Multilevel determinants of indigenous land use in the Northern Ecuadorian Amazon: a cross-cultural study.

Clark L. Gray[1*], Jason L. Bremner[2], and Flora Lu Holt[3]

[1]Department of Geography and Carolina Population Center, University of North Carolina at Chapel Hill
[2]Department of City and Regional Planning and Carolina Population Center, University of North Carolina at Chapel Hill

[3]Department of Anthropology and Curriculum in Ecology, University of North Carolina at Chapel Hill

* Corresponding author (cgray@email.unc.edu)

I. Introduction

Tropical forests are currently being lost at a rate approaching 0.5% per year (Achard et al., 2002), which represents one the most significant anthropogenic impacts on the global environment as well as a serious threat to biodiversity conservation (Brooks et al. 2002), carbon storage (Fearnside & Laurance, 2004), and the livelihoods of forest-dependent peoples (Byron & Arnold, 1999). The forests of the Amazon basin constitute the world's largest tropical wilderness area (Mittermeier et al., 2002), but over 20,000 km^2 are lost each year in Brazil alone (Laurance et al., 2004), primarily to agricultural colonization (Pichón 1997, McCracken et al., 2002), logging (Anser et al., 2004), and fire (Cochrane et al., 1999). Despite its designation as a wilderness area, many if not most intact areas of Amazonian forest are inhabited by indigenous peoples, and indigenous reserves have become an important conservation tool in the region (Zimmerman et al., 2001; Fearnside, 2003). Studies by biological and cultural ecologists suggest that traditional indigenous land uses such as shifting cultivation, agroforestry and forest product collection can be ecologically sustainable in the context of low population density and isolation from markets (Posey and Balée, 1989; Kleinman et al., 1995; Fujisaka et al., 1996; Lawrence and Schlesinger, 2001). However, indigenous forest peoples of the Amazon and elsewhere are facing rapid and profound socio-demographic, economic, and cultural change, the environmental impacts of which are unclear (Hammond et al., 1993; Rudel et al., 2002). This uncertainty has contributed to a polarized debate in the conservation literature on the proper role of indigenous peoples in conservation efforts, in which indigenous peoples have commonly been oversimplified as the heroes or villains of forest conservation (Redford & Sanderson, 2000; Schwartzman et al., 2000). Despite this high level of attention, few studies have systematically investigated the drivers or impacts of indigenous resource use (for exceptions see Godoy, 2001), and existing studies typically suffer from small samples of communities and households and lack multivariate analyses (e.g. Behrens et al., 1994; Henrich, 1997; Santos et al., 1997; Rudel et al. 2002). Studies that supplement ethnographic techniques by controlling for confounding factors and allowing generalization to the regional scale are important to better understand the patterns and diversity of indigenous resource use, and to inform the debates that will shape the future of indigenous livelihoods and Amazonian forests.

To better understand the drivers and impacts of indigenous resource use, project investigators Bilsborrow and Holt combined survey, ethnographic, and spatial approaches for a study of five indigenous populations in the Northern Ecuadorian Amazon (NEA) (Lu et al., 2004). Among Amazonian countries Ecuador has the highest rate of deforestation (FAO, 2001), and the five indigenous groups inhabit a forest frontier region where their traditional territories have steadily been encroached upon by oil exploration, road construction, and smallholder colonization (Pichón, 1997; Sierra, 2000; Vina et al., 2004; Bilsborrow et al., 2004). Quichua, Shuar, Huaorani, Cofán, and Secoya communities, encompassing peoples with diverse histories and diverse strategies for interaction with markets and outsiders, (Macdonald, 1981; Vickers, 1993; Lu, 2001; Rudel et al., 2002; Perreault, 2003) participated in an ethnographic data collection, a household and community survey, and collection of Global Positioning System points. As agricultural extensification is the greatest threat to the region's forests, this paper focuses on their agricultural land use, ranging from traditional shifting cultivation to colonist-style frontier agriculture. We use data from the nested household (n = 498) and community (n = 36) survey to investigate the geographic, cultural, demographic and economic factors influencing household cultivated area. The use of multilevel statistical models (Goldstein, 2003) allows us to systematically investigate the role of community context in household land use, including geographic variables derived from a spatial database. The cross-cultural data collection allows us to explore the effects of ethnicity while controlling for other correlated factors, and interpretation of the results is informed by ethnographic data collection from all five groups. With this article we hope to shift the debate away from the intrinsic conservationist nature of indigenous peoples and towards empirical assessment of the drivers and impacts of indigenous resource use.

II. Household and Indigenous Land Use at Tropical Forest Frontiers

This paper draws on studies of land-use and land-cover change (LULCC), and on cultural and political ecologies of indigenous livelihoods. Driven by concerns about biodiversity loss and carbon sequestration, there is now a large literature investigating the pattern and drivers of LULCC at tropical forest frontiers through spatial, survey and qualitative methods (Walsh and Crews-Meyer, 2002; Fox et al., 2003). This work has identified several key regional-scale drivers of tropical deforestation, including road construction, natural resource extraction, in-migration by colonists, commercial agriculture, and facilitating government policies (Lambin et al., 2001; Geist and Lambin, 2002). As the largest amount of forest clearing is done by smallholder agriculturalists, the household has emerged as a key unit of analysis. Characteristics of households that have been shown to influence forest clearing include demographic composition, human and physical capital, and economic status and activities (Pichon 1997; Godoy et al., 2001; McCracken et al., 2002; Vance & Geoghegan, 2002). Theory and intuition predict that the community and regional context of households should also influence their land use (Blaikie & Brookfield, 1986), but few studies have incorporated contextual variables to understand forest clearing (for exceptions see Shivakoti et al., 1999; Pan & Bilsborrow, In press). Most household-level LULCC studies have focused on colonists, who are responsible for the majority of forest clearing. Indigenous forest peoples, however, often control and inhabit the largest areas of intact forest, and intensification and extensification of their land uses can lead to considerable forest degradation (Simmons, 1997; Sierra, 1999; Smith, 2001).

We also draw on cultural and political ecologies of indigenous livelihoods. These studies employ primarily ethnographic and qualitative methods, and are often motivated by concerns for the human development and cultural survival of indigenous peoples. Cultural ecologists have documented the diversity of management practices, cultivars, and social relations that constitute indigenous systems of resource use, as well as the intricate agroecological knowledge that underlies them (Posey and Balée, 1989; WinklerPrins & Barrera-Bassols, 2004). Shifting cultivation (also known as swidden-fallow or slash-and-burn) is the primary source of calories for many forest peoples (Beckerman, 1987; Denevan & Padoch 1988; Fujisaka et al., 1996; Coomes et al., 2000). Shifting cultivators clear small plots from the forest, mulch or burn much of the vegetation, plant a diverse mix of crops for one or more agricultural cycles, and finally fallow the plots for multiple years. In the NEA, plots are typically mulched rather than burned due to the perennially moist climate. This article contributes to a rising tide of interest across human-environment research in swidden agriculture (Sprague & Oyama, 1999; Walker, 1999; Coomes et al., 2000; Gupta, 2000; Fox, 2000; Metzger, 2003; Rasul et al., 2004) and associated secondary forests (Moran et al., 2000; Perz & Skole, 2003; Neeff et al., 2005). Farther along a spectrum of market integration and intensification is colonist-style frontier agriculture, in which commercial and mono-cropping are more common though (shorter) forest fallows still play a key role (e.g. Pichón, 1997). At the far end of the spectrum are plantation agriculture and large-scale cattle ranching; these activities are fully integrated to the market and dominated by external capital (e.g. Walker et al., 2000).

Many forest frontiers have witnessed a transition from the first to the last of these, and political and cultural ecologists have described the mechanisms of these changes and their effects on indigenous peoples. Processes of frontier deforestation and land use intensification articulate with processes of population displacement, changes in land tenure, cultural change, market integration, colonist encroachment, and large-scale natural resource extraction, which together are driven by a combination of endogenous and exogenous forces (Gross et al., 1979; Behrens et al. 1994; Hammond et al., 1995; Santos et al., 1997; Steinburg, 1998). In the Ecuadorian Amazon, ethnographic studies have described how road construction and colonist encroachment have encouraged agricultural expansion and cattle raising in Quichua (MacDonald, 1981), Secoya (Vickers, 1993), and Shuar (Rudel et al., 2002) communities. These processes are not unidirectional, and Rudel et al. (2002) and Santos et al. (1997) have documented agricultural dis-intensification under changing market conditions. Though an important source of hypotheses for our research, these studies are mostly limited by small sample sizes which prevent multivariate analyses and generalization to the regional scale. An important exception is the work of Godoy (2001) and colleagues, who have used household survey data from indigenous forest peoples in Honduras and Bolivia to model determinants of forest clearing, private time preference, household production, and plant and animal knowledge.

The current study also draws on ongoing research in the NEA by Bilsborrow and Walsh (Walsh et al., 2001; Pan et al., 2004; Pan and Bilsborrow, In press) on the drivers of colonist land use and by Holt on resource management by the Huaorani (Lu, 2001). The study of colonists has collected panel survey data (1990 and 1999) from a probability sample of NEA farms and assembled a time-series of remotely sensed images, which have been linked for analyses using multilevel and cellular automata models. This work has documented rapid subdivision of household farms in the 1990s and increasing fragmentation of regional forests. Holt's work has described Huaorani hunting practices, interaction with oil companies, and management of forest resources. In two study villages the Huaorani were found to manage forest resources through a common property regime upheld through the exclusion of outsiders. The current project applied the survey methods of the colonist study and the ethnographic methods of the Huaorani study to investigate land use and market integration by a broad spectrum of indigenous populations in the NEA.

In conceptualizing land use decision-making by indigenous households, we adopt an interdisciplinary approach. In our study area, land use decisions are made most often by (usually male) household heads in consultation with other adult members of the household, and with an awareness of possibilities to participate in external markets and of alternative economic opportunities, both subsistence and market-oriented. These decisions are made in particular local and regional contexts, which are critical to understanding household land use (Shivakoti et al., 1999). To fully describe the nature of the household and the local context within our study area, we construct a series of cultural, demographic, economic, biophysical and geographical variables at both household and community scales. The use of multilevel statistical models allows us to explore these effects simultaneously.

III. Context of the Study

The NEA study area includes parts of the provinces of Sucumbios, Orellana, Napo, and Pastaza and borders the Ecuadorian highlands to the west and the Colombian and Peruvian Amazons to the north and east (Figure 1). The region's moist tropical forests are among the world's most biodiverse (Pitman et al., 2002) and are part of the Amazon tropical wilderness area (Mittermeier et al., 2002). Following the initiation of oil exploration and associated road construction in the 1970s, the region has experienced significant agricultural colonization from highland and coastal Ecuador, as well as deforestation, urbanization, and displacement of indigenous peoples (Brown & Sierra, 1994; Pichón, 1997; Sierra, 2000; Bilsborrow et al., 2004). The central and northern part of the study area is a zone of colonization which is dominated by smallholder agriculture but also includes several urban areas and two large oil palm plantations. Indigenous peoples inhabit portions of this zone as well as less accessible forested areas, including Yasuni National Park and the Cuyabeno Wildlife Reserve to the east and the Huaorani territory to the south. Despite protests by indigenous organizations and international calls for conservation action, oil exploration, colonization and selective logging continue to occur in these forested areas.

The total indigenous population of the Ecuadorian Amazon is approximately 100,000 or 30% of the regional population (INEC, 2003). The five populations included in the study are the largest indigenous populations of the NEA, and vary in population size, linguistic affiliation, history of contact, and economic activities (Lu et al., 2004). The lowland Quichua are the most numerous group, with an estimated population of 85,000 in the Ecuadorian Amazon. This group emerged in the aftermath of the violence and depopulation associated with the Spanish conquest, when the Andean language Quichua was adopted as a *lingua franca* in mission villages of mixed ethnicity (Macdonald, 1981). The Shuar are members of the Jivaroan language group and native to the southern Ecuadorian Amazon and adjacent areas of Peru (Rudel et al., 2002). Numbering approximately 45,000 individuals, they are the second largest indigenous population in the Ecuadorian Amazon, and have arrived to the NEA as agricultural colonists from the south.. The language of the A'i people or Cofán is believed by some to be unique, while others group it with the Chibcha family of Colombia (Califano & Gonzalo, 1995; Cerón, 1995). Many Cofán were displaced from their ancestral lands in the northern NEA by the initiation of oil extraction in the 1970s, and 500-600 Cofán now live in four settlements dispersed across the NEA. The Secoya belong to the Western Tucanoan linguistic family and number 700 people along the Aguarico River and its tributaries in the NEA and adjacent Peru (Vickers, 1993). Finally, the Huaorani, whose language is a linguistic isolate, are one of the least assimilated of Ecuador's indigenous peoples and were peacefully contacted for the first time in 1958 (Sierra et al., 1999; Lu, 2001; Rival, 2002). They are estimated to number 1500 and occupy the largest legal indigenous territory in Ecuador (679,130 hectares) in the south of the study area.

All five groups depend on shifting agriculture as a key component of their livelihoods, along with hunting, gathering, fishing, and waged and self-employment. Households typically cultivate multiple non-adjacent plots in a matrix of forest, which may be part of a larger area to which they have usufruct rights or a larger community area managed under a common property regime (Lu, 2001). Legally, lands in nearly all indigenous communities in the region are communally held or owned by the state, and many land transactions can only take place with approval of the community assembly. Cassava, bananas and corn are the subsistence staples, a portion of which is often sold at market. Coffee and secondarily cacao are the main cash crops, though the attractiveness of coffee has fallen with the regional market price over the last decade. Cattle production on non-native pastures is also an important form of commercial agriculture in the region, and cattle serve as an important form of savings for some households. Hunting is typically performed with shotguns for subsistence, though blowguns and other implements are still used in some communities and game is occasionally sold. Waged employment occurs most commonly with oil companies working in or near the indigenous territories, but self-employment is also common. Other important livelihoods strategies include the raising of small stock (i.e. chickens, pigs and fish), participation in tourism (Wunder, 2000), and the sale of timber, other forest products, and handicrafts.

IV. Data Collection

The data collection in 2001 involved two phases of fieldwork: (1) an ethnographic study in 8 communities, and (2) household and community surveys in 36 communities. For the ethnographic study, pairs of ethnographers were trained for two weeks and lived in each of 8 communities for 5 months. Study villages were selected of all five ethnicities from a set of communities familiar to the research team based on their willingness to participate. Both quantitative and qualitative data were collected from households and community leaders on a wide range of subjects, including demographic behavior, land use and agricultural production, time use and labor, household economics, and socioeconomic attitudes and values. Methods used included participant observation, structured interviews, spot-check time allocation (Mulder and Caro, 1985), post-hunt interviews (Lu, 1999), input-output household diaries, and life history interviews. The ethnographic data collection preceded the survey collection phase of the project and provided insights into people's decisions concerning reproduction, migration, land use, agriculture, and participation in the market economy.

This analysis focuses on the survey data, which were collected from communities and households following a two-stage sampling procedure. Controlled sampling (see Kish, 1965:494; Goodman and Kish, 1975:351) was used to select communities that represented a range of different conditions in terms of accessibility, biophysical characteristics, and population size and density. The number of communities from each ethnic group was chosen to be roughly proportional to the size of the different indigenous populations. Therefore Quichua and Shuar communities make up over half of the sample, with the other indigenous groups--Huaorani, Cofán, and Secoya--sampled in smaller numbers to capture different degrees of exposure to colonization as well as different cultural characteristics. Table 1 presents sample totals by ethnicity for sampled communities and households.

Within selected communities, households were sampled according to two rules. In most of the 36 communities, due to the small number of households per community, all households were interviewed. In larger communities, a maximum of 22 households per community was determined sufficient to normally yield 20 completed interviews[1]. A sample frame was prepared by the field supervisor and the community leaders showing the location of each occupied dwelling, and 22 households were randomly selected from this map-listing. This differential sampling procedure leads to different probabilities of selection for households from large versus small communities. Selection weights were calculated for each household for use in this analysis. The original sample included a total of 565 households, including the eight communities already covered in the ethnographic phase, plus an additional 28 communities covered in the survey. Due to refusals and temporary absences of household members, the number of completed household interviews (both head and spouse) is 498. The refusal rate was lower than 10%, which is low for a survey of indigenous communities that have traditionally resisted such research efforts. This was due to good relationships established with indigenous federation leaders during the ethnographic fieldwork, prior visits of senior project staff to many of the prospective survey communities, the cultural sensitivity and interviewing skills of the Ecuadorian project coordinator and field supervisors, and the receptivity of most indigenous community leaders and residents.

Interviews were separately conducted with the male and female household heads (or the head and spouse) by male and female interviewers. The questionnaires used for data collection are similar to the instruments used with colonists in the study area in 1990 and 1999, allowing for future comparisons of the factors influencing land and resource use by the two populations. The male household head's questionnaire covered household location, origin and migration of the head, land tenure and use, production and sale of crops, raising of cattle, off-farm employment, hunting and fishing, technical assistance and credit, perceptions of environmental

[1] A household was defined as individuals sharing a dwelling, which typically included a nuclear family and some extended family members. The ethnographic study confirmed that this was an appropriate unit to understand land use decision-making.

contamination, and attitudes and aspirations for children's education and permanence in the community. Previous studies of household land use have found respondents' reports of current land use to be highly accurate (Vadez et al., 2003). These reports draw on indigenous peoples' sophisticated understanding of their local environments, as documented by ethnoecological studies (Posey and Balée, 1989; WinklerPrins & Barrera-Bassols, 2004).

Besides covering the same topics in connection with migration origins, the environment and aspirations, the females head's questionnaire included a household roster listing all members of the household by age, sex, education, marital status, etc., and also asked about out-migration from the household; household assets; and fertility, mortality and health. If either the female or male head of household was absent due to death, divorce, or migration, both questionnaires were implemented with the person available to ensure complete data collection for each household. A community level survey was also implemented with village leaders in each community. The questionnaire covered a variety of topics, including: land title history, hunting and fishing resources, population (number of households as well as in- and out-migration), community infrastructure, location and access to external facilities (markets, health centers, secondary schools, etc.), contact with other communities, and contact with outside organizations and individuals.

Spatial data, including Global Positioning System (GPS) coordinates and satellite imagery, were acquired and integrated in a Geographic Information System (GIS). GPS coordinates were collected in order to (1) identify the geographic location of dwellings and a sample of agricultural plots; (2) validate land-use and land-cover classifications; and (3) identify the location of roads, markets, schools, and other key community and regional infrastructure. Landsat Thematic Mapper satellite imagery with 30 meter spatial resolution has been acquired, processed and classified for the entire study area, and a time series of images has been analyzed for the zone of colonization (Frizzelle, 2005). The classified imagery has provided an important independent data source to compare with household survey results on land use, and the GIS has also been used to derive key geographic variables for the analysis.

V. Descriptive Results

Table 1 displays descriptive results by ethnicity from the household survey data for the 478 households included in this analysis[2], including information on characteristics of households, household heads (typically male)[3], and household farms. Ethnicity is defined as observed ethnicity of the male head, as 14 of the 36 communities and 27 of the 478 households were of mixed ethnicity. Cases are weighted for this and other analyses to reflect the probability of selection within communities and of successful participation. Based on previous knowledge of the ethnic groups, Bilsborrow and Holt hypothesized that they would be arrayed along a spectrum of assimilation, agricultural expansion, and market integration in approximately the following order: Shuar > (Quichua ≈ Secoya) > Cofán > Huaorani. This hypothesis is largely confirmed by a review of the descriptive data.

The Huaorani were expected to be least assimilated group, and this is confirmed by their low levels of education and knowledge of Spanish, distance from urban centers, and large households, which primarily reflect extended family structures. Many households had recently participated in subsistence hunting, but few participate in sales of timber or crops or use of credit. Interestingly, wage labor *is* common among the Huaorani, most often with nearby oil companies. Agricultural practices reflect a traditional and extensive shifting cultivation system in that cattle ownership is very rare, few households claim to have private or usufruct land rights[4], and agricultural parcels are widely dispersed, only recently cleared (suggesting longer fallow times), and encompass a small total area. Huaorani households cultivated approximately three parcels on average, a number that was similar across the ethnic groups. The Cofán were expected to be the next-most assimilated group. Though on average they live much closer to urban centers, their relatively low levels of Spanish fluency, private land tenure, cattle ownership, timber sales, and credit use confirm that they are a relatively less-assimilated group.

The livelihoods of the Quichua, Secoya, and Shuar are clearly more market-oriented. The Quichua commonly sell crops and timber, most households claim to have private land rights, and plots are on average three times older than those of the Huaorani, reflecting more intensive land use. Though Quichua households are relatively distant from urban centers, they often live along

[2] Of 498 completed interviews, 20 cases were dropped from this analysis, including 13 households that had no farm or a farm smaller than 0.1 hectare, and 7 households with missing data for the regression predictors.
[3] Data on male heads was selected over female heads or spouses where both were present as males are more likely to be the decision-makers about household agriculture; this is confirmed by data from the female interviews on household decision-making.
[4] Male heads were asked: "Do you have a farm with your own land for cultivation?" "Yes" implies usufruct rather than communal land rights.

rivers or roads with frequent transportation. The Shuar and Secoya appear to be the most assimilated overall. The Secoya are the most likely to own cattle, to have a secondary education, to speak Spanish, to use credit, and to claim private land tenure, though all households continue to participate in hunting. The Shuar are the most likely to have sold timber and the least likely to have hunted in the past two weeks, and frequencies of other activities all reflect a high level of assimilation and relatively intensive land use. The recent migration of the Shuar from the southern Ecuadorian Amazon is reflected in the small proportion of household heads born in their community of residence.

These characterizations of the five indigenous groups are also supported by analysis of time allocation data from the ethnographic data collection and of remotely sensed data on land-cover change. Time allocation data were collected by randomized "spot checks" for all individuals in the eight ethnographic communities. The Shuar were found to spend the most time in commercial activities and the least time in subsistence activities (together with the Secoya), whereas the Huaorani were found to spend the least time in commercial activities (together with the Cofán) and the most time in subsistence activities (Holt et al., unpublished). Frizzelle et al. (2005) analyzed land-cover change from 1996-2002 for two colonist and two indigenous communities using imagery from Landsat Thematic Mapper. This analysis found that little deforestation occurred in an isolated indigenous community, that some deforestation in a more accessible indigenous community was attributable to colonist encroachment, and that the most change occurred in the colonist communities.

VI. Regression Hypotheses

To better understand household and community-level influences on indigenous land use, we construct cross-sectional multilevel regression models of the cultural, geographic, biophysical, demographic and economic determinants of household cultivated area. We select total cultivated area (summed across all parcels) as reported by the respondents to be the dependent variable because it is an important measure of both household economic activity and impact on the forest[5]. Table 2 presents descriptive statistics for the dependent variable and the predictors, together with the hypothesized direction of effects. These predictions draw on numerous previous household studies of frontier land use, including Pichón (1997), Godoy

[5] Fallowed areas that are not currently producing are not included in this total.

(2001), McCracken et al. (2002), Vance and Geoghegan (2002), Walker et al. (2002), and Pan and Bilsborrow (In press)

As described above, ethnicity is expected to play a key role in household decision-making, and communities were selected specifically to capture this source of variation. Ethnicity of the head is thus included as a set of indicator variables. Consistent with the set of predictions described above, Shuar and colonist ethnicity are expected to have positive effects relative to Quichua, the reference category, and Cofán and Huaorani ethnicity are expected to have negative effects.

Variables at the community level capture important contextual effects on land use, including accessibility and economic opportunities in the community. Accessibility reflects transaction costs for participation in the market and barriers to the flow of information about the outside world[6] (Chomitz & Gray, 1996). As market participation is a primary motivation for increasing the cultivated area (along with subsistence), we expect cultivated area to increase with bus service to the community (a key form of transportation in rural areas) and to decrease with travel time to the preferred market[7], distance to the market[8], and distance to the closest city[9]. The presence of an oil company in or near the community is likely to increase accessibility due to improvements in infrastructure and movement of vehicles, increase local demand for staple crops due to the presence of oil workers, and increase exposure to capital in the form of "development projects". Thus the presence of an oil company is likely to also increase cultivated area, particularly when controlling for household participation in wage labor. At the community level we also control for the presence of a store, as the opportunity to spend cash locally might also encourage cash cropping.

At the household level we include a series of biophysical, demographic, and economic variables to capture their direct influences on household land use. Suitability of the environment for cultivation on household lands, represented by three biophysical variables, is likely to have a positive effect on cultivated area given the importance of commercial agriculture and alternative economic opportunities such as wage labor. Thus cultivated area should increase with flat land

[6] These accessibility variables may also capture some of the effects of circumscription and colonist encroachment as independent measures of these factors were not available.
[7] As reported by community leaders to the preferred local market.
[8] Straight-line distance derived from the GIS.
[9] None of the correlations among these three variables exceed 0.5, thus collinearity is not likely to be a problem.

and self-rated soil quality and decrease with uneven topography[10]. We also include predictors for components of the household's lifecycle stage, human capital, and demographic composition. Cultivated area is expected to initially increase with age and years of residence by the head[11] in the community and then eventually to stabilize over the life of the household and farm (Walker et al., 2002). Household human capital in form of level of education and Spanish fluency by the head should also encourage larger cultivated area as they facilitate interaction with the market and exposure to commercial livelihood strategies (Godoy et al., 1998). The demographic composition of the household affects both subsistence needs and the labor supply for agriculture. Area should increase with the number of women and children primarily because of the former, and with the number of men for both reasons as they are the primary agricultural laborers in commercial agriculture.

The economic status and non-agricultural livelihood activities of the household also have important impacts on land use[12]. Households' usufruct land rights, manufactured assets, electrification, and use of credit all reflect a certain degree of access to capital, a commercial orientation, and/or connections to the outside world, and are likely to have a positive impact on cultivated area. Households claiming "private" or usufruct land rights are likely to have more flexibility in expanding the cultivated area, and many loans were reported to have been invested directly in agricultural production. Agricultural assistance is also likely to increase area as it is typically targeted to commercial production, and recipients are likely to have more contacts with the outside world. Accessibility is likely to mediate the effects of many household variables, and we test for a subset of cross-level interactions below.

VII. Regression Analysis

Multilevel or hierarchical linear models extend multiple regression to include predictors and error terms at multiple levels of a hierarchical or nested data structure (Goldstein, 2003). In the context of a household study, the use of multilevel models controls for clustering and allows the unbiased estimation and testing of community-level effects. Despite widespread discussion of the importance of contextual effects in household decision-making, few studies of household

[10] Respondents were asked whether flat and/or uneven land was present in the area they cultivated, thus these indicators are not mutually exclusive.
[11] These variables are correlated at r = 0.4; collinearity does not appear to be a problem in the regression model.
[12] Adding these variables does not substantively change the nature of effects by the biophysical, lifecyle, demographic and human capital variables.

land use have properly accounted for the spatial structure of their data, and fewer have used multilevel models to explicitly examine contextual effects (for a counterexample see Pan & Bilsborrow, In press).

The two-level multilevel model has the following form:

Level 1: $Y_{ij} = \beta_{0j} + \beta'_{ij}X'_{ij} + r_{ij}$ where $r_{ij} \sim N(0, \sigma^2)$

Level 2: $\beta_{0j} = \gamma_{00} + \gamma'_j W'_j + u_{0j}$ where $u_{0j} \sim N(0, \tau_{00})$

Combined: $Y_{ij} = \gamma_{00} + \beta'_{ij}X'_{ij} + \gamma'_j X'_j + r_{ij} + u_{0j}$ where $r_{ij} \sim N(0, \sigma^2)$ and $u_{0j} \sim N(0, \tau_{00})$

In the level 1 equation Y_{ij} is the outcome for household *i* in community *j*, β_{0j} is a community-specific intercept, β'_{ij} is a vector of household-level coefficients, X'_{ij} is a vector of household-level predictors, r_{ij} is the household-level error term, and σ^2 is the variance of r_{ij}. In the level 2 equation the intercept β_{0j} is decomposed into γ_{00}, a common component, u_{0j}, a community-specific component or error, and $\gamma'_j W'_j$, where γ'_j is a vector of community-level coefficients, W'_j is a vector of community-level predictors, and τ_{00} is the variance of u_{0j}. The final equation combines the two levels by substituting the formula for the intercept back into equation 1.

As the distribution of cultivated area is skewed to the right, we model the natural logarithm of area (log-area) in order to prevent problems with large outliers and heteroskedasticity. Table 3 presents the results of the multilevel regression models. Model 1 is the unconditional or intercept-only model, which reveals that as expected there is significant variance in log-area at the community level, which accounts for 23% of the total variance (the intra-class correlation). Model 2 adds predictors for ethnicity of the head with Quichua as the reference category. Consistent with our predictions, Huaorani and Cofán ethnicity have large negative effects on log-area, though Shuar does not have a significant effect. Controlling for ethnicity reduces the intra-class correlation in log-area to 13% as ethnicity is highly clustered at the community level. Model 3 adds the community level predictors: three of the four accessibility variables (all but travel time) have significant effects in the predicted direction, as does the presence of an oil company but not the presence of a store. The intra-class correlation is further reduced to 3%, and the community-level error variance becomes only marginally different from zero, suggesting that nearly all community-level variance has been explained.

Model 4 adds biophysical, demographic, and economic variables at the household level. Contrary to predictions, only two of three biophysical variables were significant predictors of log-area. Among demographic variables, lifecycle variables (age and the residence time of the head) showed the predicted pattern, lack of any formal education had a significant negative effect, and the number of adult men had a significant positive effect. Spanish ability and the number of women and children did not have significant effects. Among characteristics of the household economy, assets, credit and wage labor had the expected effects but the effects of household electrification and agricultural assistance were not significant. Interestingly, the effects of Huaorani ethnicity become non-significant when other characteristics of the community and household are controlled. Model 5 retains significant and marginally significant predictors from Model 4 in a trimmed model.

We also tested cross-level interactions between accessibility variables (distance to urban and market) and significant household-level predictors that might be mediated by accessibility. We expected that ‘private’ land tenure, the number of adult men, and education might be more important for households near urban areas or markets, and that wage labor might have a larger effect in more distant communities where needs for cash income are less and employment-related absences might be longer. Only the market-distance-by-private-land and urban-distance-by-wage-labor interactions were significant or marginally significant; these are presented in model 6. The effect of wage labor on cultivated area was marginally more negative for households distant from cities, as expected, and this interaction absorbed most of the main effects of these two variables. Also as expected, private land tenure has a larger effect closer to markets, accounting for most of the effect of the tenure variable.

Tables 4 and 5 present a decomposition of the cultivated area crossed with values of the predictors. The total cultivated area is decomposed into the area in staple crops (cassava, bananas, and corn), coffee, pasture, and all other crops, with a comparison of group means. Descriptive results on crops sales (not shown) reveal that staple crops are sold by a large proportion of households. Unlike the regression analysis described above these comparisons do not control for the effects of other variables, but they do give some insight into the mechanisms of the effects. Overall a large proportion of cultivated area (57%) is devoted to purely commercial crops (coffee and pasture), though a substantial proportion of other crops are likely to be sold at market as well. Table 4 presents the decomposition by ethnicity, revealing that the Quichua cultivate the largest areas in staples, the Shuar in coffee, and the Secoya in pasture. The Cofán have some coffee, but the Huaorani participate very little in coffee and pasture. Table 5 presents the decomposition by categories of values of the predictors from the trimmed model.

Interestingly, accessibility variables are less related to staple area than areas of other crops, age of the head is significantly related to coffee area, and the number of men is most significantly related to area in staples. Exploratory models of log-area in staples (not shown) suggest that the number of men and good soil increase staple area and participation in wage labor decreases it.

VIII. Discussion

Though limited by the cross-sectional nature of the analysis, the results of the regression give substantial insight into the processes influencing household decision-making about agriculture and forest clearing. The significant effects of ethnicity validate the cross-cultural nature of the design and suggest that generalizations about indigenous resource use may be limited by fundamental differences between ethnic groups. In the case of the Huaorani but not the Cofán we are able to explain these differences by controlling for a series of household and community-level variables. A set of reduced form models (not shown) reveal that accessibility variables and 'private' land tenure are particularly important in explaining the effect of Huaorani ethnicity. Decomposition of the agricultural areas reveals that the most assimilated groups appear to specialize in different forms of cash cropping: the Quichua in staple crops and secondarily in coffee, the Shuar in coffee and secondarily in pasture, and the Secoya primarily in pasture.

Contextual variables at the community level were also important predictors of cultivated area, validating the multilevel aspect of the design. As in many studies of household land use, we find accessibility to be an important stimulant of forest clearing. The multi-dimensionality of this concept is emphasized by the significant effects of three separate measures of accessibility, suggesting that studies that control for only one measure may not fully control for the effects of access. Also at the community level, the marginally significant positive effect of oil company presence (both with and without controls for participation in wage labor) suggests that oil company activities may stimulate forest clearing above their direct impact on the forest or on households through opportunities for wage labor. As discussed above, possible mechanisms for this effect include unmeasured differences in accessibility, local food demand, and distribution of "development" assistance.

At the household level, the non-significance of two of three biophysical variables in determining cultivated area is interesting and contrasts with earlier finding for colonists as well as the known heterogeneity of the NEA environment in terms of agricultural productivity. The key difference may be that indigenous communities and agricultural parcels are selectively located in the most productive parts of the landscape, whereas little choice is available for colonists in the relatively densely-populated zone of colonization. Nonetheless uneven topography had a marginally significant effect in the expected negative direction. Both lifecycle variables, short residence time and youth of the head, had the predicted negative effects on area. The impact of youth appears to be primarily on area in coffee, which is likely a period effect as the price of coffee has recently declined. Education of the head has a positive effect on area as expected, but the only significant contrast was between any formal education and lack of any education. It may be that only minimal school-related knowledge (or knowledge of Spanish, which had no effect) is sufficient to facilitate participation in agricultural markets. Alternatively lack of formal education may be related to the context of heads' childhoods as many heads were not born in their community of current residence. The only effect of household composition was through the number of adult men, which appears to most affect the area in staples. This finding suggests that subsistence demands (reflected in the number of women and children) are not an important determinant of cultivated area, and that extra labor in the form of adult men is invested in the cultivation of labor-intensive staple crops, most likely as cash crops.

Household economic status and non-agricultural activities are also important determinants of cleared area, as reflected in the significant effects of 'private' land tenure, household assets, receipt of a loan, and participation in wage labor. We take a cautious approach in interpreting these effects as unobserved characteristics of households could potentially influence both these variables and cultivated area, and feedbacks may occur between agricultural activities, other activities, and economic status. Nevertheless these results suggest that changes in land tenure (particularly near market communities), expansion of small-scale capital markets, and wealth accumulation are important component processes of agricultural expansion and market integration. Consistent with effects for colonists, participation in wage labor had a negative effect on cleared area which is most pronounced for isolated households, presumably due to decreased labor availability and demand for cash income. These effects emphasize the integration of indigenous household economies with wider markets, as well as the continuity between the experiences of indigenous and colonist households at the frontier.

IX. Conclusion

The results of the descriptive and regression analyses support the role of market integration as the key process influencing agricultural land use by indigenous households in the NEA. Descriptive analyses show that a large proportion of total cultivated area is devoted to commercial crops, that agricultural expansion is connected to other processes of market integration, and that commercial specialization is connected to ethnicity. The regression analysis reveals that access to external markets, to market-driven oil companies, to market-influenced tenure systems, to credit markets, to wealth in the form of market goods, and to labor markets are all important determinants of forest clearing. Indigenous communities in the NEA are likely to become more market-integrated over time as expansion of the zone of colonization leads to further growth of regional markets, and as continued oil exploration directly and indirectly promotes forest clearing. Demographic, lifecycle, and human capital effects are also important determinants of cleared area, and as indigenous populations continue to grow and primary education becomes more common these processes are also likely to stimulate further forest clearing.

Though market integration may seem inevitable in a globalizing world, the minimal landscape impacts of the Huaorani and Cofán across their large territories show that deforestation is not inevitable in indigenous communities and suggest that, in the right context, indigenous peoples can be effective stewards of tropical forests. As market integration is driven in part by the desires of indigenous households for cash income and market goods, policies to discourage market participation are not likely to be successful or to meet international goals for conservation-with-development and self-determination of indigenous peoples. However, environmentalists and indigenous peoples in the NEA have found common cause in protests against the continued expansion of oil exploration and associated transportation infrastructure into forested indigenous territories and national parks. Oil companies' disbursement of extensive "development funds" in isolated areas have effectively purchased the cooperation of many indigenous communities, but several indigenous groups have now reached an impressive level of political organization that should facilitate promotion of their collective and long-term interests (Perreault, 2003). Unfortunately, the enormous appetite and dependence of the Ecuadorian state on oil revenue means that national (and commercial) interests are likely to often overrule local and indigenous concerns.

This analysis demonstrates the power of an approach to indigenous resource use that draws on LULCC research and combines ethnographic, survey, and spatial methodologies. Household data collection from a wide spectrum of indigenous communities across the region allows us to make the type of policy-relevant conclusions that are often not possible from small-scale case studies. On-going and future analyses with this unique dataset include the nature of common property regimes, participation in strategies for agricultural commercialization, and the determinants of participation in wage labor and out-migration. Future analysis will also link to the colonist dataset to compare the two populations. Issues of biodiversity conservation, human development, and cultural survival are urgent in the forest territories of indigenous peoples, and demand further interdisciplinary integration in human-environment research.

X. Acknowledgements

Funding for this research was provided by the National Institutes of Health (R01-HD38777-01, June 1, 2000 to May 31, 2003) to Principal Investigators Richard Bilsborrow and Flora Lu Holt. Clark Gray and Jason Bremner were supported as graduate assistants at the Carolina Population Center by an Integrated Graduate Education, Research and Training grant from the National Science Foundation as well as other sources. We are indebted to our Ecuadorian partners: the Centro de Estudios de Poblacion y Desarrollo Social (CEPAR), Ecociencia, Ana Oña, Alicia Ruíz, the team of field researchers, and foremost the participating indigenous communities and federations. We would also like to thank Steve Walsh and Brian Frizzelle for their work on spatial analysis, and Thomas Whitmore and members of the CPC IGERT reading group for their comments on an earlier version of this manuscript.

XI. References

Achard, F., H. Eva, H. Stibig, P. Mayaux, J. Gallego, T. Richards, and J. Malingreau. (2002). "Determination of deforestation rates of the world's humid tropical forests." *Science* 297 (5583): 999-1002.

Asner G., M. Keller, R. Pereira, J. Zweede, and J. Silva. (2004). "Canopy damage and recovery after selective logging in Amazonia: Field and satellite studies." *Ecological Applications* 14(4): S280-S298.

Beckerman, S. (1987). “Swidden in Amazonia and the Amazon Rim.” In: *Comparative Farming Systems*. Eds. B. Turner and S. Brush. The Guilford Press.

Behrens, C., M. Baksh, and M. Mothes. (1994). "A regional analysis of Bari land-use intensification and its impact on landscape heterogeneity." *Human Ecology* 22: 279-316.

Bilsborrow, R., A. Barbieri, and W. Pan. (2004). “Changes in population and land use over time in the Ecuadorian Amazon.” *Acta Amazonica* 34(4): 635-647.

Blaikie, P., and H. Brookfield. (1986). *Land Degradation and Society*. Methuen.

Brooks, T., R. Mittermeier, C. Mittermeier, G. da Fonseca, A. Rylands, W. Konstant, P. Flick, J. Pilgrim, S. Oldfield, G. Magin, and C. Hilton-Taylor. (2002). "Habitat loss and extinction in the hotspots of biodiversity." *Conservation Biology* 16(4): 909-923.

Brown, L., and R. Sierra. (1994). “Frontier migration as a multi-stage phenomenon reflecting the interplay of macroforces and local conditions: the Ecuadorian Amazon.” *Papers in Regional Science* 73(3):267-288.

Byron, N., and Arnold M. (1999). "What futures for the people of the tropical forests?" *World Development* 27(5): 789-805.

Califano, M., and J. Gonzalo. (1995). *Los A’i (Cofan) del Río Aguarico, Mito y Cosmovisión, Serie Pueblos del Ecuador*. Abya Yala.

Chomitz, K., and D. Gray (1996). “Roads, land use, and deforestation: a spatial model applied to Belize.” *World Bank Economic Review* 10(3):487-512.

Cerón, M. (1995). *Etnobiología de los Cofánes de Dureno*. Serie Pueblos del Ecuador. Abya Yala.

Cochrane M., A. Alencar, M. Schulze, C. Souza, D. Nepstad, P. Lefebvre, and E. Davidson. (1999). "Positive feedbacks in the fire dynamic of closed canopy tropical forests." *Science* 284(5421): 1832-1835.

Coomes, O., F. Grimard, and G. Burt. (2000). "Tropical forests and shifting cultivation: secondary forest fallow dynamics among traditional farmers of the Peruvian Amazon." *Ecological Economics* 32:109-124.

Denevan, W., and C. Padoch, Eds. (1988). *Swidden-fallow Agroforestry in the Peruvian Amazon*. New York Botanical Garden.

FAO. (2001). *Global Forest Resources Assessment 2000*. Food and Agriculture Adminstration.

Fearnside, P. (2003). "Conservation policy in Brazilian Amazonia: Understanding the dilemmas." *World Development* 31(5): 757-779.

Fearnside, P., and W. Laurance. (2004). "Tropical deforestation and greenhouse-gas emissions." *Ecological Applications* 14(4): 982-986.

Fox, J. (2000). "Swidden farming and fallow vegetation northern Thailand." *Geographical Journal* 166(3): 271-271.

Fox, J., R. Rindfuss, S. Walsh, V. Mishra. Eds. (2003). *People and the Environment: Approaches for Linking Household and Community Surveys to Remote Sensing and GIS*. Kluwer Academic Publishers.

Frizzelle, B., S. Walsh, C. Mena, and C. Erlien. (2005). "Land use change patterns of colonists and indigenous groups in the Northern Ecuadorian Amazon: a comparison of Landsat TM spectral and spatial analyses." Presentation to the Annual Meeting of the American Society of Photogrammetry and Remote Sensing, Baltimore, Maryland.

Fujisaka, S., L. Hurtado, R. Uribe. (1996). "A working classification of slash-and-burn agricultural systems." *Agroforestry Systems* 34(2): 151-169.

Geist, H., and E. Lambin (2002). "Proximate causes and underlying driving forces of tropical deforestation." *Bioscience* 52(2): 143-150.

Goldstein, H. (2003). *Multilevel Statistical Models*. Halstead Press.

Godoy, R. (2001). *Indians, Markets and Rainforests: Theory, Methods, Analysis*. Columbia University Press.

Godoy, R., S. Groff., and K. O'Neill. (1998). "The role of education in Neotropical deforestation: household evidence from Amerindians in Honduras." *Human Ecology* 26(4): 649-675.

Goodman, R. and L. Kish. (1975). "Controlled selection: a technique in probability sampling." *Journal of the American Statistical Association* 45: 350-372.

Gross, D., G. Eiten, N. Flowers, F. Leoi, M. Ritter, and D. Werner. (1979). "Ecology and acculturation among native peoples of central Brazil." *Science* 206: 1043-1050.

Gupta, A. (2000). "Shifting cultivation and conservation of biological diversity in Tripura, Northeast India." *Human Ecology* 28(4): 605-629.

Hammond, D., P. Dolman, and A. Watkinson. (1995). "Modern Ticuna swidden-fallow management in the Colombian Amazon: ecologically integrating market strategies and subsistence driven economies." *Human Ecology* 23(3): 335-356.

Henrich, J. 1997. "Market incorporation, agricultural change, and sustainability among the Machiguenga Indians of the Peruvian Amazon." *Human Ecology* 25: 319-351.

Holt, F., B. Fariss, R. Bilsborrow, and A. Ruiz. (Unpublished). "A cross-cultural analysis of time allocation among indigenous peoples in the Ecuadorian Amazon."

INEC. (2003). *Sistema Integrado de Consultas a los Censos Nacionales*. Instituto Nacional de Estadística y Censos de Ecuador.

Lambin, E., Agbola, S., Angelsen, A., Bruce, J., Coomes, O., Dirzo, R., Fischer, G., Folke, C., George, P., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E., Mortimore, M., Ramakrishnan, P., Richards, J., Skånes, H., Steffen, W., Stone, G., Svedin, U., Veldkamp, T., Vogel, C., Xu, J., Turner, B., and Geist, H. (2001). "The causes of land-use and land-cover change: moving beyond the myths." *Global Environmental Change* 11(4), 261-269.

Laurance, W., A. Albernaz, P. Fearnside, H. Vasconcelos, L. Ferreira. (2004), "Deforestation in Amazonia." *Science* 304(5674): 1109-1109.

Lawrence, D., and W. Schlesinger. (2001). "Changes in soil phosphorus during 200 years of shifting cultivation in Indonesia." *Ecology* 82(10): 2769–2780.

Lu, F. (1999). *Changes in Subsistence Patterns and Resource Use of the Huaorani Indians in the Ecuadorian Amazon*. Dissertation in the UNC-CH Curriculum in Ecology.

____. (2001). "The common property regime of the Huaorani Indians of Ecuador: Implications and challenges to conservation." *Human Ecology* 29(4): 425-447.

Lu, F., R. Bilsborrow, and A. Oña. (2004). *Demography, Household Economies, and Land and Resource Use of Five Indigenous Populations in the Northern Ecuadorian Amazon: A Summary of Ethnographic Research.* Carolina Population Center Occasional Paper. Chapel Hill, North Carolina.

Kleinman, P., D. Pimentel, and R. Bryant. (1995). "The ecological sustainability of slash-and-burn agriculture." *Agriculture, Ecosystems and Environment* 52: 235-249.

Kish, L. (1965). *Survey Sampling*. Wiley and Sons.

Macdonald, T. (1981). "Indigenous response to an expanding frontier: Jungle Quichua economic conversion to cattle ranching." In: N. Whitten, ed. *Cultural Transformations and Ethnicity in Modern Ecuador*. University of Illinois Press. pp356-383.

McCracken, S., A. Siqueira, E. Moran, and E. Brondizio. (2002). "Land use patterns on an agricultural frontier in Brazil: insights and examples from a demographic perspective." In: *Deforestation and Land Use in the Amazon*. Eds. C. Wood and R. Porro. University Press of Florida. pp162-192.

Mittermeier, R., C. Mittermeier, T. Brooks, J. Pilgrim, W. Konstant, G. da Fonseca, and C. Kormos. (2003). "Wilderness and biodiversity conservation." *Proceedings of the National Academy of Sciences* 100(18): 10309-10313.

Metzger, J. (2003). "Effects of slash-and-burn fallow periods on landscape structure." *Environmental Conservation* 30(4): 325-333.

Moran E., E. Brondizio, J. Tucker, M. da Silva-Forsberg, S. McCracken, I. Falesi. (2000). "Effects of soil fertility and land-use on forest succession in Amazonia." *Forest Ecology and Management* 139 (1-3): 93-108.

Mulder, M., and T. Caro. 1985. "The use of quantitative observational techniques in anthropology." *Current Anthropology* 26: 323-335.

Neeff, T., P. Graca, L. Dutra, C. Freitas. (2005). "Carbon budget estimation in Central Amazonia: successional forest modeling from remote sensing data." *Remote Sensing of Environment* 94(4): 508-522.

Pan, W., and R. Bilsborrow. (In press). "The use of a multilevel statistical model to analyze factors influencing land use: a study of the Ecuadorian Amazon." *Global and Planetary Change*.

Pan, W., S. Walsh, R. Bilsborrow, B. Frizzelle, C. Erlien, and F. Baquero. (2004). "Farm-level models of spatial patterns of land use and land cover dynamics in the Ecuadorian Amazon." *Agriculture, Ecosystems, and Environment* 101: 117-134.

Perreault, T. (2003). "Social capital, development, and indigenous politics in Ecuadorian Amazonia." *Geographical Review* 93(3): 328-349.

Perz, S., and D. Skole. (2003). "Social determinants of secondary forests in the Brazilian Amazon." *Social Science Research* 32(1): 25-60.

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

Pitman N., J. Terborgh, M. Silman, P. Nunez, D. Neill, C. Ceron, W. Palacios, and M. Aulestia. (2002). "A comparison of tree species diversity in two upper Amazonian forests." *Ecology* 83 (11): 3210-3224.

Posey, D. and W. Balée. (1989). *Resource Management in Amazonia: Indigenous and Folk Strategies.* Volume 7: Advances in Economic Botany. New York Botanical Garden.

Rasul, G., G. Thapa, M. Zoebisch. (2004). "Determinants of land-use changes in the Chittagong Hill Tracts of Bangladesh." *Applied Geography* 24(3): 217-240.

Rival, L. (2002). *Trekking Through History: The Huaorani of Amazonian Ecuador*. Columbia University Press.

Redford, K., and S. Sanderson. (2000). “Extracting humans from nature.” *Conservation Biology* 14(5): 1362-1364.

Rudel T, D. Bates, and R. Machinguiashi. (2002). “A tropical forest transition? Agricultural change, out-migration, and secondary forests in the Ecuadorian Amazon.” *Annals of the Association of American Geographers* 92 (1): 87-102.

Santos, R, N. Flowers, C. Coimbra, and S. Gugelmin. (1997). “Tapirs, tractors, and tapes: the changing economy and ecology of the Xavante Indians of Central Brazil.” *Human Ecology* 25(4): 545-566.

Schwarzman, S., A. Moreira, and D. Nepstad. (2000). “Rethinking tropical forest conservation: people in parks.” *Conservation Biology* 14(5): 1351-1357.

Shivakoti, G., W. Axinn, P. Bhandari, N. Chhetri. 1999. "The impact of community context on land use in an agricultural society." *Population and Environment* 20 (3): 191-213.

Sierra, R. (1999). "Traditional resource-use systems and tropical deforestation in a multiethnic region in North-west Ecuador." *Environmental Conservation* 26(2): 136-145.

______. (2000). "Dynamics and patterns of deforestation in the western Amazon: the Napo deforestation front, 1986-1996." *Applied Geography* 20:1-16.

Sierra, R., F. Rodriguez, and E. Loses. (1999). "Forest resource use change during early market integration in tropical rain forests: the Huaorani of upper Amazonia." *Ecological Economics* 30(1): 107-119.

Simmons, C. (1997). "Forest management practices in the Bayano region of Panama: cultural variations." *World Development* 25(6): 989-1000.

Smith, J. (2001). “Land cover assessment of indigenous communities in the BOSAWAS region of Nicaragua.” *Human Ecology* 29(3): 339-347.

Sprague, D., S. Oyama. (1999). "Density and distribution of citemene fields in a miombo woodland environment in Zambia." *Environmental Management* 24(2): 273-280.

Steinberg, M. (1998). "Political ecology and cultural change: Impacts on swidden-fallow agroforestry practices among the Mopan Maya in southern Belize." *Professional Geographer* 50(4): 407-417.

Vadez, V., V. Reyes-García, R. Godoy, L. Williams, L. Apaza, E. Byron, T. Huanca, W. Leonard, E. Pérez, D. Wilkie. (2003). "Validity of self-reports to measure deforestation: evidence from the Bolivian lowlands." *Field Methods* 15: 289-304.

Vance C., and J. Geoghegan. (2002). “Temporal and spatial modelling of tropical deforestation: a survival analysis linking satellite and household survey data.” *Agricultural Economics* 27(3): 317-332.

Vickers, W. (1993). “Changing tropical forest resource management strategies among the Siona and Secoya Indians.” In: *Tropical Forests, People and Food: Biocultural Interactions and Applications to Development*. Eds. C. Hladik, A. Hladik, O. Linares, H. Pagezy, A. Semple and M. Hadley. Man and the Biosphere Series Vol. 13. UNESCO. pp. 463-477.

Vina, A., F. Echavarria, D. Rundquist. (2004). "Satellite change detection analysis of deforestation rates and patterns along the Colombia-Ecuador border." *Ambio* 33(3): 118-125.

Walker, R. (1999). "The structure of uncultivated wilderness: Land use beyond the extensive margin." *Journal of Regional Science* 39(2): 387-409.

Walker, R., E. Moran, and L. Anselin. (2000). “Deforestation and cattle ranching in the Brazilian Amazon: external capital and household processes.” *World Development* 28(4):683-699.

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

Walsh, S., and K. Crews.-Meyer, Eds. (2002). *Linking People, Place, and Policy: A GIScience Approach*. Kluwer Academic Publishers.

Walsh, S., J. Messina, K. Crews-Meyer, R. Bilsborrow, and W. Pan. (2002). “Characterizing and modeling patterns of deforestation and agricultural extensification in the Ecuadorian Amazon.” In: *Linking People, Place, and Policy: a GIScience Approach*. Eds. S. Walsh and K. Crews-Meyer. pp187-214. Kluwer Academic Publishers.

WinklerPrins, A., and N. Barrera-Bassols. (2004). "Latin American ethnopedology: A vision of its past, present, and future." *Agriculture and Human Values* 21(2-3): 139-156.

Wunder, S. (2000). "Ecotourism and economic incentives - an empirical approach." *Ecological Economics* 32(3): 465-479.

Zimmerman, B., C. Peres, J. Malcolm, T. Turner. (2001). "Conservation and development alliances with the Kayapo of south-eastern Amazonia, a tropical forest indigenous people." *Environmental Conservation* 28(1): 10-22.

Figure 1. Map of the study area, with approximate distribution of the five indigenous populations.

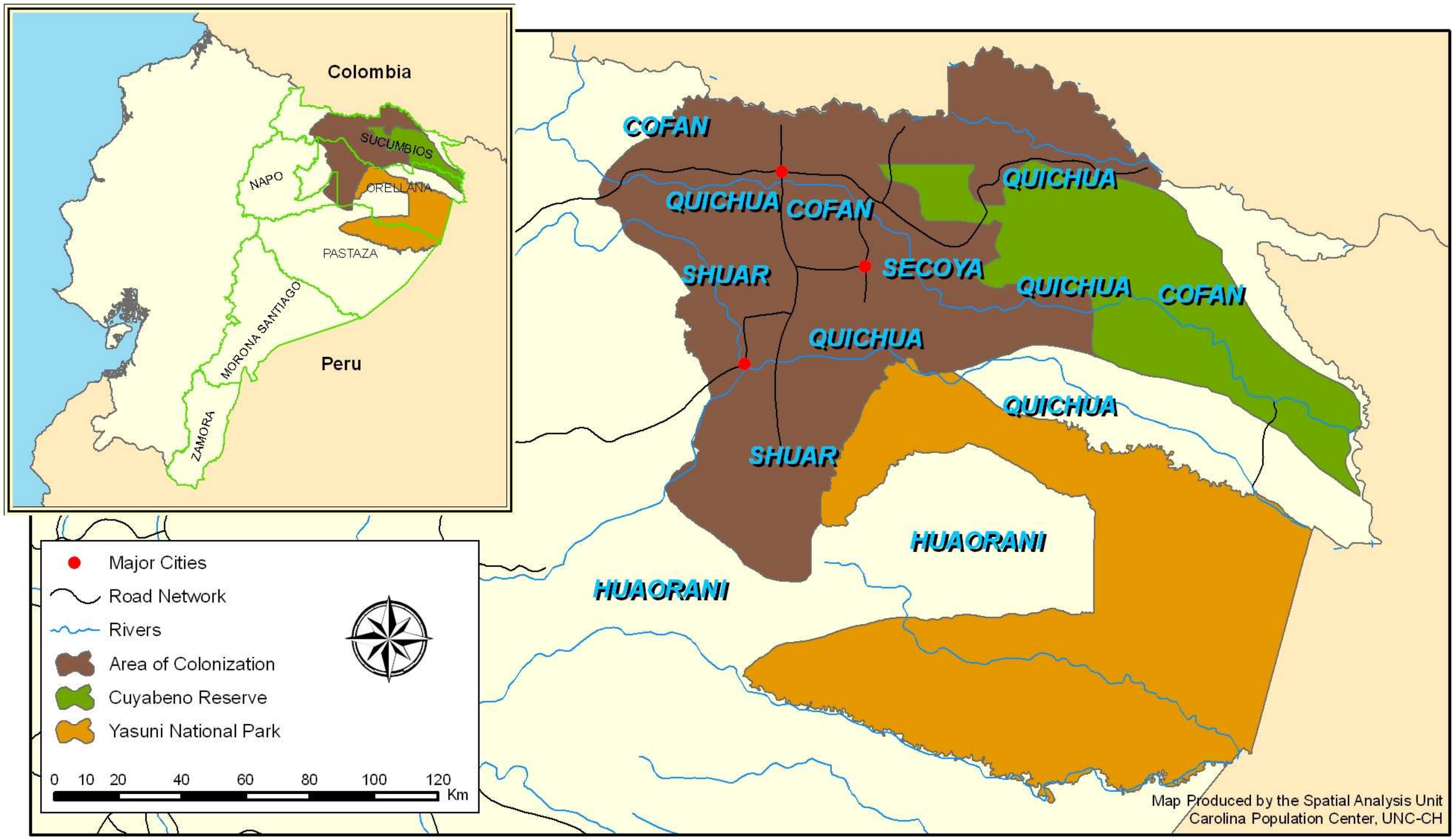

Table 1. Sample totals and weighted mean sample characteristics by ethnicity.

	Overall*	Quichua	Shuar	Huaorani	Cofán	Secoya
Community Characteristics						
Sampled communities by majority ethnicity	36	14	10	7	3	2
Household Characteristics						
Sampled households by ethnicity of head	478[#]	227	96	76	43	28
Distance to closest city (km)	55.5	65.7^{c}	39.4^{b}	74.2^{d}	35.8^{ab}	29.9^{a}
Household size	6.16	6.53^{c}	6.57^{bc}	6.68^{c}	5.42^{b}	4.06^{a}
Head born in community (%)	33.4	35.6	2.1	35.5	50.0	43.2
Primary education of head (%)	79.9	85.6^{b}	74.6^{ab}	61.7^{a}	59.8^{b}	74.6^{a}
Secondary education of head (%)	21.4	16.3^{ab}	33.9^{cd}	23.2^{bc}	4.5^{a}	55.2^{d}
Head speaks Spanish (%)	83.7	90.6^{b}	92.8^{b}	54.8^{a}	58.3^{a}	98.5^{b}
'Private' land tenure (%)	63.2	70.3^{c}	96.9^{d}	2.3^{a}	22.0^{b}	100^{d}
Sold crops in the past year (%)	66.2	79.8^{c}	74.6^{c}	20.5^{a}	58.0^{bc}	44.8^{ab}
Owns cattle (%)	28.6	28.8^{bc}	33.9^{c}	1.5^{a}	12.6^{b}	70.2^{d}
Wage labor by head in the past year (%)	48.3	40.7^{a}	55.9^{bc}	73.2^{c}	35.6^{ab}	52.2^{a}
Sold timber in the past year (%)	18.4	19.6^{b}	31.8^{b}	8.9^{a}	5.8^{a}	21.0^{ab}
Hunted in the past two weeks (%)	66.3	64.8^{a}	58.9^{a}	78.2^{a}	63.6^{a}	73.1^{a}
Received a loan in the past three years (%)	14.2	10.5^{b}	20.5^{bc}	7.5^{ab}	1.2^{a}	47.8^{c}
Number of agricultural parcels	3.00	3.17^{a}	2.79^{a}	2.78^{a}	2.93^{a}	2.89^{a}
Total cultivated area (hectares)	3.65	4.00^{c}	4.84^{c}	1.35^{a}	2.02^{ab}	4.93^{c}
Parcel Characteristics						
Sampled parcels by ethnicity of head	1397[&]	719	257	212	127	69
Walking distance to the parcel (min)	14.0	12.7^{a}	9.3^{a}	26.6^{b}	15.0^{ab}	13.0^{a}
Years since establishment of parcel	3.28	3.69^{b}	3.42^{b}	1.18^{a}	3.98^{b}	2.15^{a}

* Includes 8 households with colonist heads sampled in indigenous communities.
[#] Households included in this analysis, from 498 in full dataset.
[&] Parcels of included households with no missing data.
[abcd] Letters join means by ethnicity that are not statistically different at p = .05.

Table 2. Variable definitions, weighted descriptive statistics, and hypotheses (n = 478).

Variable	Definition	Mean	SD	Min	Max	Hypothesis
Dependent Variable						
Total cultivated area	Total cultivated area of the household	3.65	4.76	0.06	41.25	NA
Log-area	Log(total cultivated area)	0.82	1.40	-2.90	3.72	NA
Ethnicity of Head #						
Quichua	Head is Quichua ethnicity	0.52	0.64	0	1	
Shuar	Head is Shuar ethnicity	0.13	0.43	0	1	+
Huaorani	Head is Huaorani ethnicity	0.11	0.40	0	1	-
Cofan	Head is Cofan ethnicity	0.13	0.43	0	1	-
Secoya	Head is Secoya ethnicity	0.10	0.38	0	1	
Colonist	Head is colonist ethnicity	0.01	0.14	0	1	+
Community Predictors						
Distance to city	Distance to closest city in 100km	0.55	0.48	0.06	1.38	-
Distance to market	Distance to preferred market in 100km	0.50	0.62	0.03	2.15	-
Travel time to market	Travel time to preferred market (hours)	3.26	3.73	0.08	16.50	-
Bus service	Bus service to community	0.30	0.59	0	1	+
Oil company	Presence of oil company	0.42	0.64	0	1	+
Store	Presence of a store	0.74	0.56	0	1	+
Household Predictors						
Good soil	Self-rated soil quality of “good”	0.84	0.47	0	1	+
Flat land	Lands with flat topography	0.74	0.57	0	1	+
Broken land	Lands with broken topography	0.23	0.55	0	1	-
Young head*	Head <25 years old	0.17	0.49	0	1	-
Short residence*	Head resident in community <10 years	0.21	0.52	0	1	-
Spanish	Head speaks Spanish	0.84	0.48	0	1	+
No education*	Head has no formal education	0.20	0.52	0	1	-
Men	Number of males >15 years old	1.47	1.02	0	6	+
Women	Number of females >15 years old	1.36	0.86	0	5	+
Children	Number of members ≤ 15 years old	3.33	2.92	0	10	+
Private land	Household has 'private' land	0.63	0.62	0	1	+
Household assets	Number of durable manufactured assets	4.08	3.12	0	14	+
Electricity	Household electrification	0.24	0.56	0	1	+
Credit	Received loan in past three years	0.26	0.57	0	1	+
Agricultural assistance	Received external agricultural assistance	0.26	0.57	0	1	+
Wage labor	Wage labor by household in past year	0.48	0.64	0	1	-

Reference is Quichua ethnicity
*These variables were included as full sets of categorical predictors in preliminary models. Statistically identical categories have been combined here and in the subsequent model for the sake of space and interpretability.

Table 3. Results of the multilevel regression of log-area on community and household-level predictors, n = 478 households and 36 communities.

Parameter	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Intercept	0.82***	1.02***	1.35***	0.49	0.87***	0.44
Ethnicity of Head #						
Huaorani		-0.97***	-0.62*	0.01	0.05	0.06
Cofan		-0.70*	-0.92***	-0.58*	-0.51*	-0.46*
Secoya		0.33	0.10	0.12	0.19	0.17
Shuar		0.06	-0.28	-0.09	-0.10	-0.08
Colonist		-0.19	-0.46	-0.02	-0.05	-0.10
Community Predictors						
Distance to city			-0.98***	-0.69*	-0.57*	-0.10
Distance to market			-0.57***	-0.56**	-0.51**	-0.39*
Travel time to market			0.03	0.03		
Bus service			0.39*	0.39*	0.33*	0.35**
Oil company			0.30+	0.31+	0.29*	0.31**
Store			0.24	0.21		
Household Predictors						
Good soil				0.10		
Flat land				-0.05		
Broken land				-0.20+	-0.21*	-0.19+
Young head				-0.34**	-0.38***	-0.40***
Short residence				-0.28*	-0.27*	-0.28*
No education				-0.25*	-0.32**	-0.36**
Spanish				0.13		
Men				0.14*	0.15**	0.16**
Women				0.02		
Children				0.02		
Private land				0.36*	0.41*	0.84***
Household assets				0.05*	0.05**	0.05*
Electricity				-0.04		
Credit				0.35**	0.37**	0.37**
Agricultural assistance				0.12		
Wage labor				-0.34***	-0.31***	-0.04
Interactions						
City x Wage						-0.46+
Market x Private						-0.75**
Variance Components						
τ_{00} (community)	0.39***	0.21**	0.04+	0.06+	0.04+	0.03
σ^2 (household)	1.21***	1.39***	1.38***	1.19***	1.19***	1.18***
Intra-Class Correlation	0.24	0.13	0.03	0.04	0.03	0.02
Fit Statistics						
-2 Log Likelihood	1376.7	1367.6	1345.7	1316.6	1293.7	1284.6
AIC	1380.7	1371.6	1349.7	1320.6	1297.7	1288.6
BIC	1383.9	1374.8	1352.9	1323.8	1300.9	1291.7

Reference is Quichua ethnicity
*** p<.001, ** p<.01, *p<.05, +p<.10

Table 4. Mean weighted composition of the household cultivated area by ethnicity of head with comparison of means (one-way analysis of variance), n = 478.

	Overall[1]	**Quichua**	**Shuar**	**Huaorani**	**Cofán**	**Secoya**
All Crops	3.65	4.00[c]	4.84[c]	1.35[a]	2.02[ab]	4.93[a]
Staples	1.42	1.65[b]	1.10[a]	1.21[a]	1.13[a]	1.28[ab]
Coffee	1.14	1.43[c]	2.08[c]	0.06[a]	0.66[b]	0.18[a]
Pasture	0.93	0.70[b]	1.41[bc]	0.00[a]	0.16[a]	3.44[c]
Others	0.16	0.21[b]	0.25[b]	0.08[a]	0.05[a]	0.03[a]

[1] Includes 8 households with colonist heads
[abc] Letters join ethnic means that are not statistically different at p = .05 by one-way analysis of variance.

Table 5. Mean weighted composition of the household cultivated area (hectares) by selected predictors with comparisons of means (pooled t-tests), n = 478.

Variable	Value	All Crops	Staples	Coffee	Pasture	Others
Overall		3.65	1.42	1.14	0.93	0.16
Distance to city	< 50 km	4.54***	1.50	1.52***	1.30***	0.22***
	> 50 km	2.42	1.31	0.61	0.42	0.08
Distance to market	< 50 km	4.63***	1.51+	1.48***	1.45***	0.19***
	> 50 km	2.39	1.30	0.69	0.26	0.14
Bus service	No	3.38*	1.39	0.97*	0.88	0.12***
	Yes	4.29	1.48	1.49	1.07	0.26
Oil company	No	3.78	1.40	1.18	1.00	0.19+
	Yes	3.46	1.44	1.06	0.83	0.13
Broken land	No	3.62	1.41	1.07	0.99	0.14+
	Yes	3.74	1.44	1.36	0.71	0.23
Young head	No	3.75	1.45	1.24*	0.88	0.18
	Yes	3.17	1.27	0.62	1.16	0.11
Short residence	No	3.72	1.45	1.05+	1.05*	0.16
	Yes	3.38	1.28	1.45	0.48	0.18
No education	No	3.95***	1.48*	1.24*	1.04+	0.19*
	Yes	2.44	1.15	0.71	0.50	0.07
Men	≤ 2	3.54+	1.35***	1.08+	0.95	0.16
	> 2	4.55	1.97	1.57	0.78	0.22
Private land	No	1.89***	1.22*	0.38***	0.23***	0.05***
	Yes	4.67	1.53	1.57	1.34	0.23
Household assets	≤ 5	3.32***	1.32***	1.18	0.64***	0.18
	> 5	4.65	1.71	0.99	1.81	0.13
Wage labor	No	4.08**	1.55*	1.31+	1.01	0.21*
	Yes	3.19	1.28	0.95	0.84	0.12
Credit	No	3.34***	1.43	1.03**	0.72***	0.16
	Yes	5.49	1.30	1.76	2.24	0.20

*** p<.001, ** p<.01, *p<.05, +p<.10