

Agricultural Colonization in the Ecuadorian Amazon: Population, Biophysical and Geographical Factors Affecting Land Use/Land Cover Change and Landscape Structure

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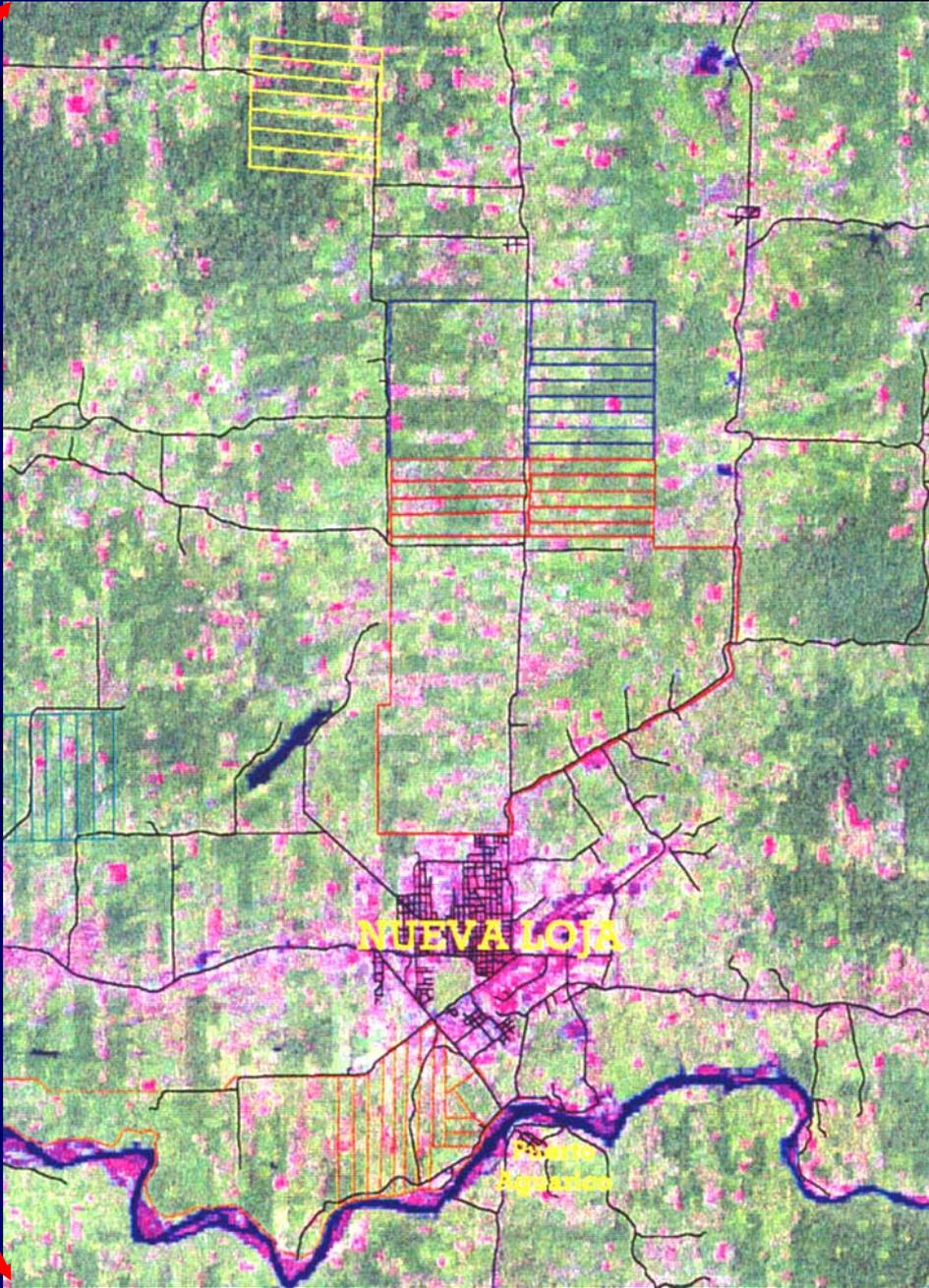
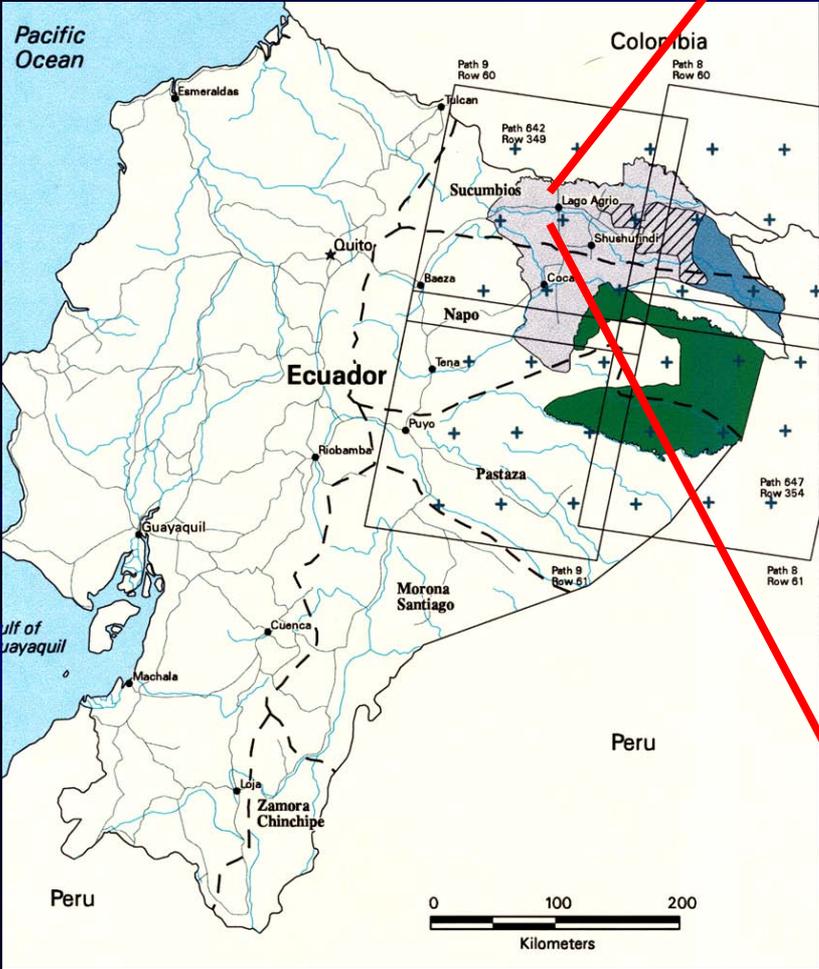
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The Northern Oriente



Settlement Patterns

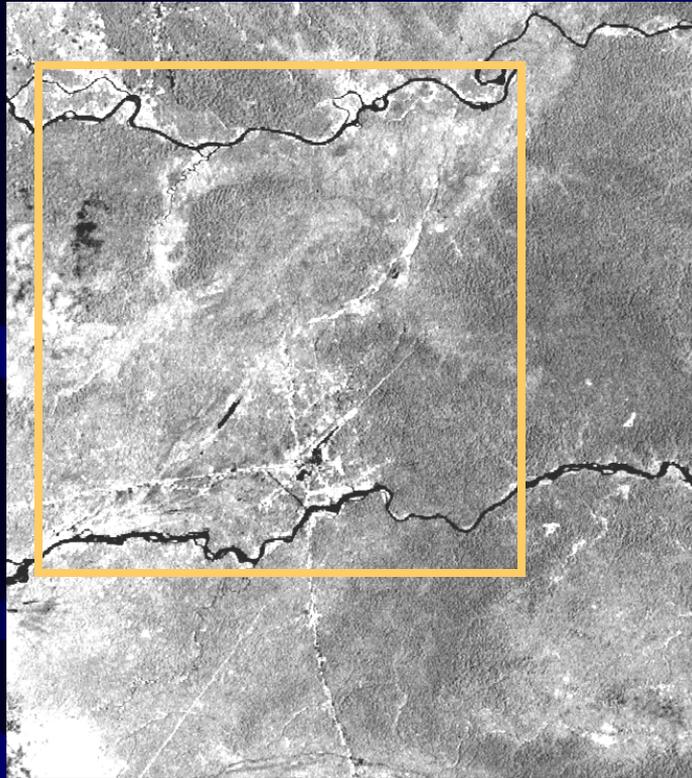
Second Lines

~2000 meters



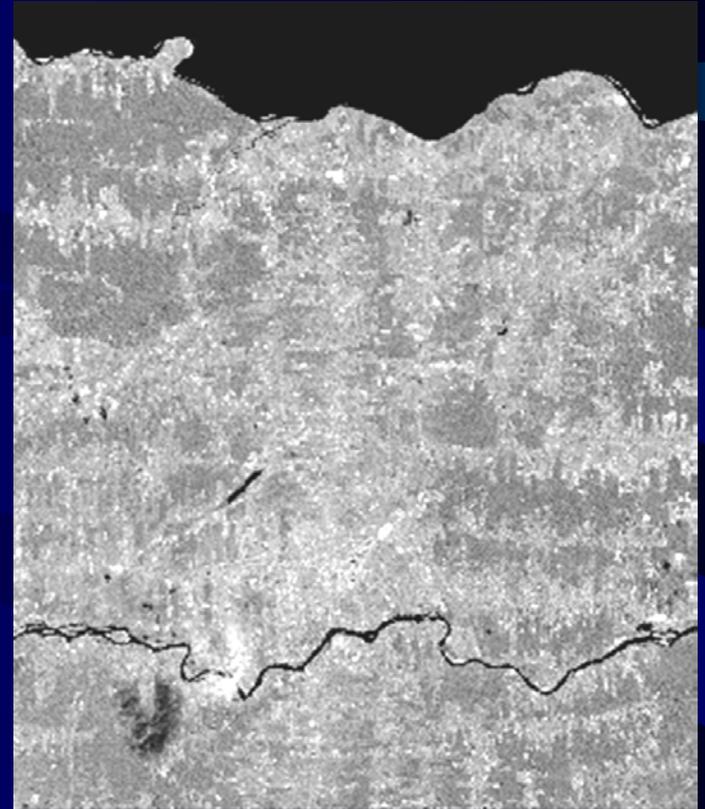
Rio Aguarico

Digital Image Data

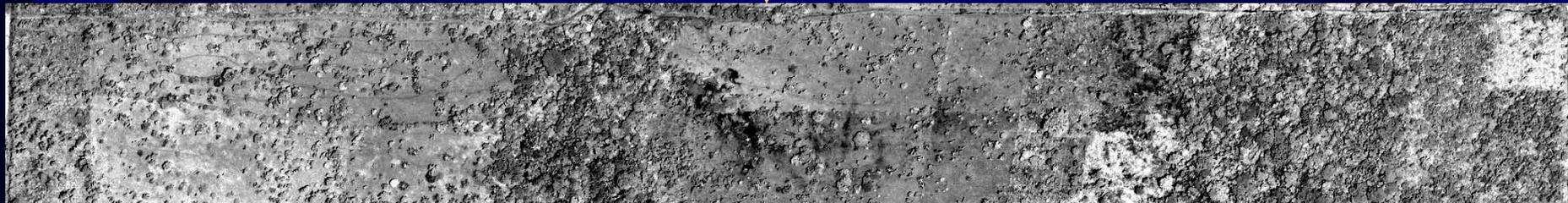


← MSS 1973

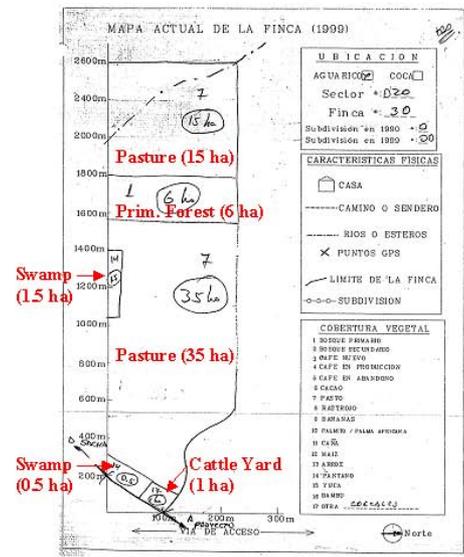
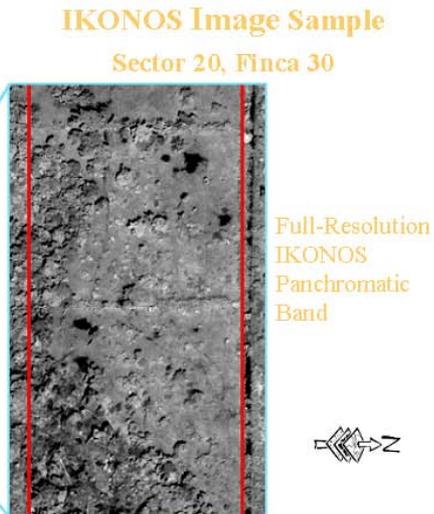
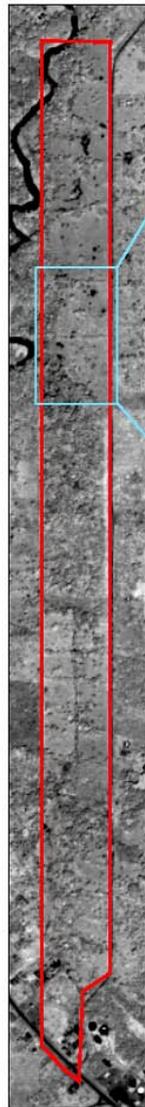
TM 1999 →



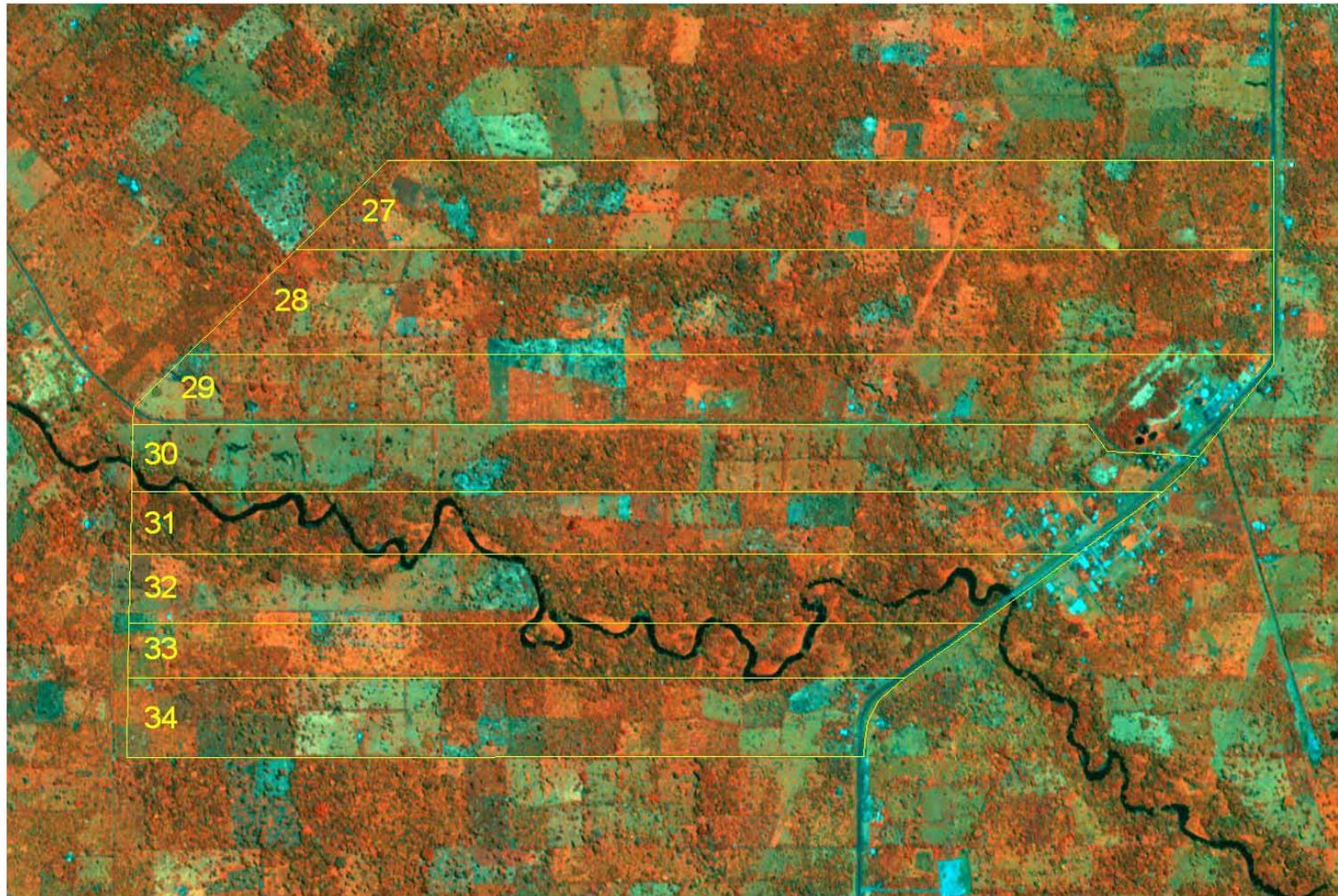
IKONOS 1999



Ikonos Images & Survey Sketch Map



IKONOS Multispectral (1999) & Survey Fincas



Static LULC Process Model Flow

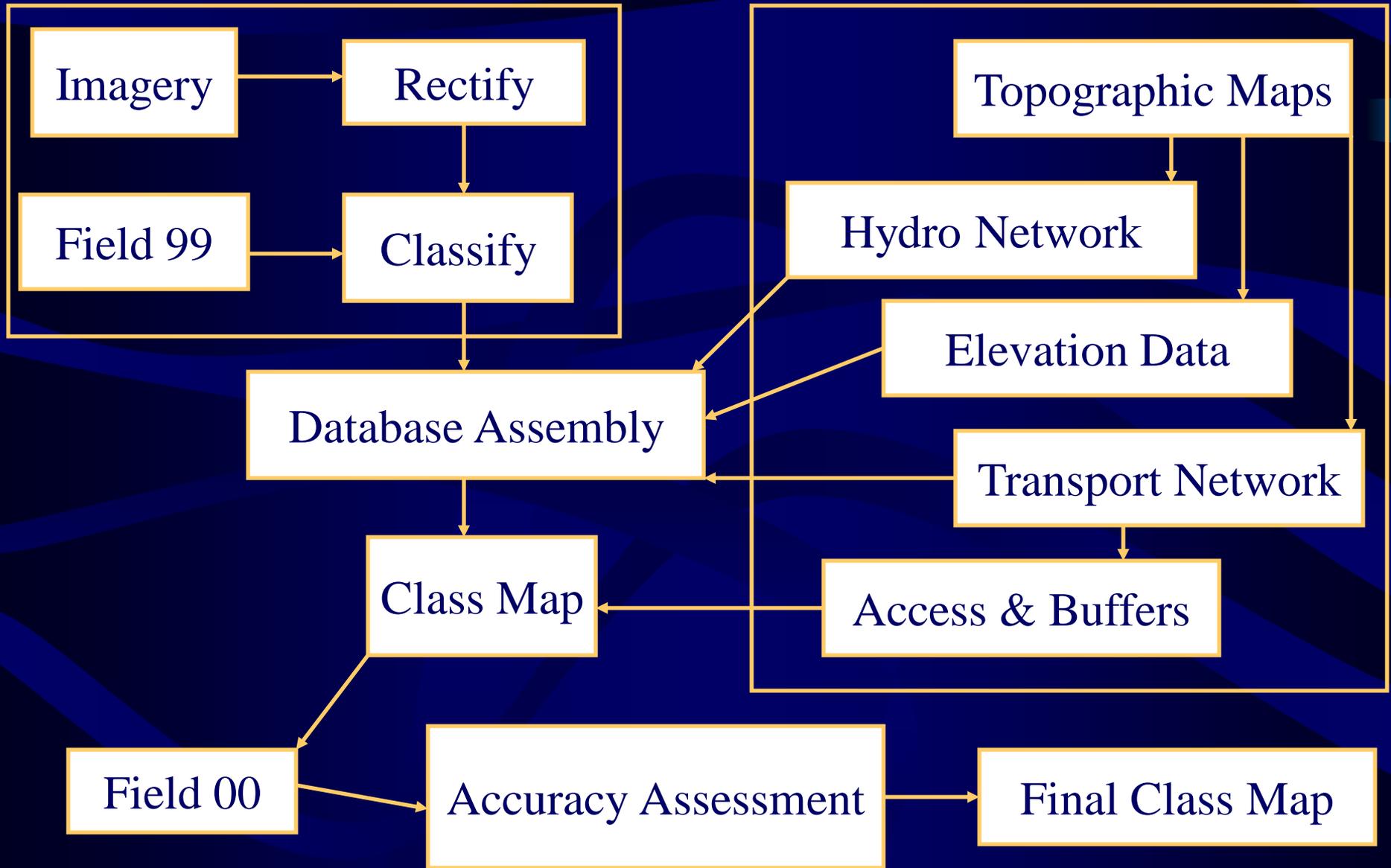


Image Classification Process 1973 - 1999

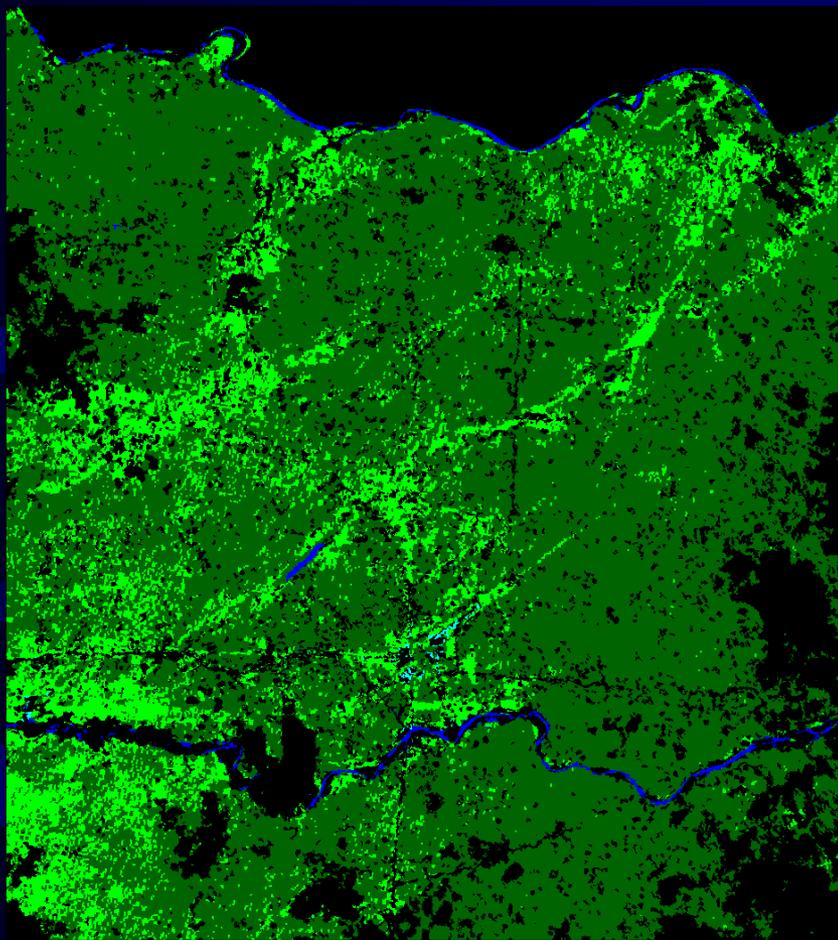
- Hybrid Classification
 - Unsupervised
 - Transformed Divergence
 - Supervised
 - Field Work 1999
 - Attribution



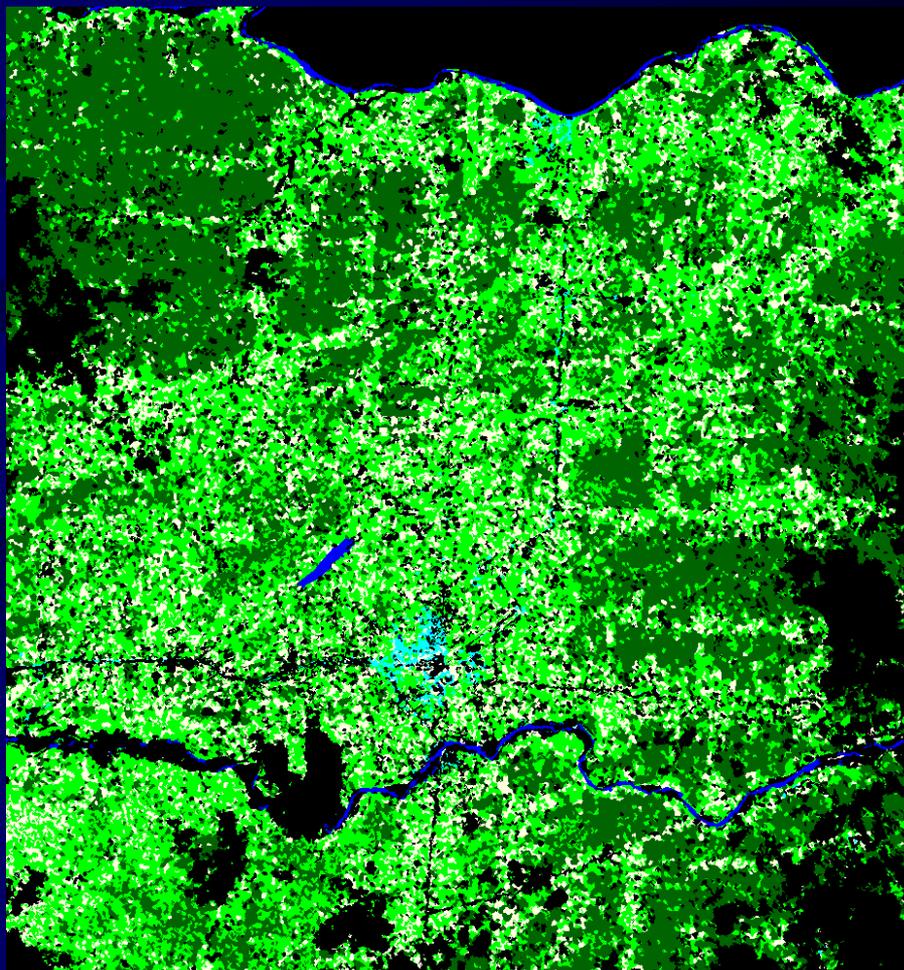
Provided a baseline

Image Classification

1973 MSS



1986 TM



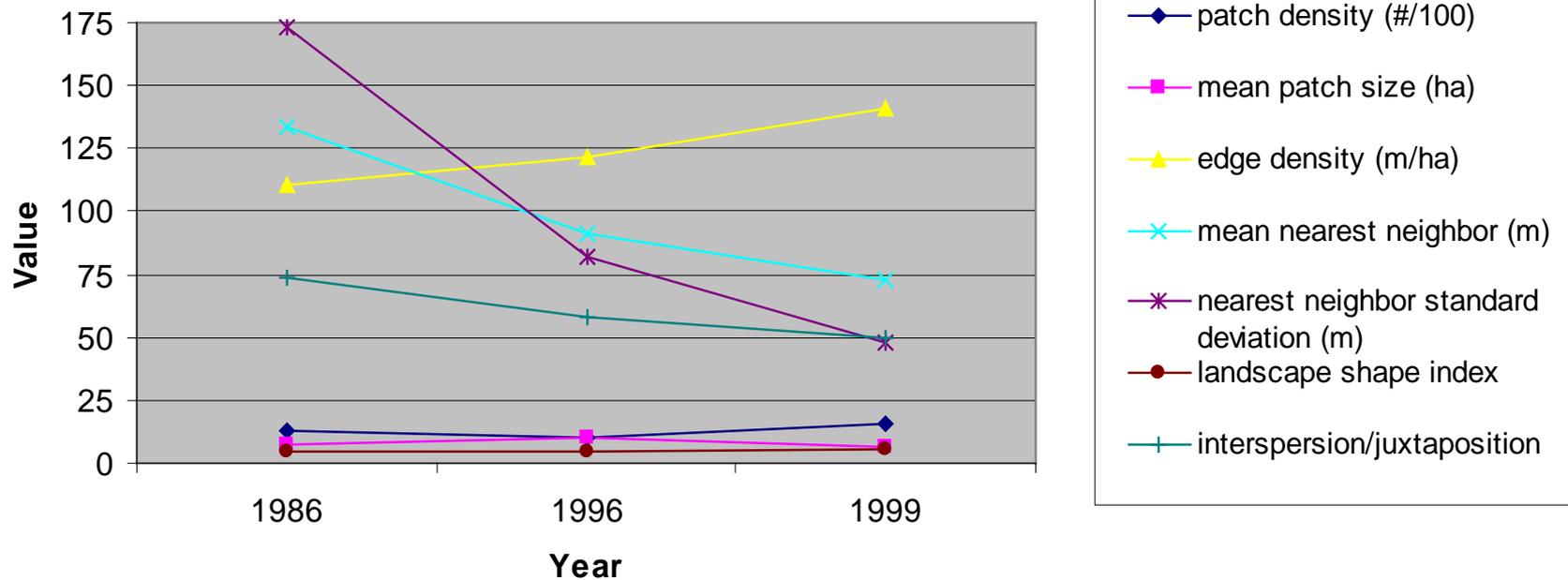
Pattern Metrics: Linkage of Landscape Form & Function

- Pattern metrics applied at the landscape level for survey fincas within selected Intensive Study Areas (ISAs).
- Classified Landsat TM data for selected years of the image time series, 1973-1999.
- Metrics were selected to represent fragmentation, edge, patch size, shape, nearest neighbor, and interspersion/juxtaposition of LCLU types – forest, agriculture, urban/bare, water.

Pattern Metrics: Eastern ISA

Sector 46

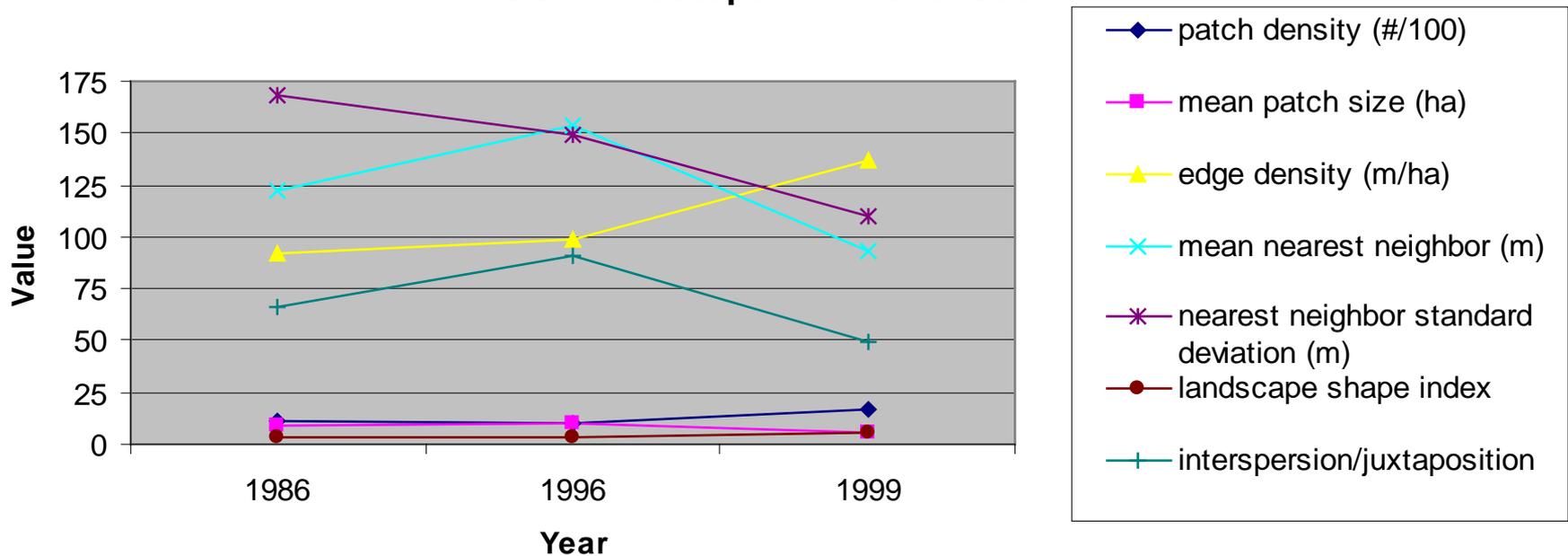
NISA Landscape Metrics for Sector 64



Pattern Metrics: Southern ISA

Sector 41

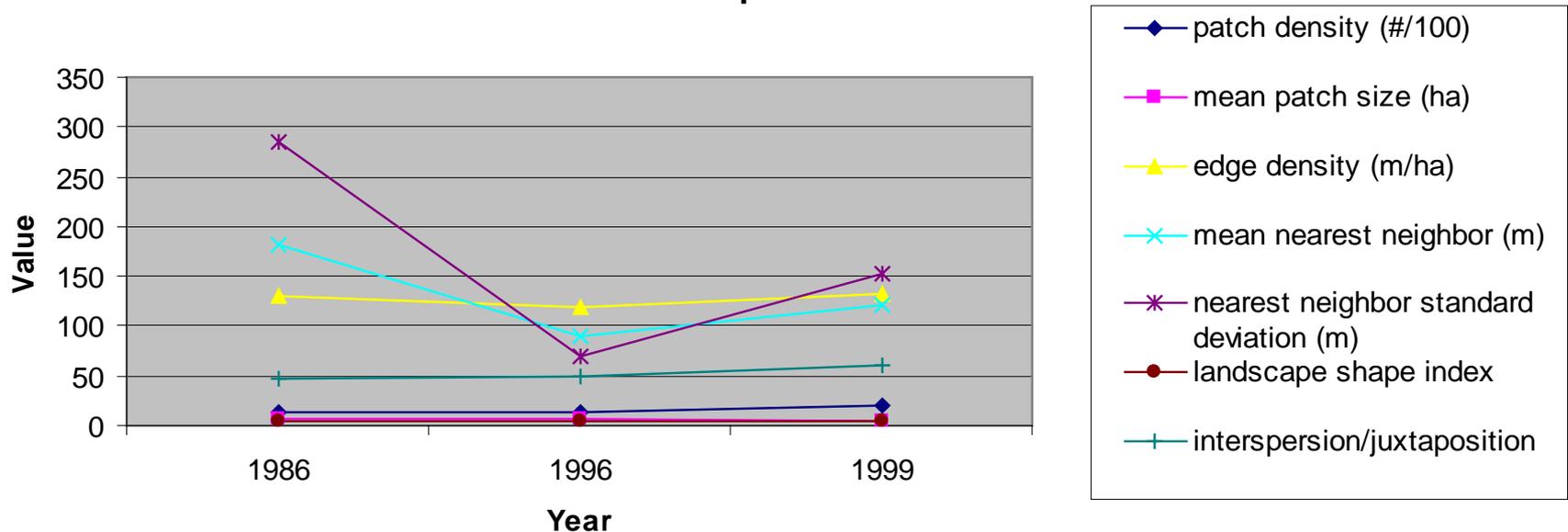
SISA Landscape Metrics for Sector 41



Pattern Metrics: Southern ISA

Sector 2

NISA Landscape Metrics for Sector 2



Time-Sensitive Approaches for LULCC

- Remote Sensing Time-Series
- Image Algebra
- Post Classification
- Multi-date Composites
- Change Vector
- Texture-Based Classifiers
- Panel Approach
- Dynamic Simulation Models, notably Cellular Automata

Theoretical Perspectives in the Geographic Study of LULC Dynamics

- **Hierarchy Theory** - Describes the structure of ecological systems through their spatial and temporal organization. Hierarchies can change with time: issues of resilience and adaptability are of critical importance.
- **Complexity Theory** - Systems that contain more possibilities than can be actualized, and descriptions not constrained by an *a priori* definition. The goal is to understand how simple, fundamental processes can be combined to produce complex holistic systems.

Complex Systems and Cellular Automata

- **Complex Systems Attempt to Model the World**
 - Multiple interactions of a limited number of components
 - Interactions constrained by a list of rules
 - Emergent phenomena are persistent patterns occurring in generated systems
 - The whole is more than the sum of the parts
- **Cellular automata operate in a GISc framework to model the complex conditions via spatial simulations**

CA: How It Works

- Dynamic, discrete space-time systems
- Regular grid of cells, each in a fixed state
- A cell state is determined by the states of the neighboring cells in the previous time step
- Grid is iteratively updated via discrete time steps
- Can grow, vary rates of change, or reverse direction
- Is capable of including thresholds, feedbacks, and hierarchy

CA Simulation Model

- **Follows Classical CA Approaches:**
 - Study space is reduced to a grid or tessellation of cells
 - Initial conditions and transition rules are established
 - Rules are applied in a recursive sequence of iterations
- **Development of the Model Involves:**
 - Determining the rules from an existing system
 - Calibrating CA for results consistent with historical data
 - Predicting the future by allowing the model to continue to iterate into the future

LULC

GIS Layers

Access

Terrain

IDL Model

Spatial Partitioning

Markov Probs.

Cellular Coeff.

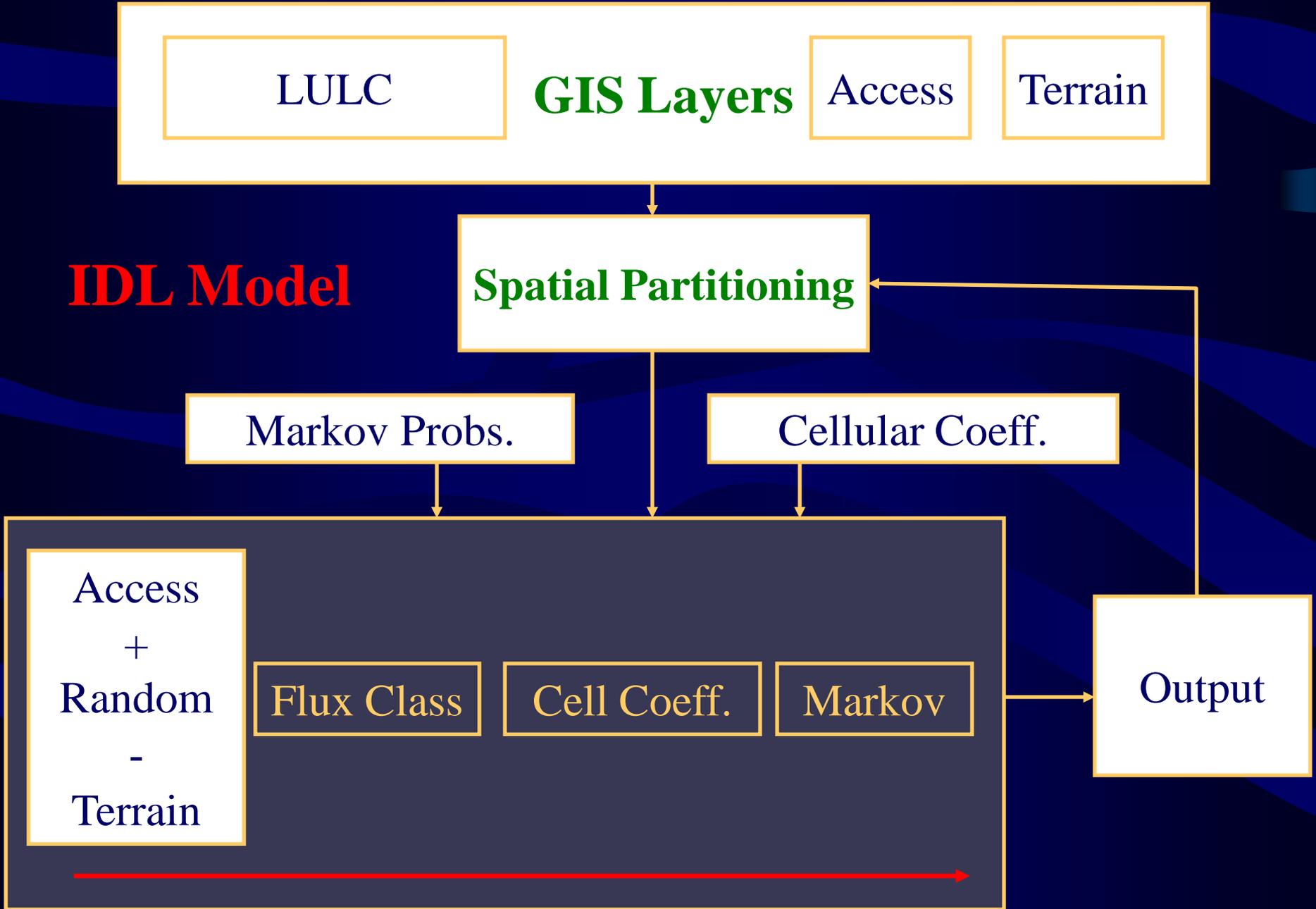
Access
+
Random
-
Terrain

Flux Class

Cell Coeff.

Markov

Output



10 Year CA Simulation

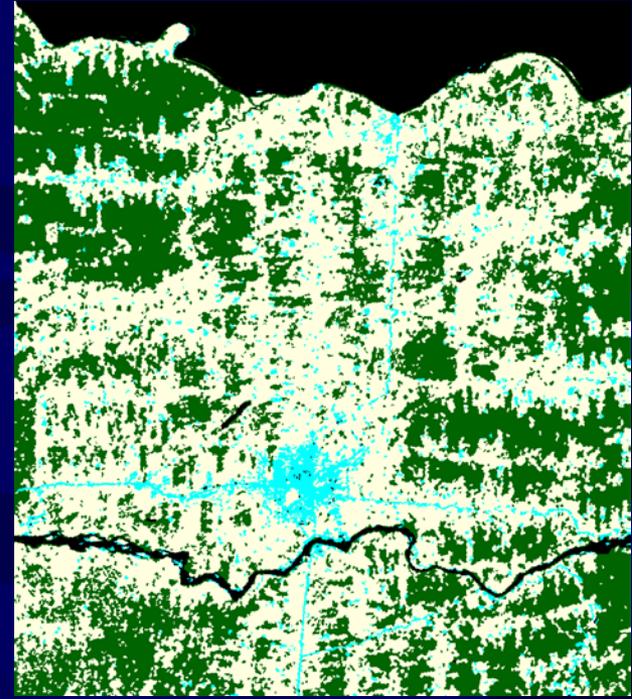
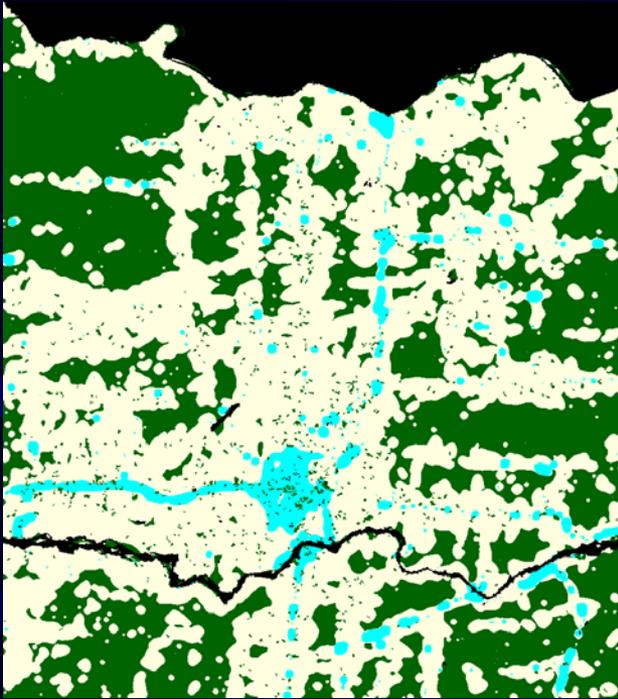
- Based on data from 1986 to 1996
- Growth and transition rules held constant
- Calibration is via summary correlations

Important Considerations:

- LULC scheme dependency
- Diffusion Theory
- Neighborhood effects



Model Calibration



Total Area in Hectares

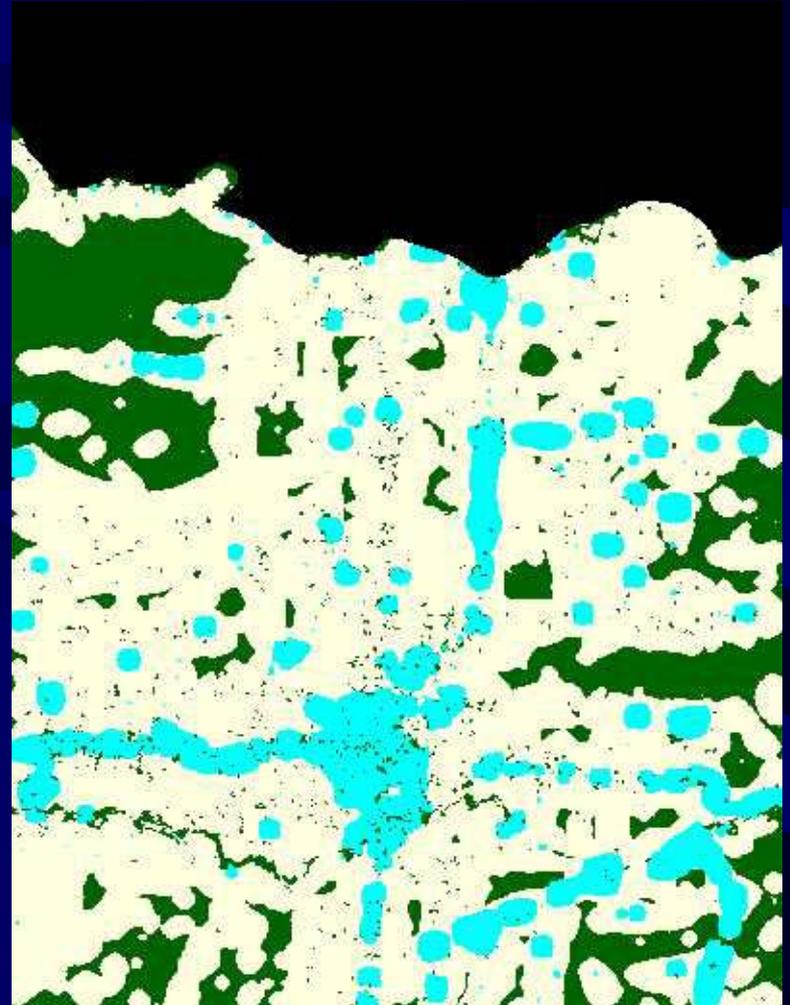
	1986	1996 Predicted	1996 Actual	Forested	Urbanized	Agriculture
Forested	48036	30015	31853	70.95%	7.80%	23.08%
Urbanized	1050	3591	3774	2.15%	54.50%	3.94%
Agriculture	27158	45072	43029	26.90%	37.70%	72.98%

Summary Correlations

Simulation to 2010 and Validation

Validation

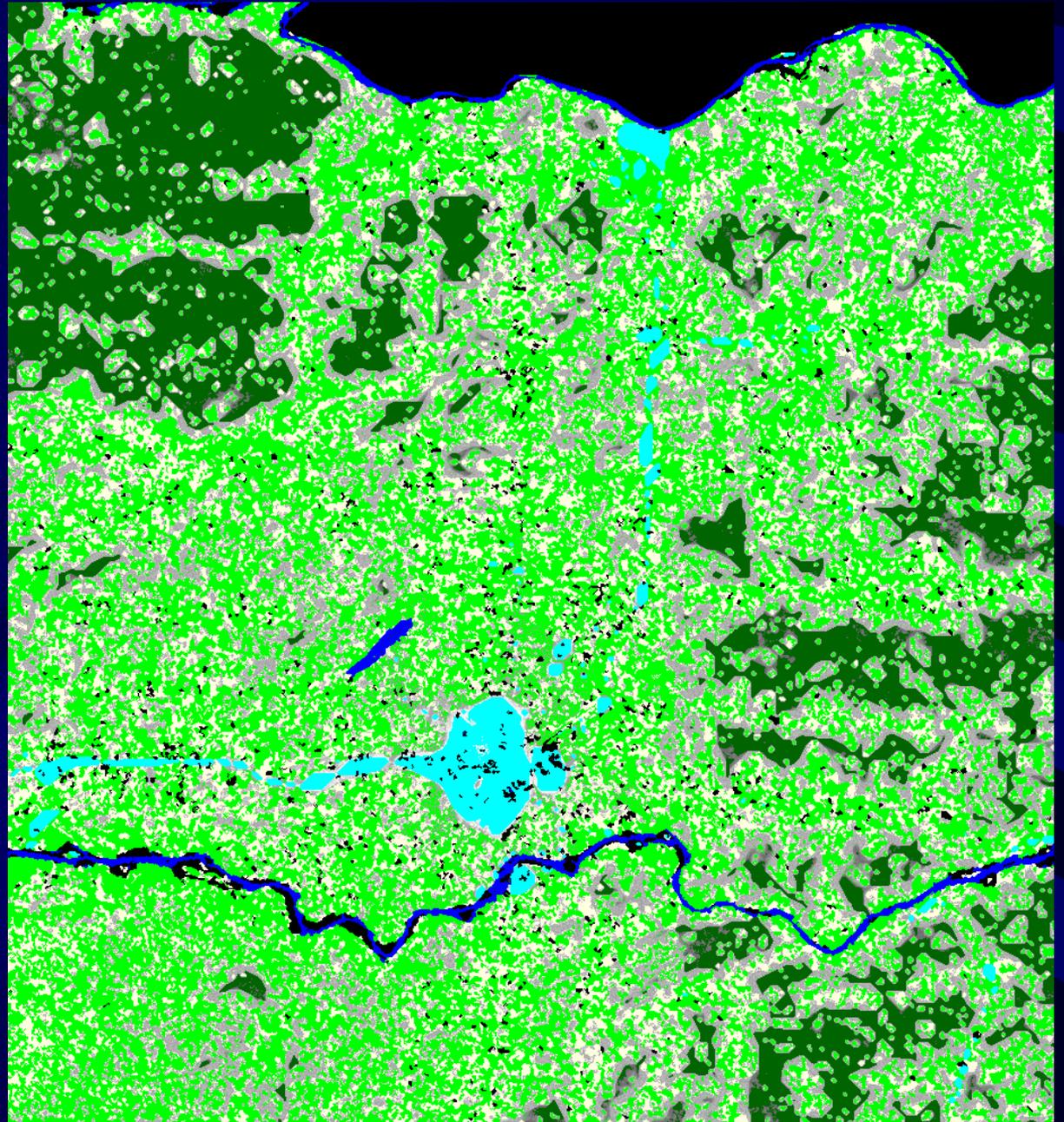
- Pattern metrics - Fragstats
 - e.g., number of patches (NP), mean patch size (MPS), etc.
- Autoregressive time series (IDL)
- Comparison using paired t-tests



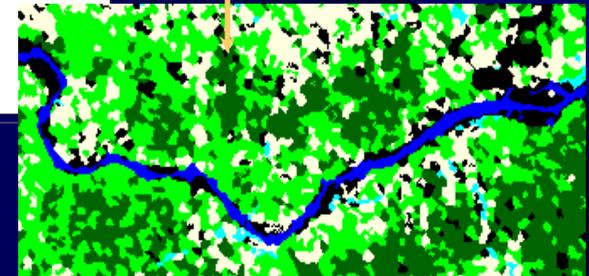
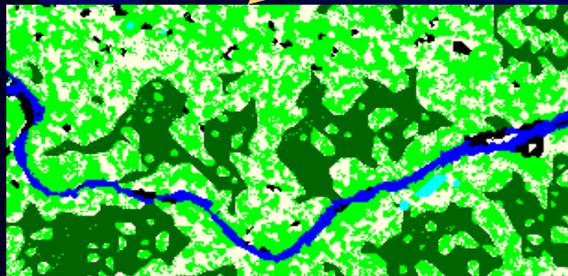
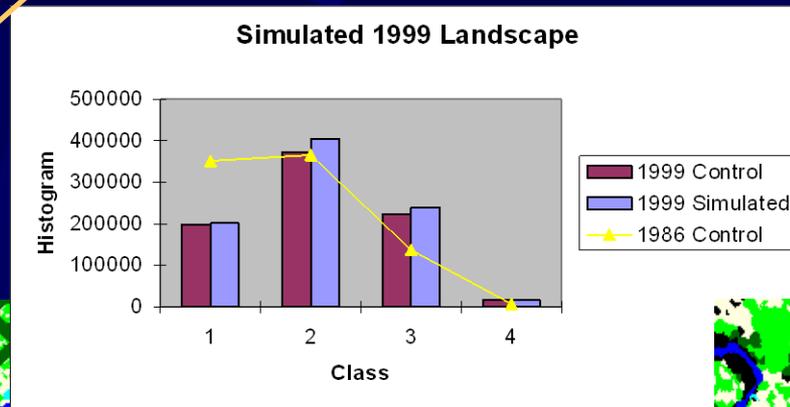
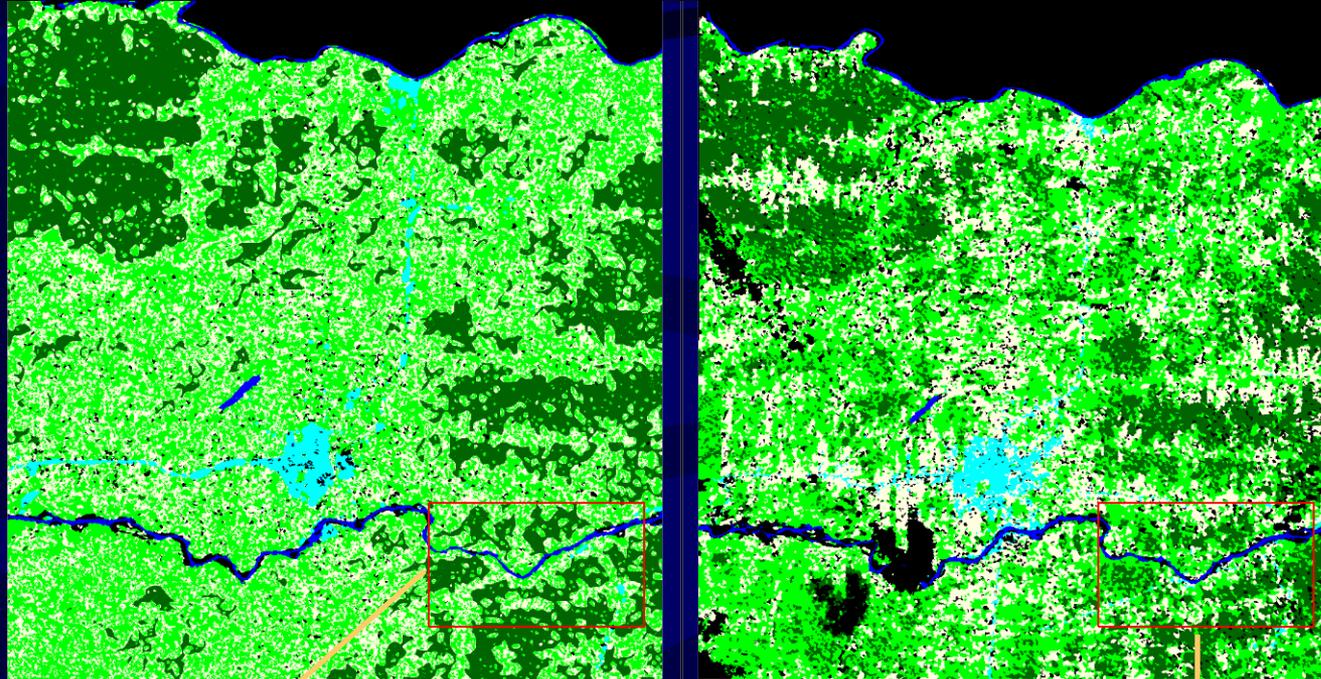
Simulated 2010

Gray tones: various
change probabilities

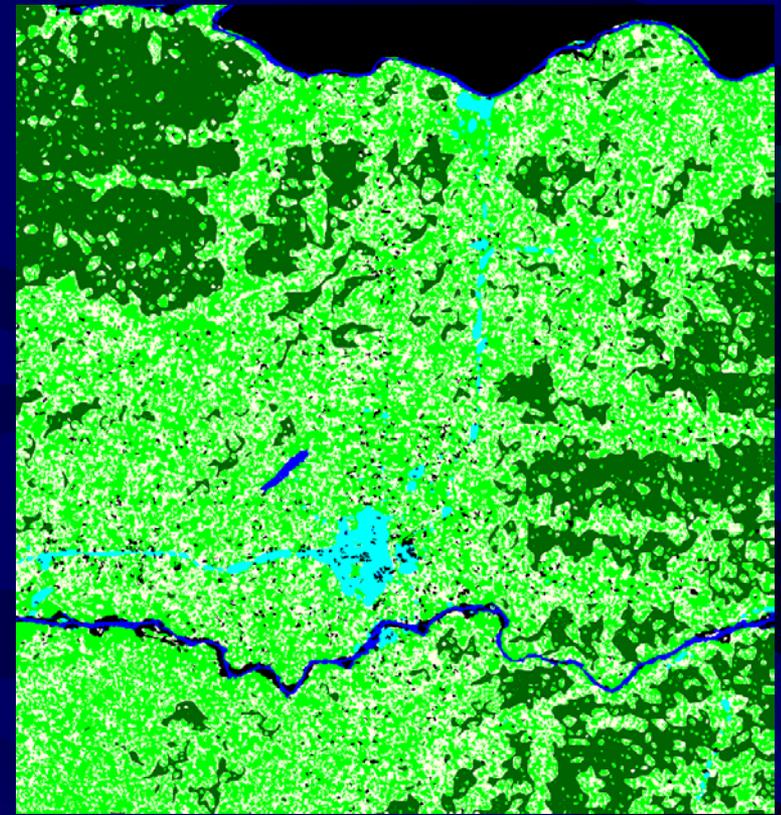
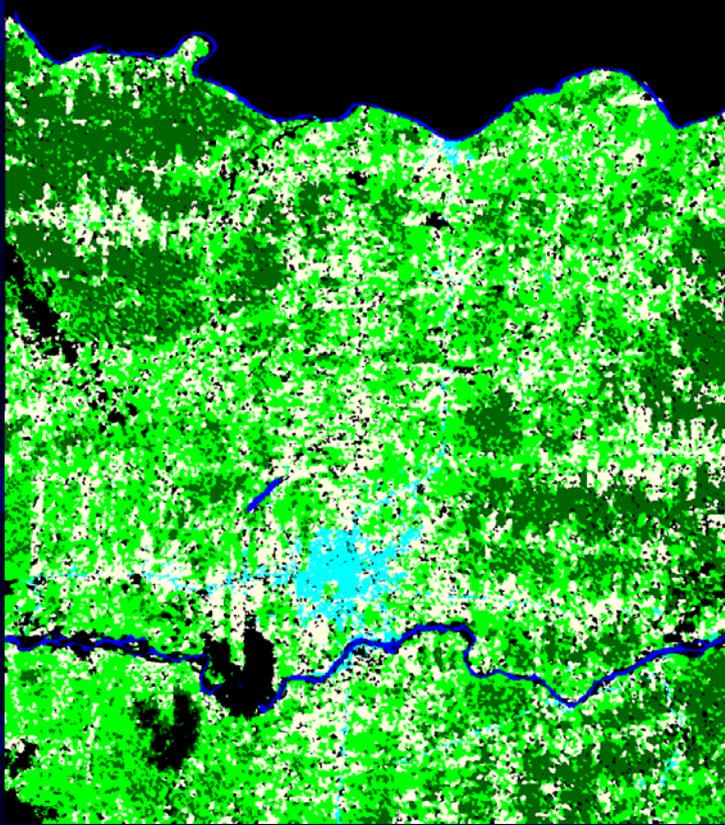
Note: the cloud
spaces are absent



Expected vs. Observed Patterns



IDL Model Evaluation



Total Area in Hectares

	1999 Pred.	Actual	1986
Forested	18419	17882	31649
Sec. For	36136	33501	32891
Agriculture	21426	20114	12305
Urbanized	1469	1494	604

Summary Correlations

	For.	Sec.For.	Ag.	Urban
Forested	62%	11%	13%	0%
Sec. For	25%	58%	50%	9%
Agriculture	13%	29%	35%	31%
Urbanized	0%	1%	1%	58%

Future CA Modeling Plans

• Model

- Export the whole system to IDL
- Build in automatic Monte Carlo simulation tools
- Explore better validation procedures: pattern metrics
- Explore the early growth dynamics

• LBA / Oriente

- Enhance growth rules to explicitly link demographic, socio-economic, and physical phenomena
- Develop environmental gradients and a transportation cost surface
- Explore scale dependency and social constraints

Contagion versus PPU

- Contagion is a measure of clumping or aggregation of pixels used to show degree of fragmentation, BUT is dependent upon pixel adjacency
 - Measurement resolution
 - Raster and landcover type orientation
 - Variable numbers of LULC classes

Patch Per Unit Area

$$PPU = m / (n * \lambda)$$

m = total patches

n = total # pixels in the study area

λ is a scaling constant equal to the area of a pixel

(Frohn, 1998)

Findings: Remote Sensing/GIS

- Change detection and pattern metrics analyses indicate different LULCC patterns for different colonist areas and time periods.
- Customized Level-4 LULC classification scheme characterized the region.
- Fuzzy and crisp accuracy assessments were used for the QA/QC.
- Optimized pattern metrics (patch per unit area & a modified version of the fractal metric) characterize the nature of landscape stability and complexity.
- LULC trajectories indicate relative stability and dynamics of LULC at the pixel-level.
- Cellular Automata models use the above to predict LULC dynamics for the Lago area for selected periods.

Modeling Land Use Change

Theoretical Approaches

- **Malthus (1798, 1802):** The “natural” tendency of population to grow exponentially and agriculture to expand arithmetically leads to Land Extensification (and also to environmental degradation--Neo-Malthusians).
- **Boserup (1965, 1981):** Population pressures MAY lead to increased labor intensity and increased food production through Intensification of Land Use.
- **Bilsborrow (1987, 2001):** Land intensification and extensification are among the possible economic, demographic and ‘economic-demographic’ responses to increased population and economic pressures
- **Blakie and Brookfield (1987):** Regional Political Ecology – HH decisions are linked to broader socio-economic processes and institutions.
- **McCracken (1999), Perz (2000 - Brazil):** Stages of HH settlement and family lifecycle affect LCLUC.

Reconciling Different Theoretical Arguments

- **Responses (of rural households to increased demographic or economic pressures)**
 - Economic (land intensification and land extensification)
 - Demographic (fertility decline, postponing marriage)
 - Economic-demographic (seasonal out-migration)
 - Economic-demographic (“permanent” out-migration)
 - Economic options tend to be tried first
- **Response Drivers**
 - The strength, order and timing of responses are affected by human and biophysical factors operating on multiple scales
 - Socio-economic, biophysical, and geographic domains operate through scale-dependent relationships (exogenous and endogenous factors)

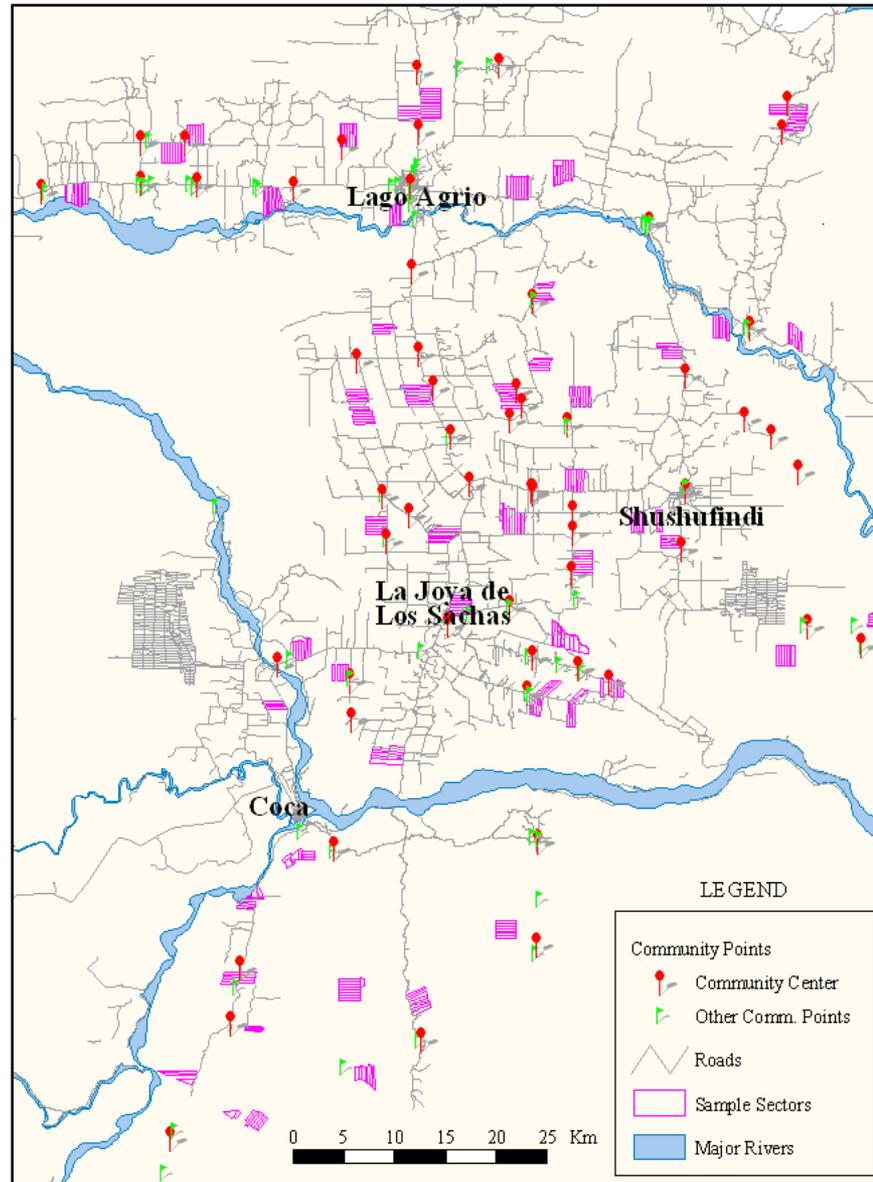
Migration into the Amazon

- Most population growth since the discovery of oil around 1970 due to migration, notably from densely populated rural Sierra
- Even in the 1990s substantial in-migration continues, accounting for over half of the fragmentation of fincas
- Population growth of 5% per annum in the 1990s in rural settlement study area contrasts with declining rural populations in most of country and overall

Fertility in Settlement Region

- Fertility is very high but now declining- with a Total Fertility Rate of 5.0 in the late 1990s vs. over 7.0 in the 1980s
- Most settler women do not want any more births, 70-74%, vs. 59% in the country as a whole
- Family planning use is rising rapidly, from 33% using any method in 1990 to 45 % in 1999, though a quarter of this is ineffective methods (rhythm)
- Facilities providing family planning methods are few and far between

Sample Households and Sectors



General Statistical Modeling

Approach

- Descriptive statistics: use frequencies, cross-tabulations and cross-breaks to determine overall picture and trends and to develop hypotheses
- Dependent variables: shares of land (cover) in forest, annual crops, perennial crops, pasture
- Formulate and test statistical models: to test hypotheses and to compare cross-sectional results, 1990/1999, based on testing a wide range of explanatory variables, based on data for 765 farms (1999)

Comparison of 1990 vs. 1999 Household Demographics, Assets, Tenure Characteristics

	1990 (N = 418 HH's)	1999 (N = 763 HH's)
Average people per HH	6.6	5.7
Population (farms only)*	2761	3813
Average distance to market	28.2 km	20.4 km
Road distance	24.2 km (n=394)	19.1 km (n=682)
Walking to road	5.3 km (n=214)	2.6 km (n=333)
Canoe	34.1 km (n=35)	18.7 km (n=30)
Head born in Oriente	4.6 %	8 %
Electricity in dwelling	14 %	32 %
Own chainsaw	30 %	20 %
Have full legal title	50 %	34 %
Gini Coefficients for Landholdings	0.26	0.50

*Excludes population living in *solares* (housing lots)

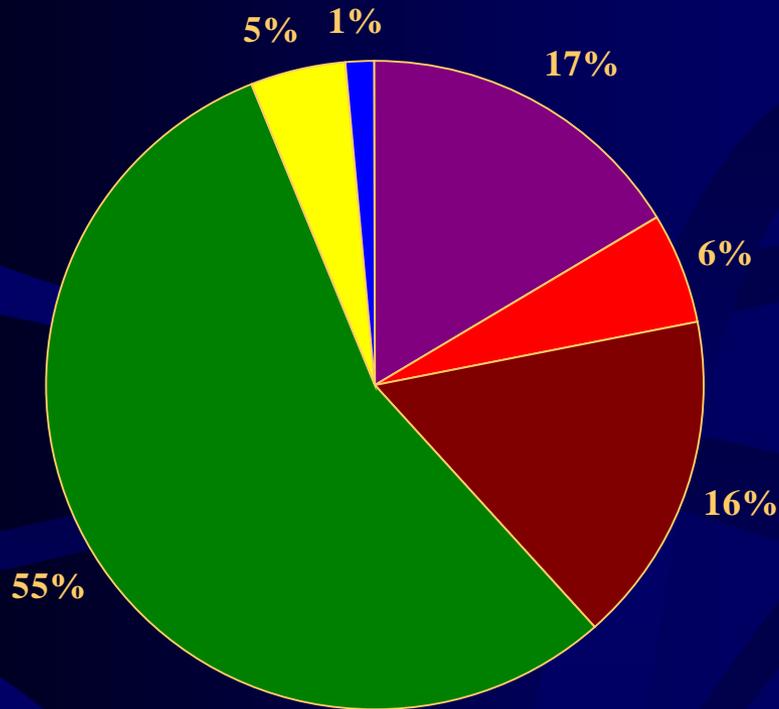
Differences in Plots of Long Term (>9 yrs) vs. New Owners, 1999

	Long Term	New Owner
Number of households	315	393
Head born in Oriente	6 %	12 %
Off-farm employment	49 %	60 %
Hire day laborers	48 %	40 %
Intact farm (no subdivision since 1990)	40 %	21 %
Hold Full Legal Title	53 %	21 %
Receipt of credits/loans	34 %	12 %
Cattle	75 %	31 %

HH & Farm Characteristics: 1990 vs. 1999

	1990	1999
<u>Sample Size</u>		
• Number of <i>Fincas</i>	405	393
• Number of Farms	418	765
• Number of Owners / Managers	418	708
<u>HH Demographics</u>		
• Population	2761	3813 ¹
• CEB	2.93	2.67
• Head of HH Born in <i>Oriente</i>	143 (35%)	64 (9%)
• Off-Farm Employment	15 (4%)	389 (55%)
• Hire Day Laborers	243 (60%)	307 (43%)
<u>Land Tenure</u>		
• Hold Full Legal title	208 (50%)	251 (35%)
• Hold Certificate of Possession	179 (43%)	93 (13%)
• Received Credits	78 (18%)	136 ² (18%)
• Intact <i>Finca</i> (no subdivisions)	338 (82%)	309 (44%)
<u>Assets</u>		
• Own Cattle	236 (57%)	307 (43%)
• Gini Coefficient for Land Ownership	0.26	0.50
<u>Plot Location</u>		
• Road Distance to Market (Km)	24.2 (N=394)	19.1 (N=682)
• Walking Distance to Road (Km)	5.3 (N=214)	2.5 (N=333)
• Distance by Canoe (Km)	34.1 (N=35)	15.3 (N=26)
1 – This does not include the solares population of 521		
2 – Received Credit since 1990		

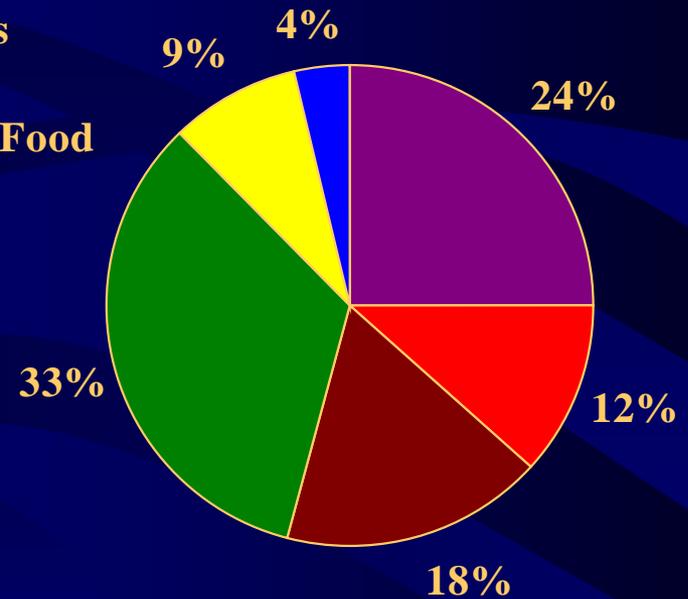
1990 vs. 1999: Land use



1990

Mean Area = 43.6 Ha

- Perennials
- Annuals / Food Crops
- Pasture
- Forest
- Fallow
- Swamp



1999

Mean Area = 23.3 Ha

Model Coefficients for Selected Variables

Independent Variables	Forest ^a	Pasture ^a	Perennials ^a	Annuals ^a
Intercept	0.59	0.39	0.57	0.15
≥ Secondary Education	-0.10	-0.00	0.08	0.01
# Adult Males	-0.03	0.02	0.02	0.01
# Adult Females	0.01	0.01	-0.03	0.001
# Kids < 12	0.01	0.02	-0.02	0.01
Population Density ¹	-0.06	-0.05	0.04	0.04
Flat Land	-0.15	0.01	0.05	0.08
Black Soil	0.01	0.02	-0.08	0.07
Farm Area (Ha) ²	0.22	-0.02	-0.15	-0.02
KM by Road or Boat	0.003	-0.002	-0.00	-0.001
KM Walking to Road	0.02	-0.02	-0.002	0.003
Indicator for boat	0.28	-0.23	-0.06	-0.02
Title / Land Cert.	-0.01	0.13	-0.10	0.01
Years on the Farm ²	-0.04	0.02 *	0.05	-0.01
Months of OFE ²	0.06	-0.04	-0.03	-0.01
Months Hired Labor ²	-0.05	0.05	0.01	-0.01

1 – Centered; 2 – Centered and Scaled

a – Response variables are transformed using the ARC-SIN Root Transformation

Determinants of LULC

1999 Models

- Forest

- + : Plot Size, Distance, Off-Farm Employment (OFE)

- : Adult Males, >Secondary Education, Population Density, Flat Land, Duration on Farm, Hired Labor

- Pasture

- + : Adult Males, Children, Title, Duration on Farm, Hired Labor

- : Population Density, Distance, OFE

- Perennial Crops

- + : Population Density, >Secondary Education, Duration on Farm

- : Adult Females, Children, Black Soil, Plot Size, Title, OFE

- Annual (Food) Crops

- + : Population Density, Flat Topography, Black Soil

- : Plot Size, Distance

Summary of Statistical Results for 1999

- **Demographic Variables** (notably population density) :
less forest cover, more perennials and annual crops
- **Duration of residence:** less forest cover, more perennials and pasture
- **Land Title:** more pasture, less perennials
- **Labor supply:** less forest cover, more pasture and perennials
- **Natural resources:** flat land leads to less forest cover and more annuals; better soils lead to more annuals and less perennials
- **Accessibility:** closeness leads to less forest cover, more pasture

MAIN POINTS

Preliminary Conclusions from 1999 Data

Population

- **Doubling in population, # plots**
- **Subdivision & “urbanization”**
- **Inheritance by second generation**
- **Acquisition by new in-migrants**
- **More subdivisions exist in areas with better soils, flat land, older settlements, on road, near town**
- **Increase in wage labor in region, increased linkages between farm plots and towns**

Land Use Changes

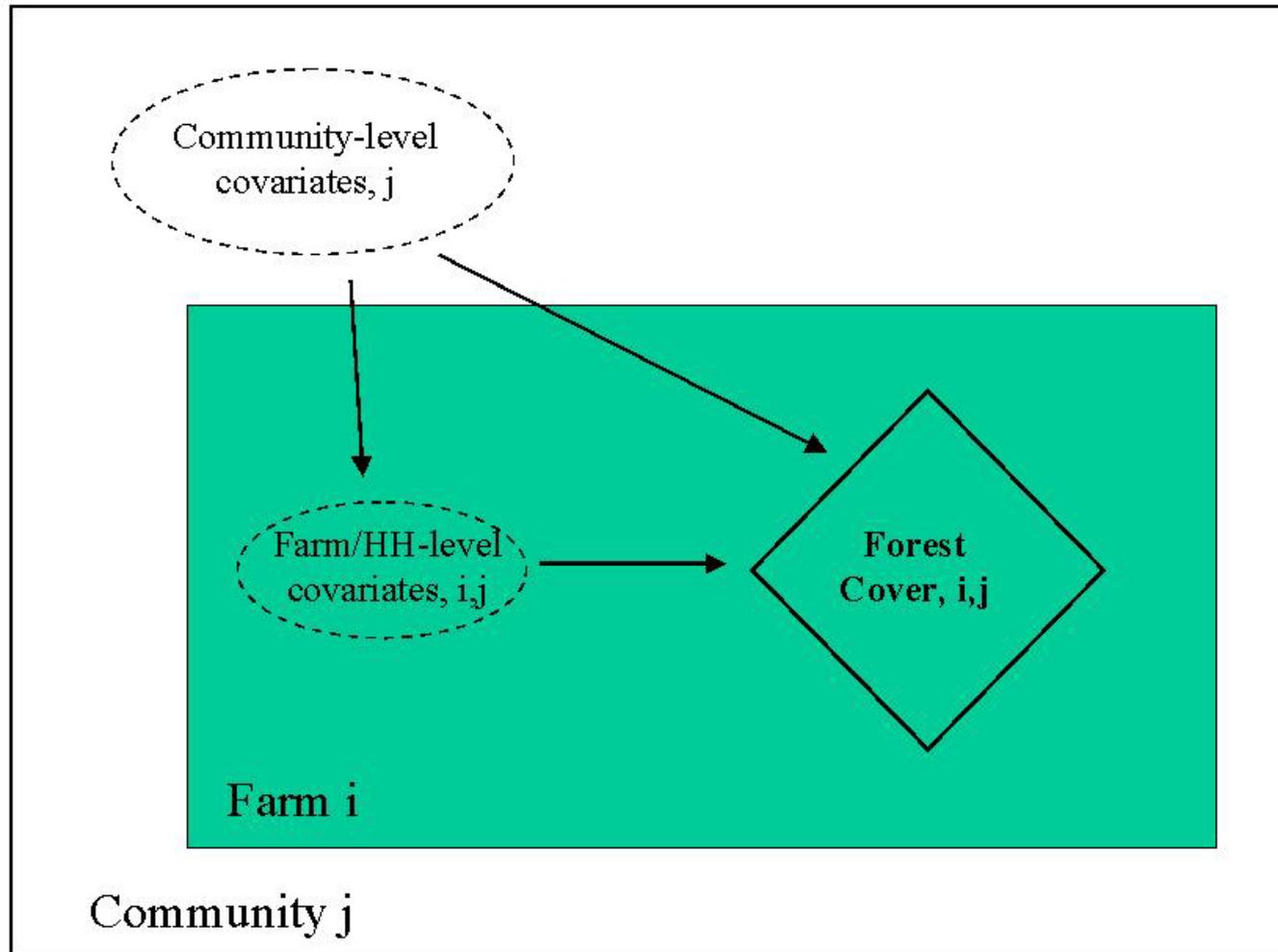
- **Continuing deforestation, linked to both causative factors indicated and fragmentation of plots**
- **Smaller size farm units has led to more perennial and annual crops, and less pasture and cattle-raising**
- **More tenure insecurity since most farm subdivisions not legalized**
- **Small increase in area in secondary forest**
- **No major changes in land use (yet), but less coffee**

Policy Implications

Distinguish Between the Effects on LCLU of the Current Population of Migrant Colonists and the (Underlying) Reasons They Migrated There in the First Place:

- **Demographic factors are important.**
- **Settler families are poor → priorities need to be focused on technical assistance, commercialization, and improvements in local community services.**
- **Road access is fundamental, requiring careful planning of roads, settlement areas, conservation sites**
- **Reduce out-migration from areas of origin in the Sierra by improving land distribution/land tenure, rural development, less urban bias**

Multilevel Model Conceptualization



Multilevel Model

- Purpose: Estimate effects of farm-level variables on LULC taking into account the contextual setting (community) for each farm
 - Farm-level variables: Demographic characteristics, Natural resources, Spatial location/distance variables, Land tenure, Labor, Duration of residence, Migration origins, etc.
 - Community-level: Transportation services/linkages; economic infrastructure such as sawmills, coffee roasters, etc.; presence of agricultural market; technical assistance programs; availability of schools, health facilities, etc., or distance to nearest if not
- Advantages: Incorporates broader theoretical framework; can use to develop longitudinal model to relate changes over time (1990-1999); can be adapted to incorporate spatial tendencies (spatial autocorrelation)
- References: Kreft and deLeeuw, 1998; Goldstein, 1995; Byrk and Raudenbush, 1992

Multilevel Model Equations (ex)

- Develop 2-level model (e.g., Y =Forest cover, X =Population, W =Community infrastructure)
 - Level-1 Equations:

$$Y_{ij} = \beta_{0j} + \beta_{1j}X_{ij} + e_{ij}$$

- Level-2 Equations:

$$\beta_{0j} = \gamma_{00} + \gamma_{01}W_j + u_{0j}$$

- Combined Equations:

$$\beta_{1j} = \gamma_{10} + u_{1j}$$

$$Y_{ij} = \gamma_{00} + \gamma_{10}X_{ij} + \gamma_{01}W_j + u_{1j}X_{ij} + u_{0j} + e_{ij}$$

Roadblocks to Multilevel Models

- Linking farms to communities difficult (farms in same sector sometimes link to different or multiple communities); develop linking criteria
- 1990 and 1999 data sets have so far been linked only at the *Finca-Madre* level; we are currently linking individual farm households on each *finca madre* over time, which will make possible linking each to its “reference” community
- The theory to incorporate spatial autocorrelation in multilevel models is not completely worked out and existing software needs to be modified.

Some Challenges

- Little work has been done that links specific households to satellite based measures of LULC on household plots--linking people to pixels
- Compare satellite-imagery-based estimates of LULC at the sector and *finca madre* level with those based on household survey responses and digitized sketch maps
- Distinguish the forces that drive LULCC decisions, including individual/farm household factors and contextual factors, to determine their separable roles, and thereby to assess the effects of policy and environmental processes at higher levels

Some Methodological Issues to Explore

Compare measures of LCLU from satellite imagery (Landsat and Ikonos)
digitized sketch maps, and household survey data

Explore ways to improve classification of land use, notably to distinguish coffee,
with further ground-truthing of Ikonos images

Compare image change detection analyses based on different approaches,
including change vector analysis, use of accessibility/isolation index, etc.

Explore new ways to better link satellite data and survey data in
studying LCLU

Future Research Directions

- Compare the analysis of change at different scales and using different methodologies (imagery-based and survey based) and interpret differences: (1) levels of farm, *finca madre*, sector, ISA, region; (2) patch, class, and landscape; (3) pixel and pixel aggregations
- Extend the multivariate (GLM) model of household LULC decisions to analyze changes over time (first differencing variables for 1990-1999 or using random effects models), providing stronger results
- Develop and estimate multilevel GLM model of household LULC decisions incorporating contextual (community) effects and providing more useful policy results
- Extend cellular automata simulation models to the other ISA areas if not to the whole region and explicitly include parameters (transition probabilities) estimated from survey-based models above