Hum Ecol (2008) 36:97–109
DOI 10.1007/s10745-007-9141-6

Indigenous Land Use in the Ecuadorian Amazon: A Cross-cultural and Multilevel Analysis

Clark L. Gray · Richard E. Bilsborrow · Jason L. Bremner · Flora Lu

Published online: 19 October 2007

Abstract Among the remaining tropical forests of lowland Latin America, many are inhabited by indigenous peoples, and the sustainability of their land uses is a point of heated debate in the conservation community. Numerous small-scale studies have documented changes in indigenous land use in individual communities in the context of expanding frontier settlements and markets, but few studies have included larger populations or multiple ethnic groups. In this paper we use data from a regional-scale survey of five indigenous populations in the Northern Ecuadorian Amazon to describe their agricultural land use practices and investigate the factors that affect those practices. We find the areas cultivated by indigenous households to be small compared to those of nearby mestizo colonists, but a large proportion of indigenous cultivated area is in commercial land uses. We also construct multilevel statistical models to investigate the household and community-level factors that affect indigenous land use. The results reveal significant influences on cultivated area from contextual factors such as access to markets, oil company activities, and the land tenure regime, as well as from household characteristics such as demographic composition, participation in alternative livelihood activities, and human, social and physical capitals. Overall the results are most consistent with market integration as an underlying driver of land use change in indigenous territories of the study area.

Keywords Indigenous land use · Swidden-fallow agriculture · Multilevel analysis · Amazon

C. L. Gray (✉)
Department of Geography,
University of North Carolina at Chapel Hill,
Chapel Hill, NC, USA
e-mail: cgray@email.unc.edu

R. E. Bilsborrow
Department of Biostatistics, University of North Carolina at Chapel Hill,
Chapel Hill, NC, USA

J. L. Bremner
Department of City and Regional Planning,
University of North Carolina at Chapel Hill,
Chapel Hill, NC, USA

F. Lu
Department of Anthropology and Curriculum in Ecology,
University of North Carolina at Chapel Hill,
Chapel Hill, NC, USA

Introduction

It is well known that the remaining tropical forests of lowland Latin America have high conservation value but are threatened by human activities, particularly those of the Amazon basin (Mittermeier *et al.* 2003). Many of these forests are inhabited by indigenous forest peoples who depend on forest resources for a variety of subsistence and market-oriented livelihood activities, as described by numerous small-scale studies. However, the overall scale, ecological impacts, and proximate and underlying drivers of resource use by indigenous forest peoples remain unclear. Given the crucial importance of indigenous territories for biodiversity conservation (Nepstad *et al.* 2006), the rapid deforestation of lands inhabited by non-indigenous peoples (FAO 2005), and the rapid growth of lowland indigenous populations (McSweeney and Arps 2005), this uncertainty has contributed to a polarized debate in the conservation community on the proper role of indigenous peoples in conservation efforts (Redford and Sanderson 2000; Schwartzman *et al.* 2000).

Researchers have traditionally addressed questions about indigenous resource use through small-scale intensive studies employing primarily ethnographic methods (e.g., Humphries 1993; Santos *et al.* 1997; Vickers 1993). More recently, these studies have been supplemented by spatial analyses using remotely sensed imagery (Behrens *et al.* 1994; Nepstad *et al.* 2006; Rudel *et al.* 2002; Sierra 1999; Stocks *et al.* 2007) and by statistical analyses of structured survey data collected from a sample of individuals, households, or communities (Godoy *et al.* 1997, 1998a; McSweeney 2004; Rudel *et al.* 2002). Survey data collection at multiple scales (e.g., household and community) allows multivariate analyses of both household and contextual influences on resource use, and responds to recent calls for rigorous empirical studies of indigenous resource use that incorporate community attributes (Godoy *et al.* 1998b, 2005a), and for land use studies which address the effects of structural factors as well as human agency (Chowdhury and Turner 2006).

To better understand the drivers and impacts of indigenous resource use, Bilsborrow and Lu combined survey, ethnographic, and spatial methods in a 2001 data collection effort including five ethnic groups in the Northern Ecuadorian Amazon (NEA) (Holt *et al.* 2004). The study included Kichwa, Shuar, Huaorani, Cofán, and Secoya communities, encompassing peoples with diverse histories, resource use practices, and strategies for interaction with markets and outsiders. We draw on multilevel survey data collected as part of this interdisciplinary effort to describe and investigate the drivers of agricultural land use by these five indigenous populations. Following a descriptive analysis of the land use systems of each group, we develop multilevel statistical models to investigate household and contextual influences on cultivated area, a primary component of deforestation. This analysis provides insight into the relative importance of various factors for indigenous land use, including market access, oil company activities, land tenure regimes, biophysical conditions, ethnocultural differences, demographic composition, livelihood strategies, and human, social and physical capitals. With this study, we hope to shift the debate away from whether indigenous peoples are intrinsically conservationist (or not) and towards empirical assessments of indigenous resource use, which in turn should inform conservation and development policies for indigenous lands.

Household and Indigenous Land Use at Tropical Forest Frontiers

Indigenous peoples of the lowland forests of Latin America depend on forest resources for a variety of livelihood activities, including hunting, forest product collection, and shifting cultivation. Of these, agricultural activities such as shifting cultivation commonly represent the most intensive use of forest resources as well as the most important source of household calories (Beckerman 1987). In shifting cultivation systems, also known as swidden-fallow or slash-and-burn agriculture, cultivators typically clear small plots from primary or secondary forest, mulch or burn the felled vegetation, plant a diverse mix of crops for one or more agricultural cycles, and finally fallow the plot for multiple years, though fallowed areas may continue to be drawn upon for extraction of forest products (Denevan and Padoch 1988; Posey and Balée 1989). These activities have often been shown, under conditions of isolation from external markets and low population density, to have neutral or even positive impacts on biodiversity (Andrade and Rubio-Torgler 1994; Kleinman *et al.* 1995; Pulido and Caballero 2006). However, in the contemporary context of frontier expansion and associated market opportunities, some indigenous households and communities have also adopted market-oriented livelihood strategies, including wage labor, tourism, commercial agriculture, and the sale of timber and other forest products (Behrens *et al.* 1994; Godoy *et al.* 2005b; Hammond *et al.* 1995; Perreault 2005; Sierra *et al.* 1999; Valdivia 2005; Wunder 2000; Zimmerman *et al.* 2001). Where market-oriented agricultural activities have been established they often parallel the land uses of mestizo colonists (though on a smaller scale), and may include cash cropping, raising cattle, shortened fallow times, and the use of chemical inputs, activities which raise questions about the long-term sustainability of indigenous management of forested territories.

These variations in indigenous land use arise in part from contextual and historical factors, as emphasized by many small-scale case studies of indigenous land use. For many indigenous communities in lowland Latin America, land use activities occur in the context of past and ongoing population displacement, territorial circumscription, natural resource extraction by outsiders, and encroaching frontier settlement (Behrens *et al.* 1994; Gross *et al.* 1979; Henrich 1997; Macdonald 1981; Rudel *et al.* 2002; Schmink and Wood 1992; Vickers 1993). These changes have brought most indigenous communities into closer contact with market economies (a process known as integration to the market, see Lu 2007) and have been associated with transitions to market-oriented forms of land use (e.g., Humphries 1993, Rudel *et al.* 2002). However authors differ on whether these transitions are externally imposed by political conditions such as the need to establish land tenure (Macdonald 1981), or driven by the desire of indigenous households to acquire the consumer goods available in the market economy (Godoy *et al.* 2005b). Additional potential drivers of change in indigenous communities include the extension of government services such as schools and health care (Rival 2002; Santos *et al.* 1997), rapid population growth connected to declines in mortality and continued high fertility (McSweeney and Arps 2005), and the creation of national parks containing indigenous communities as well as legally recognized indigenous territories (Simmons 2002; Vickers 1993; Zimmerman *et al.* 2001).

Variations in indigenous land use may also result from differences between households, which have been the focus of survey-based studies of frontier land use by mestizo colonists. Key household characteristics influencing frontier land use identified by these studies include household size and composition, position in the household lifecycle, natural resource endowments, livelihood diversification strategies, and geographic accessibility (Carr 2005; Caviglia-Harris and Sills 2005; Pan and Bilsborrow 2005; Perz 2001; Pichón 1997; Vance and Iovanna 2006). Building on the work of Chayanov, land use is seen to vary with position in the household lifecycle and associated changes in household composition, subsistence needs and labor supply (Chayanov 1986; Barbieri *et al.* 2006; Marquette 1998; McCracken *et al.* 2002; Perz 2001; VanWey *et al.* 2005; Walker *et al.* 2002). Households also differ in their access to human, social, physical and natural capital endowments (Ellis 2000; Scoones 1998), which may facilitate agricultural expansion and/or diversification into alternative livelihood activities. Ethnicity and associated ethnocultural variations in world-view, agroecological knowledge, and social organization can also affect land use, as shown by a small number of survey-based land use studies which have included multiple ethnic groups (Carr 2005; Chowdhury and Turner 2006; Godoy *et al.* 1998b; Rudel *et al.* 2002). Nonetheless, some authors have predicted no ethnic differences in land use when other factors such as accessibility are controlled (Godoy *et al.* 1998b; Simmons 1997).

We draw on these bodies of research to consider both household and contextual influences on indigenous land use systems. We view these influences through the livelihoods framework (Ellis 2000; Scoones 1998) which identifies the household as the primary locus of agricultural decision-making, and capital endowments, contextual factors, and alternative livelihood strategies as key potential influences on those decisions. This framework guides our multivariate analysis, which extends previous research by (1) describing indigenous agricultural land use in a comparable way for five ethnic groups in a region undergoing rapid socioenvironmental change, and (2) investigating the relative importance of a variety of potential factors affecting indigenous land use using a multilevel multivariate approach. This analysis also extends previous research on colonist land use in the NEA by Bilsborrow and collaborators (Pan and Bilsborrow 2005; Pichón 1997) by applying a similar approach to indigenous land use in the same study area.[1]

Context of the Study

The NEA is a frontier forest region inhabited by mestizo colonists and growing urban populations as well as the five indigenous groups (Fig. 1). In 1967 when significant petroleum deposits were discovered, the region was occupied primarily by dispersed indigenous populations and land cover was dominated by highly biodiverse humid tropical lowland forest (Pitman *et al.* 2002). Subsequent oil exploration and extraction necessitated extensive road construction which led to agricultural colonization, widespread deforestation and ultimately the growth of urban areas (Hiraoka and Yamamoto 1980; Pichón 1997; Sierra 2000). During this period local indigenous populations were displaced and other indigenous peoples in-migrated from elsewhere in the Ecuadorian Amazon. Some indigenous communities continue to exist within the core zone of colonization but others have retreated east and south from the roads into the surrounding forests and protected areas, including Yasuní National Park, the Cuyabeno Wildlife Reserve, and the large Huaorani indigenous territory (see Fig. 1).

The total indigenous population of the Ecuadorian Amazon is estimated at over 150,000 (INEC 2003), which is about 30% of the total population of the Ecuadorian Amazon, and roughly equivalent to the indigenous population of the much larger Brazilian Amazon (Kennedy and Perz 2000). The five indigenous populations included in the study are the largest in the NEA and live in close proximity. Nonetheless they differ markedly in linguistic affiliations, history of contact, sociocultural aspects, and economic activities. The lowland *Kichwa* are the most numerous, with an approximate population of 30,000 in the NEA (INEC 2003). In the context of colonist encroachment and proximity to new market towns, some Kichwa communities have adopted colonist-style production and tenure systems (Macdonald 1981), while others have resettled away from the zone of colonization (Irvine 2000). Members of the *Shuar*, the second largest indigenous population in the larger Ecuadorian Amazon, migrated to the NEA from the southern Ecuadorian Amazon during the colonization period, and currently number about 2,000 individuals in the NEA (INEC 2003). Rudel *et al.* (2002) described how some southern Shuar communities adopted cattle ranching and cash cropping in the context of an expanding agricultural frontier.

[1] Future analyses will combine these two datasets to attempt to explain differences between colonist and indigenous land use. This paper focuses on variation among indigenous land uses.

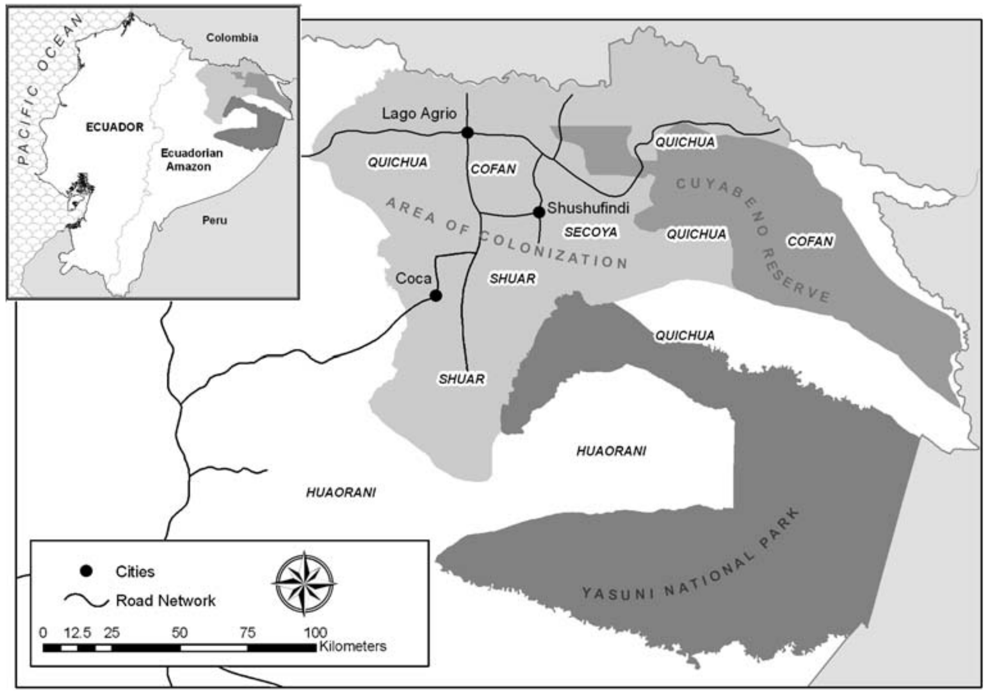

Fig. 1 Map of the study area, with approximate location of communities of the five ethnic groups. Indigenous peoples are a small minority in the area of colonization

The *Cofán* were displaced from ancestral lands in the northern NEA by the initiation of oil extraction, and less than 1,000 Cofán now live in six settlements dispersed across the NEA (Townsend *et al.* 2005). The Cofán have resisted oil exploration in their territories and actively participated in conservation programs (Townsend *et al.* 2005; Valdivia 2005). The *Secoya* (and the linguistically related Siona) number approximately 800 people and live along the Aguarico River and its tributaries in the central and eastern NEA. Secoya communities have been highly exposed to oil exploration, and many Secoya have adopted cattle ranching as a livelihood strategy, originally promoted in the Secoya territory by missionaries from the Summer Institute of Linguistics (Vickers 1993). Finally, the *Huaorani* 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). Around 2,000 Huaorani occupy a large area in the southern NEA including Yasuni National Park.

Drawing on data collected during an initial ethnographic phase of the project, Holt *et al.* (2004) describe livelihood strategies and social organization for eight study communities representing all five ethnic groups. In all cases, the communities possess legal communal title to their lands but the state has retained subsurface use rights. Overall these lands remain primarily forested. The use of these lands for agriculture is allocated to members in some communities through traditional usufruct rights, in which lands are claimed through cultivation and the claims persist through fallow periods. In other communities, agricultural lands are subdivided into semi-private colonist-style farms of 50–100 contiguous hectares, and it is often possible to sell the land to members of the same ethnic group with the consent of the community assembly (Bremner and Lu 2006). All five ethnic groups have interacted with oil companies working in their territories, including through negotiations for access and working as manual laborers. Given this overall context, land use decision-making in these communities is likely to be influenced by ethnocultural differences and land tenure regimes, as well as exposure to oil extraction, market opportunities and colonist settlement.

Data Collection

In 2001 household and community surveys were implemented in 36 indigenous communities selected to represent the five indigenous groups and to capture variation in community size and accessibility. In each selected 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 for 464 indigenous households with one or more agricultural plots.[2] Household interviews were conducted by Ecuadorian interviewers with the male and female household heads

[2] Thirteen households with no active agricultural plots and 14 households with missing data on the regression predictors have been excluded from the analysis. Households with missing data for variables included only in the descriptive analysis were not excluded; thus sample sizes are noted in Table 1.

Table 1 Descriptive Statistics for Sample Households by Ethnicity with Results from Pair-wise Comparisons of Means

	Overall	N	Kichwa	Shuar	Huaorani	Cofán	Secoya
Sample distribution							
Communities by majority ethnicity	36	36	14	10	7	3	2
Households by ethnicity of male head	464	464	224	96	74	43	27
Household distance to market (km)[e]	48.6	464	35.8	43.3	142.6	41.0	29.6
Demographic characteristics[f]							
Population under age 15 (%)	51.7	2,961	52.7[a]	57.7[a]	50.8[a]	51.4[a]	31.8[b]
Adults born in community (%)	42.9	1,388	47.3[b]	9.3[d]	34.5[c]	66.0[a]	44.4[b]
Adults with full primary education (%)	57.8	1,387	62.0[b]	72.0[a]	47.0[c]	25.7[d]	67.7[ab]
Adults who speak Spanish (%)	89.5	1,389	94.7[a]	97.4[a]	70.0[b]	69.5[b]	98.3[a]
Household-level land use							
Total cultivated area (ha)	3.65	464	4.00[a]	4.84[a]	1.28[b]	2.02[b]	4.93[a]
Total area in pasture (ha)	0.93	464	0.71[bc]	1.41[b]	0.00[c]	0.17[c]	3.46[a]
Total area in coffee (ha)	1.14	464	1.42[a]	2.08[a]	0.06[b]	0.66[b]	0.18[b]
Total area in staples (ha)	1.42	464	1.66[a]	1.10[b]	1.16[b]	1.14[b]	1.26[ab]
Total area in other crops (ha)	0.16	464	0.21[a]	0.25[a]	0.07[b]	0.05[b]	0.03[b]
Number of plots	3.01	464	3.16[a]	2.79[a]	2.74[a]	2.93[a]	2.92[a]
Reported fallow time (years)[g]	2.25	389	2.32[ab]	1.92[b]	2.88[a]	1.98[b]	2.00[b]
Area cleared in past three years (ha)	2.13	453	2.20[b]	2.01[bc]	1.20[c]	1.10[c]	4.28[a]
Owns cattle (%)	16.9	464	13.2[bc]	19.3[b]	0.0[d]	3.3[cd]	69.7[a]
Hired agricultural labor (past year, %)	22.2	464	17.8[b]	29.1[b]	0.0[c]	20.9[b]	62.1[a]
Sold crops (past year, %)	66.1	464	79.5[a]	74.6[a]	21.1[c]	58.0[b]	43.9[b]
Plot-level land use							
Age of plot (years)	3.29	1,368	3.68[a]	3.43[a]	1.24[b]	3.98[a]	2.00[b]
Travel time to plot (min)[g]	16.5	1,187	15.1[b]	11.1[b]	31.6[a]	16.9[b]	15.4[b]
Monocropped plots (%)	62.0	1,397	66.1[b]	48.5[c]	37.7[d]	60.6[b]	82.9[a]

Household values are weighted means, and *N* is the total sample size accounting for missing data. *Letters* (abcd) indicate means that *cannot* be distinguished from one another at α=0.05 by one-way analysis of variance

[e] Distance from the community center weighted by number of households

[f] Adults are taken to be persons over age 15

[g] Based on data collected in 28 of the 36 study communities

separately. Interviews were conducted in Spanish or as necessary in the appropriate indigenous language with the aid of a local interpreter. The male head's questionnaire covered land tenure and use, production and sale of crops and cattle, off-farm and non-farm employment, and technical assistance and credit, among other topics. Questions on land use recorded information on the size, composition, age (i.e., time since most recent clearing), and travel time from the dwelling for all plots currently in agricultural use.[3] Intercropped areas were divided among their constituent land uses based on estimated proportional coverage, and the identities of all crops occupying 10 m^2 or more were recorded. The female head's questionnaire included a household roster and also asked about out-migration from the household, household assets, and other topics. In single-headed households or in the case of a prolonged absence of one head both questionnaires were administered to the head available.

[3] Previous studies of indigenous land use in the Amazon found such reports of current land use to be accurate (Vadez *et al.* 2003).

At the community-level, a survey was implemented with leaders in each community, covering population, community infrastructure and organization, and contacts with external institutions. Also, Global Positioning System points were collected at each sample dwelling, at a subset of agricultural plots, and at points of community infrastructure and analyzed in a Geographic Information System. These two data sources, together with data aggregated from the household surveys, allowed the construction of community-level contextual variables.

Descriptive Analysis

To describe and compare the five indigenous populations and their land use, we first carried out a descriptive analysis on this dataset using one-way analysis of variance followed by a pairwise comparison of means (Table 1). Ethnicity of the household was taken to be the ethnicity of the male head, typically the primary decision-maker on land use, and was replaced by ethnicity of the female head in female-headed households. In 21 mixed ethnicity communities, ethnicity was identified by surname, languages spoken and place of birth. In Table 1, letters are used to identify ethnic means which cannot be distinguished from each other by the pairwise comparison with $\alpha=0.05$. For example, in the row for total cultivated area the means for the Kichwa, Shuar, and Secoya are not significantly different from each other, which is indicated by the letter *a*. The cultivated areas of the Huaorani and Cofán are also not statistically different from each other but are both significantly smaller than the means of the other three groups; they thus share the letter *b*. Note that multivariate controls are not present in this analysis (see Multivariate Methods below), thus these differences cannot be interpreted as the effects of ethnicity independent of other factors such as community accessibility. Also, to account for different probabilities of selection across households, household data are weighted by the inverse of the probabilities of selection throughout this paper.

The first panel of the table presents information on the distribution of the sample by number of communities and the households by ethnicity, and on the mean distances of communities to the nearest market. Overall, the study communities are relatively remote from market towns, with the Huaorani communities most isolated on average. The second panel presents data on demographic characteristics for the 2,961 individuals in the dataset, showing that most people from all ethnicities speak Spanish (typically as a second language), though the proportion is significantly lower for the Cofán and Huaorani. These two ethnic groups also have the lowest levels of education. The Cofán are also the least likely to be lifetime migrants, whereas the Shuar and Huaorani are the most mobile (see Context of the Study above). The proportion of the population under age 15 is generally high, and over half for four of the five ethnicities, the only exception being the Secoya. These values suggest a rapidly growing population with high fertility (Bilsborrow *et al.* 2007), and are comparable to findings for mestizo colonists in the region (Bilsborrow *et al.* 2004), to Shuar populations south of the study area (Rudel *et al.* 2002), and to other lowland indigenous populations in Latin America (McSweeney and Arps 2005).

The following sections of the table present household and plot-level measures of land use for the 464 households and 1,397 plots in the database. The overall cultivated area per household (mean of 3.7 ha) is large compared to some traditional swidden systems (Beckerman 1987; Godoy *et al.* 1997), but is small compared to the area used by mestizo farm households in the NEA (15.4 ha) (Bilsborrow *et al.* 2004), to Shuar households in the southern Ecuadorian Amazon (14.8 ha only in pasture) (Rudel *et al.* 2002), and to the total area accessible to each household (50–100 ha in many cases). Large and significant differences are also present between ethnicities: the Secoya, Shuar, and Kichwa have significantly larger areas (means of 4–5 ha) than the Huaorani (1.3 ha) and the Cofán (2.0 ha). Overall, the average household cultivated area is composed of 39% staple crops (manioc, plantains and maize); 31% coffee; 25% pasture; and 4% in other crops such as rice, cacao and tree crops. Areas in coffee and pasture vary substantially and significantly among ethnicities: the Secoya specialize in pasture for cattle, with 3.5 ha per household, and the Shuar and Kichwa in coffee with 2.1 and 1.4 ha, respectively. The area in staple crops varies little across ethnicities, and hence as a proportion of land use is by far the highest for Huaorani and Cofán. In fact, it accounts for 90% of the cultivated area for the Huaorani, who grow almost nothing but manioc and plantains, while the Cofán grow some coffee to sell in the market.

The Huaorani also stand out as fallowing their plots for the longest period (2.9 years), and also have used their current plots for significantly shorter periods (1.2 years), have more distant plots on average (32 min away), have the lowest proportion of monocropped plots (38%), and are the least likely to hire agricultural labor (0%) or sell crops (21%), all of which are consistent with previous descriptions of subsistence-oriented indigenous agricultural systems (Denevan and Padoch 1988; Posey and Balée 1989; Vickers 1993). The Huaorani and Cofán also have the lowest rates of clearing over the past three years as well as of cattle ownership. In contrast, the Secoya have the highest rate of clearing (4.3 ha), are by far the most likely to own cattle (70%), to hire agricultural labor (62%), and to monocrop their plots (83%), all consistent with their large areas in pasture. Across all five ethnic groups only 17% of households owned cattle. These households owned 6.3 animals on average, which is similar to the mean herd size for mestizo households in the NEA (6.8 animals) (Bilsborrow *et al.* 2004). Together, these results suggest that agricultural systems are quite diverse across ethnic groups in the study area, varying from small-scale subsistence systems such as those of the Huaorani to larger-scale, market-oriented systems typified by the activities of the Shuar and Secoya.

Multivariate Methods and Hypotheses

To assess potential explanations for the variations in indigenous land use described above, we implement a multilevel statistical model of the effects of household and community characteristics on household cultivated area. Multilevel models (also known as hierarchical linear models or mixed models) are an extension of linear regression that can be used to account for clustered sampling designs and to explicitly model contextual effects (Bryk and Raudenbush 1992). These models are highly appropriate for analyses of household land use due to the

Table 2 Definitions of Variables, Descriptive Statistics, and Hypotheses for Multivariate Analysis

Variable	Definition	Mean	SD	Min	Max	Hypothesis
Dependent variable						
Total cultivated area	Total cultivated area in hectares	3.65	4.82	0.06	41.25	NA
Log-area	Ln (total cultivated area + 1)	1.30	0.86	0.05	3.74	NA
Ethnicity of head						
Kichwa	Head is Kichwa	0.53	0.65	0	1	Reference
Shuar	Head is Shuar	0.13	0.44	0	1	No effect
Huaorani	Head is Huaorani	0.11	0.40	0	1	–
Cofan	Head is Cofan	0.13	0.43	0	1	–
Secoya	Head is Secoya	0.10	0.39	0	1	No effect
Community predictors						
Market distance	Distance to preferred market in 10 km	4.86	6.20	0.31	21.45	–
Walk	Primary access includes walking	0.15	0.47	0	1	–
River	Primary access includes river transport	0.69	0.60	0	1	–
Road	Primary access includes road transport	0.64	0.62	0	1	+
Oil company	Oil company activities nearby	0.42	0.64	0	1	+
Usufruct[a]	Usufruct land tenure regime	0.39	0.63	0	1	–
Household predictors						
Men	Number of males >15 years old	1.47	1.03	0	6	+
Women	Number of females >15 years old	1.37	0.87	0	5	+
Children	Number of members ≤15 years old	3.34	2.94	0	10	+
Young head	Head ≤25 years old	0.17	0.49	0	1	Reference
Middle-aged head	Head 26–40 years old	0.41	0.64	0	1	+
Older head	Head >40 years old	0.41	0.64	0	1	+
Short residence	Head resident in community ≤10 years	0.20	0.52	0	1	Reference
Medium residence	Head resident in community 10–25 years	0.37	0.62	0	1	+
Long residence	Head resident in community >25 years	0.43	0.64	0	1	+
No education	Head has no formal education	0.21	0.52	0	1	Reference
Primary education	Head has some primary education	0.58	0.64	0	1	+
Secondary education	Head has some secondary education	0.21	0.53	0	1	+
Spanish	Head speaks Spanish	0.92	0.36	0	1	+
Organizations	Number of community organizations	2.62	1.60	0	6	+
Goods	Number of manufactured goods in 1996	0.97	1.81	0	11	+
Employment	Non-own-farm employment in past year	0.51	0.65	0	1	–
Migrants	Number of out-migrants since 1990	0.74	1.81	0	10	?
Remittances	Receipt of remittances in past year	0.11	0.40	0	1	–

n=464

[a] Reference category is semi-private land tenure regime

recognized importance of contextual effects, the hierarchical nature of many land use datasets, and the biasing effects of household clustering in the absence of such corrections.[4] Nonetheless, few studies of household land use have incorporated these models (for exceptions see Pan and Bilsborrow 2005; Overmars and Verburg 2006; Vance and Iovanna 2006; Vanwambeke *et al.* 2007).

[4] An alternative approach is to model using ordinary least squares regression (OLS) and to correct for clustering using Huber–White standard errors as available in Stata and other software packages. This approach typically produces results similar to the multilevel approach, but the estimation is somewhat less efficient and the intra-class correlation interpretation is not available (Angeles *et al.* 2005). For the model described here, OLS with the cluster correction produces similar results but with slightly larger standard errors for the household-level predictors, consistent with the less efficient estimation.

The dependent variable for our analysis is the total household cultivated area, summed across all plots currently in agricultural use including pasture. This is an important measure of both the household economy and of impacts on the forest, as each hectare of cultivated area represents an investment by the household, production that the household will receive (to consume or sell), as well as primary or secondary forest that has been cleared.[5] As the distribution of cultivated area is skewed to the right, we transform the cultivated area by taking the natural logarithm.

[5] Modeling this outcome also simplifies issues of censoring (e.g. many zero values) and cross-equation error correlations which would arise from modeling multiple areas separated by land use, issues which we plan to address in future research.

The two-level random-intercept model that we construct has the following form:

$$Y_{ij} = \gamma_{00} + \beta X_{ij} + \gamma w_j + r_{ij} + u_{0j}$$

where $r_{ij} \sim N(0, \sigma^2)$, $u_{0j} \sim N(0, \tau_{00})$, Y_{ij} is the outcome (log-area) for household i in community j, γ_{00} is the common intercept, $\boldsymbol{\beta}$ is a vector of household-level coefficients, $\boldsymbol{X}_{ij}$ is a vector of household-level predictors, γ is a vector of community-level coefficients, $\boldsymbol{w}_j$ is a vector of community-level predictors, r_{ij} is the household-level error term, u_{0j} is the community-level error term, σ^2 is the variance of r_{ij}, and τ_{00} is the variance of u_{0j}. Following the recommendations of Halvorsen and Palmquist (1980) for log-transformed dependent variables, we transform the coefficients of dummy variables (e.g. categorical variables) by ($e^{\beta} - 1$). This allows the coefficients of both continuous and categorical variables to be interpreted as the proportional increase in cultivated area resulting from a unit increase in the predictor, or alternatively as the percentage increase divided by 100.

Table 2 presents the hypothesized direction of effects of the predictors on cultivated area in the full model, as well as variable definitions and descriptive statistics for the outcome and predictors. These predictions draw on the studies cited above, on our field experiences in the study area, and on the useful reviews by Angelsen and Kaimowitz (1999) and Walker *et al.* (2002). The first category of predictors is a set of dummy variables for household ethnicity, and we expect effects consistent with the descriptive differences presented in Table 1. When other controls are added, ethnicity effects are likely to be attenuated but remain significant.

At the community level, we investigate the effects of accessibility, oil company activities, and the land tenure regime.[6] Accessibility variables include the straight-line distance from the community to the preferred market town, along with dummy variables for the types of transportation used (walking, river, or road) on the most commonly used route to the market town. We expect cultivated area to be lower the farther the community is from town and if walking or river transportation are used as these represent barriers to the flow of agricultural goods, information about markets, and exposure to colonist encroachment. Conversely, area should increase with use of rapid road transportation. Cultivated area is similarly likely to increase with oil company activities in the community as these typically include improvements in infrastructure and the availability of transportation in company vehicles. We also expect cultivated area to decrease with usufruct tenure regimes relative to semiprivate regimes (see "Context of the Study" above), as the greater tenure security enjoyed by semiprivate landholders likely encourages agricultural investment and expansion of the cultivated area. These community-level predictors are correlated but not collinear with ethnicity. For example, Kichwa and Cofán communities in the sample have mixed tenure systems but all Shuar and Secoya communities have semiprivate land tenure and all Huaorani communities have usufruct tenure.

At the household level, we control for household composition and household lifecycles, stocks of human, social and physical capital, and participation in alternative livelihood activities. We include three measures of household composition (numbers of men, women and children in the household), one of the household lifecycle (age of the male head), and one reflecting the lifecycle of agricultural activities (residence time of the male head in the community). Cultivated area is likely to increase with the number of people in the household due to labor availability and consumption needs. This effect should be greater for the number of men since they have the primary responsibilities for commercial agriculture. We expect the cultivated area to peak at intermediate values of age of the head, as the ability and necessity of households to practice agriculture are likely to peak at these ages. Finally, cultivated area should increase with residence time in the community, reflecting a farm lifecycle in which more areas can be cleared cumulatively over time.[7]

Moving on to household capitals, human capital is captured by the level of education and Spanish language ability of the male head. Social capital is measured by participation in community organizations, which reflects contacts and access to information. Physical capital is evaluated by the number of manufactured goods in the dwelling from a list of common goods; goods purchased after 1996 were excluded to reduce endogeneity with current land use. As the expansion of household cultivated area is an entrepreneurial and resource-demanding activity, cultivated area is likely to increase with each of these forms of capital. Household-level controls for natural capital, including soil quality and topography, were included in preliminary models but were removed from the final model as they did not improve model fit. This may reflect the ability of indigenous communities to preferentially locate in and cultivate the most productive parts of the landscape. Similarly, a community-level measure of hunting produc-

[6] These factors are largely exogenous to current household land use as they change only over long time scales and/or are driven by regional-scale processes.

[7] To capture nonlinear effects, age and residence time have each been included in the model as a trichotomous categorical variable. This specification provides a better fit than a linear and squared term, and maintains consistency with the other categorical and count predictors.

Table 3 Results from Regression of the Natural Logarithm of Cultivated Area on Community and Household-level Predictors

Parameter	Model 1	Model 2	Model 3
Intercept	1.435**	1.818**	0.826**
Ethnicity of head[a]			
Shuar	0.024	−0.110	−0.046
Huaorani	−0.450**	−0.031	0.145
Cofan	−0.360*	−0.120	−0.030
Secoya	0.278	0.290	0.393
Community predictors			
Market distance		−0.036**	−0.036**
Walk		−0.139	−0.128
River		−0.308**	−0.307**
Road		0.022	0.016
Oil company		0.225*	0.308**
Usufruct[b]		−0.315**	−0.274**
Household predictors			
Men			0.100**
Women			0.025
Children			0.009
Middle-age head			0.152
Older head			0.233*
Medium residence			0.185*
Long residence			0.101
Primary education			0.182*
Secondary education			0.267*
Spanish			0.156
Organizations			0.063**
Goods			0.041*
Employment			−0.106*
Migrants			0.036
Remittances			−0.209*
Variance components			
τ_{00} (community)	0.105**	0.028	0.023
σ^2 (household)	0.488**	0.488**	0.438**
Intra-class correlation	0.177	0.055	0.050

Coefficients of dummy variables have been transformed by $e^{\beta} - 1$
n=464
*p<0.05, **p<0.01
[a] Reference category is Quichua
[b] Reference category is semi-private land tenure regime

tivity[8] was included in preliminary models but was non-significant and removed, suggesting that access to hunting resources does not significantly affect cultivated area in our study area.

Finally, we control for participation in two alternative livelihood activities: non-own-farm employment (employment away from one's own lands, whether within the community or not and whether agricultural or non-agricultural) as well as migration and receipt of migrant remittances. We expect cultivated area to decrease with employment as it removes labor which would otherwise be available for agricultural activities. Due to the potential endogeneity of this variable we interpret the effect cautiously and monitor for effects of its inclusion on other coefficients. The past departure of migrants from the household might reduce cultivated area due to agricultural abandonment, or alternatively cultivated area of these households might be larger due to the labor of migrants prior to their departure or the contacts they provide with urban areas, facilitating agricultural sales. We control separately for the receipt of migrant remittances by the household, which are likely to provide a disincentive for maintaining or expanding the cultivated area and thus will decrease the area.

Multivariate Results

Table 3 presents the results of the multilevel regression analysis of household cultivated area, including regression coefficients with significance tests and household and community-level variance components. Model 1 includes only ethnicity of the male head, with results that are consistent with the descriptive analysis above: cultivated areas of Huaorani and Cofán households are respectively 45% and 36% smaller than the area of Kichwa households,

[8] The measure was the number of animals caught per hour on the most recent hunting trip, calculated at the community-level as a mean across all households that hunted in the past year.

the reference category, with Shuar and Secoya households not significantly different.

Model 2 adds the community-level variables, which are mostly significant and of large magnitude. Significant effects on cultivated area include a 31% decrease with river transport, a 32% decrease with usufruct tenure, a 23% increase with oil company activities, and a 3.6% decrease per 10 km of distance to the market, all of which conform to predictions. Once distance is controlled for, both the need to walk to get products to market and the use of roads as a primary mechanism are non-significant. Alternative specifications such as community distance to road were also non-significant, suggesting that proximity to colonists along roads does not increase cultivated area when distance to market is controlled. These results suggest that (1) distance and river transportation are the major barriers for indigenous participation in agricultural markets, (2) communal forms of tenure can help preserve tropical forests in indigenous territories (see Lu 2001), and (3) large-scale natural resource extraction in indigenous territories is likely to stimulate increased agricultural clearing.

In addition, in Model 2 the intra-class correlation (i.e., the proportion of error variance between communities) drops to 6% and the community-level error variance is not significantly different from zero, suggesting that together the community-level predictors account for most of the variation across communities in cultivated area. Adding the community-level variables also causes the effects of Huaorani and Cofán ethnicity to become non-significant. This suggests that ethnicity per se does not directly influence cultivated area, but that correlated factors such as accessibility and nature of the land tenure regime do play important roles (Godoy *et al.* 1998b). Ethnicity and associated differences in worldview and social organization likely act as mediating factors which influence settlement location and land tenure over long time scales. To take the Huaorani as an example, the results suggest that Huaorani households have smaller cultivated areas because they live in remote areas with river access and usufruct tenure regimes, factors which in turn are likely affected by ethnicity over a period of decades. Cultural factors not available in our dataset (e.g., knowledge of local ecology or external markets) likely do influence land use, but if so our results suggest that these factors are likely to be only weakly correlated with ethnicity.

Model 3 adds household-level controls for demographic composition, stocks of human, social and physical capital, and participation in alternative livelihood activities. Among demographic variables, each adult male in the household increases cultivated area by 10% as hypothesized, but the numbers of women and children have no significant effect, though the relative sizes of the coefficients are correct. These results suggest that the availability of male labor for agriculture rather than subsistence demands linked to household size is the most important influence of household composition on land use. Cultivated area is also significantly higher among households with older household heads (23%) and with medium duration of residence (19%). These are not the patterns predicted but nonetheless provide support for the existence of separate household and farm lifecycles in indigenous land use, reflecting both the "age" of the household as well as its history of agricultural activities in the community. The effects of residence time are not as strong as in studies of colonist land use (Pan and Bilsborrow 2005; Pichón 1997; VanWey *et al.* 2005), perhaps because indigenous plots are more quickly returned to fallow.

The effects of household capitals and livelihood diversification are generally significant and consistent with our hypotheses. Among controls for household capitals, primary education significantly increases cultivated area by 18% whereas secondary education increases it by 27%. Knowledge of Spanish has no significant effect, perhaps because it increases opportunities for alternative strategies such as wage labor more so than for commercial agriculture. The positive effects of education contrast with studies of indigenous land use in Honduras and Bolivia (Godoy *et al.* 1998a, c), but are consistent with effects for colonists in the NEA (Pan and Bilsborrow 2005; Pichón 1997), and suggest the possibility of a negative environmental externality arising from increases in indigenous access to education[9] (Godoy *et al.* 1998c). Participation in community organizations and the number of goods owned also have the predicted positive effects, confirming that social and physical capitals play a key role in indigenous land use. Receipt of non-agricultural income from non-own-farm employment or migrant remittances reduces cultivated area as expected (by 11 and 21% respectively), suggesting that these serve as alternatives to agricultural production. The number of migrants has no significant effect when receipt of migrant remittances was controlled.

Discussion

The results of this analysis hold three key messages for practitioners, including conservationists focused on the sustainability of indigenous land use as well as indigenous rights activists concerned about the maintenance of traditional livelihoods and indigenous autonomy. The first, positive, message is that the scale of indigenous agricultural land use in our study area (3.7 ha per household) is still small relative to both the large land areas under indigenous

[9] Increases in education might also lead to increases in out-migration (and thus fewer agricultural laborers) and remittances, thus the overall impact on land use is difficult to predict.

control and the levels of forest clearing by mestizo farm households in the same region. This is particularly true of the Huaorani and Cofán, who typically live far from the zone of colonization, manage land through usufruct property regimes, and maintain plots with small areas and other management characteristics consistent with other subsistence-oriented indigenous agricultural systems. The implication is that in areas of the NEA remote from the zone of colonization, state and non-state interventions are likely not necessary to ensure the sustainability of indigenous agricultural activities. This finding remains to be tested, however, for other livelihood activities such as hunting and logging.

The second, more cautionary, message for practitioners is that some indigenous communities and households living close to or within the zone of colonization and managing property under semiprivate regimes, the Shuar and Secoya in particular, maintain relatively large areas in commercial agricultural uses such as coffee or pasture and their agricultural systems in general are intermediate between subsistence-oriented indigenous agricultural systems and those of mestizo colonists. Future increases in population and continued oil company activities and road construction are also likely to stimulate greater agricultural impacts, both overall and per household. The implications are that the future sustainability of agricultural land use in accessible and market-oriented indigenous communities should not be assumed, and that policies designed for agricultural colonists, such as payments for maintaining forest cover, may also be appropriate for these communities.

The third message for practitioners is that these results support previous calls for restrictions on oil company activities in indigenous territories. Previous studies have shown that oil company activities such as road construction promote agricultural settlement and deforestation (Greenberg *et al.* 2005; Wunder 2003) and undermine the autonomy of indigenous communities (Sabin 1998; Sawyer 2004). We find that oil company activities increase cultivated area in indigenous communities, likely due to improvements in accessibility. Provision of non-own-farm employment by oil companies and other sources does a have a small mitigating effect, but overall the impacts of oil companies on forest cover are clearly negative. Motivated by these processes, environmentalists and indigenous peoples in the NEA have found common cause in protests against the oil companies, but the enormous dependence of the Ecuadorian state on oil revenue (Gerlach 2003) means that national and commercial interests will likely continue to overrule local, indigenous and environmental concerns.

The results also contain two key messages for social scientists investigating indigenous resource use, one theoretical and the other methodological. Regarding theory, previous explanations for land use change and deforestation in indigenous communities have variously invoked political, cultural and economic drivers, as described above. We find that a majority of cultivated area is devoted to commercial activities, that distance to market is an important predictor of cultivated area, and that household characteristics influence land use in ways similar to those described for nearby mestizo colonists. We also find that ethnicity, biophysical characteristics, and proximity to roads do not have significant independent effects on cultivated area. Thus overall our results are most consistent with a process of integration to the market (Godoy *et al.* 2005b; Lu 2007) as an underlying driver of variations in indigenous land use in our study area. In a transformed regional context of expanding market opportunities, indigenous households near market communities likely act to improve their livelihoods through market agriculture and expansion of the cultivated area. To further test these findings future fieldwork will collect additional measures of cultural factors and colonist encroachment, and longitudinal data collection from the same households will allow analyses of changes over time, potentially revealing disengagement from the market as described by Rudel *et al.* (2002) and Santos *et al.* (1997).

The second, methodological message for social scientists is the utility, as demonstrated by this analysis, of population-based survey data collection and statistical analysis for understanding indigenous resource use. This approach allows a quantitative assessment of the magnitude and drivers of household activities, and integrates well with ethnographic, spatial and ecological approaches. Future interdisciplinary studies which combine these approaches will be well equipped to address urgent issues of biodiversity conservation, human development, and cultural survival.

Acknowledgements Funding for this research was provided by the National Institutes of Health (R01-HD38777-01) to Principal Investigator Richard Bilsborrow. Clark Gray and Jason Bremner were supported as predoctoral trainees at the CPC by an Integrated Graduate Education, Research and Training (IGERT) grant from the National Science Foundation as well as other sources. We are indebted to our Ecuadorian partners Ana Oña, Alicia Ruíz, CEPAR (Centro de Estudios de Poblacion y Desarrollo Social), Ecociencia, the team of field researchers, and foremost the participating indigenous communities and federations. We also thank Brian Frizzelle for spatial analysis, and Lori Hunter, Thomas Whitmore, members of the CPC IGERT working group, and the anonymous reviewers for their comments. This research is part the Ecuador Projects at the Carolina Population Center (CPC) (http://www.cpc.unc.edu/projects/ecuador).

References

Andrade, G., and Rubio-Torgler, H. (1994). Sustainable Use of the Tropical Rain-forest: Evidence from the Avifauna in a Shifting-cultivation Habitat Mosaic in the Colombian Amazon. *Conservation Biology* 8(2): 545–554.

Angeles, G., Guilkey, D., and Mroz, T. (2005). The Impact of Community-level Variables on Individual-level Outcomes: Theoretical Results and Applications. *Sociological Methods and Research* 34(1): 76–121.

Angelsen, A., and Kaimowitz, D. (1999). Rethinking the Causes of Deforestation: Lessons from Economic Models. *World Bank Research Observer* 14(1): 73–98.

Barbieri, A., Bilsborrow, R., and Pan, W. (2006). Farm Household Lifecycles and Land Use in the Ecuadorian Amazon. *Population and Environment* 27(1): 1–27.

Beckerman, S. (1987). Swidden in Amazonia and the Amazon Rim. In Turner, B., and Brush, S. (eds.), *Comparative Farming Systems*, Guilford Press, New York, pp. 55–94.

Behrens, C., Baksh, M., and Mothes, M. (1994). A Regional Analysis of Bari Land-use Intensification and its Impact on Landscape Heterogeneity. *Human Ecology* 22(3): 279–316.

Bilsborrow, R., Barbieri, A., and Pan, W. (2004). Changes in Population and Land Use Over Time in the Ecuadorian Amazon. *Acta Amazonica* 34(4): 635–647.

Bilsborrow, R., Bremner, J., Holt, F., and Oña, A. (2007). *El Comportamiento Reproductivo de Poblaciones Indígenas: Un Estudio de la Amazonía Ecuatoriana*, United Nations Population Fund, Quito.

Bremner, J., and Lu, F. (2006). Common Property among Indigenous Peoples of the Ecuadorian Amazon. *Conservation and Society* 4(4): 499–521.

Bryk, A., and Raudenbush, S. (1992). *Hierarchical Linear Models*, Sage, Thousand Oaks, CA.

Carr, D. (2005). Forest Clearing among Farm Households in the Maya Biosphere Reserve. *Professional Geographer* 57(2): 157–168.

Caviglia-Harris, J., and Sills, E. (2005). Land Use and Income Diversification: Comparing Traditional and Colonist Populations in the Brazilian Amazon. *Agricultural Economics* 32(3): 221–237.

Chayanov, A. (1986). *A.V. Chayanov on the Theory of Peasant Economy*, The University of Wisconsin Press, Madison, WI.

Chowdhury, R., and Turner, B. (2006). Reconciling Agency and Structure in Empirical Analysis: Smallholder Land Use in the Southern Yucatán Peninsula. *Annals of the Association of American Geographers* 96(2): 302–322.

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

Ellis, F. (2000). *Rural Livelihoods and Diversity in Developing Countries*, Oxford University Press, New York.

FAO. (2005). *State of the World's Forests 2005*, United Nations Food and Agricultural Organization, Rome.

Gerlach, A. (2003). *Indians, Oil, and Politics: A Recent History of Ecuador*, Scholarly Resources, Wilmington.

Godoy, R., O'Neill, K., Groff, S., Kostishack, P., Cubas, A., Demmer, J., McSweeney, K., Overman, J., Wilkie, D., Brokaw, N., and Martinez, M. (1997). Household Determinants of Deforestation by Amerindians in Honduras. *World Development* 25(6): 977–987.

Godoy, R., Jacobson, M., De Castro, J., Aliaga, V., Romero, J., and Davis, A. (1998a). The Role of Tenure Security and Private Time Preference in Neotropical Deforestation. *Land Economics* 74(2): 162–170.

Godoy, R., Franks, J., and Claudio, M. (1998b). Adoption of Modern Agricultural Technologies by Lowland Indigenous Groups in Bolivia: The Role of Households, Villages, Ethnicity, and Markets. *Human Ecology* 26(3): 351–369.

Godoy, R., Groff, S., and O'Neill, K. (1998c). The Role of Education in Neotropical Deforestation: Household Evidence from Amerindians in Honduras. *Human Ecology* 26(4): 649–675.

Godoy, R., Reyes-García, V., Byron, E., Leonard, W., and Vadez, V. (2005a). The Effect of Market Economies on the Well-being of Indigenous Peoples and on their use of Renewable Natural Resources. *Annual Review of Anthropology* 34: 121–138.

Godoy, R., Reyes-Garcia, V., Huanta, T., Leonard, W., Vadez, V., Valdes-Galicia, C., and Zhao, D. (2005b). Why do Subsistence-level People Join the Market Economy? Testing Hypotheses of Push and Pull Determinants in Bolivian Amazonia. *Journal of Anthropological Research* 61(2): 157–178.

Greenberg, J., Kefauver, S., Stimson, H., Yeaton, C., and Ustin, S. (2005). Survival Analysis of a Neotropical Rainforest Using Multitemporal Satellite Imagery. *Remote Sensing of Environment* 96(2): 202–211

Gross, D., Eiten, G., Flowers, N., Leoi, F., Ritter, M., and Werner, D. (1979). Ecology and Acculturation Among Native Peoples of Central Brazil. *Science* 206(4422): 1043–1050.

Halvorsen, R., and Palmquist, R. (1980). The Interpretation of Dummy Variables in Semi-logarithmic Equations. *American Economic Review* 70(3): 474–475.

Hammond, D., Dolman, P., and Watkinson, A. (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(2): 319–351.

Hiraoka, M., and Yamamoto, S. (1980). Agricultural Development in the Upper Amazon of Ecuador. *Geographical Review* 70(4): 423–445.

Holt, F., Bilsborrow, R., and Oña, A. (2004). Demography, household economics, and land and resource use of five indigenous populations in the Northern Ecuadorian Amazon: A summary of ethnographic research. Occasional Paper, Carolina Population Center, University of North Carolina, Chapel Hill.

Humphries, S. (1993). The Intensification of Traditional Agriculture among Yucatec Maya Farmers: Facing up to the Dilemma of Livelihood Sustainability. *Human Ecology* 21(1): 87–102.

INEC (2003). Sistema integrado de consultas a los censos nacionales. National Census and Statistical Institute of Ecuador.

Irvine, D. (2000). Indigenous federations and the market: the Runa of Napo, Ecuador. In Weber, R., Butler, J., and Larson, P. (eds.), *Indigenous Peoples and Conservation Organizations: Experiences in Collaboration*, World Wildlife Fund, Washington, DC, pp. 21–46.

Kennedy, D., and Perz, S. (2000). Who are Brazil's Indigenas? Contributions of Census Data Analysis to Anthropological Demography of Indigenous Populations. *Human Organization* 59(3): 311–324.

Kleinman, P., Pimentel, D., and Bryant, R. (1995). The Ecological Sustainability of Slash-and-burn Agriculture. *Agriculture, Ecosystems and Environment* 52(2): 235–249.

Lu, F. (2001). The Common Property Regime of the Huaorani Indians of Ecuador: Implications and Challenges to Conservation. *Human Ecology* 29(4): 425–447.

Lu, F. (2007). Integration into the Market among Indigenous Peoples: A Cross-Cultural Perspective from the Ecuadorian Amazon. *Current Anthropology* 48(4): 593–602.

Macdonald, T. (1981). Indigenous response to an expanding frontier: Jungle Quichua economic conversion to cattle ranching. In Whitten, N. (ed.), *Cultural Transformations and Ethnicity in Modern Ecuador*, University of Illinois Press, Urbana, pp. 356–383.

Marquette, C. (1998). Land Use Patterns among Small Farmer Settlers in the Northeastern Ecuadorian Amazon. *Human Ecology* 26(4): 573–598.

McCracken, S., Siqueira, A., Moran, E., and Brondizio, E. (2002). Land use patterns on an agricultural frontier in Brazil: insights and examples from a demographic perspective. In Wood, C., and Porro, R. (eds.), *Deforestation and Land Use in the Amazon*, University Press of Florida, Gainesville, pp. 162–192.

McSweeney, K. (2004). Forest Product Sale as Natural Insurance: The Effects of Household Characteristics and the Nature of Shock in Eastern Honduras. *Society and Natural Resources* 17(1): 39–56.

McSweeney, K., and Arps, S. (2005). A “Demographic Turnaround”: The Rapid Growth of Indigenous Populations in Lowland Latin America. *Latin American Research Review* 40(1): 3–29.

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

Nepstad, D., Schwartzman, S., Bamberger, B., Santilli, M., Ray, D., Schlesinger, P., Lefebvre, P., Alencar, A., Prinz, E., Fiske, G., and Rolla, A. (2006). Inhibition of Amazon Deforestation and Fire by Parks and Indigenous Lands. *Conservation Biology* 20(1): 65–73.

Overmars, K., and Verburg, P. (2006). Multilevel Modelling of Land Use from Field to Village Level in the Philippines. *Agricultural Systems* 89: 435–456.

Pan, W., and Bilsborrow, R. (2005). The Use of a Multilevel Statistical Model to Analyze Factors Influencing Land Use: A Study of the Ecuadorian Amazon. *Global and Planetary Change* 47(2–4): 232–252.

Perreault, T. (2005). Why Chacras (Swidden Gardens) Persist: Agrobiodiversity Food Security and Cultural Identity in the Ecuadorian Amazon. *Human Organization* 64(4): 327–339.

Perz, S. (2001). Household Demographic Factors as Life Cycle Determinants of Land Use in the Amazon. *Population Research and Policy Review* 20(3): 159–186.

Pichón, F. (1997). Colonist Land-allocation Decisions, Land Use, and Deforestation in the Ecuadorian Amazon Frontier. *Economic Development and Cultural Change* 45(4): 707–744.

Pitman, N., Terborgh, J., Silman, M., Nunez, P., Neill, D., Ceron, C., Palacios, W., and Aulestia, M. (2002). A Comparison of Tree Species Diversity in Two Upper Amazonian Forests. *Ecology* 83 (11): 3210–3224.

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

Pulido, M., and Caballero, J. (2006). The Impact of Shifting Agriculture on the Availability of Non-timber Forest Products: The Example of Sabal Yapa in the Maya Lowlands of Mexico. *Forest Ecology and Management* 222(1–3): 399–409.

Redford, K., and Sanderson, S. (2000). Extracting Humans from Nature. *Con*servation Biology 14(5): 1362–1364.

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

Rudel, T., Bates, D., and Machinguiashi, R. (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.

Sabin, P. (1998). Searching for Middle Ground: Native Communities and Oil Extraction in the Northern Central Ecuadorian Amazon, 1967–1993. *Environmental History* 3(2): 144–168.

Santos, R., Flowers, N., Coimbra, C., and Gugelmin, S. (1997). Tapirs, Tractors, and Tapes: The Changing Economy and Ecology of the Xavante Indians of Central Brazil. *Human Ecology* 25(4): 545–566.

Sawyer, S. (2004). *Crude Chronicles: Indigenous Politics, Multinational Oil, and Neoliberalism in Ecuador*, Duke University Press, Durham.

Schmink, M., and Wood, C. (1992). *Contested Frontiers in Amazonia*, Columbia University Press, New York.

Schwartzman, S., Moreira, A., and Nepstad, D. (2000). Rethinking Tropical Forest Conservation: Perils in Parks. *Conservation Biology* 14(5): 1351–1357.

Scoones, I. (1998). Sustainable rural livelihoods: a framework for analysis. Institute for Development Studies Working Paper 72.

Sierra, R. (1999). Traditional Resource-use Systems and Tropical Deforestation in a Multiethnic Region in North-west Ecuador. *Environmental Conservation* 26(2): 136–145.

Sierra, R. (2000). Dynamics and Patterns of Deforestation in the Western Amazon: The Napo Deforestation Front, 1986–1996. *Applied Geography* 20(1): 1–16.

Sierra, R., Rodríguez, F., and Losos, E. (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.

Simmons, C. (2002). The Local Articulation of Policy Conflict: Land Use, Environment, and Amerindian Rights in Eastern Amazonia. *The Professional Geographer* 54(2): 241–258.

Stocks, A., McMahan, B., and Taber, P. (2007). Indigenous, Colonist and Government Impacts on Nicaragua’s Bosawas Reserve. *Conservation Biology* (in press).

Townsend, W., Borman, R., Yiyoguaje, E., and Mendua, L. (2005). Cofán Indians’ Monitoring of Freshwater Turtles in Zabalo, Ecuador. *Biodiversity and Conservation* 14(11): 2743–2755.

Vadez, V., Reyes-García, V., Godoy, R., Williams, L., Apaza, L., Byron, E., Huanca, T., Leonard, W., Pérez, E., and Wilkie, D. (2003). Validity of Self-reports to Measure Deforestation: Evidence from the Bolivian Lowlands. *Field Methods* 15(3): 289–304.

Valdivia, G. (2005). On Indigeneity, Change, and Representation in the Northeastern Ecuadorian Amazon. *Environment and Planning A* 37(2): 285–303

Vance, C., and Iovanna, R. (2006). Analyzing Spatial Hierarchies in Remotely Sensed Data: Insights from a Multilevel Model of Tropical Deforestation. *Land Use Policy* 23(3): 226–236.

Vanwambeke, S., Somboon, P., and Lambin, E. (2007). Rural Transformation and Land Use Change in Northern Thailand. *Journal of Land Use Science* 2(1): 1–29.

VanWey, L., D’Antona, A., and Brondizio, E. (2005). Household Life Cycle and Land Use in Santarém and Altamira, Pará, Brasil. Paper presented to the International Union for the Scientific Study of Population, Tours, France, July 18–23.

Vickers, W. (1993). Changing tropical forest resource management strategies among the Siona and Secoya Indians. In Hladik, C., Hladik, A., Linares, O., Pagezy, H., Semple, A., and Hadley, M. (eds.), *Tropical Forests, People and Food: Biocultural Interactions and Applications to Development*, Parthenon Publishing Group, New York, pp. 463–477.

Walker, R., Perz, S., Caldas, M., and Silva, L. (2002). Land Use and Land Cover Change in Forest Frontiers: The Role of Household Life Cycles. *International Regional Science Review* 25(2): 169–199.

Wunder, S. (2000). Ecotourism and Economic Incentives: An Empirical Approach. *Ecological Economics* 32(3): 465–479.

Wunder, S. (2003). *Oil Wealth and the Fate of the Forest: A Comparative Study of Eight Tropical Countries*, Routledge, New York.

Ziegler-Otero, L. (2004). *Resistance in an Amazonian Community: Huaorani Organizing against the Global Economy*, Berghahn, New York.

Zimmerman, B., Peres, C., Malcolm, J., and Turner, T. (2001). Conservation and Development Alliances with the Kayapo of South-eastern Amazonia, a Tropical Forest Indigenous People. *Environmental Conservation* 28(1): 10–22.