Land-Cover Land-Use Change
in the
Southern Yucatán Peninsular Region

LCLUC - SYPR

HARVARD

ECOSUR

Major Participants

- George Perkins Marsh Institute & Graduate School of Geography - Clark University
- Harvard Forest - Harvard University
- El Colegio de la Fronter Sur (ECOSUR)

[with cooperation of CIS-CMU]

For a list of individual researchers and their contributions to the project see the SYPR web page (earth.clarku.edu/lcluc)

Funding Sources

Overall Project

- NASA - LCLUC Program
- Higgins Professorship, Clark University
- ECOSUR

Ecological Research

- Harvard Forest
- Conservation Research Foundation
- National Science Foundation

Modeling Research

- Center for Integrated Studies, Carnegie Mellon University
- NASA Young Investigator Fellowship

Specific Dissertation Research

- Fulbright Fellowship (Garcia Robles)

Problem Overview

LCLUC-SYPR seeks

- to understand land changes in the region by bridging understanding gained from historical-empirical narratives, behavioral, structural, and ecological theory, and remote sensing and GIS analysis and
- to develop theory-based and empirical diagnostic models capable of explaining and projecting use and cover changes, and
- to advance models for integrative assessment relevant for policy analysis.

Specific Goals and Components of LCLUC-SYPR

Understand the dynamics of land-use/cover changes in SYPR, especially deforestation and agriculture since the 1960s

- History of land-use and land-cover changes
- Recent political economy
- Socio-economic inventory & econometric analysis
- Structure & function of forest types
- Successional dynamics from land-use
- Advanced classification from TM imagery
- Link socio-economic & ecological understanding to TM imagery

Specific Goals of LCLUC-SYPR

Develop and test the applicability of three types of spatially explicit models that explain and project land-use/cover changes, especially forests and agriculture

- Theory-based models built from the household survey to the remotely sensed imagery (pixelizing the social = Focus 1 research)
- Empirical diagnostic models built from the remotely sensed imagery but incorporating biophysical and social information (socializing the pixel = Focus 2 research)
- Integrative assessment models used to project land-use/cover changes under different scenarios (Focus 4 research)

Status of Components of the LCLUC-SYPR
[summer 1999]

- History & political economy: data collection [85%], interpretation begun
- Socio-economic inventory & econometric analysis: inventory [95%], data transformation [75%], analysis begins Summer 1999
- Structure-function forest: first yr. field study completed
- Successional dynamics from land uses: field study has begun
- Image classification & GIS data: class. [90%], GIS [50%]
- Theory-based modelling [econometric]: begin Fall 1999
- Empirical-based modelling [remote sensing]: begin Fall 1999
- Integrative modelling [projection-policy]: framework completed, construction begins Fall 1999

Focus 1: Historical Narrative and Household Surveys

leading to econometric analysis and theory-based models

The following slides illustrate [1] the kind of evidence being used to construct the history of land change in SYPR and the drivers and responses to this change. This information is used to inform the survey data and resulting analyses. The slides then illustrate [2] the kinds of questions explored in order to frame an econometric model of contemporary land change, and some of the initial results from the survey. Surveys of 210 households were undertaken in 10 ejidos throughout the SYPR.

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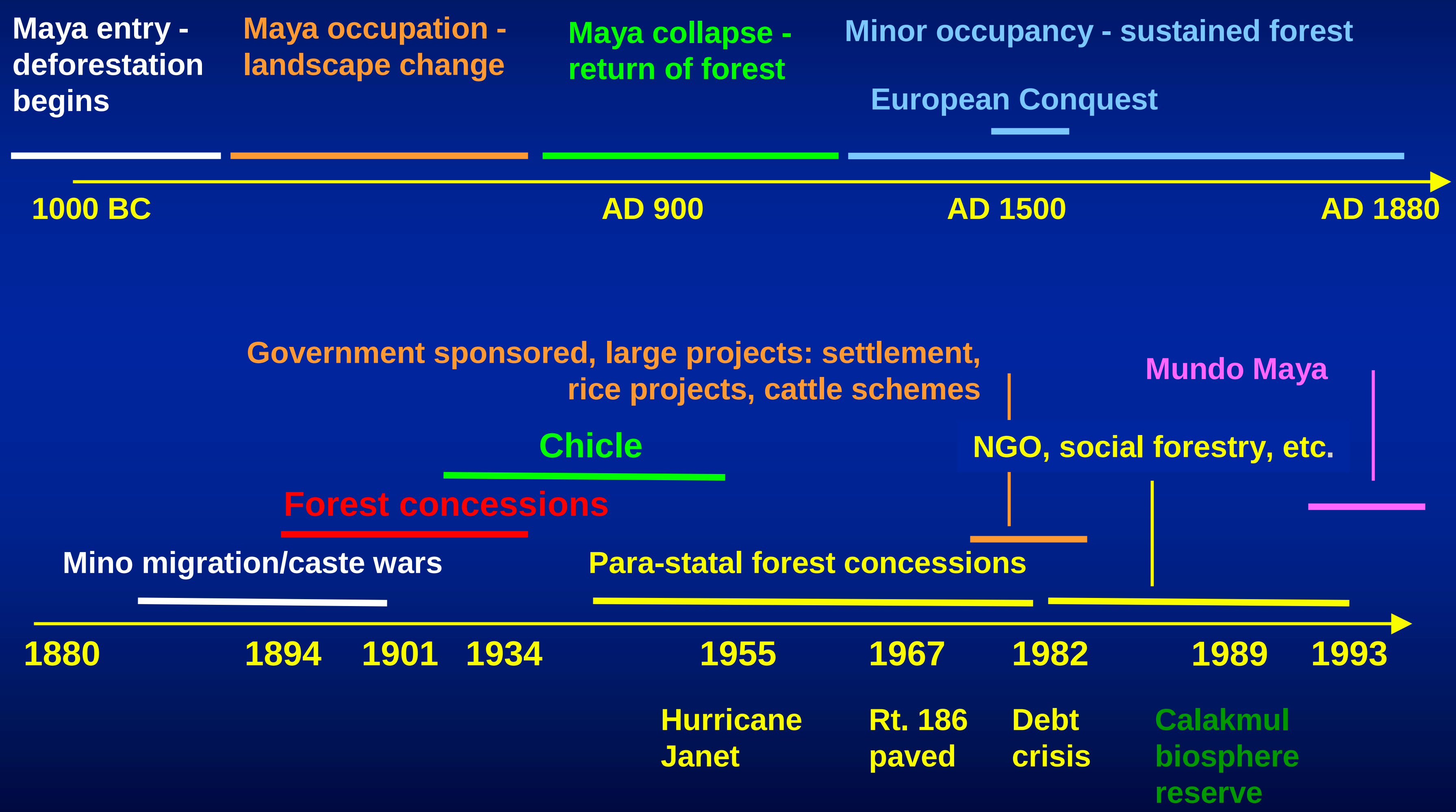
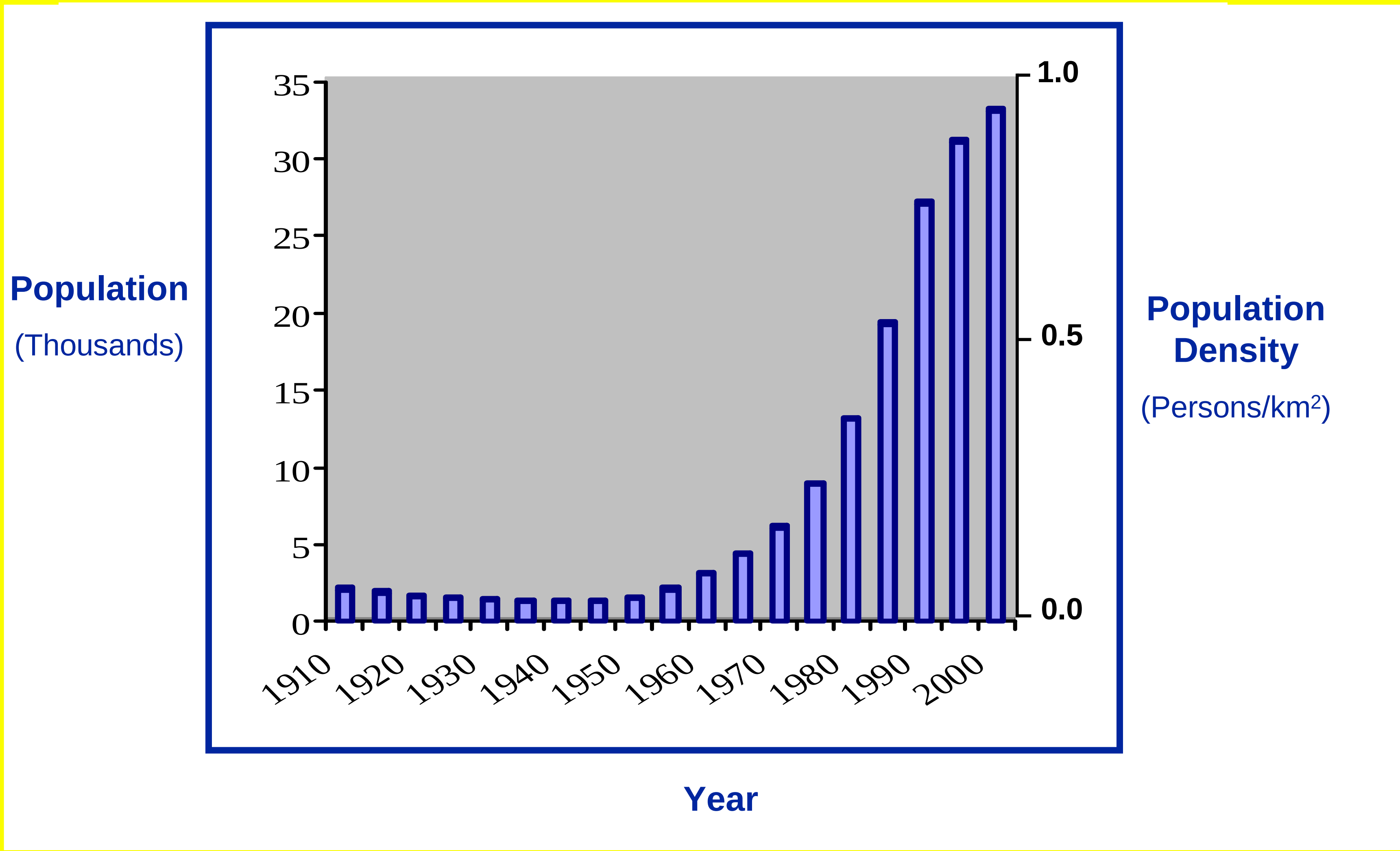
Human Impacts in SYPR*

(1000 BC - Present)



Initial findings suggest that large structural and policy changes link strongly to major shifts in rates of deforestation

Example Historical Data
SYPR Population (1910 - 2000)*



Ancient Maya population densities in SYPR previous of A.D. 900 was well over 100/km^2.
From that time until recently, the density was extremely low.

Example Historical Data
SYPR in Transition*

1915

Laguna Corporation controls 760,460 ha in Campeche 1915-1935

Forest clearing for agriculture

Ejido	Year	Hectares	Use
Nicolas	1976-1979	2500 cleared	Rice
Bravo	1980	2500	Rice
	1997	1500	Cattle
	1997	700	Rice
Tomas	1973-1980	2000 cleared	Cattle
Garrido	1997	1600	Re-growth
	1997	400	Milpa

Logging in Quintana Roo

Ejido	Year	Caoba (M^3)
Nicolas	1948	1200
Bravo	1967	400
	1991	300
	1992	300
	1993	300
	1994	400
	1995	400
	1996	400
	1997	400
Caobas	1958	830
	1962	812
	1963	829
	1964	830
	1967	830

Eco-archeological tourism in the Calakmul zone

Year	Visitors
1993	3500
1994	4810
1995	11045

2000

Spatially Explicit Land Models: Econometric Approach

Previous spatially-explicit econometric models

- **Aggregate socioeconomic data**
- **Profit maximizing behavior**

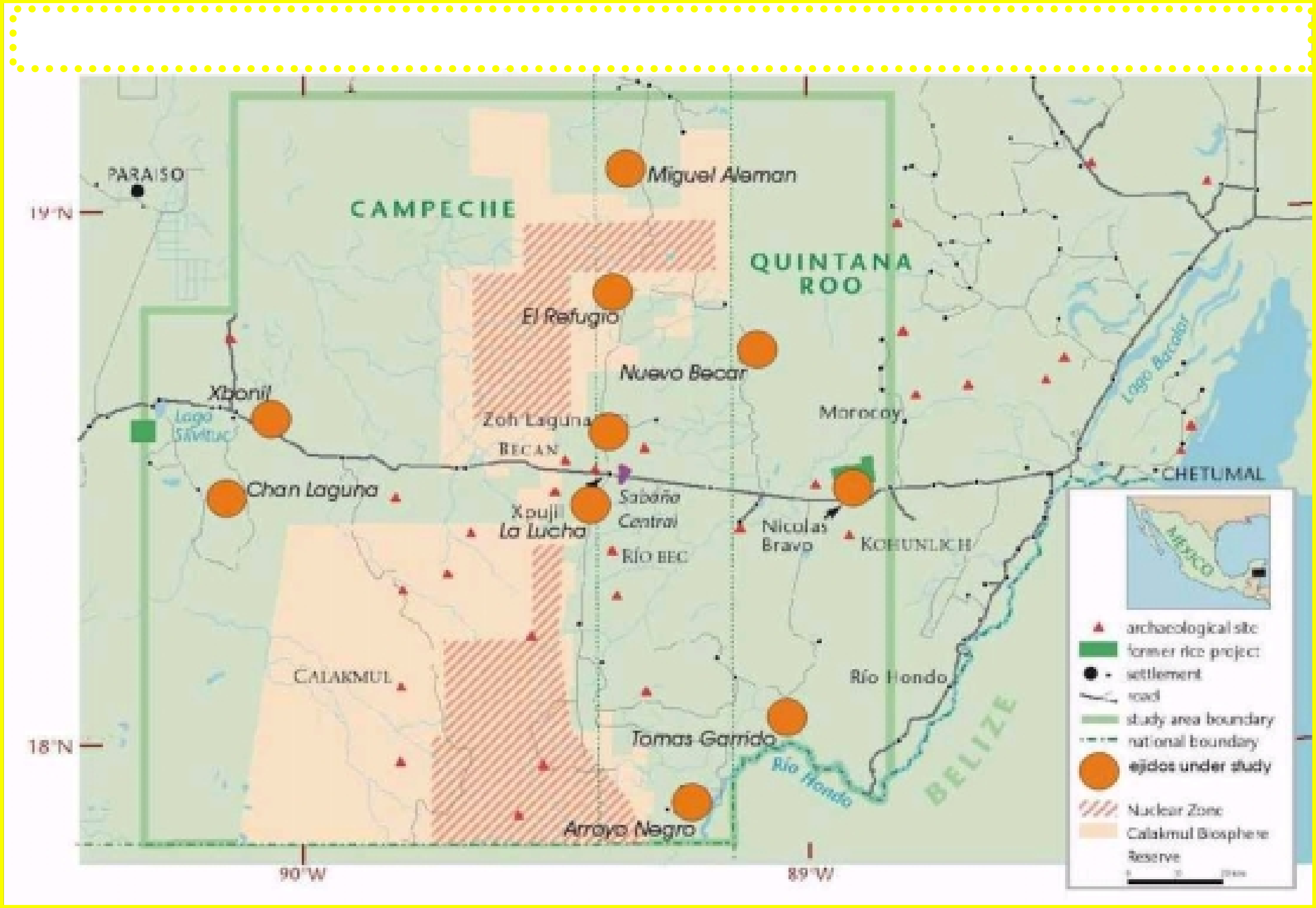
LCLUC-SYPR Project

- **Individual land manager linked to the pixel**
- **Test hypotheses concerning behavior linked to structural and infrasrtuctural changes**

Specific hypotheses will be selected once initial associations are identified but will include the role of transportation, land tenure, and subsistence-market changes.

SYPR Study Site and Ejidos Surveyed

[N households = 210]



LCLUC-SYPR: Example Question Guiding Theory Construction and Household Surveys

To what extent is the expansion of agriculture (i.e., forest to open land) propelled by:

[1] On-site demands for subsistence crops

or

[2] External markets for commercial crops?

Predominant Land Uses in SYPR: Tentative Survey Results*

Land Use	% sample	Mean plot size (ha)	S.D. plot size (ha)	Median plot size (ha)
Maize	100	4.65	4.34	4
Chili	52	1.34	1.36	1
Pasture [used]	28	25.9	28.9	15
Pasture [unused]	23	12.9	20.8	5.75

Indicators of Economic Links to Subsistence & Market Production*

Selling maize	41
Purchasing maize	27
Self sufficient in maize	31

% of households

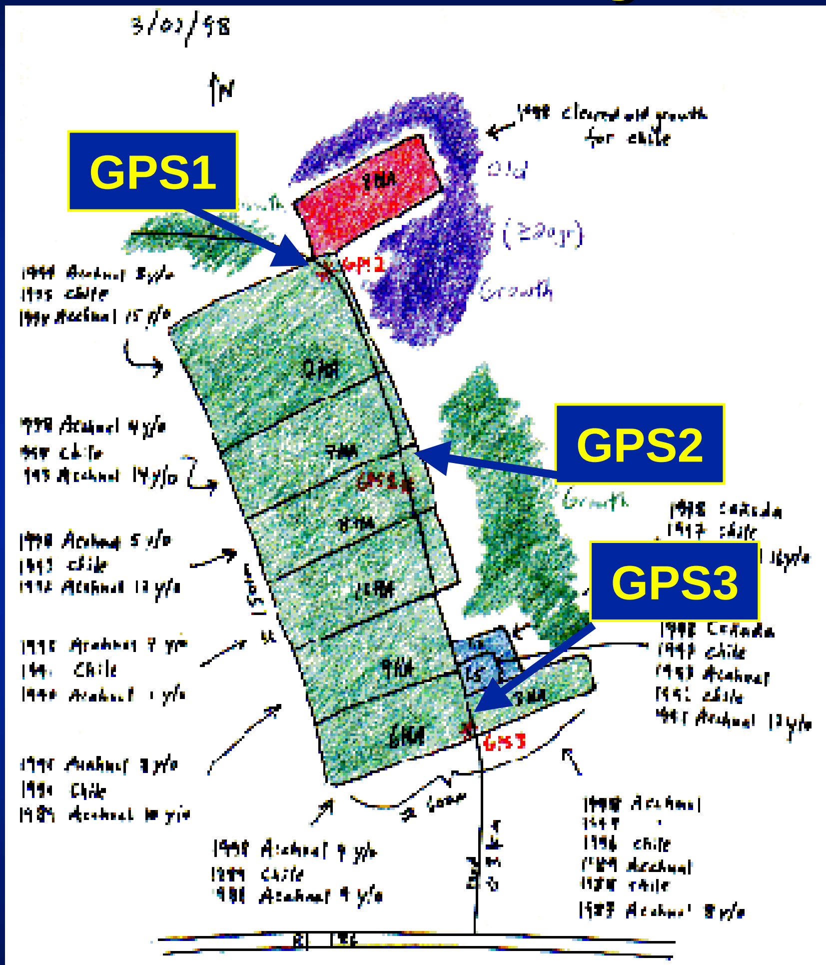
	Sell chili	No sell chili
Sell maize	27	15
No sell maize	24	34

	Sell labor	No sell labor
Hire labor	57	14
No hire labor	23	6

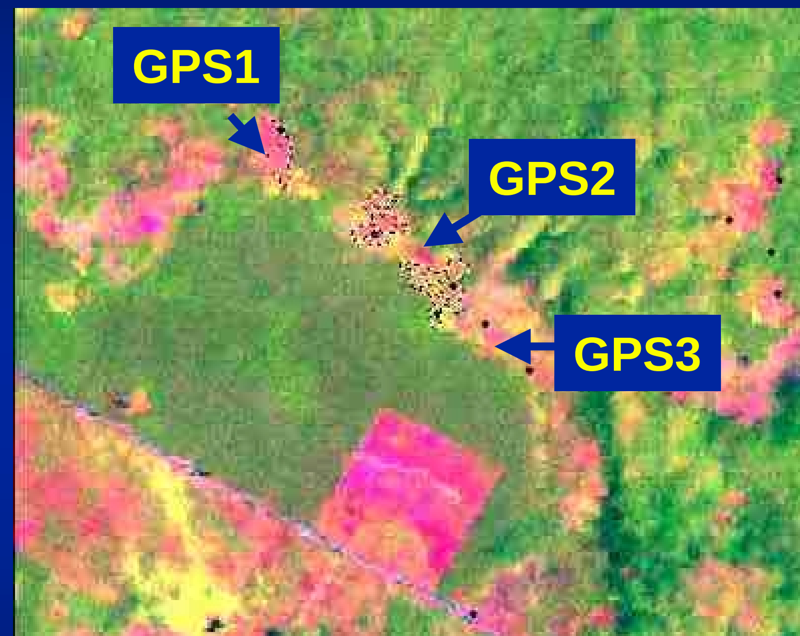
Initial Results via Regressions: Maize Production*

Ha-maize	Coef.	Std. Err.	t	p>|t|
All households [n = 180]				
Consumer-labor ratio	.340	.087	3.89	0.00
Total labor	.978	.230	4.24	0.00
Households not selling maize [n = 100]				
Consumer-labor ratio	.471	.096	4.90	0.00
Total labor	.949	.283	3.25	0.00

Signature Development & Sketch-Maps of Surveyed Household Fields*



Land Use History (>20 yrs) via sketch-map



Parcels linked to imagery by GPS

Sketch maps and GPS link the actions of the land managers with land-use/cover change. The maps not only aid in classification, they facilitate spatially explicit analysis of change and ultimately permit regional assessment.

Focus 2: Imagery-Based Approaches

leading to empirical diagnostic models

The following slides illustrate the approaches used to address land change from the use of TM imagery analysis, including the development of spatially explicit analysis of this change. [1] The first set of slides demonstrate the ability to push imagery classification to a level detailed required for the kind of analysis in question. [2] The second set demonstrates how the project intend to pursue model development from time series analyses of the changes detailed in the imagery and informed by GIS-based information.

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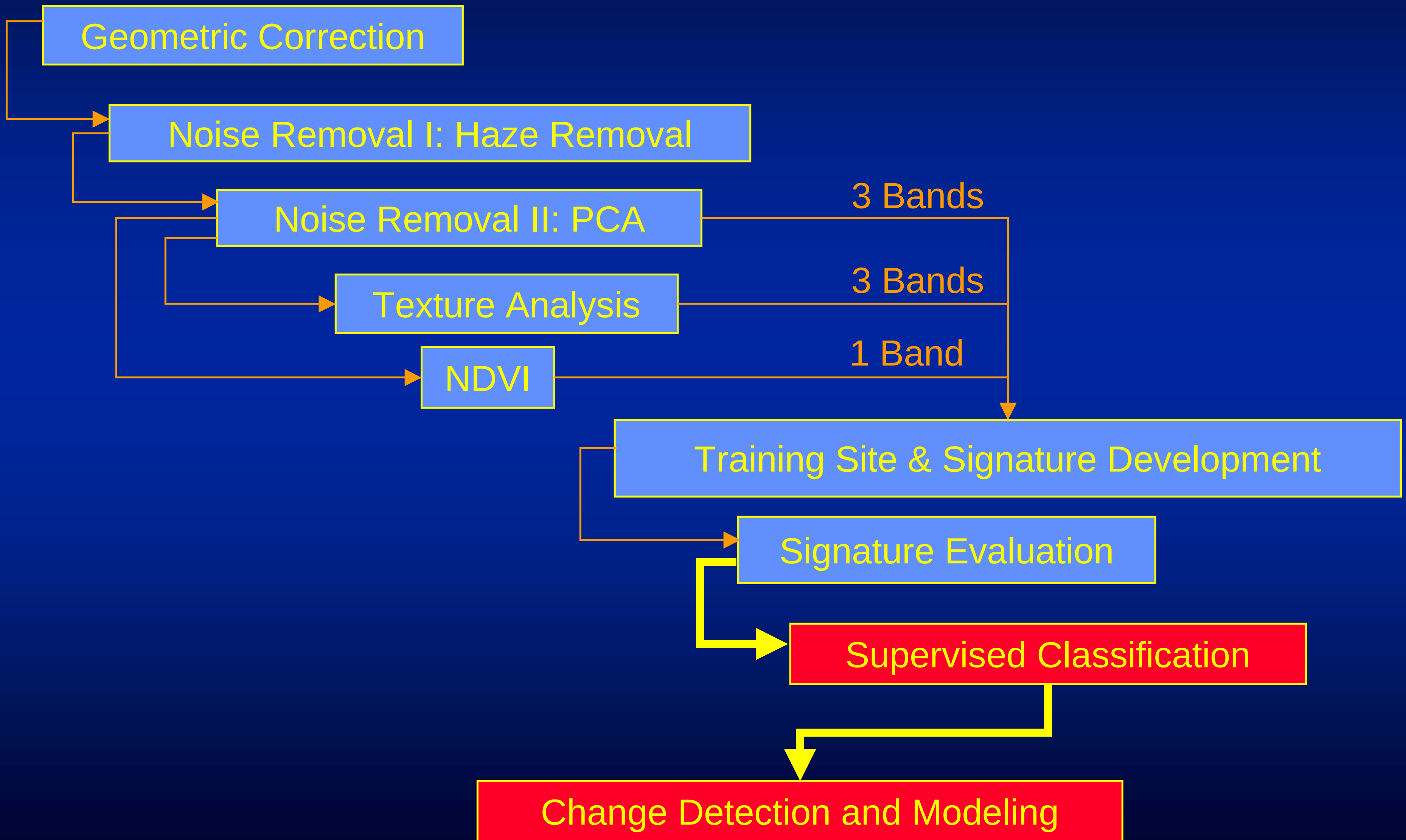
Target Classification Scheme

Clouds
Cloud Shadows
Urban, Roads and Quarries
Water
Savanna
Herbaceous Wetland Vegetation
Seasonally Inundated Lowland Forest
Well-drained Upland Forest
Cropland
Pasture
Successional Forests
- herbaceous
- shrub-dominated
- arboreal

Successional Pteridium (bracken fern)
Successional “Tahonal” (herbaceous species)

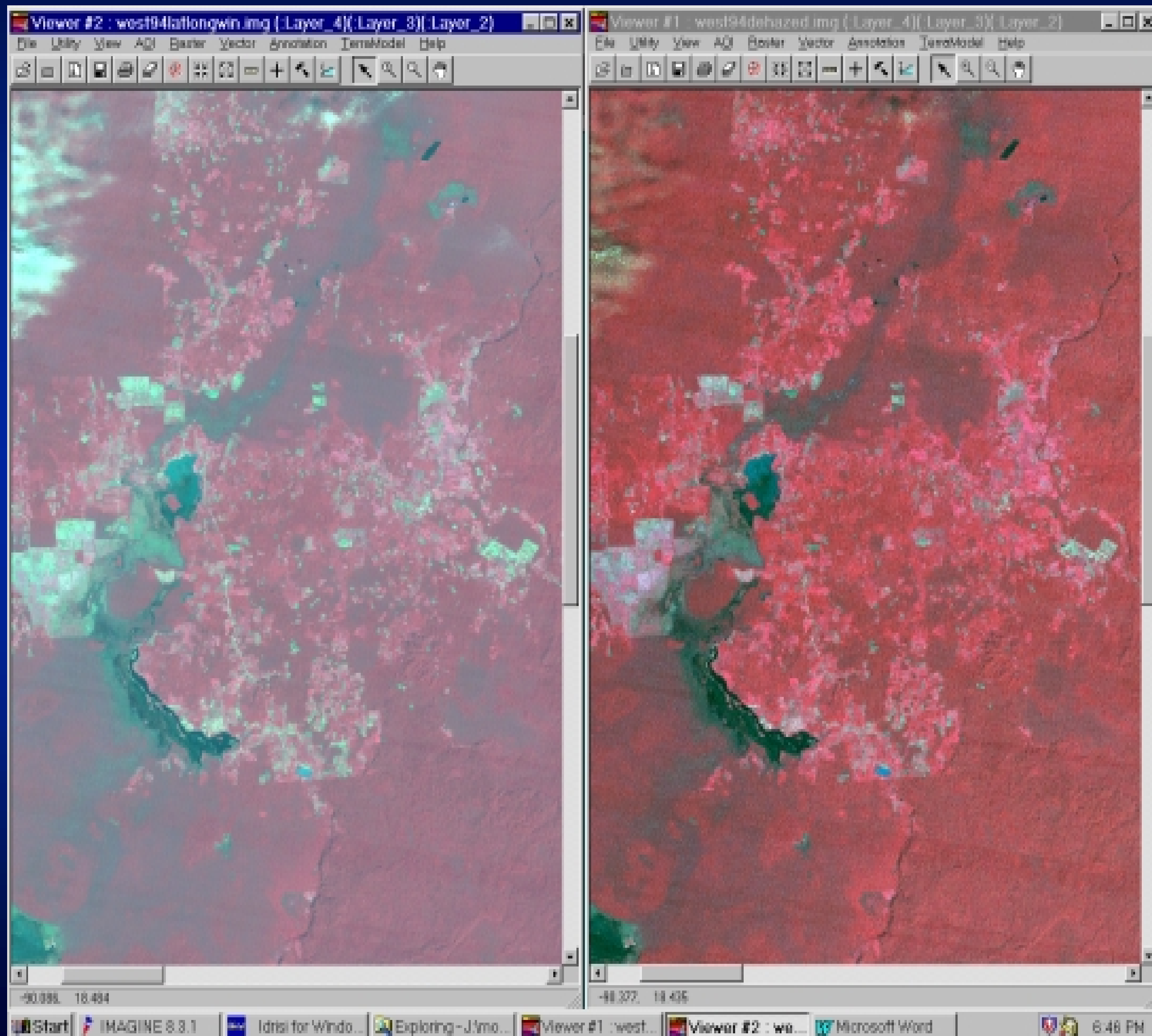
Image Processing Methodology: Overview



Noise Removal of Landsat TM: DEHAZING

ERDAS Imagine Dehazing algorithm, using Tasselled Cap Transformation

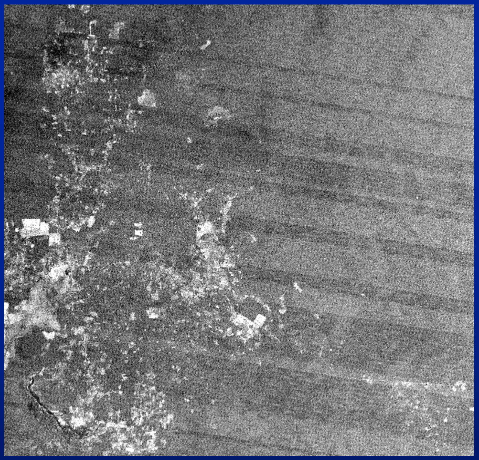
RGB False Color Composite: TM Bands 4,3,2



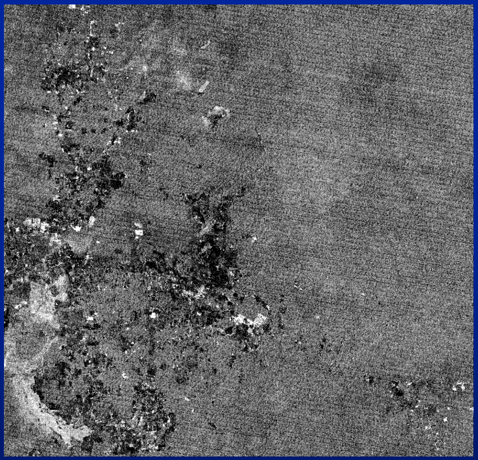
Noise Removal of Landsat TM: Principal Components Analysis

- Perform PCA on 6 of 7 Landsat TM bands (exclude thermal band)
- Results: striping and other noise eliminated, data redundancy greatly reduced

PC1, Visual bands



PC2, Visual bands



PC3, Visual bands

Incorporating Spatial Context: Texture Analysis*

- Image texture -- distinctive spatial and spectral relationships among neighboring pixels
- Focus on overall pattern of variation in each category, rather than spectral average
- Texture Analysis on PCA results: (1) greatly improved separability of upland and lowland forests, cropland and pasture, transitional edges, (2) allowed the detection and separation of 4 classes of secondary (successional) vegetation

RGB Composite: 3 PCA bands

3x3 variance

RGB Composite: 3 Texture bands

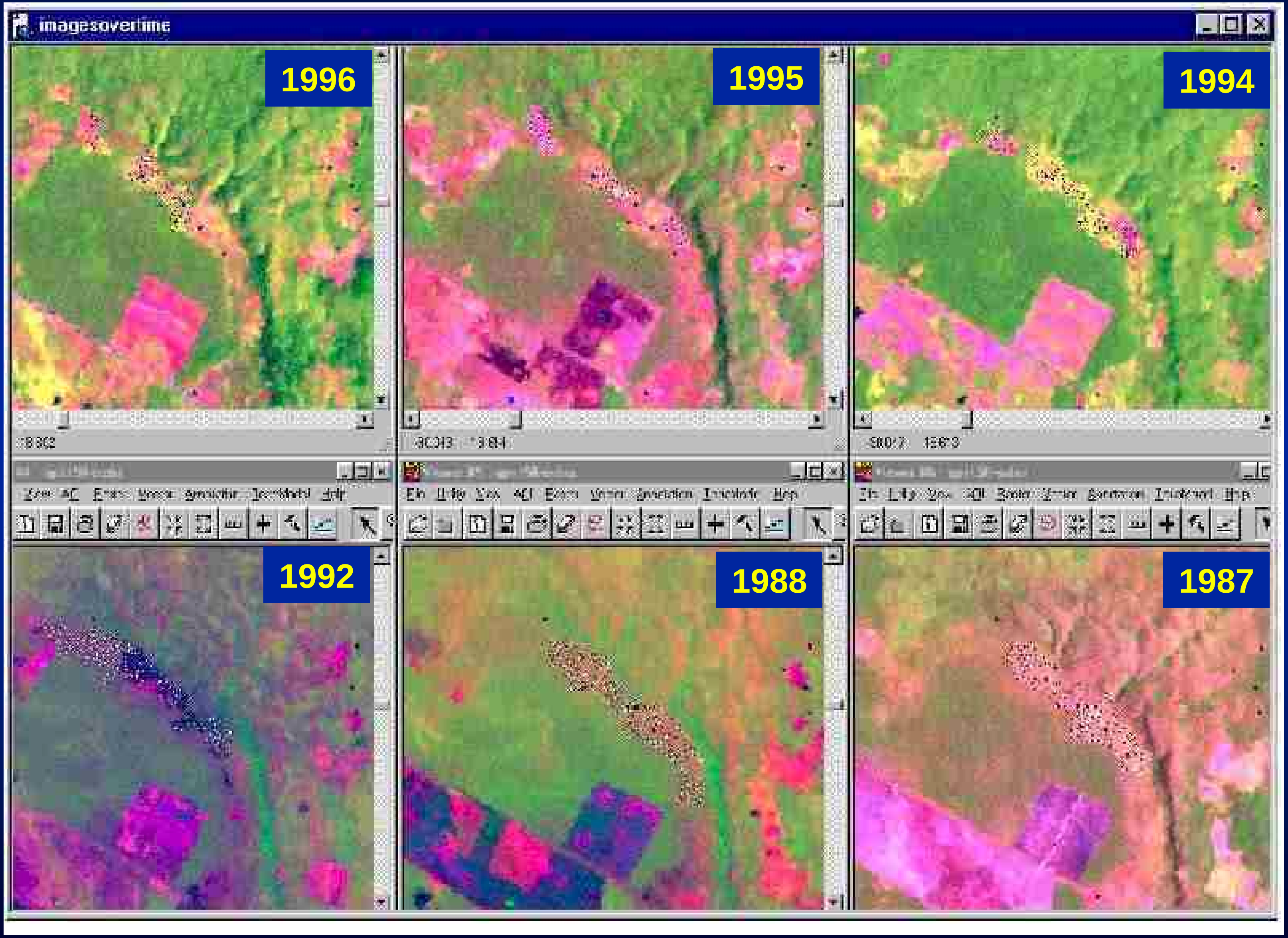
Compilation of PCA, Texture and NDVI Bands

- Normalized Difference Vegetation Index (NDVI) is a measure of relative biomass

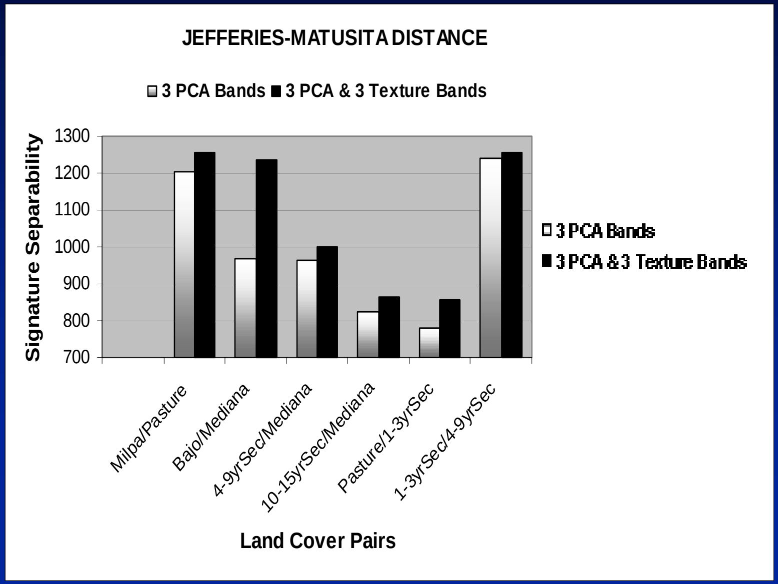
  NDVI = (IR-R)/(IR+R)

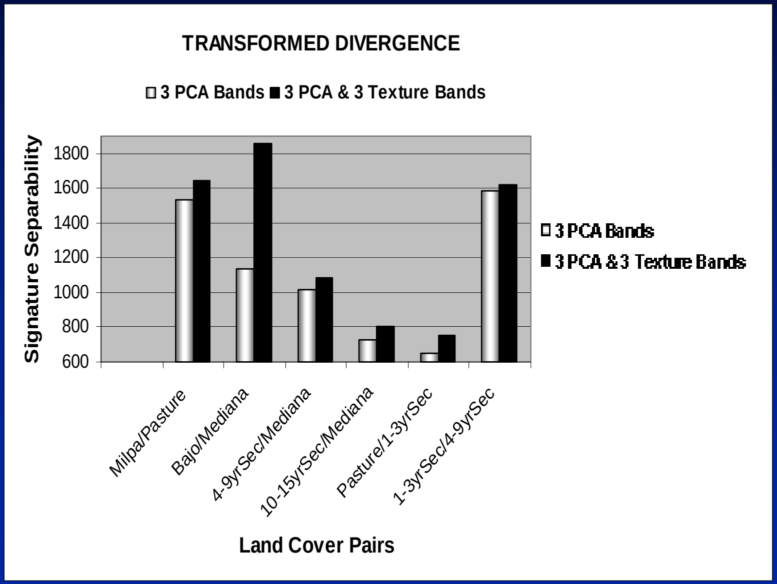
- 3 PCA bands, 3 Texture Bands, 1 NDVI band layer-stacked to produce final 7-band image for signature development and classification

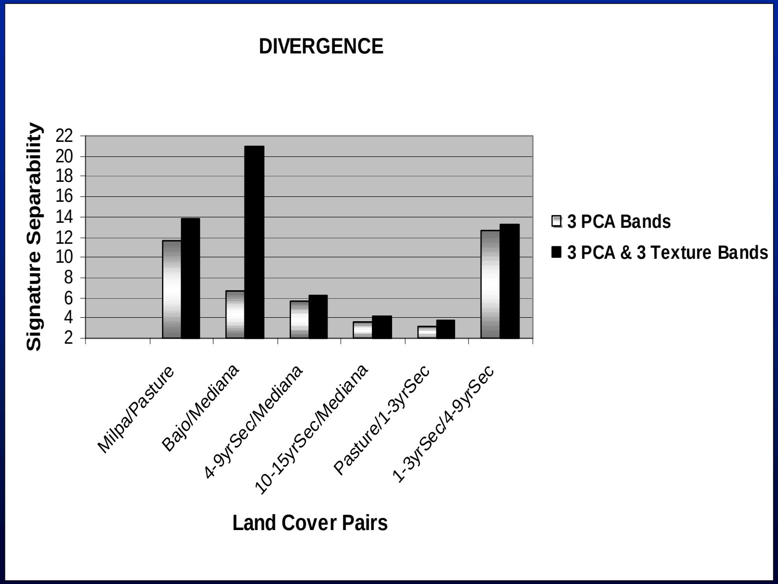
Training Sites for Signatures for Multiple Years
[see sketch map above]

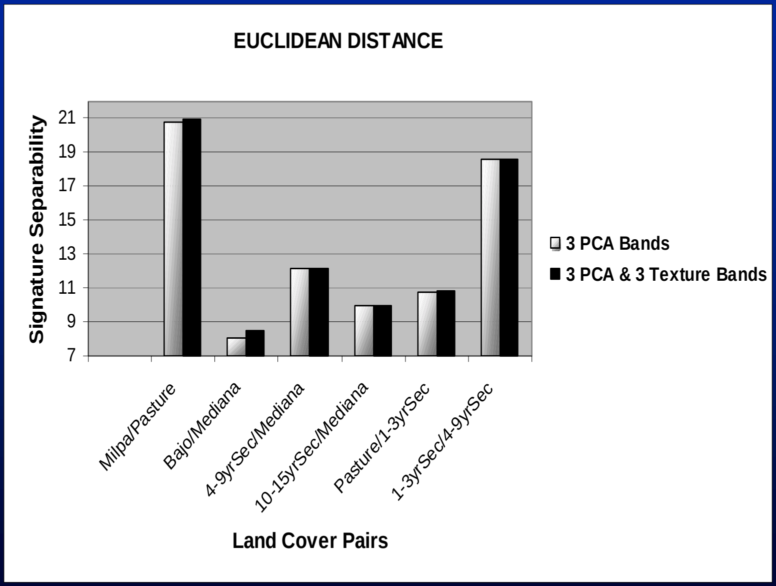


Improvements in Signature Separability using Texture*









Improvements in Classification Contingency using Texture & NDVI*

IMPROVED SIGNATURE SEPARABILITY IN SUCCESSIONAL FORESTS:

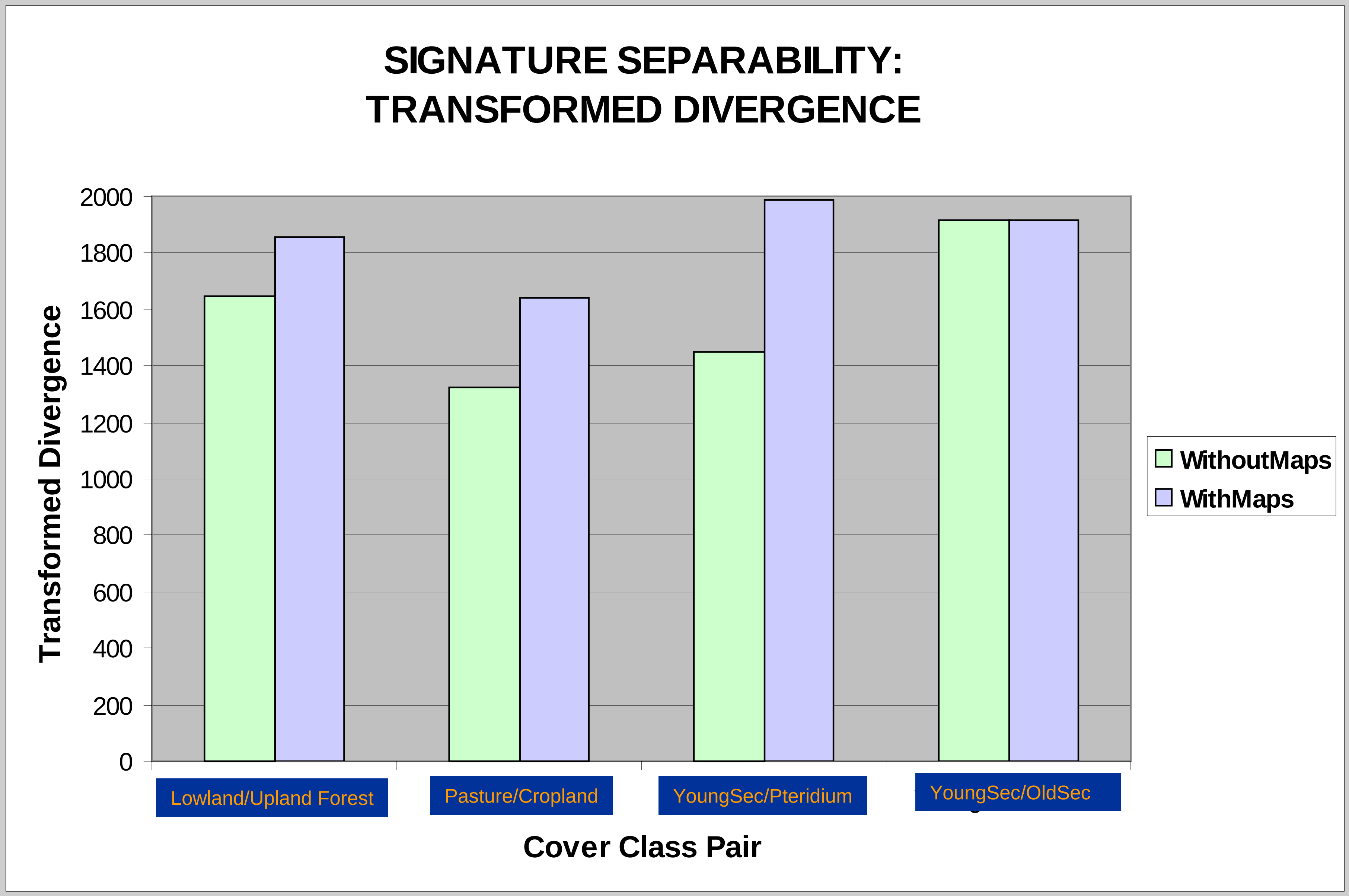
Experiments with Texture & NDVI Bands

1996	3 PCA BANDS			3 PCA + 3 TEXTURE BANDS			3 PCA + 3 TEXTURE + NDVI		
	Reference			Reference			Reference		
Classified	1-3yrs	4-9yrs	>10yrs	1-3yrs	4-9yrs	>10yrs	1-3yrs	4-9yrs	>10yrs
1-3yrs	***89.26***	6.10	0.00	***89.42***	5.66	0.15	***90.25***	6.10	0.15
4-9yrs	10.74	***75.82***	10.94	10.58	***83.44***	9.27	9.75	***84.31***	7.29
>10yrs	0.00	18.08	***89.06***	0.00	10.89	***90.58***	0.00	9.59	***92.55***

1992	3 PCA BANDS			3 PCA + 3 TEXTURE BANDS			3 PCA + 3 TEXTURE + NDVI		
	Reference			Reference			Reference		
Classified	1-3yrs	4-9yrs	>10yrs	1-3yrs	4-9yrs	>10yrs	1-3yrs	4-9yrs	>10yrs
1-3yrs	***66.47***	35.61	0.31	***68.85***	9.30	0.31	***80.62***	10.75	0.92
4-9yrs	30.32	***63.19***	5.52	28.18	***89.06***	4.29	16.05	***85.83***	0.00
>10yrs	3.21	1.20	***94.17***	2.97	1.64	***95.40***	3.33	3.42	***99.08***

1988	3 PCA BANDS			3 PCA + 3 TEXTURE BANDS			3 PCA + 3 TEXTURE + NDVI		
	Reference			Reference			Reference		
Classified	1-3yrs	4-9yrs	>10yrs	1-3yrs	4-9yrs	>10yrs	1-3yrs	4-9yrs	>10yrs
1-3yrs	***66.37***	9.09	1.80	***70.21***	9.09	1.80	***71.99***	7.14	0.90
4-9yrs	29.18	***80.52***	0.90	26.37	***81.17***	1.80	24.52	***82.47***	3.60
>10yrs	4.45	10.39	***97.30***	3.42	9.74	***96.40***	3.49	10.39	***95.50***

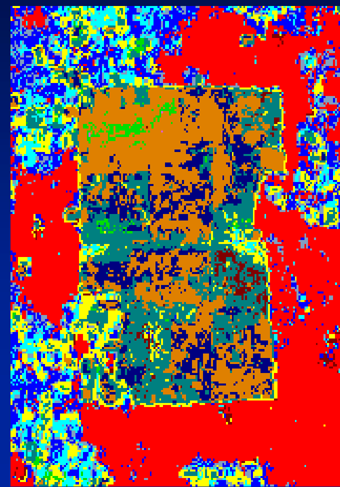
Improvements in Signature Separability Using Sketch-Maps*



Characterizing Uncertainty: Soft Classifiers*

PCA Composite

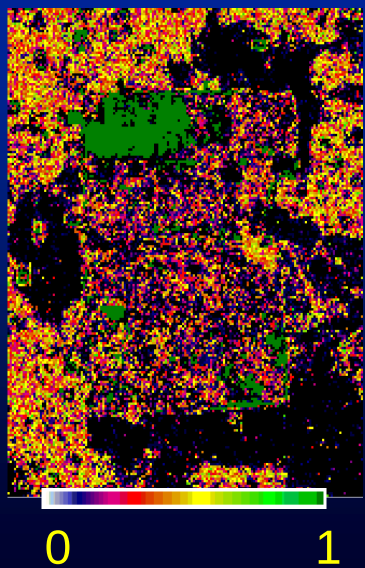
Bayesian Maximum Likelihood Classifier



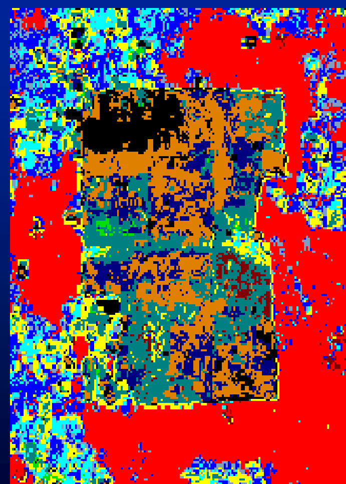
Land-cover Categories

- Secondary veg : Trees
- Secondary veg : Shrubs
- Seasonally Inundated Semi-evergreen Lowland Forest
- Clouds
- Cloud Shadow
- Pteridium (Bracken Fern)
- Semi-deciduous Upland Forest
- Cropland
- Pasture
- Savanna
- Herbaceous Wetland Vegetation
- Water
- Secondary veg : Herbaceous
- Semi-evergreen Upland Forest

Classification Uncertainty



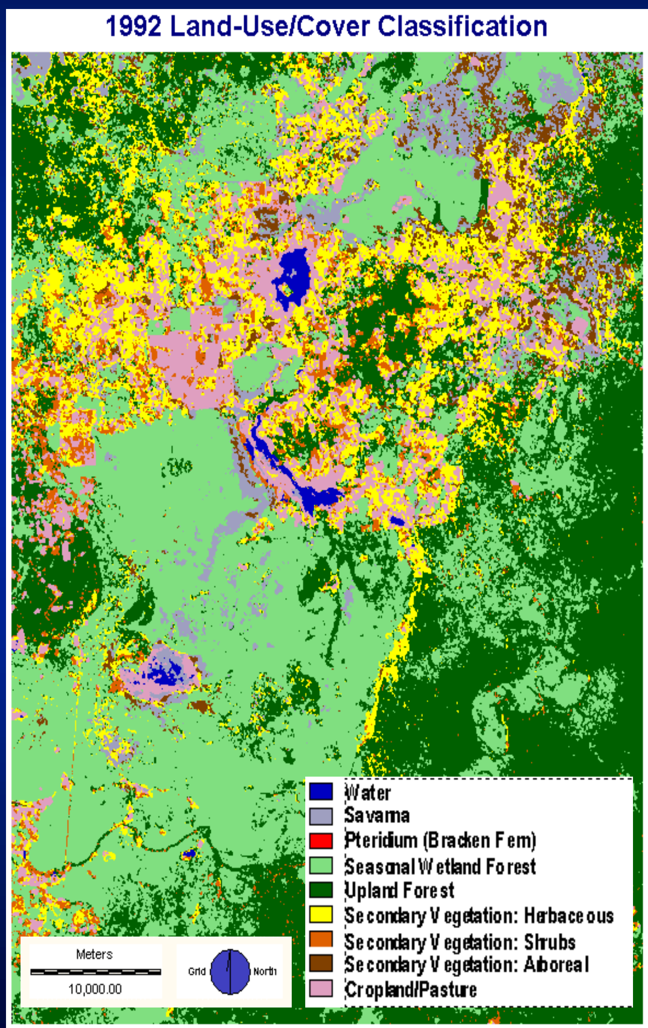
Bayesian Classifier w/ uncertain area unclassified

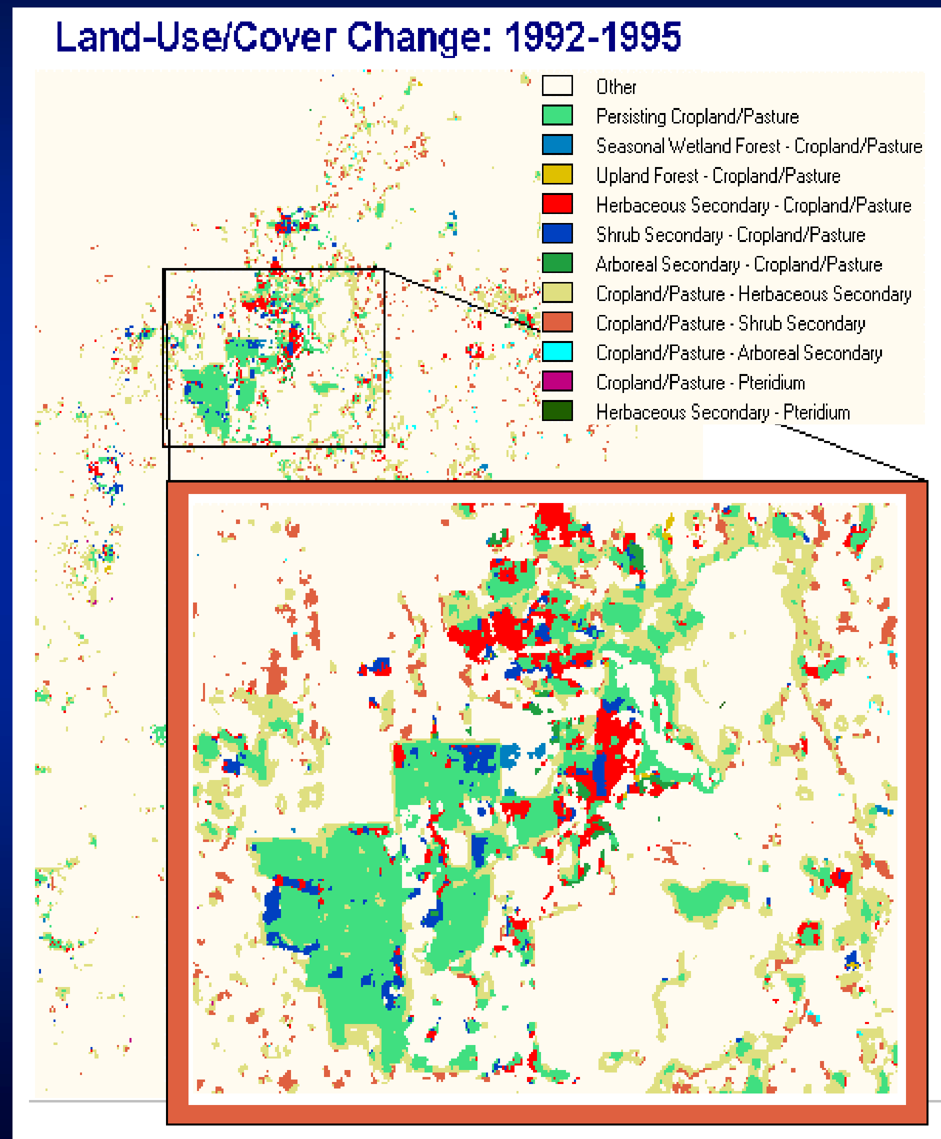


Average Uncertainty

0.37 Secondary Vegetation: Trees
0.29 Secondary Vegetation: Shrubs
0.19 Secondary Vegetation: Herbaceous
0.41 Upland Forest
0.13 Cropland
0.23 Pasture

Example Classification for Modeling Land-Use/Cover Change





Example Model of Land-Use/Cover Change

- Deforestation: Land-cover changes from Forest (mature and successional) to Cropland/Pasture
- Succession: Land-cover changes from Cropland/Pasture to young secondary vegetation
- Model 2 time periods: 1988-1992, 1992-1995

Explanatory Variables

- Biophysical: soils, topography, initial cover class
- Locational and infrastructure: distances to roads, village centers, markets, nearest other land cover
- Landscape pattern indices: fragmentation, diversity, richness, number of different classes (NDC)
- Socioeconomic: demographic, wealth indicators

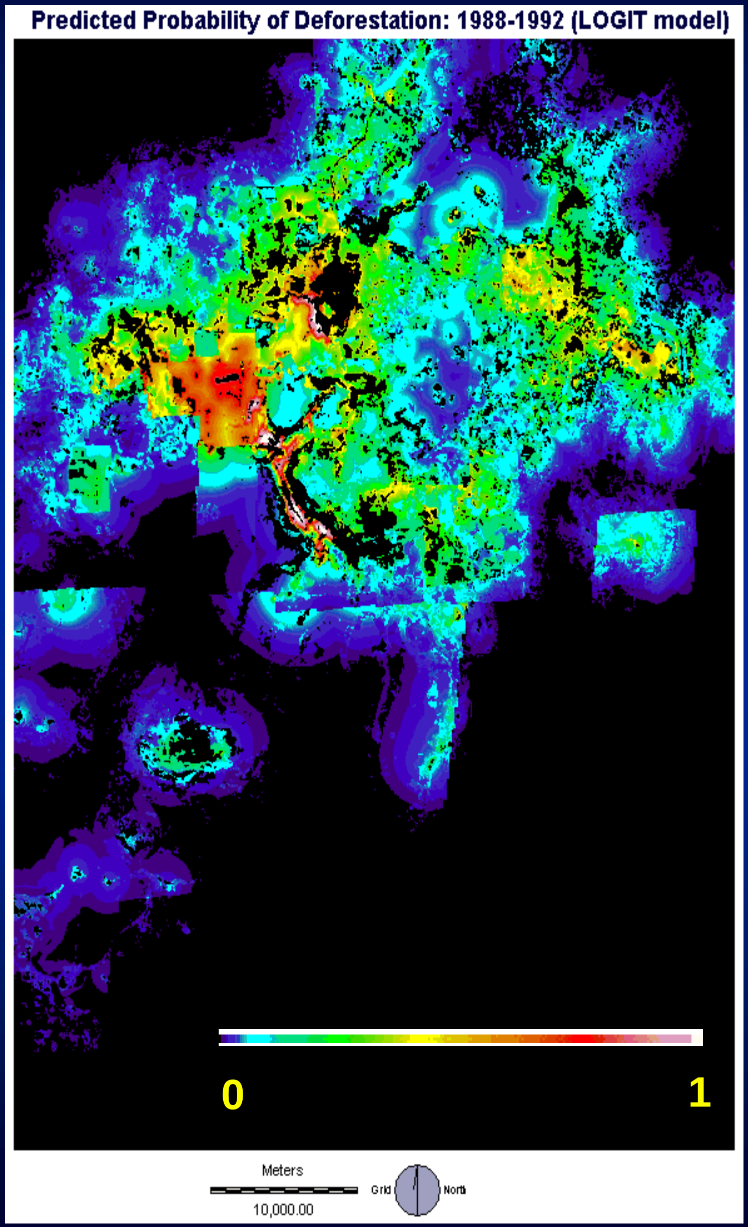
Model Estimation

- Binomial LOGIT model
  - Endogenous Variable: Forest Persistence vs. Deforestation
  - Exogenous Variables: GIS layers
- Base Case: Forest Persistence
- Estimate Parameters
  - evaluate significance of exogenous variables in model explanation
  - enable prediction of deforestation probability

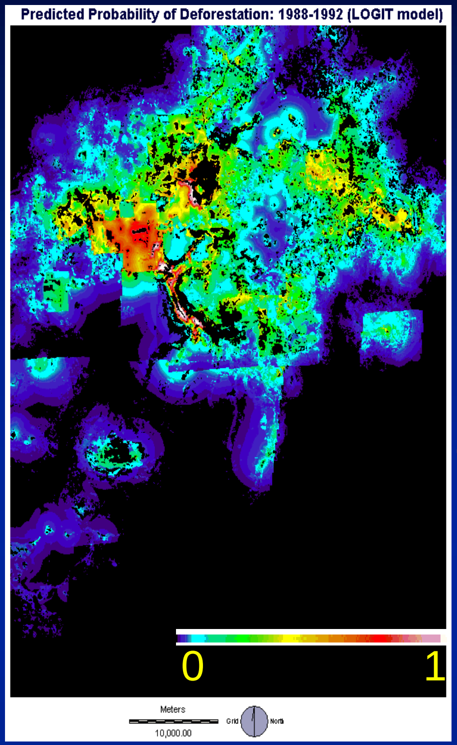
Spatially Explicit Probability Maps*

DEFORESTATION PROBABILITY: 1988-1992

$$\Pr(y_j \neq 0 \mid x_j) = \frac{e^{\beta_0 + \beta_1 x_1 + \beta_2 x_2 \cdots}}{1 + e^{\beta_0 + \beta_1 x_1 + \beta_2 x_2 \cdots}}$$

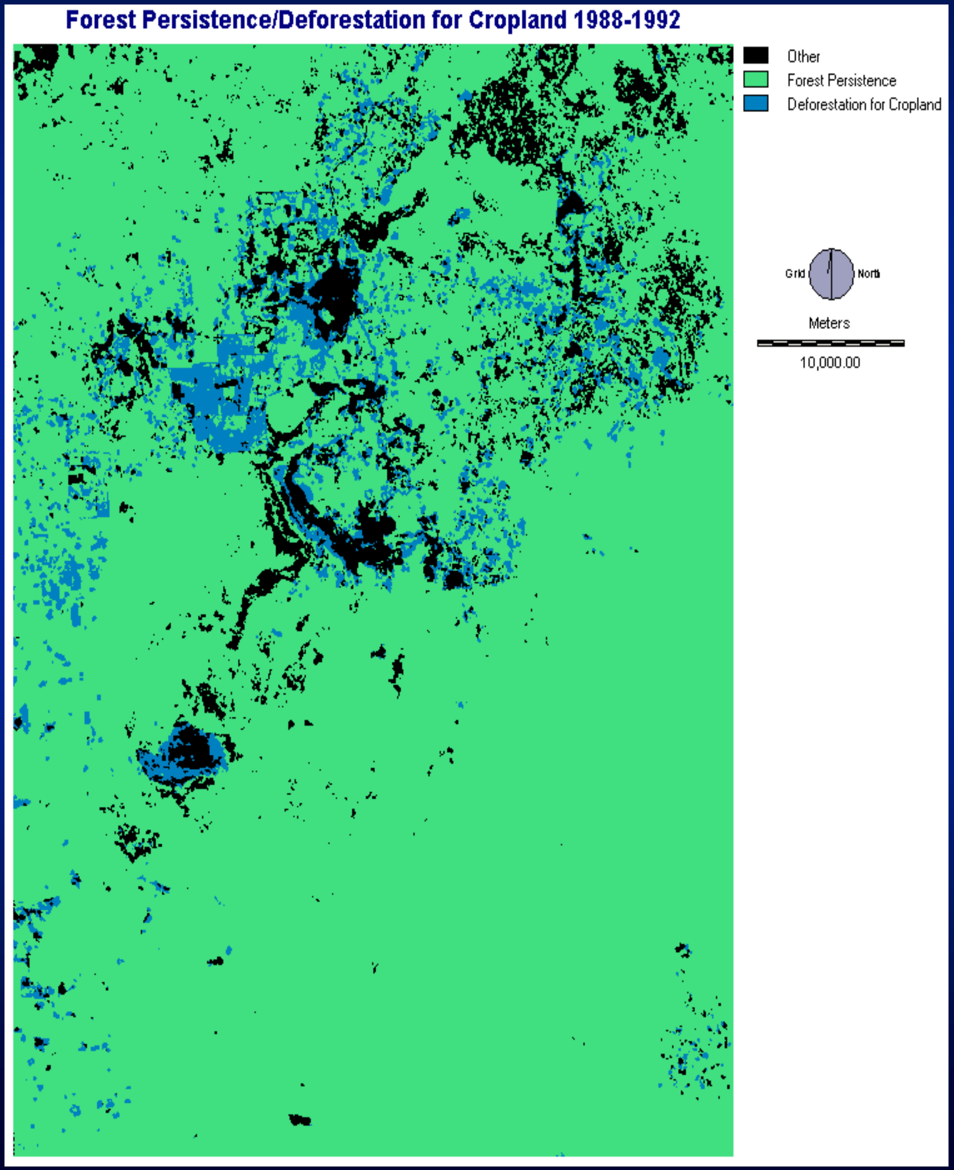


"Hardening" Predictions*



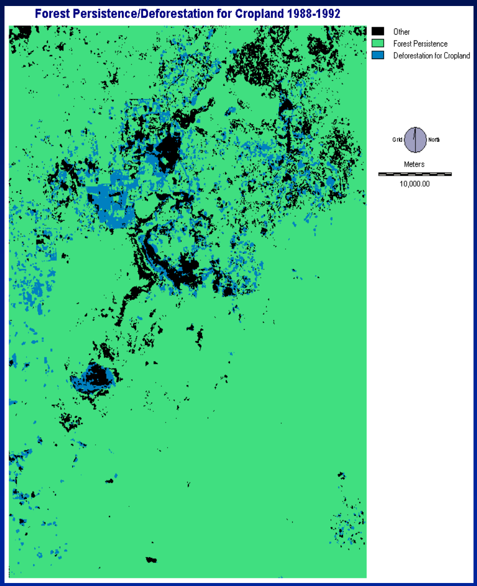
FOREST PERSISTENCE/DEFORESTATION 1988-1992

Threshold at p=0.5

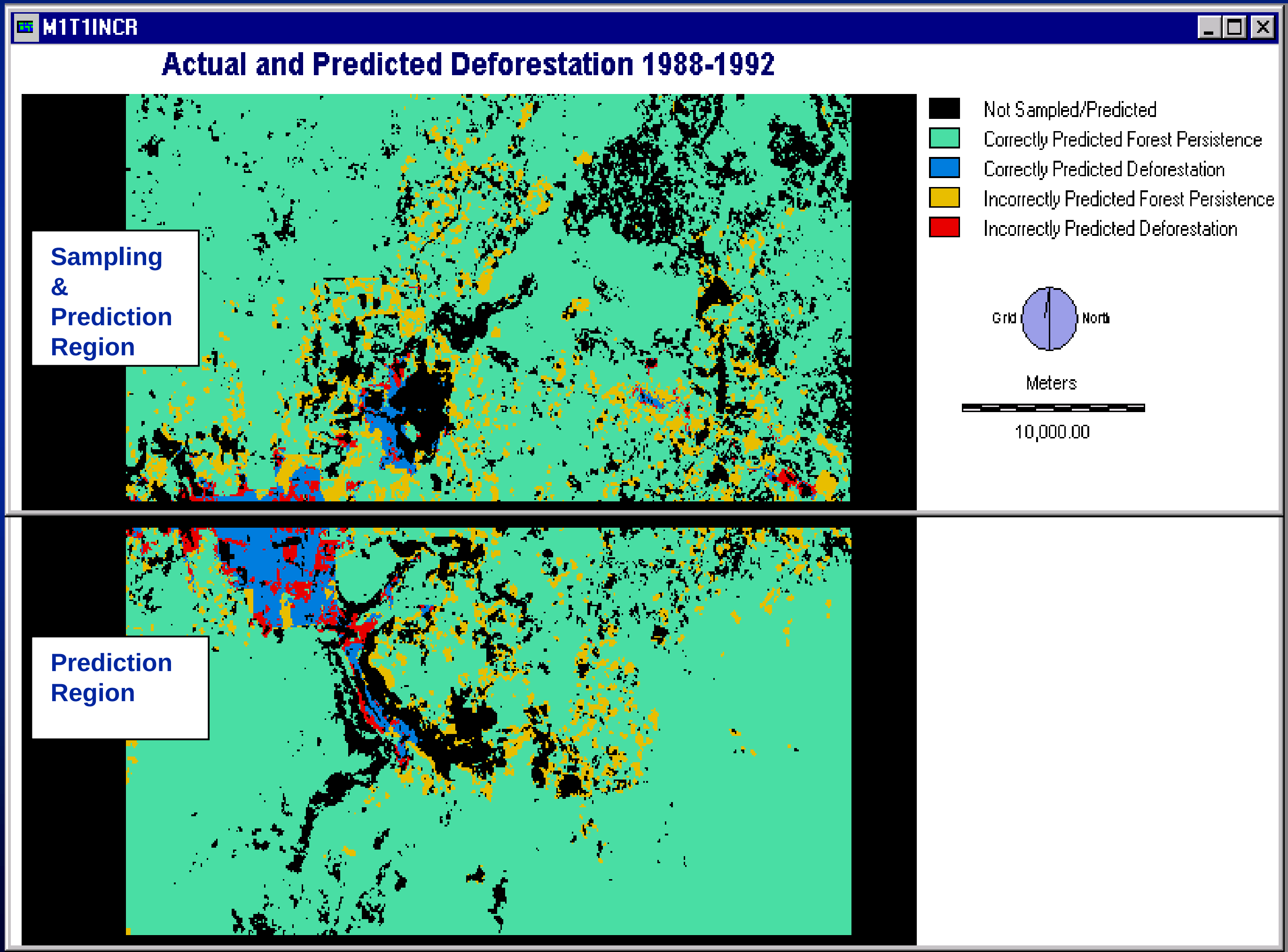


Comparing Predicted & Actual Change

Predicted Change



Crosstabulate Predicted Change with Actual Change



Kappa Index of Agreement Statistics*

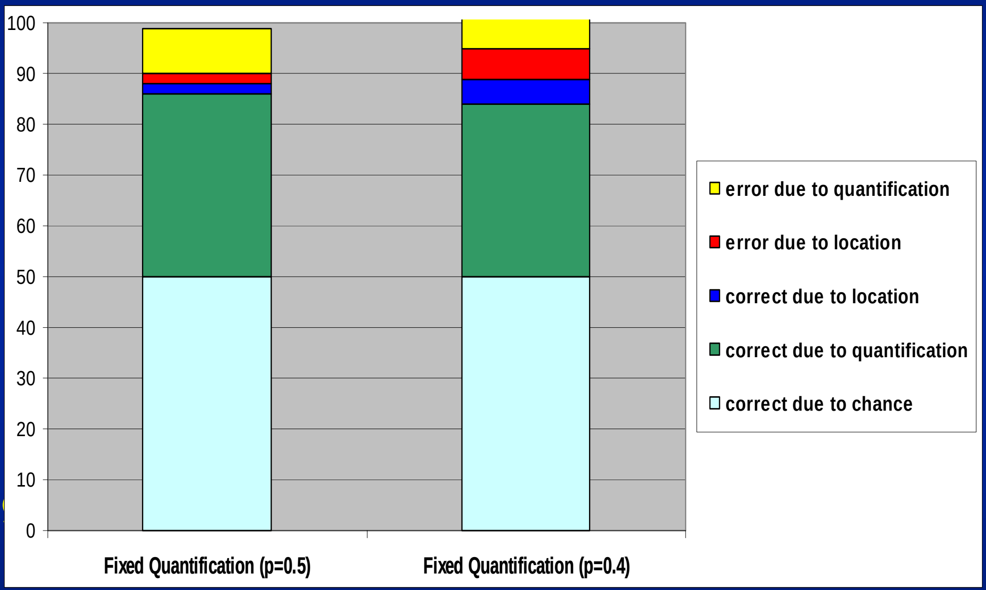
MODEL: FOREST PERSISTENCE/DEFORESTATION 1988-1992

Traditional Kappa (-1 ≤ K ≤ 1)

$$K = \frac{P_{RM} - P_R P_M}{P_R - P_R P_M}$$

Category	KIA		
	(p=0.5)	*(p=0.4)*	
Forest Persistence		0.9873	0.
Deforestation	0.1224	0.2427	
Overall	0.9310	0.9280	

Modified Kappa (R. Pontius)



p=0.5	
Kappa standard	0.1775
Kappa No Information	0.7746
Kappa Location	0.5727
Kappa Quantity	0.9319

p=0.4	
Kappa standard	0.2792
Kappa No Information	0.7642
Kappa Location	0.4398
Kappa Quantity	0.9977

Focus 3: Ecological Approaches

leading to the effects of and constraints on land change

This set of slides illustrates how the constraints on current and future ecological conditions and dynamics (disturbance and biophysical feedbacks) are determined and integrated with the other parts of the project. [1] Major environmental disturbances are reconstructed and [2] integrated with [2] studies of the structure and function of the dominant vegetation types (primarily upland and bajo forests, and secondary growth following cultivation, and [3] the processes of forest recovery, primarily ecosystem function and community.

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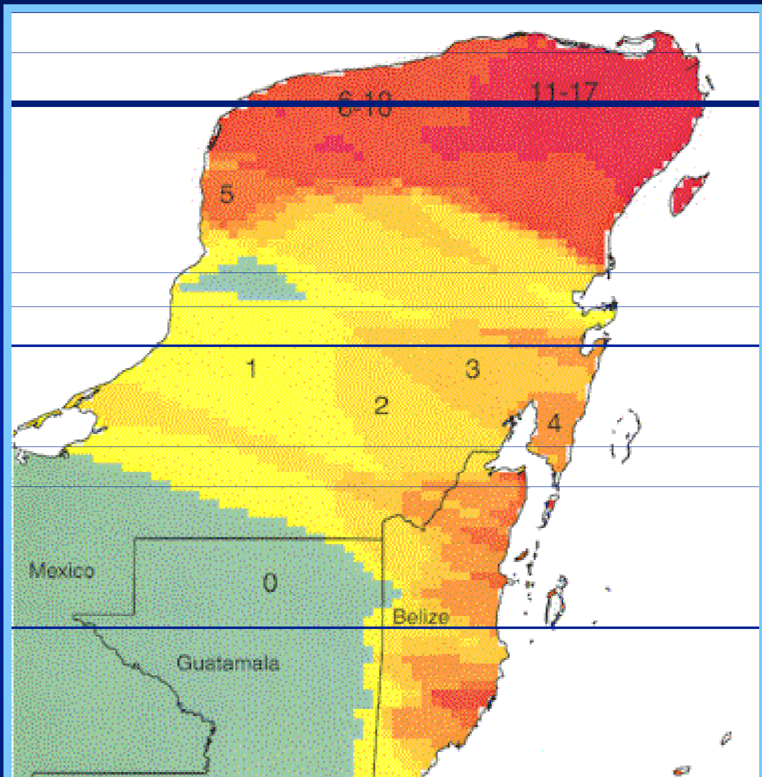
Hurricane Simulation*

a major historical disturbance

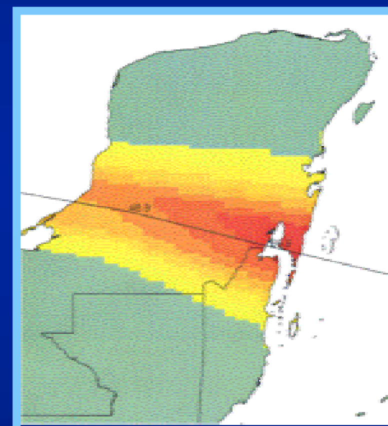


Hurricane frequency (1886-1996)

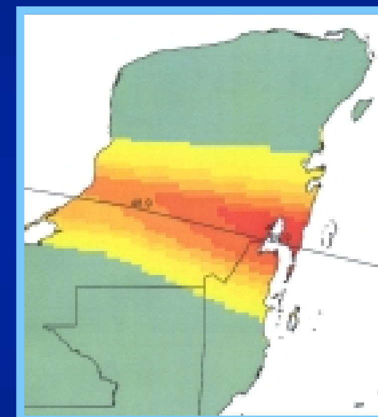
Modeled from wind speed, direction, and duration, producing estimates of potential damage.

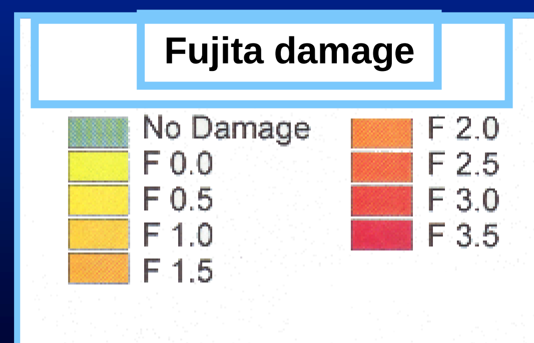
Simulated hurricanes

Janet 1955

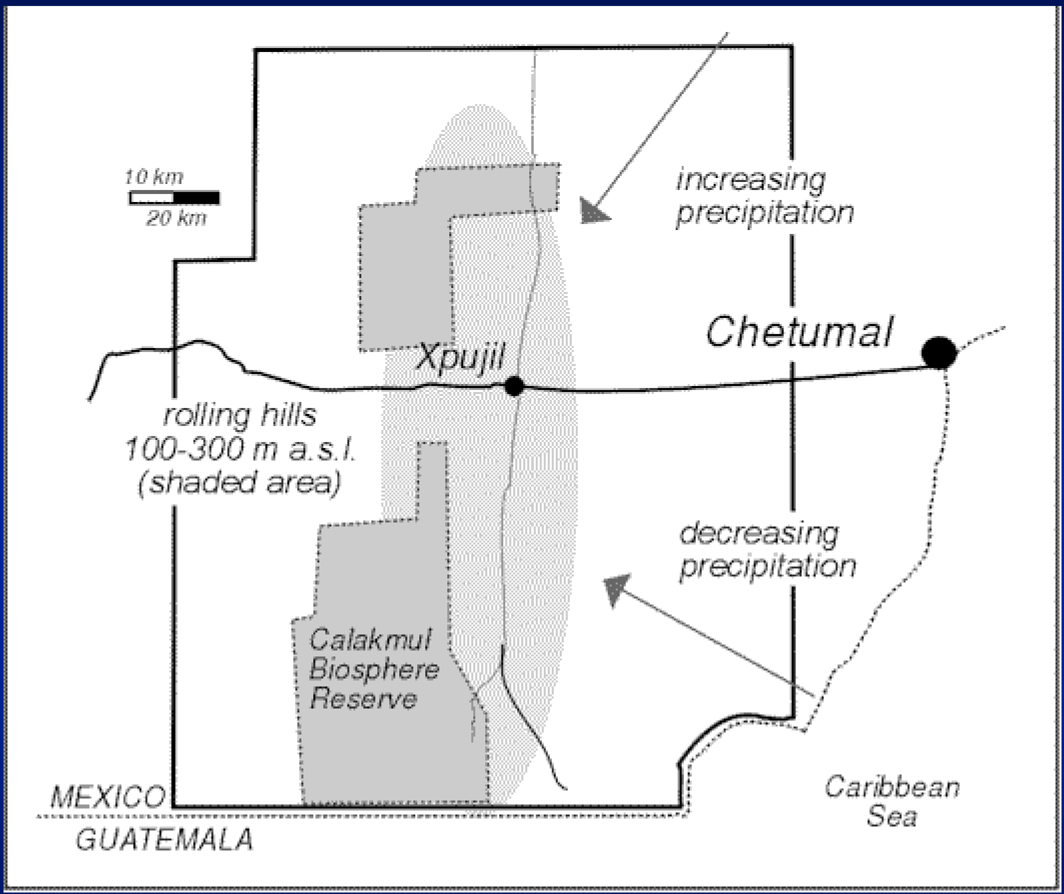


Gilbert 1988



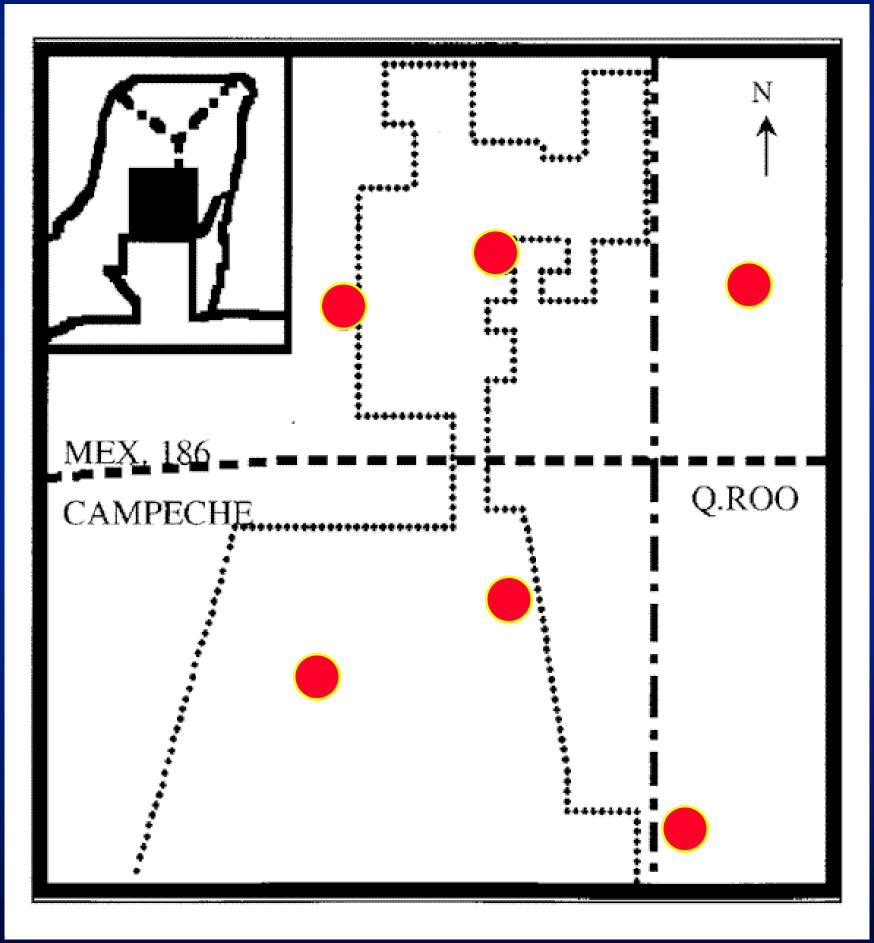


Environmental Schema of Region



The entire SYPR is karst with large, seasonally inundated poljes (*bajos*) dispersed throughout. These features increase in number and size on the low-lying eastern and western flanks of the region and support *bajo* forest. The center of region consists of rolling hills with moderate topography (100-300 m asml) dominated by *mediana* or upland forest and secondary forest. Poljes and uplands constitute the major soil distinction, with minor variation on uplands linked to depth of the limestone bedrock. A strong precipitation gradient exists: diminishing east to west and increasing north to south.

Composition, Structure, Dynamics, and Regeneration of Forests: SYPR study sites

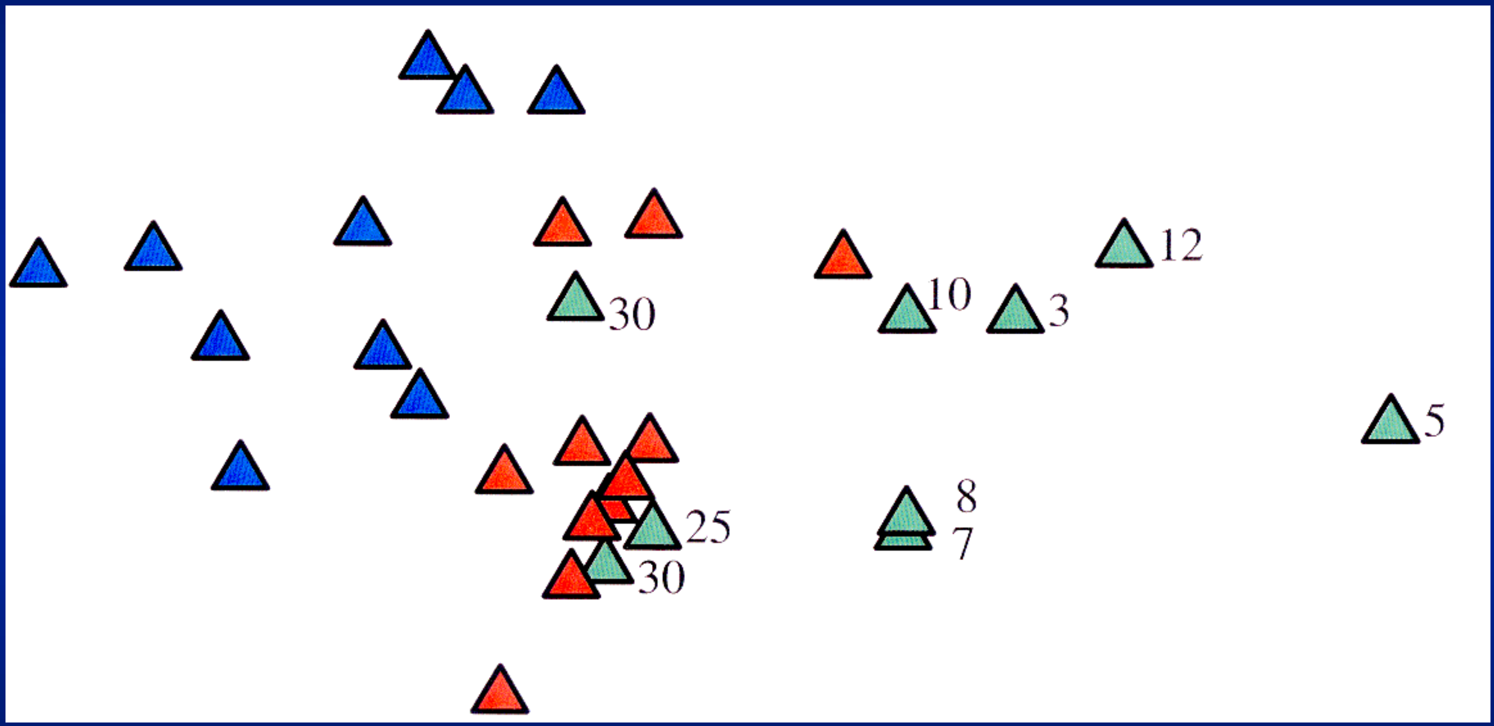


Composition, Structure, Dynamics, and Regeneration of Vegetation

- Six vegetation sites established across the region representing gradient of precipitation, soil depth, topography, and hurricane exposure.
- Minimally 10 vegetation plots (circular 500 m^2 each) per forest type at each site.
- Tree (>10 cm dbh) and liana species composition and structural characteristics of forest record for each plot (as well as epiphyte load).
- In nested 100 m^2, stems >5 cm dbh or >2 m in height are recorded.
- Seedling layer to be investigated in future.

Primary Axes of Variation in Detrended Correspondence Analysis

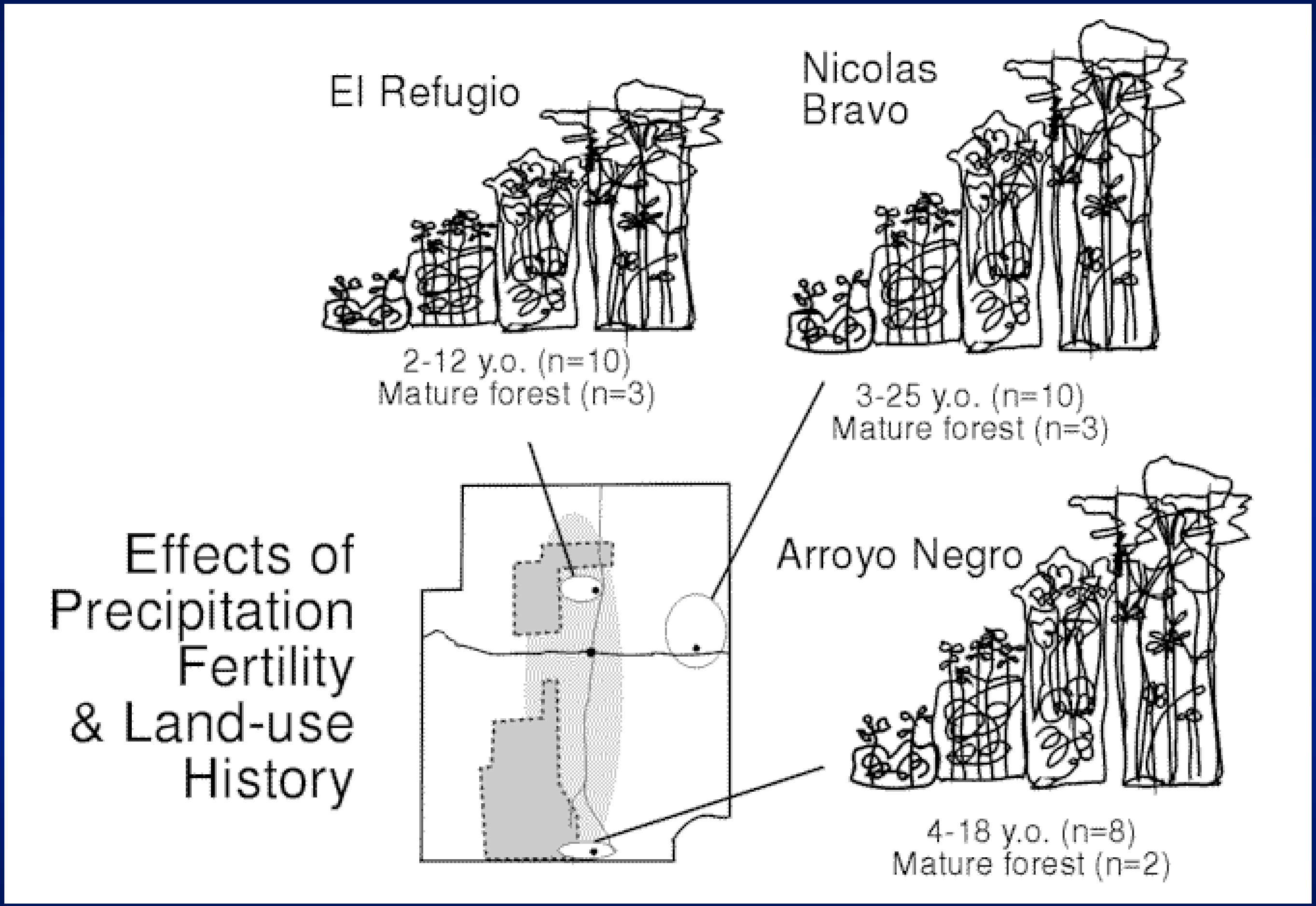
Axis 2



Axis 1

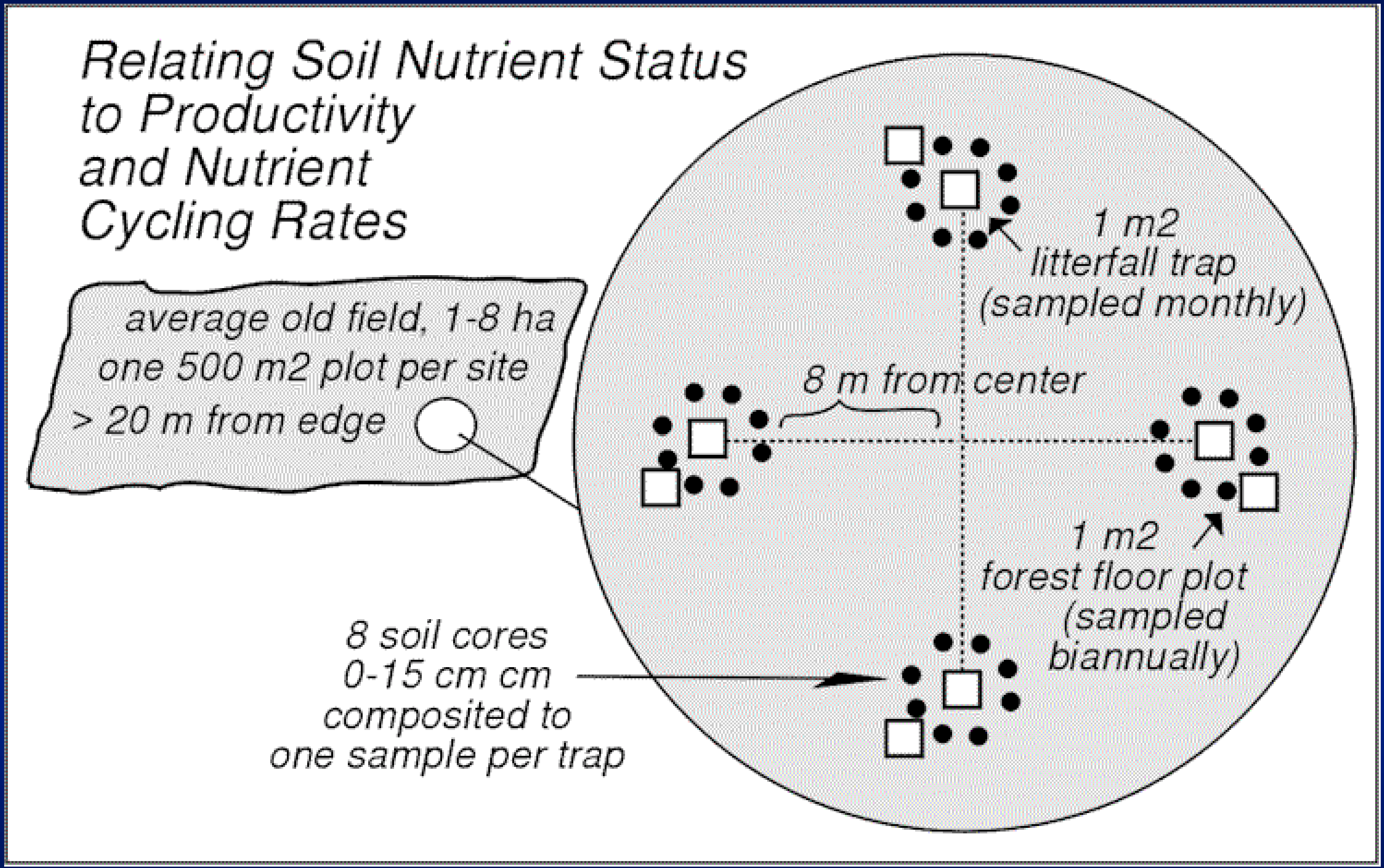
Initial results from northern site suggesting that tree communities are distinctive among bajos (blue) medianos (red), and young secondary forest (green).

Changes in Nutrient Cycling During Succession



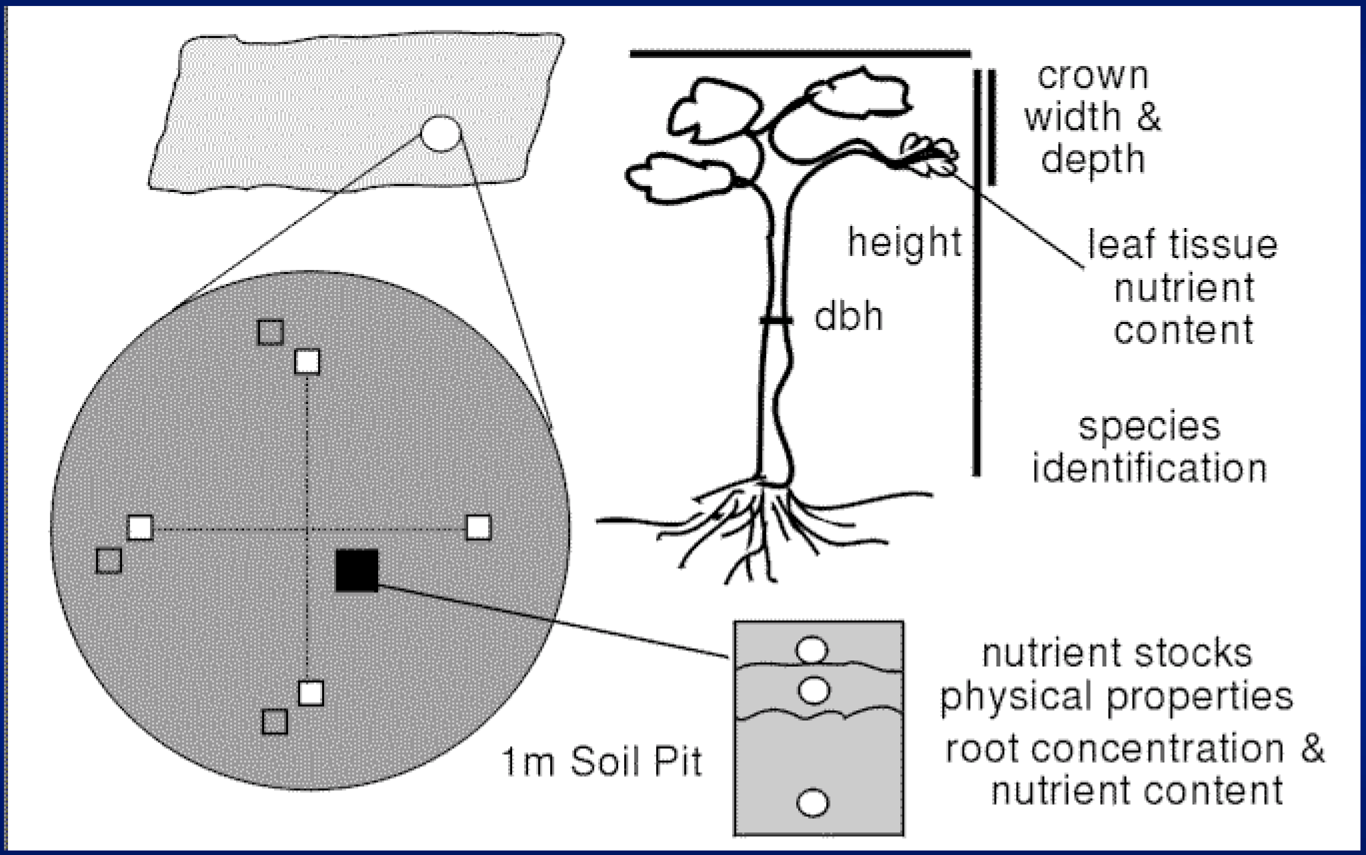
Three sites serve studies of nutrient stocks (biomass & soil) and cycling (production, turn over & constraints) as function of forest age under the dominant shifting or swidden cultivation in the region.

Relating Soil Nutrient Status to Productivity and Nutrient Cycling Rates



Successional sequence studied by way of 10-13 plots in each of three sites under growth ranging from 2 to 25 years since cultivation.

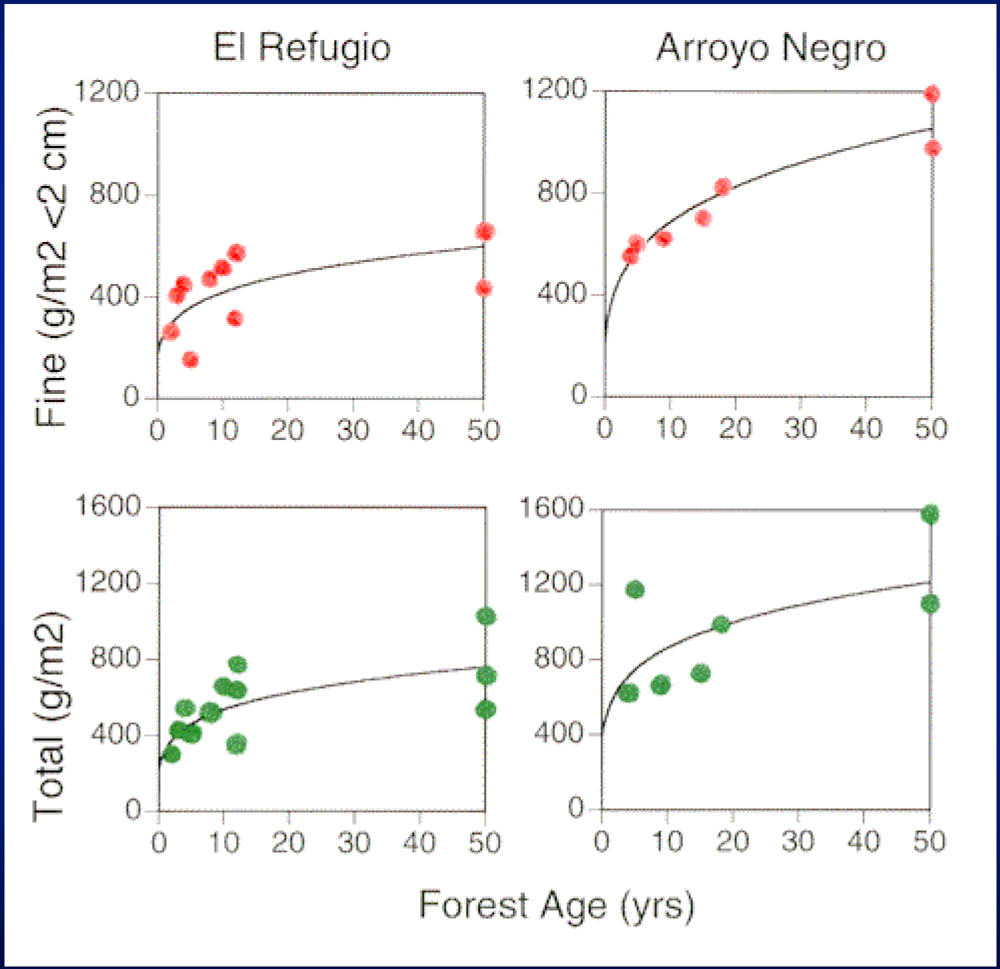
Linking Biomass and Species Composition to Nutrient Cycling Processes



Litter production as an index of productivity with links to soil nutrient status.

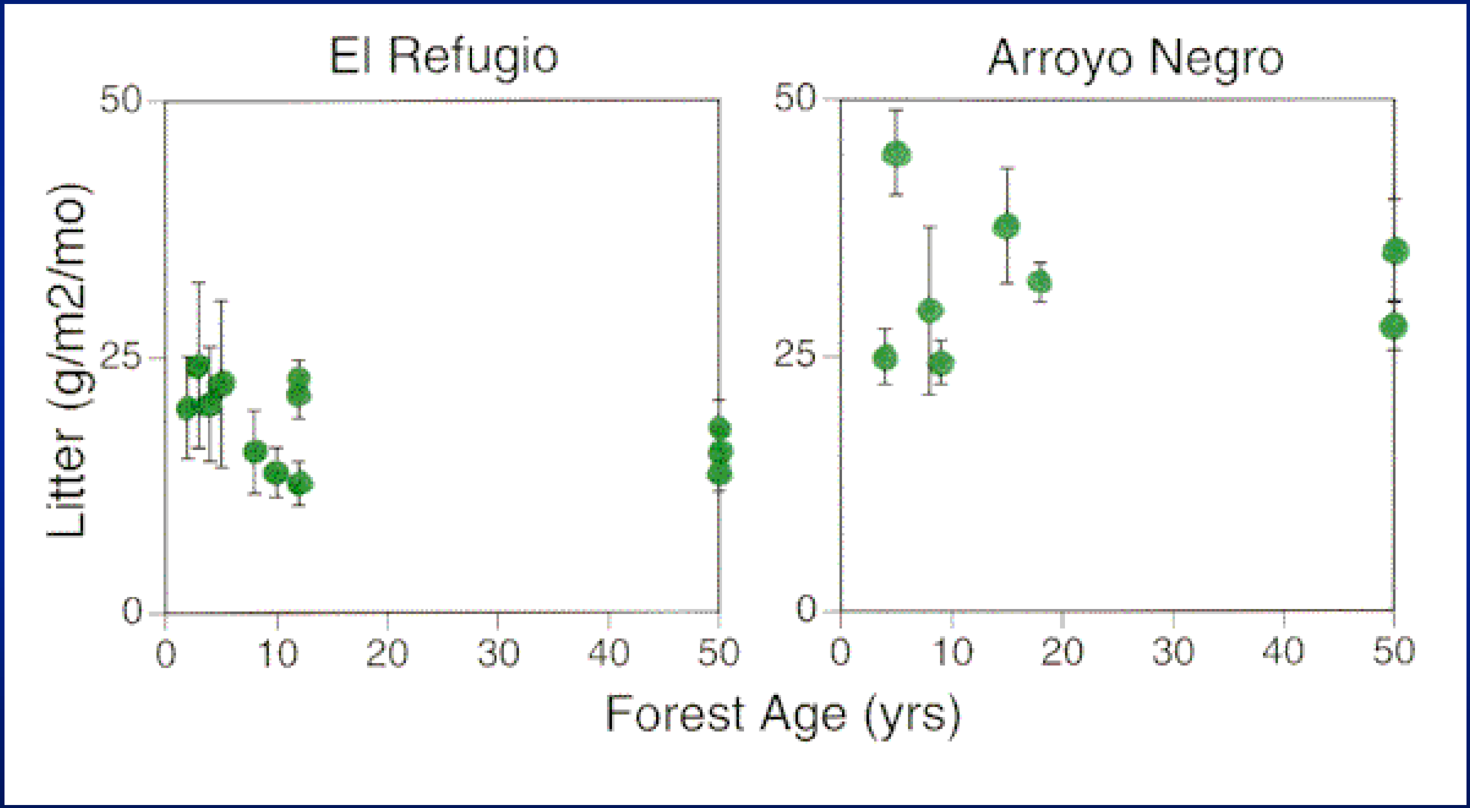
Variation in Forest Floor Mass vs. Age*

[Across Study Area]



Variation in Monthly Litter Fall vs. Age*

[Across Study Area]



Focus 4: Integrative Modeling

leading to scenario assessment for policy

A conceptual actor-institution-environment framework is mapped onto a computer model to form an Agent-based Dynamic Spatial Simulation (ADSS).

The conceptual framework joins:

- Actors: agrarian decision making interpreted by bounded rationality & resource profiles
- Institutions: land tenure & subsidies
- Environment: simple ecological relationships

ADSS Implementation

The conceptual framework is mapped onto an agent-based model and generalized cellular automata within an operating shell.