Contrasting Colonist and Indigenous Impacts on Amazonian Forests

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Abstract

In the most common narrative of tropical deforestation, agricultural clearing by migrant colonists is assigned much of the blame and the activities of indigenous peoples are assumed to be ecologically sustainable. We test this hypothesis using regional-scale survey and spatial datasets from colonist and indigenous territories in the Northern Ecuadorian Amazon. We compare measures of land use derived from surveys and satellite imagery for colonist and indigenous households, and discuss regression models of the influences on land use for each of these populations. The results confirm that forest impacts by colonists are greater than those of indigenous peoples in terms of area cleared, rates of deforestation, and measures of forest fragmentation. Nevertheless, substantial variation in land use patterns exists among five indigenous groups. The results indicate that stereotypes of rapacious colonists and sustainable indigenous peoples should be set aside as part of a more nuanced understanding of frontier land use.

Introduction

The destruction of Amazonian rainforests, estimated at 2,500,000 ha/year through the 1990s (Malhi et al. 2008), has important implications for biodiversity loss, global climate change, and livelihood security. Human residents of Amazonian forests and the forest frontier include both indigenous peoples and *mestizo* colonists, populations which vary greatly in access to land, labor and capital, degree of market involvement, and land tenure regimes. In addition, these groups are widely assumed to differ in their environmental stewardship and conservationist behaviors, with colonists seen as seeking material gain through extensive land clearing for commercial agriculture while indigenous peoples are thought to possess cultural norms and values that promote sustainable methods of resource use and conservation (Stocks et al. 2007). The generalizations of rapacious colonists and ecologically noble indigenous groups belie significant variation and highlight the importance of studies to illuminate the diversity of demographic, economic and land and resource use practices within and between these groups.

The debate on indigenous conservation and sustainable land use illustrates the polarized characterizations of these rainforest residents, with alternate portrayals as either a solution or as a major threat to conservation (see, for instance, the debates in *Conservation Biology* volumes 7, 8, 14, and 15). In the former portrayal, they have been depicted as static, isolated, "ecologically noble" conservationists living in harmony with nature (Brosius 1997; Conklin and Graham 1995; Redford 1990). More recently, however, some biologists have become disillusioned due to the contrast between the real-world behaviors of indigenous peoples and the "ecologically noble savage" ideal, perceiving indigenous resource use as yet another threat to ecological viability especially in light of population increase, technological change and market incorporation (e.g., Terborgh 1999). Their call to a return to people-free parks has been deemed by Wilshusen et al. (2002) as a resurgent "protection paradigm" in international biodiversity conservation. In rebuttal, Schwartzman, Colchester and others (Schwartzman et al. 2000a,b; Colchester 2000) assert that indigenous peoples are potent political actors and an essential component of the constituencies that are necessary for the long-term conservation of tropical forests, as seen from examples such as the Kayapo in Brazil (Peres & Zimmerman 2001; Zimmerman et al. 2001; Schwartzman & Zimmerman 2005). The framing of Native Amazonians in these debates as homogeneous in terms of cultural values and use of land and resources has potentially negative ramifications for developing more nuanced policies and long-lasting collaborations between indigenous and non-indigenous stakeholders (Anderson 2001).

Views of colonists have tended to focus on their detrimental ecological impact on rainforests due to land use strategies that, in their adaptation to former origin areas, are inappropriate for Amazonian ecosystems and/or devised for income accumulation in a capitalist economy. Research conducted among colonists in the Ecuadorian Amazon has highlighted the importance of cash cropping, cattle raising, and wage labor to the household economy, and land degradation occurs not only through intensive use (e.g., clearing and chemical inputs) but also fragmentation and subdivisions of plots to multiple users (cite Dick's work here). As proximate agents of tropical deforestation, it is critical to understand the patterns, decision making, and impacts of colonist land use, as demographic growth of migrants and their families in frontier areas like the Amazon will continue to have a significant impact on ecosystem viability. Understanding these processes among indigenous peoples is just as important, as these populations are undergoing rapid processes of cultural, economic, and social change (citations) and also control substantial areas of Amazonian rainforests (Peres 1994; Schwartzman & Zimmerman 2005; Nepstad et al. 2006). However, in the literature there has been a relative lack of studies comparing indigenous and colonist land use in the same region (exceptions include Garland 1995; Godoy et al. 1997, 1998; Rudel et al. 2002; Hvalkof 2006; Stocks et al. 2007).

In this paper we report findings based on fairly large and representative samples of indigenous peoples *and* colonists occupying the same forest frontier region in the Northern Ecuadorian Amazon (NEA). The NEA is a particularly important study area because of its high biological and cultural diversity, both threatened by ongoing rapid deforestation and forest degradation. Since 1990 Ecuador has had the highest rate of deforestation in South America (FAO 2005) due to rapid agricultural expansion, urbanization, land use intensification, and petroleum exploitation. To compare colonist and indigenous land use in the NEA, we draw upon parallel household surveys (Vadez et al. 2003) of the two populations conducted in 1999 and 2001.[1] The 1999 survey of colonists involved return visits to farm plots originally visited in a 1990 survey, and collected data from 778 agricultural households in 64 colonization sectors or areas (Bilsborrow et al. 2004). For indigenous households, surveys implemented with both household heads and spouses were carried out among 499 households from 36 communities in 2001 (Holt et al. 2004). Unlike previous studies that of indigenous land and resource which are commonly small-scale intensive studies, typically of one community (e.g. Santos et al. 1997; Perrault 2005), our research encompasses five indigenous populations in the NEA study region: the Huaorani, Kichwa, Cofán, Secoya, and Shuar. These groups span a gamut of population size and density, history of contact with outsiders and settlement, and linguistic affiliation (Holt et al. 2004).

The emerging field of Land Change Science (Gutman et al. 2004; Rindfuss et al. 2004), provides a framework for understanding the dynamics of forest frontiers such as those in the Amazon (Lambin et al. 2001; Rindfuss et al. 2004). In following this approach, we integrate survey, statistical, and spatial approaches to understand the human dimensions of environmental and land use/land cover change. We present descriptive analyses of household land use, summarize findings of multivariate models of factors influencing deforestation, and then present key results from spatial analyses drawing on remotely sensed data. We use a remote sensing image time-series (1986, 1996, 2002) to link biophysical data with household surveys and to capture spatial and temporal contexts, providing characterization of landscape states and conditions at a host of space-time scales. While a number of studies have now utilized remotely sensed imagery to quantify land cover and land cover change in the Amazon (e.g., Behrens et al. 1994; Sierra 1999; Rudel et al. 2002a; Schwartzman & Zimmerman 2005; Nepstad et al. 2006), fewer have used survey and statistical methods to investigate the drivers of forest resource (Pattanayak & Sills 2001; Escobal & Aldana 2003; Coomes et al. 2004; McSweeney 2004) and agricultural land use (Godoy et al. 1997; Godoy et al. 1998; Rudel et al. 2002a). Decades of work by the authors in the NEA with its diverse human populations provides the kind of multifaceted, large-sample data sets increasingly required to understand the complexities of these coupled natural and human systems (cite).

Background and Study Site

The NEA study area includes parts of the provinces of Sucumbios, Orellana, Napo, and Pastaza and borders the Andean foothills to the west and the Colombian and Peruvian Amazons to the north and east (Figure 1). The region's lowland 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. 2003). The annual temperature averages 25 degrees Celsius with extremes of 15 degrees and 38 degrees. The annual rainfall is 2425-3145 mm, with an average humidity of

88% (Herrera-MacBryde & Neill 1997). The warm, wet climate fosters a wealth of biodiversity. For instance, in the 600,000 acre Yasuni National Park (Figure 1), a UNESCO World Biosphere Reserve, scientists have identified more than 600 species of birds, 500 species of fish, and 120 species of mammals (Kimerling 1991: 33). Moreover, a detailed assessment of tree biodiversity in 16 tropical sites around the world conducted by the Smithsonian Tropical Research Institute concluded that the park contained 1104 species (of at least one cm dbh) in a 25 hectare area, the most of any site studied in the world (Romoleroux et al. 1997). In the Cuyabeno Reserve (Figure 1), another important Amazonian conservation area within the study region, 313 species of trees have been identified within a single hectare, and 500 species of birds and 100 species of mammals have been reported.[2]

The discovery of significant oil reserves at Lago Agrio by a Texaco-Gulf consortium in 1967 set in motion processes of road construction and agricultural colonization from highland and coastal Ecuador which were facilitated by government settlement policies and fundamentally driven by oil extraction (Hiraoka & Yamamoto 1980; Brown & Sierra 1994; Pichón 1997). These processes have transformed the central part of the study area into an agricultural and urbanizing landscape inhabited primarily by *mestizo* colonists from Ecuador's coast and Andes regions (Pichón 1997; Bilsborrow et al. 2004). This zone of colonization is bordered to the east by Yasuní National Park and the Cuyabeno Wildlife Reserve and to the south by the large Huaorani territory (Figure 1), all of which have also experienced peripheral agricultural colonization (Greenberg et al. 2005; Messina et al. 2006). Agricultural colonization and oil extraction have also dramatically altered the lives of Amerindian populations of the NEA who have inhabited the region for millennia.

The total indigenous population of the Ecuadorian Amazon is over one hundred and fifty thousand (INEC 2003), which is thirty percent of the total regional population and roughly equivalent to the indigenous population of the entire Brazilian Amazon (Kennedy & Perz 2000). The five populations included in the study—the Kichwa, Shuar, Huaorani, Cofán, and Secoya—vary in population size, linguistic affiliation, history of contact, and economic activities (Holt et al. 2004). The lowland *Kichwa* are the most numerous, with an approximate population of thirty thousand in the NEA (INEC 2003) who primarily occupy discontinuous communal territories (*comunas*) (CODENPE 2004). This group emerged in the aftermath of the violence and depopulation associated with the Spanish conquest, when the Andean language Kichwa was adopted as a lingua franca in mission villages of mixed ethnicity (Macdonald 1981). Under the pressure of colonist encroachment, some Kichwa communities have adopted colonist-style production and tenure systems (Macdonald 1981), and others have resettled away from the colonization front (Irvine 2000), including along the region's major rivers. The *Shuar* are members of the Jivaroan language group and native to the southern Ecuadorian Amazon and adjacent areas of Peru (Rudel et al. 2002a). Numbering approximately two thousand individuals in the NEA (INEC 2003), they are the second largest indigenous population in the Ecuadorian Amazon as a whole. Rudel and collaborators (2002a, 2002b) have described how agricultural colonization of the Shuar traditional territory in the province of Morona-Santiago has pressured some Shuar communities to adopt cattle raising and cash cropping. These experiences also likely encouraged households to migrate to the NEA, where they have arrived as agricultural colonists and settled in communal territories in a manner similar to the Kichwa.

The study also included three smaller indigenous populations. 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, and around 1000 Cofán now live in six settlements in three separate territories (Townsend et al. 2005), including areas within the heart of the zone of the colonization and within the Cuyabeno Wildlife Reserve and the Cofán Bermejo Ecological Reserve (to the west of the study area) (CODENPE 2004). The *Secoya* and related Siona, descendents of a larger group referred to as the Encabellado, belong to the Western Tucanoan linguistic family and number approximately 800 people along the Aguarico River and its tributaries in the NEA and adjacent Peru (Vickers 1993). Six Secoya and Siona communities in the NEA occupy a contiguous ethnic territory, including areas within the Cuyabeno Wildlife Reserve (CODENPE 2004). Finally, the *Huaorani*, whose language is a linguistic isolate, are the least assimilated of Ecuador's indigenous peoples and were peacefully contacted for the first time only in 1958, having previously repelled outsiders through threats and acts of violence (Rival 2002; Ziegler-Otero 2004). They are estimated to number two thousand persons in twenty-eight communities and occupy a large contiguous ethnic territory in the south of the study area, including areas within Yasuní National Park (CODENPE 2004). Most Huaorani communities are distant from roads and market, but many have interacted with oil companies which are active in the Huaorani territory (Lu 1999; Ziegler-Otero 2004).

Methodology

Survey Data Collection

This section describes the parallel survey data collections among colonists in 1999 and indigenous peoples in 2001. The 1999 colonist survey was the second round of a longitudinal data collection initiated in 1990. Prior to the 1990 survey, a probability sample of colonist farms in the NEA was selected through a two-stage cluster sample with a sampling fraction of 5.9%. A map of colonization sectors and farms from the government land reform and colonization agency provided the sampling frame. Of 480 farms sampled in 64 colonization sectors in 1990, 408 were inhabited and 418 resident households were interviewed. When these same farms were visited a second time in 1999 they were inhabited by 778 agricultural households on large plots and 111 urban households on small residential plots due to rapid subdivision of farm properties. The 778 agricultural households interviewed in 1999 constitute the colonist sample analyzed in this paper. The response rate for sample households in 1999 was 93%.

In 2001 a parallel household survey was carried out in 36 indigenous communities representing five ethnicities: Huaorani, Kichwa, Cofán, Secoya, and Shuar. Since no sampling frame was available for indigenous communities, a judgment sample of communities was selected in the NEA region from the five ethnicities to capture a range of exposure to colonization and external markets. In each study community a list of households was prepared and used as a sampling frame to randomly sample 22 households per community, with all households included in smaller communities. Complete information was obtained from 499 households with a response rate of 89%; these constitute the indigenous household sample analyzed in this paper.

In both the 1999 and 2001 surveys two structured questionnaires were implemented in each sample household, one with the male head of household and another with the female head or spouse. These interviews were respectively conducted by male and female interviewers, most commonly in Spanish but when necessary in the appropriate indigenous language with the aid of a local interpreter. In single-headed households or in the case of a prolonged absence of one head both questionnaires were administered to the person available. The 1999 questionnaires were partially modified for the 2001 survey in order to better capture indigenous livelihoods and land uses, but the two sets of questionnaires contain many common elements. In both cases the male head's questionnaire covered land tenure and use, production and sale of crops and cattle, off-farm employment, and receipt of technical assistance and credit among other topics. Questions on land use collected self-reports of the land area in various uses, and intercropped areas were divided among constituent uses based on proportional coverage. The female head's questionnaire included a household roster and also asked about out-migration from the household, household assets, and other topics.

Spatial Data Collection

Imagery

A classified time series of Landsat TM images (1986, 1996, 2002; Path 9/Row 60) was used in this research. The time series imagery was classified using a hybrid supervised-unsupervised classification method (Messina & Walsh 2001). An unsupervised classification was applied first; the spectral signatures generated were evaluated using transformed divergence. The results from the initial unsupervised classification were evaluated, and any classes that displayed confusion were subset and run through the unsupervised classification separately. These new signatures were added to the original signature set; this augmented signature set was used for supervised classification. Training data for the supervised classification were obtained from fieldwork in the study area.

Land cover classes in these images include forest, pasture, crops, barren, urban, and water. Radiometric correction was applied, as examination of landscape change over time necessitates radiometric correction so that pixel values are comparable between images (Song et al. 2001). The 5s (Tanre et al. 1990) absolute radiometric correction algorithm was applied to the image time series after the images had been converted to top of the atmosphere (TOA) reflectance values.

Ground data for the classification of the Landsat Imagery were collected between 1999–2001 by the Ecuador Project. Validation data were collected in 2002. Ground data were collected using Global Position System (GPS) data with differential correction. The overall fuzzy accuracy for the 2002 classification was 75.2%; however, the users' accuracy for the forest class used in this study was 95%.

Pattern Metrics

The term "pattern metrics" refers to a group of indices that have been developed for evaluation of categorical maps (McGarigal et al. 2002). Landscape pattern metrics focus on the composition and configuration of the classes included in categorical maps and thus the spatial and geometric properties of these maps. Pattern metrics are commonly defined at three levels, the patch, class, and landscape. Patch-level metrics are defined for individual patches and characterize their spatial character and context, while class-level metrics examine all the patches of a particular type, producing an average or weighted-average value depending on whether large patches contribute more heavily to the index. Landscape-level metrics are integrated over all the class types over the extent of the data, producing an average or weighted average value. The metrics chosen for use in this study were chosen to represent composition (PLAND, PD, LPI) and configuration (COHESION, AI) while minimizing redundant information. Metrics were thus chosen carefully, as many pattern metrics are correlated, since they are based on a small number of measurable patch characteristics, including patch type proportion, area, edge, and connectedness (Riitters 1995).

Deforestation Rates

Forest cover may be described simply as the area affected by change by calculating forest area at two time points and determining the difference between the two measurements. An additional way of describing change in forest area is by calculating the rate of change. Studies examining deforestation rates include Sader and Joyce (1988), Dirzo and Garcia (1992), and Ochoa-Gaona and Gonzales-Espinosa (2000). Equation 1 shows yearly deforestation rate as calculated by Sader and Joyce (1988), where F_1 is forest area at the beginning of the period, F_2 is the forest area at the end of the period, and N is the number of years in the reference period.

$$\text{Percent per year} = \frac{\left(\frac{F_1 - F_2}{F_1}\right)}{N} \text{ x } 100 \qquad (1)$$

This study uses the formula used by both Dirzo and Garcia (1992) and Ochoa-Gaona and Gonzales-Espinosa (2000) that calculate yearly deforestation rate as presented in equation 2, where $A_1$and A_2 are the forested areas at the start and end of the period being evaluated, and t is the number of years within the period.

$$r = 1 - \left(1 - \frac{A_1 - A_2}{A_1}\right)^{\frac{1}{t}} \qquad (2)$$

Findings

Descriptive Analysis of Survey Data

To compare colonist and indigenous land use, we derived the total agricultural area managed by each household as well as three constituent measures: area in pasture (almost exclusively for cattle); area in crops planted for market sale ("cash crops"), primarily coffee; and area in other crops that might be used for subsistence or sale, such as corn, rice and plantains ("other crops"). Table 1 presents descriptive statistics of these measures for the colonists and indigenous groups combined and separately. We also performed non-parametric Wilcoxon rank-sum tests to compare the distributions of each measure between the colonists and the combined indigenous (Table 1). Despite substantial heterogeneity across the five indigenous groups, the results show that colonist households clear significantly larger agricultural areas overall, for both pasture and cash crops, but indigenous households manage larger areas in other crops. Colonist areas in all uses combined, in cash crops, and in pasture are, respectively, 2.1, 1.8 and 5.5 times as large on average as those of indigenous populations, but the area in annual crops is only half (0.48 times) as large. For both colonists and indigenous populations, a majority of the agricultural area is devoted to market-oriented uses, which include pasture and cash crops.

To put these results in context, Table 2 presents mean values by ethnicity for key aspects of the sample populations related to land use, including the percentages of households owing cattle, using modern agricultural inputs (fertilizer, herbicides or pesticides), selling crops, and hiring agricultural laborers in the past year. Consistent with their much larger areas in cash crops and pasture but smaller areas in other crops, colonist households were more likely to participate in all of these activities, and to participate in agricultural markets. The Secoya are a partial exception, with many owning cattle, a livelihood strategy which was originally promoted by missionaries from the Summer Institute of Linguistics (Vickers 1993), but has more recently been facilitated by state-led development programs in the 1970s and 1980s and by the current capital influx from Occidental Exploration and Petroleum Company who operate a concession block in Secoya territory (Valdivia 2005).

Previous explanations of such differences between colonists and indigenous peoples have focused on ethnocultural factors, such as different worldviews and value systems, but our data show that the two populations also differ in other ways that might explain differences in land use. As shown in Table 2, indigenous peoples are much more isolated from markets, have less access to human capital such as formal education and Spanish language ability, and are less likely to claim individual tenure over their agricultural lands—all of these factors are likely to limit the extent of agricultural activities (see section below). Another key difference between the two populations is that fertility is substantially higher for the indigenous groups, suggesting that in the future indigenous agricultural activities are likely to grow relative to those of colonists as they need to clear more land to feed an expanding population.

Comparison of Land Use Models

Previous analyses based on these data have used multivariate statistical models to investigate the determinants of colonist and indigenous land use. Drawing on the 1999 colonist survey dataset, Pan, Bilsborrow and colleagues used general linear models and multilevel models to analyze the influences of demographic, socioeconomic, ecological and contextual factors on colonist land use as divided among four categories: forest, pasture, perennial crops and annual crops (Pan & Bilsborrow 2005; Pan et al. 2007). Drawing on the 2001 indigenous survey data, Gray et al. used a hierarchical linear model to investigate the effects of a similar set of factors on the agricultural area of indigenous households (Gray et al. 2008). Despite differences in the models, they illustrate the effects of similar factors on colonist and indigenous land use and can be meaningfully compared. The models used for estimating land use of colonist and indigenous populations both include controls for the numbers of men, women, and children in the household; age, education and duration of residence of the household head; household participation in wage labor; security of land tenure; distance to the closest market; and key natural resource characteristics of the farm as such soil quality and topography.

The results show that household composition and characteristics of the head have similar effects on colonist and indigenous land use: a larger number of adult males in the household is associated with a significantly larger agricultural area, while the numbers of women and children have little effect. This suggests that it is the farm labor available from men rather than food demands that are the primary effects of household composition on land use. Consistent with this, the participation of household members in wage labor significantly decreases the agricultural area for both colonists and indigenous households. We find that the higher the education of the household head, the larger the agricultural area for both, perhaps because education facilitates interaction with the market and is linked to higher consumption aspirations.

Security of land tenure, distance to market, and biotic factors also have generally similar effects on colonist and indigenous land use. Agricultural area significantly increases with secure land tenure and decreases with distance to market. Soil quality and flatness of land on the farm were both linked positively to the area in agricultural use of colonists but not to indigenous land use, perhaps due to the much smaller and adaptable plots of the latter. Overall, comparison of the results reveals many similarities and few differences in the significance and direction of effects, suggesting substantial consistency in the drivers of land use between colonist and indigenous households.

Analysis of Landscape Change

To understand how land change processes in indigenous and colonist areas transform the areal extent and spatial arrangement of forests, we use remotely-sensed data to calculate landscape pattern indices, which are key tools in the field of landscape ecology (Gustafson 1998). Of the communities included in the household surveys, Landsat TM satellite imagery was available for 54 colonization sectors and 16 indigenous territories. The boundaries for each colonization sector or indigenous territory were estimated based on maps from the Ecuadorian Institute for Agrarian Development (INDA). Land use and land cover maps were derived from the satellite imagery using hybrid methods of classification, and landscape pattern metrics were calculated for a set of land use-land cover classes; we focus here on change in the primary forest class.

Pattern metrics were calculated for each territory for two periods—1986-1996 and 1996-2002—and subtracted to obtain the relative difference (Δ). These differences were then contrasted between colonist and indigenous areas using t-tests. The calculated landscape pattern metrics include: the annual deforestation rate; the proportion of the landscape covered by primary forest (PLAND); patch density (PD), an indicator of fragmentation measured as the number of primary forest patches per 100 hectares (McGarigal et al. 2002); the largest patch index (LPI), which is the percentage of the area constituted by the largest *forested* patch; and the patch cohesion index (COHESION), which measures the physical connectedness among patches of primary forest. COHESION is almost zero when the proportion of area covered by primary forest is maximally subdivided and increases up to 100 as forest connectedness increases (McGarigal et al. 2002). Finally, the aggregation index (AI) measures spatial aggregation or dispersion of forested patches. AI equals zero when the patch types are maximally disaggregated (i.e., there are no adjacent primary forest patches) and equals 100 when the landscape consists of a single patch (McGarigal et al. 2002). These metrics were chosen to represent landscape change while balancing explanatory power (Riitters et al. 1995) and sensitivity to map extent (Saura & Martinez-Millan 2001) and spatial resolution (Cain et al. 1997).

Table 3 shows the mean annual rate of deforestation for colonist farms and indigenous community territories in the two study samples, along with measures of changes in the primary forest landscape as captured by changes in the pattern metrics within the two time periods. Overall, for both periods, colonists have considerably higher annual deforestation rates than the indigenous groups. For example, the area in primary forest (PLAND) decreased by 24% between 1986 and 1996 in the sample of colonist farms compared to only 13% in indigenous territories. The rate of deforestation in indigenous territories is lower for 1996-2002 than 1986-1996. However, the deforestation rate for colonist areas is higher in 1996-2002, and significantly higher than that of the indigenous territories in both periods. Forest patch density (PD) increases seen in 1986-1996, as well as 1996-2002, reflect forest fragmentation resulting from deforestation. Largest patch index (LPI) values indicate that the largest forest patches decreased significantly in size 1986-1996. While the largest patches decreased by lower percentages 1996-2002, deforestation in colonist areas show a greater impact on largest forest patches. COHESION values are very low for both time periods, which indicate that although more patches of forest exist, they are not well-connected. The low values for the aggregation index (AI) point to a landscape in which forest patches are disaggregated. The metrics of landscape fragmentation, aggregation and connectedness of primary forest patches all indicate a more fragmented and less connected forest landscape in colonist areas relative to indigenous territories.

Conclusion

This paper compares the land use practices of agricultural colonists and indigenous populations in the NEA, showing that colonists have cleared much larger areas for agriculture than indigenous populations to date. We found evidence that these five indigenous populations have had a much lighter ecological footprint than colonists, whose lands exhibit substantially higher deforestation rates and greater forest fragmentation. However, our data also call into question stereotypes of ecologically noble indigenous peoples and rapacious colonists. First, there exists substantial heterogeneity in land use patterns among the five indigenous groups which cautions against generalizations regarding indigenous land use. For example, the Secoya exhibit cattle holdings and land areas in pasture more akin to those of colonists than to the other indigenous study populations (Valdivia 2005). Furthermore, the similarities in the results from multivariate models of colonist and indigenous land use suggest that other factors beyond ethnocultural differences, such as accessibility (to roads and market towns), population density, and human capital, might help to explain the differences. We now know, from our work and that of others, that key factors in understanding variations in Amazonian land use across cultural groups and over time include differences in demographic characteristics and dynamics; proximity to infrastructure, especially roads and towns; cultural as well as economic influences of markets on indigenous populations; the prevalence and types of off-farm or extra-community employment; and the strength of cultural ties to the land and values associated with the land. As indigenous groups come to be more integrated into the market economy (Godoy 2001; Lu 2007), adopt more sedentary settlement patterns, and acquire titles to huge areas of tropical forests (but still find their lands circumscribed by alternative land users), efforts to understand the changing human/environment interrelationships of indigenous populations become of paramount importance.

Future studies of frontier land use need to take into account the complex interplay of cultural, economic, demographic, and biophysical factors, and explore the competing and complementary roles of multiple stakeholders in the same study area, including colonists, indigenous peoples, *ribereños*, rubber-tappers, oil and mining companies, managers of protected areas, tourists, and local and national government agencies. The better the behaviors of these agents acting on the same common Amazon areas is understood, the better the prospects for designing policies to grapple with the ongoing disappearance of biological and cultural diversity in the Amazon.

Endnotes

1. Household surveys are an important data source for studies of land use change because the household is a key decision-making unit for land use and because surveys allows data linkages between reported land use and household characteristics and activities. Survey reports of land use draw on land managers' detailed knowledge of the local environment and have been shown many times to accurately capture household characteristics and land use as well as local environmental conditions (e.g., Vadez et al. 2003).

2. http://www.worldwildlife.org/wildworld/profiles/terrestrial_nt.html

Acknowledgements: We thank many colleagues for assistance, especially B. Frizelle, B. Torres, F. Vaquero, A. Oña, K. Álvarez, D. Chávez, A. Ruíz, F. Pichón, L. Murphy, W. Pan, and P. Suarez. Our gratitude goes to EcoCiencia, Centro de Estudios de Población y Desarrollo Social (CEPAR), Carolina Population Center's Spatial Analysis Unit and UNC's Department of Geography's Landscape Characterization and Spatial Analysis Lab, IERAC (the former Institute of Agrarian Reform and Colonization), CONADE (the former National Planning Agency), Ecuador's Ministry of Agriculture, and INIAP (National Institute for Agricultural Research). Many thanks to our dedicated field researchers and especially to the indigenous and colonist households and communities who participated in this research. Supported by the National Institutes of Health (R01-HD38777-01), National Science Foundation, US National Aeronautics and Space Administration (NCC5-295), Mellon Foundation, Summit Foundation, Compton Foundation, and PROFORS (Proyecto Forestal, in Lago Agrio, Ecuador).

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Table 1. Mean household land use by ethnicity (standard deviations in parentheses).

Measure	Colonists	Indigenous	1 vs. 2	Quichua	Shuar	Huaorani	Cofan	Secoya
Total agricultural area (ha)	7.85 (9.24)	3.70 (3.91)	***	4.18 (3.63)	4.89 (5.57)	1.35 (1.26)	2.30 (2.20)	4.38 (3.18)
Area in cash crops (ha)	2.44 (2.70)	1.31 (1.96)	***	1.64 (2.13)	2.07 (2.20)	0.06 (0.36)	0.89 (1.32)	0.25 (0.50)
Area in other crops (ha)	0.74 (1.37)	1.56 (1.52)	***	1.79 (1.70)	1.44 (1.61)	1.28 (1.09)	1.26 (0.94)	1.33 (1.10)
Area in pasture (ha)	4.67 (7.86)	0.84 (2.65)	***	0.76 (1.81)	1.43 (4.71)	0.00 (0.00)	0.14 (0.50)	2.80 (3.07)
Number of households (N)	778	499		239	99	79	49	33

Note: *** signifies $p<0.001$

Table 2. Mean values of selected characteristics of colonist and indigenous populations (percentages except as indicated).

Measure	Colonists	Indigenous	Quichua	Shuar	Huaorani	Cofan	Secoya
Owns cattle	60.0	28.3	31.8	34.3	1.3	14.3	69.7
Used modern agricultural inputs[1]	33.8	6.3	6.3	12.2	0.0	4.9	4.3
Sold crops[1]	81.6	65.7	82.4	74.7	21.5	55.1	39.4
Hired agricultural laborers[1]	67.4	20.6	18.4	29.3	0.0	22.4	57.6
Travel time to market (minutes)	62.0	229.2	144.6	206.3	446.1	240.8	160.0
Household head speaks Spanish	100.0	89.4	95.8	97.0	67.1	75.5	93.9
Adult men with primary education	68.7	66.4	70.1	81.7	54.8	32.7	70.0
Adult women with primary education	61.9	43.6	48.1	59.3	32.7	14.0	38.9
Individual land ownership[2]	100.0	67.1	78.7	97.0	2.5	36.7	93.9
Household size (mean number)	5.90	6.37	6.56	6.60	6.63	5.62	4.68
Population under age 12	38.4	44.5	44.7	49.6	40.8	42.0	36.6
Total fertility rate[3]	5.0	7.6	-	-	-	-	-

[1] In the previous 12 months.
[2] Land tenure described by the head of household as private rather than land in usufruct or communal tenure.
[3] Mean number of births that a woman would expect to have over her lifetime based on current fertility of women of different age groups. Not calculated for indigenous sub-groups due to small numbers of women of reproductive age.

Table 3. Annual rates of forest clearing, changes in landscape change metrics for primary forest, and statistical significance of differences between colonist sectors and indigenous community territories, 1986-1996 and 1996-2002 (standard deviations in parentheses).

	1986-1996			**1996-2002**		
	Colonist	**Indigenous**	**1 vs. 2**	**Colonist**	**Indigenous**	**1 vs. 2**
Deforestation rate (% per year)	3.93 (1.65)	1.67 (1.41)	***	4.16 (3.51)	0.73 (1.87)	***
ΔPLAND (%)	-24.42 (7.65)	-13.26 (10.33)	***	-9.47 (5.34)	-2.40 (7.32)	***
ΔPD (patches per 100ha)	9.62 (5.21)	3.35 (3.92)	***	0.92 (3.84)	1.89 (2.66)	
ΔLPI (%)	-33.63 (17.43)	-14.37 (13.27)	***	-8.79 (8.63)	-2.37 (7.67)	**
ΔCOHESION (0 to 100)	-0.09 (0.20)	-0.12 (0.14)		0.08 (0.04)	0.11 (0.09)	***
ΔAI (0 to 100)	-1.71 (1.87)	-0.18 (0.34)	***	-1.82 (2.60)	-0.17 (0.37)	*

Note: *** signifies $p<0.001$, ** $p<0.01$, *<0.05