

Human and Biophysical Dimensions of Land Use/Cover Change in Amazonia:

Towards a Multi-scale Synthesis
LC-09

Emilio F. Moran, PI

Co-PIs and collaborators

- Eduardo Brondizio, Indiana U.
- Mateus Batistella, Embrapa Satellite Monitoring
- Dalton Valeriano, INPE
- Jose Simeao de Medeiros, INPE
- Paul Mausel, Indiana State
- Ryan Jensen, Indiana State
- Lars Hedin, Princeton U.

Goals

- Integrate research on human dimensions, land use drivers, demographic dynamics, and institutions
- Develop a multi-sensor analysis of LC using artificial neural networks
- Understanding landscape level controls by nitrogen and phosphorus dynamics in sustainability of forests in the Basin
- Collaboration with up to 7 other LBA projects to ensure synthesis
- Dissemination of a data management CD for all of LBA

The study areas



1. Altamira
2. Marajo
3. Tome-Acu
4. Igarape-Acu
5. Yapu
6. Rondonia
7. Santarem

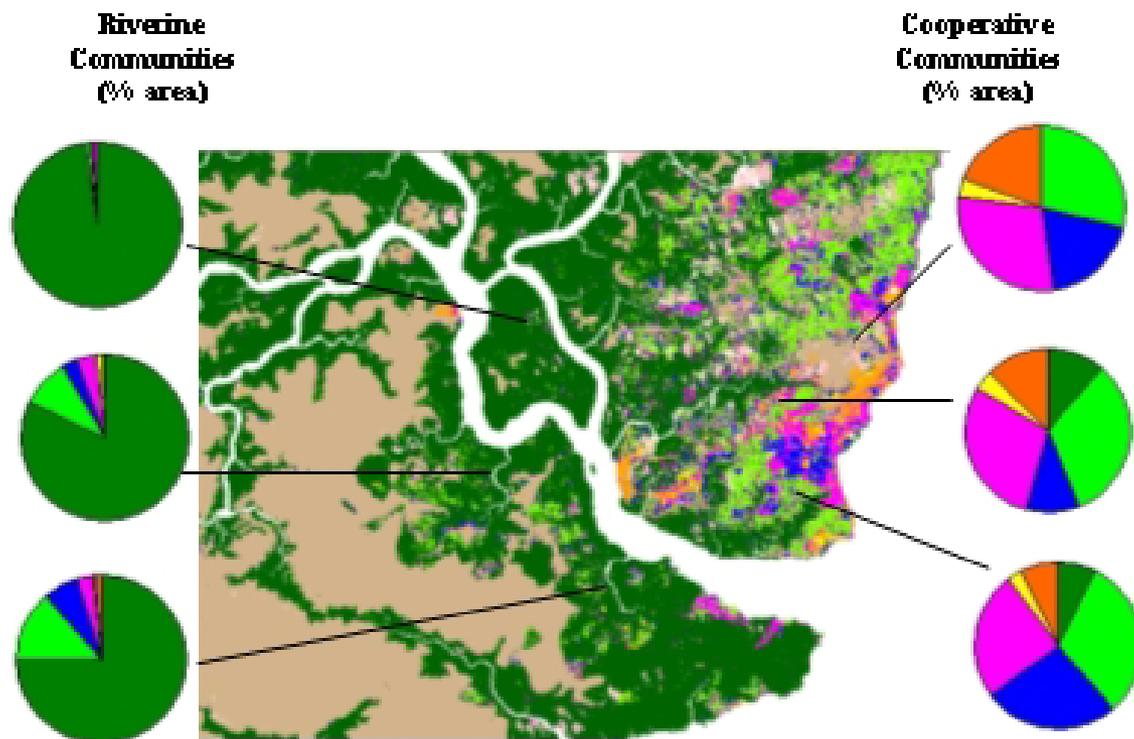
History of regional occupation and colonization phases

It is important to consider the history of regional occupation underlying contemporary dynamics of land use and cover change. Esp. account for the different stages and phases of regional occupation and the dynamics of land cover change associated with each stage. We have found high level of heterogeneity in spatial and temporal patterns as a result of these process:

Regionally, heterogeneity evolves from the arrival of different groups, creation of access routes, and economic policies promoting particular forms of institutional arrangements and economic systems.

Locally, heterogeneity evolves from factors underlying the decision-making of land users, including variation in types of owners and users, length of occupation, land tenure condition, availability of resources, experience, knowledge, available technology and labor, and access to capital.

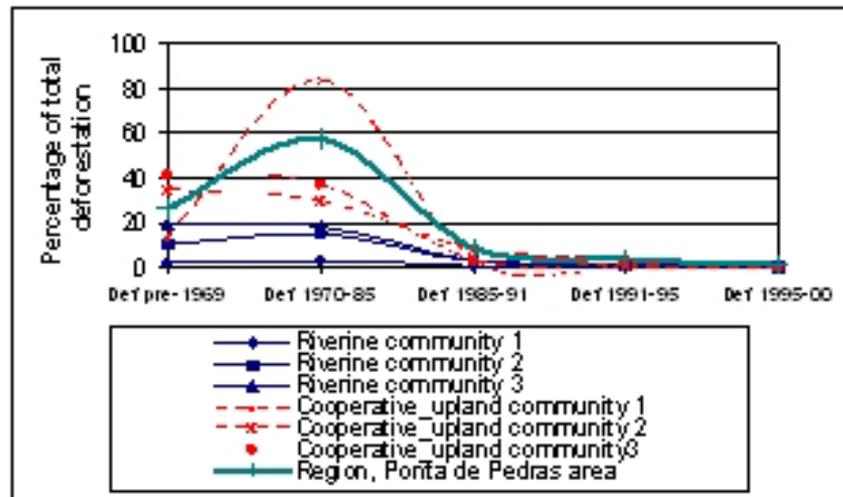
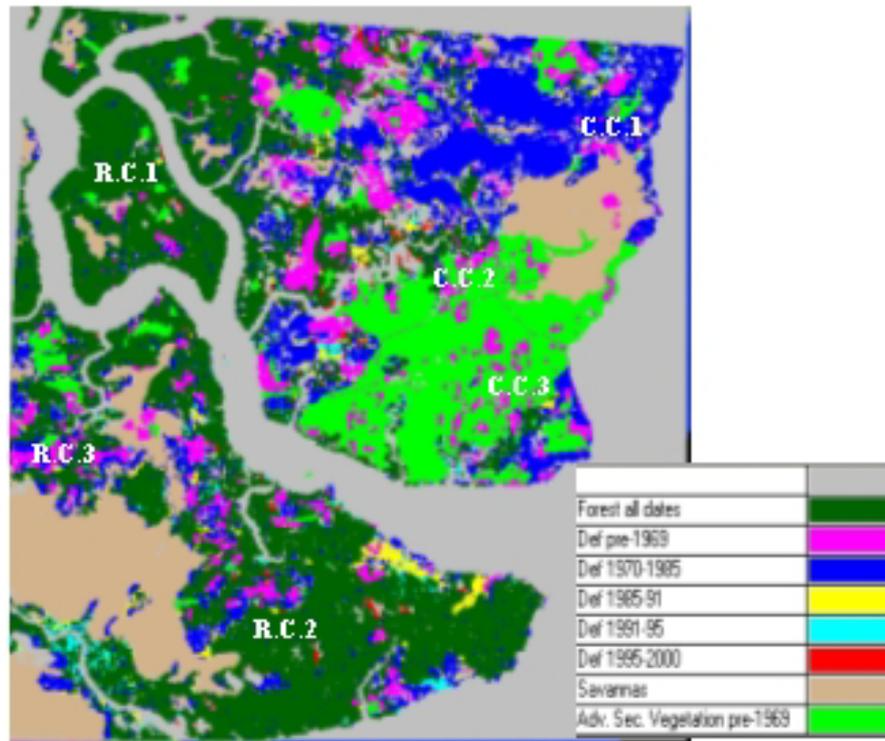
Intra-regional variability in land use trajectories (1970-2000), Amazon estuary



Water
Forest
Use after 1970 Fallow by 1985
Use by 1985 Fallow by 1991
Use by 1991 Fallow by 2000*
Use since 1991
Use by 1970/1985
Savanna not included in area calculation
*include areas of upland perennials



Intra-regional variability
in Deforestation
trajectories (1970-2000),
Amazon estuary

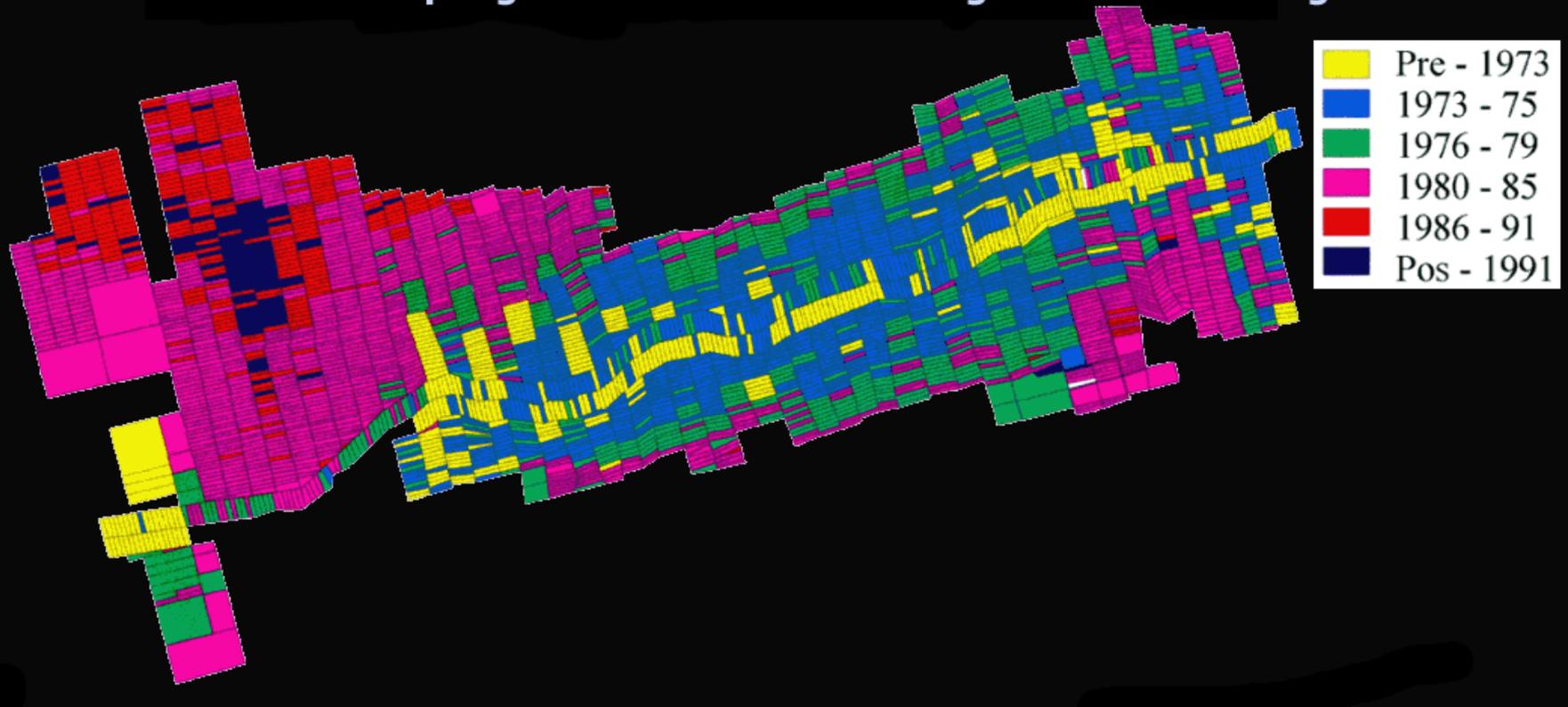


Population and Environment Findings

- Dramatic decline in female fertility in the frontier
- Different arriving cohorts of settlers follow similar deforestation trajectory, but magnitude shows response to period effects (e.g. macroeconomic factors)
- Farmer persistence is affected by soil quality on the property
- Crop choice is affected by proportion of good soils

Integrating Social Survey Data with Parcel Boundaries

Stratified Sampling Frame: Cohorts - Timing of Initial Clearing



Average Deforestation of Farm Lot/Cohort: Trajectories

The colonist footprint: Average deforestation trajectories across cohorts

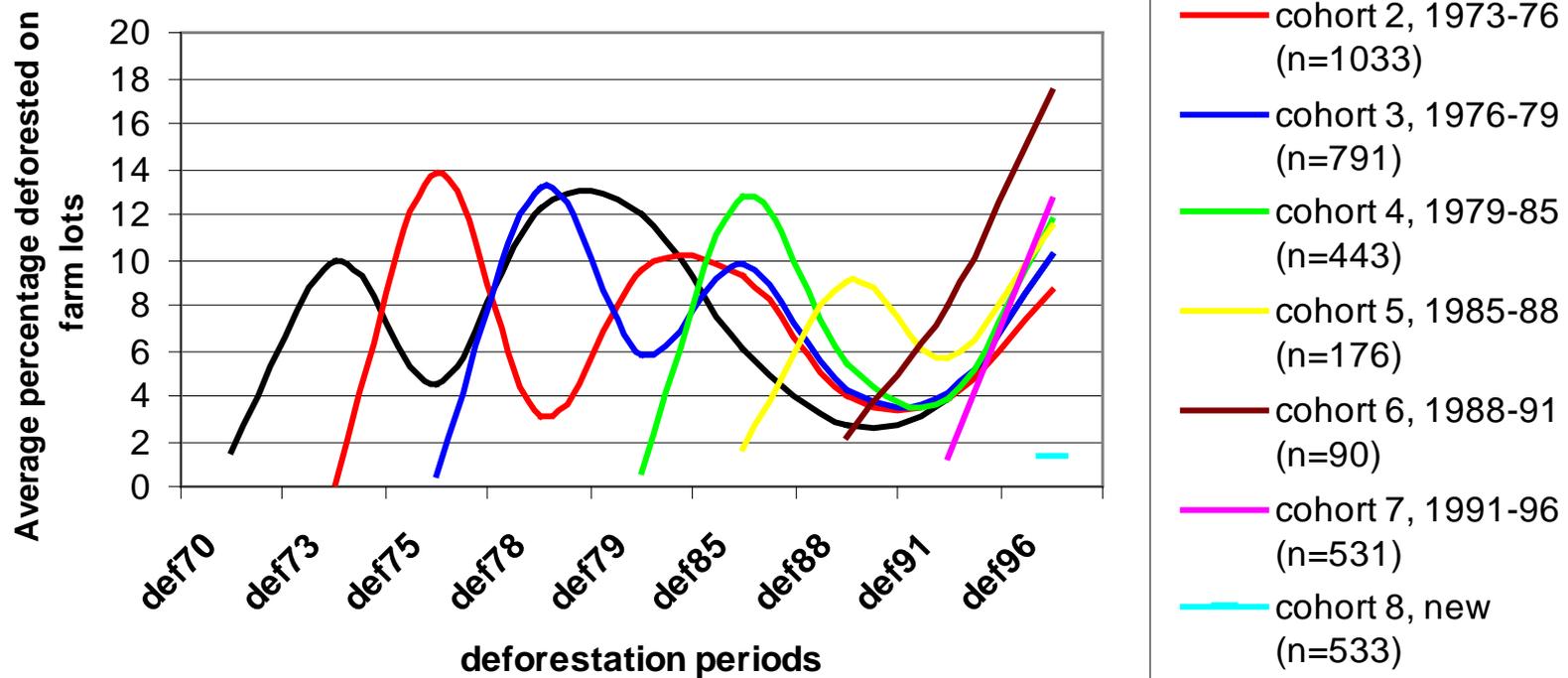
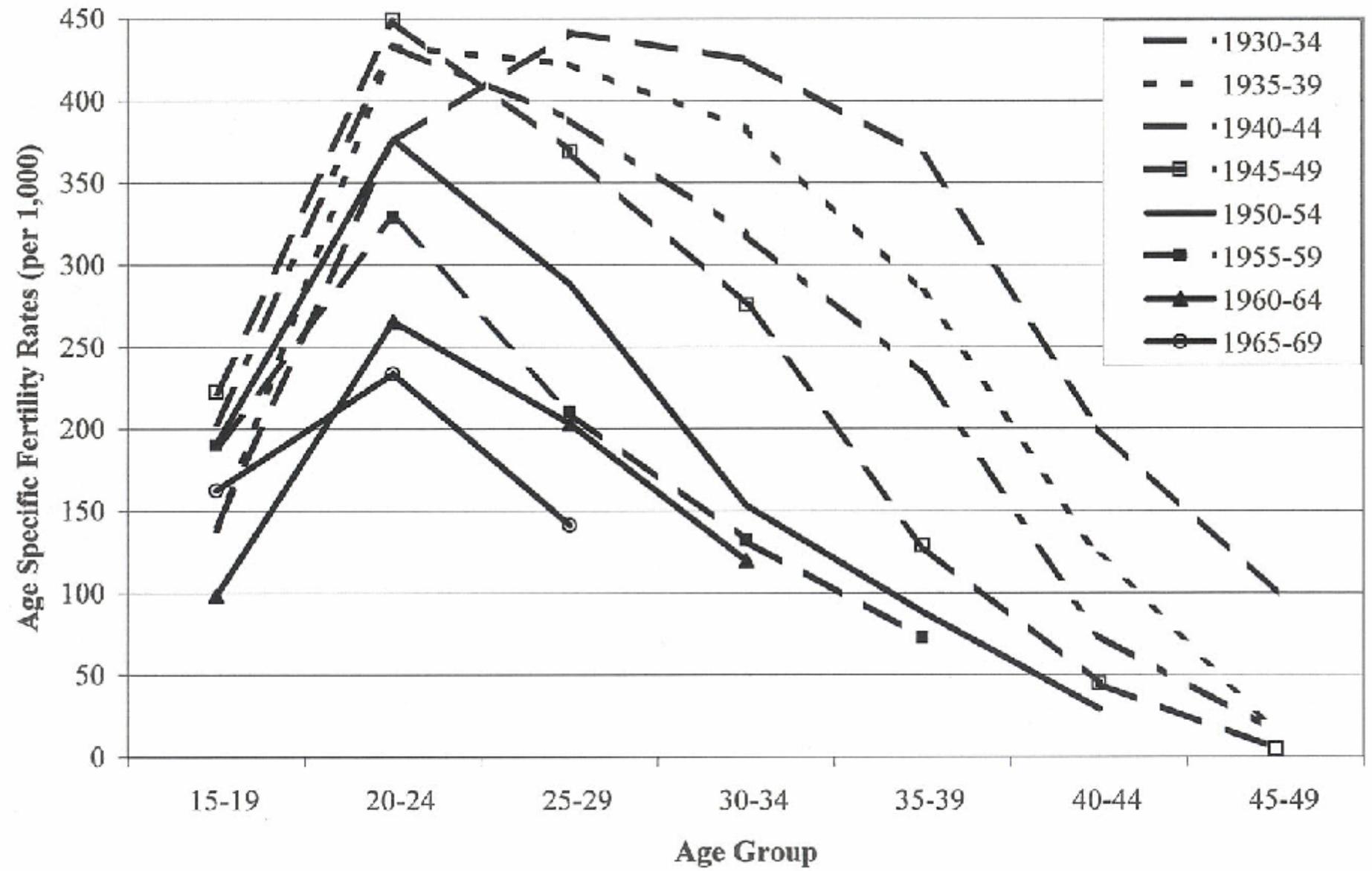


Figure 2: Age Specific Fertility Rates by Birth Cohort, Altamira Survey



LUCITA II

Agent Based Simulation Modelling of Farmer Household Decision Making on Land Use/Land Cover Change in the Brazilian Amazon

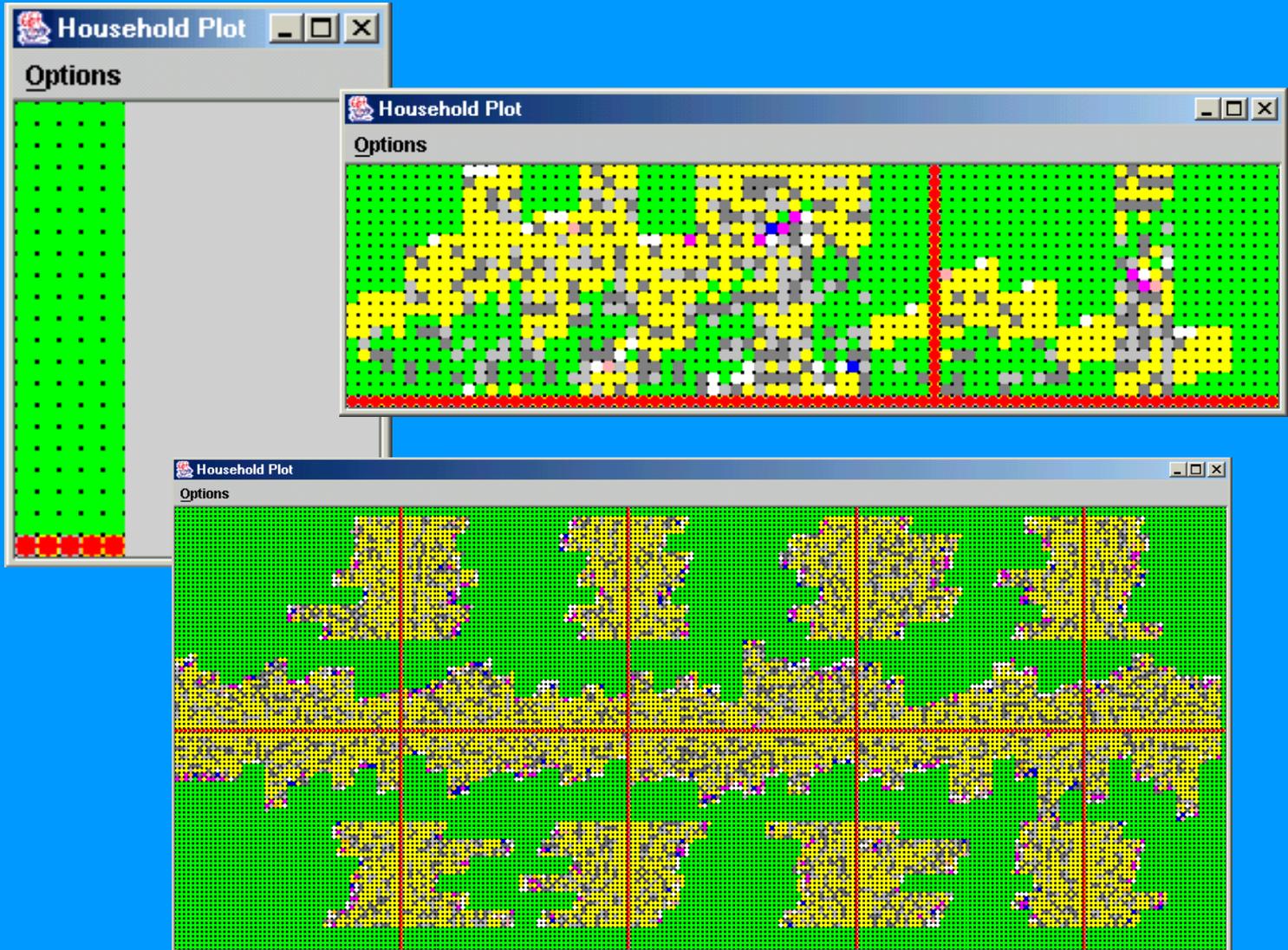
Peter J. Deadman, Derek Robinson

Department of Geography, University of Waterloo, Waterloo, Ontario, Canada

Emilio Moran, Eduardo Brondizio

Center for the Study of Institutions, Population, and Environmental Change
and Anthropological Center for Training and Research on Global
Environmental Change, Indiana University

Adjustable Study Area



Land Cover and Soil Grids

Displayable & Probe-able

The image displays a simulation interface with two main grid windows and a legend. The left window shows a land cover grid with various colored pixels. The right window shows a soil grid with yellow and grey pixels. A legend window is positioned between them, listing various land cover and soil types with corresponding color swatches. Two probe windows are open, displaying detailed data for selected agents.

Household PL... Legend

- Rice
- Beans
- Vigna Cowpeas
- Forest
- Maize
- Manioc
- Cacao
- BlackPepper
- Pasture
- Fallow/Sec.Succession
- Roadway
- Soil Legend
- Good Soil
- Fair Soil
- Poor Soil

SoilAgent Probe Window

AgentType:	SoilAgent
Aluminum:	0.14871743465
Carbon_pct:	1.35838097033
Class:	Class
Clay_pct:	52.3740801215
ContinuousUse:	1
Nitrogen:	0.10811149788
PH:	0.56291323535
Phosphorus:	1.0897543245
X:	4
Y:	23

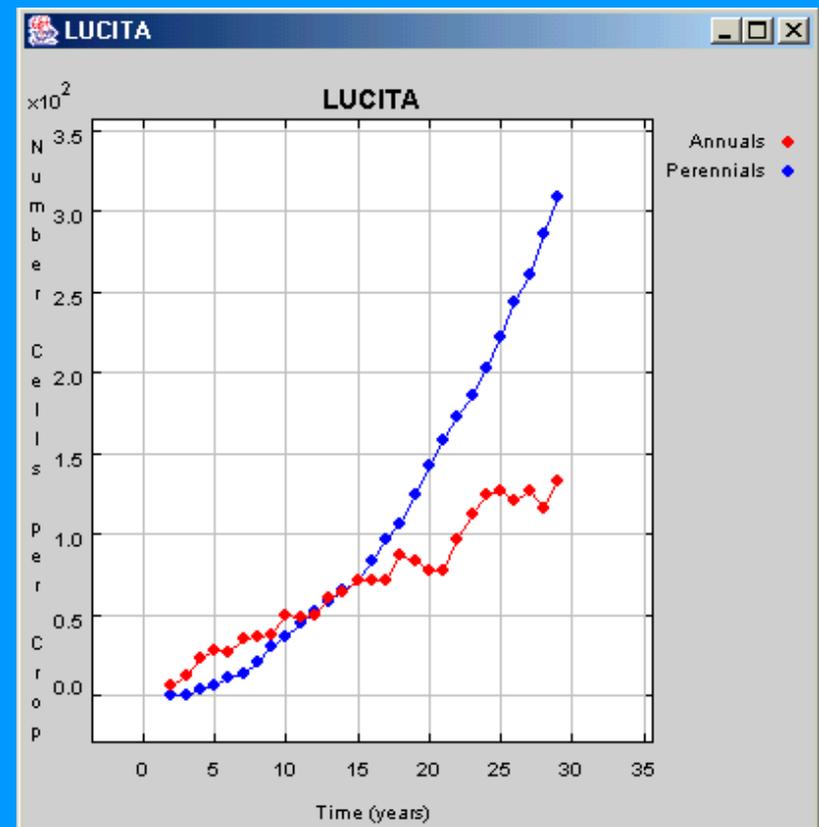
BlackPepper Probe Window

Age:	
AgentType:	BlackPepper
Class:	Class
DeathAge:	12.5
InitialFixedCost:	16.38
MaintenanceCost:	995.12
ReqLabour:	408.0
X:	4
Y:	23

Object Oriented

And Much More...

- Ability to alter cell selection
- Ability to alter plot selection
- Farmers leave or are removed if they can not provide for themselves. Plots are then opened up for new farmers
- Households have a number of children who donate variable amounts of labour.
- Automatic road and plot creation with identification IDs



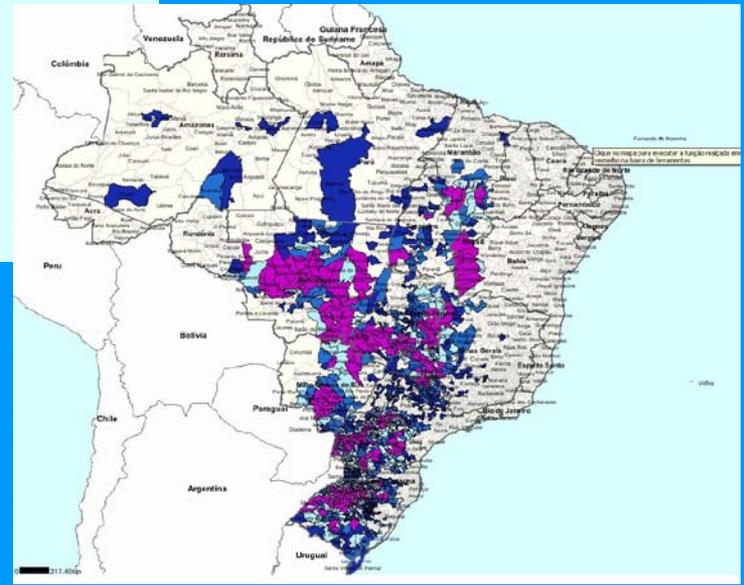
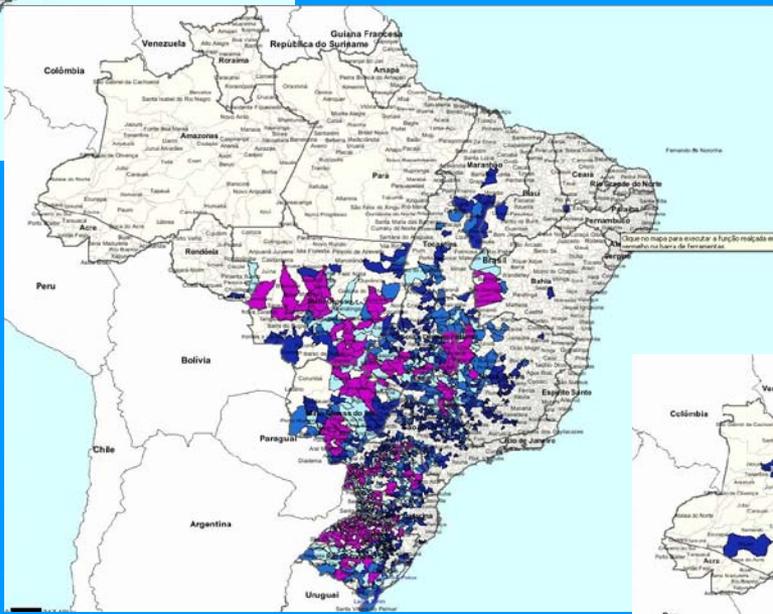
Markets and land use change

→There is a coupling between market signals (e.g., commodity price) and farmers' decision-making on land allocation influencing land cover change in the Amazon.

→We have found that small-scale land use systems in the Amazon are closely related to and adapting to change in market dynamics, though presenting variability in the level of responses according to household conditions (e.g., labor, knowledge of resources), available resources (e.g., soil, forest), and access to capital (e.g., credit), and land tenure condition.

→Changes prompted by national and regional commodity markets, such as inter-annual and decadal price of agricultural and forest products have considerable and measurable consequences to land cover.

Municipalities producing Soybeans 1990 – 1995 - 2000 (Map derived from IBGE – SIDRA)*



External markets and expansion of acai fruit production areas, 1985 - 2000



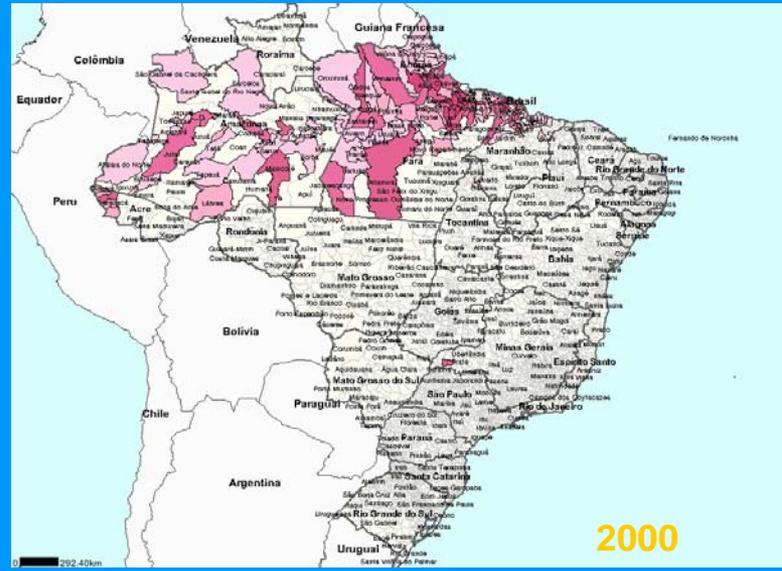
~1985*



1990



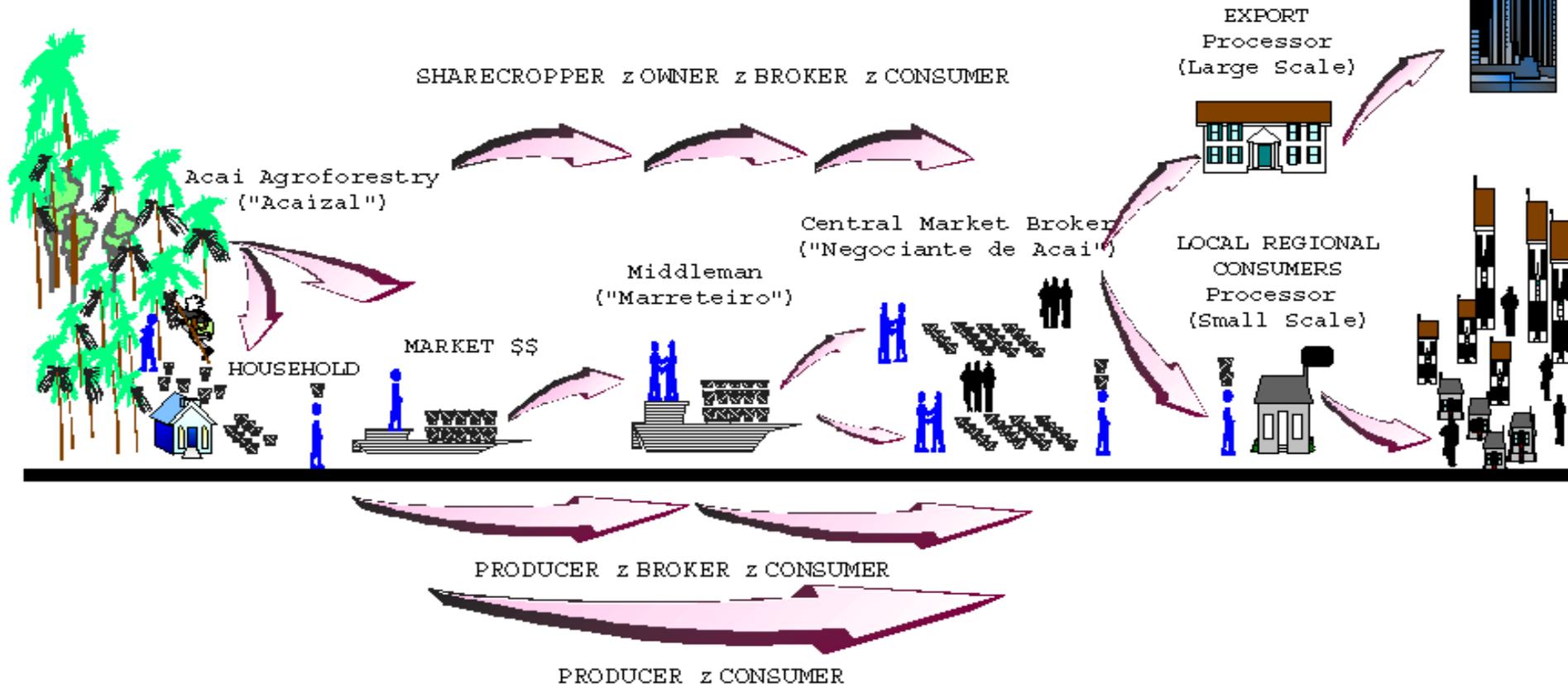
1995



2000

*Three shades of color indicate ranks of fruit production: low (lighter) to high (darker)
** 1985 data not available at IBGE-SIDRA; map approximated from areas of heart of palm production

The Acai fruit commodity chain: Producer – Consumer interactions



Producer – Intermediaries – Processor - Consumers

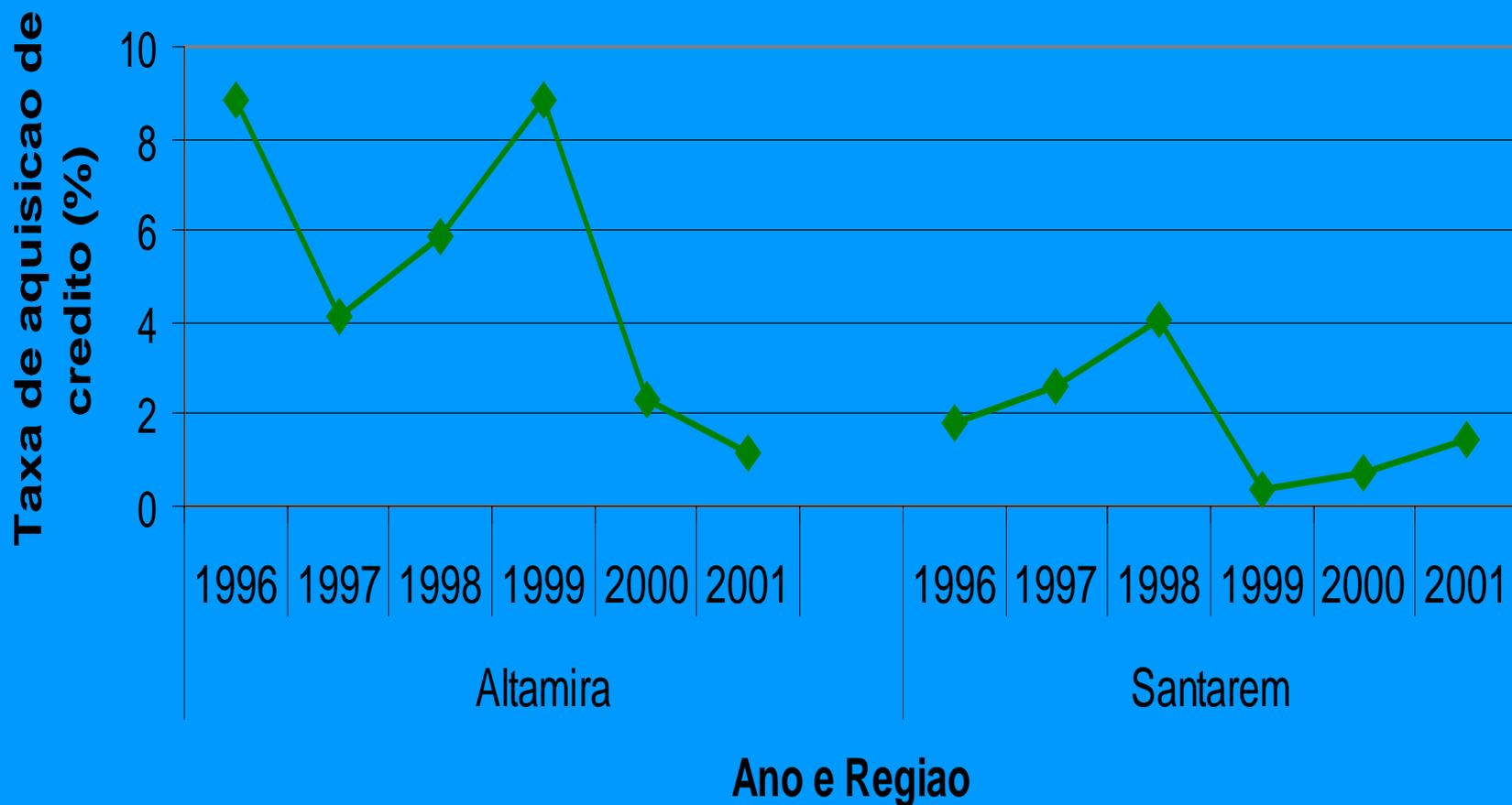
Credit incentives, technology, and land use

Santarem and Altamira regions

- low rates of credit availability and acquisition
- Lack of technological support
- Lack of defined land tenure condition

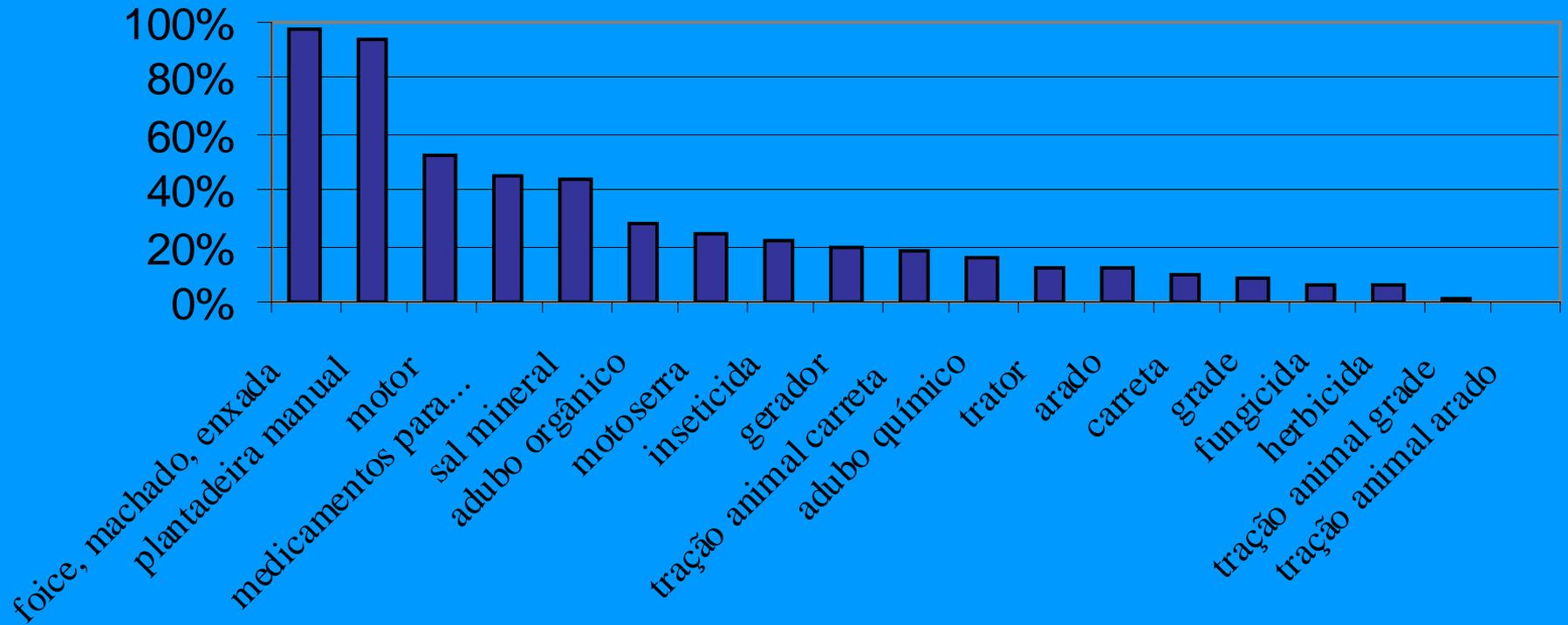
General Credit acquisition rate: 1996 a 2001

Taxa geral de aquisicao de credito (%)



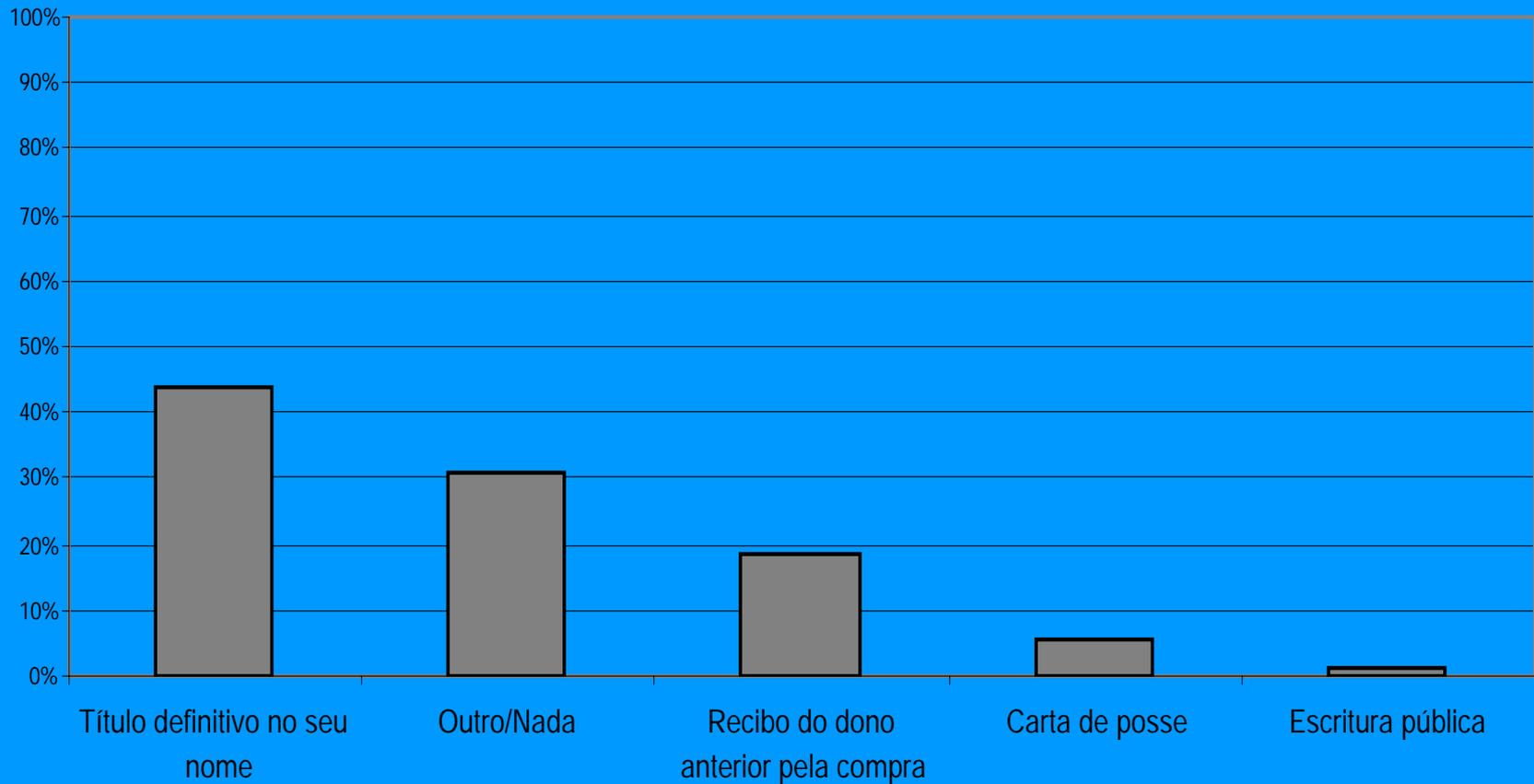
Agricultural technology (Santarem region)

Tecnologia e Implementos para Agricultura e Pecuária



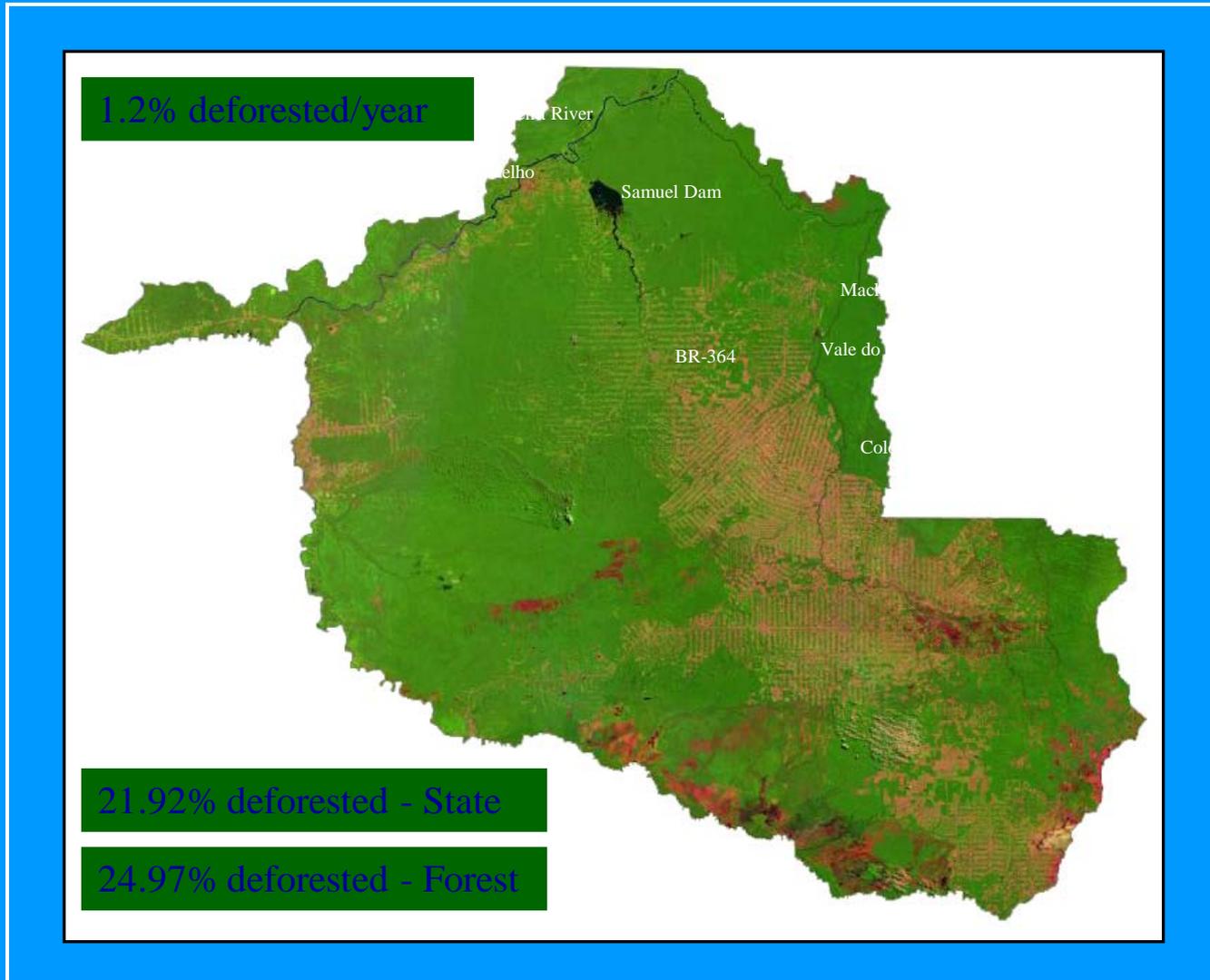
Land tenure condition (Santarem region)

Situação Fundaria Anos 2001 e 2002



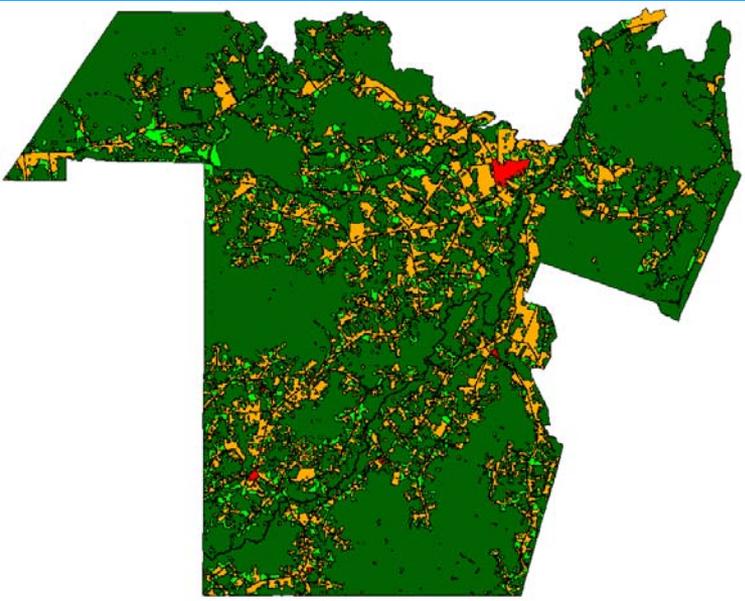
Institutions and land use change

- The role of local people organizing protect the forest reserves in Machadinho was crucial
- Deforestation rates were the same in fishbone and in topographically adjusted settlement pattern
- Only difference was the creation of reserves, and local self-organization to protect the reserves from neighbors



The State of Rondônia seen through a mosaic of Landsat TM images from year 2000 (Embrapa 2001)

Landscape Structure and Change



LPI (%)	MACHADINHO D'OESTE INCLUDING RESERVES			MACHADINHO D'OESTE EXCLUDING RESERVES			VALE DO ANARI		
	1988	1994	1998	1988	1994	1998	1988	1994	1998
	Forest	17.7	13.3	10.7	15.2	8.0	2.6	13.2	5.5
Succession	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.3
Production	0.1	0.4	0.5	0.2	0.5	0.8	0.3	1.1	2.9
Others	0.2	0.3	0.3	0.3	0.4	0.4	0.2	0.2	0.2



MPS (ha)	MACHADINHO D'OESTE INCLUDING RESERVES			MACHADINHO D'OESTE EXCLUDING RESERVES			VALE DO ANARI		
	1988	1994	1998	1988	1994	1998	1988	1994	1998
	Forest	319.0	219.1	167.4	182.1	107.8	65.7	556.4	224.9
Succession	2.0	4.2	5.9	2.0	4.1	5.9	2.4	4.4	8.3
Production	7.0	12.9	15.0	7.2	12.9	15.2	13.5	27.8	25.2
Others	0.4	0.4	0.4	0.3	0.4	0.4	0.7	0.7	0.8



- Mean patch size of forest decreases at a higher rate in fishbone. In 1994, MPS is similar in both settlements
- Mean patch size of farmland is greater in fishbone

Change detection techniques

- Many change detection techniques have been developed, but selection of a best suitable approach for a specific study area is not straightforward task (Lu et al. in press, IJRS).
- A comparative study of different methods is often used to identify a suitable approach and result (Lu et al. in revising and resubmission, IJRS).

Change detection techniques (cont.)

- The change detection based on spectral mixture analysis of multi-temporal images provides the flexibility of some specific change purposes, such as forest degradation (Lu et al., 2004 (forthcoming), CJRS).
- Change detection based on biophysical parameters are especially useful for detection of vegetation changes (Lu et al. 2002, ASPRS conference)

Biomass Estimation

- TM/ETM+ data are more suitable for SS biomass estimation, instead of mature forest biomass estimation (Lu et al., in press, CJRS).
- Incorporation of spectral responses and texture improves biomass estimation performance (Lu et al. 2002, In: *Advances in Spatial Data Handling*)

Biomass Estimation (cont.)

- Different biophysical conditions affect biomass estimation, leading to the difficulty to transfer the models for different study areas (Lu et al. 2004 (forthcoming), In: *Seeing the Forest and the Trees: Human-Environment Interactions in Forest Ecosystems*).
- Textures are less important for SS biomass estimation, but important for advance SS or mature forest biomass estimation, or those forest sites with complex stand structures (Lu and Batistella, in press, *Acta Amazonica*).

Soil fertility

(Lu et al. 2002, LD&D)

- Vegetation biomass has significant relationships with soil fertility and certain nutrients.
- Different soil types, such as alfisols, ultisols, and oxisols, affect these relationships. For example, the nutrients in surface layer soils in alfisols are more important for vegetation biomass accumulations, but ultisols and oxisols deeper horizons significantly influence vegetation growth rates.
- The biomass accumulation is more significantly related to soil fertility in alfisols than in ultisols and oxisols.

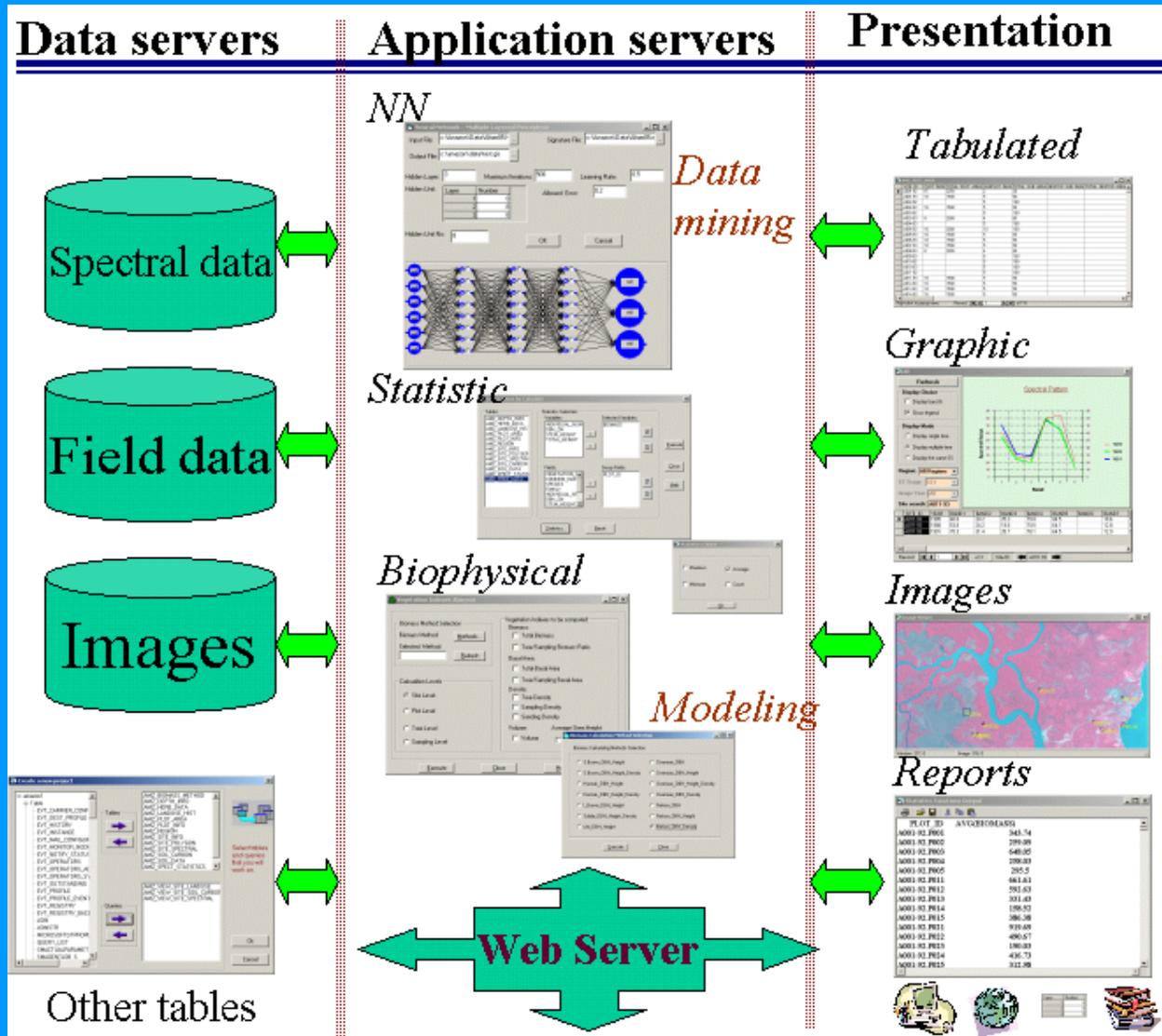
Evaluation of Soil Erosion Risk (Lu et al., in press, LD&D)

- Soil erosion is a common phenomenon resulting in land degradation and environmental deterioration.
- Many factors, such as precipitation, soil conditions, terrain factors, and vegetation covers, interplay in soil erosion, leading to the difficulty in estimating soil erosion or mapping erosion risk.
- Remote sensing and GIS provide an effective method for evaluation of soil erosion risks in the Amazon basin.
- Majority of advanced successional and mature forests are in very low and low risk, but some areas that fall in initial succession, agroforestry, and pasture are in medium and high risk.

Amazon Information System

- We have developed a comprehensive information management system to store, display, integrate, manage, analyze, and model both regular data and image data
- Integrates ERDAS, Oracle, SQL, arcinfo, arcview, visual basic and spss
- Uses artificial neural networks to enhance modeling capabilities
- Currently being tested by other LBA collaborating projects

AIS – Amazon Information System



Education and Training

- **Educational CD:**
- Dias, N.W., P. Mausel, G. T. Batista, E. M. L. Novo, and T. Krug, Indiana State University Geo-Technology Center successfully completed the development of a two CD-ROM set entitled "*Sensoriamento Remoto: Aplicações para a Preservação, Conservação e Desenvolvimento Sustentável da Amazônia*" [Remote Sensing: Applications for Preservation, Conservation and Sustainable Development of the Amazon].

6 Doctoral Dissertations completed:

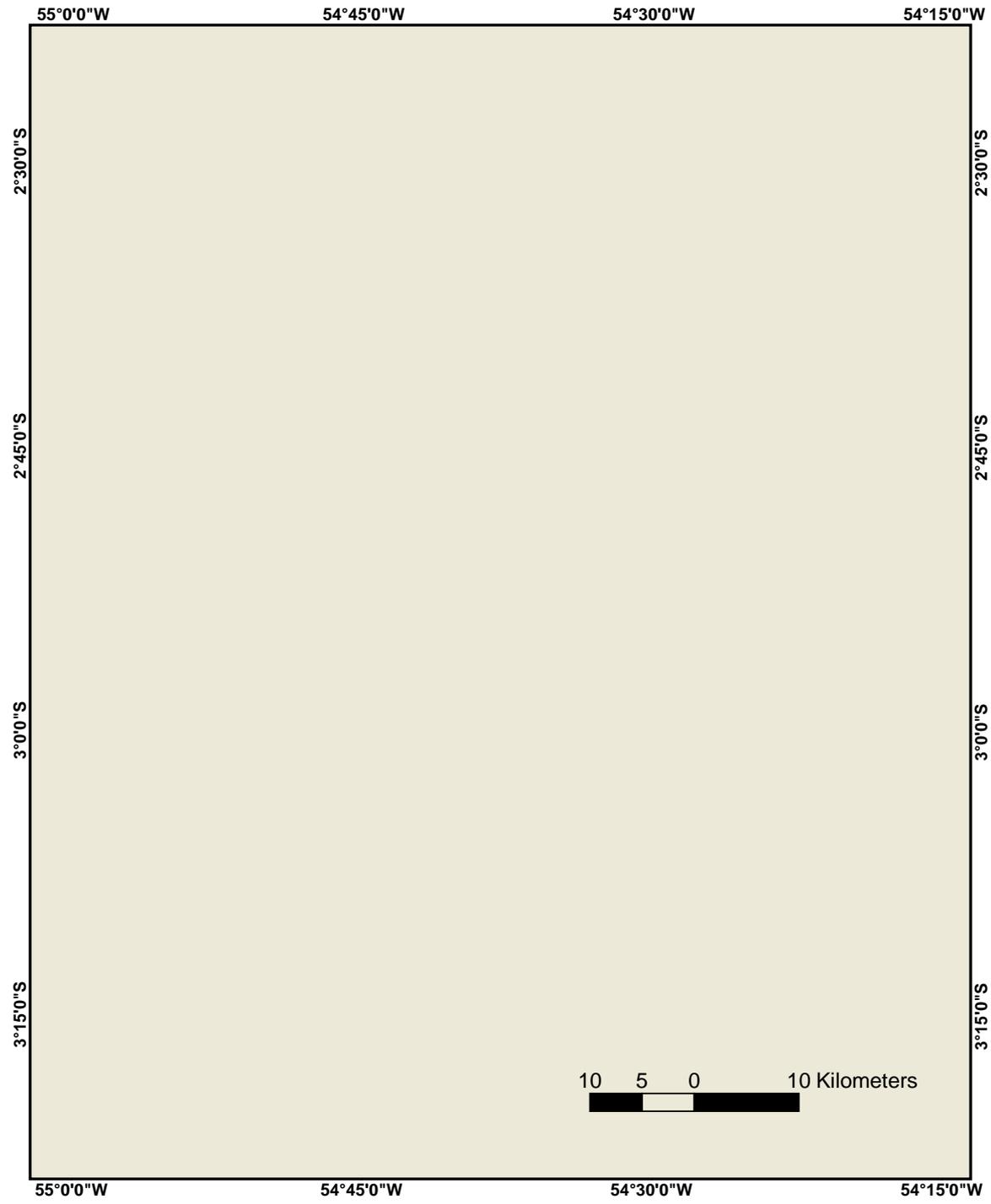
- **1999:** *Maria Clara da Silva Forsberg**. 1999. Title: "Protecting an urban forest reserve in the Amazon: A multi-scale analysis of edge effects, population pressure, and institutions." School of Public and Environmental Affairs, Indiana University.
-
- **2000:** *Fabio de Castro**. 2000. Title: "Fishing Accords: The Political Ecology of Fishing Intensification in the Amazon." School of Public and Environmental Affairs, Indiana University.
- *Celia Fudemma**. 2000. Title: "Collective Action and Assurance of Property Rights to Natural Resources: A Case Study from the Lower Amazon Region, Santarem, Brazil." School of Public and Environmental Affairs, Indiana University.
- *Dengsheng Lu*. October 2000. Title: "Estimation of Forest Stand Parameters and Application in Classification and Change Detection of Forest Cover Types in the Brazilian Amazon Basin." Indiana State University, Dept of Geography.
- **2001:** *Mateus Batistella**. 2001. Title: "Landscape Change and Land-Use/Land-Cover Dynamics in Rondônia, Brazilian Amazon." School of Public and Environmental Affairs, Indiana University.
- **2002:** *Hui Li*. 2002. Title: "Identification of Spatial and Temporal Patterns of Secondary Succession Changes in Altamira, Brazil: Integrating Remote Sensing and GIS Technology." Geography, Indiana State University

• *Courses and training in Brazil:*

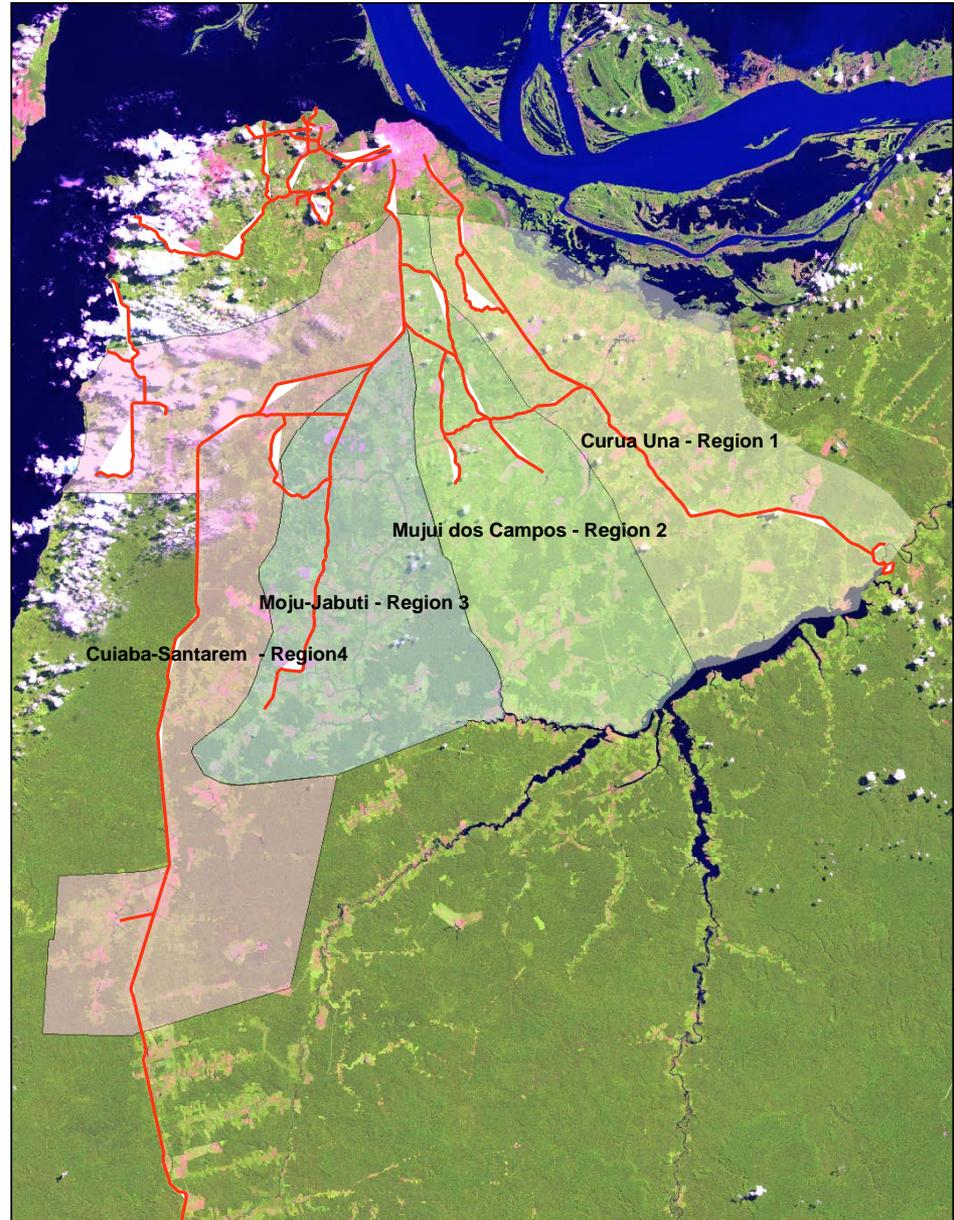
- UFAC, Acre: Human dimensions of LCLUC
- GISBrasil 2002 and 2003: Course in Geotechnologies and the Environment
- GEOBrasil 2002: Course in Geotechnologies and the Environment
- SENAC: Course in Human Dimensions of Land-Use/Land-Cover Change in 2002
- PUC-Campinas: Courses in GIS and Land-Use Planning
- INPE: Seminar in Human Dimensions of Land-Use/Land-Cover Change in 2002
- EMBRAPA: Seminar in Human Dimensions of Land-Use/Land-Cover Change in 2002

Image with
property
grid and
major roads
in red.

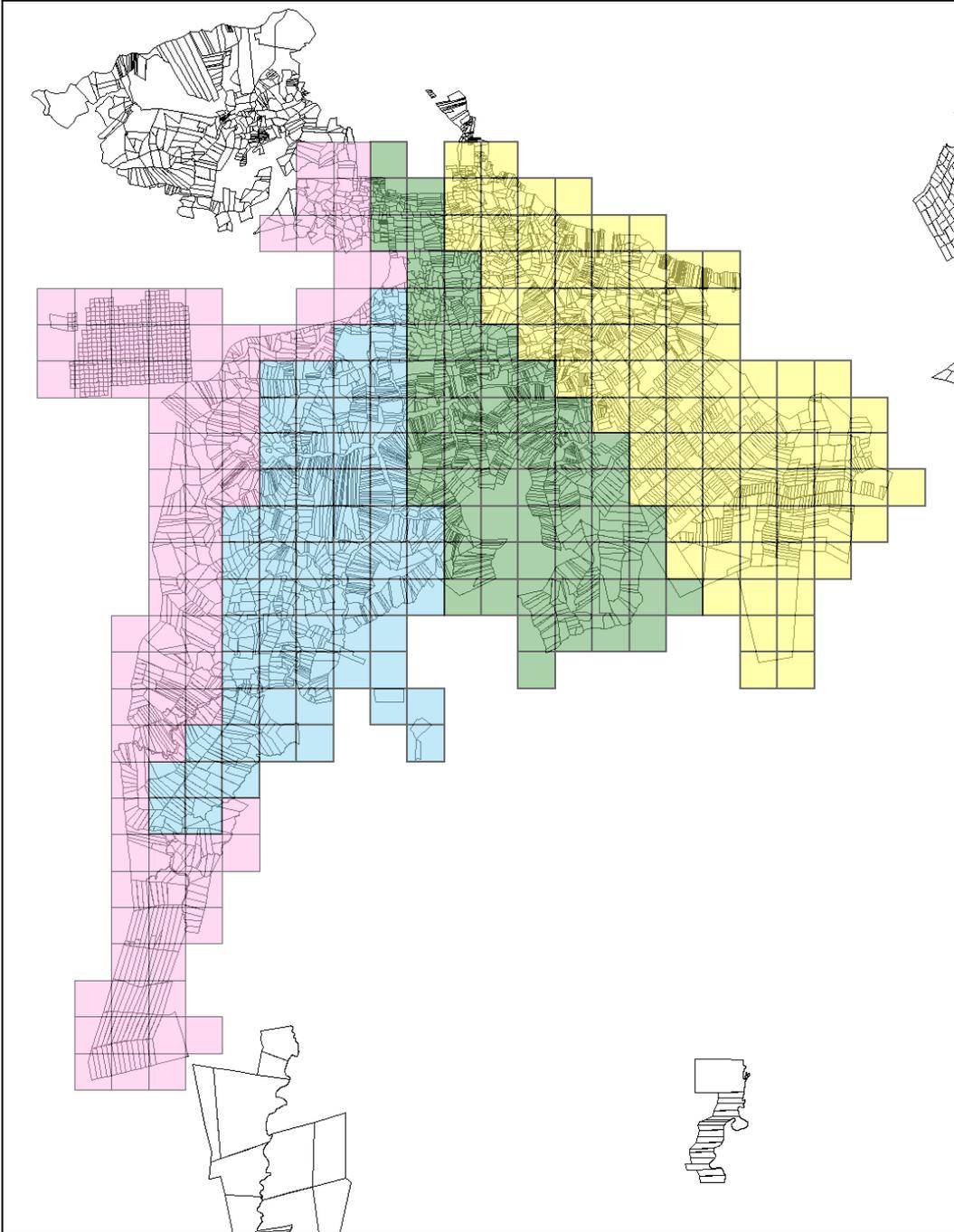
Sampling
approaches
in Santarem



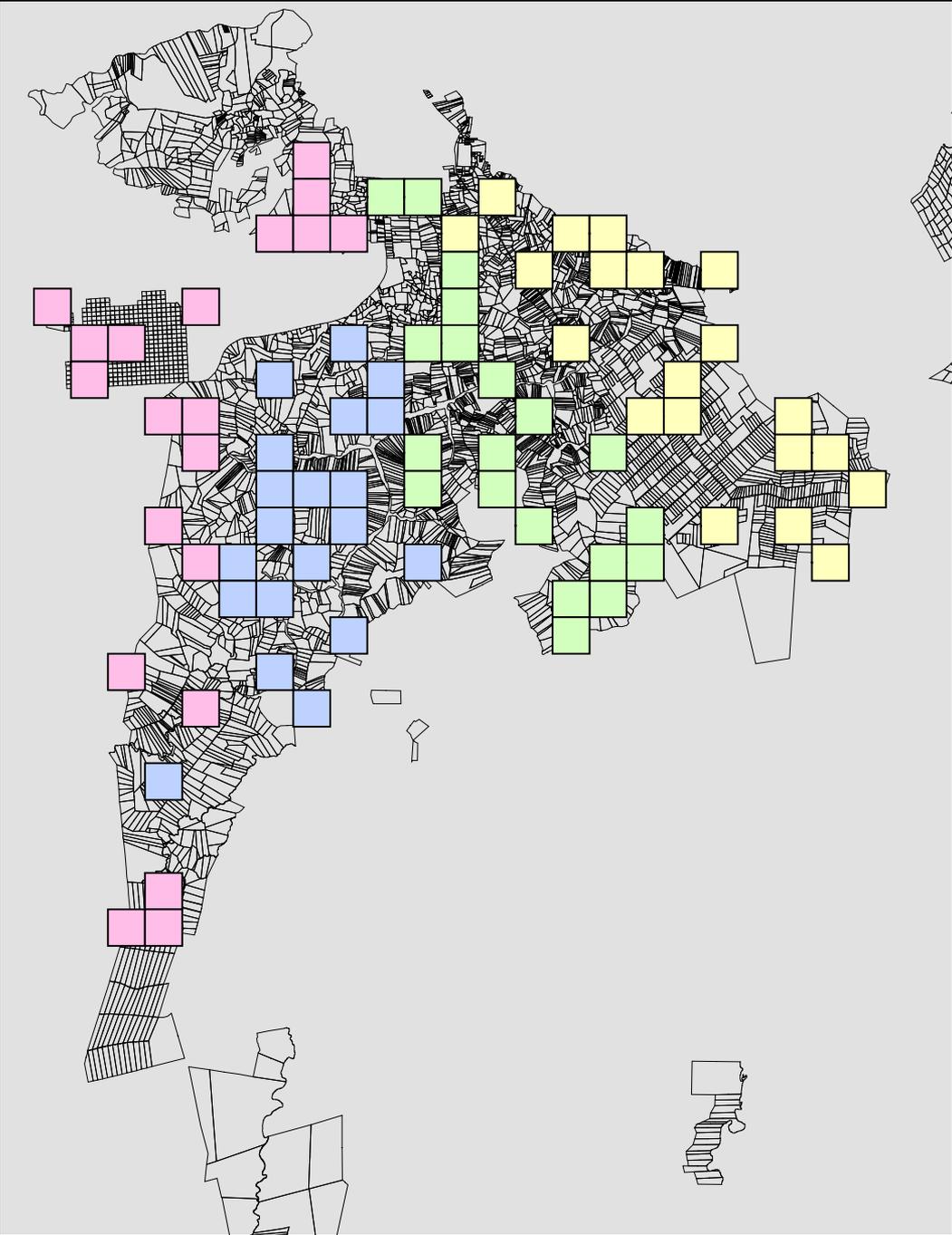
- We identified four regions following the four major road networks which determined the timing of settlement.
- Halfway between these was used to delineate each of the four regions.



- Each region was divided into 3km X 3km cells

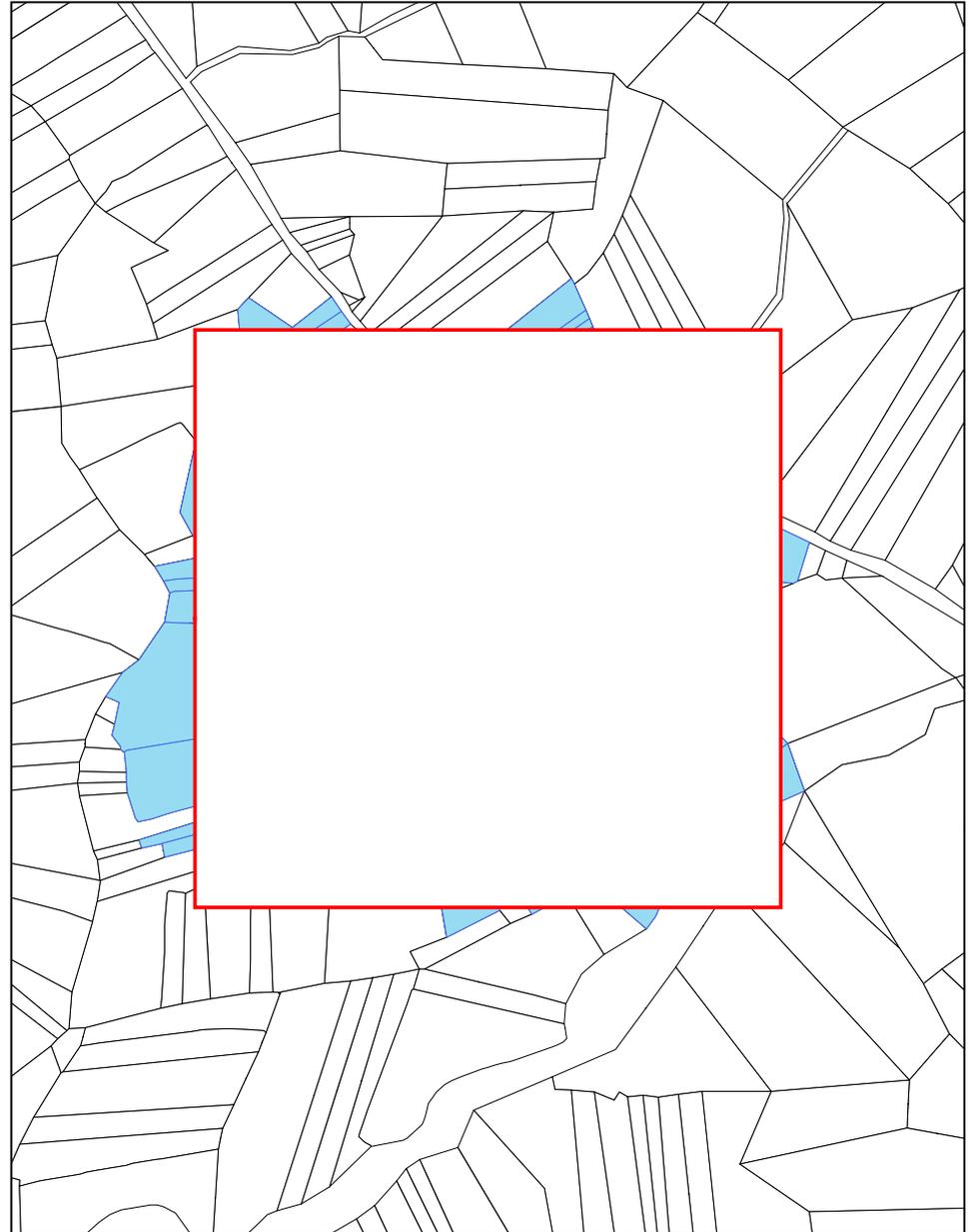


- A random sample of 20 target grid cells were then selected for each region.

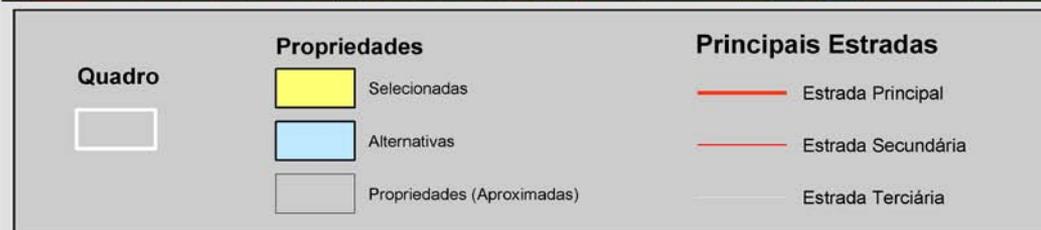
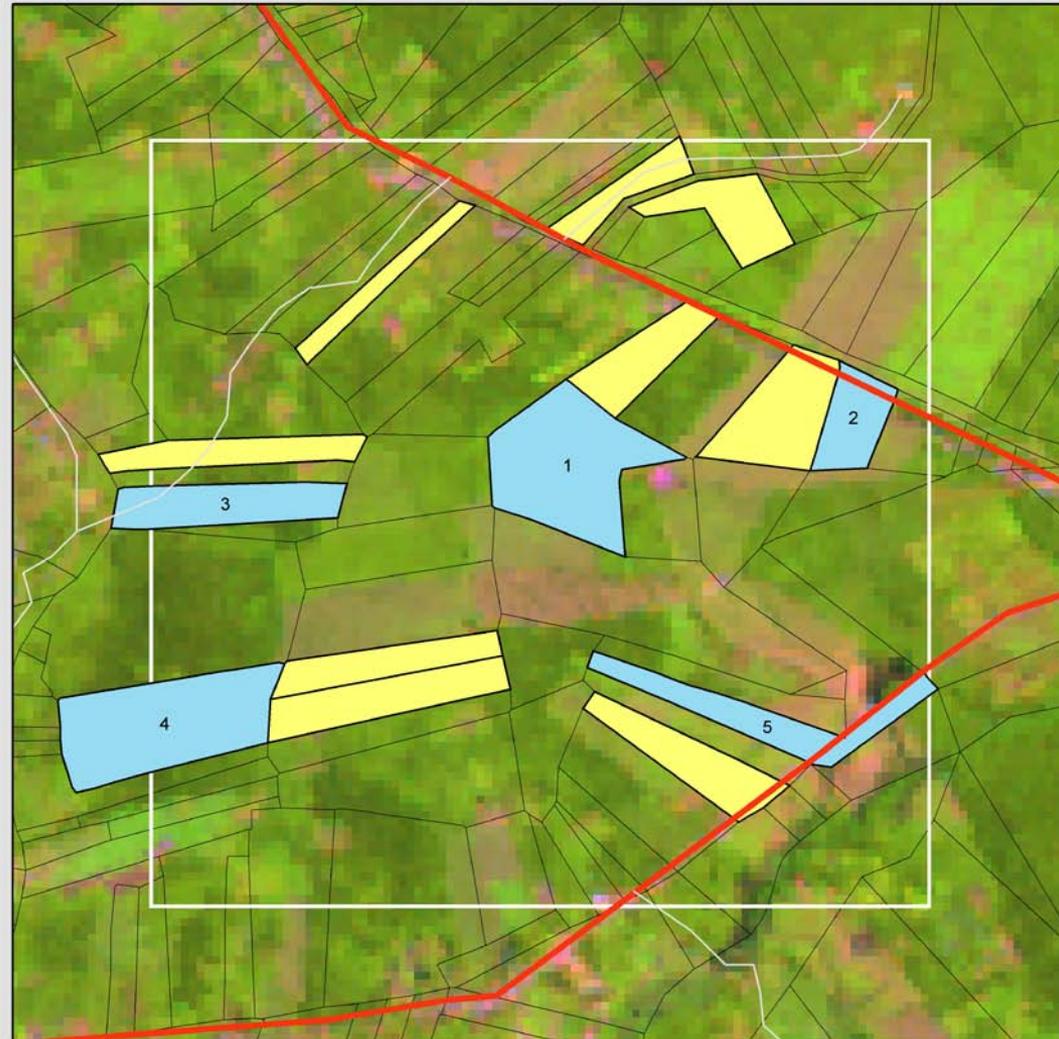


Region 1 - Target Grid Cell 9

- All properties whose center point lie within a particular grid cell boundary were considered to be within that grid cell.



Region 1 -Grid Target 9



- From each of these groups of selected properties 14 (maximum) properties were selected at random.
- The first 9 randomly selected properties were assigned as target properties the final 5 as alternates.
- In the cases where 9 or fewer properties had their center within a target grid cell, all properties would be assigned as targets.

Thanks!

Relevant modeling issues 1 :

→ We have found that simple, dichotomous land cover classifications hinder the understanding of intra-regional variability and limit the linkages between land use systems and spatial land cover patterns.

→ We found that some of the most relevant land use systems (e.g., agroforestry and agricultural sites) may disappear from regional analysis, thus posing enormous implication to understanding and projecting land cover change. These findings should caution against the use of generalized variables to predict future land use and cover change.

Relevant modeling issues 2 :

→ Data limitations, for instance, regarding soil patchiness as well as poor understanding of the role of different types of access (e.g., roads versus waterways) needs to be considered in any attempt to model factors influencing regional land use change.

→ We have found that capturing 'process-pattern' linkages in land use and cover analysis is scale dependent. While spatial land cover patterns resulting from land use activities may be somewhat clear at the community level, these tend to disappear at the regional level due to variations in land use systems and environmental characteristics across short distances.

Relevant modeling issues 3:

→ We have found that inter-regional differences in rates of regrowth are best explained by the differences between soil fertility, whereas intra-regional differences are best explained by the differential impact of land use history on forest recovery. This difference in results, stemming from differences in aggregation and scale of analysis serves as a warning to facile generalization, but also raises the question whether this difference may be due to limits on the quantity and quality of data at the right scale for the analysis at each scale.

→ We have found that biomass estimation is region specific, and that allometric equations are still limited in their accuracy beyond the forest type from which they were derived. There is a clear need for further developments of more accurate estimation approaches combining advanced remotes sensing techniques and a greater range of allometric equations. We found that a combination of spectral and texture components in the analysis of remote sensing data improves AGB estimation performance.

Publications 1:

- *Integration of units of analysis in the study of LCLUC (farm, settlement, regional levels)*
- -Related publications: McCracken et al 1999 (PERS), , Fudemma and Brondizio 2003 (Human Ecology); Brondizio et al 2002, Moran et al 2002, McCracken et al 2002 (all Wood and Porro book), Siqueira et al 2003 (Gender book), Evans et al 2001 (Ecological mModeling), Lim et al 2002 (ABM book), Brondizio book under review (book manuscript Columbia U.P.), Batistela et al 2003 (PE&RS); Castro et al 2002 (Field methods); Batistela and Brondizio 2001 (paper1st. prize GIS-BRASIL); Moran and Brondizio 2001 (Rappaport ort book); Brondizio, Castro, and Batistela et al 2000 (LBA science poster)

Publications 2:

- *Study of Land-Use Driving Forces.*
- -Related publications: McCracken et al 1999 (PERS), Brondizio 1999 (book chapter), Fudemma and Brondizio 2003 (Human Ecology) Batistela e Moran in press (Acta Amazonica); Brondizio et al 2002, Moran et al 2002, McCracken et al 2002 (Wood and Porro book), Siqueira et al 2003 (Gender book), Evans et al 2001 (Ecological Modeling), Lim et al 2002 (ABM book), Brondizio in press (Culture and Agriculture), Brondizio book under review (Columbia U.P.), Brondizio in press (Working Forests book), Brondizio et al 2003 (Urban Ecosystems).

Publications 3:

- *Comparative remote sensing methodologies and biomass estimation methods (image calibration and spectral modeling)*
-
- -Related publications: Tucker, Brondizio, Moran et al 1998 (Interciencia), Moran et al 2000 (FE&M), Lu et al in press (Canadian Journal of RS); Lu et al 2003 (FE&M), Lu et al (RSE), Lu et al (IJRS), Lu et al submitted (cipec book chapter), Lu et al 2002 (Land degradation and development), Moran et al 2000 (A. Hall's book chapter); Lu et al 2002 (Advances in Spatial data handling book); Ponzoni and Rezende in press (Arvovre)

Publications 4:

- *Study of Comparative Forest Regrowth Rates.*
- **-Related publications:** Tucker, Brondizio, Moran 1998 (Interciencia), Moran et al 2000 (FE&M), Lu et al in press (Canadian Journal of RS); Lu et al 2003 (FE&M), Lu et al submitted (book chapter), Lu et al 2002 (Land degradation and development), Moran et al 2000 (book chapter); Lu et al 2002 (Advances in Spatial data); Ponzoni and Rezende in press (Arvovre)

Publications 5:

- *Study of Land-use Footprints.*
- -List of publications: Batistela et al 2003 (PE&RS); Castro et al 2002 (Field methods); Batistela and Brondizio 2001 (1st. prize GIS-BRASIL); Moran and Brondizio 2001 (Rappaport ook); Batistela et al 2000 (Int'l archives of the ISPRS); Brondizio, Castro, and Batistela 2000 (LBA science poster)