Modeling Deforestation & Agricultural Extensification in the Ecuadorian Amazon

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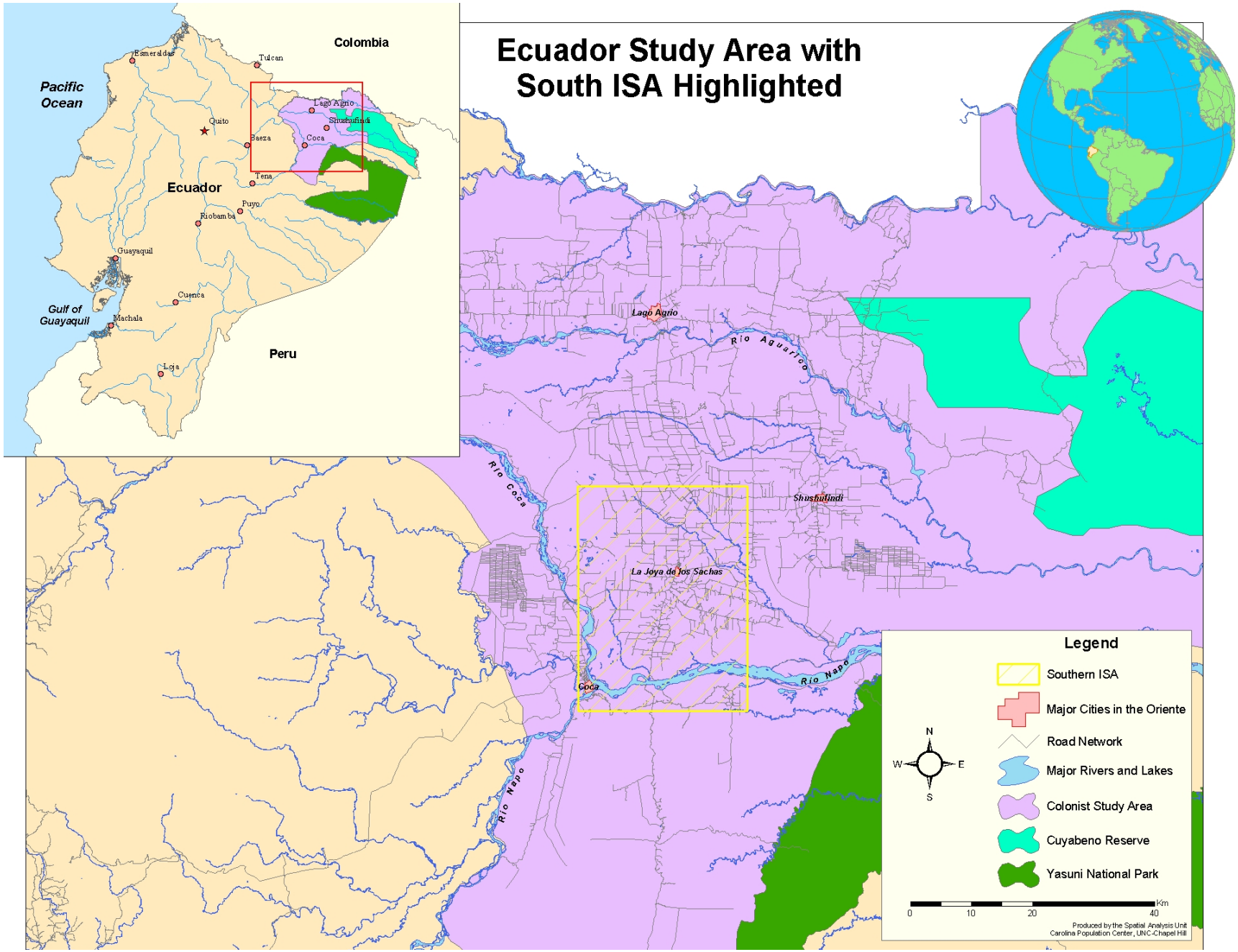
http://www.cpc.unc.edu/projects/ecuador


Ecuador Study Area with South ISA Highlighted
Colombia
Pacific Ocean
Esmeraldas
Tulcan
Lago Agrio
Shushufindi
Quito
Baeza
Coca
Tena
Ecuador
Puyo
Riobamba
Guayaquil
Cuenca
Gulf of Guayaquil
Machala
Peru
Loja
Río Aguarico
Río Coca
La Joya de los Sachas
Río Napo
Río Napo
Legend
Southern ISA
Major Cities in the Oriente
Road Network
Major Rivers and Lakes
Colonist Study Area
Cuyabeno Reserve
Yasuni National Park
N
W
E
S
0
10
20
40
Km
Produced by the Spatial Analysis Unit
Carolina Population Center, UNC-Chapel Hill

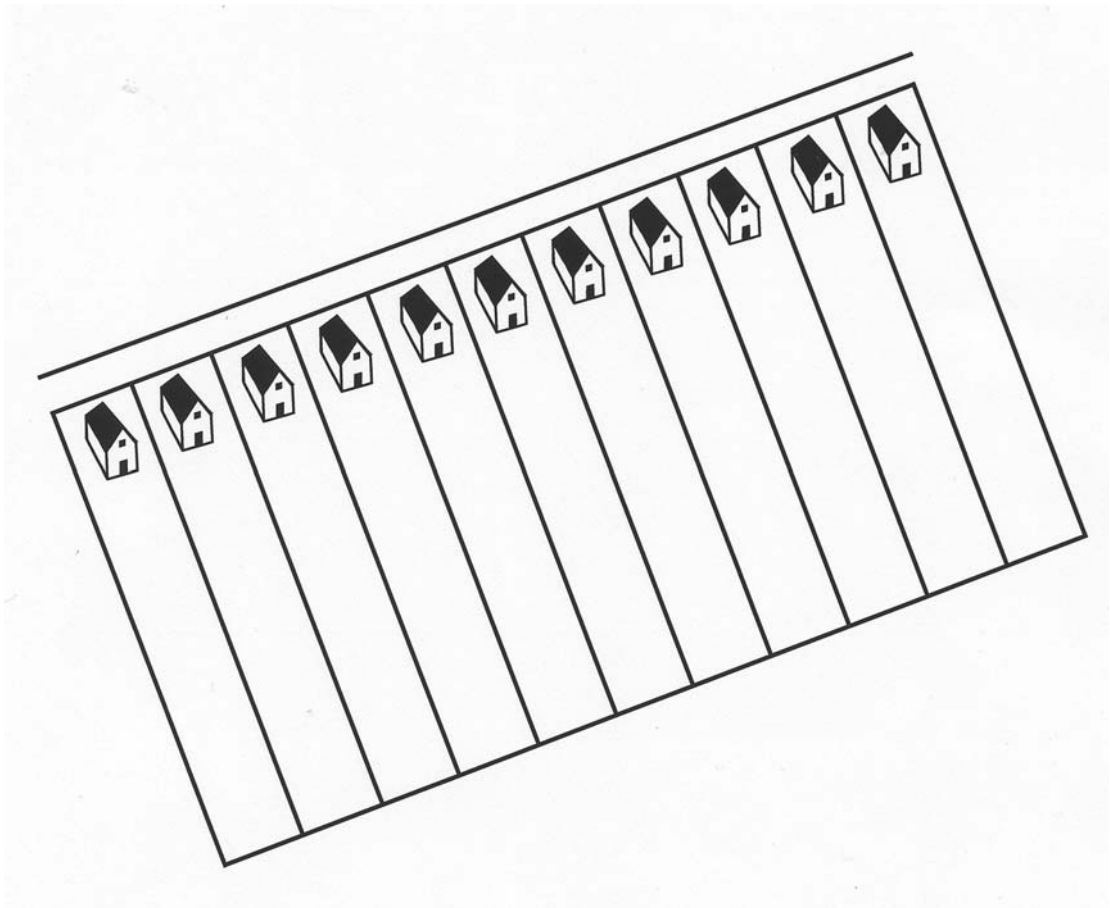
Introduction

- **Some Questions:** What are the rates, patterns, and mechanisms of forest conversion to agriculture, pasture, secondary plant succession, and urban uses? What are plausible scenarios of future land cover change and their policy implications?

- **Some Goals:** Spatially simulate and model patterns of landscape change (e.g., deforestation, urbanization, crops/pasture, land fragmentation, change patterns), assess their causes and consequences, experiment with alternative scenarios, and derive and disseminate policy implications.

- **Some Approaches:** Multi-level statistical models, spatial regression models, satellite image change-detections, GIS, spatial simulations & cellular automata.

Settlement Patterns Affecting Analysis Design

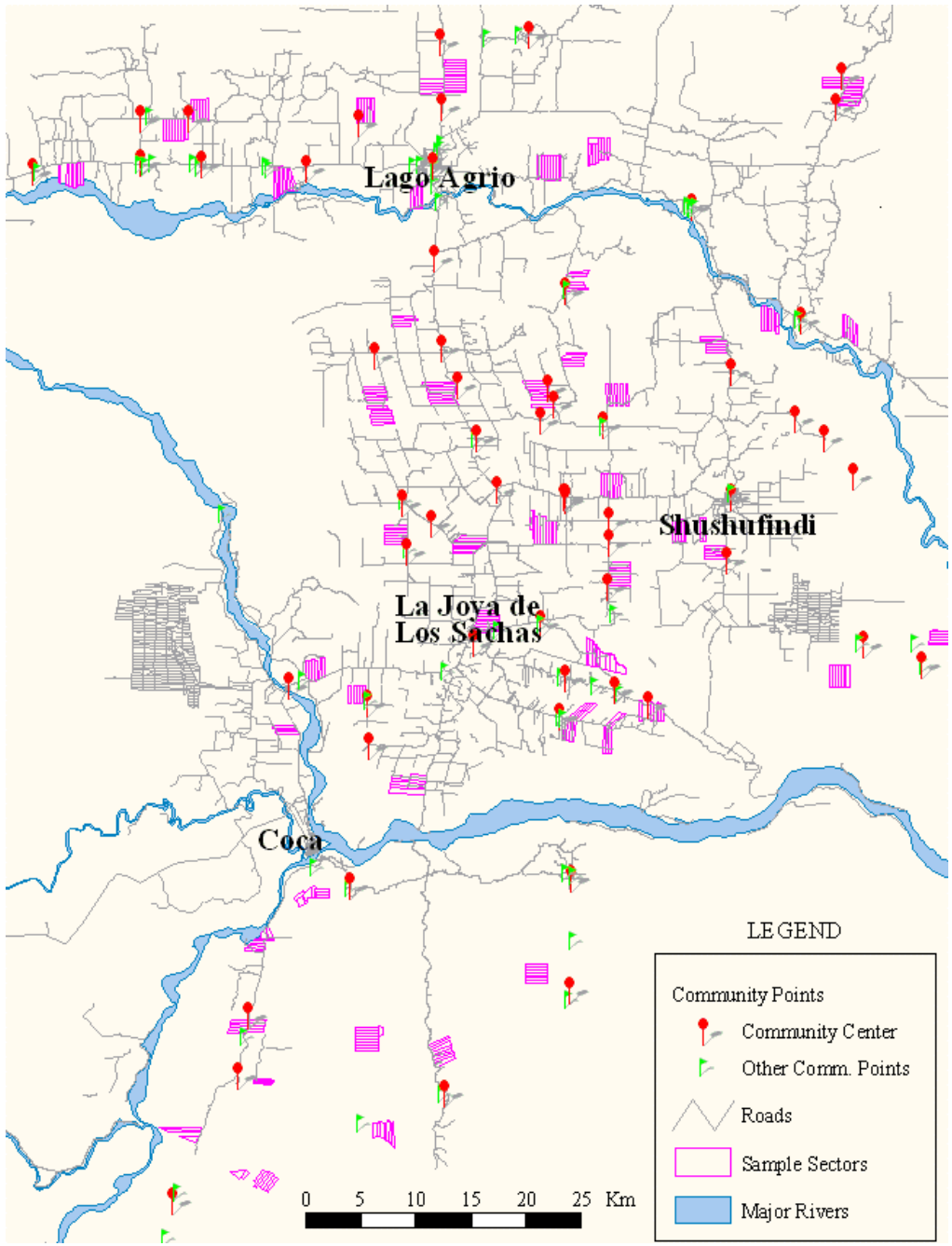


The Ecuadorian "fishbone" or "piano key" settlement pattern is characterized by on-premise management and a distinct linear pattern

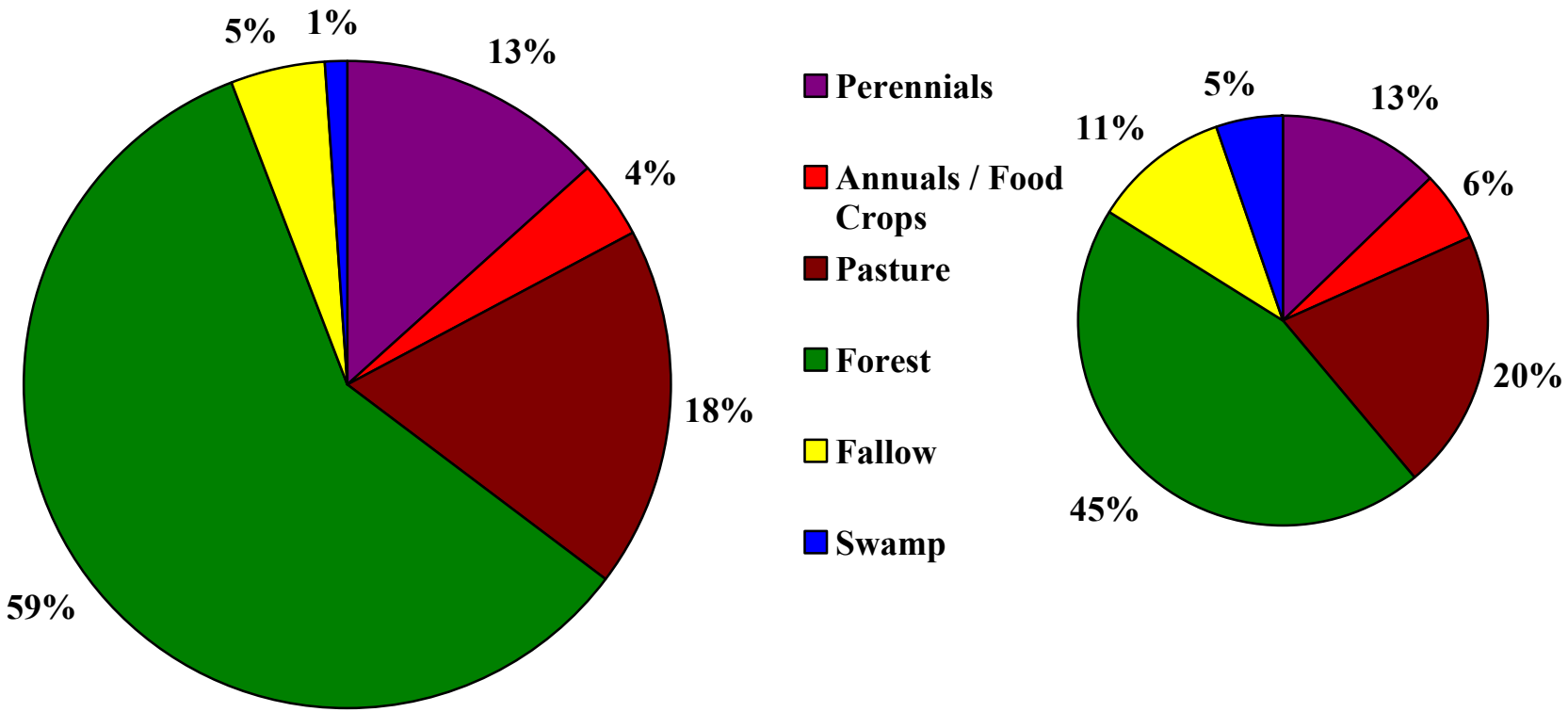
Survey Data Collection

- Longitudinal survey of households in fincas: 1990 & 1999.
- In 1990, 64 sectors sampled; 2-stage sample.
- 5-10 contiguous plots selected randomly from each sample sector.
- 418 settler plots on 405 *fincas* interviewed.
- In 1999, the survey found 767 farms on the same settler plots (land subdivision), plus 109 *solares* created by “parcelization” near several major towns.
- In 2000, community level survey of community leaders in 61 communities

Sample Households & Survey Sectors

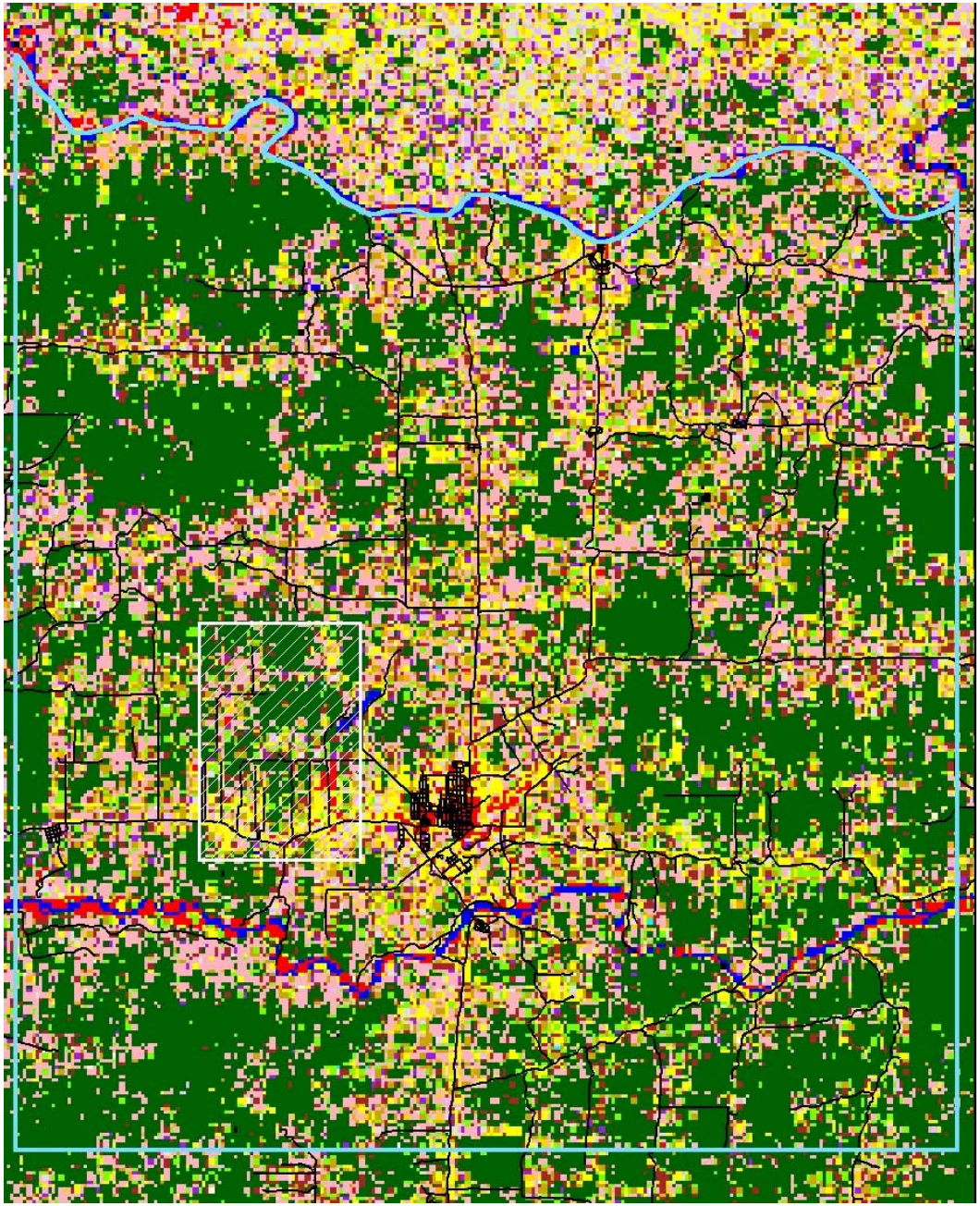


Land use distribution in colonization areas of the Northeast Ecuadorian Amazon



1990
Mean Area = 45.9 Ha

1999
Mean Area = 25.3 Ha

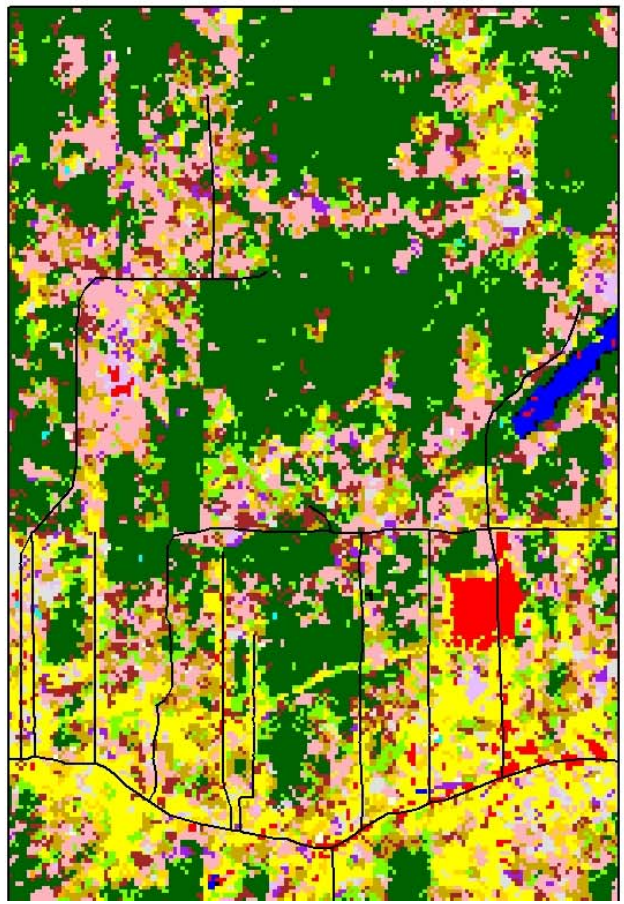


Detailed LULC Classification Focused on the Northern ISA

12 September 2002

Classes

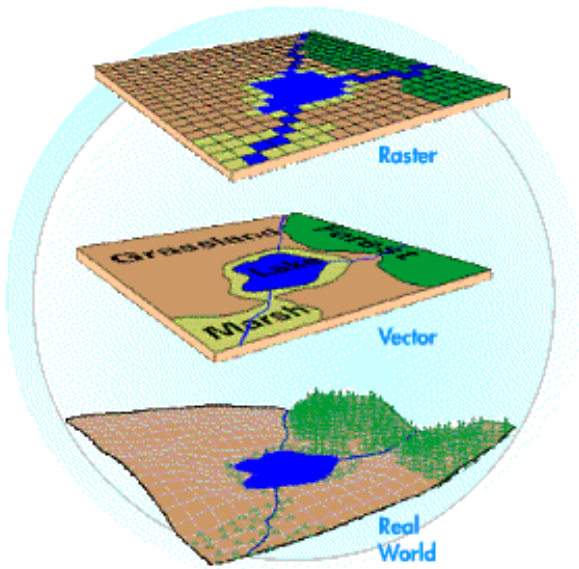
- African Palm
- Banana
- Barren
- Cacao
- Coffee
- Corn
- Palmito
- Pasture Few Trees
- Pasture Many Trees
- Pasture No Trees
- Primary Forest
- Rastrojo
- Secondary Forest
- Swamp
- Unclassified
- Urban
- Water



GIS Data Inventory

- Political & Cultural
  - Provinces
  - Parroquias
  - Cantons
  - Major Cities in the Oriente
  - Cuyabeno Wildlife Reserve
  - Yasuní National Park
  - Sector boundaries (Sucumbios, Orellana, Napo)
- Sample fincas
- Road Network
- Physical Environment
  - Rivers & Lakes
  - Morphology & Edaphology
- Topography
  - Elevation and terrain data

- Remotely-Sensed Imagery
  - Air photos (1990)
  - Landsat TM Satellite Imagery (1973 – 2003)
  - IKONOS Satellite Imagery (1999 – 2002)
  - Land Use/Land Cover Classifications (1986 – 2003)



Models of Land Use/Cover Change: Some Examples of Recent Research

- (1) Land fragmentation studies using pattern metrics
- (2) Secondary forest succession
- (3) Patterns of land use and land use change: statistical models, including multilevel
- (4) Simulations of LULC change – Cellular Automata
- (5) Simulations based on Agent Based Models

(1) Forest Fragmentation

A measure of clumping or aggregation of pixels used to show degree of fragmentation, but dependent upon pixel adjacency:

- Measurement resolution
- Raster and landcover type orientation
- Variable numbers of LULC classes
- Linked to: soil quality, topography, land use, access, labor supply , wealth, household characteristics

Pan, W.K.Y., S. J. Walsh, R.E. Bilsborrow, B.G. Frizzelle, C.M. Erlien, F.D. Baquero. 2004. Farm-Level Models of Spatial Patterns of Land Use and Land Cover Dynamics in the Ecuadorian Amazon. *Agriculture, Ecosystems, and Environment*, 101: 117-134.

Generalized Linear Mixed Model -- Pattern Metrics (e.g., Contagion) as dependent variable

- **1990 Model**
  - Intercept[a] (55.35)
  - Median slope[c]
  - Flat (% of fincas)[b]
  - Ave. age of head[a]
  - Year plot established[a]
  - Population density[b]
  - #subdivisions[c]
  - # subdivisions within 3-km[a]
  - Person-month of Off-Farm Employment[a]
  - Euclidean dist. to Ref. Commun[b]
  - Residual 112.37, random intercept 42.38, rho 0.27

- **1999 Model**
  - Intercept[a] (37.23)
  - Population density[c]
  - Access to electricity[b]
  - Euclidean dist. to ref. commun[c]
  - Distance to water[a]
  - Residual 72.09, random intercept 5.48, rho 0.07

"a" indicates p-value<0.01; "b" indicates p<0.05, "c" indicates p<0.10

Selected Findings

- Rapid population growth caused substantial subdivisions of plots, which in turn has created a more complex and fragmented landscape in 1999 than in 1990.

- Key factors predicting landscape complexity are population size and density on the finca, plot fragmentation through subdivisions, expansion of road and electrical networks, age of the plot, and topography, though some effects are not consistent over time.

(2) Secondary Forest Succession

- Objectives are to (a) quantify the proportion of secondary forest and fallow and changes over time, and (b) statistically investigate factors contributing to the presence and change of successional vegetation at the farm level.

- One of the uncertainties related to the generation of successional vegetation is what are the relevant socio-economic factors that affect it.

Mena, C.F., Walsh, S.J., Bilsborrow, R.E., 2005. Secondary Forest Succession in the Northern Ecuadorian Amazon: Interactions among People, Place, and Environment. *Regional Environmental Change*, in review.

Selected Findings

	1986		1996		2002	
	Ha	(%)	Ha	(%)	Ha	(%)
Primary Forest	599,532.21	(84.61)	467,828.01	(66.02)	426,785.76	(60.30)
Secondary Forest	17,683	(2.50)	67,114	(9.47)	47,706	(6.74)
Rastrojo	6,188	(0.87)	5,457	(0.77)	16,796	(2.37)

Probability of Secondary Forest

1990

Age of the Head (+)
Walking distance to the farm (-)
Has legal title (+)
Good soil (+)
Number of males (+)

1999

Off-farm employment (+)
Education (-)
Walking distance to the farm (+)
Has legal title (-)
Number of males (+)

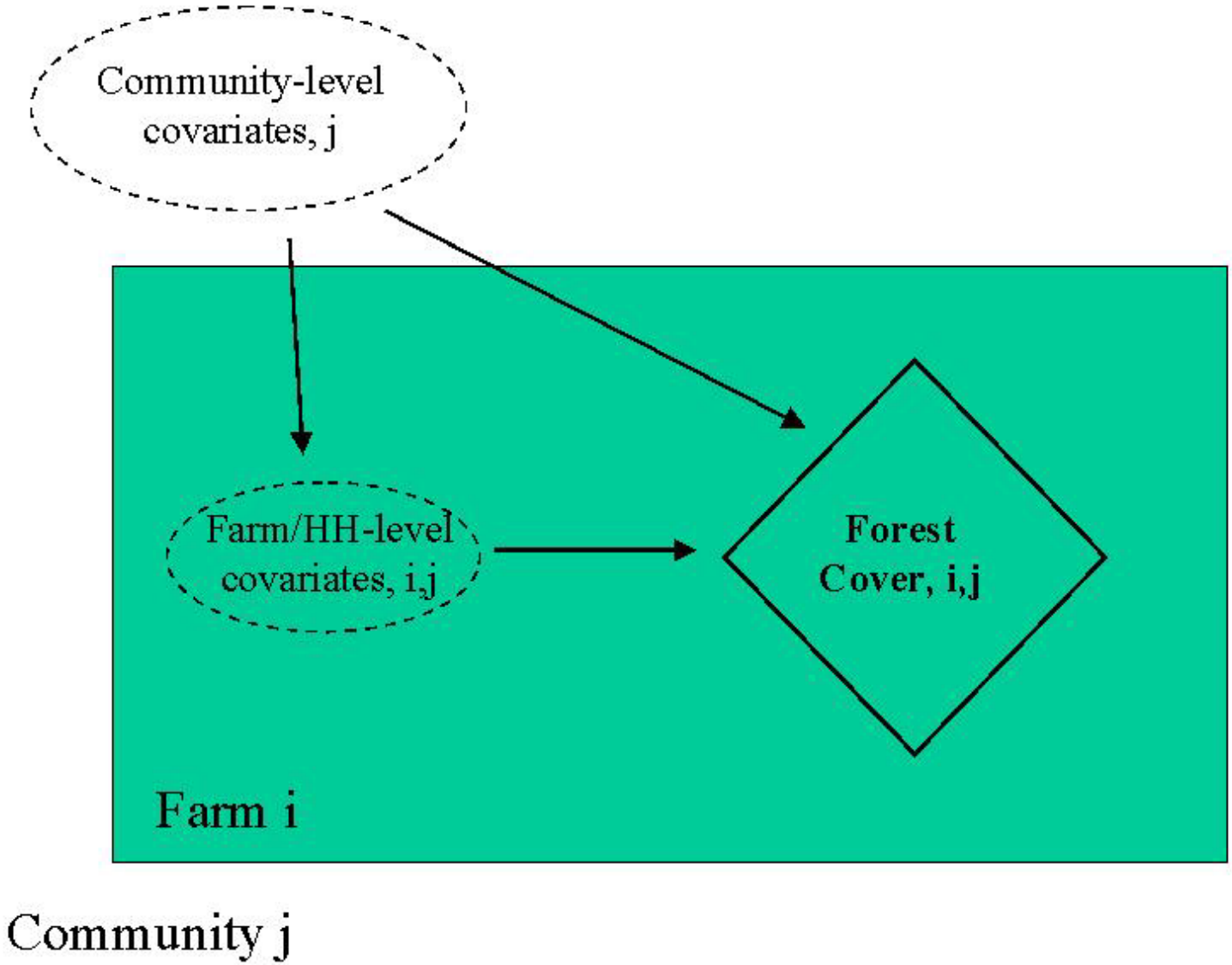
(3) Multi-Level Models: How farm LULC is affected by community as well as farm factors

- Analysis based on 5 dependent variables from multiplicative ipsative survey data: shares of farm in 5 different forms of land use—forest, annual crops, perennial crops, pasture, other (fallow plus swamp).
- Hypotheses: Population density, locational features, and other farm household factors are linked to LULC (deforestation as well as patterns of use of cleared land) and to increased plot complexity over time; contextual factors including local community characteristics also influence land use decisions of farmers.

Pan, W.K., and R.E .. Bilsborrow. 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: 2332-252.

Bilsborrow, R.E., ABarbieri, W.K. Pan, 2004. Changes in Population and Land Use over Time in the Ecuadorian Amazon. *Acta Amazonica* 34(4): 635-647.

Multi-Level Model



Main results from multilevel model based on 5 land use shares, 1999

- Forest cover affected negatively by no. of males, hired labor, outmigrants, education of head, secure land title, vehicle access; and positively by closeness to nearest community and major towns.
- Pasture area affected positively by hired labor, migrants, education of head, land title, flat topography; negatively by subdivisions and closeness to towns.
- Area in perennials affected positively by males, migrants, subdivisions; negatively by land title.
- Area in annual crops affected positively by no. children, flat topography.
- Area in other affected positively by no. children and negatively by distance to nearest community and major towns.

Selected Findings

- Communities with a civil registrar are rural centers, capitals of parroquias, this appears to influence LULC on *fincas,* leading to less fallow land because of market opportunities.

- Other contextual factors at the community level probably affect LULCC at the farm level, including bus transport availability, closeness to cities, etc.

- Important factors at the farm-level in LULC change include hired labor, size of farm, duration since establishment, household size (or population density once size controlled)

Community-level effects

- Variables tested include pop size, availability of piped water, electricity, coffee roaster, health center, nurse, distance education, number of shops/restaurants, year community founded, etc.
- No. of shops/restaurants found positive and significant on area in Annual crops, reflecting effect of closeness to markets; civil registrar as proxy for community size and political importance positively linked to area in Pasture and negatively to area in Other; coffee roaster positively linked to area in land in Other but not to current area in Perennials. All results expected except latter.
- Need to further examine effects of other community variables representing other health facilities/personnel, secondary school, other economic infrastructure

(4) Spatial Simulation & Cellular Automata (CA)

- **Goal**: Generate LULC simulations based upon actual conditions observed through the satellite time-series and extended in time & space through derived growth rules and neighborhood interactions.

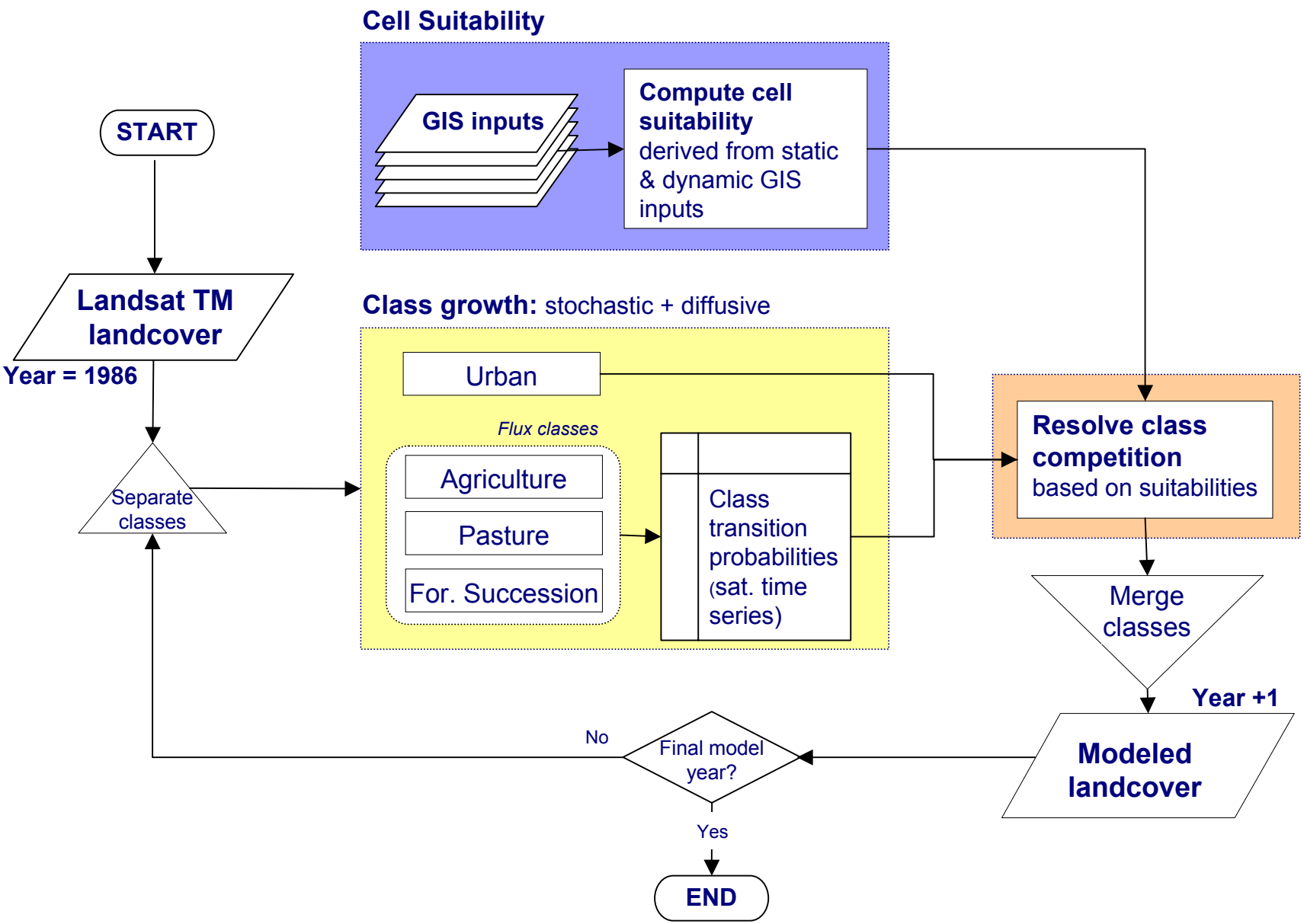
- **Approach**: CA consists of a regular grid of cells, each of which can be in one of a finite number of K possible states, updated over time synchronously in discrete steps according to a local, identical interaction rule. The state at any time is determined by the previous states of a surrounding neighborhood of cells, and the rule is usually specified in the form of a transition function.

Messina, J.P. and Walsh, S.J., 2005. Dynamic Spatial Simulation Modeling of the Population-Environment Matrix in the Ecuadorian Amazon. *Environment and Planning B*, in press.

Messina, J.P. and S.J. Walsh, 2001. 2.5D Morphogenesis: Modeling Land use and Land cover Dynamics in the Ecuadorian Amazon. *Plant Ecology*, 156(1): 75-88.

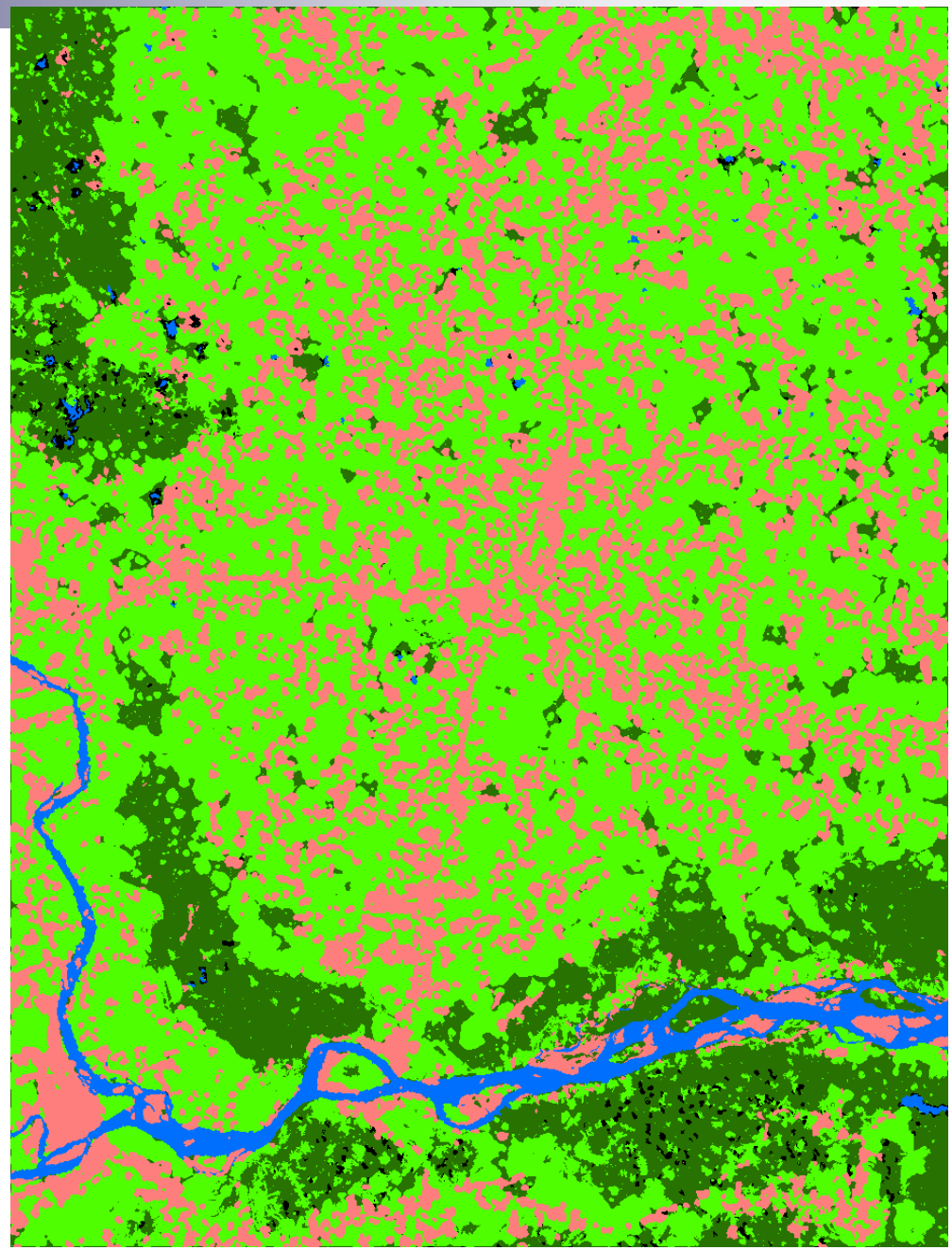
Factors affecting transitions of pixel from forest to non-forest vegetation

- Travel distance to nearest of 3 major communities: lower means higher probability of change (computed as Euclidean distance to nearest road plus distance along road network to the community).
- Population density on farm: higher density means greater probability of change.
- Slope angle: lower (flatter) means higher probability of change.
- Soil moisture index: lower means higher probability of change.
- Other parameters: stochastic (0.06), kernel threshold (4 cell units), masking threshold (0.4).


Cell Suitability
GIS inputs
Compute cell suitability derived from static & dynamic GIS inputs
START
Landsat TM landcover
Year = 1986
Class growth: stochastic + diffusive
Urban
Flux classes
Agriculture
Pasture
For. Succession
Class transition probabilities (sat. time series)
Separate classes
Resolve class competition based on suitabilities
Merge classes
Year +1
Modeled landcover
Final model year?
No
Yes
END

South ISA: CA Simulation

2010



(5) Agent-Based Models

- Autonomous decision-making entities (agents) act and interact in an environment; rules define the relationships between agents and their environment as well as the sequence of actions in the model.
- Complex adaptive systems are self-organized systems that combine local processes to produce holistic systems.
- Macro-level behaviors emerge from the actions of agents as they learn through experience and change, and develop feedbacks with finer scale building blocks agents.
- Need to initially create simulated or "virtual" environments and agents, with sets of LULC change scenarios.

Proposed Agents: Alternative Scenarios

- Colonists farm households living on *fincas*
- Oil companies
- Urban communities
- Indigenous populations living in scattered communities covering large areas of forest, with communal land titles
- National parks and protected areas (defining fixed or porous limits to encroaching activities of the other four agents)
- Postulate alternative plausible scenarios for simulation

Expected Findings

- Human frontier settlements exhibit self-organized complexity; feedbacks exist between spatial pattern and process.
- Emergent behavior of farmers is seen at macro-level development fronts.
- Spatial structure of LULC and LULCC patterns is related to farm size, year of establishment, size of household, population density, labor availability.
- Forest succession and fallow are linked to off-farm employment, male adults, & whether has legal title.

Future Directions

- Further improve multilevel models, including explicit controls for spatial autocorrelation.
- Explore spatial & temporal dynamics of population mobility and how to integrate into models.
- Study growth of communities and associations with LULCC on farms to include in models.
- Use spatially explicit approaches and simulations based on cellular automata and agent based models to address nonlinear systems with feedbacks, integrating people, place, and environment, and consider policy implications of LULCC.
- Combine the behavior of the five agents or stakeholders (i.e., colonists, indigenous groups, communities, oil companies, and protected areas) in a dynamic environment using spatial simulations and nonlinear systems approaches.