



Pattern-Process Relations in Coupled Human-Natural Systems: Modeling LULC Dynamics in the Ecuadorian Amazon

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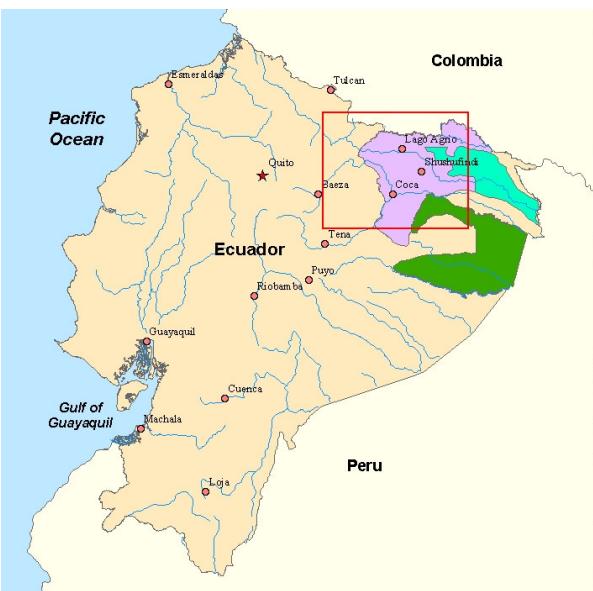
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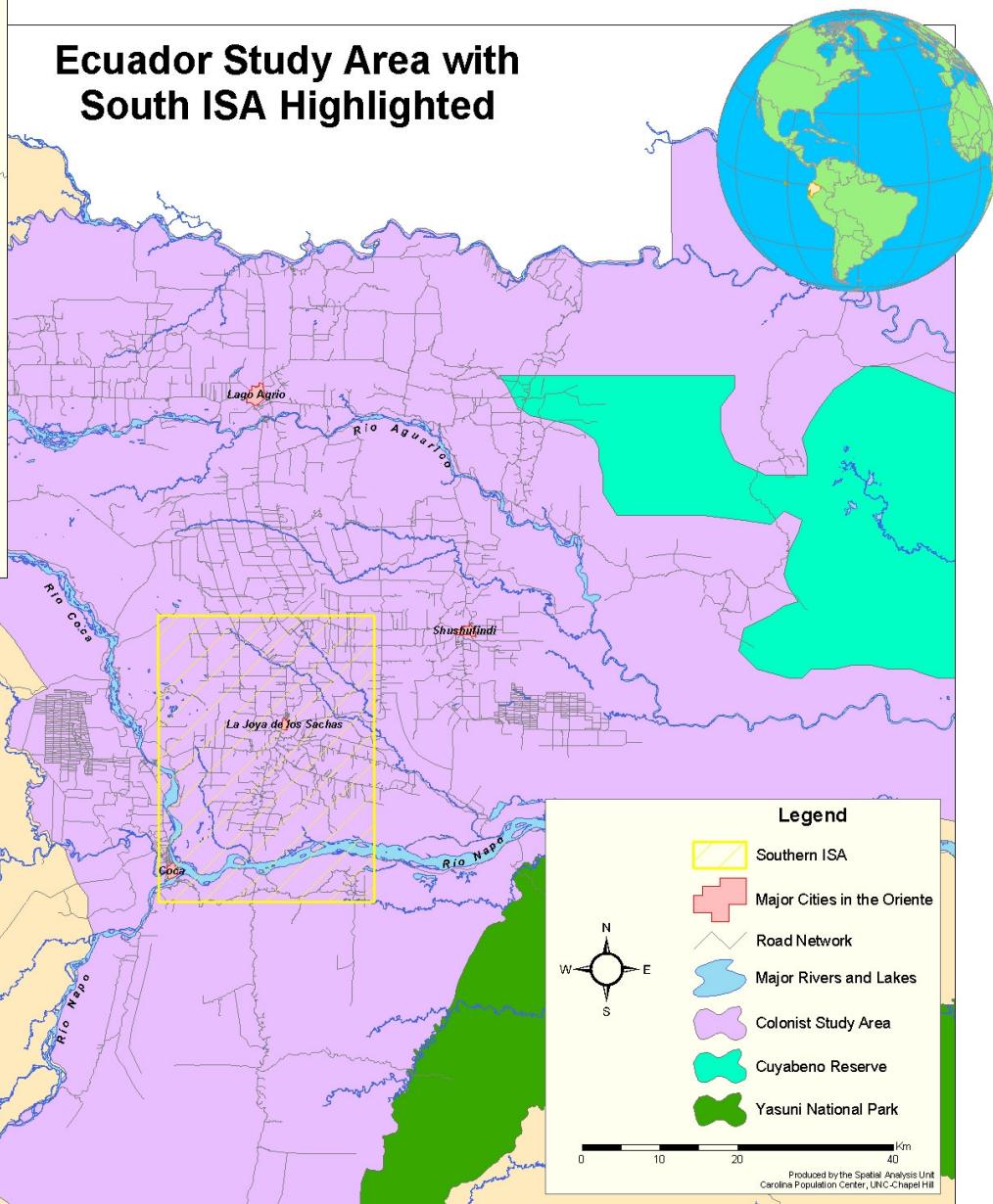
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<http://www.cpc.unc.edu/projects/ecuador>



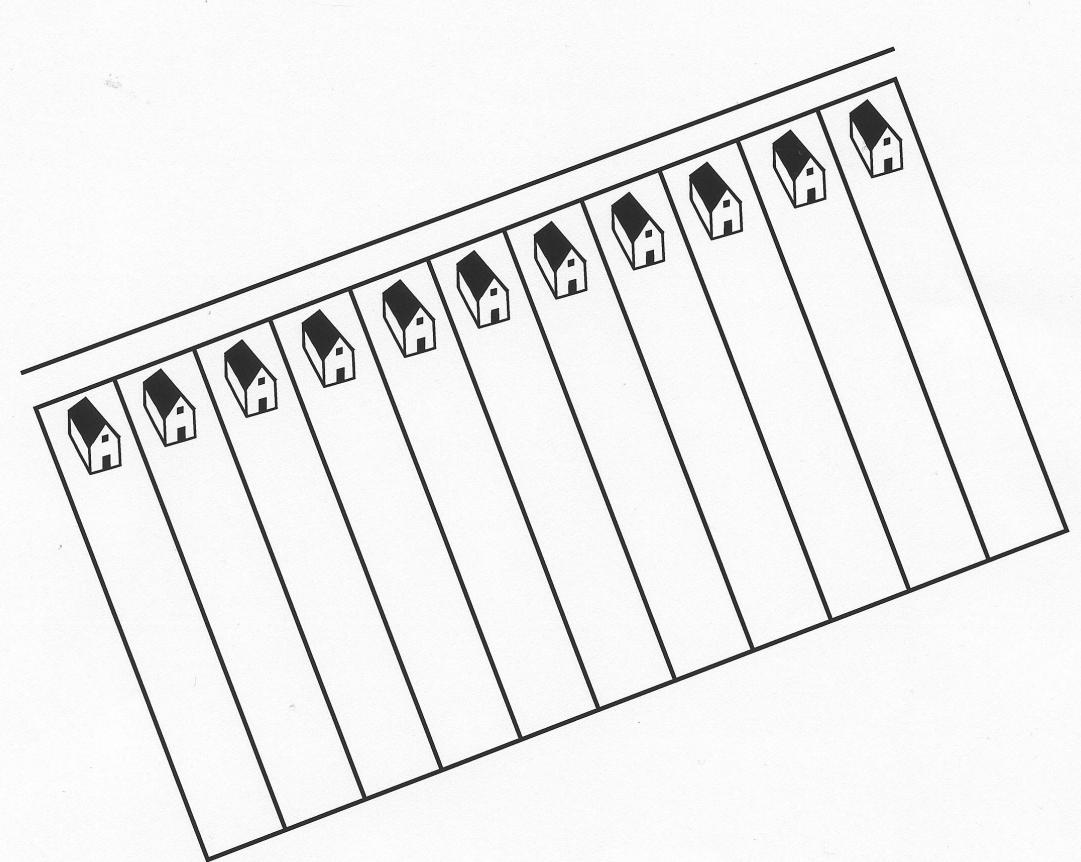
Ecuador Study Area with South ISA Highlighted



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 and derive policy implications.
- ★ **Some Approaches:** Generalized Linear Mixed Models, Spatial Regression Models, Multi-Level Models, Neutral Models, and Spatial Simulations using Cellular Automata & Agent Based Models.

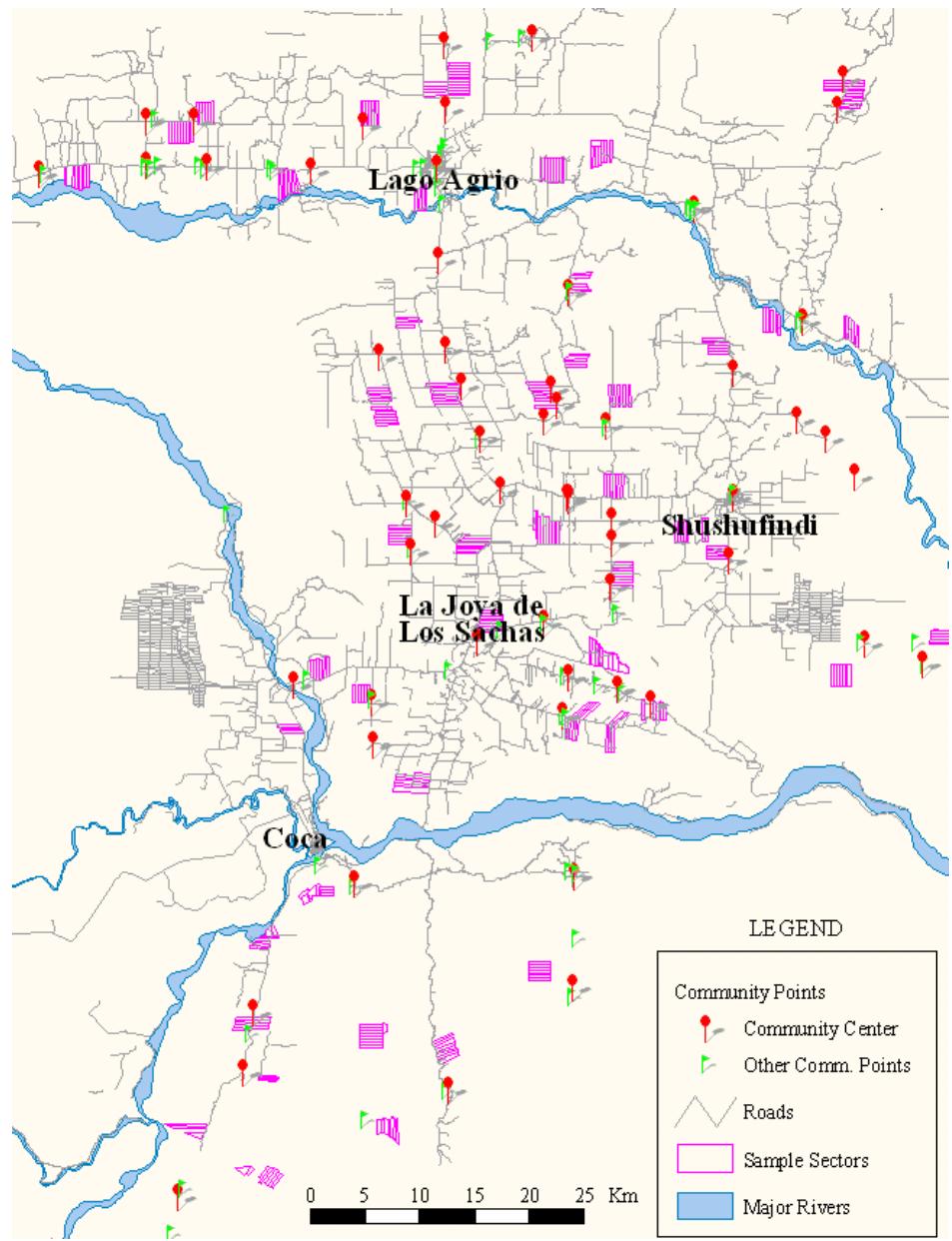
Settlement Patterns Affecting Analysis Design



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

Sample Households & Survey Sectors

1990 & 1999



GIS Data Inventory

★ Political & Cultural

- Provinces
- Parroquias
- Cantons
- Major Cities in the Oriente
- Cuyabeno Wildlife Reserve
- Yasuní National Park
- Sector boundaries (Sucumbios, Orellana, Napo)

★ Social Surveys: Fincas (1990 & 1999), Communities (2000), Indigenous Groups (2001)

★ Road Network

★ Physical Environment

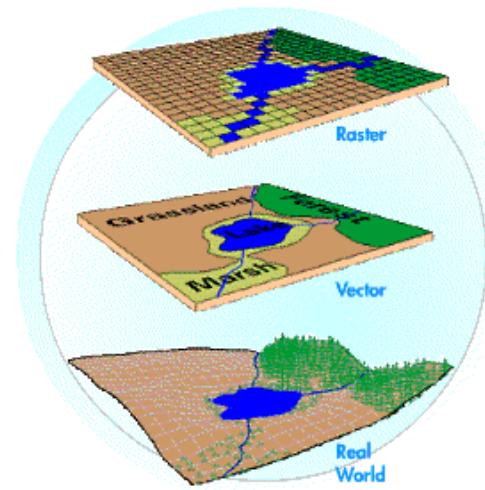
- Rivers & Lakes
- Morphology & Edaphology

★ 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)
- Hyperion Hyper-spectral (2005)
- Radarsat (2005)
- Digital aircraft Hyper-spatial (2005)





Models of Land Use/Cover Change: Recent Research

★ (1) Land fragmentation

Generalized Linear Mixed Model

★ (2) Spatial simulations - LULC Change

Cellular Automata

★ (3) Household adaptations & LULCC

Agent Based Models



(1) Land Fragmentation

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**

Generalized Linear Mixed Model

-- Contagion --

1990 Model

-  Intercept^a (55.35)
-  Median slope^c
-  Flat (% of fincas)^b
-  Ave. age of head^a
-  # adult females^c
-  Yrs plot established^a
-  Population density^b
-  #subdivisions^c
-  # sub within 3-km^a
-  Per-mon of OFE^a
-  Euclidean distance to Ref. Com^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. com^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 composition of households, plot fragmentation through subdivisions, expansion of the road and electrical networks, age of the plot (1990 only), and topography.**

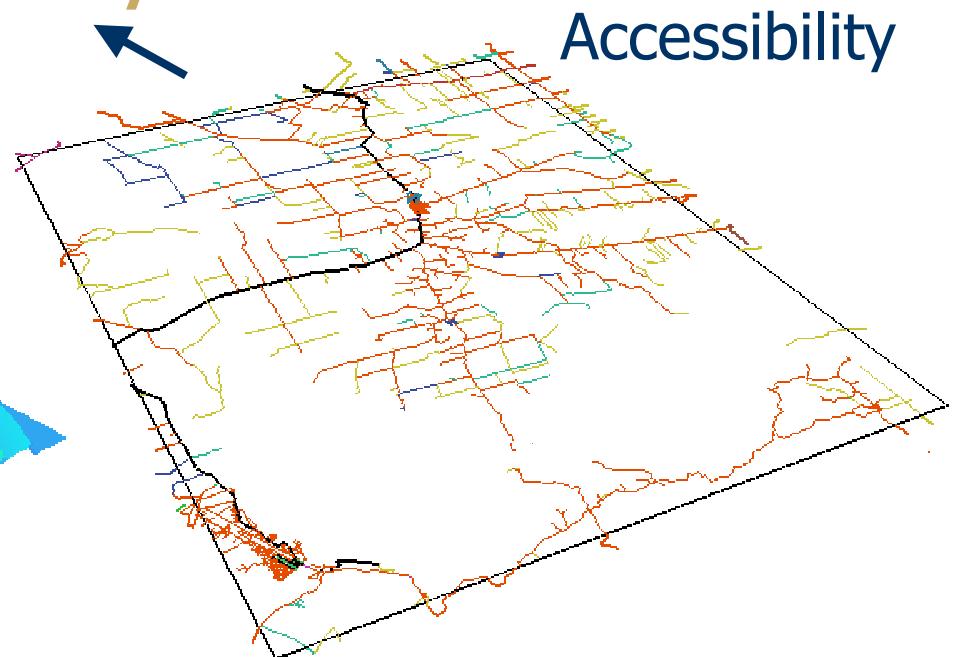
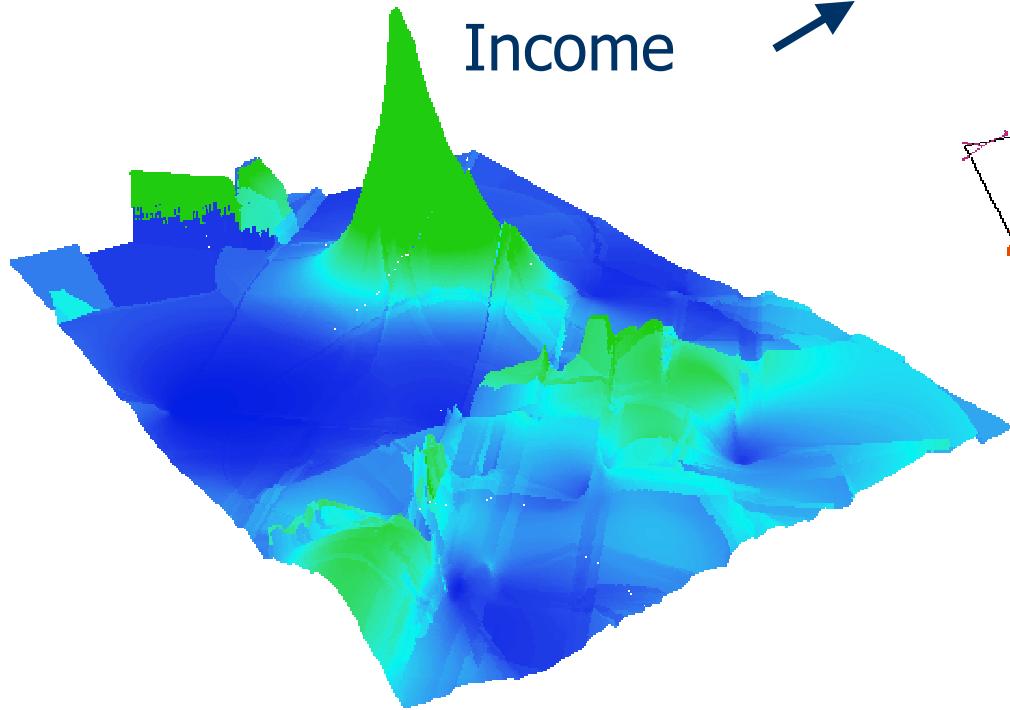
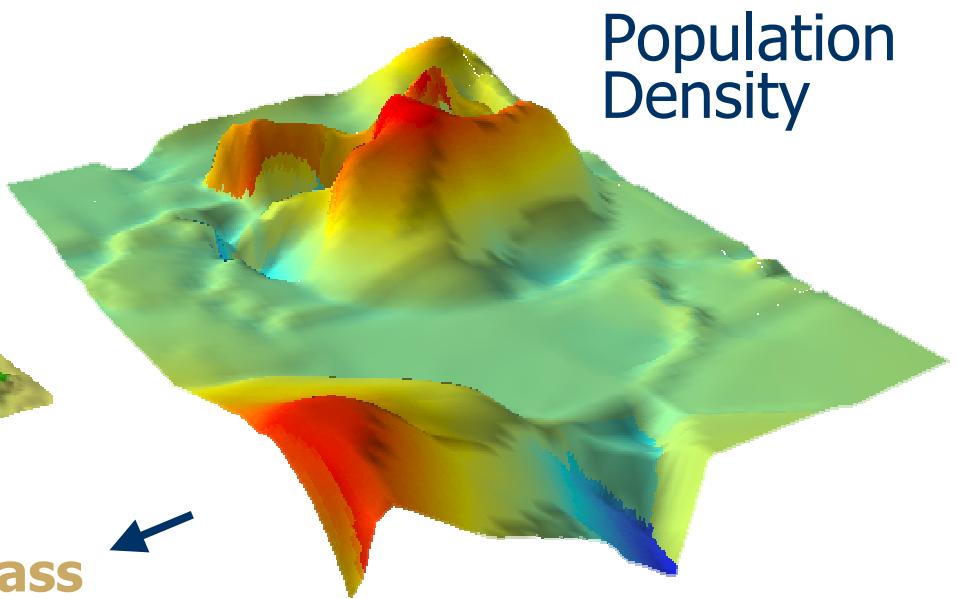
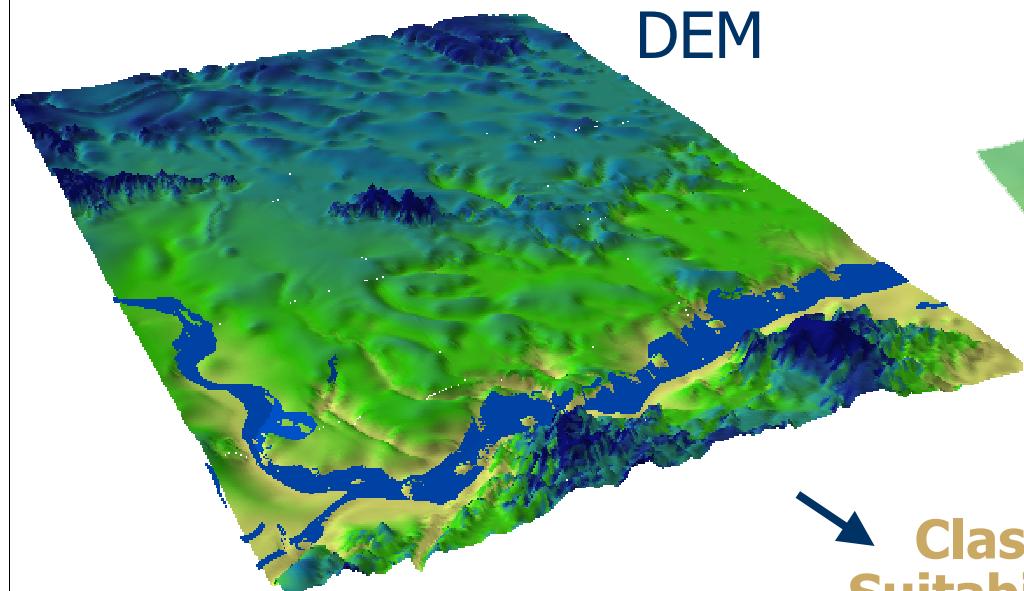


(2) Spatial Simulation of LULC Change & Cellular Automata

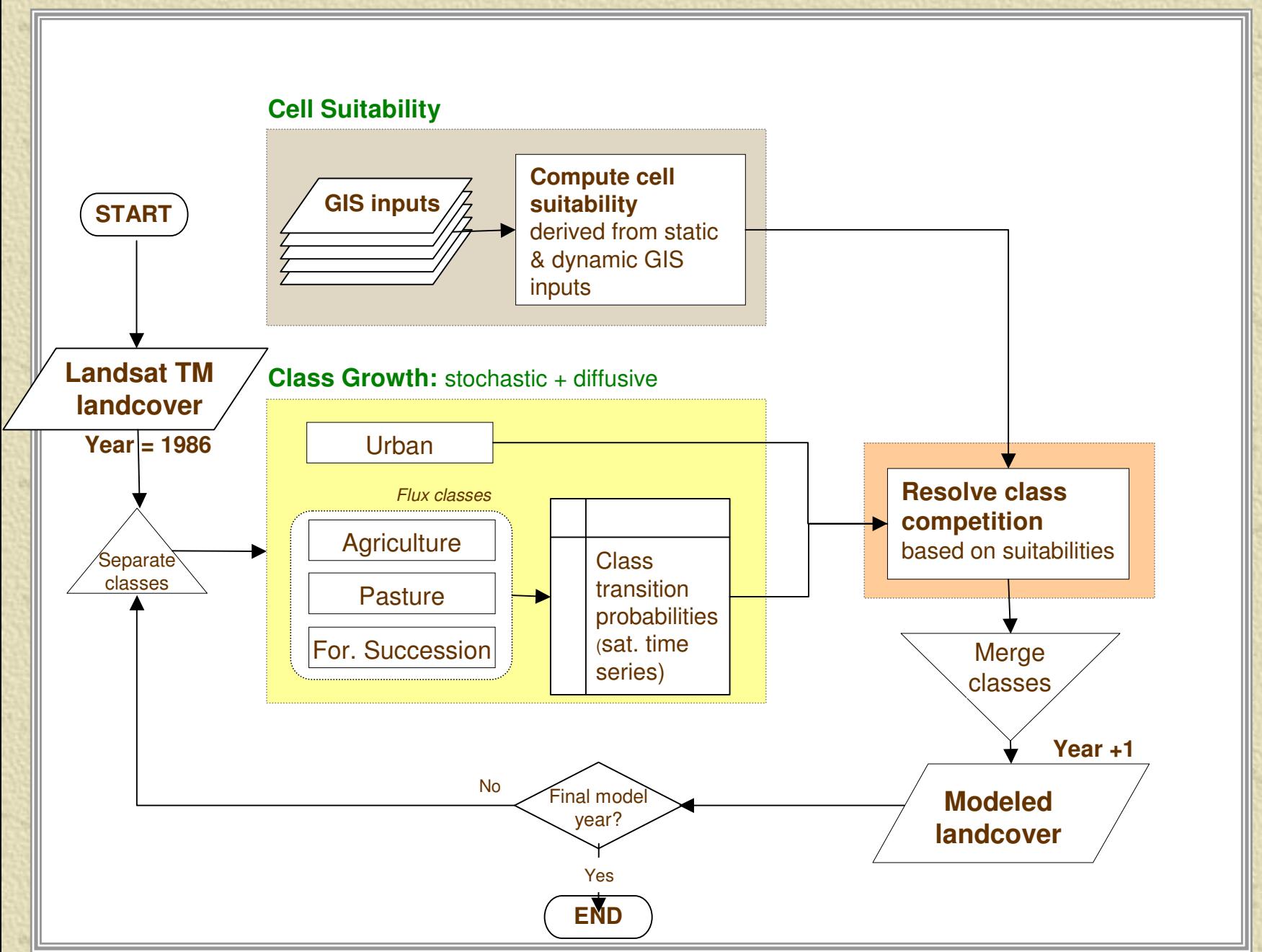
- ★ **Goal:** Generate LULC simulations based upon actual conditions observed through the satellite time-series and extended in time & space through derived growth rules and neighborhood interactions.
- ★ **Approach:** Regular grid of cells, each of which can be in one of a finite number of K possible states, updated synchronously in discrete time steps according to a local, identical interaction rule. The state is determined by the previous states of a surrounding neighborhood of cells, and the rule is specified in the form of a transition function.

Forest to Non-Forest Vegetation

- ★ Travel distance to nearest of 3 major communities; lower, greater change probability; computed as Euclidean distance to the nearest road and then simple distance along network to the community.
- ★ Euclidean distance to nearest road; lower, greater change probability.
- ★ Sector population; higher, greater change probability.
- ★ Slope angle; lower, greater change probability
- ★ Soil moisture index; lower, greater change probability.
- ★ Parameters: stochastic (0.06), kernel threshold (4 cells), masking threshold (0.4).

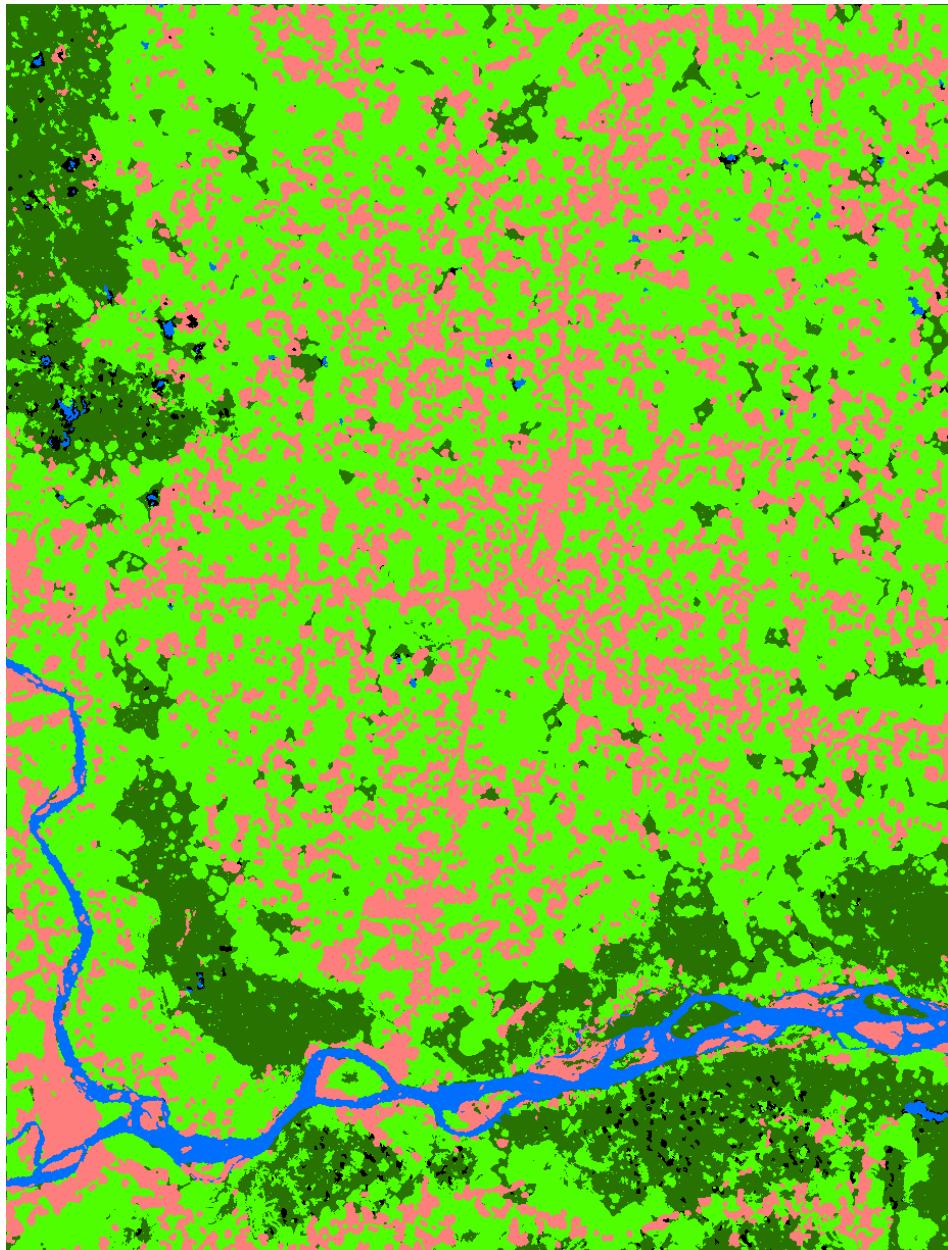


Class
Suitability



South ISA: Simulation

2010



(3) Household Adaptations & Agent Based Models

- * Autonomous decision-making entities (agents), an environment through which agents interact, rules that define the relationship between agents and their environment, and rules defining 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 individual agents as they learn through experiences and change and develop feedbacks with finer scale building blocks as agents.**

Multi-Phasic Response Theory

LULC change is the spatial explicit response of the set of household adaptations to the changing socioeconomic conditions and environmental factors.

The strategies that the household take to improve life conditions are:

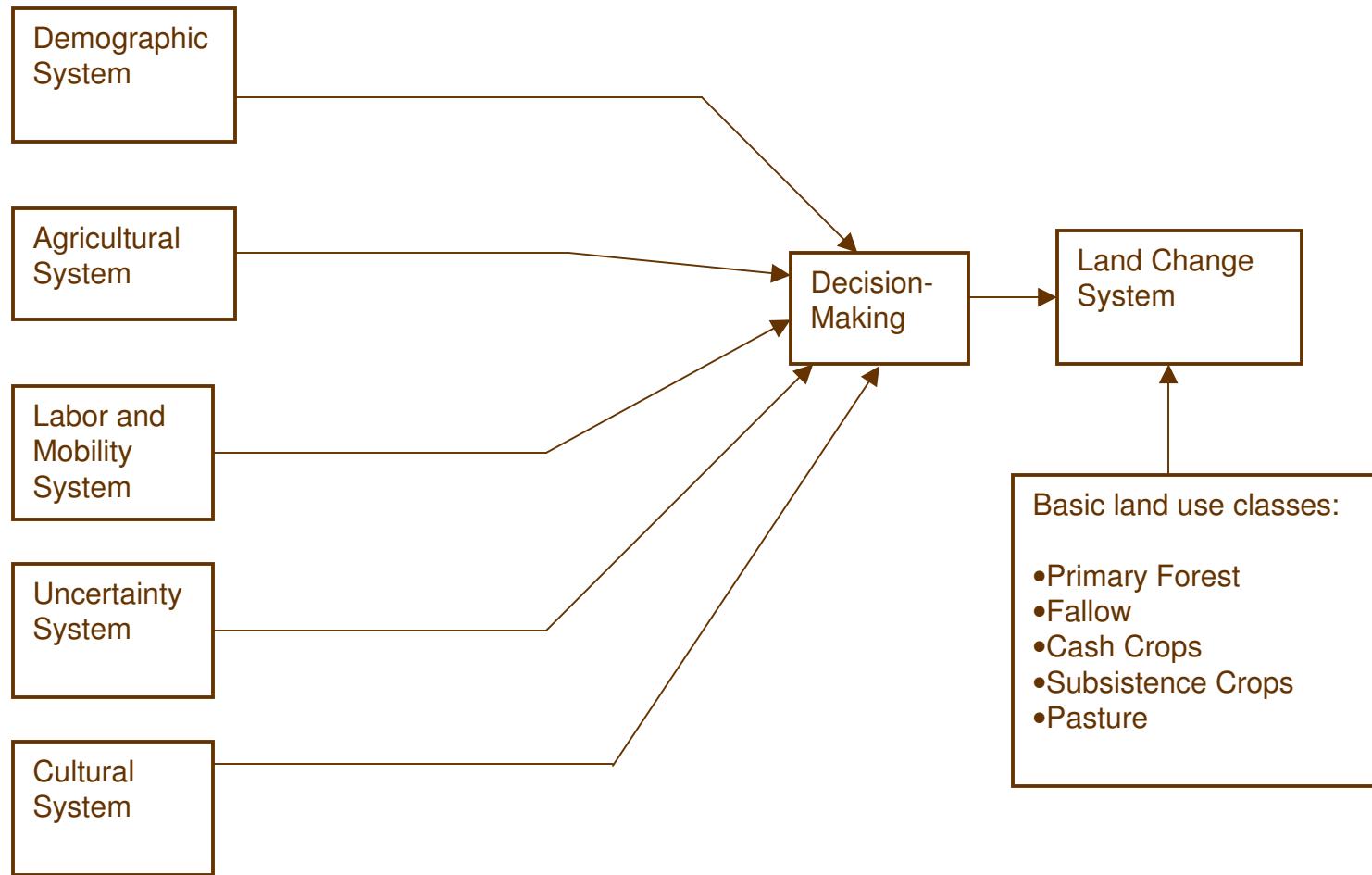
- Intensifying land use
- Extensifying land use
- Temporary migration
- Permanent migration to areas with available land
- Fertility decline

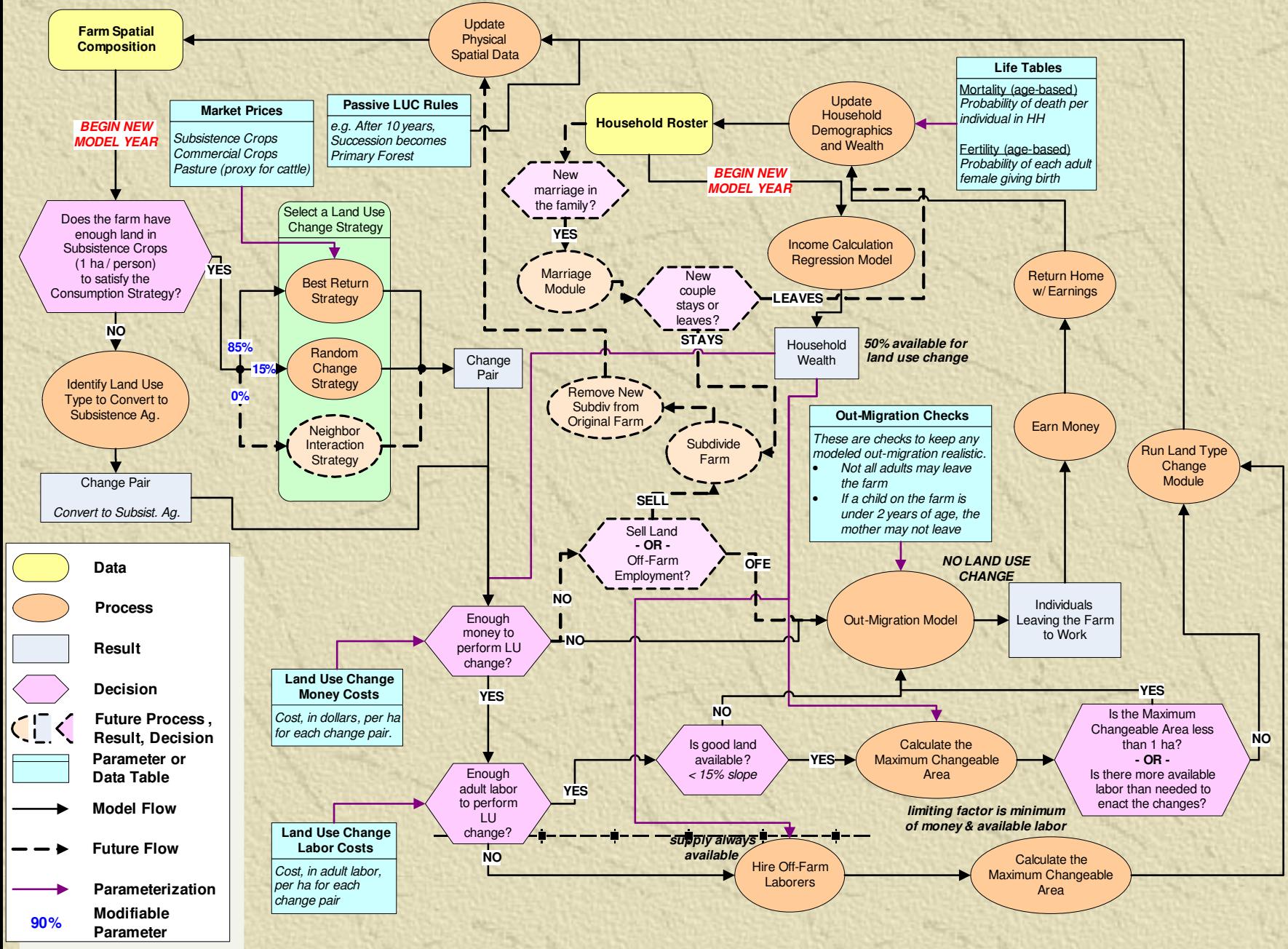


Household Life Cycle

- 1) Young parents who recently arrived in the area initiate forest clearings for subsistence crops.
- 2) Parents with growing children become engaged in the cultivation of cash crops and pasture.
- 3) Older parents with teenage children are related to a decrease in the cultivation of annuals and an increase in cattle raising and secondary vegetation.
- 4) Pasture and perennial crops dominate with increasing proportions of secondary forest as parents age and children reach young adulthood.
- 5) Children begin to leave the household or subdivide the farm.

Basic Components of the System





Repast Screen Capture: Year 2

Java - Agricult Repast

Farm window

Options

CellArea: 625.0
CellSize: 25.0
Class: Class
DistToHome: 475.6574
DistToRoad: 525.0
Edge: 0
EdgeCell: false
LulcType: Pasture
LulcVal: 3
ParcelID: 19
PropertyID: 1304800
SoilQuality: 0.0
SuitabilityScore: 172.0
Types: Is Write-only
UniqID: 1304800_19
X: 21
XY: 25
Y: Is Write-only

Farm Model Setti... Custom Actions Repast Actions Parameters del Parameters ms: 0 centageBestPolicy: 0.85 centageNeighborPolicy: 0.0 centageRandomPolicy: 0.15 tionOfmoneyForChange: 0.5 esOfConsumptionPerPerson: 1.0 Inspect Model Past Parameters Depth: 5

Use best return strategy
change Commercial agriculture to: Pasture
Labors on farm: 7.0
The farm hired labors: 0
Nothing change. Can not find a Commercial
no
population:7; assets:17.0; education of he

Age Distribution

Total Persons In Farms Assets In Farms Percentage of forest in farms

Total Persons In Farms

Assets In Farms

Percentage of forest in farms

The screenshot shows a Java application window titled "Java - Agricult Repast". The main area contains a "Farm window" displaying a 2D grid of colored cells representing land parcels. A status bar at the bottom indicates "Tick Count: 2.0" and "Run: 1". To the right of the grid is a "Farm Model Settings" panel with tabs for "Custom Actions" and "Repast Actions". The "Parameters" tab is selected, showing various simulation parameters like CellArea, CellSize, and EdgeCell. Below this is a "Past Parameters" section with a "Depth" dropdown set to 5. A message log at the bottom left lists actions taken in the simulation. At the bottom of the window are three line graphs: "Total Persons In Farms", "Assets In Farms", and "Percentage of forest in farms", all plotted against "Year" from 1.0 to 2.0. The "Total Persons In Farms" graph shows a slight decrease from approximately 38 to 35. The "Assets In Farms" graph shows an increase from approximately 10 to 15. The "Percentage of forest in farms" graph shows a decrease from approximately 85 to 75.

Repast Screen Capture: Year 8

Java - Agriculture Repast

Farm window

Options

Farm Model Settings

Parameters Custom Actions Repast Actions

Model Parameters

- Farms: 0
- PercentageBestPolicy: 0.85
- PercentageNeighborPolicy: 0.0
- PercentageRandomPolicy: 0.15
- PortionOfmoneyForChange: 0.5
- RatesOfConsumptionPerPerson: 1.0

Inspect Model

RePast Parameters

- CellDepth: 5
- CellHeight: 10
- CellWidth: 10

RePast Output

```
change Subsistence Agriculture to: Pasture
Labors on farm: 4.0
The farm hired labors: 3
1305000_18
change size(in hectare):8.75
population:9; assets:25.0; education of he
```

Age Distribution

Total Persons In Farms

Assets In Farms

Percentage of forest in farms

Population Cor

Double Mark sel>,

Figure 1: Repast screen capture showing the simulation environment for Year 8. The main window displays a 2D grid of colored cells representing different land uses or farm types. A legend on the left identifies colors for various categories. To the right is the 'Farm Model Settings' panel, which includes parameters for farms, cell dimensions, and Repast-specific settings. Below the main window are three line graphs: 'Total Persons In Farms', 'Assets In Farms', and 'Percentage of forest in farms', all plotted against time from Year 2 to Year 12. The 'Total Persons In Farms' graph shows a steady increase from about 10 to 40. The 'Assets In Farms' graph shows a similar trend, starting at 10 and reaching nearly 80. The 'Percentage of forest in farms' graph shows a sharp initial drop from 90% to around 50%, followed by a gradual recovery.

Repast Screen Capture: Year 28

Repast

Farm window

Options

<img alt="A 2D grid simulation showing agricultural land (green) and forest (yellow) patches. Some patches are labeled with numbers like 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 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Selected 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.
- ★ Changes in land tenancy and the implementation of protective buffers around and within protected areas can increase deforestation and land fragmentation.
- ★ Forest succession and fallow are related to OFE, household assets, male adults, & legal title.
- ★ Spatial structure of LULCC are related to household demographics, labor, change in pop density, year of farm establishment, & farm size.