveal that the average household is farming less land in 2009 than in 1998. While some intensification practices such as farming higher-value crops and fertilizer use are on the rise, more land extensive uses are also on the rise, such as pasture. Fewer households have a portion of forest on their land, and households also have less area and proportion of their land in forest on average. Households do not seem to be engaging in productive conservation (Hall 1997; Perz 2001), which for conservationists is the motive behind encouraging intensification strategies. Population change has been uneven across the different communities, with some communities experiencing growth and others experiencing decline, although the overall trend is towards growth. As such, the area can not yet be classified as post-frontier, which is characterized in part by population decline (Browder et al. 2008).

One section looked at changes in land cover over time, relating to the technology phase of the multiphasic model. We examined households which had remained in the area from the time of the initial interview in 1998 and who were therefore available for re-interview in 2009. We modeled the changes in the amount of land area under the management of each household between the two interviews, as well as the changes in the area and proportion of land cleared and of land in forest. These outcomes were modeled as a function of the other possible multiphasic responses, as well as the other theoretically important variables profiled in the previous chapters.

Overall, households had substantially less absolute and relative amounts of land in forest in 2009 vs. in 1998. Perz (2003) noted that whereas in densely populated, market-integrated areas land use intensification can offset households' needs for additional land, households in the agricultural frontier do not appear to intensify in order to preserve forest cover on the land they manage. The findings of my case study are consistent with that statement. For example, the intensification variable *Either green manure OR herbicide (0/1=n/y)* was not significant for any of the models, meaning that intensifying in 1998 did not negatively impact deforestation rates as would be predicted by productive conservation (Perz 2001). The majority of the variables relationships' to the outcomes seem to derive from their representation of the economic wellbeing of the household more than as a household's effort to conserve forest or make do without increasing the amount of land under their management. Many of the variables which showed a relationship with increasing or decreasing the absolute area or proportional amounts of land cleared were those that Carr (2002) found to be significant in predicting a higher or lower area or proportion of land cleared in his cross-sectional analysis. This suggests that those households with more absolute and proportional areas of forest in 1998 are catching up with their neighbors, and ultimately few households will maintain any substantial swaths of forest on their land.

The following section examined land ownership in the area over time, relating to the tenurial response of the multiphasic model. By returning to the area in 2009, Dr. Suter was able to ascertain which of the original 1998 interviewees who claimed to own land at that time still held their land in 2009 and which households had sold out their holdings. Understanding how land turnover in the frontier proceeds is an important step towards understanding how frontier development occurs (Pan et al. 2004; Browder et al. 2008; de Sherbinin et al. 2008).

Models predicting land sales revealed that the multiphasic variables did have some success in predicting whether or not a household sold land by 2009, but the multiphasic variables did not always predict the outcome in the direction one might expect. An intensification variable such as *% land higher value crops* in 1998, for example, would be expected to have a positive relationship with a household selling some of their land under the multiphasic model by 2009. However, it showed a negative relationship with the outcome. Instead of intensifying in anticipation of working with less land, households' intensification seemed to represent an economic well-being that offset the need to sell their land to meet the financial demands of a family crisis. The logical sequence of events in that modeled scenario remains incorrect, however, as we would expect a household to reduce land access first, then intensify production to eek out their living on a smaller area. Future work will examine that sequence, looking at land sales and *% land higher value crops* in 2009. However, that will allow the inclusion of only the households who remained in the area through 2009, as households who left did not provide land use data in 2009.

Another multiphasic variable, out-migration of offspring from the household, did prove to be significant under some circumstances. The overall conclusion from this section, however, is that household economy, aside from the labor provided by household members, may play a stronger role in determining land sales in the area then the influences deemed important by the multiphasic model, household lifecycle model, or property lifecycle model.

References Cited

Barbier, E. B. (2004). "Agricultural Expansion, Resource Booms and Growth in Latin America: Implications for Long-run Economic Development." World Development **32**(1): 137-157.

Barbieri, A. F., R. E. Bilsborrow, et al. (2005). "Farm household lifecycles and land use in the Ecuadorian Amazon." Population and Environment **27**(1): 1-27.

Basok, T. (2003). "Mexican seasonal migration to Canada and development: A community-based comparison." International Migration **41**(2): 3-26.

Bilsborrow, R. and M. Geores (1994). Population Change and Agricultural Intensification in Developing Countries. Population and Environment: Rethinking the Debate. L. Arizpe, M. P. Stone and D. C. Major. Boulder, CO., Westview Press.

Bilsborrow, R. E. (1987). "Population pressures and agricultural development in developing countries: a conceptual framework and recent evidence." World Development **15**(2): 183-203.

Bilsborrow, R. E. and H. Okoth-Ogendo (1992). "Population-Driven Changes in Land-Use in Developing-Countries." Ambio **21**(1): 37-45.

Boserup, E. (1965). The Conditions of Agricultural Growth: The Economics of Agrarian Change Under Population Pressure. New York, Aldine Publishing Company.

Brandon, K. and M. Wells (1992). "Planning for People and Parks." World Development **20**(4): 557-570.

Brondizio, E. S., S. D. McCracken, et al. (2002). The colonist footprint: Toward a conceptual framework of land use and deforestation trajectories among small farmers in the Amazonian frontier. Deforestation and land use in the Amazon. C. H. W. R. Porro. Gainsville, FL, University Press of Florida**:** 133–161.

Browder, J. O., M. A. Pedlowski, et al. (2008). "Revisiting theories of frontier expansion in the Brazilian Amazon: A survey of the colonist farming population in Rondonia's post-frontier, 1992-2002." World Development **36**(8): 1469-1492.

Carr, D. L. (1999). Un perfil socio-económico y demográfico del Parque Nacional Sierra de Lacandón. Santa Elena, Guatemala, Presidencia de la Republica, Consejo Nacional de Areas Protegidas (CONAP) Secretaria Ejecutiva, The Nature Conservancy/Proyecto de la Biosfera Maya**:** 69.

Carr, D. L. (2002). Rural-frontier migration and deforestation in the Sierra de Lacandón National Park, Guatemala. Ph.D. dissertation. Department of Geography. University of North Carolina. Chapel Hill, NC**:** 327.

Carr, D. L. (2005). "Forest clearing among farm households in the Maya Biosphere Reserve." Professional Geographer **57**(2): 157-168.

Carr, D. L., A. Barbieri, et al. (2006). Agricultural change and limits to deforestation in Central America. Agriculture and climate beyond 2015: A new perspective on future land use patterns. F. Brouwer and B. A. McCarl. Dordrecht, The Netherlands, Springer**:** 91-108.

Carr, D. L., A. C. Lopez, et al. (2009). "The population, agriculture, and environment nexus in Latin America: country-level evidence from the latter half of the twentieth century." Population And Environment **30**(6): 222-246.

Central Intelligence Agency. (2010). "The World Factbook: Guatemala."   Retrieved October 28, 2011; Updated October 21, 2011.

CONAP (2005). Plan Maestro 2006-2010 Parque Nacional Sierra del Lacandón. Santa Elena, Petén, Guatemala, Consejo Nacional de Áreas Protegidas.

Davis, J. (2010). International Migration, Remittances, Fertility, and Development: Quantitative and Qualitative Evidence from Central America. Department of Geography. Santa Barbara, UC Santa Barbara. **PhD Dissertation:** 185.

Davis, J. and D. Lopez-Carr (2010). "The effects of migrant remittances on population–environment dynamics in migrant origin areas: international migration, fertility, and consumption in highland Guatemala." Population & Environment **32**(2-3): 216-237.

Davis, K. (1963). "The theory of change and response in modern demographic history." Population Index **29**(4): 345-366.

de Haas, H. (2006). "Migration, remittances and regional development in Southern Morocco." Geoforum **37**(4): 565-80.

de Sherbinin, A., L. K. VanWey, et al. (2008). "Rural household demographics, livelihoods and the environment." Global Environmental Change-Human and Policy Dimensions **18**(1): 38-53.

Durand, J. and D. S. Massey (1992). "Mexican Migration To The United-States - A Critical-Review." Latin American Research Review **27**(2): 3-42.

Eakin, H. (2006). Weathering Risk in Rural Mexico: Climatic, Institutional, and Economic Change. Tucson, AZ, University of Arizona Press.

Fairhead, J. and M. Leach (1995). "False Forest History, Complicit Social Analysis - Rethinking Some West-African Environmental Narratives." World Development **23**(6): 1023-1035.

Fearnside, P. M. (2001). "Soybean cultivation as a threat to the environment in Brazil." Environmental Conservation **28**(1): 23-38.

Fujisaka, S., W. Bell, et al. (1996). "Slash-and-Burn Agriculture, Conversion to Pasture, and Deforestation in Two Brazilian Amazon Colonies." Agriculture, Ecosystems and Environment **59**(1-2): 115-130.

Geist, H. J. and E. F. Lambin (2001). What drives tropical deforestation? A meta-analysis of proximate and underlying causes of deforestation based on sub-national case study evidence. Louvain-la-Neuve, Belgium, LUCC International Project Office**:** 116.

Godoy, R., M. Jacobson, et al. (1998). "The role of tenure security and private time preference in neotropical deforestation." Land Economics **74**(2): 162-170.

Grandia, L. (2006). Unsettling: Land Dispossession and Enduring Inequity for the Q'eqchi' Maya in the Guatemalan and Belizean Frontier Colonization Process. Ph.D. dissertation. Department of Anthropology. UC Berkeley. Berkeley, CA.

Hall, A. (1997). Sustaining Amazonia: Grassroots action for productive conservation. Manchester, Manchester University Press.
Hecht, S. (1983). Cattle Ranching in the Eastern Amazon: Environmental and Social Implications. The Dilemma of Amazonian Development. E. F. Moran. Boulder, Westview Press**:** 155-188.
Hecht, S. B. (2005). "Soybeans, Development and Conservation on the Amazon Frontier." Development and Change **36**(2): 375-404.
Immink, M. D. C. and J. A. Alarcon (1992). "Household Food Security and Crop Diversification Among Smallholder Farmers in Guatemala: Can Maize and Beans Save the Day." Food, Nutrition and Agriculture **2**(4): 32–41.
INE (2004). Características generales de las fincas censales y de productoras y productores agropecuarios: Tomo 1. IV Censo Nacional Agropecuario. Guatemala City, Instituto Nacional de Estadística.
Jokisch, B. (2002). "Migration and agricultural change: the case of smallholder agriculture in highland Ecuador." Human Ecology **30**(4): 523-550.
Jones, R. C. (1995). Ambivalent Journey. Tuscan, AZ, The University of Arizona Press.
Loker, W. M. (1993). "The Human Ecology of Cattle Raising in the Peruvian Amazon: The View from the Farm." Human Organization **52**(1).
Margoluis, C. (2004). Tragic Choices and Creative Compromises: Managing Protected Areas with Human Settlements. School of Forestry. Ph.D. dissertation. School of Forestry. Yale University. New Haven, CT.**:** 231.
Marquette, C. M. (1998). "Land use patterns among small farmer settlers in the Northeastern Ecuadorian Amazon." Human Ecology **26**(4): 573-598.
McCracken, S. D., E. S. Brondizio, et al. (1999). "Remote sensing and GIS at farm property level: Demography and deforestation in the Brazilian Amazon." Photogrammetric Engineering And Remote Sensing **65**(11): 1311-1320.
Naughton-Treves, L., M. B. Holland, et al. (2005). "The role of protected areas in conserving biodiversity and sustaining local livelihoods." Annual Review of Environment and Resources **30**: 219-252.
Pan, W., D. Carr, et al. (2007). "Forest clearing in the ecuadorian amazon: A study of patterns over space and time." Population Research and Policy Review **26**(5-6): 635-659.
Pan, W., D. L. Carr, et al. (2004). Causes and Consequences of Farm Fragmentation in Ecuador's Amazon. International Geographical Union. Aberdeen, Scotland.
Pan, W. K. Y. and R. E. Bilsborrow (2005). "The use of a multilevel statistical model to analyze factors influencing land use: a study of the Ecuadorian Amazon." Global And Planetary Change **47**(2-4): 232-252.
Pan, W. K. Y., S. J. Walsh, et al. (2004). "Farm-level models of spatial patterns of land use and land cover dynamics in the Ecuadorian Amazon." Agriculture Ecosystems & Environment **101**(2-3): 117-134.
Perz, S. G. (2001). "From sustainable development to "productive conservation": Forest conservation options and agricultural income and assets in the Brazilian Amazon." Rural Sociology **66**(1): 93-112.
Perz, S. G. (2001). "Household demographic factors as life cycle determinants of land use in the Amazon." Population Research and Policy Review **20**(3): 159–186.

Perz, S. G. (2003). "Social determinants and land use correlates of agricultural technology adoption in a forest frontier: A case study in the Brazilian Amazon." Human Ecology **31**(1): 133-165.

Perz, S. G. and R. T. Walker (2002). "Household life cycles and secondary forest cover among small farm colonists in the Amazon." World Development **30**(6): 1009-1027.

Pichón, F. J. (1996). "Land-use strategies in the Amazon frontier: Farm-level evidence from Ecuador." Human Organization **55**(4): 416-424.

Pichón, F. J. (1997). "Colonist land-allocation decisions, land use, and deforestation in the Ecuadorian Amazon frontier." Economic Development and Cultural Change **45**(4): 707-744.

Pichón, F. J. (1997). "Settler Households and land-use patterns in the Amazon frontier: farm-level evidence from Ecuador." World Development **25**(1): 67-91.

Rudel, T. and J. Roper (1996). "Regional Patterns and Historical Trends in Tropical Deforestation, 1976-1990." Ambio **25**(3): 160-166.

Rudel, T. K., D. Bates, et al. (2002). "A Tropical Forest Transition? Agricultural Change, Out-migration, and Secondary Forests in the Ecuadorian Amazon." Annals of the Association of American Geographers **92**(1).

Sader, S. A., C. Reining, et al. (1997). "Human Migration and agricultural expansion: an impending threat to the Maya Biosphere Reserve." Journal of Forestry. **95**(12): 27-32.

Shriar, A. J. (2001). "The dynamics of agricultural intensification and resource conservation in the buffer zone of the maya biosphere reserve, Peten, Guatemala." Human Ecology **29**(1): 27-48.

Shriar, A. J. (2002). "Food security and land use deforestation in northern Guatemala." Food Policy **27**(4): 395-414.

Sundberg, J. (1998). "NGO landscapes in the Maya Biosphere Reserve, Guatemala." Geographical Review **88**(3): 388-412.

Suter, L. (2012). Land succession and intensification in the agricultural frontier: Sierra del Lacandón National Park, Guatemala. Department of Geography. Santa Barbara, University of California, Santa Barbara. **PhD:** 300.

Suter, L. and D. L. López-Carr (2010). El Nivel de Desarrollo Humano en el Parque Nacional Sierra del Lacandón. Santa Elena, Guatemala, Fundación Defensores de la Naturaleza, The Nature Conservancy and Consejo Nacional de Areas Protegidas (CONAP)**:** 126.

Suter, L. and D. L. López-Carr (2010). Human development indicators in the Sierra del Lacandón National Park, Guatemala. Santa Elena, Guatemala, The Nature Conservancy, Fundación Defensores de la Naturaleza, and Consejo Nacional de Areas Protegidas (CONAP)**:** 126.

Suter, L. and D. L. López-Carr (2010). Land parcel fragmentation in the Agricultural Frontier: Sierra del Lacandón National Park, Guatemala. European Population Conference. Vienna, Austria.

Taylor, M. J., M. J. Moran-Taylor, et al. (2006). "Land, ethnic, and gender change: Transnational migration and its effects on Guatemalan lives and landscapes." Geoforum **37**(1): 41-61.

VanWey, L. K., A. O. D'Antona, et al. (2007). "Household demographic change and land use/land cover change in the Brazilian Amazon." Population and Environment **28**(3): 163-185.

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

Zimmerer, K. S. and E. D. Carter (2002). "Conservation and sustainability in Latin America." Yearbook of the Conference of Latin Americanist Geographers **27**: 22-43.