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RESEARCH

Socioeconomic Drivers of Deforestation in the Northern Ecuadorian Amazon

CARLOS F. MENA*
Department of Geography and Carolina Population Center
University of North Carolina at Chapel Hill
321 Saunders Hall, CB# 3220
Chapel Hill, North Carolina 27599, USA

RICHARD E. BILSBORROW
Department of Biostatistics and Carolina Population Center
University of North Carolina at Chapel Hill
Chapel Hill, North Carolina 27599, USA

MICHAEL E. McCLAIN
Environmental Studies Department
Florida International University
Miami, Florida, USA

ABSTRACT / Investigations of land use/land cover (LULC) change and forest management are limited by a lack of understanding of how socioeconomic factors affect land use. This lack also constrains the predictions of future deforestation, which is especially important in the Amazon basin, where large tracts of natural forest are being converted to managed uses. Research presented in this article was conducted to address this lack of understanding. Its objectives are (a) to quantify deforestation in the Northern Ecuadorian Amazon (NEA) during the periods 1986–1996 and 1996–2002; and (b) to determine the significance and magnitude of the effects of socioeconomic factors on deforestation rates at both the parroquia (parish) and finca (farm) levels. Annual deforestation rates were quantified via satellite image processing and geographic information systems. Linear spatial lag regression analyses were then used to explore relationships between socioeconomic factors and deforestation. Socioeconomic factors were obtained, at the finca level, from a detailed household survey carried out in 1990 and 1999, and at the parroquia level from data in the 1990 and 2001 Ecuadorian censuses of population. We found that the average annual deforestation rate was 2.5% and 1.8%/year for 1986–1996 and 1996–2002, respectively. At the parroquia level, variables representing demographic factors (i.e., population density) and accessibility factors (i.e., road density), among others, were found to be significantly related to deforestation. At the farm level, the factors related to deforestation were household size, distance by road to main cities, education, and hired labor. The findings of this research demonstrate both the severity of deforestation in the Northern Ecuadorian Amazon and the array of factors affecting deforestation in the tropics.

Global deforestation is recognized as one of the core problems of global environmental change (Cassel-Gintz and Petschel-Hels 2001; Klepeis and Turner II 2001). Recent data illustrate the rapid rate of deforestation. According to the United Nations Food and Agriculture Organization (FAO), 93,900 km^2 of forest were cleared per year during the 1990s, with annual rates of forest loss (positive for all continents with tropical forests): Africa 0.8%, Asia 0.1%, Oceania 0.2%, North and Central America 0.1%, and South America 0.4% (Food and Agriculture Organization 2001). Specific locations in Latin America showed annual deforestation rates much higher than the continental rates, such as Tuxtlas (Mexico) at 4.3%/year between 1976 and 1986 (Dirzo 1992); the Western Amazon (Colombia, Ecuador, and Peru) at 0.65%/year between 1986 and 1996 (Sierra 2000); and the Andean foothills of Colombia at 4.4%/year between 1938 and 1988 (Viña and Cavelier 1999). Among the countries of South America, Ecuador had the highest deforestation rate between 1990 and 2000, averaging 1.2%/year (Food and Agriculture Organization 2001). The FAO estimated overall deforestation in Ecuador to be 2380 km^2/year from 1980 to 1990 and 1370 km^2/year from 1990 to 2000. Deforestation in Ecuador is concentrated along two fronts: the Chocó (northwestern coast, in Esmeraldas Province) and the Northeastern Amazonian region (Sierra 2000).

This article draws upon population environment theory in frontier settings to investigate the factors that contribute to deforestation in the Northern Ecuadorian Amazon (NEA). We find that single-factor theoret-

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*Author to whom correspondence should be addressed; *email:* mena @email.unc.edu

Figure 1. Ecuador and the study area: the Northern Ecuadorian Amazon.

ical approaches to explain deforestation in the NEA present incomplete pictures of the deforestation process. In a recent meta-review of case studies, Geist and Lambin (2001) conclude that tropical deforestation is determined by different combinations of proximate causes and underlying driving forces that characterize social, political, economic, geographical, and historical circumstances. The methodological approach used in this article includes (1) the quantification of the deforestation process between 1986 and 2002 in the NEA using classified satellite imagery; and (2) the analysis of the demographic, socioeconomic, and biophysical drivers of the deforestation by linking deforestation rates to household survey and census data to create statistical spatial models of deforestation for the periods 1986–1996 and 1996–2002. For this analysis, two areal units are used: (1) *parroquia* (parish)—the smallest political unit in Ecuador; and (2) *finca* (farm)—the original farms of approximately 0.50 km^2, granted to the initial settlers arriving in the Ecuadorian Amazon in the 1970s and 1980s and prior to the subdivisions of the 1990s.

The results of this research show the importance of demographic and socioeconomic forces as drivers of deforestation. The research also shows some of the predictors of deforestation function at different spatial scales. This study serves as an exploratory analysis of the complex problem of deforestation in the tropics and provides a basis for future modeling of land use and land cover (LULC) dynamics in tropical forests.

The Northern Ecuadorian Amazon (NEA)

In this study, we have defined the NEA as an area of about 7700 km^2 (Figure 1), which encompasses 18 parroquias located in the provinces of Napo, Orellana, and Sucumbios. The Napo rainforest, where the NEA is located, is among the most biologically diverse and unique environments in the world and has been considered one of the world hotspots—areas with high biodiversity and under high human pressure (Myers 1988, Orme and others 2005). The discovery of petroleum marked the division between two periods in the history of the NEA. Prior to the exploitation of petroleum, the natural landscape was essentially intact and populated by indigenous people and a very few colonists. The petroleum era began after 1967 when Texaco drilled its first successful oil well and roads were subsequently built, enabling colonists to move to the Amazon and settle along these roads. Population growth between 1974 and 1982, between 1982 and 1990, and between 1990 and 2001 was 8%, 6%, and 5%/year respectively—almost double those of the national population. As result, the total population grew from 384,616 in 1990 to 548,419 in 2001 (Bilsborrow 2003).

Theories Regarding the Drivers of Amazonian Deforestation

The connection between population growth and environmental degradation was studied two centuries ago by Malthus (1803), who pointed out that human populations might collapse because their size tended to increase at geometric rates while the food supply only increased at an arithmetic rate. In terms of LULC change, neo-Malthusian theories are built on the assumption that land productivity is fixed and returns to increasing inputs of labor lead to diminishing returns (United Nations 2001). Consequently, it is necessary to expand agricultural lands to feed the growing population. Some cross-national and regional studies in frontier settings have shown that population growth creates higher rates of deforestation (Ehrhardt-Martinez 1998; Parayil and Tong 1998). In an increasingly closed frontier environment, such as the NEA, we expect to see that population pressure from increased members of colonist leads to farm subdivision, and increases in population density contribute to more deforestation (Pan and Bilsborrow 2005).

In contrast to the Malthusian view, Boserup (1965, 1981) argued that more people stimulate technological changes that intensify land use so higher populations per unit area can be supported without an overall decline in living standards. Boserupian theory sees the role of population pressure on natural resources as a catalytic factor in land use intensification. According to Boserup, the increase in labor per unit of land through time creates stages of intensification. Although not always linked to population change, more modern conceptualizations of land use intensification are associated with increases in other inputs besides labor (e.g., chemical fertilizers, pesticides, and irrigation); these measure increases in production over constant units of land area and time (e.g., calories/hectare/years) (Bilsborrow and Carr 2000; Lambin 2000). The decrease in soil nutrients in some areas of the NEA, coupled with the expensive cost of remedial technology (e.g., fertilizer), may make the process of intensification unsustainable for long periods of time; therefore, we expect to see that technology—defined broadly, including loans and technical assistance—will initially have a negative effect on deforestation rates but will change with time.

The household life cycle is another relevant parameter that explains land use change based on demographic change. The household life cycle indicates how variations in consumption and labor availability of the household drive land use—in this case, deforestation. McCracken and others (1999) and Perz and Walker (2002) identify five stages of a household life cycle of small farmers in the Brazilian Amazon. They describe the life cycle as the periods when (1) young parents recently arrive in the area (duration of settlement <5 years) and initiate forest clearing to grow annual crops for subsistence; (2) parents with growing children (duration of settlement ~5 years) become engaged in the cultivation of perennials and pasture, in addition to annual crops; (3) older parents with teenage children (duration of settlement ~10 years) decrease the cultivation of annuals but increase cattle raising and secondary vegetation begins to appear; (4) cultivation of pasture and perennial crops dominates, with increasing secondary forest, as parents age and children reach young adulthood (duration of settlement ~15 years); and (5) children begin to leave the farm (duration of settlement >15 years), the presence of perennials remained a large portion of farm land use, and secondary forest succession further increases. We infer the effects of the household life cycle on land use from the age of the head and duration of settlement. Consistent with the household life cycle approach, we expect that farms with older heads of household and longer durations of settlement will have a negative effect on the primary forests and therefore higher deforestation rates.

Pure demographic approaches ignore socioeconomic factors underlying deforestation. Studies of environmental change in the developing world should consider the local social and economic factors involved in population and social change, rather than solely population (Taylor and Garcia-Barrios 1995). For example, there is little demand for land in the Bolivian Amazon, where population density is low. Thus, in areas where deforestation is highest, agricultural production for export, governmental policies (e.g., road building), and subsidies have been identified as the main drivers of deforestation (Kaimowitz 1997). One of the paradigms that explain the link between the different paths of development and land use change is the dual-economy theory. In this approach, there are two sectors: (1) a core—the urban, modern, productive center and (2) a periphery comprising mainly a rural, subsistence sector (Lewis 1954). The core and periphery sectors are linked by mechanisms of polarization (core growths) and spread (periphery growths) (Brown 1991). The modernization approach extends dual-economy theory to argue that environmental degradation (e.g., deforestation) is a function of the level and rate of development within a given country (Ehrhardt-Martinez 1998). Thus, it is expected that development—defined in this study as the increasing use of infrastructure, urbanization, and extractive practices to achieve economic growth—will affect deforestation in the NEA. The construction and improvement of roads will contribute to deforestation because increases in accessibility open new lands for settlement and facilitate the transportation of cash crops. Increasing levels of other basic services (e.g., electricity, piped water, and sewerage) might affect deforestation in different ways. Besides being indicators of urbanization, they can modify the farmer's expectations about living conditions in urban and rural areas and constitute a push/pull factor for location of residency and mobility.

It is important to note that the factors mentioned above must be considered interactive (e.g., in the Peruvian lowland Amazon, where roads are rare and access is difficult, deforestation is driven more by the availability of fertile lands (Imbernon 1999)). Economic policies and credit are among other underlying factors that may contribute to deforestation. In the Brazilian Amazon, especially during the 1970s and 1980s, credit and tax cuts to cattle ranchers were primary drivers of deforestation (Fearnside 1993; Moran 1993; Skole and Chomentowski 1994). In the Ecuadorian Amazon, agrarian reform and a colonization law supported deforestation by legalizing spontaneous colonization along roads that had been opened by oil companies (Uquillas 1984). We hypothesize that deforestation in the NEA cannot be explained by a single factor, but rather is driven by a number of physical, biotic, and socioeconomic agents. Technological and infrastructure changes (e.g., the form of loans, road networks, and public services expansion) and population growth are also important drivers of the deforestation.

Data and Methods

Rates of Deforestation

Three Landsat Thematic Mapper (TM) scenes from 1986; 1996, and 2002 were classified for this study by the Carolina Population Center (CPC)-Ecuador Project at the University of North Carolina at Chapel Hill and by Joseph Messina at Michigan State University. Image preprocessing steps included geometric and atmospheric corrections. Extensive fieldwork was used to build a ground control database that allows the identification of several vegetation types and cultural features in the landscape. A hybrid supervised classification of images was performed to identify several land cover classes including, primary forest, successional vegetation, pasture, agriculture, urbanization, water, and so forth (Walsh and others 2002). Postprocessing included positional and thematic quality assessments. The overall accuracy achieved for the classification was 78.4%, and the users' accuracy for the primary forest class—the class used in this study—was 90%. Annual deforestation rates were quantified at parroquia and finca levels using the following formula (Dirzo 1992; Ochoa-Gaona and Gonzales-Espinosa 2000):

$$r = 1 - \left[1 - \frac{A_1 - A_2}{A_1}\right]^{1/t} \quad (1)$$

where A_1 is the area of forest at the beginning of the period, A_2 is the area at the end, and t is the number of years for the period.

Statistical Models, Data, and Hypothesis

Ordinary least squares (OLS) or spatial regression models are used to assess the magnitude and significance of the relationships between the dependent variable, annual deforestation rates, and various socioeconomic variables, controlling for spatial autocorrelation. We used a weighted neighbor matrix W to characterize neighbors and their relative spatial weights. At the parroquia level, we used the Rook continuity, which defines two neighbors as those that share a common border. At the finca level, we considered every farm within a 5-km area as a neighbor of the ''target'' farm. Therefore, the definition of neighborhood captured all farms from the corresponding cooperative or sector. Lagrange multiplier test statistics determined if OLS or spatial regressions (Anselin 1988, 2002, 2005) should be used to fit the models. OLS regression is defined as

$$y = X\beta + \varepsilon \quad (2)$$

and the spatial lag model as

$$y = \rho W y + X\beta + \varepsilon \quad (3)$$

where y is the dependent variable, β the vector of coefficients, X the set of dependent variables, ρ the autoregressive parameter, and ϵ is the vector of random error terms.

Four sets of models were created, at the parroquia level and at the finca level for the periods 1986–1996 and 1996–2002, where the dependent variables are defined as the annual deforestation rates for the two periods and for the two levels of aggregation. Official parroquia boundaries and finca boundaries were used to extract the amount of primary forest from the LULC classifications. The finca boundaries were built up from using Global Positioning System (GPS) in ground surveys; sketch maps were prepared jointly by the farmers and interviewers. Annual rates of deforestation were transformed using an inverse-sine transformation (Bartlett 1947) to stabilize variance.

At the parroquia level, 18 parroquias in the core of the colonization area were selected for the analysis. This set of parroquias covers an area where satellite imagery was available. In terms of independent variables at the parroquia level, socioeconomic and demographic data came from two information systems produced by the Ecuadorian government (INFOPLAN and SIISE); both providing information on local development for several years. INFOPLAN and SIISE provide data on population, infrastructure, poverty, and housing based on the 1990 and 2001 National Ecuadorian Census of Population and Housing, respectively.

At the parroquia level, explanatory or independent variables include POPDEN—population density—the number of persons per km^2 for 1990 and 2001. Accessibility is measured by ROADEN—kilometers of roads per km^2—in each parroquia in 1990 and 1999/2001. The road network for 1990 was obtained from 1:50,000 topographical maps of the study area and updated using GPS data collected during fieldwork. Education data were captured by (a) EDUPRI—the net rate of attendance at primary school (percentage of the 6–11-year-old population attending); and (b) EDUSEC—the net rate of attendance at secondary school (percentage of 12–17-year-old population attending). Infrastructure was reflected by (a) PORELEC—the percentage of houses with electricity; (b) PORAGUA—the percentage of houses with access to piped drinking water; and (c) PORALCA—the percentage of houses connected to public sewage disposal. Poverty was represented by POV—the percentage of persons estimated to not be able to afford the basic goods and services required to satisfy basic human necessities. The INFOPLAN measurement of poverty chosen for this study differed slightly; it used the average of the poverty gaps of the population. Poverty gap is the deficit below the poverty line expressed in percentage of poverty line.

At the finca level, dependent variables were selected from a longitudinal household survey carried out in the study area in 1990 and 1999 by the UNC-Ecuador Project. The sampling design for this survey was made used a two-stage sampling procedure based on IERAC (Ecuadorian Institute of Agrarian Reform and Colonization) records. Pre-cooperatives or sectors of settlement were chosen at the first stage sectors, while farms were chosen in the second stage within selected sectors based on the sector size and measured by the number of plots (Bilsborrow and others 2004). This present research used information from a subsample of 144 farms—extracted from the larger sample of 408 farms interviewed in 1990—located in Intensive Study Areas where cloud-free satellite images were possible and allowed further analysis based on time series.

Independent variables at the finca level included demographic, socioeconomic, and biophysical factors. Demographic variables are represented by HHSIZE—the number of people on the farm in 1990 or 1999, AGE—the head of household, and YRSET—the year since settlement. In the case of a farm with several households, AGE and YRSET are the average age and time since settlement of the heads of household; similar averaging was done for other variables. Accessibility factors are represented by (1) ROAD—the distance traveled via primary road to the nearest town or market (main roads connecting capitals of provinces or main towns generally had gravel surfaces in 1990, but a few short segments were paved by 1999); (2) ACCESS—the identification of whether farms have, or do not have, vehicle access for 1990 and 1999; and (3) WALK—the distance traveled by foot from the farm house to the nearest road.

In terms of socioeconomic variables, education is represented by (1) EDUC—the average education level of the head of household; (2) LABORH—persons-months of hired labor within the farm; (3) ASSETS—the average assets on the farm; (4) LOAN—whether the farm has received loans or not; (5) LABORO—whether any household member was engaged in off-farm employment during the year previous to the survey; (6) TITLE—percentage of the finca that has legal title. As the fragmentation of the plot increased, new subdivision often lacks the legal property documents; and (7) POWER—whether a finca has electricity. In terms of biophysical variables, GOOD is the proportion of the finca considered to have good soil; FLAT is the proportion of the finca considered by the farmer to have gentle topography; and NCROPS is the number of types of crops planted on the farm. Other variables analyzed in previous models but not shown here due to issues of overlap or endogeneity include numbers of males, females, and children living on the farm; annual income; wealth; mean slope; and type of soil.

It is important to note that the deforestation estimated between 1986 and 1996 were linked to the 1990 census and farm data, whereas deforestation rates between 1996 and 2002 were linked to the 1999 household survey and 2001 census parroquia data. The intention in both cases was to locate the socioeconomic/demographic data near the midpoint of the deforestation rate periods, although this is limited by the availability of satellite imagery and the dates when the surveys and censuses were made.

Results

Rates of Deforestation

This research found that 1896 km^2 (25.02% of the landscape) was deforested in the NEA between 1986 and 2002, with an annual rate of 2.49% between 1986 and 1996 and 1.78% between 1996 and 2002 (Table 1). These rates indicate a continuous process of deforestation in the region, although lower rates are observed for the latter time period (1996–2002). When disaggregated, however, some parroquias still had increasing deforestation rates between 1996 and 2002 (Table 2). The speed of deforestation was very evident

Table 1. Proportion of area in forest and deforestation rates for the NEA

Forest cover	1986	1996	2002
Area (km^2)	6267.7	4868.6	4371.7
(% of landscape)	83.2	64.6	58.0
Deforestation rate (%/yr)	1986–1996: 2.49		1996–2002: 1.78

Table 2. Extent of primary forest and annual deforestation rates among parroquias of the NEA

	Primary forest			Annual deforestation rate	
Parroquia	1986 km^2	1996 km^2	2002 km^2	1986–1996 (%/year)	1996–2002 (%/year)
Jambeli	397.7	351.8	317.8	1.22	1.68
General Farfan	399.4	321.2	275.2	2.16	2.54
Nueva Loja	288.6	208.1	166.8	3.22	3.62
Pacayacu	825.3	731.9	694.1	1.19	0.88
Sta. Cecilia	179.8	130.3	111.8	3.17	2.52
Dureno	220.1	173.9	160.3	2.33	1.35
El Eno	365.8	262.8	229.1	3.25	2.26
Shushufindi	347.6	231.8	193.5	3.97	2.97
San Pedro de los Cofanes	47.7	27.2	17.0	5.49	7.52
Siete de Julio	102.2	58.4	41.7	5.44	5.44
San Roque	499.8	405.7	387.6	2.06	0.76
Limoncocha	526.8	422.5	431.4	2.18	−0.35
Puerto Fco. de Orellana	1115.2	884.8	808.5	2.29	1.49
Enokanqui	190.0	112.2	77.9	5.13	5.90
San Sebastian del Coca	326.3	255.2	229.0	2.43	1.79
La Joya de los Sachas	168.3	95.1	59.1	5.54	7.63
Pompeya	148.1	114.2	111.7	2.56	0.37
San Carlos	119.2	81.6	59.5	3.72	5.13

in some places; for example, the parroquia La Joya de los Sachas lost about 64.8% of its 1986 forest cover and its annual deforestation rate increased to 2.09% for the second period (1996–2002). Higher deforestation rates were clustered in the lower-central part of the study area on the main Nueva Loja to Pto. Francisco de Orellana road (Figure 2), which matches the more oil-developed area. The parroquias studied had annual deforestation rates ranging from 1.19 to 5.54%/year between 1986 and 1996 and from –0.35 to 7.63%/year between 1996 and 2002. At the finca level, the mean deforested area in the period between 1986 and 1996 was 13.5 ha (standard deviatio 6.6 ha), whereas it fell to 6.84 ha (standard deviatio 4.67 ha) between 1996 and 2002.

Results for Statistical Analysis

Descriptive statistics for the parroquias studied (Table 3) illustrate the changes in the region and their expected relationships with deforestation. Increases in the coverage of basic services (i.e., electricity [PORELEC], piped water [PORAGUA], sewerage [PORALCA], and secondary education [EDUSEC]) indicate an improvement in living conditions, but mainly reflect the growth of urban centers, because piped water, sewers, and high schools are present almost exclusively in urban or semiurban areas. Electricity, which increased by almost 27%—much more than sewers and piped water—has been established in some rural areas along main roads, and therefore can have an impact on rural economic activities, welfare, and perceptions of living conditions in the city and the farms. Other evident change in the region is the increase in population density (POPDEN), which reflects the continuing population growth led by the inmigration to the NEA and the natural increase of the population. Road density (ROADEN) was almost constant, because most of the main road network was built during the 1980s. Most changes in the road network in the study period were due to surface improvements (not captured in our road density measure) and secondary roads.

Table 4 shows the descriptive statistics at the finca level. In many cases, this information complements what is seen at the parroquia level; the average population living on a farm (i.e., population pressure [HHSIZE]) in rural areas in 1990 was 8.4 persons, whereas in 1999 it was 12.4 persons. Also related to

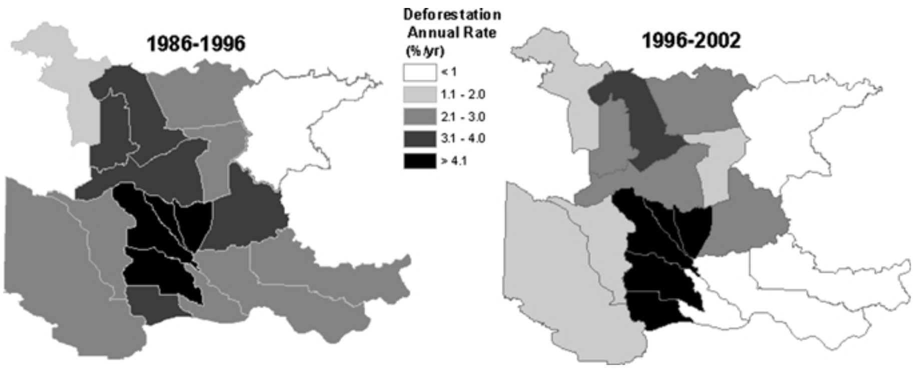

Figure 2. Deforestation among parroquias between 1986 and 1996 and between 1996 and 2002.

Table 3. Descriptive statistics of independent variables at the parroquia level

		1990		2001		
Variable name	Definition	Mean	Std.Dev	Mean	Std.Dev	Expected effect
EDUPRI	Net rate of attendance to primary school (% of 6–11 y.o.)	85.71	4.71	85.31	6.54	(+/−)
EDUSEC	Net rate of attendance to secondary school (% of 12–17 y.o.)	15.95	10.17	31.71	8.65	(+/−)
PORAGUA	Percentage of houses with piped water	1.68	2.87	6.56	8.86	(+)
PORALCA	Percentage of houses connected to public sewage disposal	2.19	4.20	8.94	14.25	(+)
PORELEC	Percentage of houses with electricity	20.45	21.67	47.39	23.52	(+)
POV	Percentage of persons under the poverty line[a]	27.37	5.57	89.25	10.23	(−)
ROADEN	Road density (km of roads/parroquia area — km^2)	0.57	0.28	0.59	0.29	(+)
POPDEN	Population by parroquia area (persons/parroquia area — km^2)	13.93	12.95	22.94	23.96	(+)

[a]For 2001 the poverty gap is used to measure poverty.

population pressure, Table 4 shows data on the number of land subdivisions in a finca (SUBDIV): 1.15 in 1990 and 2.63 in 1999. Other notable differences between 1990 and 1999 at the farm level are related to accessibility: mean walking distance to main road (WALK: 2.00 km in 1990 vs. 0.58 km in 1999), distance traveled by road to main town (ROAD: 16.97 vs. 14.09), and vehicle access to the farm (ACCESS: 0.65 vs. 0.85) improved considerably. As mentioned before, improvements in road conditions facilitated connectivity between farms and towns. The increase in off-farm employment is also noticeable. In our sample, almost 74% of the farms had a person working outside of the farm by 1999, whereas in 1990 just 38% of the farms had someone engaged in off-farm employment. Other relevant changes were related to land titling; the percentage of land with a legal title (TITLE) decreased about 5% between 1990 and 1999 because of farm subdivisions.

Table 5 shows the regression results at the parroquia level for 1986–1996 and 1996–2002. Table 5a, where the dependent variable is the annual rate of deforestation between 1986 and 1996, shows two models with different combinations of independent variables. In Model 1a, poverty (POV), and percentage of houses with piped water (PORAGUA) are statistically significant and negatively related to annual deforestation rates. On the other hand, population density (POPDEN) is significant and positively related to deforestation. Model 2a shows that road density (ROADEN) is statistically significant and positively related to deforestation, whereas percentage of houses with electricity (PORELEC) is statistically significant and negatively related to deforestation.

Table 5(b) shows the regression models where the annual deforestation rate between 1996 and 2002 is the dependent variable; two models are arranged in the same combinations as in Table 5a. In Model 1b, primary education (EDUPRI) and population density (POPDEN) are statistically significant and positively related to deforestation. In Model 2b, the percentage of houses with sewer (PORALCA) is statistically significant and negatively related to deforestation, whereas the percentage of houses with electricity (PORELEC) is positively related to deforestation. Model 2b also shows road density (ROADEN) strongly related to deforestation between 1996 and 2002.

Now we consider whether results will be similar or different at the farm level. Table 6 shows the results of the regression analysis to explain annual rate of deforestation between 1986 and 1996 at the farm level. Table 6 shows two models; Model 1 includes all

Table 4. Descriptive statistics of the independent variables in the sample fincas of the NEA and hypothesized effects

				1990		1999	
Type	Variable Name	Definition	Expected Effect	Mean	Std.Dev	Mean	Std.Dev
Economic & Technology	LABORH	Person-months of hired labor on farm	(+)	7.68	16.54	5.16	6.94
	LABORO	Off-farm employment by any member of the household (0/1)	(−)	0.38	0.48	0.71	0.45
	INCOME	Total annual income of the household[a]	(+)	65.87	110.29	1357.10	1990.60
	ASSETS	Average assets within the farm	(+)	7.89	2.32	6.65	2.13
	LOAN	Loans received (0/1)	(+)	0.25	0.43	0.46	0.49
	TITLE	Proportion of the farm under title (excludes certificate of possession)	(−)	0.67	0.46	0.62	0.45
	TECH	Proportion of the farm received technical assistance	(+)	0.39	0.48	0.37	0.48
	EDUC	Education of head of household	(−/+)	1.46	0.71	2.66	0.98
	POWER	Electricity in the farm (0/1)	(+)	0.2	0.4	0.66	0.48
Demographic	HHSIZE	Persons living in the farm	(+)	8.40	4.90	12.35	8.91
	POPF	Number of adult females living on the farm	(+)	2.36	1.68	3.45	2.66
	POPM	Number of adult males living on the farm	(+)	3.05	1.83	4.72	3.59
	AGE	Age of the head of household	(−)	46.89	12.73	46.21	10.12
	YRSET	Years since settlement	(−)	9.96	4.57	19.84	5.10
	SUBDIV	Number of farm subdivisions	(+)	1.15	0.44	2.63	2.04
Biophysical	FLAT	Proportion of flat land on the farm	(+)	0.57	0.49	0.68	0.43
	BLACK	Proportion of the farms with black soils	(+)	0.79	0.41	0.59	0.46
	NCROPS	Number of crops grown	(+)	3.2	1.61	3.81	2.06
	GOOD	Proportion of good soil on the farm	(+)	0.4	0.48	0.38	0.43
	MEANSLP	Mean slope of the farm	(−)	1.21	1.53	1.21	1.52
Accessibility	WALK	Walking distance to main road	(−)	2.00	2.86	0.58	0.95
	ROAD	Distance traveled by road to reference town	(−)	16.97	11.78	14.09	9.26
	TOWATER	Euclidean distance to rivers	(−)	397.54	296.94	390.48	299
	TOREFCOM	Euclidean distance to reference community	(−)	9.99	7.29	10.32	7.57
	ACCESS	Vehicle access to the farm (0/1)	(+)	0.65	0.48	0.85	0.36

[a]Transformed to US dollars (1 US Dollar = 25,000 Sucres on 1999); income is not corrected for inflation.

Table 5. OLS regression models at the parroquia level

	5(a) Deforestation between 1986 and 1996				5(b) Deforestation between 1996 and 2002			
	Model 1 (OLS)		Model 2 (OLS)		Model 1 (OLS)		Model 2 (OLS)	
Variable	Coefficient	Std. Error	Coefficient Std.	Error	Coefficient	Std. Error	Coefficient	Std. Error
CONSTANT	0.5388	(0.2168)***	0.0945	(0.0088)***	−0.5240	(0.3629)	0.0648	(0.0300)
EDUPRI	−0.0033	(0.0021)			0.0034	(0.0011)***		
EDUSEC			0.0009	(0.0008)			−0.0043	(0.0014)
POV	−0.0038	(0.0016)*			0.0033	(0.0034)		
PORAGUA	−0.0105	(0.0046)**			−0.0501	(0.3947)		
PORALCA			0.0010	(0.0011)			−0.2088	(0.0932)**
PORELEC			−0.0009	(0.0004)*			0.2969	(0.0854) *
POPDEN	0.0030	(0.0010)**			0.0046	(0.0012)***		
ROADEN			0.1447	(0.0107)***			0.1928	(0.0308)**
n	18		18		18		18	
Adj R^2	0.40		0.91		0.44		0.86	

***$P < 0.01$, **$P < 0.5$, *$P < 0.1$.

[a]Annual rate of deforestation between 1986 and 1996 and 1996 and 2002 are the dependent variables.

Table 6. Regression lag-models where the dependent variable is deforestation rates at the farm level between 1986 and 1996

	Model 1 (lag)		Model 2 (lag)	
Variable	Coefficient	Std. Error	Coefficient	Std. Error
ρ	0.1222	(0.1252)	0.2105	(0.1163)*
CONSTANT	0.2388	(0.0562)***	0.2491	(0.0419)***
WALK	0.0013	(0.0039)		
ROAD	0.0002	(0.0005)		
AREA	−0.0016	(0.0007)**	−0.0017	(0.0006)***
FLAT	0.0177	(0.0120)		
NCROPS	0.0050	(0.0034)		
YRSET	0.0017	(0.0012)		
LABORH	−0.0008	(0.0003)**	−0.0008	(0.0003)**
LOAN	−0.0096	(0.0134)		
ACCESS	0.0032	(0.0233)		
TITLE	0.0155	(0.0132)		
LABORO	0.0021	(0.0117)		
GOOD	0.0136	(0.0114)		
ASSETS	−0.0025	(0.0028)		
EDUC	−0.0180	(0.0080)**	−0.0169	(0.0075)**
AGE	−0.0004	(0.0005)		
POWER	0.0290	(0.0172)*	0.0239	(0.0136)*
HHSIZE	0.0027	(0.0011)**	0.0030	(0.0011)***
n	144		144	
Log likelihood	198.60		192.37	

***$P < 0.01$, **$P < 0.5$, *$P < 0.1$.

the possible variables, while Model 2 includes only the variables that are statistically significant. The statistical significant variables are (1) area of the farm (AREA), (2) hired labor (LABORH), (3) average education of the head of household (EDUC), and (4) number of people living in the farm (HHSIZE). As expected, HHSIZE and POWER are positively related to deforestation. Increases in AREA, LABORH, and EDUC imply a decrease in the deforestation annual rates.

Table 7 shows the results of the regression models at the farm level that examines deforestation between 1996 and 2002. Model 1 shows the results for all the independent variables, whereas Model 2 includes just the significant variables. As expected, distance by primary road to the main town (ROAD) and the propor-

Table 7. Regression lag-models, where the dependent variable is deforestation rates at the farm level between 1996 and 2002

	Model 1 (lag)		Model 2 (lag)	
Variable	Coefficient	Std. Error	Coefficient	Std. Error
ρ	0.3345	(0.0861)***	0.3421	(0.0853)***
CONSTANT	0.1219	(0.0721)*	0.0615	(0.0408)
WALK	0.0012	(0.0098)		
ROAD	−0.0027	(0.0010)***	−0.0025	(0.0010)**
AREA	−0.0007	(0.0006)		
FLAT	0.0820	(0.0226)***	0.0899	(0.0213)***
NCROPS	0.0050	(0.0049)		
YRSET	−0.0006	(0.0017)		
LABORH	0.0046	(0.0013)***	0.0043	(0.0012)***
LOAN	0.0002	(0.0057)		
ACCESS	0.0390	(0.0271)	0.0439	(0.0238)*
TITLE	−0.0438	(0.0210)**	−0.0497	(0.0195)**
LABORO	−0.0163	(0.0204)		
GOOD	−0.0057	(0.0209)		
ASSETS	−0.0029	(0.0049)		
EDUC	0.0204	(0.0094)**	0.0171	(0.0087)**
AGE	−0.0003	(0.0009)		
POWER	0.0193	(0.0188)		
HHSIZE	0.0000	(0.0011)		
n	121		121	
Log likelihood	124.26		121.46	

***$P < 0.01$, **$P < 0.5$, *$P < 0.1$.

tion of the farm with legal title (TITLE) were negatively related to deforestation and statistically significant. Also, as expected, gentle topography (FLAT), hired labor (LABORH), and education of the household head (EDUC) are positively related to deforestation.

The results at the parroquia and farm levels support the importance of population pressure and the road network as drivers of deforestation. The high coefficients and adjusted-R^2 for the models containing road density at the parroquia level suggest that accessibility is an important factor explaining deforestation in NEA, not only because it facilitates spontaneous colonization to forested areas, but it also generates uncontrolled development in the form of nonplanned urbanization and illegal timber extraction. At the farm level, accessibility variables are only statistically significant for the period from 1996 to 2002.

In terms of theoretical approaches, we found little support for the household life cycle approach because the variables ''year of settlement'' and ''age of the head of household'' were not statistically significant. This research, however, is at the farm level and grouped multiple households living within the fincas. Therefore, what we explored is the ''farm'' life cycle and the effect of individual household might have been lost. Other demographic variables, such as population density at the parroquia level and household size (for 1986–1996) support the notion that population pressure in the form of farm subdivision is a strong driver of deforestation.

Hired labor was significantly linked to deforestation at the finca level for the two time periods, but with different directions. Descriptive statistics showed a slight decrease in the use of outside labor within the farms between 1990 and 1999, which is consistent with the fall of the prices of coffee, cacao, and other cash crops. For the second deforestation time period (1996–2002), where increasing amounts of hired labor (LABORH) contributed to deforestation, workers might be hired to work in more extensive land use activities (i.e., cattle ranching). This, linked to the fact that household size (HHSIZE) and (AREA) were statistically significant only for the period 1986–1996, indicates that for 1986–1996 decisions about deforestation were based on household internal consumption needs restricted by land availability rather than driven by agricultural markets. In the second period, despite relative lower prices of cash crops and cattle, but benefited by improvements in accessibility characteristics and education, deforestation decisions seem to be more oriented to the market.

Infrastructure variables (i.e., PORAGUA and PORALCA), which are indicators of urbanization, were negatively related to deforestation. In a cross-national study, Ehrhardt-Martinez (1998) suggests that the relationship between the level of urbanization and the rate of deforestation is curvilinear: As countries become more urbanized, the rates of deforestation increases until moderate levels of urbanization are achieved, after which deforestation is slower. This exploratory study at the regional level suggests that once other factors are controlled (including population), improvement in public services attracts local rural population to urban areas which will, in turn, diminish deforestation. Ryder and Brown (2000) suggest that in the absence of new road-building projects (that allow access to new areas of land), young household members prefer to search for income in urbanized zones. Rudel and Horowitz (1996) observed a similar trend earlier in province of Morona Santiago, where the second generation of colonists tended to migrate away from their farms to larger towns in search of a better or easier life.

Our research found a significant relationship between annual deforestation and the type of land tenure for 1996–2002, although not for the earlier period. Rudel (1995), using ethnographic data from the southern Ecuadorian Amazon, found that formal tenure regimes did not affect deforestation because groups of small holdings already own and defend their lands within an informal system of land tenancy, which appears to have been the case here as well. Almost every farmer had a land title (escritura) or provisional certificate of possession, in the 1990 survey, but this changed dramatically after IERAC was eliminated in 1993. In the 1999 household survey, many farmers did not have title, in fact, most of the farmers acquired part of a farm through subdivision. Baribieri and others (in press) also observe the negative effect of title on deforestation, which mainly reflects the effect of farm subdivision on stimulating further deforestation.

Education shows mixed directions in relation to deforestation in the two time periods analyzed. The signs of the relationship, however, are consistent at the parroquia and finca levels. For 1986–1996, primary education (EDUC) in the parroquias studied and education of the heads of households were negatively related to deforestation, whereas for the 1996–2002 period, primary education at the parroquia and farm level were positively linked to deforestation. Although off-farm employment is not statistically significant, this research suggests that in the early period more educated people were attracted by the insipient labor market, but later, better opportunities for educated people to have access to agricultural loans and markets led to the extensification of land use in the farms. Education, and other socioeconomic factors such as electricity, can also change perceptions about opportunities in the farm and in the city and therefore create different strategies of land management. On the other hand, poverty at the parroquia level and assets at the finca level, were not statistical significant. The exception is poverty (POV) for the 1986–1996 parroquia model. In this model, less poverty created more deforestation. Richer parroquias might have the necessary resources to expand crop cultivation and increase cattle ranching. Other variables at the finca level were considered to explore the relationship between wealth and deforestation (e.g., annual income) but problems of endogeneity limited their use. The cautionary note about the statistical modeling is related to the sample size and the sample selection effect and our inability to control for unobserved events.

Discussion and Conclusions

We found that annual deforestation rates at the regional level were consistent with the estimates of Sierra (2000). He calculated that approximately 55,600 ha per year were cleared in the Napo Region during the period from 1986 to 1996 at an annual rate of 0.6%. However, this rate was for a much larger area, including larger tracks of undisturbed forest. This article shows the severity of the deforestation in the core of the colonization area during the two time periods studied (1986–1996 and 1996–2002). Nevertheless, deforestation rates were not homogeneous across parroquias. For example, San Pedro de los Cofanes, Joya de los Sachas, and Siete de Julio exhibited deforestation rates almost eight times as high as the average of the Northern Oriente, whereas others such as San Roque or General Farfan had far lower rates.

Official reports have pointed to colonization and agricultural expansion, timber extraction, monocultivation plantations, oil and mining, weak land titling programs, and poverty as the main overall causes of forest cover change in Ecuador (Food and Agriculture Organization 2000). Earlier studies, conducted with the same 1990 household survey data that was used in this study and that rely in deforestation reports from farmers, show patterns in which larger cleared areas emerged among households with greater farm labor resources (in terms of male workers per household) (Marquette 1998), duration of settlement, soil quality, road access, and education (Pichón 1997; Pichón and others 2002; Pan and Bilsborrow 2005). This study, linking remotely sensed estimations of deforestation and socioeconomic survey and census data, is consistent with earlier findings and suggests that the rate of deforestation is driven by roads, demographic factors, education, infrastructure, hired labor, and topographic characteristics.

The set of factors that drive LULC change is scale dependent and it is mediated by decisions made at the individual, household, and communities levels (Walsh and others 2001). Roads in the NEA, for example, are direct and underlying drivers of deforestation across spatial scales. At the national level, the Ecuadorian government encourages roads construction for oil exploration and exploitation through pristine forests, protected natural areas, and indigenous ancestral territories. Roads then facilitate in-migration of a growing population of poor peasants from the provinces of the Costa and the Sierra regions of Ecuador to cheap lands in the NEA (Uquillas 1984). At the local scale, besides the direct impact created during road building, labor and input costs, wealth, commodity prices, and transportation costs depended on the availability and quality of roads (Murphy and others 1997). The results of this research confirm the importance of roads as drivers of deforestation at both the parroquia and finca levels but also suggest that the impact of strong predictors of deforestation, such as the effects of accessibility and population pressure, can be observed at different levels of socioeconomic data aggregation.

The National and local governments must consider future land use patterns created by the extensification and improvement of the road network. The oil reserves found in the NEA imply a continuous development of the oil infrastructure in the region. Although the opportunities of off-farm employment in the oil industry would benefit the local labor force and the forest conservation by maintaining farmers out of the forest remnants and encouraging forest succession by the abandonment of unproductive plots, it is more likely that the emergent employment opportunities will be transitory and the long-term effects will result in the advance of the deforestation front and forest fragmentation in protected areas and indigenous territories. Another important policy implication is related to education. Although this research found that in the later period (1996–2002) more education resulted in more deforestation, we believe that increasing levels of specialized education that enhance the value of the forest for households and communities will curb the current tendency.

One of the purposes of this research was to make use of freely available socioeconomic and spatial information to explore the relationships between socioeconomic activities and environmental degradation by linking remote sensing and geographic information systems. The variety of detailed studies discussed here shed light on the complex interplay of factors driving deforestation. The intensity and expense of gathering household data to sort out this complexity, however, exceeds the budget possibilities of most local and regional resource managers attempting to form policies that balance development with conservation. Managers and political decision-makers need rapid and inexpensive methods to predict the extent of environmental problems as a function of various aspects of development. The approach and results documented here show that useful information can be obtained through relatively simple analyses involving publicly available data such as national censuses. We think, however, that the analyses at different levels of socioeconomic and demographic data aggregation are complementary due the scale dependency of the LULC drivers. Our approach is particularly suited to the case of the Northern Ecuadorian Amazon, where internal/external migration is an essential factor to understanding socioeconomic dynamics and their effects on the environment.

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