POPULATION, MULTI-SCALE PROCESSES, AND LAND USE TRANSITIONS IN THE AMAZON

William KY Pan
David L. Carr

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ABSTRACT

A growing literature has identified agricultural expansion by small farmers in the tropics as an important cause of global forest clearing, yet institutional factors affecting small farmers' decisions have rarely been taken into account in empirical analyses. We examine the influence of context on household land use/cover change (LUCC) decisions and estimate a multilevel model of LUCC for forest, pasture, perennials, annuals and fallow in Ecuador's northern Amazon from 1990 to 1999. We draw upon four strands of theoretical research to test relationships and interpret the findings: the peasant pioneer cycle, the hollow frontier, forest transition theory, and household lifecycle theory. We also examine differences within the study region, viz., sub-regional differences, and use descriptive and empirical model results to show that LUCC is jointly influenced by natural resource endowments, population changes, and community context, which may be moderated by location via road access. Off-farm employment and *finca* subdivision, which are affected by changes in population, are also strong predictors of LUCC. Community context plays a statistically significant role in land use change, accounting for 10% of total variation in our models. From a theoretical perspective, therefore, models that fail to take into account the effects of context, particularly in rapidly changing frontier environments, are missing a key component in explaining LUCC, which may result in incorrect statistical inferences. From a policy perspective, the results of this research suggest that policies in the Amazon must be targeted not just toward farmers, but toward structural factors at the community level.

Key words: *Land use, longitudinal analysis, population-environment, multilevel model, Ecuador*

INTRODUCTION

Human-induced land use/cover change (LUCC) is attracting increasing attention in research and political circles, particularly for tropical regions where deforestation has been linked to global climate change (Fearnside 1996; O'Brien 1995; Fearnside 2000), vector-borne disease (Patz et al. 2004; Vittor et al. 2006; Castro et al. 2006), and loss of biodiversity and threats to advances in science and medicine (Smith and Schultes 1990; Wilson 1992). Concerns regarding the pace and location of forest clearing have expanded the breadth of LUCC studies to identifying drivers at multiple levels. Large-scale studies often focus on political or economic factors shaping land cover in tropical regions, for example: studies focusing on shifting government policies such as neo-liberal, macro-economic or frontier governance (Mahar 1989; Rudel 2007; Alvarez and Naughton-Treves 2003; Naughton-Treves 2004; Nepstad et al. 2002); expansion of mechanized and plantation agriculture, particularly soybean production (Fearnside 2001, 2007; Morton et al. 2006; Bickel and Dros 2003); and logging and road expansion (Asner et al. 2005; Soares-Filho et al. 2004; Chomitz and Gray 1996; Rudel 2006). Alternatively, micro-scale (household) studies have focused on and debated the drivers of LUCC, such as the influence of population dynamics (Carr et al 2006; Allen and Barnes 1985; Barbieri and Carr 2005; Mather and Needle 2000; Pan et al. 2007; Armenterasa et al. 2006), the role of household and plot lifecycles (Perz 2001; Perz and Walker 2002; Walker et al. 2002; Barbieri, Bilsborrow, and Pan 2005; Vanwey, D'Antona, and Brondizio 2007; McCracken, Siqueira et al. 1999), socioeconomic status and tenure security of farm households (Carr 2008a; Vasquez-Leon and Liverman 2004; Walker, Moran, and Anselin 2000; Moran, Brondizio, and VanWey 2005), and natural resource endowments (Browder, Pedlowski, and Summers 2004; Pichón 1997a). These latter types of studies draw upon demographic, geographic, ecological and economic theories to construct conceptual models of LUCC, which are often tested using regression or simulation-based models to examine relationships and draw inferences for policy. However, despite the breadth of literature, only a handful have focused on the "change" part of LUCC, and even fewer have incorporated individual and contextual variables simultaneously, regardless of the near ubiquitous recognition of their joint importance in conceptual models. This is due in part to the lack of appropriate data sets and conceptual frameworks, which in turn are due to ambiguities about what is relevant about the context that affects LUCC, along with issues associated with data collection, sampling design and statistical methods that properly adjust for data hierarchies and spatial variation (Rindfuss et al 2007).

In this paper we contribute to advancing the study of LUCC by demonstrating the application of more relevant and advanced methods, both in survey design and statistical modeling. Substantively, the primary objective of this study is to examine and test multi-scale factors influencing changes in land cover from 1990 to 1999 in the Northern Ecuadorian Amazon (NEA or *Oriente*). We examine changes between seven land use types: forest, pasture, perennial crops, annual crops, fallow, swamp, and urban. Ecuador's Amazon, the NEA in particular, is among the world's most diverse tropical forests but is undergoing rapid deforestation, with deforestation rates almost three times as high as other Amazon Basin countries: 1.6% per year from 1990 to 1995, 1.2% per year in 1990-2000, and 1.7% in 2000-2005 (FAO 1997, 2001, 2005). This forest clearing has its origins in the discovery of significant petroleum deposits near Lago Agrio in 1967, which led to the construction of oil pipelines and roads by oil companies (including a major road between Lago Agrio and Quito in 1972), facilitating a large-scale migration of migrant colonists seeking to establish farms in the region. Road construction thus prompted *spontaneous* colonization and rapid forest clearing, which has continued albeit less intensively up to the present. It is estimated that the population of the region increased from perhaps only 50,000 (mostly indigenous groups) in 1960 to over 500,000 in the last census in 2001, with intercensal growth rates double the national rates: 8% from 1974 to 1982, 6% from 1982 to 1990, and 3.5% from 1990 to 2001 (INEC 1992, 2001). Working in tandem with overall population growth is the rapid expansion of urban areas, particularly during the last inter-censal period in which the four primary cities in the region (Lago Agrio, Shushufindi, La Joya de los Sachas, and Coca) grew at a rate of 5.1% per year, compared to Quito and Guayaquil, whose urban population increased at 2.3% per year.

With these dynamic driving forces as a backdrop, we will examine contextual and plot-level changes in our study region over time and test the importance of a range of demographic, socio-economic, geographic, and contextual factors hypothesized to influence LUCC. The following sections describe the importance of scale and context, introduce relevant theoretical structures and empirical research that we draw upon to formulate our estimation models, describe the study site and data collection methods, and then conclude with a summary of results and discussion of research and policy implications.

IMPORTANCE OF SCALE AND CONTEXT

The importance of scale and context in LUCC studies has been widely recognized by LUCC scientists as a whole (Geist and Lambin 2001; Bilsborrow and Geores 1992; Turner, Moss, and Skole 1993; Galvin et al. 2002; Perz and Skole 2003). However, due to the multi-disciplinary nature of population-environment research, the terms scale and context are sometimes used synonymously, which can cause confusion in practice. Scale has been used to refer to the geographical area of an analytical unit as well as the hierarchical data structure for statistical analysis in which factors at higher levels or scales are seen as influencing outcomes at lower levels. The first usage is related to the idea of ecological fallacy in social sciences (Robinson 1950) and the modifiable areal unit problem (MAUP). Gibson et al. (2000) provides an overview of issues associated with scale for several science disciplines. For studies of land use, Walsh and colleagues (Walsh et al. 1999; Walsh et al. 2001) demonstrated how the relationship between population, sex ratio, and number of households with land use (both NDVI and land under cultivation) varies for different scales of land units examined (i.e., increasing aggregations of satellite data). Similarly, Veldkamp et al. (2001) compared regression results that predicted crop yields measured at low and high spatial resolution using socio-economic and biophysical factors as predictors to demonstrate the differences that can occur due to scale. These examples show that the results of studies on land use can be scale-dependent: inferences and relationships observed at one scale or level are not necessarily the same for larger or smaller scales.

The issue of scale overlaps with the concept of context since both address the extent to which household LUCC decisions are not just a function of household characteristics but also of broader socio-economic and institutional factors.[i] This concern is not unfamiliar to the LUCC community, as land use models typically note the importance of context in land use decision-making. A recent study by (Rudel 2007) highlights its importance in a meta-analysis of 268 land use case studies. He demonstrates that local community markets influence LUCC decisions as a function of market size and growth. Further, he shows that the rise of neo-liberal regimes during the 1980s and 1990s has reshaped the drivers of deforestation through minimalist agendas that were influenced by plantation owners, large scale farmers, and, in the case of the NEA, oil producers[ii].

However, it is crucial to distinguish scale and context as the latter requires special statistical methods to properly adjust for the hierarchical data structure. In practice, only a handful of studies have been conducted in which individual and contextual variables are incorporated into land use models (Overmars and Verburg 2006; Vance and Iovanna 2006; Pan and Bilsborrow 2005; Pan et al. 2007; Agarwal et al. 2005). Micro-level land use studies often apply multivariate regression, particularly OLS, which assumes independence across observational units and does not account for problems associated with clustered data, non-random or multi-stage sampling, or spatial correlation (e.g., Barbieri, Bilsborrow, and Pan 2005; Pichón 1997b; Brondizio et al. 2002; Vanwey, D'Antona, and Brondizio 2007; Perz 2004). A meta-analysis of over 140 economic studies of tropical deforestation by Angelson and Kaimowitz (1999) found that microeconomic approaches also primarily use OLS and rarely include hierarchical data that describe market influence or institutional factors. Recent applications using spatial econometrics are promising for land use research (Walker, Moran, and Anselin 2000; Mena et al. 2006; Pan et al. 2007; Munroe, Southworth, and Tucker 2004; Caldas et al. 2007), but are no substitute for multilevel models, particularly when spatial variation is modeled as spatial error (spillover). In some cases, multilevel models are superior to spatial econometric models in terms of capturing spatial variation due to the relatively small distances at which spatial dependency affects land use decisions (see Pan et al. 2007). Most LUCC investigators explain data clustering from the standpoint of spatial continuities – i.e., an underlying spatial process that results in similar characteristics among observational units in close proximity. However, analytical approaches to handle spatial variation fail to recognize that there are often unobserved or unmeasured community- (or regional) effects that differ across communities and are better handled in a hierarchical or multilevel analytical framework.

EMPIRICAL & THEORETICAL MODELS OF LAND USE

A review of the recent literature finds that only recently have there emerged a handful of longitudinal studies on forest transitions in frontier environments. While existing approaches sometimes disallow clear generalization or systematic hypothesis testing (Rindfuss et al 2007), two studies from Ecuador and Brazil in South America, and from Costa Rica and the Dominican Republic in Central America, provide some insights about land transitions in Latin American tropical frontiers.

Using satellite imagery from 1987 and 1997 coupled with interviews with key informants and households, Rudel found large landowners converted land to pasture at a rapid pace in the 1980s and 1990s in the Ciguaza region of the southern Ecuadorian Amazon (Rudel, Bates, and Machinguiashi 2002). Simultaneously, some *mestizos* formed medium sized farms of 150 hectares. Some portions of these were subsequently sold, leading some men to migrate away to take up off-farm employment. Yet there was no subsequent consolidation by rural elites. Whereas all 12 communities in the small study experienced high deforestation between the 1960s and 1980s, since 1987, four had net reforestation. Meanwhile, the process of transition from cattle back to shifting cultivation among Shuar indigenous farmers in the same area led to a net *increase* in forest cover. According to Rudel, the distribution of landholdings, number of rural landless, and out-migration patterns are all keys to future forest transitions in the region.

In the Brazilian Amazon, Brondizio et al (Brondizio et al. 2002) found intensive and extensive activities together accompanying land consolidation, with diversification into perennials and cattle simultaneously, contradicting the peasant pioneer cycle, which expects continuing forest clearing by small farmers. There is also an aging effect as the farm is consolidated and fragmented by second generation family members occupying the farm. Recently, the introduction of a new highly competitive grass (*brachiaria brizantha* or *braquirao*) spurred further forest clearing for pasture formation. Although older farms do show in general more secondary succession, considerable variability is observed across settler cohorts. This, along with the strong influence of external period effects means that individual decisions and macro-scale endogenous factors both likely play important roles (Brondizio et al. 2002).

Evidence of a forest transition in Central America is seen in two studies in Costa Rica and the Dominican Republic. Schelhas' study of the Costa Rican Canton of Sarapiquí illustrates an evolution of colonization, deforestation, and the expansion of livestock production accompanied by an intensification of land use (Schelhas 1996). The first wave of colonists acquired 50-100 hectare plots of farmland, but soon farms came to be concentrated in larger holdings. At the same time, rising population density was associated with both increasing off-farm employment and agricultural intensification. The stocking rate of dual-purpose producers (raising both crops and cattle) with less than 25 ha of land was twice that of those with more than 25 ha. Returns to land for small, dual purpose operations were thus double those of large ones, as were labor inputs per hectare. It is also interesting that despite better returns for raising beans than cattle per unit of labor time, small landholders cannot afford the lower returns to land relative to livestock and thus intensify into cattle production. In terms of crops, international demand for certain perennial cash crops led to intensification in coffee and black pepper, which occurred during the study period without the attendant declines in returns to labor. But farmers did not totally embrace these perennials because they represent a high risk in a lowland environment as well as market risk. Furthermore, they require a high initial investment and a wait for 4 or 5 years for good crops to commence. Thus farms with the low population density which also had large livestock holdings were able to accumulate savings from the latter to invest in intensifying land use on part of their plots via high-value perennials.

Zweifler, Gold, and Thomas (Zweifler, Gold, and Thomas 1994) link air photo time series with household survey and interview data to examine processes influencing land use change in two hill region communities of the Dominican Republic. By the early 1940s, settlers had cleared almost all of the original forests in the community and soil fertility began to decline. Farmers responded first by reducing the cultivation of nutrient-demanding crops, such as peanuts, tobacco, and rice, while increasing land devoted to less soil demanding perennials, such as pasture and coffee. Following World War II, until 1959, the village became increasingly incorporated into the market economy, which spurred crop intensification. In the ensuing decade, land under production expanded rapidly. By the 1960s, as a response to population growth, fallow rotations were shortened, reducing the fertility regeneration of the soils, so that by the 1970s soil productivity had fallen dramatically. Meanwhile, the local urban center, Santiago, was growing rapidly, pulling young adult labor from the village. The out-migration of much of the young male population led to a greater dependence on land uses that demanded lower labor inputs and were more tolerant of depleted soils, such as coffee and pasture. The low labor requirements of *cafetales* was thus both a stimulus and response of young male out- migration in the context of a population growing over time and market changes in Las Auyumas.

The four studies described above illustrate four key theories of land use change: the peasant pioneer cycle, the hollow frontier, forest transition theory, and the household / farm life cycle. While each contributes to defining our hypotheses and variables, our conceptual model takes a broader approach which combines these concepts with findings from the literature. This model, depicted in Figure 1 in a simplified format, places Land Management Decisions of the *finca* or farm household at the center, since this is the focus of the study. These decisions are affected by four inter-related categories representing community context, household characteristics, labor and life cycles, and natural resources endowments. Each of these four broad categories has direct and indirect relationships with other categories, as is evident in the more detailed descriptions of the four theories below. Community context is generally captured via community-level variables, but their effects on land use decisions are moderated by both community / household access and household wealth, which determine a household's ability to interface with local markets. Community context is an important local proxy for structural conditions within which farm families make decisions (Chowdury and Turner II 2006). Natural resource endowments generally refer to the physical resources available on a plot, including the size of the plot. These resources are generally linked to location of the plot (i.e., one can assume for the majority of farms that during the original settlement, plots were chosen based on closeness to a road, viz., the perceived ability to bring goods to the market). The use of agricultural inputs is tied to household wealth and labor availability. The former depends, *inter alia*, on the conditions of the family or migrant in the previous place of residence (Murphy 1998), while the latter is a function of household characteristics and the stage of the life cycle (Marquette 1998). Details of the intricate relationship among variables are clarified with descriptions of the four theories below.

The peasant pioneer cycle

According to the peasant pioneer cycle, deforestation continues unabated as migration to new frontiers follows the exhaustion of land resources after years of settlement (Rudel, Bates, and

Machinguiashi 2002; Bilsborrow 2002; Carr 2008b). This cycle usually begins with road construction in previously impenetrable forests, which makes possible the migration of poor farmers to the region in search of land. In such remote rural environments of abundant land and scarce labor, agricultural intensification is unnecessary--a labor burden which is also too risky for small, semi-subsistence producers (Pichón and Bilsborrow 1999). The result is a pattern of swidden land-use, with extensive clearing of forests, first to plant annual crops for subsistence, then cash crops such as coffee or cacao. In the case of Ecuador, where Amazonian soils are nor uniformly poor, most farmers then accumulate some savings and invest in cattle, which, unfortunately involves another cycle of deforestation since cattle on average require one hectare of Amazon land per animal. But there is virtually no land abandonment. In contrast, in other areas of the Amazon, notably Brazil, soil nutrients are depleted over time in the typically poor, oxidized tropical soils in two to four years, leading to farm abandonment or sale at low prices. Over time farms are consolidated in the hands of rural elites, who create cattle ranches. Meanwhile, the poor move on to further extend the forest frontier, where the deforestation cycle begins anew (Walker et al. 2002).

Forest transition theory

According to forest transition theory, regions of rapid in-migration and deforestation ultimately evolve to places of net out-migration and reforestation. As Europe and North America industrialized in the 18th and 19th centuries, forests eventually recovered. As economies transitioned from predominantly agricultural and rural to industrial and urban, farm families abandoned rural livelihoods to seek employment in burgeoning industrial centers. As agricultural regions became depopulated, abandoned farms reverted to forest. The advent of mechanized agriculture concentrated production on the best lands, leaving parts of the once cultivated rural landscape returning to forest, particularly country sides located on marginal lands, such as mountainous regions (Mather, Needle, and Fairbairn 1998). Nevertheless, recent modeling evidence from developing nations shows limitations of theory built on from developing world in the conceptualization and generalizability of forests, their dynamics and related transitions (Perz 2007). Indeed, not all regions have followed this traditional evolution,with Mediterranean Europe one exception (Mather 1992), and contemporary transitions in the developing world differ considerably from those of industrializing Europe and North America during past centuries (Rudel, Bates, and Machinguiashi 2002). For example, industrialization in the developing world is more precarious, with fewer and lower paying employment opportunities. Consequently, rural households are more chary of abandoning their farms and, instead broaden their resource acquisition strategies by engaging in temporal migration or in the migration of one or more family members from the farm (Laurian, Bilsborrow, and Murphy 1998) Decreases in farm labor could mean forest regrowth (Bebbinton 2000) or further deforestation if the out-migrants send remittances which are used to purchase cattle, which requires little labor, but leads to pasture expansion and further forest clearing, as suggested by household lifecycle theories. Evidence exists for both in Latin America (Aide and Grau 2004).

The hollow frontier

On the "hollow frontier", socio-economic change does not lead to forest cover conversion (Rudel, Bates, and Machinguiashi 2002). The hollow frontier transition has been observed in tropical humid forests in Central America (Jones 1989) and South America, where consolidation and continued deforestation has been recurrent throughout the Brazilian Amazon (Moran 1993). As small farmers leave the initial frontier, a space or "hollow" of people is left in its place. People become scarce and cattle become abundant as the land shifts from annual crops to pasture. Forest clearing remains unchanged or is expanded as ranchers convert more primary forest to pasture, which requires little labor. In some instances, out-migration is no longer to new frontiers as in the peasant pioneer cycle, but to the city, as in the rapidly urbanizing Brazilian Amazon (Browder and Godfrey 1997).

In the case of either of these theories, most of the land cleared initially for agriculture fails to revert back to forest as pasture dominates the agricultural landscape. Indeed, in South America, pasture accounts for over three-quarters of all agricultural land and nearly a third of the total land area originally in Bilsborrow and Carr (Bilsborrow and Carr 2001). Further, its share has grown with decreases in cropland in virtually all South American nations and commensurate increases in intensification to compensate for dwindling and degraded cropland (Carr 2004) . Hollow frontiers are created from the encroachment of large plantations on former small farmer colonization frontiers, as happened in eastern Guatemala in the 1940s and 1950s with the expansion of export fruit plantations (Carr 2002; 2008b) or more recently in the Brazilian Amazon as a result of soybean expansion (Kaimowitz and Smith 2001). Ultimately, whether for bananas, soy, or cattle, the region once settled by small farmers becomes largely depopulated as people are replaced by land intensive forms of land use.

A key difference between the notion of the forest transition and the hollow frontier is the role of migration. In the latter, labor lost to migration does not necessarily lead to forest change, whereas in forest transition theory lost labor means forest regrowth (Rudel, Bates, and Machinguiashi 2002). Thus a key difference in the two scenarios is whether land is consolidated or abandoned. However, it is possible that neither occurs as a rule, as in the Ecuadorian Amazon, where soil quality is often of sufficient quality to sustain agriculture for long periods, though eventually land use practices that do not further deplete the soils must come into play, but this was not the case up to 1999.

Household / farm life cycle

An understudied aspect of land use in rural areas is the role of the family life cycle (Walker et al. 2002; McCracken, Brondizio et al. 1999; Marquette 1998). According to this perspective, the age and sex composition of households affects labor supply and, therefore, land use and forest conversion over time (Carr 2004). As children enter working-age, food needs increase as does labor supply, so further land clearing can occur to expand cash crops, which may partially replace subsistence crops. As children become adults, if they out-migrate, this decreases the need to use the family farm to produce food or income to sustain them or to intensify agriculture (Murphy, Bilsborrow, and Pichón 1997; Laurian, Bilsborrow, and Murphy 1998; Moran, Schumann, and Partridge 1989; Findley and Oberai 1988). Moran et al (Moran, Siqueira, and Brondizio 2003) note the importance of examining the effects of household composition on deforestation in the Brazilian Amazon, exploring the effects of changes in age and gender composition. In other studies from Brazil and Guatemala, Perz (2001) and Carr (2005) find only the number of children having statistically significant effects on forest cover, suggesting a mainly consumption needs effect. However, recent empirical research has identified shortcomings in the household life cycle theory (Vanwey, D'Antona, and Brondizio 2007; Walker et al. 2002), including different findings of demographic composition across studies (Vanwey, D'Antona, and Brondizio 2007). Barbieri et al (Barbieri, Bilsborrow, and Pan 2005) and Vanwey et al (2007) argue that it is much more useful and appropriate to interpret the change over time as dominated by a *plot* life cycle than a household life cycle. Indeed, HH life cycle theories may conflate household and plot lifecycles even though doins so is commission of the ecological fallacy since one is endogenously determined by the other. One of the consequences is that period effects – which are much more likely to affect plot lifecycles (e.g., credit and tenure policies, market prices, roads) do not play a key role in determining land use change.

STUDY SITE, DATA, & HYPOTHESES

STUDY SITE

The study site and sample design have been previously described (Bilsborrow, Barbieri, and Pan 2004; Pichón 1997b; Pan et al. 2007). Briefly, the study site is located in the NEA or *Oriente* (Figure 2), and is one of the most biodiverse regions in the world. Rapid LUCC has been ongoing since the discovery of oil in 1967 near the city of Lago Agrio, which induced road construction by oil companies to lay oil pipelines and subsequently prompted massive migration and colonization to the region by migrant settler families. They applied for land titles from the Ecuadorian Institute of Agrarian Reform and Colonization (IERAC) up to its elimination in 1993 as part of neo-liberal policies of shrinking the public sector. Since 1993, the National Institute for Agrarian Development (INDA) replaced it, but had litttle resources to process title applications. Although title-holding is therefore much more tenuous since 1993, lack of a *de jure* title has not significantly affected tenure security, since many land transactions are a result of *finca* subdivision among kin or friends that involve *de facto* contracts and recognized rights of use.

In 1990, a household survey of migrant settlers was carried out, using a 2-stage probability sample consisting of 64 settlement sectors (stage 1) and 470 government-defined plots, or *fincas* (stage 2). Two interviews (one for the economic head and one for the spouse) were administered to each household living on sample *fincas.* A follow-up survey was carried out on the same *fincas* in 1999, creating a longitudinal data file on land use. A wide range of topics were covered in both household surveys, including: demographic composition; land acquisition, land titling, and land use; agricultural production; use of inputs and technology; commercialization; hired labor and off-farm employment (OFE); out-migration; household assets; fertility and health; and dwelling quality. The 1990 sample provided complete data for 418 farm households on 398 *fincas* [iii], while the 1999 sample comprised 708 independently owned farms on 392 *fincas*.

Community survey data were also collected in 2000 (including retrospective data back to 1990) in 59 communities in the region. These data provide a wealth of policy-relevant contextual information on the availability of economic, physical and social infrastructure. All household and community questionnaires are available on the web (www.cpc.unc.edu/projects/ecuador).

DATA

Only *fincas* with complete data in 1990 and 1999 were included in the analysis here (i.e., data were needed from all households on the *finca*, which was complicated by the extensive process of subdivisions that occurred after 1990), which limited the study to 361 *fincas*. We divided the study site into three regions representing distinct areas of agricultural and infrastructure development. Each region is circumscribed by major rivers, creating natural boundaries, and also linked to the four largest cities: Region 1 is the area north of the Aguarico River to the San Miguel River on the border with Colombia, and includes Lago Agrio, the largest city in the study site; Region 2 is located between the Napo and Aguarico Rivers and associated with La Joya de los Sachas and Shushufindi; and Region 3 is south of the Napo River and associated with Coca (Figure 2). Seven land use categories are defined for each year on each *finca*: forest, pasture, perennials, annuals, swamp, fallow, and urban. Data were provided by the head of the farm household, and aggregated across households for each finca in the case of subdivisions. Forest includes primary forest plus (small areas in) secondary forest with more than 7 years' re-growth; fallow refers to secondary growth under 7 years; and urban is land allocated to non-agricultural uses (mainly *solares*), which came to exist only in the 1990s. The remaining four categories are those of agricultural land use: Perennials includes coffee, cacao, African palm and most fruit trees; Annual crops includes corn, rice, maize, plantain and bananas, and sugar; Pasture was defined as land for livestock, used currently or within the past year; and Swamp includes unused areas under water.

It is important to note that the measures of land use in 1990 and 1999 here are derived from the household surveys rather than satellite data. This involved some difficulties due to slight differences in reported finca size in 1990 and 1999 (i.e., in 1990 a farmer may report his *finca* as 50 ha, while in 1999 the size may be slightly larger or smaller). Differences were mostly small (under 5 hectares) and adjustments were managed using sketch maps of the settlement sectors and spatial data collected (GPS points for plot corner points closest to the nearest road) and satellite information, when available [iv]). Note also that the analysis is based on the *finca* rather than the household farm, thus representing a "meso-scale" analysis, as *fincas* do not always represent household-level dynamics. Although *fincas* in 1990 were almost entirely comprised of one family, by 1999 almost half the *fincas* were owned and operated by more than one family due to *finca* subdivisions among relatives, especially children as they grow up to adulthood, and to new migrants who purchased portions of the *finca*. The hierarchy defined to examine LUCC at multiple scales is thus defined as the *finca*, sector and community, which is more policy-relevant on where and why land cover is changing.

PRIMARY HYPOTHESES

Based on previous research, we know that the region has evolved into a phase of considerable fragmentation through subdivision of plots due to increasing population growth and in-migration into the region, both consistent to some degree with neo-malthusian arguments in addition to the theories we describe above. This involves elements of the peasant pioneer cycle, household/farm plot lifecycle, and forest transition theory, but the jury is still out as to whether the hollow frontier stage will be reached. Following our conceptual model and these theories that inform our work, we hypothesize that land in cattle and perennial crops continues to expand in the Ecuadorian Amazon at the expense of forests, annual crops, and possibly fallow land. Driving the expansion in pasture and perennials are reductions in on-farm labor due mainly to fewer adult males being available due to either out-migration or greater participation in off-farm employment. We hypothesize that the former is due to variables capturing the plot life cycle (year of *finca* establishment) as aging of a plot and younger family members tends to result in migration off the plot, while the latter is occurring due to the expansion of local towns (i.e., demand for labor linked to infrastructure expansion, population growth, and economic expansion). Both out-migration and off-farm employment are linked to the process of *finca* subdivision as plots are believed to be partitioned among sons and daughters reaching adulthood (part of the life cycle process) and sales of portions to new in-migrants are believed to be somewhat smaller in which new migrants establish small plots and engage in local employment. We hypothesize that subdivided *fincas* will see expanded perennials relative to annuals as households become more incorporated into the market economy as a function of increasing accessibility linked to the continuing expansion and improvement (paving) of roads.

However, the processes of change are manifested in different ways within the NEA, which can be seen within the three sub-regions. Evidence of the peasant pioneer and farm lifecycles in the three regions (Figure 2) appear to be distinct, beginning with differences in the mean dates of *finca* and community establishment (Tables 2 and 4). Thus in the older north and central regions, which include the large communities of Lago Agrio, Shushufindi and La Joya de los Sachas, we expect greater market influence on fincas, which means that the effect of increasing population on the finca is often offset by out-migration and increasing participation in off-farm employment. This is expected to result in more pasture and perennial land, with reductions in other forms of land use. In the southern region, in contrast, where there is much less population and town growth, we expect continued swidden agriculture (slash and mulch) resulting in expansion of annuals, perennials, and fallow. In regard to intensification, our focus on *fincas* rather than each individual household farm on the finca precludes our seeing differences in intensification based on farm size, although we do expect to see less fallow and forest on subdivided *fincas* that have increases in population size.

In the next section, we define the variables to be used in both the descriptive and statistical analyses.

VARIABLE DEFINITIONS

Table 1 lists and defines the variables considered and organizes them into five categories corresponding to the four categories in the conceptual model plus Location and Accessibility as a fifth category. Table 1 also indicates whether a variable in the model is centered about its mean (with the mean indicated), and whether it was defined as a baseline measure (1990), a change variable, or both in our statistical model. Variables were centered to help reduce numerical errors in estimation and to ease interpretation of parameters in the sense of measuring the extent to which a *finca* differs from the average *finca*. Variables in each category are described briefly below:

Natural Resource Endowment variables define the natural resource characteristics of the *finca*. They include size of the *finca* (in hectares), land use composition in 1990, accessibility to water, topography, and soil quality. The first three are centered around their grand means and do not change over time (water distance was computed using a 1999 LandSat image as in Pan et al. 2004); however, soil and topography were taken from survey data, and vary across farms. Evidence suggests that soil quality and topography reported by household heads may apply only to the portion of the plot cleared for agriculture at the time of survey and not the entire *finca* area. Satellite-derived measures of topography do not exist for the entire sample.

Demographic and Socioeconomic Characteristics of the *finca* capture population and economic pressures on the plot. Demographic variables are broken down by age (0-11, 12-49, 50+) and gender to determine the potentially different effects on LUCC. Consistent with household life cycle theories, age-gender distributions are also a means of separating producers from consumers, i.e., adult males, and to some extent a portion of adult females, are the primary producers on a farm, while children and elderly are primarily consumers. Population density is also considered, measured as total population per hectare. It is important to remember that population measures are highly correlated, with population density having correlations greater than 0.7 with all other population measures (both baseline and change measures), adult males and adult females having correlations all greater than 0.65, and adult females and children having correlations greater than 0.58. Therefore, only a subset of these variables will be included in the final model.

Socioeconomic characteristics include type of legal land title (full title or *certificado* – certificate of possession) and household income in 1990. These measures control for variations in levels of wealth across households in the study site. As mentioned earlier, title holding of any form is more applicable to 1990 data as government titling activities virtually ceased after IERAC was replaced by INDA: 93% of farm owners held some form of land title in 1990 compared to just 50% in 1999 (Bilsborrow, Barbieri, and Pan 2004). Income data were derived by previous work and integrated into this analysis (Murphy 2001). Changes in income were not considered as these may be construed as endogenous.

Labor, Lifecycles and Agricultural Input variables help capture the extent to which *finca* households are engaged in local communities. Labor variables, apart from the household composition, are measured as total person-months of off-farm employment (OFE), which subtracts labor from household supply, and hired labor, which adds it, both measured for the 12 months prior to the survey. OFE and hired labor are not significantly correlated, but do show associations with demographic measures: OFE is positively correlated with all population measures above, but at low levels. Not surprisingly, hired labor (in 1999) is only significantly correlated with children (in 1990) as the presence of children can preclude the need to hire additional labor over time; however the correlation is low. Life cycle indicators are variables that capture the natural course of land use change (see Barbieri, Bilsborrow, and Pan 2005; Vanwey, D'Antona, and Brondizio 2007) that roughly correspond to the farm and household life cycles. These variables thus are year of *finca* establishment, number of subdivisions between 1990 and 1999, and creation of *solares*. The latter two are both consequences of population change as well as improved road access and growth of towns. Other variables here include whether fertilizers or pesticides are used, receipt of bank credit, and receipt of technical assistance of any kind (for agriculture, commercialization of products, fish farm management, health care, etc.). The first two are closely related to socioeconomic characteristics as several farmers purchased inputs, which generally requires higher wealth, and having a bank loan usually requires having a land title as collateral. Bank credit was most often used for pasture creation and purchasing cattle.

Location and Accessibility to the *finca* is evaluated by several measures. Geographic sub-region of the *finca*, described previously, captures many of the differences in access and also creates natural groupings of *fincas* and communities. Road access is a classification variable, with the reference being no road access in 1990 or 1999, compared to access in 1990 or access in 1999. Walking distance to the road is taken directly from the household survey, while distance to the closest of the four major cities and distance to the nearest market community are both based on GPS readings taken from each *finca* and community in 1999 and 2000.

Community Contextual variables were difficult to define as scant empirical research exists regarding the effects of community-level characteristics on household LUCC. With the exception of the two variables that measure the number of communities within a 5km and 10km radius of the *finca*, all community variables refer to the *nearest market community* to the *finca*. For these nearest market communities, we relied on theory and exploratory analyses to define three types of variables: duration of community existence, community population size, and infrastructure. Community duration and size are straightforward, meant to capture the relative degree of influence a particular community may have on *fincas* in its vicinity, which can change over time. In addition, specific types of infrastructure were chosen to include based on an examination of community variation across the region and correlations with other infrastructure variables. Piped water, electricity, health and transportation infrastructure are just four among over 25 types of infrastructure collected for each community. These four, along with whether an agricultural cooperative or community improvement organization existed in the community, seem to best differentiate communities across the region based on exploratory analysis.

DESCRIPTIVE ANALYSIS

We compared *finca* characteristics and land use in 1990 and 1999 using t-tests of differences between means. Differences between the three regions were identified using F-tests corrected for multiple comparisons using the Tukey-Kramer adjustment (Kleinbaum et al. 1997). In addition, we examined differences in community characteristics by region using F-tests; however, since the numbers of communities per region is much smaller than the numbers of *fincas*, the comparisons are primarily to provide contextual comparisons rather than statistical inference. Descriptive analyses were conducted using SAS 9.1 (SAS 2003).

Land Use

Fincas have a mean size of 47.1 ha, with 40.2% cleared in 1990 and 52.1% in 1999, implying an annual deforestation rate of 2.4% (Table 2). Significant LUCC was observed for all forms of land use except perennial crops (at the 0.05 significance level). Thus from 1990 to 1999, an average size *finca* increased land in pasture by 4.9 ha, in annual crops by 1.3 ha, in swamps by 3.3 ha, in fallow by 2.9 ha, and in urban use by 0.3 ha (*solares*). On average, land allocated to perennial crops decreased by 0.7 ha, but the decrease was not statistically significant. The changes in swamp and fallow are suspect since better data were collected in 1999 than in 1990 for both, but discussions with farmers suggest that more farmers were allowing land to rest in 1999 before replanting. Increasing urbanization of plots over time, although small, is a new phenomenon linked to population growth and hence plot fragmentation, which has been the focus of related studies by the authors (Barbieri, Bilsborrow, and Pan 2005; Pan, Carr, and Bilsborrow 2005).

Regional differences in land use in 1990 and 1999 are also apparent from Table 2. Regions 1 and 2 had the most land cleared in 1990, including the most land in pasture and perennial and annual crops. Region 2 experienced the largest changes in the 1990's, with the biggest percentage points change in land use from forest to agriculture, with almost 16% of the forest cleared, mainly for additional pasture and annual crops. Region 3 had the least change in land use, with 75.3% and

65.6% of the land in forest in 1990 and 1999, respectively, but it did experience the largest increase in pasture. Annual rates of deforestation were statistically quite different between Region 1 (1.8%) and Region 2 (3.7%), but not different between Region 1 and Region 3 (1.5%). Other notable, yet not statistically significant, differences in LUCC by Region (Table 4) include: more pasture creation in Regions 2 and 3 (2.6 and 2.8 ha, respectively) than Region 1 (1.3 ha); less additional land for annual crops in Regions 1 and 3 (0.3 and 0.2 ha) compared to Region 2 (1.0 ha); greater increases in land in fallow in Regions 1 and 2 than Region 3; and finally, almost 0.5 ha of land was allocated for urban uses on average in each finca in Region 2 compared to non-detectable amounts in Regions 1 and 3: that is, *solares* were a phenomenon in Region 2 only.

Finca Characteristics

Much of these inter-regional differences in LUCC may be related to changes at the *finca* and community (contextual) levels (Tables 3, 4 and 5). In fact, we observe significant changes occurring over time and space in regard to population distribution, socio-economic indicators, natural resources, and infrastructure. First, at the *finca* level, Tables 3 and 4 report changes in the mean levels of a number of key variables hypothesized to influence LUCC. All *finca* population size and labor endowment variables significantly increased over time, except for hired labor, which significantly decreased from 1990 to 1999. The decline was likely due to the subdivision of *fincas* creating smaller farms that have less need or ability to contract extra workers as well as the replacement of hired workers needed during early settlement by younger children who have grown into adulthood. But meanwhile, note the spectacular increase in the months of off-farm work (OFE), as farm households sought alternative sources of income to supplement farm income.

Related to the replacement of IERAC by INDA is a significant drop in the percentage of *fincas* having some form of land title, especially provisional titles (Certificates of Posession). There was a *doubling* in the number of subdivisions on a *finca*, a massive change in such a short time period and occurring primarily in Regions 1 and 2. Accessibility of *fincas* generally improved (lower walking distance to roads and shorter distances to market towns, thanks to more road construction), but this did not lead to an increase in the use of modern inputs or technical assistance. The decline in the percentage of *fincas* receiving any form of technical assistance, from 76% in 1990 to 34% in 1999, is mostly due to the neo-liberal policies leading to further shrinkage in the technical staff of the Ministry of Agriculture and Cattle and of the main agricultural research agency in the Amazon region (INIAP, near Coca). This means that virtually no one who arrived in the region since 1990 ever received any assistance for anything since arrival,

Very strong differences within the study site are also apparent, providing further support for taking the view in this paper of breaking down the analysis by sub-region. Thus Regions 1 and 2 experienced much more population growth than Region 3, manifest in data for all age-sex groups. Population growth, however, was clearly most rapid in Region 2, with a net increase of 4.2 people per *finca* (i.e., an average increase of 5 people per 50 ha compared to fewer than 2 people per 50 ha in Regions 1 and 3). The differential population increase is directly caused by the far greater process of subdivision in Region 2, from 1.1 to 2.6 on average, compared to Region 1 (where subdivisions rose from 1.2 to 1.9) and especially Region 3 (increase from 1.1 to only 1.3). The population increase in turn is related to the much greater increase in mean OFE in Region 2 (22.5 person-months) compared to Regions 1 and 3 (7-8 months each). Part of the decline in hired labor across the study region, is likely due to the fact that hired labor in 1990 was still primarily used to clear forest, while hired labor in 1999 was primarily for tending pasture or harvesting. The regional differences in the change in land titling are striking. The decline in agricultural input use was significant in Regions 1 and 3 but not Region 2, because the latter has the best soils, leading to more subdivisions and land clearing, more people, and more intensification of land use involving modern inputs. Finally, Region 1 experienced far more of an *increase in the accessibility* of *fincas* over the period due to the greater degree of expansion of the road network there. It is also worth noting, from the bottom line of Table 3, that in 1999 *fincas* in Region 3 were in general much farther from the nearest major community than those in Regions 1 or 2.

Community Infrastructure

Differences in community infrastructure across the three regions and between the four primary cities are shown in Table 5. The differences by region generally follow a North-South trend (i.e., Region 1 to Region 2 to Region 3). The total population living in communities was much higher in Regions 1 and 2 in both years compared to Region 3; however, Region 3 had the largest percent increase of people living in its small sample of communities. Compared to Region 3, Regions 1 and 2 had fewer people illiterate in 2000; Region 1 had fewer families in the towns dependent solely on agriculture; and overall, Region 1 had much higher proportions of its sample communities with infrastructure and organized community groups in both 1990 and 1999 than Region 3, and slightly higher proportions than Region 2 (notably in 2000 in piped water, agricultural markets, health centers, and cooperatives). These differences in infrastructure are related to the process of development in the region, which began in the north, tied to the discovery of petroleum near Lago Agrio. Subsequent exploration and discoveries of oil followed southward, as did the roads and then the people.

INFERENTIAL ANALYSIS (MULTILEVEL MODEL)
METHODOLOGICAL ASPECTS

Multilevel models were used to investigate a range of multi-scale factors potentially affecting land use change. The data hierarchy defined was based on *fincas* nested in sectors, and sectors nested within communities. (Pan et al. 2007) showed that nesting *fincas* within settlement sectors for these data using a multilevel model adequately captures spatial autocorrelation as well, in fact, better than a spatial econometric model that explicitly models the spatial correlation. Thus, settlement sectors are used here to capture the spatial context, while the nearest market community is used to capture economic, social, and physical context. Community-level variables are defined for each *finca* with reference to the nearest market community to test contextual factors that may influence LUCC decisions in the multilevel model.

To specify our multilevel model, we defined a 5x1 vector of land use for each *finca* representing the change in a specific land use category from 1990 to 1999. Thus, we define LUCC, *y*, for land use type *l* on finca *i* in sector *j* and community *k* as:

$$y_{lijk} = LU_{lijk,1999} - LU_{lijk,1990}$$

The five categories of land use modeled are forest, pasture, perennial crops, annual crops, and fallow, which are the land uses most likely affected by land management decisions on the *finca*. Two models are fit to this outcome variable: one that considers the outcome as a function of baseline characteristics, including land use in 1990; and the other that considers the outcome as a function of baseline characteristics plus changes over time. Thus, for $\boldsymbol{y}_{ijk}$ representing the 5x1 vector of land uses, model 1 can be written as:

$$\mathbf{y}_{ijk} = f(\mathbf{X}_{ijk,90}, \mathbf{Z}_{k,90})$$

$$\mathbf{y}_{ijk} = \beta_0 + \sum_{q=1}^{Q} X_{qijk,90}\beta_{qijk} + \sum_{p=1}^{P} Z_{pk,90}\beta_{pk} + \mathbf{e}_{ijk} + \mathbf{u}_{jk} + \mathbf{v}_k$$

where $X_{qijk,90}$ represents (q=1...Q) baseline characteristics measured at the *finca* level in 1990 with corresponding parameters β_{qijk}; $Z_{pk,90}$ represents (p=1...P) baseline characteristics measured at the community level in 1990 with corresponding parameters β_{pk}; and $\boldsymbol{e}$, $\boldsymbol{u}$, and $\boldsymbol{v}$ are vectors of random effects for the *finca*, sector and community levels, respectively. Model 2, incorporating both baseline and change variables, is similarly written as:

$$\mathbf{y}_{ijk} = f(\mathbf{X}_{ijk,90}, \mathbf{X}_{ijk,90-99}, \mathbf{Z}_{k,90}, \mathbf{Z}_{k,90-99})$$

$$\mathbf{y}_{ijk} = \beta_0 + \sum_{q=1}^{Q1} X_{qijk,90}\beta_{qijk} + \sum_{q=1}^{Q2} X_{qijk,90-99}\beta_{qijk} + \sum_{p=1}^{P1} Z_{pk,90}\beta_{pk} + \sum_{p=1}^{P2} Z_{pk,90-99}\beta_{pk} + \mathbf{e}_{ijk} + \mathbf{u}_{jk} + \mathbf{v}_k$$

where $X_{qijk,90\text{-}99}$ represents the (q=1...$Q2$) variables that change over time at the *finca* level, and $Z_{pk,90\text{-}99}$ the (p=1...$P2$) variables that change over time at the community level. For both models, $\boldsymbol{e}$, $\boldsymbol{u}$, and $\boldsymbol{v}$ are assumed to be independent with each following a multivariate normal distribution with mean 0 and variances Σ_e, Σ_u, and Σ_v, respectively (Σ is a 5x5 covariance matrix). The initial model fit was completed using iterative generalized least squares (IGLS), which provides maximum likelihood estimates when normality assumptions are met (Goldstein 1986). Parameter estimates were also verified using the Monte Carlo Markov Chain (MCMC) method (Browne 2003). Multilevel models were fit using MLwiN 2.02 (Rasbash et al. 2000).

Model selection proceeded in two steps. First, a collinearity analysis was conducted to remove redundant variables by examining a correlation matrix between variables. Second, a stepwise selection process was applied to a maximum model for Model 1, with variables removed one at a time using a likelihood-based criterion such that if the p-value for the contribution of a variable was greater than 0.25 it was removed. Once a final baseline model was determined, these variables were used as the basis for adding change variables with the same stepwise selection procedure in Model 2. Model assumptions were checked via residual analysis.

MODEL DIAGNOSTICS & VARIABLE SELECTION

Controversy usually surrounds the choice of variables used for modeling land use, thus we thoroughly describe our variable selection. Collinearity diagnostics for the maximum model identified several pairs of highly correlated variables that measure similar things. The number of subdivisions in 1990 was removed as 90% of *fincas* were comprised of just 1 farm (8% had 2 farms and only 1.7% had more than 2 farms). Similarly, in 1999 only 26 *fincas* (7%) reported *solares*, 14 of these being in Region 2, with 7 in one settlement sector near Joya.[v] We considered removing the number of females 12-49 in 1990 due to its high correlation with number of adult males (rho=0.57), female children 0-11 (rho=0.41) and male children 0-11 (rho=0.53) in 1990, but instead removed population density, which was highly correlated with all age-sex baseline and change measures of population (correlations all above 0.5). This was justified as measuring population by gender and age allows measuring both population pressure and household composition, while population density only captures population pressure. Holding a *certificado* in 1990 was highly correlated with the change in title (rho=0.53). Since virtually all *fincas* held a full land title or *certificado* in 1990, we removed *certificados* from model selection. Distance variables (kilometers to nearest major city and market community) were obviously highly correlated, but were also highly differential by region and clustered by sector (i.e., *fincas* in the same sector have nearly identical distances reported, while across sub-regions, *fincas* show some differences). Thus we will focus on the broader Region variable rather than include actual distances in the model. Community presence around a *finca* in a 5 km and 10 km radius was highly correlated, but the latter was less correlated with other community measures. Community infrastructure (presence of electricity, piped water, health care, transportation cooperative, and farming cooperative) and population (in 1990 and the change over time) were also highly correlated, while presence of electricity was highly correlated with all other community infrastructure (rho>0.6). Since all of these variables have never been tested empirically in terms of their effects on LUCC, we decided not to exclude them but rather to enter them into the model after a final set of non-community level variables was determined and in a forward-stepwise fashion (i.e., based on the likelihood ratio test, variables would be added if the test yielded a p-value less than 0.25). The following order was used, based on the theoretical importance of variables in capturing relevant aspects of community structure that might affect LUCC: number of communities within 10 km, community population in 1990 (Model 1 only), change in community population (Model 2 only), year community was established; availability of electricity, piped water, then health infrastructure; presence of transportation cooperative, community improvement organization, and agricultural cooperative.

Other variables that comprised the maximum model for Model 1 are listed in Table 1. Model 1 estimation ultimately led to the removal of the following non-community variables, originally included, based on selection criteria: soil quality, distance to water, males 0-11, females 12-49, person-months of hired labor, agricultural inputs, receipt of credit, technical assistance, and walking distance to the road. Community variables entering the final model were: number of communities within 10 km, existence of piped water, and existence of an agricultural cooperative. Selection of non-community variables for Model 2 resulted in the removal of the following change variables: females 0-11, females 12-49, person-months of hired labor, agricultural inputs, credits, and technical assistance. Selection of community variables had similar results as for Model 1, with the inclusion of the number of communities within 10 km, existence of piped water, and change in community population. Presence of an agricultural cooperative was not significant ($p=0.30$). The final model is shown in Table 6.

RESULTS

Following results from previous research (Pan et al. 2007) and the discussion above, only sector-level random effects were fit, as the sector-level variance adequately captures both spatial and community-contextual variance. To examine how variation is partitioned, an unconditional model (no variables included) was used to compute rho, the percent of variation between sectors. Variance partitioning allows us to define how much variation in LUCC can be explained by spatial / community context vs. all other *finca* characteristics. The unconditional model resulted in 8.5% of forest, 8.4% of pasture, 12.1% of perennials, 11.9% of annuals, and 4.9% of fallow variation being explained at by the sector (spatial/community) level. These percentages are not insignificant in that they: (1) re-enforce the importance of taking into account context in land use models since their exclusion may result in spurious results and conclusions; and (2) inclusion of contextual variables to LUCC models *can* help explain factors associated with change.

Model results (Table 6) are interpreted as the change in the number of hectares in a specific land use (the dependent variables) for a one unit change in the explanatory variable. The effects of variables that are centered are interpreted similarly, except that units are measured as deviations from the centered value (i.e., the average *finca*). Therefore, *fincas* larger (smaller) than the mean are expected to have a net reduction (increase) in forest cover and net increase (decrease) in all other land uses over time. For example, using the coefficients for Area of *Finca* in Table 6, a 57.1 ha *finca* (10 ha above the mean--see Table 1) will have an expected 2.7 ha increase in forest, 3.0 ha increase in pasture, 0.5 ha increase in perennials, 0.7 ha increase in annuals, and 1.2 ha increase in fallow land. However, a 42.1 ha *finca* (5 ha below the mean) will have an expected 1.4 ha decrease in forest cover,1.5 ha decrease in pasture, 0.25 decrease in perennials, 0.35 ha decrease in annuals, and 0.6 ha decrease in fallow. LUCC occurring on an average *finca* is determined by setting all baseline and change values for a *finca* to their mean values. Therefore, an average *finca* is expected to have a 5.8 ha decrease in forest from 1990-99 (12.2%), including a 0.12 ha decrease in perennials (0.2%), a 2.2 ha increase in pasture (4.7%), a 0.6 ha increase in annual crops (1.4%), and a 1.2 ha increase in fallow (2.5%). Note that the changes do not sum to zero due to the exclusion of the urban category, which will cause slight differences in the predicted sums away from zero. Model results for individual variables are interpreted sequentially below.

Natural Resource Endowments at the *finca* level strongly predict LUCC. *Finca* size, discussed above, significantly affects all LUCC observed (except for perennial crops). One of the most important results is the transition from specific land uses in 1990 to new forms of land use by 1999. These results can be interpreted in two complimentary, yet distinct, ways: (1) a particular land use in

1990 being transitioned into a separate land use in 1999; and (2) the likelihood of retention / expansion (or vice-versa) for land uses given the presence of other land use types in 1990. These explanations vary according to land use type – i.e., it is plausible that more fallow or annual crops in 1990 can lead to creation of virtually any land use, but it is unlikely that land for pasture and perennial crops in 1990 are being transitioned to forest over such a short period of time. In general, we can conclude, with the exception of 1990 forest cover, that land allocated to a specific use in 1990 is associated with a significant *decrease* in the respective land use type by 1999: i.e., a *finca* that has one more hectare than the 1990 mean for pasture will have a predicted 0.6 ha reduction in pasture and 0.4 ha increase in forest between 1990 and 1999. While this does not necessarily mean having pasture in 1990 causes reforestation, it does indicate forest retention is more likely on plots with large amounts of pasture in 1990 since these plots likely do not require additional clearing of forest. In general, pasture land in 1990 appears to be associated most to the creation of forest compared to other land uses, and is moderately associated with reductions in annuals and fallow land over time. Perennial land in 1990 is also significantly related to forest creation and perennial land reduction by 1999, with similar reasoning as explained for pasture above. Annual crops in 1990 are strongly associated with the creation of fallow and reductions in annuals by 1999, while more fallow in 1990 is associated with increases in both forest and perennial crops, and decreases in fallow by 1999. It is likely that these latter relationships are explained through direct transitions of land from annuals (fallow) to fallow (forest and perennials) due to aging of the plot and household through the life cycle.

Demographic and Socioeconomic Characteristics also strongly influence LUCC. Consistent with related research, the most important demographic variable is clearly the presence of adult males, both at baseline and in terms of the effects of its change over time. Land use research has often noted the importance of adult males as a key factor to predict deforestation and land subdivision, particularly compared to adult females (Barbieri and Carr 2005; Pan et al. 2007; Mena et al. 2006; Caldas et al. 2007) Each additional adult male in 1990 results in a 1 ha decrease in forest cover in the nine years following, while, in addition, an *increase* of one adult male from 1990 to 1999 results in another 0.6 ha decrease in forest cover. The number of adult males at baseline also significantly changes subsequent perennial cover (each male increases perennial crops by 0.7 ha), while the increase of each adult male in the 1990-99 interval results in an increase of 0.3 ha of land in both perennials and annuals.

Before discussing results for children, it is useful to briefly discuss the choice of variables used in the model as the inclusion of female children at baseline and the change in male children from 1990 to 1999 is a very parsimonious parameterization both statistically and conceptually. Statistically, the number of male and female children in 1990 is significantly correlated with each other and with total children in 1990. In addition, the change in the number of children by gender is not strongly correlated between genders, but they show stronger correlation with baseline measures than adults (i.e., the correlation between the change in adult males and adult males in 1990 is -0.23, while the correlation between the change in males 0-11 and males 0-11 in 1990 is -0.47). This indicates that inclusion of baseline and change variables for children of the same gender can result in instability of the estimates. Conceptually, 75% of children at baseline will be classified as adults by 1999, thus the number of male children in 1990 will be directly correlated with the change in adult males by 1999. Thus, female children at baseline is a much better predictor. In addition, given the importance of males in predicting LUCC, it is also more prudent to measure changes in male than female children over time. Results indicate that more (female) children at baseline was associated with reductions in forest cover as well as increases in fallow. In addition, changes in the number of (male) children was associated with a decrease in perennial crops.

Holding a full legal title (which may be considered a proxy for wealth) in 1990 and changes in title status are both associated with having increased land in pasture and less in perennials in 1999. This suggests that farmers with titles were already converting land from perennial crops by 1990, a process which was continuing to 1999, providing evidence for the forest transition hypothesis and indications that the beginning of a hollow frontier may be forming.

Three variables entered the model to capture the effects of Labor (beyond those of adult males on the *finca*, discussed above), Lifecycles and Agricultural Inputs. Baseline OFE is significantly associated with less land on the *finca* in perennials and fallow and more in forest, which is consistent with our previous work (Pan et al 2006): OFE reduces the amount of labor available to clear and work the land. Surprisingly, change in OFE over time was not significantly related to LUCC, yet was significant according to the likelihood ratio test (p=0.008). It is possible that large increases in OFE is sector-dependent (i.e., household members are more likely to engage in local labor employment if they are located near opportunities to do so, which is spatially dependent by sector). Year of *finca* establishment has been shown to be a better indicator for capturing LUCC cycles than traditional measures of age of the household head (Vanwey, D'Antona, and Brondizio 2007; Barbieri, Bilsborrow, and Pan 2005), and is manifested here mainly in its association with more land in perennials, other things equal.

Finally, change in *finca* subdivisions is strongly related to increasing the land in perennials. This shows that the new farms resulting seek to ensure some basic cash income for the household, so clear additional small areas for perennials. Note the variable is correlated with changes in population variables, such as change in adult males (ρ= 0.52). In the case of Ecuador, an increasingly number of *fincas* became subdivided in the 1990's, a process which is totally different from the Brazilian Amazon, and drives the changing plot cycle of land use and labor allocation. Pan et al. (Pan, Carr, and Bilsborrow 2004) demonstrated that the process of subdivision is not interpreted just as a division of land among progeny and others, but part of a larger process related to natural resource availability, proximity to markets, rural out-migration and off-farm employment opportunities.

Location and Accessibility factors are captured by two variables, study region and road access. The study region variable, with Region 3 as the reference group, was found to significantly contribute to model variance, as anticipated (likelihood ratio test, p= 0.04). However, only Region 2 demonstrated a significant difference in LUCC compared to Region 3, with 3.7 ha more of forest being cleared. This indicates that even after controlling for *finca* regional differences, forest clearing over time continues to be more rapid in Region 2. This reflects the better soil quality prevailing in the region (which did not enter the final model) as well as flat topography and more common subdivisions. Similar to region, road access significantly explains model variance in land use (p=0.054), with such access in 1990 responsible for significantly less forest cover nine years later (3.7 ha decrease). Achieving such access during the decade also results in a decrease of 2.7 ha of forest by 1999 and an increase in perennials (1.9 ha increase). One variable not collected from surveys was road quality (i.e., paved, dirt, etc.), which may further clarify the influence of road access on LUCC.

Community Context also has demonstrated linkages to LUCC. The number of communities within 10 km of the *finca* reflects the total size of the local population (including food demand) and infrastructure around the *finca*, so it is not surprising that it is strongly linked to a decrease in forest cover and increase in pasture. Changes in community population size (average increase of 1441) showed similar results for forest and pasture, but were not significant (note changes in males and subdivisions are already controlled for). However, changes in community population were significantly related to reductions in annuals, which follows the idea that annuals require more on-farm labor while larger communities tend to reduce on-farm labor by providing more opportunities for off-farm employment. Availability of piped water in 1990--an overall proxy for community infrastructure--along with getting piped water in the community during the decade, was associated with increases in annual crops and fallow land, perhaps responding to population growth effects of being located along main roads where pipelines were easier to install. Higher local demand for food would tend to lead to more annual crops grown.

DISCUSSION

The objective of this study was to investigate the factors at various levels influencing land use change from 1990 to 1999 in the Northern Ecuadorian Amazon (NEA). It is important to note that this is not a study of household-level land use decisions; rather, we examine decisions at a higher scale, that of the land plot or *finca* which may comprise several farm households. While the household level analysis is important, as farmers within *fincas* often grow different crops due to facing very different circumstances in their households and on their plots, the analysis at the *finca*-level is equally important as it facilitates observing and predicting factors influencing LUCC, and hence more directly measure the influence of those factors on a specific location over time.

Of the types of land use studied in the tropical forest setting, the type that changed most in the NEA in the 1990's was pasture. Note that the estimated forest cleared for an average *finca* in the model was 5.8 ha, which compares favorably to 5.6 ha in the raw data, indicating a good fit. The subsequent raw and model-estimated deforestation rates (2.4% and 2.5%, respectively) are higher than those reported by FAO for the same time period (1.2%). Mena et al (2006) estimated deforestation rates to be 2.6% from 1986-1996 and 1.1% from 1996-2002 for the same region, based on satellite data. Population growth estimates by INEC were also close to those reported in the study (INEC estimated 3.5% per year; study data indicate 3.7% per year). Changes in other forms of LUCC, namely pasture and fallow, provide evidence that increasing population continues to be a factor contributing to the ongoing conversion of forest to agriculture, primarily pasture. The findings here are more consistent with the peasant pioneer and household lifecycles, both of which refer to households, than to the hollow frontier theory. The findings also show some support for a neo-malthusian argument. The growth of population—both at the *finca* and community levels—has important impacts on forest conversion in the Ecuadorian Amazon, through multiple pathways. The increase in population on the farm increases household labor supply (with a lag), affects decisions to participate in OFE (and thus affects household income and wealth), and adds to consumption demands. The growth in community population also has influences on farm decisions, providing markets for farm products and places for farm members to work to diversify sources of household incomes. Examining the effects at these different in scales makes it possible to realize that population changes can affect LUCC in opposite directions: Thus increases in *finca* population appear to drive forest clearing, but it is possible that population growth at the community level (as indicated by total community population size and the number of households in a community) can attract members of farm households to migrate to or commute to work in towns, reducing the availability of farm labor, stopping forest clearing on the farm, and making it possible for forest cover to regenerate.

On the other hand, previous research has found that deforestation leads to more migration away from the plot { Barbieri and Carr 2005). It is likely that time censoring is occurring, in which the exactly timing of migration and forest clearing is not captured properly. Regardless, two processes are being captured with these variables: (1) as the farm becomes more developed (cleared), there is less demand for labor and young adults have more incentive to migrate away; and (2) on the other hand, as youths migrate away whether there is land or not, this alleviates pressures on the land and tends to reduce subsequent forest clearing.

In addition to population numbers per se, participation of farm household members in labor markets has a very strong effect on land transitions. The dramatic change in hired labor and OFE speaks to the impact of markets and economic opportunities on farm households in the region. However, another conundrum occurs in trying to tease out the influence of OFE on LUCC—namely, the farm families that participate in OFE in 1999 include many families with very small plots created through subdivision (see Pan et al., 2001). Some of the demand for labor was generated on larger farms, sometimes the larger part of the same *finca* as the small plots containing families seeking OFE. Indeed a cycle emerges: original settlers sell small parts of their plots to new migrants who they can then hire to help work their land. At the household level, this phenomenon can be seen clearly, but for aggregate *finca* data, the identification is difficult and the linkages between total *finca* population, population density, and number of males, for example, and OFE are obscured. Fortunately, it is clear that community factors including markets have strong impacts on land transitions that need to be studied in greater detail.

Descriptive results in this paper demonstrate important regional differences in LUCC patterns, in characteristics of *fincas*, and in the context in which the *fincas* operate. The results of the multilevel model demonstrate that a model explaining LUCC works for all regions, finding effects of factors at the lower or smaller scale, such as *finca* characteristics, as well as at the larger scale of the community context. At the latter scale, we have shown that context is important, accounting for approximately 10% of the variation observed for changes in forest, pasture, perennials and fallow even after controlling for other factors. From a statistical point of view, the results imply that farm-level LUCC models that do not take into account contextual factors likely suffer from misspecification, including potentially incorrect estimates of parameters for lower level/scale factors. Thus estimates of the effects of household or farm factors on LU decisions may lead to incorrect inferences (see, e.g., Raudenbush and Bryk 2002; Goldstein 2003). Nevertheless, the statistical strength of the contextual factors is not so strong, suggesting thatfurther research is needed to better understand the relationships between context and LUCC, including how to better specify context and variables capturing context for studies of land use on the frontier.

Related to context is the interplay between *fincas* and communities, which is usually considered a function of geographic accessibility. Foremost in this cross-scale dynamic is the participation by household members in OFE. Several researchers have demonstrated the importance of labor market participation in household land use decision-making (Mather, Needle, and Fairbairn 1999; Rudel and Roper 1996). The findings here support the results of cross-sectional studies of NEA data which found that higher levels of OFE are linked to increased market accessibility and opportunities for non-farm employment (Pan and Bilsborrow 2005; Pan et al. 2001). Previous work also has found OFE crucial to small-scale farmers (resulting from the increase in *finca* subdivisions) for sustaining livelihoods living on smaller plots. A greater number of subdivisions cause a decrease in land per farm household, inducing more families to participate in OFE and reducing pressures on the land, ultimately allowing the forest to partially regenerate.

Following this line of interplay between *fincas* and communities is the important role of migration from the *finca*. This out-migration has been shown to have a severe impact on the agricultural frontier to the extent most migrants are young adults who move to new locations along the frontier to create new farms, extending the frontier (Barbieri and Carr 2005). This is part of the peasant pioneer cycle. The present data cannot show the impact of migration directly because we do not know where the out-migrants from our sample *fincas* actually ended up, whether on neighboring plots, on new farms advancing the frontier and deforestation, or nearby towns. Unfortunately, project resources have not permitted tracing migrants from sample *fincas*. What we do know is that the ongoing, substantial process of subdivision is due to both (a) landowners of large plots, often those who came in the 1970's and 1980's, giving part of their plots to sons and daughters; and (b) sales of part of the *finca* to non-relatives, mostly new migrants coming from other parts of Ecuador. Carrying out an analysis of the forms of land use of these two groups could be instructive in clarifying whether they are adopting different land use strategies, for example, are the new migrants focusing on annual crops to guarantee their subsistence while they look for OFE? In addition, decomposing population growth into its three components--fertility, migration and mortality--could improve our understanding of the specific effects of population change on LUCC. While this impact is partially due to changes in total household labor supply, variations in the number of children at baseline and over time also alter land use transitions.

Some researchers have linked demographic change and especially differences in the age of the household head to the lifecycle stage of the household, but we see the lifecycle of the *finca* as the central stage, i.e., initially planting annuals for subsistence, adding cash crops (perennials), and ultimately transitioning to pasture, in a modified peasant pioneer cycle. We had explored several definitions of the traditional head of household age variable, such as average (and weighted by farm size) age of the household heads on a *finca*, and an age and area-weighted household-head person years on a plot, which essentially used epidemiological methods for computing age-weighted person-years of a household head operating a plot. However, none were as informative as the simple definition of year of *finca* establishment. The finding that year of establishment predicts land use, notably perennials, supports the idea that *finca* cohorts (Barbieri, Bilsborrow, and Pan 2005), which define blocks of time during which *fincas* are established, more accurately capture transitions than other definitions of time.

After controlling for the important regional differences indicated here, the cycle of land use over the 9-year observation period is one in which the usual transitioning of mature farms on the frontier into pasture has been arrested in the NEA, with two different tendencies: some large farms continuing the peasant pioneer cycle and clearing small areas for pasture or switching land from perennials to pasture, while other *fincas* that are subdivided have fewer heads of cattle and clear land for annuals and perennials. It is likely that both processes are occurring since 1999, with previous perennials (coffee plants as they become old and non-productive) being replaced by, for example, cacao, African palm, and palmito (heart of palm).

At the same time, OFE rose dramatically during the 1990's, making it possible for the many new families to survive with little land. A compelling question remains: What has occurred in the interim? Is there further subdivision occurring, and if so, with what effects on land use? In particular, is there increased intensification, including more use of modern inputs? It should be noted that the Ecuadorian Amazon, unlike Brazil, is essentially a closed frontier, with very few areas even potentially available for new colonization, given the very large areas set aside in protected areas or titled to indigenous populations. Therefore, the issue of technology needs to be examined in detail in future work. And by the same token, the importance of providing technical assistance to farmers may be more important than ever. But equally the issue of halting the destruction of the forest with its rich biodiversity and developing incentives to protect it cannot be ignored. Future studies could fruitfully pursue some of these remaining questions by building on methods proposed here, both in survey design and statistical modeling. Perhaps such integration would reduce barriers preventing more widespread incorporation of context to LUCC models.

NOTES

[i] Context is also sometimes used synonymously with Spatial Scale, which refers to the combining of individuals, households, communities, regions, etc. to create a hierarchy. However, spatial scales can only serve as a proxy for context.

[ii] Rudel further describes that although context appears to play a larger role in LUCC decisions, the ongoing dynamic of population migration, agricultural intensification, labor scarcity and demand by urban markets is consistent with the forest transition theory of Mather and Needle. Rudel claims that as farms intensify their production in the context of decreasing labor availability, farmers will increasingly fallow marginal land such that re-growth of forest exceeds clearing.

[iii] Most non-responses occurred where the farm did not yet show evidence of economic activity or lacked a dwelling and suitable respondent.

[iv] Satellite data are not used in this analysis as they were not available for all *fincas,* the images available are also for 1986, 1996, and 2002, rather than for the exact survey years. The satellite image data have been analyzed by Mena et.al (2006)

[v] While most of the *solares* are located near La Joya, it is important to note that there is likely an underestimation of the true number of *solares*. Field researchers only started recording *solare* presence when they realized the extent of their creation near La Joya. Thus, other areas near large or growing towns in the south likely have uncounted *solares.*

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TABLES

Table 1. Variables entered into multivariate multilevel model

	DESCRIPTION	CENTERED Y/N	CENTERED Value	MODEL INPUT Baseline	MODEL INPUT Change
NATURAL RESOURCE ENDOWMENTS					
Area	Area of the *finca* in hectares	Y	47.1	Y	n/a
LAND USE (hectares)					
Forest	Primary and Secondary Forest Regrowth over 7 years	Y	28.1	Y	n/a
Pasture	Land allocated to pasture	Y	7.8	Y	n/a
Perennials	Perennial crops (coffee, cacao, African Palm, fruit trees)	Y	6.5	Y	n/a
Annuals	Annual crops (rice, maize, sugar, yucca, potatoes, etc.)	Y	1.7	Y	n/a
Fallow	Young and old fallow (under 7 years)	Y	1.96	Y	n/a
Topography	% of the finca that is classified as flat	N		Y	N
Soil Quality	% of the finca classified as having black soil	N		Y	N
Distance to water	Distance from the *finca* center to nearest water edge	Y	0.74	Y	n/a
DEMOGRAPHIC & SOCIOECONOMIC CHARACTERISTICS					
Females 0-11	# of females aged 0-11 living on the *finca*	N		Y	Y
Males 0-11	# of males aged 0-11 living on the *finca*	N		Y	Y
Females 12-49	# of females aged 12-49 living on the *finca*	N		Y	Y
Males 12-49	# of males aged 12-49 living on the *finca*	N		Y	Y
Population Density	Total finca population per hectare	N		Y	Y
Land Title	% of finca claimed with full legal title	N		Y	Y
Certificate of Possession	% of finca claimed with a Certificate of Possession	N		Y	Y
Income in 1990	Log of income (in dollars)	Y	13.3	Y	N
LABOR, LIFECYCLES, & AGRICULTURAL INPUTS					
Off-Farm Employment (OFE)	In past 12 months, person-months of OFE, all adults on the *finca*	Y	3.5	Y	Y
Hired Labor	In past 12 months, total person-months of hired labor on *finca*	Y	6.2	Y	Y
Year *Finca* established	Earliest known year of *finca* establishment	Y	1980	Y	n/a
Subdivisions of the finca	Number of independently owned farms on the *finca*	Y	1.1	Y	Y
Solares	Number of solares on the *finca*	Y	0.3	n/a	Y
Agricultural Inputs	Any farm on the *finca* uses fertilizers or pesticides	N		Y	Y

Receipt of Credit	Any farm on the *finca* received bank credits or loans	N		Y	Y
Technical Assistance	Any farm on the *finca* received technical assistance (of any kind)	N		Y	Y
LOCATION & ACCESSIBILITY					
Region (1, 2, or 3)	*Finca* location in Region 1, Region 2 , or Region 3 as shown in Figure XXX	N		Y	n/a
Road Access	*Finca* road access: (1) Existed in 1990; (2) Existed by 1999; (3) Did not exist	N		Y	Y
Walking distance to the road	Average walking distance from HHs on the *finca* to the road edge	Y	2.8	Y	Y
Distance to major city	Distance to nearest major city (Lago Agrio, La Joya de los Sachas, Shushufindi, or Coca)	N		Y	n/a
Distance to Market Community	Road distance to nearest market community	Y	25.9	Y	n/a
COMMUNITY CONTEXT (Nearest Market Community)					
Communities within 5 km	# of communities within 5 km of the *finca*	N		Y	n/a
Communities within 10 km	# of communities within 10 km of the *finca*	N		Y	n/a
Year Community Established	Year community was established	N		Y	n/a
Community Population	Community Population size, in thousands	N		Y	Y
Piped Water	Piped water: (1) Existed in 1990; (2) Existed by 1999; (3) Did not exist	N		Y	Y
Electricity	Electricity: (1) Existed in 1990; (2) Existed by 1999; (3) Did not exist	N		Y	Y
Health Infrastructure	A Health Center, Health Stand, or Nurses office: (1) Existed in 1990; (2) Existed by 1999; (3) Did not exist	N		Y	Y
Transportation System	Bus / Ranchero service or Transportation Cooperative: (1) Existed in 1990; (2) Existed by 1999; (3) Did not exist	N		Y	Y
Agricultural Cooperative	A Farmers Association or Agricultural Cooperative: (1) Existed in 1990; (2) Existed by 1999; (3) Did not exist	N		Y	Y
Community Improvement Org.	A Community Improvement Organization: (1) Existed in 1990; (2) Existed by 1999; (3) Did not exist	N		Y	Y

Table 2. Regional *Finca* Differences in Percent Land Use / Cover [mean(sd)]

	All Fincas (mean = 47.1 ha)		Region 1 (mean = 49.3 ha)		Region 2 (mean = 47.7 ha)		Region 3 (mean = 43.9 ha)	
	1990	**1999**	**1990**	**1999**	**1990**	**1999**	**1990**	**1999**
Forest	59.8(27.2)	47.9(28.1)††	53.6(25.7)$^{\#\#}$	45.6(25.5)$^{\dagger\dagger,\#\#}$	54.1(26.1)$^{@@}$	38.6(26.9)$^{\dagger\dagger,@@}$	75.3(24.4)	65.6(24.5)††
Pasture	16.3(18.9)	21.2(20.7)††	17.7(18.1)$^{\#\#}$	20.3(19.2)	20.2(20.3)$^{@@}$	25.6(20.8)$^{\dagger\dagger,@@}$	8.4(14.5)	14.7(20.4)††
Perennials	14.1(11.7)	13.3(11.5)	16.3(12.8)$^{\#\#}$	14.4(10.5)$^{\#\#}$	15.6(11.9)$^{@@}$	15.8(13.2)$^{@@}$	9.3(8.3)	8.3(7.0)
Annuals	3.8(4.4)	5.0(6.2)††	4.5(4.7)$^{\#\#}$	5.1(7.9)$^{\#}$	4.1(4.8)$^{@}$	6.2(6.2)$^{\dagger\dagger,@@}$	2.5(3.0)	3.1(3.4)
Swamp	2.0(7.4)	5.2(9.8)††	2.3(8.3)	5.8(12.5)††	2.0(6.9)	5.7(8.1)††	1.7(7.3)	3.8(9.5)††
Fallow	4.1(9.8)	7.0(9.9)††	5.6(9.9)	8.7(11.0)$^{\dagger\dagger,\#\#}$	4.1(9.8)	7.5(10.6)$^{\dagger\dagger,@}$	2.8(9.4)	4.4(6.8)
Urban		0.3(2.6)		0.1(0.5)		0.6(3.8)		0.1(0.5)

* Region 1 and Region 3 have 99 fincas each, Region 2 has 163

†† p<0.01 comparing means in 1990 vs. 1999, † p<0.05 comparing means in 1990 vs. 1999 – for All Fincas and by Region

** p<0.01; * p<0.05 comparing Region 1 vs. Region 2 (Type III F-test with p-values adjusted for multiple comparisons using the Tukey-Kramer adjustment)

p<0.01; # p<0.05 comparing Region 1 vs. Region 3 (Type III F-test with p-values adjusted for multiple comparisons using the Tukey-Kramer adjustment)

@@ p<0.01; @ p<0.05 comparing Region 2 vs. Region 3 (Type III F-test with p-values adjusted for multiple comparisons using the Tukey-Kramer adjustment)

Table 3. Regional Differences in finca characteristics [mean (SD)]

	All Fincas		Region 1		Region 2		Region 3	
	1990	1999	1990	1999	1990	1999	1990	1999
Natural Resource Endowments								
Black Soil [a, b]	0.64(0.48)		0.63(0.48)$^{*,\#}$		0.78(0.42)$^{@@}$		0.46(0.50)	
Flat Topography [a, b]	0.39(0.48)		0.33$_{\#}$(0.47)$^{**,\#}$		0.63(0.48)$^{@@}$		0.12(0.33)	
Distance to Water (km)	0.8(0.94)		0.3(0.29)$^{\#\#}$		0.6(0.53)$^{@@}$		1.5(1.35)	
Demographic & Socioeconomic Characteristics								
Population Size	7.0(4.91)	9.7(7.52)††	7.5(5.86)$^{\#}$	9.2(7.46)††,**	7.8(4.75)$^{@@}$	12.0(8.21)$^{\dagger\dagger,@@}$	5.7(3.92)	7.1(5.93)†
Population Density (ppl/Ha)	0.16(0.11)	0.22(0.18)††	0.17(0.14)	0.20(0.20)†,*	0.17(0.10)$^{@}$	0.26(0.18)$^{\dagger\dagger,@@}$	0.13(0.10)	0.17(0.15)†
Children (<12 years)	2.6(2.50)	3.4(3.38)††	2.9(2.96)	3.1(3.15)**	2.8(2.45)	4.4(3.92)$^{\dagger\dagger,@@}$	2.2(2.04)	2.4(2.81)
Adult Males (12+)	2.5(1.89)	3.5(2.83)††	2.5(1.93)	3.5(2.94)$^{\dagger\dagger,\#}$	2.8(1.91)$^{@@}$	4.3(3.01)$^{\dagger\dagger,@@}$	2.1(1.73)	2.6(2.11)†
Adult Females (12+)	1.9(1.58)	2.7(2.21)††	2.1(1.85)$^{\#\#}$	2.6(2.26)†,*	2.2(1.50)$^{@@}$	3.4(2.32)$^{\dagger\dagger,@@}$	1.4(1.19)	2.0(1.82)††
Certificate of Possession [a, b]	0.47(0.49)	0.15(0.34)††	0.40(0.49)$^{\#\#}$	0.18(0.18)††	0.33(0.46)$^{@@}$	0.11(0.11)††	0.72(0.44)	0.18(0.18)††
Land Title (%) [a, b]	0.50(0.50)	0.52(0.47)	0.59(0.49)$^{\#\#}$	0.59(0.59)$^{\#\#}$	0.64(0.47)$^{@@}$	0.53(0.53)$^{\dagger\dagger,@}$	0.25(0.44)	0.39(0.39)†
# Cattle	6.3(11.8)	5.1(8.43)†	5.9(8.49)	4.1(4.13)†,*	11.3(35.46)$^{@}$	8.2(8.18)$^{@@}$	2.7(6.19)	3.0(2.98)
Labor, Lifecycles & Inputs								
Months of Hired Labor	5.9(8.38)	2.2(3.81)††	6.8(10.32)	2.4(3.70)††	7.5(14.87)$^{@}$	2.8(5.25)$^{\dagger\dagger,@}$	3.5(5.71)	1.4(2.55)††
Months OFE	3.3(7.58)	16.2(27.6)††	3.9(7.89)	11.0(19.26)††,**	3.4(8.26)	25.8(46.54)$^{\dagger\dagger,@@}$	3.5(6.01)	11.1(19.12)††
# Subdivisions	1.1(0.38)	2.0(1.65)††	1.2(0.48)	1.9(1.95)$^{\dagger\dagger,**,\#}$	1.1(0.39)	2.6(2.61)$^{\dagger\dagger,@@}$	1.1(0.26)	1.3(1.31)††
# Solares		0.2(1.17)		0.1(0.10)		0.5(0.52)		0.1(0.14)
Year Finca Established	1980(5.9)		1978(6.0)$^{\#\#}$		1980(5.1)$^{@@}$		1982(6.1)	
Inputs to land (%)	0.61(0.48)	0.49(0.50)††	0.65(0.47)	0.40(0.49)††,**	0.68(0.45)$^{@@}$	0.67(0.47)$^{@@}$	0.49(0.50)	0.29(0.46)
Received Technical Asst (%)	0.76(0.43)	0.34(0.47)††	0.82(0.39)$^{\#\#}$	0.32(0.47)††	0.80(0.40)$^{@@}$	0.31(0.46)	0.61(0.49)	0.39(0.49)††

Context & Accessibility								
Walking distance to road (km)	2.9(3.4)	1.3(2.1)††	2.5(3.1)	0.5(1.0)††,*,##	2.8(3.3)	1.3(1.9)††,@@	3.1(3.6)	2.3(2.7)††
Road Access to Finca (%)	46.0(49.9)	53.7(49.9)††	54.5(50.0)	71.7(45.3)††,**,##	44.2(49.8)	50.9(50.1)†	41.4(49.5)	40.4(49.3)
Nearest community (km) [c]	3.6(3.12)		3.5(2.93)		2.3(1.73)		6.0(3.54)	

* Region 1 and Region 3 have 99 fincas each, Region 2 has 163; a -- Proportion of fincas; b -- Weighted variables that indicate the proportion of the finca that has the characteristic if the finca is subdivided; c -- Only 3 fincas were linked to a community that did not exist in 1990. The next nearest community that existed in 1990 was only 3 km further.

†† $p<0.01$ comparing means in 1990 vs. 1999, † $p<0.05$ comparing means in 1990 vs. 1999 – for All Fincas and by Region

** $p<0.01$; * $p<0.05$ comparing Region 1 vs. Region 2 (Type III F-test with p-values adjusted for multiple comparisons using the Tukey-Kramer adjustment)

$p<0.01$; # $p<0.05$ comparing Region 1 vs. Region 3 (Type III F-test with p-values adjusted for multiple comparisons using the Tukey-Kramer adjustment)

@@ $p<0.01$; @ $p<0.05$ comparing Region 2 vs. Region 3 (Type III F-test with p-values adjusted for multiple comparisons using the Tukey-Kramer adjustment)

Table 4. Regional differences in changes (1990-1999) in land use and *finca* characteristics

	All *Fincas*	Region 1 (n=99)	Region 2 (n=163)	Region 3 (n=99)
Natural Resource Endowments				
LUCC (1999-1990)				
Forest	-11.8[††]	-8.0[††,*]	-15.5[††]	-9.7[††]
Pasture	4.9[††]	2.6	5.4[††]	6.3[††]
Perennials	-0.7	-1.9	0.2	-1.0
Annuals	1.3[††]	0.6	2.1[††]	0.6
Swamp	3.3[††]	3.5[††]	3.8[††]	2.2[††]
Fallow	2.9[††]	3.2[††]	3.4[††]	1.7
Urban	0.3[†]	0.1	0.6[†]	0.1
Demographic & Socioeconomic Characteristics				
Population Size	2.8[††]	1.7[††,#]	4.2[††,@@]	1.4[†]
Population Density (ppl/Ha)	0.06[††]	0.03[†,##]	0.10[††,@@]	0.04[†]
Children (<12 years)	0.9[††]	0.2[##]	1.6[††,@@]	0.2
Adult Males (12+)	1.1[††]	1.1[††]	1.4[††,@]	0.5[†]
Adult Females (12+)	0.8[††]	0.4[†,#]	1.2[††]	0.7[††]
Certificate of Possession [a, b]	-0.3[††]	-0.21[††,**]	-0.22[††,@@]	-0.54[††]
Land Title (%) [a, b]	0.0	0.01	-0.11[††,@@]	0.14[†]
# Cattle	-1.8[†]	-1.7[†]	-3.2	0.2
Labor, Lifecycles, & Inputs				
Months of Hired Labor	-3.9[††]	-4.5[††]	-4.7[††]	-2.2[††]
Months OFE	14.2[††]	7.2[††,##]	22.5[††,@@]	7.7[††]
# Subdivisions	1.0[††]	0.8[††,##,*]	1.5[††,@@]	0.2[††]
Inputs to land (%)	-0.1[††]	-0.24[††,#]	-0.01	-0.20[††]
Received Technical Asst (%)	-0.4[††]	-0.49[††,**]	-0.49[††,@@]	-0.21[††]
Context & Accessibility				
Walking distance to road (km)	-1.5[††]	-2.0[††,**]	-1.6[††]	-0.9[††]
Road Access to Finca (%)	0.1[††]	0.17[††,#,**]	0.07[†]	-0.01

Change from 1990 is the change in percent cover (1999 land use) – (1990 land use)

[††] $p<0.01$, [†] $p<0.05$ is the probability level that the observed change from 1990 to 1999 is different from zero (t-test)

[##] $p<0.01$; [#] $p<0.05$ is the probability level that changes in Region 1 are different from changes in Region 3 (Type III F-test)

[**] $p<0.01$; [*] $p<0.05$ is the probability level that changes in Region 1 are different from changes in Region 2(Type III F-test)

[@@] $p<0.01$; [@] $p<0.05$ is the probability level that changes in Region 2 are different from changes in Region 3 (Type III F-test)

Table 5. Regional Differences in Community Infrastructure

	REGIONS[1] I (n=17)	II (n=29)	III (n=9)	Lago Agrio	La Joya	Shushufindi	Coca
No. Communities in 1990	**17**	**29**	**8**				
Year Established	1973.8	1976.4	1981	1970	1970	1972	1953
POPULATION							
1990 - Mean (15, 24, 6 communities)	441 [b]	326 [c]	113	4000	3000	N/A	N/A
2000 – Mean	1555	1249	1803	28000	12000	18000	20000
% Change in Total Population	304%	363%	2297%	600%	300%		
PERCENT ILLITERATE (2000)							
Males	14.8	14.7	28.9	20	10	0.5	20
Females	17.8	16.9 [c]	35.6	40	10	0.5	20
FAMILIES PRIMARY ECONOMIC ACTIVITY							
Agricultural	79.1	87.9	89.2	55	60	20	50
Non-Agricultural (company / professional)	9.7	8.4	7.7	25	25	40	30
Merchant/Trader	4.1	2.9	3.1	10	10	20	10
Transportation company / Other	1.2	0.7 [c]	0.0	10	5	20	10
CATTLE OWNERSHIP							
Families with cattle, 1990 (%)	41%	48%	26%	30%	30%	80%	70%
# Heads, 1990	10.1	11.4 [c]	4.1	4	5	20	5
Families with cattle, 2000 (%)	50%	56%	53%	90%	60%	90%	90%
# Heads, 2000	11.1	11.4	11.8	15	20	10	10
COMMUNITIES WITH INFRASTRUCTURE, (% in 1990)							
Electricity (from power lines)	24 [b]	17 [c]	0	Y	Y	Y	Y
Piped Water	6	3	0	Y	N	Y	N

Church / Chapel	53	59	44	Y	Y	Y	Y
Agricultural Market	18	3	0	Y	N	Y	N
Health Center or Health Stand	29	21	11	Y	Y	Y	Y
Pharmacy / Botiquin	18	14	22	Y	Y	Y	Y
Primary School	82	83	67	Y	Y	Y	Y
Secondary School	35	10	11	Y	Y	Y	Y
Bus or Ranchera service	65 [b]	45	22	Y	Y	Y	Y
COMMUNITIES WITH INFRASTRUCTURE (% in 2000)							
Electricity (from power lines)	77 [b]	66	33	Y	Y	Y	Y
Piped Water	35	21	22	Y	Y	Y	Y
Church / Chapel	94	90	78	Y	Y	Y	Y
Agricultural Market	18	3	0	Y	Y	Y	Y
Health Center or Health Stand	53	35	33	Y	Y	Y	Y
Pharmacy / Botiquin (n)	41 (1.7)	55 (1.2)	44 (1.0)	Y (3)	Y (3)	Y (3)	Y (3)
Primary School (n)	94 (1.4)	100 (1.0)	100 (1.0)	Y (3)	Y (3)	Y (5)	Y (3)
Secondary School (n)	100 (1.0)	100 (1.0)	100 (1.0)	Y (8)	Y (4)	Y (2)	Y (5)
Bus or Ranchera service	82	83	89	Y	Y	Y	Y
COMMUNITIES WITH LOCAL ORGANIZATIONS (% in 1990)							
Community Improvement Organization	24 [b]	21 [c]	0	Y	Y	Y	N
Farmers Association	6	14	11	Y	Y	N	Y
Agricultural Cooperative	6	10	0	Y	Y	Y	Y
Transportation Cooperative	0	0	0	Y	Y	Y	Y
COMMUNITIES WITH LOCAL ORGANIZATIONS (% in 2000)							
Community Improvement Organization	47	48	22	Y	Y	Y	N
Farmers Association	24	21	22	Y	Y	Y	Y
Agricultural Cooperative	18	10	11	Y	Y	Y	Y

Transportation Cooperative	18	0	0	Y	Y	Y	Y

[1] Statistics are shown excluding the 4 main communities (Lago Agrio, La Joya de los Sachas, Shushufinda, Coca); [2] Assumes a conversion of 25,000 Sucres per US$; [a] $p<0.05$ for the comparison of Region I vs. Region II; [b] $p<0.05$ for the comparison of Region I vs. Region III; [c] $p<0.05$ for the comparison of Region II vs. Region III

Table 6. Final Multivariate Multilevel Model

	Forest		Pasture		Perennials		Annuals		Fallow	
	□ (SE)	p-val	□ (SE)	p-val	□ (SE)	p-val	□ (SE)	p-val	□ (SE)	p-val
Intercept	5.13	0.009	-2.84	0.129	-1.98	0.057	-0.87	0.173	0.23	0.814
	(1.970)		(1.872)		(1.040)		(0.639)		(0.996)	
NATURAL RESOURCE ENDOWMENTS										
Area of *Finca*	-0.27	0.015	0.30	0.004	0.05	0.370	0.07	0.030	0.12	0.053
	(0.110)		(0.103)		(0.058)		(0.034)		(0.060)	
1990 LAND USE										
Forest	-0.08	0.477	-0.12	0.262	0.01	0.907	0.00	0.998	-0.09	0.154
	(0.114)		(0.106)		(0.060)		(0.035)		(0.061)	
Pasture	0.43	0.000	-0.59	0.000	0.01	0.839	-0.05	0.180	-0.07	0.262
	(0.122)		(0.114)		(0.064)		(0.038)		(0.066)	
Perennials	0.31	0.028	0.16	0.213	-0.69	0.000	0.05	0.236	-0.07	0.392
	(0.139)		(0.130)		(0.074)		(0.043)		(0.076)	
Annuals	0.27	0.278	-0.31	0.177	0.11	0.418	-0.76	0.000	0.34	0.013
	(0.249)		(0.232)		(0.131)		(0.076)		(0.136)	
Fallow	0.47	0.001	-0.03	0.838	0.19	0.010	0.01	0.820	-0.90	0.000
	(0.142)		(0.132)		(0.075)		(0.044)		(0.077)	
% Flat Topography, 1990	-1.82	0.080	1.28	0.189	0.73	0.186	0.58	0.076	-1.09	0.049
	(1.042)		(0.974)		(0.548)		(0.325)		(0.551)	
DEMOGRAPHIC & SOCIOECONOMIC CHARACTERISTICS										
Males 12-49, 1990	-0.99	0.002	0.47	0.123	0.66	0.000	0.11	0.263	-0.10	0.602
	(0.327)		(0.305)		(0.173)		(0.100)		(0.182)	
Females 0-11, 1990	-0.60	0.051	-0.15	0.589	-0.01	0.946	0.04	0.659	0.37	0.028
	(0.306)		(0.285)		(0.161)		(0.093)		(0.169)	
% land in Title, 1990	-0.60	0.612	2.72	0.014	-1.87	0.003	-0.09	0.808	-0.14	0.827
	(1.186)		(1.107)		(0.625)		(0.366)		(0.639)	
Change in Males 12-49	-0.59	0.015	0.26	0.248	0.27	0.034	0.28	0.000	0.10	0.471
	(0.244)		(0.227)		(0.129)		(0.074)		(0.136)	
Change in Males 0-11	-0.15	0.477	-0.10	0.610	-0.19	0.086	0.08	0.225	0.12	0.317
	(0.215)		(0.200)		(0.113)		(0.066)		(0.119)	
Change in % land in Title	-1.00	0.345	1.79	0.071	-0.87	0.120	-0.03	0.932	0.73	0.207

	(1.062)		(0.990)		(0.560)		(0.326)		(0.578)	
LABOR, LIFECYCLES & AGRICULTURAL INPUTS										
Off-Farm Employment, 1990	0.12 (0.058)	0.040	0.00 (0.054)	0.999	-0.07 (0.030)	0.021	-0.01 (0.018)	0.505	-0.06 (0.031)	0.071
Change in OFE	-0.02 (0.014)	0.175	0.00 (0.013)	0.878	0.00 (0.007)	0.775	0.00 (0.004)	0.453	0.00 (0.007)	0.668
Year *Finca* established	-0.10 (0.082)	0.232	0.00 (0.077)	0.979	0.11 (0.043)	0.013	-0.02 (0.025)	0.472	-0.01 (0.044)	0.856
Change in Subdivisions	-0.39 (0.377)	0.307	-0.78 (0.351)	0.027	1.08 (0.199)	0.000	-0.01 (0.116)	0.945	0.15 (0.206)	0.469
LOCATION & ACCESSIBILITY										
Region 1 vs. Region 3	-0.49 (2.012)	0.810	-1.96 (1.897)	0.302	-0.02 (1.043)	0.984	-0.86 (0.659)	0.192	1.27 (0.958)	0.186
Region 2 vs. Region 3	-3.66 (1.839)	0.046	0.98 (1.732)	0.573	0.75 (0.954)	0.430	-0.35 (0.599)	0.564	0.31 (0.886)	0.727
Road Access, 1990 vs. None	-3.74 (1.147)	0.001	1.78 (1.083)	0.867	0.35 (0.594)	0.561	0.53 (0.378)	0.159	0.19 (0.538)	0.720
Road Access, 1990-99 vs. None	-2.66 (1.671)	0.111	0.82 (1.564)	0.600	1.91 (0.877)	0.030	0.51 (0.524)	0.327	-0.89 (0.863)	0.302
COMMUNITY CONTEXT										
No. Communities within 10 km	-0.29 (0.115)	0.011	0.22 (0.108)	0.046	-0.03 (0.060)	0.617	0.05 (0.038)	0.226	0.03 (0.055)	0.623
Change in Community Pop	-0.09 (0.107)	0.385	0.12 (0.101)	0.247	0.01 (0.056)	0.929	-0.08 (0.034)	0.027	-0.08 (0.053)	0.113
Piped Water on/before 1990 vs. None	0.70 (2.882)	0.807	-1.30 (2.705)	0.631	0.04 (1.506)	0.979	2.47 (0.918)	0.007	1.95 (1.446)	0.179
Piped Water bw 1990-1999 vs. None	0.36 (1.860)	0.845	0.06 (1.741)	0.971	-1.61 (0.975)	0.099	1.68 (0.585)	0.004	1.81 (0.959)	0.060

Outcome is defined as the change in land cover (1999 land use – 1990 land use). Joint tests with 10df were run for each of these varaibles: Region (Chi-sq = 17.07, p-val = 0.073); Road Access (Chi-sq = 18.818, p-val = 0.043); Piped Water (Chi-sq = 28.49, p-val = 0.002). The -2 Log L for this model was 10049.18.

FIGURE CAPTIONS

FIGURE 1. CONCEPTUAL MODEL OF LAND USE MANAGEMENT
IN PREPARATION

FIGURE 2. MAP OF STUDY SITE AND REGIONS
IN PREPARATION