Statistical models and spatial simulations of land cover/land use change in the Ecuadorian Amazon

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Extended Abstract

Introduction: Studies of land cover/land use (LCLU) in frontier environments seek to understand the causes and consequences of change by integrating demographic, socio-economic, geographical, and biophysical factors in statistical and spatial models. The Northern Ecuadorian Amazon (NEA) is a frontier region being transformed primarily by household decisions at the farm-level that involve deforestation and extensification of agriculture. However, over time the conversion of primary forest to secondary forest and early successional vegetation has created a complex transitional landscape in response to exogenous and endogenous factors. Land management at the farm-level is affected by the demographic and socio-economic characteristics of households, geographic location, resource endowments, economic opportunities, prices, off-farm employment, etc.

Objectives: This research (a) examines deforestation and secondary forest succession in the Northern Ecuadorian Amazon, (b) assesses the value of integrating different types of data linking people, place, and the environment to understand land use change patterns at the farm-level, and (c) develops and uses statistical and spatially-explicit models of LCLU change scenarios in a key policy-relevant context.

Data and Methods: Data are integrated from a longitudinal household survey that covers farm and household characteristics; from a GIS that covers resource endowments and geographic accessibility of sample farms; and a satellite time-series on LCLU change patterns. Spatial regression models have been used in prior work to study the effects of exogenous and endogenous factors on land use, and the results will be integrated into automata models to examine changes in LCLU patterns, taking into account initial conditions and postulating transition functions and neighborhood associations.

Annual rates of deforestation and the proportion of land in secondary forest succession are being quantified through processing of an assembled time-series of Landsat images and GIS coverages of resources and geographic settings. Data from a longitudinal demographic-socio-economic household survey are used to describe the characteristics of spontaneous colonist households who migrated into this frontier environment. This study uses statistical models (i.e., spatially weighted regression) to link deforestation and successional vegetation to farm (*finca*) and household characteristics. Two dependent variables are examined: the total deforested area, and the area in secondary forest, from 1986 to 1996 and from 1996 to 2002. Independent variables represent several domains: (1) the *demographic composition and household life cycle* are represented by household size, proportion of persons in the household under age 12, numbers of males and females, and age of household head; (2) *geographic accessibility* is captured from the distance traveled on primary roads to the nearest town, distance traveled on secondary roads to the nearest town, distance traveled by foot to the nearest road, and vehicle access to the farm; (3) *socio-economic* variables include the education of the head of household and percentage of household members with at least a primary education, household income or earnings, the extent of off-farm employment, and tenancy type; and (4) *biophysical* characteristics come from survey responses of the household head on the presence of black soil as a customary indicator of soil fertility, and flatness of terrain.

Cellular automata models (CA) are currently being used to create spatial simulations of landscape change patterns by integrating the effects of land use changes (e.g., urbanization, secondary forest succession) on the increasing fragmentation of forests and agricultural plots resulting from demographic change, improved accessibility to roads and markets, and biophysical dynamics. CA models are mathematical systems constructed from many identical components, which together are capable of complex behavior. CA involves a division of the space into regular cells, each characterized by a state that represents the condition of the cell at that moment; with changes in that state occurring according to a *transition function* that depends on the states of neighboring cells and of the cell itself. At time t=0, cells are in states describing initial conditions. The CA evolves by changing the state of all cells simultaneously in discrete time steps departing from cell seeds. The transition function and its constraints are based on the results of the statistical modeling and demographic, geographical, and socioeconomic farm characteristics. .

Results: Preliminary findings demonstrate the severity of deforestation, the incipient process of secondary forest succession, and the multitude of factors affecting LCLU. In the study region, one of extraordinary biodiversity, we found 116,640 hectares were deforested in the entire region between 1986 and 1996 and 60,488 between 1996 and 2002, with annual deforestation rate of 1.31 % yr^{-1}. Regression results at the finca level show a statistically significant positive effect of accessibility on deforestation, both distance walked to a road and distance to the nearest market by primary road. Demographic factors—viz., household size, and numbers of both male and female household members older than 12--are found to be positively associated with deforestation on the farm plot. Among the socioeconomic variables, more education is linked to more deforestation, while more off-farm employment leads to less clearing. No significant effects on deforestation were found for land tenure and (black) soil quality. Similarly, in spatially weighted regressions, rates of secondary forest succession were positively related to good soil and lack of road access in 1986-1996, and to the male population on the farm and the flatness of the terrain (slope angle for 1996-2002). The rate of growth of secondary forest is also inversely linked to household assets, technical assistance, education, geographic access, and slope for the period 1986-1996. Findings demonstrate the severity of deforestation, the incipient process of secondary forest succession, and the multitude of factors affecting LCLU change in the Northern Ecuadorian Amazon.

The CA model developed is capable to simulate three specific LCLU changes: forest to non-forested vegetation, forest/non-forest vegetation to urban, and non-forest vegetation to secondary forest succession. The transition functions take into consideration accessibility to major communities, population density at the sector level, slope, and soil quality, and a farm income surface. Model parameters include a stochastic value of random change, a kernel threshold of 4-cells for neighborhood change (3 x 3 moving window), and a masking threshold defined by the user. LCLU was spatially explicit simulated for 1987 to 2010 using the 1986 Landsat satellite imagery to initialize the CA model run. Error and uncertainty was assessed by comparing the 1999 Landsat classification and the 1999 outcome from the model. The comparison included evaluation of landscape patterns metrics by a moving window and stratified by distance to roads. This study shows that the CA process is a powerful tool to simulate future LCLU due it capacity to capture demographic and socioeconomic characteristics of the populations and geographic and biophysical characteristics of the landscape. CA can be used effectively to create scenarios relevant to policy and management.