Household Decision Making and Patterns of Land Use Change in LUCITA: An Agent Based Simulation of the Altamira Region, Brazil

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EXTENDED ABSTRACT

A number of agent based simulations have been designed to capture the dynamics of land use change. These simulations have focused on both abstract and real-world examples in which the actions and interactions of a collection of agents, representing individuals, households, or organizations, determine the overall patterns of land-use change produced by the simulations. In these applications, the specific attributes and the model of decision making contained within the agents is typically derived from the theoretical foundation driving the development of the simulation. Clearly, the output produced by these simulations is heavily influenced by a number of factors including the individual decision making mechanisms of the agents, the attributes of individual agents, the heterogeneity of the population of agents, and the level of interaction between agents.

This paper outlines some recent work with the LUCITA simulation system, an agent based model of land use change in the Altamira region of the Brazilian Amazon. Rapid deforestation of the Amazon in the past few decades has resulted in a great deal of concern as a result, in part, of losses to biodiversity and and the role of the Amazon as a global carbon sink. While the factors influencing land use change in the Amazon are fairly clear at the regional level, the factors operating at local levels are more difficult to understand. Agent based simulations that focus on human-environment interactions, are ideally suited for exploring the factors that affect land use change.

This study focuses on a region of the Amazon rainforest along the Transamazon highway west of Altamira, Brazil. Since the construction of the highway in 1970 and the subsequent settling of the land by families developing household farms on plots with an average size of 100 hectares, this region has experienced rapid and profound change. Numerous studies in the region have linked land use change to local factors, such as household demographics and soil quality, and regional factors, such as commodity prices, government credit policies, and inflation.

In an effort to disentangle the relative influence of some of these factors on land use change, an agent based simulation was developed to represent the human and natural systems of the region. In this simulation, household agents must make land use decisions based on their own characteristics and those of the local socio-economic and natural environment.

This paper describes the structure of the LUCITA simulation system, while focusing on the influence of household capital resources and the demographic characteristics of household cohorts on the resulting patterns of land use change produced by the model. Three sets of simulations were run in which the capital resources of the household agents were set to low, average, and high levels. The output form these three scenarios, recorded as trend in land use over time and patterns of land use quantified by landscape metrics, were compared.

With increasing levels of available household capital, household moved away from growing annuals, to growing combinations of perennials and pasture, resulting in a more complex landscape. The results raise a series of questions for future research within the region.

1.0 INTRODUCTION

Interest in the application of agent based models (ABMs) to the study of land use/cover change (LUCC) has grown considerably in the past five years. These simulations typically couple a natural system, represented by a raster grid of spatially distributed land uses within the landscape, with a human system, represented by a collection of agents making land use decisions. Temporal chages in land use arise within the simulation as a result of interagent and agent-landscape interactions.

This paper reports on the ongoing effort to develop an agent based simulation of land use change in the amazon (LUCITA) in a region of the Amazon rainforest near Altamira, Brazil. This region is characterized by the development of family farms, on plots of approximately 100 hectares, along the transamazon highway and its side roads to the west of Altamira.

LUCITA is designed to explore the interactions between human and environment systems. By varying input parameters such as household composition, household capital endowment levels, and soil quality, the model intends to explore the effect of these factors on patterns of LUCC observed in the region. From previous research in the region, these factors are thought to have an important influence on the land use decisions of individual farming households.

This paper, presents a short history of land use change in the Altamira region, focusing on the colonization activities of farming households during the period between 1970, when the area was initially developed, and the present. Research conducted during this time to understand the importance of family size and available family labour on land use decision-making at the individual property level is described. The structure of the current version of LUCITA is described with a focus on exploring the effects of initial household capital on patterns of land use change produced by the simulation.

1.1 Land-use Change in the Amazon Region

The Brazilian Government's interest in developing the Amazon has been expressed through both economic incentives, such as credit programs, and the creation of the Transamazon highway. Wherever the highway traverses the Amazon, marked changes in land use have been observed, including deforestation (Moran and Brondizio 1998). Although large scale causes of deforestation in the Amazon, such as logging, cattle ranching, mining, road construction, and hydroelectric development, are obvious, the factors and processes influencing land use change at more local scales have been more difficult to disentangle.

In some regions of the Amazon, such as that to the west of Altamira, these local scale factors predominate. These regions are frequently characterized by small land holdings, operated by individual families as opposed to corporations. In the region west of Altamira, research has begun to reveal how patterns of deforestation are affected by a variety of factors operating at local and regional scales. Locally, land-use decisions are affected by factors including household demographics, available capital, and soil fertility (McCracken *et al.*, 1999). At the regional scale, socioeconomic factors, including government credit policies, commodity markets,, and inflation also exert a significant influence on land-use decisions (Moran, 1981). In addition, there are a whole series of complex interactions between these local and regional factors that influence the patterns of observed land use.

Research conducted over the past decade has focussed on: rates and patterns of deforestation (Brondizio *et al*., 2002), the degree of secondary forest growth (Moran *et al*., 2000; Mausel *et al*., 1993), radically differing land patterns between neighbouring farms (McCracken *et al*., 2002), and the influence of soil quality on household success (Moran, 1995, Moran et al 2000). Of these studies, one that is of particular interest from an agent based modelling perspective, is based on the observation that neighbouring farms in the Altamira region often have radically different patterns of land use. This observation has raised research questions related to the relative importance of family and market factors in shaping land use decisions. One approach to this problem has been to study the individual cohorts who arrived on the Altamira frontier at different times, along with age and period effects (see McCracken *et al.*, 2002).

Research focussed on the phenomena, and based on the analysis of surveys carried out in the region, has led to the finding that land use changes in the region should be understood as a product of the age and gender characteristics of farm households as they interact with local environments and external factors (McCracken *et al.*, 1999). This research proposes that the types of agricultural activities engaged in by farm families is influenced by household characteristics, such as available capital resources and household labour. The land use strategies that these families most frequently engage in include the growing of annual cash crops, such as rice, maize, beans, and manioc; perennial crops, such as cacao and black pepper; fruit tree production; agroforestry; and the transformation of land into pasture with or without cattle. The work also has important implications for understanding how families that change over the years on the frontier, change their land use practices (McCracken *et al.*, 2002). Young families that arrive on the frontier typically have limited capital resources and young children. With such limited resources, these young families typically deforest three to five hectares of land a year to plant annual crops such as rice, beans, or manioc. This strategy generates quick income. As families grow over time and build their capital resources,, they continue to deforest their properties to grow annual crops, while also turning previously cleared land into pasture or perennial crops, or allowing the land to become fallow or enter secondary succession (McCracken *et al.* 2002)

The important observation from this research, with respect to the development of the simulation is that land use changes can be associated with the characteristics of individual households. By focussing on the individual household as the decision making unit, we hope to produce a simulation that allows the user to determine how these factors influence patterns of land use change. Here, we focus specifically on examining the influence of initial household capital on trajectories of land use change within these farm properties.

2.0 THE LUCITA SIMULATION

LUCITA is a spatially referenced ABM comprised of 2 sub-models that interact with one another through a raster landscape (Figure 1). These 2 sub-models represent the natural systems operating in the region and the collection of individual households that make land use decisions on their farms.. The current version of LUCITA is written in Java using the RePast multi agent simulation toolkit (Collier, 2000). The simulation allows the user to alter the demographic composition, as well as the labour and capital resources, of individual households to observe changes in household behaviour and resulting land use/cover changes within their plot of land (Robinson, 2003).

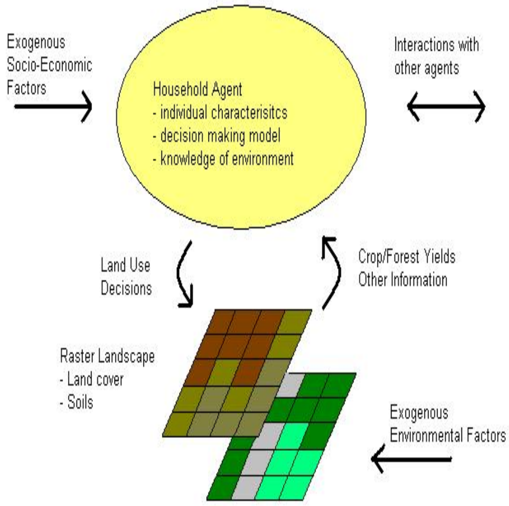


Figure 1: Conceptual model of the LUCITA simulation

2.1 The Landscape Model

The natural landscape model within LUCITA is represented as a raster landscape that is an abstraction of the Transamazon highway corridor west of Altamira. The property grid from the study region was rasterized so that each cell in the grid represents one hectare. Zones of cells comprise the individual properties controlled by a household agent. The raster landscape is represented by two spatially referenced grids, one indicating land-cover and the other soil quality.

Within the soil grid, each cell adjusts nutrient values in response to the land use activity occurring on the corresponding cell in the land-cover grid. Initial values for some soil parameters, soil changes through land-cover clearing and burning practices, and soil depletion and crop yield prediction are determined by regression equations developed by Fearnside (1984, 1986). The land cover grid, represents six annual or biennial crops (Maize, Rice, Bitter Manioc, Sweet Manioc, Phaseolus Beans, Vigna

Cowpeas) and two perennial crops (Black Pepper, Cacao) as well as pasture, virgin forest, and forest undergoing secondary succession. For the sake of visualization, annual and perennial crops are aggregated into single classes in the simulation output maps.

2.2 The Household Agent Model

Each farming household is represented in the simulation as an agent. Each agent can be parameterized with individual characteristics related to household demographics and capital. Further, the simulation can be programmed to represent different cohorts of households who arrived on the frontier in different years. This allows the simulation to replicate the cohorts that arrived in the region, as documented by Moran (1981).

Within each household agent, children of different ages and genders are tracked, their ages increasing through each round, or year, of a simulation run. By tracking the age of each child, the simulation can calculate the amount of available labour for each household in each year. Based on observations by Moran and Brondizio, most children begin to contribute noticeable amounts of farm labour after the age of 10 (Siqueira et al., 2002). By tracking the gender of each household member, available farming labour can be adjusted based on gender, as documented in Siqueira *et al.* (2002). At an age specified by the user, children leave the house in search of an independent livelihood or other economic opportunities. Although some families acquire additional plots of land for maturing children to manage, this process is not captured in the current version of the simulation.

In this version of the simulation, household agents are introduced into the simulation using a stochastic plot allocation process. This does not account for factors such as distance to market, and plot selection based on knowledge of the area, soil quality, topography, road conditions, and aquatic features. Households are permitted to arrive only if available plots exist. Available plots include those that have yet to be farmed as well as those that are abandoned by failing households, those which fail to earn enough capital to meet their subsistence requirements.

The subsistence requirement for a household indicates the level of food and other supplies, such as seed, clothing, transportation, and medicine, required by the family over a one year period. Each year, new subsistence requirements are calculated based on household composition as documented in Fearnside (1986). Subsistence food requirements are met through the production of crops for household consumption. Or the selling of cash crops and cattle

2.3 Household Decision Making

Household agents utilize a set of heuristics to make decisions regarding the agricultural land use practices they will pursue in each year of a simulation. The pros and cons of using a heuristic decision making strategy have been discussed by Geigerenzer and Todd (1999). Its usage in LUCITA is to provide a decision structure that accurately represents the majority of households in the study region. A heuristic decision tree is transparent and may be verified and validated with less confusion when compared to other types of strategies, like those based on artificial intelligence such as classifier systems of neural nets.

The decision tree employed by the agents is composed of three basic components where decisions are made regarding subsistence requirements, endowments, and soil quality. Land use decisions for each cell that is examined in a particular year are structured around three basic questions;

1) Are the households subsistence requirements met?
2) Does the household have enough resources to farm this cell?
3) Is soil suitable for the crop the household wishes to farm at a specific location?

In each round of the simulation, the agent begins by examining cells that are closest to the road and are not currently in either perennials or pasture. After expending resources to maintain the annuals and perennials, the agent considers developing new cells as farmland. If household subsistence requirements have not been met, and if enough capital and labour resources exist, then annuals are planted. If subsistence requirements have been met and surplus labour and capital resources exist then the land is cleared and, depending upon soil pH, either perennials or pasture is planted. LUCITA uses crop prices to create a weighted probabilistic function for crop selection.

In the version of LUCITA reported here, agent interaction occurs through a local labour pool. The labour pool is composed of farmers that have failed or have been removed from their plot due to the incurrence of excessive debt.

2.4 Simulation Runs and Validation

Simulation runs in LUCITA are set up to run for 30 iterations, such that the first iteration represents 1970 and the beginning of colonization in the area, iteration 15 corresponds to 1985, and so on. Households are allocated to plots at 0-50 per iteration to a site comprising 340 properties near the eastern end of the study site, the region closest to Altamira containing some of the first properties to be colonized.

Three sets of thirty simulations were run in which all parameters except household capital were held constant. In each of the three sets of simulations , household capital upon arrival was set to a value that was considered to be either low, average, or high. The purpose was to observe the effect that initial household capital has upon patterns of land use.

Within the field of MAS/LUCC modelling, a great deal of interest is currently focussed on the validation of these models . In early MAS/LUCC modelling efforts, validation was not often extensively addressed. More recently, a number of approaches have emerged which are designed to measure either the predictive or explanatory power of these models. When viewed as predictive tools, quantitative validation techniques can be employed in which simulation output is rigorously compared, by both the quantity and location of change, to known real world conditions (Pontius 2002). These approaches to validation typically employ spatial statistical measures to compare binary maps.

For a simulation like LUCITA, the goal is not to produce a specifically predictive model, but rather one in which relationships between different elements in the study system can be explored. The models serve to illustrate and explore particular phenomena, while acting as a tool for generating and testing new theories. The approach to validation taken here has been to compare overall trends in the output of LUCITA, measured as aggregate changes in land use over time for the entire study area, to quantitatively measured trends in land use, and to theoretical models of individual household decision making. Further, the spatial patterns of land use, as measured through the use of landscape metrics, are compared between the low, average, and high capital simulations. Landscape metrics, numerical measures of pattern in land cover, have been previously used to evaluate the outcomes of LUCC/ABMs by Parker and Meretsky (2004). The landscape metrics selected here are designed to measure the patchiness of the landscape under each of the three household capital scenarios. The metric used were number of patches (NP), patch density (PD), total edge (TE), and edge density (ED).

3.0 RESULTS

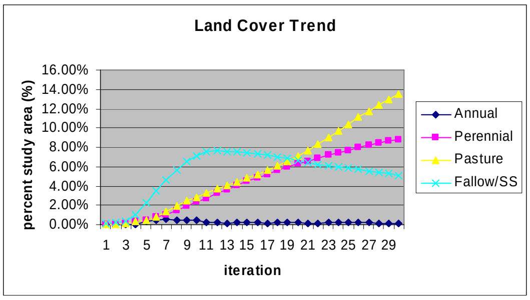
Results for the three separate simulation runs are presented for each simulation run in turn by examining aggregate trends in land use over time and the patterns of land use, as measured by the landscape metrics.

In response to varying levels of household income, distinct differences can be seen in the overall patterns of land use change shown in the three graphs in Figures 2, 3, and 4. At average income levels (Figure 2), patterns in land use display characteristics observed in the study site, with increasing levels of secondary succession over time as farmers follow a rotational pattern of planting annuals on a plot for a couple of years and then abandoning the plot as soil fertility, and hence crop yields, drop. During this time, the use of perennials and pasture increases as growing household resources facilitate the establishment and maintenance of these crops.

With low levels of household capital (Figure 3), farmers lack the resources to expand the size of their farms. As a result, the landscape is characterized by low levels of crop production and higher levels of secondary succession as more farmers devote resources to annual production.

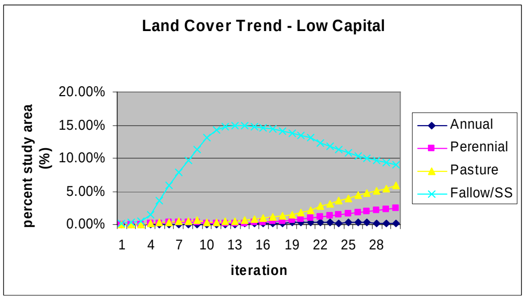
With high levels of household income (figure 4), we see a rapid transition to perennial and pasture production with associated low levels of annual production and the associated secondary succession.

The landscape metrics for the average, low and high levels of household income (Figures 2, 3,, and 4) indicate that as household income increases, so does landscape complexity. The landscape metrics reported here all increase with household income. The increasing complexity observed in the landscape is a result of the greater options available to the farming households as capital resources increase.



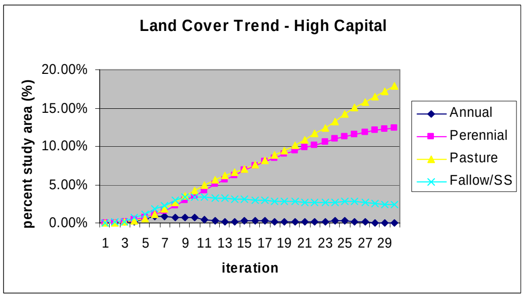
year	NP	PD	TE	ED
78	937	1.354	284700	4.1139
85	1004	1.4508	456500	6.5964
91	1028	1.4855	568600	8.2163

Figure 2: Patterns of land use over time and landscape metrics for 30 simulation runs employing average levels of initial household capital



year	NP	PD	TE	ED
78	386	1.1342	130500	3.8345
85	214	0.6288	69800	2.051
91	390	1.1459	177300	5.2096

Figure 3: Patterns of land use over time and landscape metrics for 30 simulation runs employing low levels of initial household capital



year	NP	PD	TE	ED
78	931	2.7356	279300	8.2067
85	984	2.8913	484700	14.2421
91	999	2.9354	640000	18.8053

Figure 4: Patterns of land use over time and landscape metrics for 30 simulation runs employing high levels of initial household capital

4.0 Discussion

Although the results presented here are preliminary in nature, they serve to demonstrate the potential of this tool for exploring questions related to the factors that influence land use change over time. A modelling approach such as this one in which localized decision making based on four primary factors, household composition, household endowment levels, soil quality, and burn quality, is capable of producing encouraging results.

The results seen in the average income scenario display land use/cover trends that are similar to those observed near Altamira. With some confidence in the behaviour of the simulation, the exploration of the effects of household income. As seen in the subsequent simulation runs, produce interesting results and raise research questions that could be explored in future studies.

It is important to note that none of the heuristics utilized for household decision making have a temporal component. Households do not make land use decisions on the basis of their length of time on the frontier, but simply on the basis of available household resources, the performance of past crops, and the characteristics of their property. The observed similarities between the temporal patterns of land use change in the simulation, and those observed in the field are therefore encouraging.

5.0 Acknowledgements

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