Linking spatial patterns of land-use to agents of deforestation in the Brazilian Amazon

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Summary

Changes in land use and land cover are associated with many environmental issues observed on the earth's surface. In the last decades, these changes were unprecedented, mainly in tropical forest areas. The Brazilian Amazon, the world's largest tropical forest, lost around 200.000 km² of primary forest in the last ten years (INPE, 2005). Considering this, and the consequences caused by this deforestation, it is important to know and define correctly the responsible agents, aiming at better public policies that can help preserve the forest. Searching for indicators that could help to identify the deforestation agents, some studies, such as Mertens and Lambin (1997), suggest that every deforestation process shapes the forest land in a specific way, producing a spatial pattern that can be interpreted as indicative of the agents with specific economic activities. Based on this hypothesis, the objective of this study was to contribute to a better understanding of land change processes in the Amazon forest, investigating the linkages between spatial patterns of deforestation, as visualized in satellite images, and different agents and their specific economic activities. To reach this objective, our methodological approach was based on socio-economic data acquired at a household level combined with data from satellite images. First, different spatial patterns of deforestation were identified on the satellite images, based on the typologies proposed by Husson et al. (1995). Then, some of the identified spatial patterns were isolated and analyzed for specific aspects, such as, the deforestation rate calculated through satellite images. socio-economic characteristics based on household survey data and evolution of land use and land cover based on thematic maps derived from satellite images. In addition, cluster analysis was applied using the socio-economic data (household survey) and land use and land cover data (satellite images) in a search for homogeneous groups related to the spatial pattern. In the end, an Analysis of Variance (ANOVA) was applied to confirm the differences between spatial patterns.

The results suggested that the different spatial patterns of deforestation found in the study area can be related to specific economic activities. Nevertheless, the results have indicated that the spatial configuration is not a consequence of its main economic activity. They suggest that the spatial configuration is linked to the

settlement project, and the main economic activity in the spatial patterns is a consequence of a set of factors such as: size of property, location and disposition of the property, presence or absence of infrastructure (road, market, transportation, economic and technical).

Contents

Chapter 1

Introduction

Human interactions with the terrestrial surface in search for subsistence and development brought notable advances for humanity in many aspects such as: food production and supply, shelter, transport, communication, water quality, production of fiber for clothes, energy production amongst others. However, these interactions over many centuries have transformed a large portion of the planet's land surface, damaging the environment, and consequently affecting the balance and maintenance of all life species of our planet, including humans. The environmental impacts caused by anthropogenic actions throughout the planet, range from changes in atmospheric composition, to the extensive modification on the Earth's ecosystems (Vitousek et al., 2000; Wackernagel et al., 2002). Many of the land cover changes with ecological and climatic significance are currently taking place in tropical regions (e.g. deforestation, colonization of marginal lands, dryland degradation, landscape fragmentation and rapid urbanization) (Lambin, 1994).

Amongst the most important land cover changes, the deforestation of tropical forests represents one of the biggest environmental threats of our time. This process provokes several ecological and socio-economic impacts. The deforestation affects global climate change, increase habitat degradation and fragmentation causing a series of unprecedented species extinction. In addition, deforestation changes surface albedo, affecting the energy budget and climate. The decrease in forest cover also reduces evapotranspiration and rainfall, which could have significant impacts on the maintenance of forests. At last, the carbon stocks are also reduced and carbon emissions are increased. In the last United Nations Framework Convention on Climate Change (UNFCC Bali, 2007), deforestation was considered as the second most important human-induced source of greenhouse gases, being responsible for 20% of total emissions.

Tropical deforestation is a diverse phenomenon associated with many factors, such as: high variability in forest types, physical environment, socio-economic activities and cultural context (Lambin, 1994). In the last 300 years, around 7 to 11 million km² of primary forest was lost due to the expansion of agricultural lands (including grasslands and crops area) (Ramankutty and Foley, 1999b; FAO, 2004). However, many other land use practices (e.g., mining, selective logging, and infrastructure expansion) can degrade forest ecosystem conditions in terms of productivity, biomass, stand structure and species composition, (Foley et al., 2005). Land use can also degrade forest conditions indirectly by introducing pests and pathogens, changing fire-fuel loads, changing patterns and frequency of ignition sources and changing local meteorological conditions (Nepstad et al., 1999).

The Brazilian Amazon, the largest continuous region of tropical forest in the world, has suffered an intense process of deforestation in the last 30 years, resulting in the large-scale conversion of tropical forest into cattle ranching and cropland areas. The increased human occupation of the forest areas has caused significant changes in the ability of the environment to deliver key ecosystem goods and services. It also creates an uncertain future for the sustainability from the regional to the global environment, due the interconnections between natural processes in the Amazon and the regional and global climate. It is a consensus that important changes in the Amazon ecosystems started in the 1960's, following a large scale colonization process, characterized by the expansion of the agricultural frontier through the construction of the first roads in the region - e.g., BR 010 (Brasília-DF to Belém-PA), BR 364 (Rio Branco-AC to Porto Velho-RD), BR 230 (Transamazonica) and BR 163 (Cuibá-MT to Santarém-PA). These roads have up to today, constituted vectors of colonization and border expansion, where the natural ecosystems are transformed into agricultural production systems (including cattle ranching and crops area). According to Alves et al. (1999); Alves (2002) and Escada (2004), the main characteristic of the Amazon deforestation process is the spatial concentration, occurring mainly along roads and in the pioneer frontier in the south and south-eastern limits of the Amazon forest, where the intensification of the deforestation, has social and environmental impacts, such as: conflicts for property rights (Becker, 1997), forest fragmentation and degradation through logging and fire (Skole and Turker, 1993).

Due the intense process of colonization, the Brazilian Amazon has received in the last decades over one million migrant farmers from other regions of the country. Many of them were attracted by the government-sponsored colonization programs that offer free tropical forest land. The dynamic of this colonization process resulted in complex interactions between several factors such as: cattle dynamic, opening of new areas, restoration of old infrastructure, agricultural credit availability, agrarian and productive strategies. The increasing expansion of the pastures and crops area in a disordered way have contributed to cause significant damages in some critical areas of the Amazon basin, as the south of Para State, the north of Mato Grosso State, the State of Rondônia and the western part of the Amazon basin, including the eastern region of Acre State and southwest of Amazonas State (Watrin, 1994; Santos, et al., 2001). Amongst these areas of the Amazon basin, the western Amazon suffered the consequences of the territorial occupation policy with more intensity. The economy of this region, based on natural rubber extraction, suffered from the growth and fast development of rubber production in South Asia (Fearnside, 2007), and the development of synthetic rubber. Therefore, a large extent of forest land, especially old areas of rubber extraction with sizes from 5,000 ha to 500,000 ha, were sold at low prices to economic groups from the south of the country, to be dedicated mainly to cattle ranching activities (Cruz and Ramos Neto, 1983). Specifically on the Acre State, a large process of colonization started in the 1960s, deriving from migration and establishment of people from other regions of the country, attracted by federal incentives (Allegreti, 1992). This State, the main one in the rubber extraction of the Amazon, saw its economic base substituted for subsistence crops and cattle ranching. These changes in land use resulted in large scale environmental and socio-economic problems. Amongst the environmental problems, the loss of large areas of primary forest, caused the biological impoverishment and after some time, the increase of the abandoned areas and degraded pastures. In terms of socio-economic problems, the decline of the rubber extraction areas and the abandonment of agrarian settlements provoking the increase of the shanty towns (favelas) in the urban centers.

In function of the importance and variety of deforestation impacts, much effort has been made in the last decades to understand the causes of tropical deforestation, aiming to find sustainable solutions to diminish rates of deforestation and to improve the quality of life of forest inhabitants. However, causes and drivers of deforestation are very case-specific and in most cases, causes are independent, and thus allow for diverse interpretations. In the last 30 years, many methodologies, techniques and instruments were developed to monitor, quantify and understand the deforestation process. Advances in remote sensing technology is one of the most significant contributions to the study of tropical deforestation in recent decades, being at a regional to global scales, the only feasible way to monitor the world’s forests. In this way, spatial patterns of deforestation visualized by satellite images can be observed worldwide on agricultural frontiers and along roads. Depending on coverage and quantity of remote sensing data, regional deforestation hotspots can be identified globally (Dutschke and Wolf, 2007). Some studies using satellite images (Mertens and Lambin, 1997; Mertens, 1999) have observed that certain spatial patterns of deforestation occur frequently in the tropical zone and suggested that each particular deforestation process shapes the forest landscape in a specific way and leaves a “footprint” that can be related to some specific land use activity. If well understood and interpreted, these “footprints” or spatial patterns of deforestation visualized by satellite images can be a useful indicator in future planning projects due the correlation between economic activities and deforestation. Moreover, better understanding the relations between spatial patterns of deforestation and economic activities, will help elucidate how each specific areas will be affected by an economic or occupation policy. In terms of Brazilian Amazon, each sub-region has different actors and motivations that probably shape the land in different ways. Given this large diversity and spatial heterogeneity of the Amazon region, land use analyses try to identify different spatial configurations of deforestation with the objective of better understanding the processes of land use change and creating indicators that can be useful in the elaboration of specific development policies for each region.

Nevertheless, satellite data only provide a basis for the localization of the deforestation process, quantification of the amount deforested and identification of the spatial configuration, but they do not explain the causes of deforestation. To better understand the processes of deforestation, researchers combine different sources of information at different scales, such as satellite data, census data, household survey data, biophysical data, climate data, as a way of finding evidence to identify proximate causes and driving forces of deforestation. These linkages, mainly relate to the combination between satellite data and socio-economic data (called “people-to-pixel”), appears to be the most effective approach to provide information about the causes of deforestation. While satellite images provide the amount and extension of the changes, the socio-economic data can provide insights about the causes of changes. For the present study, analyses of land use and land cover change based on satellite images and socio-economic data are developed for the colonization project “Pedro Peixoto”, in the extreme East of Acre State, taking into account the different spatial patterns of deforestation present in the area. This region underwent a strong reduction of the primary forest area during the 1990s. This reduction is related to the increase in cultivated areas, which cover about 300 km^2 in 2004, and pasture areas, representing about 1000 km^2. The area of secondary forests is also important, representing 680 km^2. Despite the increase in the cultivated and pastoral areas, the increase in secondary forests can be an indicator of an abandonment of cultivated parcels or pasture areas. This abandonment could suggest the absence of technical and economic assistance and inappropriate forest occupation policies, which were not conceived to include different types of producers in the new agricultural frontier of the Brazilian Amazon (Lorena, 2006). Good knowledge about the different spatial patterns of deforestation will provide consistent indications about land use and land managers for each region of the Amazon region.

1.1 Objectives

The main objective of this study is to better understand the linkages between spatial patterns of deforestation, land use activities and deforestation rates, by analyzing a region of the Brazilian Amazon with different spatial patterns of deforestation and that suffered from intense deforestation in the last decade. For this, I propose a methodological approach that links spatial patterns of deforestation visualized through satellite images with specific land use activities using remote sensing data and socio-economic data from field survey. This linkage would allow for a better understanding of the dynamics of land use and cover change at a regional scale. It would also allow stratification of forest frontier areas in terms of processes of land use change, and thus would facilitate a fine-tuning of policies to the particular socio-economic dynamics underlying deforestation.

This objective is based on the hypothesis that different spatial patterns of deforestation, as visualized in a time series of satellite images, are associated with different land use and land cover change processes that are distinct in terms of rate and intensity, actors involved, history, shape and age of the occupation. The relevance of this analysis is the possibility to generate different diagnostics of the causes and dynamics of deforestation for different regions, considering the main agents, history, and mode of occupation, to improve knowledge about land use and land cover change. The results of this research provide points of reference that can help elaborate policies for regional planning as well as in the construction of quantitative models that search to express local and regional differences in land use and land cover change.

To achieve the main objective, the spatial patterns of deforestation are analyzed from different aspects. Each aspect constitute one specific objective:

1) To analyze the evolution of deforestation rates for each spatial pattern of deforestation, between 1990 to 2004;

2) To analyze the socio-economic characteristics of each spatial pattern of deforestation;

3) To analyze the dynamic of land use and land cover change for each spatial pattern of deforestation between the years 1990 – 1997, 1997 – 1999, 1999 – 2004;

4) To investigate the presence of homogeneous groups of farmers in terms of economic activities related to the spatial patterns of deforestation.

1.2 Structure of the study

This study is structured in six chapters. **Chapter I** introduces the objectives of this study. **Chapter II** consists of the literature review about the main issues of this study. First, section 2.1 presents a general discussion about land use and land cover change. Then, in section 2.2, the causes and consequences of tropical deforestation are explained. The following section 2.3 addresses the Amazon occupation process, followed by a discussion in section 2.4 about the land use and land cover change in the Brazilian Amazon. In the last section the link between remote sensing data and socio-economic data is discussed, as a way to understand the causes of tropical deforestation.

Chapter III gives an overview of the study area. First the localization of the study area and the general context where it is inserted are presented. Then the physical aspects of the area in terms of geology, climate and geomorphology are outlined (including here lithology, soil, geology and vegetation for each geomorphologic unit). Finally the general agricultural practices followed in the region are described.

Chapter IV sets out the methodologies used for data generation and data analysis. The methodology was divided in five stages. First, it is demonstrated how the spatial patterns of deforestation were selected. Then, in the second stage, the activities related to the field survey are presented. The third stage concerns the land use and land cover classification process. The fourth stage shows the clustering analysis, and finally, the fifth stage presents the analyses of variance ANOVA.

Chapter V elaborates the results of the research. The organization of this chapter followed the same stages as for chapter IV. Section 5.1 shows the spatial patterns of deforestation selected for the study. This section also presents an analysis about the deforestation rates presented by each spatial pattern. In section 5.2 are presented the results of the field survey, including an analysis based on the socio-economic data acquired in the field. Section 5.3 shows the results of the land use and land cover classification and an analysis of the evolution of land use and land cover changes for each spatial pattern. In section 5.4 the groups formed through the process of clustering are described, and in section 5.5 the results obtained from the analysis of variance ANOVA are presented.

Chapter VI consists of the conclusions of this study. This chapter was divided into: synthesis of the results, main findings, methodological discussion, methodological limitations, perspective for further research, scientific contribution and policy implications.

Chapter 2

Literature Review

2.1 Land use and land cover change

With the realization that land surface processes influence climate (Lambin et al., 2003), and consequently all life forms of the planet that depends on the balance between the atmosphere, hydrosphere and biosphere to survive, the changes in land-use and land-cover became a key topic of the research agenda on global environmental change several decades ago. Although humans have been altering land cover since the advent of plant and animal domestication through the clearance of patches of land for agriculture and livestock (Sherbinin, 2002), there are evidence to suggest that in the last 100 years, changes in land use and land cover were occurring at a extraordinary magnitude, rate and spatial extent (Lambin et al., 2001; Harbel et al., 2004, Briassoulis, 2000). Due to the importance of these impacts, large research programs such as The Land Use and Land Cover Change program (LUCC), a joint initiative of the International Geosphere-Biosphere Program (IGBP) and the International Human Dimensions Program (IHDP), were created with the specific objective to better understand the causes of land use and land cover change.

The terms land cover and land use are not synonymous (Briassoulis, 2000) and the difference between them is relatively simple conceptually. However, sometimes it is difficult to discern the difference in terms of data, especially at aggregate scales and/or due the lack of adequate information (Aguiar, 2003). The term **land cover** comes from the natural sciences and denotes the physical state of the land (Turner and Meyer, 1994) or the biophysical attributes of the earth’s surface and immediate subsurface (Turner et al., 1995; FAO, 2000). Originally, this term referred to the type of vegetation that covered the land surface, but has been expanded subsequently to include human structures, such as buildings or pavement, and other aspects of the physical environment, such as soils, biodiversity, surfaces and groundwater (Moser, 1996; Lambin et al., 2003). The term **land use** is used in the social sciences and denotes the land utilization by human beings, such as: agriculture, cattle ranching, recreation, conservation (Turner and Meyer, 1994; Escada, 2004). Similarly, Skole (1994) defines land use as the human employment of a land-cover type. Finally, FAO (1995) translates land use as the function or purpose for which the land is used by the local human population and can be defined as the human activities directly related to land, making use of its resources and having an impact on them. These two concepts "land use" and "land cover" are connected by the change sources that are the human actions that modify directly the physical environment (Turner and Meyer, 1994). These sources represent the intersection between physical processes and the actions of human behaviours (Escada and Alves, 2001).

Changes in land use and land cover imply quantitative changes in the areal extent (increases or decreases) of a given type of land use or land cover (Briassoulis, 2000). Complementarily, changes in land use and land cover can be broken down into two concepts: conversion and modification (Turner et al., 1995; Skole, 1994). Land cover conversion involves a change from one cover type to another (e.g. forest to crops). Land cover modification involves alterations of structure or function without a wholesale change from one cover type to another; it could involve changes in productivity, biomass, or phenology (Skole, 1994; Lambin et al., 2003). In terms of land use, conversion means the total change from one type of use to another (e.g. crops production to cattle ranching). But modification of a particular land use can include changes in the intensity of this use as well as alterations of its characteristics (e.g. change of the crop type or its intensification) (Briassoulis, 2000). According to Lambin and Geist (2001), it is necessary to understand the utility of some type of cover to understand the process of change. Land use and land cover change were, for a long time, seen as a slow moving, continuous processes. In fact they are disjoint processes, with fast change periods, often triggered by a sudden event. The changes are determined by a complexity network of biophysical factors (soil characteristics, climate, topographic) and socio-economic factors (population, technology, economic condition, political decision, etc) denominates " forcing factors" (Kaimowitz and Angelsen, 1998). The "forcing factors" can be categorized in "immediate factors" (variables associated with the parameters of local decision such as: accessibility, product price, environmental factors, available technologies) and "underlying factors" (economic policies, global market price, macroeconomic trends). These factors interact in space and time in different historical and geographical contexts, creating different trajectories of change.

Although several land use practices are absolutely essential to satisfy basic human needs (Briassoulis, 2000; Foley et al., 2005), many of these land use practices are degrading the ecosystem goods and services upon which humans depend (Foley et al., 2005). Land use, its dynamic and consequent changes in land cover have often been considered a local environmental issue. However, given the current extension of the modified surface and its respectively impacts, it is becoming a force of global importance (Foley et al., 2005). Hannah et al. (1994) states that in the 1990s, about 36% of the Earth's biological productivity was dominated by man, 37% was partially disturbed and only about 27% is undisturbed. Similarly, Sanderson et al. (2002) states that 83% of the terrestrial surface is under direct human influence. Moreover, these alterations caused by human actions is accompanied by large increases in energy, water and fertilizer consumption, along with considerable loss of biodiversity, increase of the greenhouse gases in the atmosphere and of pollutants (Foley et al., 2005).

All these transformations in the terrestrial surface have impacts (negative or positive) on the environment and society. It is important to note that usually, all impacts of land use change are assumed to be negative. Nevertheless, whether an impact is positive or negative depends on the spatial and temporal scale concerned. In addition, some actions, such as environmental and social regulation and policies, land restoration projects and similar actions can inhibit the negative influences of land use and land cover change (Briassoulis, 2000). However, it was the negative impacts that stimulated the scientific and policy interest on land use change. In terms of environment impacts of land use change, there are evidences that these changes have direct or indirect impact on the biotic diversity worldwide (Sala et al., 2000; Daily et al., 2000; Foley et al., 2005), local, regional and global climate (Chase et al., 1999; Houghton, 1999, Fearnside, 1997 and 2000; Foley et al., 2005). It also degrades the soil (Tolba et al., 1992; Trimble et al., 2000; Ramankutty et al., 2002) and the ability for biological systems to support human needs (Vitousek et al., 1997). Moreover, land use practices play an important role in the changes in the global carbon cycle and consequently in the global climate (Foley et al., 2005). According to Houghton (2003), roughly 35% of anthropogenic CO_2 emissions between 1850 and 1950 are directly related to land use. In addition, changes in land use and land cover, mainly related to the deforestation of tropical forests, were considered by the last United Nations Framework Convention on Climate Change (UNFCCC Bali, 2007) as one the most important action responsible for the CO_2 global emission, contributing around 20 % of the total emissions. In fact, the tropical deforestation is considered as one of the biggest environmental impact and this subject will be better developed in the next section. The hydrologic cycle has also been transformed by human activity to provide freshwater for irrigation, industry, and domestic consumption (Postel et al., 1996; Vörösmarty et al., 2000). The anthropogenic nutrient inputs to the biosphere from the fertilizers and atmospheric pollutants now exceed natural sources and have affected both the quality of the coastal and freshwater ecosystems (Matson et al., 1997; Bennet et al., 2001). Finally, there are also indications that land use and land cover changes may be related to infectious diseases. Patz et al. (2004) state that habitat modification, road/dam construction, irrigation, concentration or expansion of urban areas, increases in the proximity of people, and livestock can all modify the transmission of infectious diseases. One study related the increase of bat-borne Nipha viruses occurring in Malaysia with changes in land use (Chua et al., 1999). Similarly, Patz et al. (2004) relate the increase of deforestation with the growth of malaria and/or its vectors in Africa, Asia and Latin America. Finally, Vanwambeke (2005) investigated the links between vector-borne diseases (dengue) and land cover in Thailand. Dengue is a major concern in Thailand and this study found important relations between land use changes and the occurrence of the disease.

The socio-economic impacts of land use and land cover change are also significant and give rise to serious concerns at all spatial levels. At a global level, the socio-economic impacts concern issues such as food security, water scarcity, population displacement and more generally, the issue of human security and vulnerability to natural and technological hazards (Briassoulis, 2000). At a regional level, the socio-economic impacts of land use changes are more heterogeneous due the variety of regional characteristics where theses changes occur. In general, the issues concern the availability of land for regional food production, changes (reduction) in land productivity and consequently, (lower) profitability and changes in industrial structure, employment, unemployment, poverty, population change and migration, and quality of life issues such as health and amenity (Briassoulis, 2000). Finally, at a local level, the socio economic impacts of land use and land cover change comprise similar concerns but they are restricted to the particular localities where these changes occur.

Although the consequences of land use and land cover change have been reviewed and presented systematically in the literature, the common understanding of the causes of land use and land cover changes is dominated by simplifications (Lambin et al., 2001). Identifying the specific causes of land use change requires an understanding of how people make land use decisions and how various factors interact in specific contexts to influence decision making on land use (Lambin et al., 2003). The understanding of the dynamics of land-use and land-cover has increasingly become recognized as one of the key research imperatives in global environmental change research (Turner et al., 1990; Turner and Meyer, 1994; Lambin et al., 1999; Geist, 1999; Lambin et al., 2001). In spite of the number and variety of studies about the causes of land use and land cover changes, there are still a long way to reach a complete understanding about the mechanisms of changes. Each biome and each region can possess different types of cover, each one linked to a variety of land use and consequently different types of change. The process of tropical deforestation is just one of them. However, due its environmental and socio-economic impacts, many studies about the causes of land use and land cover change are related to the process of tropical deforestation. The next section will address specifically concerns about tropical deforestation, its causes and consequences.

2.2 Tropical deforestation

The deforestation of tropical forests has been considered as one of the primary causes of global environmental change (Geist and Lambin, 2002). Although global forest loss has occurred for centuries, rapid rates of tropical deforestation have only become an international concern in the last twenty-five years (Barbier and Burgess, 2001). Only in the last decade, the tropical forests have decreased globally about 9.4 million ha (FAO, 2000). It has become a problem, because tropical forests play critical roles as repositories of biological diversity and in regulating global biogeochemical and hydrologic cycles (Eltahir and Bras, 1996; Houghton, 1999; Meyers et al., 2000). Moreover, due the amount of carbon stocked in forests and the possibility to lose this carbon to the atmosphere, the process of deforestation and degradation of tropical forests have been considered as one of the major source of CO_2 emissions and consequently one of the responsible for the climate change (Dutschke and Wolf, 2007).

Tropical deforestation is a diverse phenomenon, and many efforts had been made to improve the knowledge about its causes. The subject was considered as a priority research issue by the Land Use and Land Cover Change Project (LUCC) (Lambin et al., 1999). To better organize and understand the causes of changes, this program followed the concept of "proximate causes and driving forces" (Turner et al., 1995; Lambin et al., 1999; Geist and Lambin, 2002). Broadly, proximate causes refer to the activities that directly result in a transformation of land use/cover, while driving forces indicates the underlying processes that give rise to the proximate actions effecting landscape change (Chowdhury, 2006). More specifically, proximate causes are human activities or immediate actions at the local level, such as agricultural expansion, wood extraction and the expansion of the infrastructure that originate from intended land use and which directly impact forest cover. The underlying driving forces may be the fundamental social processes, such as human population dynamics or agricultural policies, which support the proximate causes and operate at the local level or have an indirect impact on the national or global levels (Geist and Lambin, 2001).

The proximate causes of deforestation are well known: (a) slash-and-burn cultivation, (b) settlement policies, (c) fuelwood gathering and charcoal production, (d) forest conversion for cattle ranching, (d) inefficient commercial logging operations, (e) increase of infrastructure, and (f) large scale, uncontrolled forest fires (Lambin, 1994). Although the proximate causes are clear, the driving forces of deforestation strongly depend on each case. In general, drivers of deforestation may include population dynamics (Bilsborrow and Okoth-Ogendo, 1992; Meyer and Turner, 1992; Mather and Needle, 2000), agricultural policies, economic and market factors, (Rudel and Roper, 1997; Mertens et al., 2000; Klepeis and Vance, 2003), land tenure and property regimes (Mendelsohn and Balick, 1995; Angelsen, 1999; Futemma and Brondizio, 2003), technological change (Foray and Grubler, 1996; El-

Lakany and Ball, 2001; Røpke, 2001), and cultural dynamics (Proctor, 1998; Bürgi et al. , 2005). In a large meta-analysis of proximate causes and underlying driving forces of tropical deforestation, Geist and Lambin, (2001 and 2002) analyzed 152 sub national case studies around the world. The results demonstrated that only 6% of the cases were related to a single proximate cause and that 94% were related to multi-factorial terms. The authors concluded that causes and drivers of tropical deforestation couldn't be reduced to a single cause or to only a few variables. They also concluded that tropical deforestation was determined by different combinations of various proximate causes and underlying driving forces, varying in geographical and historical contexts. Finally, they stressed the importance of understanding the complex set of proximate causes and underlying driving forces affecting forest cover changes for a given location before any policy intervention can be made.

Unfortunately, the consequences of the increase of deforestation are far from clear (Sherril, 1999). There are strong indications that tropical deforestation may be a potential long-term problem to ecological sustainability and socio-economic development (Meyers, 1980). It also plays a central role in many environmental threats, including, regional and global climate change (Shukla, 1990; Fearnside, 1996; Fearnside, 1997), habitat degradation (Lacher and Goldstein, 1997; Roth, 2001; Alin et al., 2002) and unprecedented species extinction (Mendoza and Dirzo, 1999; Metzger, 2000; Totten et al., 2003). Deforestation impacts regional and global climate through the surface-energy budget, as well as through the carbon cycle (Pielke et all., 2002). Although quantification of human influences on climate has focused largely on changes in atmospheric composition, there are evidences that changes in the vegetation cover provides an additional major forcing of climate, through the changes in the physical properties of the land surface (Pielke et all., 2002). Evidences indicating that changes in the surface albedo can be compared with greenhouse-gas emissions through the concept of radiative forcing (Betts, 2000). In regions that suffered intensive human-caused land-use change such as North America, Europe and southeast Asia, the local radiative forcing change caused by surface albedo may actually be greater than that due to all the anthropogenic greenhouse gases together (IPCC, 2001). Moreover, changes in the evapotranspiration and consequently in the water cycle is another considerable impact of tropical deforestation on climate, at a local to regional scale in this case (Lambin et al., 2003).

Despite the importance of the impacts caused by the changes in the surface albedo and in the evapotranspiration, the carbon stocked become the factor used to assess the human intervention in the Earth's climate system (Fearnside, 2004). According to this author, tropical forests contain large stocks of carbon and any change in its cover has potentially important consequences for the global carbon cycle and related climate changes. In fact, the deforestation had been considered by the United Nations Framework Convention on Climate Change (UNFCCC, Bali 2007) as the second single gas source, behind energy production, being responsible for about 20% of human GHG emissions (Dutschke and Wolf, 2007). Although the real role of terrestrial ecosystems in the global carbon budge is still uncertain (Houghton, 1999), much effort has been made to quantify CO_2 emissions (historical and contemporary) from changes in land use and land cover, primarily deforestation. The historical cumulative carbon losses to the atmosphere in function of the changes in land use have been estimated as 180-200 PgC (DeFries et al., 1999) by comparing maps of current vegetation cover derived from 1987 satellite data (House, et al., 2002). Houghton (1999) estimated a global carbon loss of 124 PgC from 1850 to 1990 based on land use statistics. The difference with the estimate from DeFries et al. (1999) is mostly due to land conversions that occurred before 1850 in Europe and Asia. Houghton (2003) presents additional results of new regional analyses of land use change and extends his previous global estimate of carbon flux (Houghton,1999), to the year 2000. Globally, the long-term (1850–2000) flux of carbon from changes in land use had improved from 124 to 156 PgC to the atmosphere, being 60% of it from the tropics. The author attributes the difference with the previous estimate to uncertainties in the rate of deforestation and in the ecosystems carbon stocks effected by humans. In addition, selective logging was not computed in these previous estimates and can be also a source of uncertainty. According to Asner et al. (2005), between 1999 and 2002, the annual extent of selective logging ranged from 12.075 to 19.823 km², representing new forest damaged not accounted for in deforestation studies. Finally, House et all. (2002, based on Houghton, 1999), have estimated total carbon loss by 2000 as 200-220 PgC.

Related to the contemporary flux of CO_2 to the atmosphere, the estimations are also uncertain due to difficulties in quantifying deforestation and regrowth rates, initial biomass, and fate of carbon in areas where vegetation has been cleared (DeFries et al. 2002). For the 1980s and 1990s, while Houghton (2003) estimated an average annual carbon fluxes from tropical deforestation around 2.0 and 2.2 PgC year respectively, DeFries et al. (2002) estimated net mean annual carbon fluxes from tropical deforestation and regrowth to average 0.6 (0.3– 0.8) and 0.9 (0.5–1.4) PgC year for the 1980s and 1990s, respectively. Finally, estimates of carbon fluxes from tropical deforestation as reported by the Intergovernmental Panel on Climate Change (IPCC) (Prentice et al., 2001) range from 0.6 to 2.5 PgC year for the 1980s, based primarily on calculations using cropland statistics from the United Nations Food and Agriculture Organization (FAO) and deforestation rates from the FAO Forest Resource Assessment (FRA) (House et al., 2002).

Global climate changes due the emission of CO_2 from deforestation are far from the only serious environmental threats caused by deforestation. Some authors consider the deforestation and habitat degradation in tropical countries as the major threats to global biodiversity (Myers, 1984 and 1988; Laurance and Bierregaard, 1997). Several studies worldwide relate deforestation with habitat degradation, such as Lacher and Goldstein (1997) in Latin America and Caribbean; Alin et al. (2002)

in Tanzania; Roth (2001) in the Dominican Republic; Dudgeon (2000) in the Asian Rivers; Sodhi et al. (2005) in Linggoasri, central Java. Furthermore, forest fragmentation can influence directly the preservation of biodiversity. Concerns about elevated species extinction rates in the tropics are also a common feature of the conservation literature (Pitman et al., 2002). The studies that relate species extinction to deforestation are numerous and vary in terms of threatened species. In general, the studies focus on the extinction of vegetal species (Metzger, 2000; Mendonza and Dirzo, 1999; Sosa and Platas, 1997; Turner et al., 1994; Monteiro et al., 2005; Hill et al., 2003; Pitman et al., 2002; Bruna et al., 2002) or insect species (Novotny et al., 2004; Koh et al., 2004; Tilberg and Breed, 2004). However, it is not difficult to find studies that associate forest degradation, bird species extinction, (Watson et al., 2004; Balmford and Long, 1994; Johns, 1991; Brooks et al., 1997) or threatened primates (Johns, 1987; Johns and Skorupa, 1987; Cowlishaw, 1999).

As the largest area of tropical forest of the world, the Amazon forest has a significant contribution to global environmental threats. Deforestation in the Brazilian Amazon has increased in the last decades, and the current rate and cumulative extent of deforestation comprise vast areas (Fearnside, 2005). The causes are diverse and not well understood at the moment and the consequences are already visible not only at a local and regional scale, but also at a global scale. The occupation of the Brazilian Amazon and its process of deforestation will be the main subject of the next section.

2.3 Brazilian Amazon: occupation and deforestation

2.3.1 Occupation

Although already occupied for centuries, the economic occupation of the Brazilian Amazon started during the 1920’s and 1930’s, with the first migrant flow coming from northeast Brazil (Escada, 2004), to work mainly in the extraction activities. The pioneer front was intensified during the 1950’s and 1960’s with the creation of SPVEA (Superintendência de Valorização Econômica da Amazônia - Supervision of Amazon Economic Valuation), the first governmental measure for occupation of the region, and the opening of the first roads of the region, the Transamazônica and Bélem – Brasília (Sherril, 1999; Escada, 2004; Fearnside, 2005; Kirby et al., 2006). In the 1970’s the occupation of the Amazon basin became a national priority (Escada, 2004). The federal government began to develop and subsidize the occupation of the land destined for the agrarian frontier expansion through the PIN program (Progama de Integração Nacional-National Integration Program) and PND

(Plano Nacional de Desenvolvimento Econômico e Social – National Plain for Socio-economic Development).

The occupation policy tried to combine the enterprises of economic exploration with geopolitical strategies (Costa, 1997). These strategies adopted by the government for the occupation of the Amazon included: (a) the implementation of spatial integration networks through the construction of roads and telecommunication lines, (b) the construction of hydroelectric energy power plants and implementation of urban projects, (c) the dispossession of unoccupied land for the implantation of colonization projects, (d) the subsidizing of capital flow, and (e) the induction of migratory flow (Becker, 1997; Machado, 1998; Sherril, 1999; Escada, 2004). One of the main projects executed in this period was the official colonization project, PROTERRA (Programa de Redistribuição de Terras – Land Redistribution Program), conduced by the INCRA (Instituto Nacional de Colonização e Reforma Agrária – National Institute for Colonization and Agrarian Reform), which distributed lands along of roads for small producers supported by the government.

The modernization of agriculture in the southern region of the country also contributed towards the colonization process of the Amazon. This modernization dismissed a large contingent of workers leading to the exodus of the Amazon regions and thus starting a process of forest opening. The construction of the BR 364 road (Cuibá – Porto Velho) motivated the flow of colonists mainly from Paraná State to Rondônia State (Mahar, 1989). In the 1980’s the POLONOROESTE program financed, through the World Bank, paved roads to improve the migratory flow. However it provoked a disordered occupation that resulted in a rapid deforestation process and also in the invasion of land occupied by indigenous population generating conflicts and negative social impacts.

In the 1980’s the occupation process became more complex. The land demands in the Amazon became more organized politically, causing the increase of violent conflicts between different groups in the new frontier: big and small agriculturists, cattle ranchers, extraction workers, worker unions, “sem-terra” (landless peasants), etc. (Sherrill, 1999). The majority of the migrants were established in the southwest/northeast Amazon frontier, in a region that extended to the east of the Acre State and North of Rondônia State to south and southwest of Para State (Teixeira, 1998). This region, known as the “Arc of deforestation” (Figure 2.1), is where the highest rates of deforestation of Amazon are still observed.

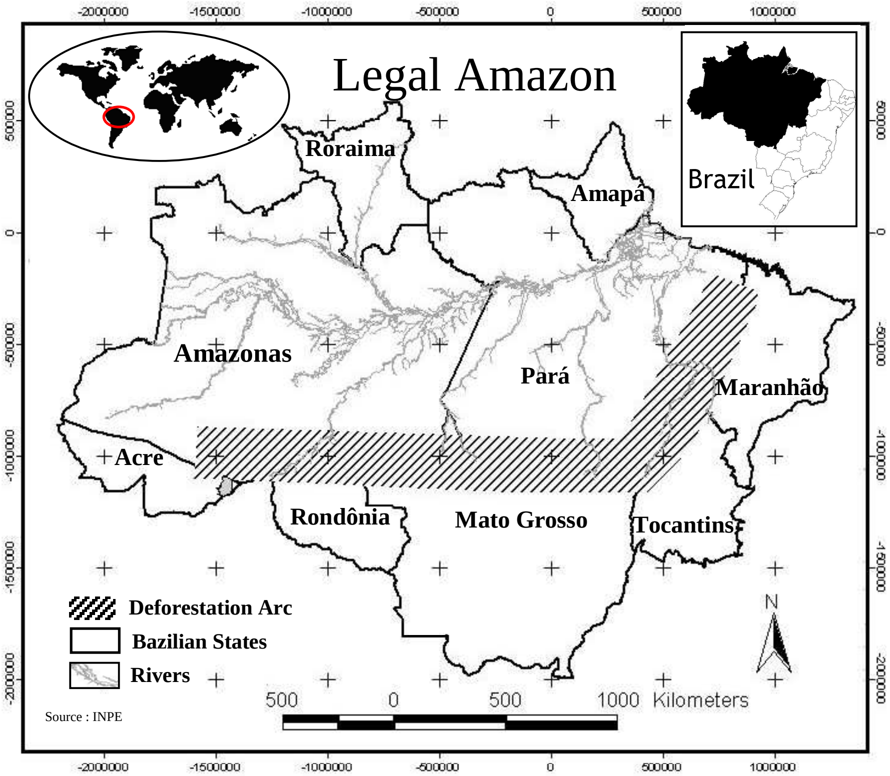

Figure 2.1 Arc of deforestation

At the end of the 1980's and early 1990's, the States' intervention in the regional economy and development was reduced. During the 1990s the focus in the Amazon exploration was changed and many important programs, some with international support, had been implemented with a more conservationist vision (Becker, 2001; Escada, 2004). Examples of these programs include:

PPG 7 – A Pilot Program for Brazilian Tropical Forest Protection, financed by the World Bank, with the objectives of genetic resources preservation and deforestation mitigation;

SIVAM – Sistema de Monitoramento da Amazônia (Amazon Monitoring System). A federal project for the protection and the monitoring of the Amazon against external territorial intervention;

LBA – Large Scale Biosphere and Atmosphere Experiment in the Amazon. An international initiative with national leadership and objectives to better understands the interactions between the Amazon basin and the global biogeophysical system. With such objectives, the leadership will be able to generate new knowledge about the climatic, ecological, biochemical, and hydrological functioning of the Amazon basin;

PBA – Programa Brasil em ação (Brazil in Action Program). A government program that develops corridors to stimulate grains exports. Stimulation occurs through the ENIDs – Eixos Nacionais de Intergração e Desenvolvimento (National Axes of Integration and Development) that include nets of circulation, communication, energy and multimode systems of transports and communication;

ZEE – Zoneamento Ecológico Econômico (Ecological Economic zoning) is a national policy environmental tool for territorial organization. The ZEE establishes measures and patterns of environmental protection destined to assure the environmental quality of hydrological resources, soil and biodiversity. The objective is to assure the sustainable development and to improve the quality life of the population. Although be a national program of territorial organization, with good examples of implementation in several Brazilian States, is in the Amazon region that the results of its implementation are more obvious.

2.3.2 Deforestation

The occupation of the Brazilian Amazon caused the loss of vast areas of primary forest. According to the National Institute for Space Research (INPE, 2007)[1,] the accumulated deforested area in 2005 was 680,000 km², approximately 17% of the Brazilian Amazon. During the 1980’s, the Brazilian Institute for Environment (IBAMA) showed that rates of Amazon deforestation reached 20.500 km²/year (Figure 2.1). In this period, fiscal incentives were a strong driver of deforestation (Mahar, 1979). Although some incentives, such as government subsidies became scarcer after 1984, given the hyperinflation dominant in the 1980’s, the fiscal incentives had prevailed through the 1980’s until 1991, when new incentives were suspended (Fearnside, 2005). In the following years, before the United Nation Conference on Environment and Development (UNCED Rio-92) and the beginning of the economic stabilization process (1990 – 1993), the rates of deforestation fell greatly, with numbers oscillating between 11.100 and 13.800 km²/year. This decline can be explained by a period of economic contraction (Fearnside, 1993, Escada, 2004) where rural producers didn’t have the means to invest in the deforestation. Moreover, during this same period, the RIO-92 conference took place (Sherryl, 1999) to discuss the relationship between planet Earth and its ecosystem sustainability, and the reduction of Amazon deforestation.

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[1] Governmental institution responsible for the Amazon deforestation monitoring by satellite images.

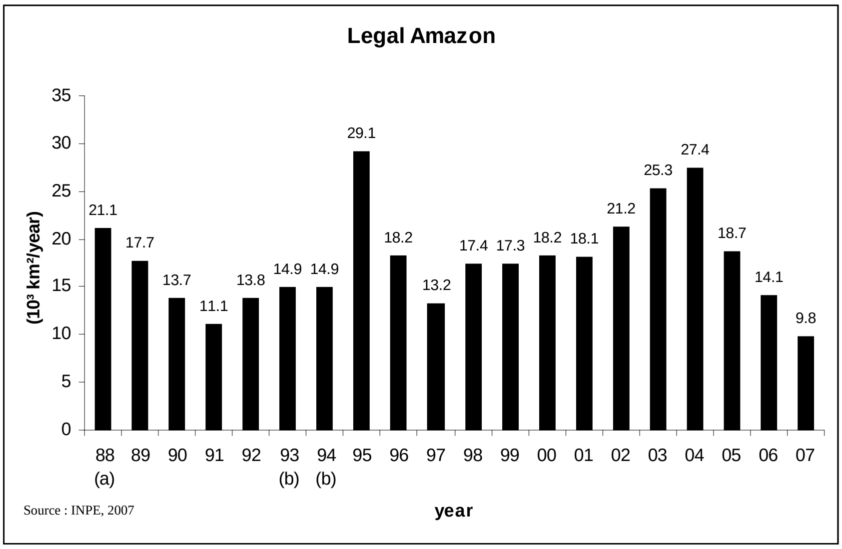

Figure 2.2 Deforestation in the Brazilian Amazon ((a) average between 1977/1988- (b) average between 93/94)

However, this situation proved to be only temporary and in accordance with the National Institute for Space Research (INPE), the Amazon deforestations rate came back to an average of 29.000 km²/year during 1994 to 1995 (Sherryll, 1999). The biggest increase in the deforestation rate was observed during the years 1994 and 1995 (Escada, 2004). This specific period was marked by the rapid recovery of the economy under the "Plano Real"[2] and the availability of capital for new investments, including cattle (Fearnside, 2005). The subsequent fall in deforestation rates in 1996 and 1997 was attributed to land speculation during this period. The decrease in the inflation rate provoked a constant decrease in the land value, with a fall of around 50% in one year. This fall in the land value made land speculation unattractive (Fearnside, 2005). Between 1996 and 2001, the rates were oscillating between 13.000 km^2/year and 18.000 km²/year and started to grow between 2002 and 2004 being around 23.000 km² (INPE, 2004). Finally, between 2004 and 2006, the rates declined to surge again in 2007.

The deforestation rates began to increase again in 2001. Some authors (Laurance, et al., 2001; Nepstad et al., 2001; Fearnside, 2002; Kirby et al., 2006) attributed this increase to the perspective of the "Avança Brasil"[3] plan. The project would cost about $43 billion and be implemented from 2000-2020. This development project

[2] Economic stabilization project developed by Fernando Henrique Cardoso's team when he was Economy's Ministry. The primary objective of this project was to control the Brazilian hyperinflation.

[3] Avança Brasil (Forward Brazil) is a large infrastructure program planned in Brazil (2000 – 2020). The portion of the plan to be carried out in Brazil's Legal Amazon region totals US$ 43 billion over 8 years, being US$ 20 billion only for infrastructure.

included large investments in the infrastructure of the Amazon region, mainly the construction of highways. Other authors (Silveira, 2001; Nepstad et al., 2002; Câmara et al., 2005, Bruna and Kainer, 2005, Schaeffer and Rodrigues, 2005) considered the linkage between deforestation and “Avança Brasil” an over-simplified view, given the diversity of factors that influenced the location and rates of land use change in a very heterogeneous region. Some studies about the Amazon deforestation show that it occurs in a concentrated way in space (Fearnside, 1987; Skole and Tucker, 1993; Alves, 1999; Alves, 2002), along the main roads (Skole and Tucker, 1993; Alves et al., 1998 e 1999; Alves, 2002; Dale et al., 1994; Fearnside, 2001; Laurence and Fearnside, 2002) and in the deforestation frontier areas (Alves et al., 1999; Alves, 2002, Escada, 2004).

In fact, the Amazon deforestation is a very complex phenomenon, not continuous and not homogeneous, varying in shape, size, amount and motivations. In function of this complexity of the Amazon, analyses of the cause of deforestation must be carried out with caution considering different scales of process, from local analyses to the analyses of external factors, policy factors, institutional and economic factors and also the international context (Skole et al., 1994, Sheryll, 1999; Escada, 2004). The next section concerns specifically the changes in land use and land cover and the process of Amazon deforestation.

2.4 Land use and land cover change in the Brazilian Amazon

Escada (2004) stated that the main land use and land cover change processes in the Amazon are related to the rural producers that occupy the Amazon and develop different strategies of land use. These rural producers can be divided into farming companies that consist of large, medium and small farmers (Becker, 1997). All these agents play an important role in the Amazon deforestation. However it is difficult to say how much of the deforestation can be attributed to the small and large rural producers. Fearnside (1993) estimated that, during 1990 and 1991, around 70 % of deforestation was related to big farm activities and only 30% was related to small properties.

In terms of land-use activities, cattle ranching and small-scale farming have historically played the most significant role in the clearing of the Amazon forest (Kirby, et al., 2006). In general, the large and medium individual farmers have been dedicated mainly to the production of cattle for the meat market and consider the land as a reserve value (Becker, 1997). In some Amazon regions, such as the Mato Grosso State, the large farms started to produce soybean for exportation (Fujisaka, 1996; Escada, 2004). The importance of soy farming as a land-demanding economic activity has grown dramatically in the last ten years (Fearnside, 2001).

Each of these activities (cattle and soy farming) tends to be strongly associated with agricultural exploitations of particular sizes. Data from the most recent national agricultural census reveal both the highly unequal distribution of land in the legal Amazon and the disproportionate contribution of cattle ranching and soy farming to deforestation (Kirby et al.; 2006). For example, properties greater than 2.000 ha in size, which tends to be extensive cattle ranches or soybean farms, constitute only 1% of all agricultural exploitations in the nine Amazonian states but control 46.8% of all land converted from forest or cerrado (savanna) to agriculture. In contrast, subsistence farms of less than 20 ha constitute over 50% of Amazon exploitations but control only 1.5% of land converted to agriculture (Chomitz, 2001).

The small producers including the landholders, leaseholders, and colonists who represent a significant proportion of Amazon inhabitants (Becker, 1997) developed diversified strategies of land use where the dynamic was related to the soil fertility (Moran et al., 2002) and the main activity was a mixture of annual and perennial cultures and pasture for cattle (Pedlowski and Dale, 1992; Pedlowski et al., 1999; McCraken et al., 1999 and 2002; Brondízio et al., 2002). According to Kirby et al. (2006), after cattle ranchers, small farmers have played the most significant role in the clearing of the Amazon forest. In the Amazon, the initial land claimed by small farmers was created using the slash-and-burn method. The extent and rate of clearing were determined by labour supply and capital. The process of farm establishment may have spanned a decade or more (Walker et al., 2000). The average small farm in the Amazon cleared 1 ha of forest per year (Homma et al., 1996). In general a plot can support annual crops during 2-3 years, after which soils are exhausted and new areas are cleared (Kirby et al., 2006). The old fields are left to rest or converted to pasture.

Although there is diversification of activities among large, medium and small farms and the presence of large soy farms, a trend to cattle already observed in the past (Buchbacher, 1986; Fearnside, 1993), is currently observed (Teixeira et al., 2000; Escada, 2004) including in the small farms (Veiga et al., 1996; Walker et al., 2000; Moran, 2002; Lorena, 2003). This phenomenon can be explained through many factors: land valorisation by pasture implantation (Pedlowski and Dale, 1992), security for the family investment (Hecht and Cockburn, 1990; Kirby et al., 2006), price stability of meat on the market (Veiga et al., 1996), and the possibility of milk production that represents a source of food in many cases. In general, the pasture is implemented in areas that were annual and perennial cultures (Walker et al, 1997). However, cattle activity requires great areas and it favours the conversion of primary forest to pasture (Walker et al, 1997). Over 10 million ha of primary forest were converted to pasture between 1960 and 1990 in the Amazon (Anderson, 1990). This conversion was stimulated by incentives, from the Supervision for Amazon Development (SUDAM – Superintendência de desenvolvimento da Amazônia), which facilitated private investments in the Amazon through tax incentives, with most support granted to large cattle ranches and corporations (Gasques and

Yocomizo, 1990; Fujisaka, 1996, Kirby et al., 2006). In 1994 cattle ranches covered 8.4 million ha, with an average 24.000 ha each, but employed only one person for every 300 ha and was profitable only with full tax advantages (Moran et al., 1994).

There are other sources of deforestation in the Brazilian Amazon such as mining, hydroelectric projects, and timber activity (Moran, 1993). Related to mining activities, Moran (1993) argued that it did not seem to have a major impact on the total area of forest clearing at the end of the 1980’s. However, the mining activities are largely responsible for the exponential rise of diseases like malaria, tuberculosis and leprosy in the Amazon basin (Sherryll, 1999). There is strong evidence to suggest that the Amazon deforestation process, mainly during the 1980’s and 1990’s, occurred in relation to the implantation of large hydroelectric and mining projects in the region (Sherryll, 1999). The more controversial examples are the Tucurui, Balbina and Samuel hydroelectric projects that flooded respectively 2.430 km², 2.360 km² and 560 km² of dense forest as well as the Mining project of Carajás called Great Carajás (Grande Carajás) controlled by the Company of Vale do Rio Doce (CVRD) whose impact on deforestation is estimated at 100.000 km² of direct and indirect areas of influence (Freitas and Soares, 1994, cited by Sherryll, 1999).

In the 1980’s the importance of timber exploitation in deforestation became noticeable (Moran, 1993). In 1984, the Brazilian Amazon accounted for 43.6% of the national roundwood production, compared with only 14.3% ten years earlier (Browder, 1988). In 2005, Asner et al. (2005) have estimated that the area logged in the Amazon forest between 1999 and 2002 ranged from 12.000 km² year to 20.000 km² year. The logging process results in the damage of almost twice the volume of the trees being harvested (Veríssimo et al., 1992). Such production greatly increased the susceptibility of the forest to fire (Fearnside, 2005). Once fire enters the forest, it kills trees, increases fuel loads and dries the under story; thus increasing the risk of future fires and the complete degradation of the forest. Amazonian forest trees are not adapted to fire, and the mortality from a first burn provides the fuel and dryness needed to make the second and subsequent fires much more damaging. The temperatures increase and the heights of flames in the second fire are significantly greater than in the first, killing many additional trees (Cochrane, 2003). After several fires, the area is cleared to the point where it appears as deforestation on TM/Landsat imagery (Cochrane et al., 1999; Nepstad et al., 1999). Public policies have also played an important role in the Amazon deforestation. Research has suggested that one of the main causes of the biological degradation in the Amazon is the absence of adequate public policy (Sherryll, 1999). Several studies (Repetto, 1988; Mahar, 1989; Biswanger, 1991; Fearnside, 1989 and 1990) provided evidence that degradation associated with inappropriate land use were caused by perverse governmental incentives and misguided policies.

2.5 Linking remote sensing and social economic data to understand the proximate causes and drivers of tropical deforestation

Landscape transformation due land use and land cover dynamics and its implications such as global climate change, changes in biogeochemical cycles, deforestation, and biodiversity loss have become central issues in environmental sciences (Turner et al., 1994; Turner et al., 1995; Kaimowitz and Angelsen, 1998; National Research Council, 1998). As a consequence, new ecological theories (Wilson, 1998), modern methods to study spatial dynamics (Costanza et al., 1993; Turner et al., 1995) and many applications to natural resources planning and monitoring have been developed (Goodland et al., 1993). Advances in remote sensing technology undoubtedly rank among the most significant contributions to the study of environmental issues in recent decades. The ability to use orbiting platforms to measure the magnitude, pace and pattern of land cover change has been particularly relevant to the study of tropical regions (Wood and Skole, 1998).

In the 1990’s, several studies attempted to understand the dynamics of land cover change at local and regional-scales by combining remote sensing data with spatially referenced biophysical, social and economic information (Rindfuss and Stern, 1998; Chowdhury, 2006). Similarly, the LUCC programme and other efforts to monitor tropical landscape increasingly used satellite remote sensing and land cover change analysis as powerful tools to monitor the rates and patterns of tropical forest change (Iverson et al., 1989; Hansen et al., 2000). Increasingly, researchers recognize the value of merging research on driving forces with spatially referenced data and methods to better understand the explicit spatial patterns and trajectories of land cover change (Chowdhury, 2006).

While the availability of extensive and timely imagery from various satellite sensors can aid in identifying the rates and patterns of deforestation, modelling techniques can evaluate the socio-economic and biophysical forces driving deforestation processes (Chowdhury, 2006). Since the 1980’s satellite data have been frequently used to monitor deforestation as well as re-growth (Cowell and Weber, 1981; Nelson, 1983; Woodwell et al., 1987; Sader et al., 1990; Kummer, 1992; Skole and Tucker, 1993; Moran et al., 1994; Alves et al., 1999, Duarte et al, 2003; Lorena et al., 2002, INPE, 2004; Fuller, 2006). It has been considered by some authors to be the most reliable source of quantitative information about deforestation, shifting cultivation and other land cover and land use changes in the tropics (Sader et al., 1994).

According to Lambin (1997), the main contribution of remote sensing to deforestation modelling are: (a) the categorization of the deforestation processes on the basis of spatial patterns of clearing, (b) the spatial stratification at a broad scale of a study area in terms of the deforestation processes, (c) the identification and/or measurement of some key socio-economic and ecological characteristics of land use systems, (d) the calibration of spatially-explicit models of land cover change, and (e) the testing of these models by comparing actual and predicted land use/cover patterns.

Allied to remote sensing techniques, models of deforestation are useful tool for understanding the dynamics of deforestation. Research shows that a wide variety of deforestation models exist. Each model displays different objectives, theoretical approaches, and modelling traditions. Lambin (1994 and 1997), Kaimowitz and Angelsen (1998), and Geist and Lambin (2002) presented a general categorization of deforestation models and a detailed review. A good review of LUCC models can be found in documents of the LUCC program, specifically in the LUCC Implementation Strategy (Lambin et al., 2001).

Deforestation modelling at a global scale has long been a focus of land use/cover change research (Lambin et al., 2003). However, currently, researchers are also concentrating efforts at regional and local scales because numerous land use decisions are made at the household level (Rindfuss, et al., 2003). Regional-level analyses have documented the spatial extent of deforestation and attempted to link deforestation to regional population changes (Skole and Tucker, 1993). Household-level analyses have focused on micro-scale factors contributing to land cover change, including soil characteristics, household income and demographic structure (Brondizio et al., 2002; McCracken et al., 2002; Moran et al., 2002).

Several excellent household-level studies of smallholders land use in the tropical forest, mainly in the Amazon, have been published in recent years (Brondizio et al., 1994; Pichón, 1996 and 1997; Moran et al., 2003; Browder et al., 2004, amongst others). Although a few researchers have been following the same population for many years (Browder et al., 2004), most of the studies conducted have been based on a single date, providing cross-sectional data from which dynamic processes of land use change are inferred. In general, land use research has been approached from three different perspectives: neoclassical economics theory – NET (focus on economy), Chayanov theory (focus on domestic life cycle), and political ecology theory (focus on the processes of environmental degradation being linked to social class, gender differentiated exploitation, government policies to export production, and transnationalization of agriculture) (Browder et al., 2004).

Pichón (1996 and 1997) and Marquette (1998) applied both NET and demographic perspectives among a sample of North-eastern Ecuadorians. To assess the dynamic of land use and land cover at the household level, they used a sample of 450 colonist-farming households. They concluded that the farms specializing on one economic activity tended to have a similar cluster of secondary activities. The authors suggested that the variability in settler land use strategies could result from various factors. Among a sample of small rural households in Rondônia, Vosti et al.,

(1998) used a NET perspective to identify several socio-economic and biophysical factors that could influence land use patterns. Similarly, Scatena et al. (1996) developed a schematic model of the factors that influenced crop fallow sequences on small farms in the Brazilian Amazon. These authors, drawing from the NET perspective, acknowledged that no single variable could determine the probable fallow length and crop selection.

From a demographic and human ecological perspective, Brondizio et al. (1994) have studied during 5 years, three different populations of "caboclos"[4] with distinct patterns of land use in the Amazon estuary. The authors concluded that there are no economic evidences between the community with the greatest impact on forest cover and the communities that have minimal impact. Moran et al. (2003) used a demographic approach to understand the role of the age factor and the general family structure of households in deforestation trajectories. The results showed that it would be necessary to further examine the role of household structures in the different changes that take place in the environment. In this case, deforestation is just one example, but there are surely others. Finally, McCracken et al. (1999) proposed a household evolution model that was composed of five stages that linked changes in the household composition to different generalized land uses. The authors suggested that while the specific land use trajectory of any given household may be influenced by exogenous factors over time, the most important determinant of land use strategy is the amount of available household labour.

In general, the linkage of socio-economic data and remote sensing data at the household level best captures the actual level of decision making (Lesschen et al., 2005). However, linking remote sensing and socio-economic data at the household level comes at a certain cost, depending on the detail of analysis required. Generally, such data requires georeferencing every plot of the interviewed households (Lambin et al., 2003). It can be a significant source of errors for research at the household level. In a study about methodological and practical problems of linking household and remotely sensed data, Rindfuss et al. (2003) suggested that, at the local level, researchers should have the flexibility of deciding what links are needed to be examined and the flexibility to choose or design the appropriate tools for making these links. For Rindfuss, the development of methodologies and techniques for these linkages would be the next step to better understand the driving forces of land use and cover change.

An interesting option for the linkages (socio-economic household level data and remote sensing data) could reside in the possible relationships among different spatial patterns of deforestation visualized by satellite images and the specific land use practices. According to Lambin (1994), Mertens and Lambin (1997), and Mertens (1999), any deforestation process could shape the forest landscape in a certain way that would leave a "footprint", which could be translated and

[4] Traditional community of the Amazon basin.

interpreted. Across the tropical belt, a few characteristic spatial deforestation patterns were recognized in terms of geometric, patchy, corridor, diffuse, fish-bone and island patterns (Husson et al., 1995; Mertens and Lambin, 1997; Geist and Lambin, 2001) and could be associated with broad categories of deforestation process.

Cartographic evidence in the form of maps, aerial views, and satellite imagery has been used to verify these patterns in some of the case studies, from the meta-analysis on the causes of tropical deforestation by Geist and Lambin (2001). It appears that diffuse, patchy and geometric patterns are comparatively more frequent among the cases (11 or 12% of all cases each) than corridor and island patterns (9%), while fishbone patterns are fewer in numbers (7% of all cases) and regionally limited to the Brazilian Amazon (Geist and Lambin, 2001). The literature contains some interpretations of these patterns, such as the ‘fishbone’ shape in Rondônia (Brazil), which is associated with planned resettlement schemes (Tucker et al., 1984; Woodwell et al., 1987). Or the large geometrically shaped clearings caused by ranching activities also founded in the Amazon Basin (Malingreau and Tucker, 1990). The corridor pattern, which is associated with deforestation along the road network, can be observed in Guatemala (Sader, 1995). Finally, the small-scattered patches of forest clearings associated with shifting cultivation can be observed in India (Dwivedi and Sankar, 1991).

However the literature about spatial patterns of deforestation is not limited to these typologies. Lambin (1986 and 1988) studied the relationship between agrarian systems practiced by different communities in the southwest of Burkina Faso and spatial configurations of deforestation observed by satellite images. The author found an interesting relationship among specific ethnic groups and different spatial configurations of deforestation. Batistella (2001) compared two different settlement designs in the Brazilian Amazon. One design was based on the fishbone settlement and the other settlement design was based on topographic features with communal forest reserves. The research showed that the fishbone design presents a higher deforestation and forest fragmentation as compared to the other settlement designs. Batistella concluded that the differences in the architectural designs of settlements suggested that the land use and land cover are also different. At last, Escada (2004) analysed land use processes and land cover change through an empirical method of spatial segmentation with the purpose of identifying different land use features. The author suggested that, with this method, it would be possible to recognize the differences in land use processes, proving that the occurrence of deforestation is different in different rural settlements with different spatial configurations.

Chapter 3

Study Area

3.1 Localization and context

The area under study (Figure 3.1), with approximately 3,700 km², is located in the west of Acre State, 90 km east from Rio Branco, between geographical coordinates S 9° 38' and S 10° 26' and W 66° 41' and W 67° 30'. This area is within the biggest settlement project of the Acre State, the PAD (Projeto de Assentamento Dirigido - Oriented Settlement Project) Pedro Peixoto. This settlement was officially created on September 31st 1977 through the federal resolution 176 for the INCRA. The objective of this project was to control the social tensions between small and large producers in the region and also to absorb a part of the unemployed and landless contingent from Rio Branco and its periphery, resultant of these tensions. Its implementation began in January 1978, with 4,025 delimited properties that varied in size from 10 to 80 ha on average, and with an initial capacity of 3,000 families. The area is limited in the north/northeast by the border with the State of Amazonas; in the east/southeastern by the Abunã river, which constitutes the border between Brazil and Bolivia; and in the west by the road BR 317. The road BR – 364 that links Rio Branco (AC) to Porto Velho (RD) cuts the whole study area transversally. Along this main highway were founded the biggest agrarian properties of the area, dedicated mainly to cattle. It was the implementation of these properties that generated conflicts and resulted in the colonization projects. The selection of this area was based on the previous knowledge of the region and on the possibility to access different spatial patterns of deforestation in a relative small area (compared with the Amazon region). The previous knowledge of the region allowed me to have access to the right persons and institution that could help in the field survey. Moreover, such knowledge also allowed me to have an idea about the localities and distances to be visited and covered. The possibility to access different spatial patterns in a relative small area is also important because, in general, the areas under human influence in the deforestation arc are huge, which make it impracticable for fieldwork without a large team. At last, in relation to the other sites of the deforestation arc such as Rondônia State, north Mato Grosso State and south Pará State, the east Acre State is the less studied, despite the presence of several institutions such as Universities, research centers and NGOs, and the high rates of deforestation over the last years.

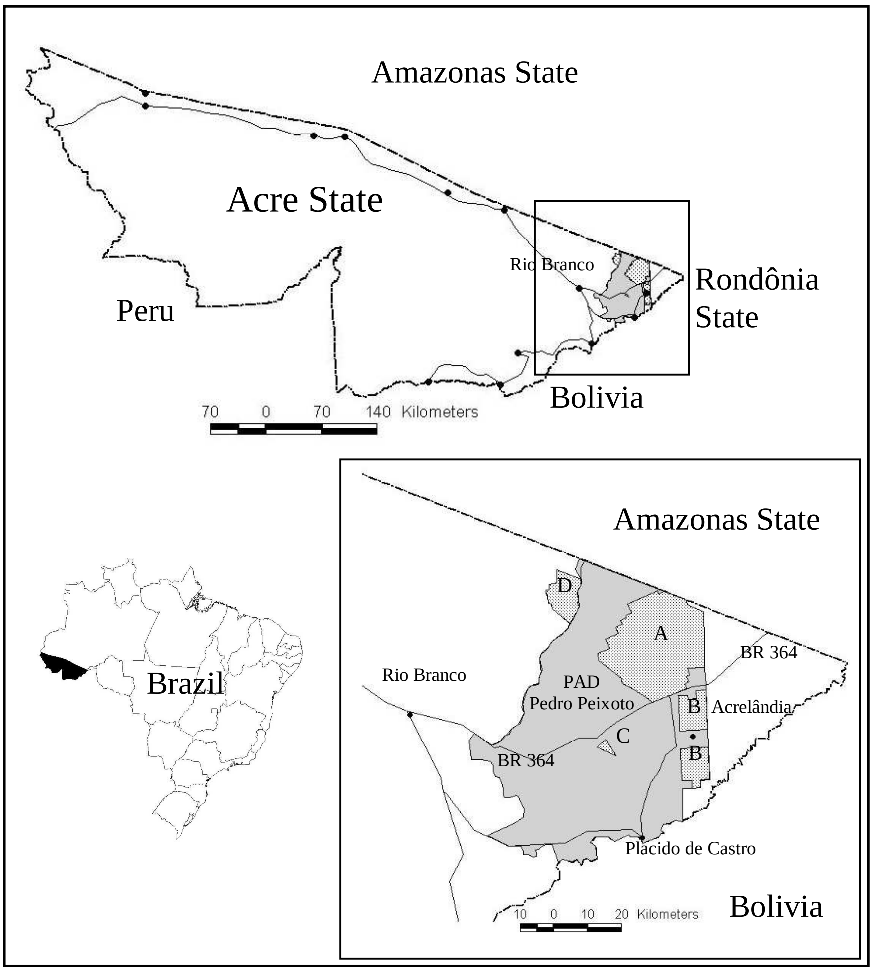

Figure 3.1 Localization of the Study Area

The distribution of land and the management of land possession in the colonization projects were done by the federal agency for colonization and agrarian reform INCRA (Instituto Nacional de Colonização e Reforma Agrária), based on the Brazilian Agrarian Reform. In general terms, the agrarian reform was done through redistribution of large private holdings rather than public lands. The legal procedure for this redistribution has been, in the case of private holdings, the expropriation and indemnity (compensation) of the landowners, as specified by Brazil's land Statute (Law 4330 of November 30th, 1964). The family contemplated with a plot of land called "lot", first received a "green card" giving them the right of use and usufruct of the land but it was nonnegotiable for ten years. After this, if the family was still there, they received the land title and the right of sale or disposal. However, one of the most important criticisms of the Agrarian Reform has been in relation to land abandonment and sale for profit before the stipulated time was up. However in the complexity of the Amazon region, the abandonment or the premature sale has occurred as a consequence of a number of things. In traditional, small-scale agriculture, which is the focus of this research, land abandonment happened mainly because of the absence of conditions to keep productivity high, such as the extreme isolation, distance to market, the absence of transportation and poor road condition, furthered by the decrease in soil fertility after two or three years.

In the beginning of the PAD Pedro Peixoto, the population colonized was composed of 70% people from Acre State and 30% by people from other States in the country, mostly from Paraná State (Cruz and Ramos Neto, 1983). Currently, the Pedro Peixoto settlement project is composed of a variety of independent sub-settlement projects, each one with a specific spatial configuration, property size, basic theoretical proposal of a specific economic activity and different actors. However it can be observed through field survey that the "deforested" landscape is dominated mainly by pastures, followed by subsistence crops (rice, beans, cassava and corn) and by some commercial crops such as coffee, lemon, or pupunha (palm fruit). In the past few years, the region has seen a constant increase in livestock breeding, regardless of property size and purpose of the subsettlement project. In function of the increase of cattle activities and consequent increase in pasture areas, the pressures over the primary forest have intensified and, as a consequence, many properties do not present any area of primary forest.

In accordance with the "Brazilian Forestry Code", the settlement properties in the Amazon are obliged to keep an area of primary forest, constituting the "legal reserve". The area of the legal reserve depends of the area and purpose of the settlement project and can vary from 80 % of the property in the settlements projects with property size between 15 to 25 ha, destined to the activities of non timber product forest exploration to 0 % in settlements destined to the small productions and livestock with properties around 10 ha or less. However, as observed in other Amazon colonization and settlement projects, the primary forest located in the PAD Pedro Peixoto since its creation is being gradually substituted by cattle and agriculture (Witcover et al., 1994). This fact reflects a land use tradition where the forest is seen as an obstacle for the development and its usage limited as an initial source of income to start the first activities in the property (Oliveira et al., 1996). This practice tends, in time, to reach areas of natural reserve, as observed in colonization projects in the States of Acre and Rondônia. In 1984, the deforestation area in the PAD Pedro Peixoto represented 21% of the total area and, in 1999, it represented 55%. This deforestation already advances over the legal reserve of the properties, resulting in the loss of a large volume of natural resources. This is a consequence of the absence of an efficient implementation of public policy promoting rational use (Sant'Anna and Oliveira, 2000; Oliveira and Sant'Anna, 2003).

3.2 Socio-economic aspects

The occupation of the Acre State can be divided into two main waves of migration. The first (1920 – 1960 approximately) was carried out mainly by people from the northeast of the country with the objective to work in the latex extraction. This first wave of migration was considered as low impact due the low population density and the interdiction by landowners to work with other activities such as agriculture or cattle ranching. The second migratory wave started in the early 1970's and involved mainly people from the south and southeast of the country who were attracted first by incentives for ranching activities and then by the settlement projects that offered free land for the people. The migrants of this second wave had been installed mainly in the extreme west of the State, in the PAD Peixoto, the older and larger settlement project in the Acre State. With an initial capacity for 3,000 families in 1987 (according to Duarte, 1987), the number of families installed reached 4,000. However, the main characteristic of the inhabitants of the INCRA Acre settlements is their mobility. Between 1995 and 2001, 1.171 families were installed in this settlement, demonstrating the high degree of land transference due mobility.

This second migratory wave was considered as a high impact process, due the adoption of inadequate production systems given the local agro-ecologic characteristics (Weinhold, 1999) and also to the low technological level of land use characterized by slash-and-burn and adoption of extensive cattle ranching (Walker *et a*l., 2000; Walker *et a*l., 2002; Caldas et al., 2003; Lira et al., 2006). The main consequences of this second wave of migration have been the high rate of deforestation and progressive loss of soil fertility (Acre, 2002b; Araujo et al., 2004). It explains the trends to pasture abandonment and the growth of abandoned areas, observed in several Amazon regions (Diez et al., 1997). Unfortunately, nowadays the land use in these settlements is still dependent on slash-and-burn of the primary and secondary forests, followed by the plantation of annual subsistence crops during 2 or 3 years, followed by the implantation of pastures. It can also be observed that forest clearing is often followed directly by pastures (Fujisaka and White, 1998; Rocha, 2000).

3.3 Physical aspects

3.3.1 Geology

The eastern portion of the Acre State, where the study area is located, is constituted of rocks from the Pre-Cambrian and is part of the Guaporé Craton. It is composed of a polymetamophic basement represented in the area by the Xingu complex. The lithology is formed essentially of granites, gneisses, migmatites, granulites, quartzite and schist (RADAMBRASIL, 1976). The area is almost totally covered by a Cenozoic sequence typically from the fluvial/continental environment and characterized by the brusque variation of horizons. They are "pelítico-psamíticos", plio-Pleistocene sediments, related in this report to the Solimões formation and are found over the parts of the Acre and High Amazon basins and limited in the surface by the High Structural of Iquitos. Old and current alluvial sediments complete the geological picture.

3.3.2 Climate

According to RADAMBRASIL (1976) the predominant climate of the study area is generically classified as AM – tropically rainy according to the Köppen criterion. The annual average temperatures are between 22° and 26° C, with annual average amplitude of about 2° C. The annual precipitation exceeds 2000 mm, concentrated in the rainy season between November and May on average, and the relative air humidity is around 85 – 90% (IBGE, 1989).

3.3.3 Geomorphology

To describe the geomorphology of an area it is important to include a description of its lithology, soil and vegetation, because all these factors are related. In the study area two main geomorphic units are distinguishable according to the RADAMBRASIL project (1976): the alluvial plains and terraces and the low Amazonian plateaus (Table 3.1).

3.3.3.1 Plains area and Alluvial Terraces

This geomorphic unit corresponds to the quaternary sediments, and consists of alluvial sediments ranging from sand to silt and clay. These sediments are found along the Abunã and Iquiri rivers. The sequence of terraces indicates a succession of erosion and deposition cycles that occurred during this geological period. There are three terrace levels: high, intermediate and low (RADAMBRASIL, 1976).

The plains and low terraces are characterized by periodic flooding that increases the water level by up to 500 m upstream into the small tributaries. The floodplain of the two larger rivers (Iquiri and Abunã) reaches 2 km of average width. During the floods, the erosive power of the rivers is substantial and it is common to find a great amount of trees being carried by the rivers. The deposition process of recent sediments associated with organic material has made the soil highly fertile in this specific area. Alluvial soil is predominant in these units. As one moves away from the river margin in direction of the interfluvial areas, associations of alluvial with hydro orphic gley soil occur. Open forest is the predominant vegetation of these areas. The humidity conditions favors the occurrence of palms trees, mainly the Paxiúba (*Iriartea Exorhisa Mart*.) and Açaí (*Euterpe spp*.). For this reason this type of vegetation is known as "floresta aberta com palmeiras" (open forest with palms) (RADAMBRASIL, 1976).

	Litology	Geomorphology	Soil	Forest Formation
Alluvial plain and terraces	Sands, silt, clay. Sediments not consolidated, recent deposits.	Alluvial plain and low terraces with meanders and lakes. High and intermediate terraces that hold closed meanders (frequent in small stretches of the Abunã and Iquiri rivers).	Alluvial soil and association of alluvial and gley soil. Hydromorphic gley soil and association of hydromorphic gley and red-yellow podzolic.	Open forest with palm. Open forest with palm and open forest with "cipó" – (liana).
Low plateaus	Solimões formation: massive mudstone or mixed with carbonatic and gipsíferous concretions, concentration of vertebrate and invertebrate fossils. Siltstone massive or fine layered. Fine and rough claystone in lenses or interfingerings, with siltstone and friable and compact clay	Hills with approximately 30 or 40 m of relative altimetry, high density of rills and gullies. Tabular interfluves, deeply incised and dense drainage network, presenting plain and conserved forms from Pleistocene.	Red-yellow podzolic. Red-yellow Latosol with association of red-yellow latosol / red yellow podzolic.	Open forest with cipó (liana) and bamboo with sub-domain of dense forest. Predominance of dense forest also occurring types of open forest. Source: Luchiari (1996)

Table 3.1 Characteristics of the main Geomorphologic Units present in the region

The intermediate and high terraces were created in the Pleistocene (Shubart, 1983). These terraces present old meanders, greater than the new meanders, evidencing different past environmental conditions in relation with the current situation (RADAMBRASIL, 1976). The hydromorphic gley soil predominates in the area in function of the moisture conditions proportionate to rainfall. In the high terraces, 10 m above the average level of the rivers, the red-yellow podzolic soil is predominant. The moisture conditions in these units favor the predominance of the Open Forest with Palms and to a lesser degree the Open Forest of "Cipó (liana)". This kind of forest is characterized by the presence of an upper layer composed of isolated trees and a sub-forest composed by a high density of small and medium sized trees and a large number of "lianas" and "epifias".

3.3.3.2 Low Plateaus

The low plateaus are on top of the "Solimões Formation", that was formed during the last phase of the Andean orogenesis in the Miocene (RADAMBRASIL, 1976). This formation is constituted of an alternation of massive mudstones or layers of gypsum. It also contains sandstone and siltstone deposited within a fluvial environment. These sediments show an alternation of very friable and compacted sections. In this unit there are two types of interfluves: hills and tabulates.

The hills are the remainders of more active erosive processes responsible for the degradation of the original relief. They contain a high density drainage network with little vertical incision. The predominant soil is Red Yellow Podzolic that presents a B-textural horizon with an accumulation of silicate clay. The leaching of alkaline and ferrous alkaline elements resulted in an increased acidification. On the other hand, the occurrence of thick sediments created better physical conditions for the soil, for example good internal drainage. The liana forest (cipó) is frequent on the hillsides. The amount of organic material generated by this forest results in eutrophication of the surface soil horizon (Brazil, 1984). The dense forest is characterized by a coverof emergent trees, amongst which the "castanheira" (*Bertholletia Excelsa*) that predominates in the highest altitudes. The superior layer of this vegetal association is formed by trees 30m tall, with closed canopy that decreases the luminosity of the inferior layers. The sub-forest is composed of seedlings from the superior layer. In accordance with Shubart (1983), this type of vegetal formation reveals a stage of maturity that is characterized by the absence of the regeneration of sub-forest and by the occurrence of individuals of the same height of the superior layer.

The tabular interfluves correspond to the plain surfaces that are on clay layers in function of the erosive action corresponding to the oldest terrace level. In these interfluves are located the majority of the first order rivers existing in the study area. The height difference between the interfluves and the alluvial plains is of the order of 100 meters. The red-yellow latosols are predominant in this geomorphic unit. The leaching of the bases provided the formation of the latossolico B-horizon equivalent to the oxic horizon of the American classification (RADAMBRASIL, 1976). In this horizon, the laterites are concentrated and according to Penteado (1983), are responsible for the plain form of this relief. Guerra (1985) found the biggest occurrence of the laterites in some places of this area with depths around 30cm from the surface.

3.4 Agricultural characteristics

In the study area shifting agriculture is practiced for the production of basic food. This land use consists in slash-and-burn practices and in the planting of crops for three years on average. The area effectively planted in agricultural exploitations, varies from 1 to 4 ha and the developed activities are adjusted to the local climatic conditions (Table 3.2). The cutting down of the sub-forest, and the felling of big trees is done in the period between June and July, the beginning of the dry season. The vegetal residues are left to dry between August and September, and burnt in September, the drier month.

The planting of rice and corn is done at the time of the first rains in September and the harvest is in December. The local inhabitants have the habit of planting through a mixed cultivation system, cultivating two or more crops in the same area, while the colonists of other regions practice monoculture. In the development of these crops, three weeding are conducted on average. However, a fourth can happen in response to the fast growth of invading plants such as the “assa peixe” (*Vermonia polyantes*) and “grama nativa” (*Paspalum amazonicum Trin*). The weeding is executed with a big knife (facão) because the ground demands greater effort for the farmer when executed with the hoe, given the high amount of clay.

Table 3.2 Calendar of the main annual cultures of the region

		JA	FE	MR	AP	MY	JU	JL	AG	ST	OT	NO	DC
Cleanness						i	a						
Falling of trees								a					
Burn									a	i			
Planting	Rice									i	a		
	Corn									a	a	a	
	Bean			i	a								
	Cassava									a	a	a	a
Harvest	Rice	i	a										
	Corn	a	a	a									
	Bean												
Source: Luchiari (1996)	Cassava						i	i	a				
								i	i	i	i	i	i
	a: period of activity i: period of intense activity												

Beans are planted soon after the corn and rice harvests, being cultivated in monocropping for all colonists, in March and April (rainy season). The harvest takes place between June and August. After the first year of harvest, the cassava is cultivated or the cycle starts again (rice-corn-beans and then cassava). Cassava is well adapted to the region because it does not demand intensive field preparation and controls the proliferation of invading plants. Cassava is widely spread because the resultant flour of its processing is a good source of income. Usually the cultivated area is abandoned or transformed into pasture after soil exhaustion. When the area is abandoned, the secondary vegetation appears and is represented (in general) by species of the *Cecropia* genus. The pasture is frequently formed by a native grass. Livestock breeding is more interesting for colonists because it guarantees the investments without risk of loss in relation to the crops. In the production system (Table 3.3) proposed by Pinho de Sá and Carpentier (1998), the producers use different arrangements of sequence of crops, which vary in function of the financial conditions and aptitude of the producer.

Table 3.3 Effective production systems in the settlement project "Pedro Peixoto"

System 1	System 2	System 3	System 4	System 5
corn / rice	corn /	corn / rice	corn / bean	corn / rice
bean	pasture	bean	coffee	bean
corn /		cassava	bean	banana
pasture		cassava		pasture
		cassava		
		pasture		

Source: Pinho de Sá and Carpentier, (1998)

In general it is observed that, in the systems 1 and 5, the rice and corn are cultivated in the same area, first the corn in September and then the rice in December. Beans are planted in April and after this, the area is destined to pasture or perennial cultures, mainly banana, being then substituted with pasture. System 2 is commonly used for capitalized producers. After slash and burn, they plant corn with grass. It clearly demonstrates the aim on pasture formation and in some cases, corn is completely ignored. In the third system, commonly used by producers owning less capital, the annual crops are planted until the total exhaustion of the soil and then the pasture is implanted after the harvest of the culture of cassava. In the system 4 the producer plants beans between the coffee trees for one or two years.

Chapter 4

Methodology

This chapter describes the stages and procedures used to analyze the linkages between spatial patterns of deforestation, land use activities and deforestation. For each procedure described, the respective material and data are also presented. The clear understanding of the determinants of land use change requires the use of interdisciplinary research techniques that combine quantitative spatial data with qualitative socio-economic data. A combination of analyses using these different data sources was used to identify the main features of each spatial pattern of deforestation. The methodology was divided in five stages (Figure 4.1) described below.

The **first stage** aimed at the identification and delimitation of the spatial patterns of deforestation by the analyze of a multi-temporal set of satellite image, using primarily typologies of spatial patterns of deforestation, complemented by a method of visual image interpretation. This stage also allowed the estimation of the deforestation during the period 1990-2004, for the entire study area, for each spatial pattern of deforestation and also for each household visited.

The **second stage** was the field survey, where the main objective was to collect the necessary data for the identification of the socio-economic characteristics of four spatial deforestation pattern selected in the first stage. This activity was lead through household interviews, guided by a pre-defined questionnaire. This stage also supported the automatic land cover classification using satellite images, through the GPS points acquired in the field and used as reference in the classification process.

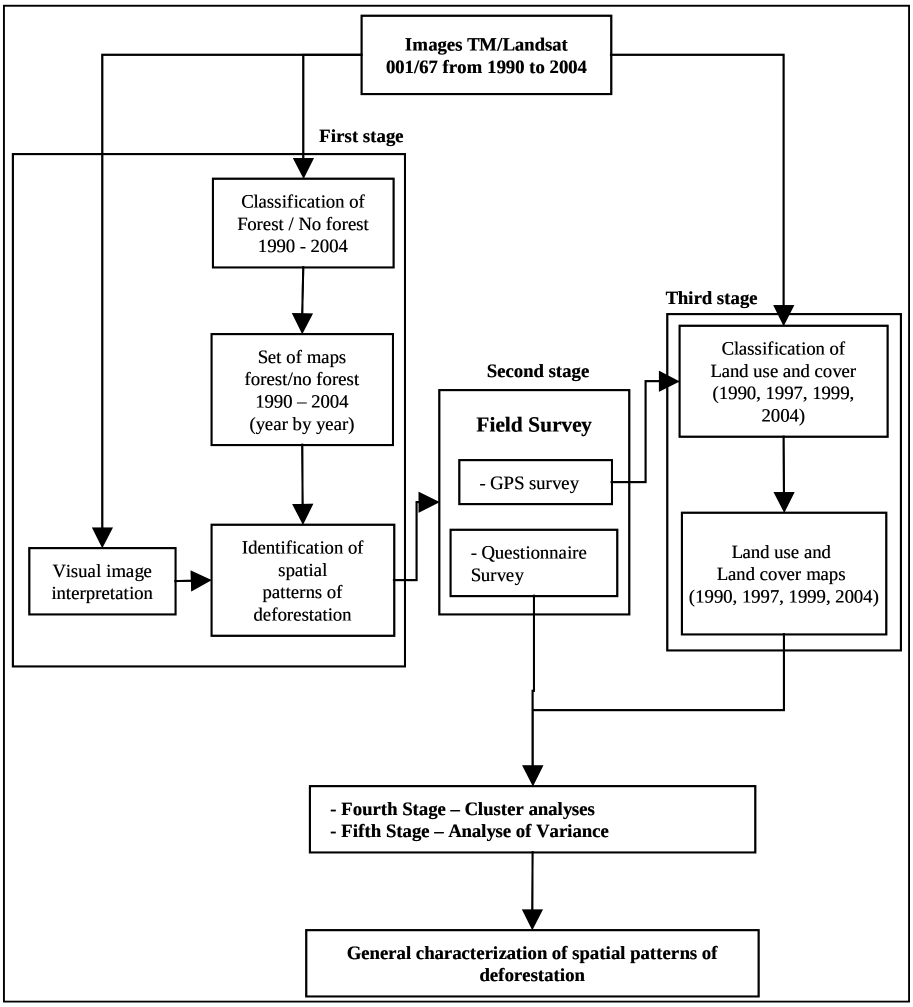

Figure 4.1 Fluxogram of activities

In the **third stage,** Landsat images from 1990, 1997, 1999 and 2004 were classified into thematic land use maps and changes between different land use classes were computed. The objective was to analyze the temporal evolution of the land use and land cover for each spatial pattern, as well as for each household visited.

The **fourth stage** was the identification of homogeneous groups in terms of land use and land cover using a clustering statistical analysis. First, the analysis considered only the socio-economic data acquired in the field survey. Secondly, the analysis considered only the data on land use and land cover from the satellite images.

In the **fifth stage,** an analysis of variance ANOVA was carried out considering the same data used in the cluster analyzes as a way of analyzing the differences within and between groups.

4.1 First stage - Identification of spatial patterns of deforestation

The identification of the spatial patterns of deforestation was based on satellite image interpretation. For this, twelve satellite images corresponding to the scene 001/67 of the systems Landsat 5 TM and Landsat 7 ETM+ (channels 1 (0,45-0,52µm), 2 (0,52-0.60µm), 3 (0,63-0,69 µm), 4 (0,76 – 0,90 µm), 5 (1,55-1,75 µm) and 7 (2,08-2.35µm)) were selected for a period between 1990 to 2004 (1990, 1991, 1994, 1995, 1996, 1997, 1998, 1999, 2001, 2002, 2003, 2004), considering the dry season between May and September, due to the low presence of clouds in the image. These images were corrected in relation to geometric distortions using an interactive standard method of georreferencing.

In general, the criterion for spatial segmentation using satellite images depends on the scale and objective of the study. The most frequent are: administrative limits (Alves et al., 1998; Théry, 1998; Reis, 2001), regular cells (Skole and Tucker, 1993; Fearnside, 1986; Laurence and Fearniside, 2002), micro-regions (Reis and Gusman, 1994) or irregular polygons (Kaimowits et al., 2002). In our case, the identification and delimitation of spatial patterns of deforestation using satellite images was primarily based on the typologies of spatial patterns of deforestation visualized in forest/no forest classified images (Figure 4.1) (Husson et al., 1995). However, due to the variety of spatial patterns present in the area, a complementary methodology based on visual image interpretation (Veneziani, 1984) was applied to identify some spatial patterns that not could be interpreted by the other method.

According to Lambin (1994) and Mertens and Lambin (1997), the typologies of spatial patterns of deforestation visualized in a forest/non forest classified images can be relate to specific deforestation process. Husson et al. (1995) proposed the following typology: geometric, island, corridor, diffuse, fishbone and patchy (Figure 4.2). The geometric pattern is in general, related to extensive cattle ranching or extensive crops. The island pattern can be related to peri-urban areas. The corridor pattern corresponds to areas of spontaneous colonization. The spatial pattern diffuse is related to subsistence crops. The fishbone pattern is related to planned settlements and the patchy pattern is related to a small-scale occupation in forest areas. These interpretations of the typologies can vary depending of the region, but in general follow the description above.

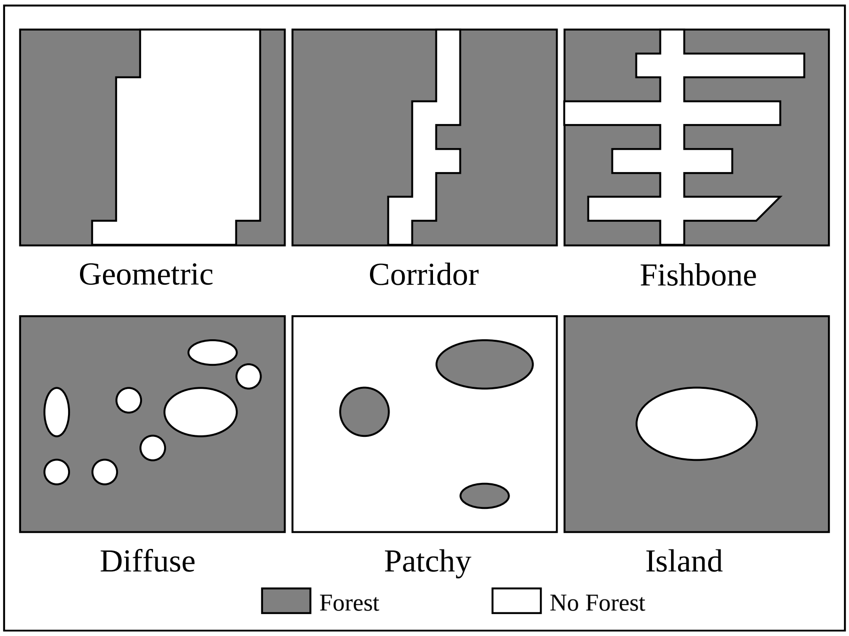

Figure 4.2 Typologies of the forest/non forest spatial patterns

The first step was to create a forest/non forest classification. The procedure applied is based on the methodology of image processing of the Brazilian Program of Deforestation Monitoring (PRODES) using satellite images, as developed by the National Institute for Space Research (INPE) of Brazil (Duarte et al., 2003). This methodology applies techniques of image processing such as spectral mixture model, segmentation, and classification by object to better separate the regions of forest and non forest. The process applied is similar but not the same. The original method uses an unsupervised classification algorithm in function of the extension of the Amazon region and consequently the amount of images to classify. In ours case, the reduced extension of the area in relation to the Amazon basin allowed the application of a supervised classification, once a sample of areas of forest and non forest were well know. First, the spectral mixture model was applied using the 6 Landsat bands with the objective to extract the cover fraction of bare soil, vegetation and shade. Then, given the contrast between the forested and deforested area on the fraction image “shade”, this band was isolated, segmented and then classified using an algorithm of supervised classification by object that considers the regions produced by the previous segmentation process. Based on the 12 images the spatial patterns from the above typology were identified.

Unfortunately, the typology does not include all types of spatial patterns of deforestation presents in the study area. To complement the interpretation and to identify all spatial patterns, a second method was applied. This method called “logical or systematic method” (Veneziani, 1984) is based on the visual image interpretation that analyzes the landscape in function of its spatial characteristics such as structure, texture and shape. The concept of this method is to analyze the image without a preconceived typology, but following the logical sequence of homogeneous structures and textures present in the image. Each continuous sequence of a given structure is analyzed based on its order and complexity. The order of the structure can be understood as the spatial organization of the structure. It is divided in: ordered (the structure possesses organized lines, as a planned settlement), disordered (the structure possesses disorganized lines, as an area of spontaneous colonization) and preferential (the structure expands in only to directions). The complexity of the structure also concerns its directions. It can be divided in: unidirectional, bi-directional and multidirectional (Figure 4.3).

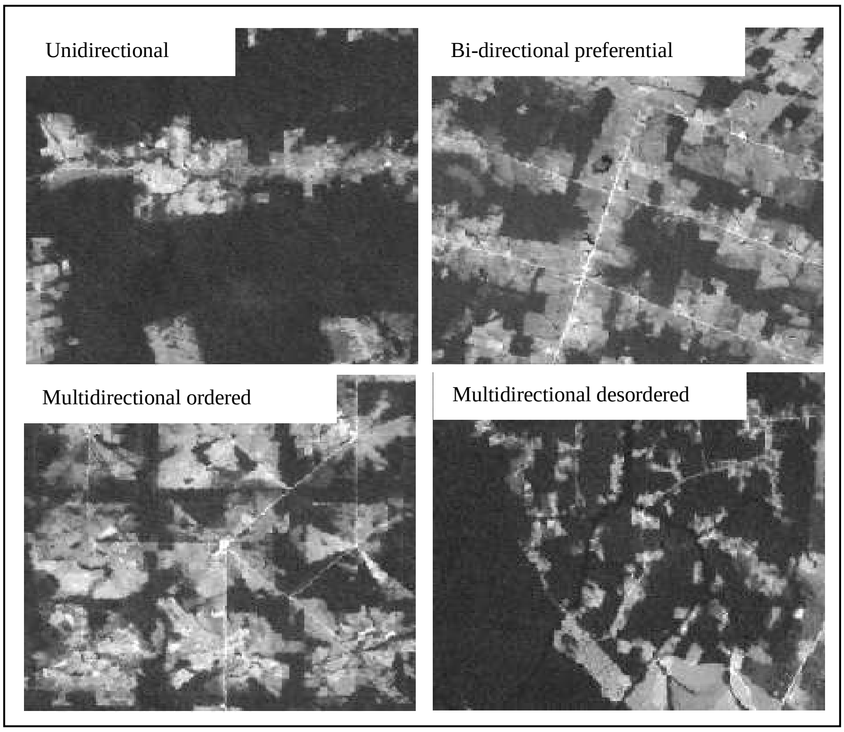

Figure 4.3 Examples of the interpretation made through the systematic or logical method

4.1.1 Auxiliary data

The auxiliary data (agrarian map and the history of the settlement) used in this stage played an important role in the determination and delimitation of the spatial patterns of deforestation. As the process of colonization occurred at different periods and with different actors, the area under study presents several different spatial patterns of deforestation. However, as will be better explained in the next section (field survey), due to the limited resources for the field survey, analyzing all spatial patterns found was not possible. We limited the analysis to just a few of the spatial patterns. First we searched for spatial patterns with different ages, probably related to different periods of the colonization process. Then, we searched for settlement projects with particular designs that could be interesting for the analysis - for example, settlement projects with a forest preservation goal as for the “reserves extrativistas” (extractive reserves dedicated only to the exploitation of non timber forest products).

Another difficulty was related to the definition of the limits of the spatial patterns. The limit between patterns is not always obvious and some criterion or criteria need to be used for a good delimitation. The possible solutions include using the administrative limits (municipal, region, settlement), natural limits (rivers, relief, vegetation) and physical limits such as roads. For our research, the agrarian (cadastral) map was available for the study area (Figure 4.3), which made possible to determine not only the limits of the spatial patterns, but also the limits of each property visited. An agrarian (or cadastral) map opens the capacity to observe the land cover change at a household level, even though it provides an “ideal” view of land ownership. Moran et al. (2003) and McCracken et al. (1999) addressed some problems related to the property grid accuracy in relation to the disposition and shape of the properties in the Brazilian Amazon. According to these authors, the main problem relates to the overlay of the property grid on the satellite images with sufficient accuracy to examine changes in land cover at both the landscape and property levels. The property grid does not consider topographic features, rivers and other natural features. In addition, the precise boundaries between properties can change depending on negotiations between neighbors (Moran et al., 2003).

To minimize these problems, for each household visited in the field survey, some GPS points were taken in strategic places in the property, such as the lateral borders, plantations, pastures and dwelling units. Furthermore, there were no great topographic variations or other natural features that could influence the disposition or size of the properties. In this work, we faced another problem related to the property grid. A small part of the property grid (corresponding to spatial pattern C) did not exist. The only option was to reconstruct empirically this part. For this, the measures of the properties are not enough and good field knowledge is also required. First, it is necessary to know exactly the area, shape and disposition of the properties in relation to some reference such as a road or river. The size is not the most important factor. However, the shape needs to be a regular polygon (e.g., a square or rectangle) and the disposition of the property in relation to some reference needs to be known. With this information and the support of GPS points, it was possible to construct the missing part. To evaluate the precision of this part of the map, a second field survey would be necessary.

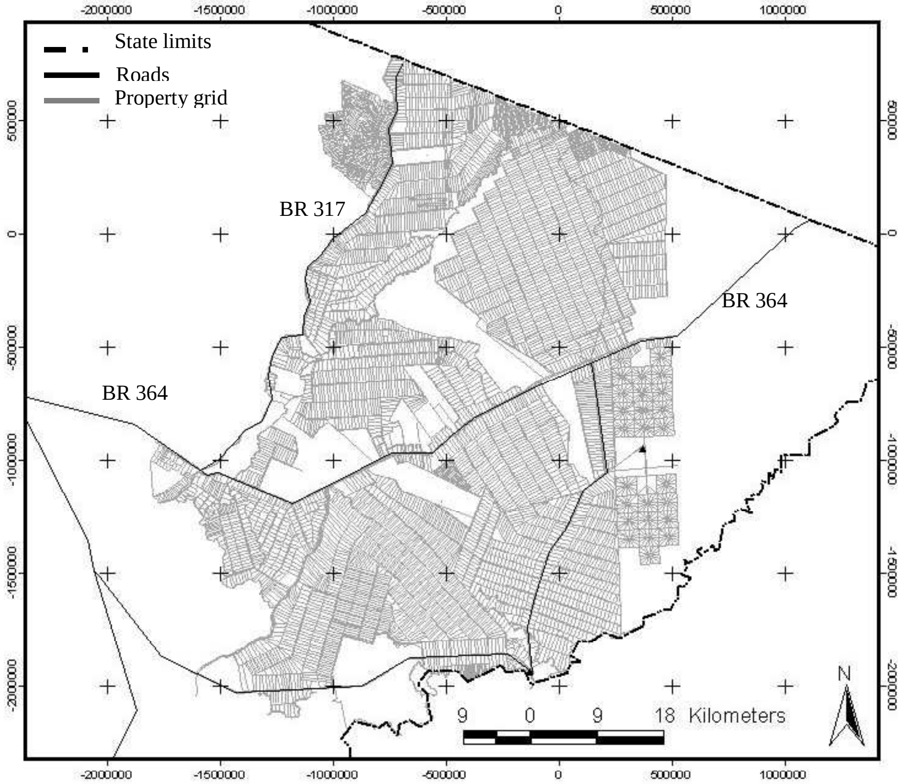

Figure 4.4 PAD Pedro Peixoto's Property grid

4.2 Second stage - Field survey

The field survey took place during three months between June and August 2005. Data acquisition considered multiple sources, both quantitative and qualitative. Two main activities were conduced: a household survey based on interviews guided by a predefined questionnaire; and a landscape survey based on GPS points to sample land cover classes and localize each interviewed household. Other activities were carried out at this stage with the objective to assist the interpretation of the primary data. The parallel activities were data mining to search for old household surveys based on questionnaires made by professionals of INCRA (National Institute for Agrarian Reform), digital maps of the settlements, and discussions with key informants, in general former employees of INCRA who knew the history and the dynamics of the settlements.

4.2.1 Household survey

A common solution to link social, natural, and spatial data has been to use census data gathered at the household level, aggregate them to some administrative boundary, and link them to remotely sensed and GIS data for the same administrative unit. However, while much can be learned from such linkages at the administrative level, numerous land use decisions are made at the household level, and aggregating up to administrative units can make some household or community decisions invisible (Rindfuss, 2003). The Brazilian census data are only available at the municipal level and for our research, household level information was required. For this reason, a survey at a property level seemed to be the most useful for this study.

The household survey was made through interviews with the inhabitants of each spatial pattern, conducted in accordance with a pre-defined socio-economic questionnaire (Annex A). The composition of the questionnaire followed the research premises: to access the main socio-demographic and economic characteristic of households for each spatial pattern. The questionnaire structure was based on an already implemented socio-economic questionnaire elaborated by the Center for International Forestry Research (CIFOR) (Survey form for 1998 study on economic crisis, farming systems and forest cover change in the humid forest zone of Cameroon). The distribution of the interviews took into account the spatial distribution of the households in relation to the spatial patterns identified in the first stage (Figure, 4.4).

Given that linking "people-to-pixels" is a relatively new scientific activity, there is limited experience about the necessary budget (financial and time), the skills needed and the adequate sample size to address the research questions (Rindfuss, et al. 2005). Based on our experience, we planned to make at least 40 interviews per spatial pattern. However, a good field survey needs financial support, trained people and time. Financial support is needed to rent a car with guide, trained people to guarantee the quality of the data, and time to make a good interview with the correct person (head or responsible for the property). Without these items, a field survey in the Amazon forest becomes a big challenge. The household survey was carried out by one person (the author) during two months, without financial support. The car and driver were provided by INCRA for 20 days (15 + 5) in exchange for some technical work. Conducted by one person with limited time, to reach the goal of 40 interviews per spatial pattern with the right person was not possible. Absent any alternative, many of the respondents were someone who lived on the property, not necessarily being the head or property. This made it difficult to evaluate the precision of some of the answers.

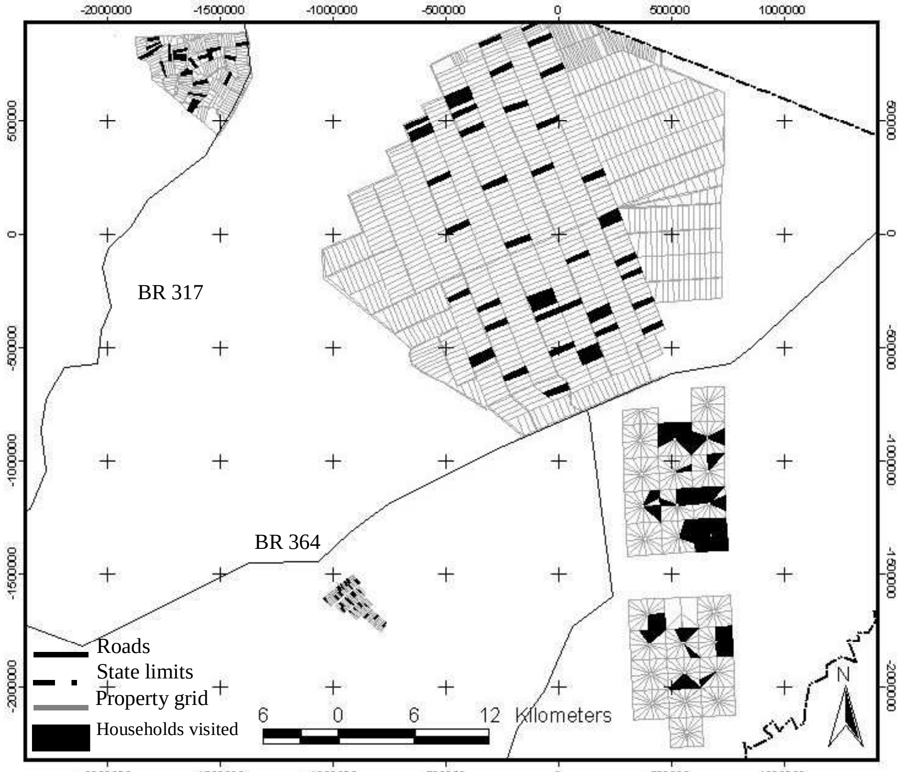

Figure 4.4 Localization of the households visited in the field survey

The questionnaire was structured in seven parts:

a) General data (identification, localization and characterization of the household)

The first part of the questionnaire aimed to localize each household interviewed in terms of geographical coordinates and spatial pattern. It also aimed to access the general characteristics of the households in terms of origin, date of occupation, age and gender of the household head, level of education, land tenure. This information allowed linking the households visited with the information derived from the satellite images and also to access important information that can aid to understand the dynamic of each spatial pattern.

b) Labor force and equipments

The second part of the questionnaire asked for the labor force and equipment available in the household. This kind of information is useful to understand the degree of development of each households interviewed. Some strategies such as off-farm activities or the labor contracted off-farm are frequent in the region and suggest the difficulties related to sustaining a family with only the income generated from agriculture. The presence or not of equipment such as a tractor or chainsaw can indicate or explain the well-being of each household.

c) Crops (surface, production and sale)

The third part of the questionnaire concerns agriculture and is composed by questions such as crop types, area of these crop productions, production/year and proportion sold. This information allowed identifying the nature of the crops planted in the property (commercial or subsistence) and the importance of this activity.

d) Cattle (number of animals, meat or milk and pasture area)

The following part of the questionnaire was related to cattle. This part was composed of questions such as the number of animals, finality (meat or milk), pasture area, type of grass and rotation time of the cattle in the pasture. The data on number of animals and pasture area can give an idea of the relative importance of this activity in the property, in relation to other economic activities practiced. The type of grass and rotation can give an idea about the level of knowledge about this activity.

e) Non Timber Forest Products (**NTFP)** (extraction of latex and harvest of "castanha do Pará" (Brazilian chestnut) and "açai" (palm fruit)).

The extraction and production of Non Timber Forest Products (NTFP) in the region is traditional and practiced since the beginning of the Amazon colonization. In the beginning, the extraction of latex (rubber) brought much wealth to the State and to the country as well. Today the economic activity in the area is varied including other productions amongst which "castanha do Pará" (Brazilian chestnuts) and açai (palm fruits). However, it is currently considered as a secondary activity in the household and depends on the presence or not of trees related to these products. This part of the questionnaire was composed of questions related to the amount of products extracted (in the case of latex, kg) or harvested (in the case of chestnuts or palm fruits, kg).

f) Cooperatives and/or associations

The presence or absence of cooperatives or producer associations in some regions can give insights on the relation between occupants and the development of some activities. In the study area, the presence of cooperatives indicates a significant production of milk, as this kind of institution in Brazil is mostly related to the milk production. The presence of producer associations indicates a significant presence of some specific crops. The participation of the households interviewed in the cooperatives indicates that they are serious producers with an income generated mainly by milk production. The participation of the household in a producer association indicates that the household is dedicated more to cultivation than to cattle. This choice, cooperatives or associations, can influence directly the rate of deforestation in some areas.

g) Infrastructure of the area

The information concerning the infrastructure of the study area is very important to understand the development of this region. Factors such as road conditions, distance to markets, water and electricity availability, presence and distance to schools and health services, presence of technical and economic assistance can explain or give insights on the level of development of some regions.

4.2.2 Landscape survey

The landscape survey consisted in field observations with acquisition of GPS points. The GPS survey had two objectives: ground control points for image geometric correction and identification of the thematic classes used in the classification process. To correct the image geometry, ground control points are related to targets that can be recognized in the image and in the field like road crossings, crossings between roads and rivers, river junctions being amongst the most common. Figure 4.4 shows examples of ground control point used for the image correction.

Figure 4.4 GPS Ground control points for image correction

For the classification process, the targets are the categories that will form the land use and land cover map such as: primary forest, pastures, secondary forest and water. For the classification process, it is common to take two sets of samples, one for the classification and another to evaluate the accuracy of the classification. Figure 4.5 shows examples of points for the classification process.

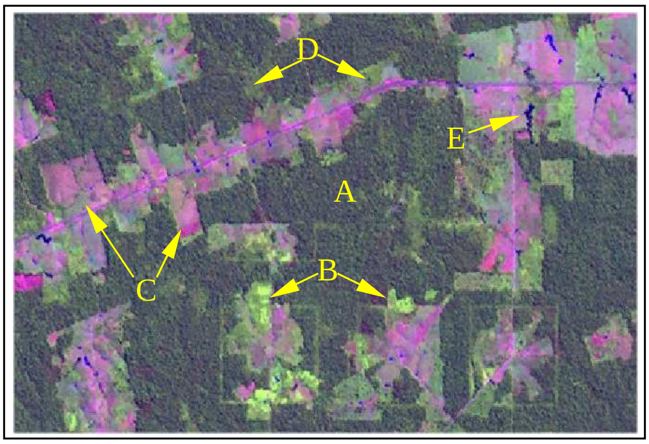

Figure 4.5 GPS points for the image classification processes. A) Forest, B) Culture, C) Pasture, D) Regeneration and E) Water

4.3 Third Stage - Automatic classification of land use and land cover

The automatic classification of satellite images consists in the identification of different targets (vegetation, sand, water…) in the satellite image that present similar spectral patterns and then relating these targets to determined classes. In general the algorithms of image classification are divided in function of the presence (supervised) or not (unsupervised) of a training stage where the analyst gives samples to orient the classification. This process can also be applied based on the isolated information of each pixel (by pixel) or considering its neighborhood (by "object").

In an unsupervised classification the analyst does not need to give any training samples and the algorithm decide how many classes the image will be divided into (Crosta, 1992; Erthal and Bins, 1996). The supervised classification requires training samples supplied by the analyst and some previous knowledge of the area. The statistical classification of images based on the analysis of isolated pixels is the most applied and conventional procedure for image classification. However, this approach presents the limitation of labeling pixels based only on its isolated spectral properties, without considering the neighborhood information (Richards, 1993). On the other hand, the contextual classification or object oriented classification uses the information of each pixel adding the information of its neighborhood. Based on the samples acquired in the field survey, the classification process was conduced using the supervised classification algorithm by region implemented in the SPRING software (Bhattacharya algorithm), preceded by a segmentation process where the spatial contexts used in the classification were extracted.

4.3.1 Segmentation process

Segmentation is a process that subdivides the image in its constituent objects, also called regions (Gonzales and Wints, 1987). This process can be accomplished in two ways: a) based on a regional growth process that divides the images into a number of homogeneous regions, each having a unique label, and b) based on the edge detection process that determines boundaries between homogeneous regions with different properties (Bins et al, 1993). This study explored a segmentation process by region growing which has demonstrated its technical feasibility for images of forest and agricultural regions and has been intensively used in the segmentation of Amazon region images to assess land use changes (Alves and Skole, 1996).

The region growing technique is an iterative process where each region is defined starting from individual pixels, and growing according to the determined thresholds. The algorithm runs iteratively until every pixel is processed. In general this process can be described by the following steps: 1) Segment the entire image into standard cells (1 or more pixels); 2) Each standard cell is compared with its neighboring cells to determine if they are similar (in relation to it’s digital numbers), using a similarity measure, if they are similar, merge the cells to form a fragment and update the property used in the comparison; 3) Continue growing the fragment looking at its neighbors until no joinable regions remain, label the fragment as a completed region; 4) Move to the next uncompleted cell, and repeat these steps until all cells are labeled.

4.3.2 Classification process

After the segmentation process, the satellite images were classified. In the SPRING software the only algorithm for classification by region available is the Bhattacharya. This algorithm permits to associate each region with one class using a distance criterion based on the Jeffries-Matusita distance. The choice of training areas was made from the previous knowledge of the field (field survey). After this, each sample of was analyzed using the option for sample analysis available in the classification module of the SPRING software. The samples with low spatial separability were excluded and another sample was selected in that case. This interactive process was repeated until a set with only good spatial separability samples was obtained, considering that each class was represented by a large number of samples.

4.3.3 Evaluation of the classification process

The quality of the classified images can be evaluated through a qualitative analysis, directly on the computer screen (visual evaluation) and also by quantitative analysis using an accuracy index (e.g. Kappa index or Global accuracy) calculated from the error matrix that expresses the concordance between the classified image and some reference data (Lorena, 2001). For the quantitative evaluation of the classifications, some statistical procedures as the Kappa index permit to verify the similarity between the classification and reference data. The Kappa index is often recommended (Medeiros, 1987; Cong and Howarth, 1990) as an appropriate accuracy measure between classification results to represent the error matrix integrally by a single index. It is a concordance measure that defines the dependence degree between two classifications (one reference and one classification) present in the same error matrix (Nascimento, 1988) or a classification and a set of samples acquired in the field. The Kappa coefficient ranges between 0 (very bad) and 1 (excellent), where 1 indicates the complete agreement and when multiplied by 100 give the accuracy of the classification. In accordance with Landis and Koch (1977), the evaluation from the coefficient Kappa can be realized based on Table 4.1. In this work, the reference data used to evaluate the degree of accuracy of the maps created from the automatic classification were the GPS samples acquired in the field.

Table 4.1 Kappa Coefficient classes

KAPPA	Concordance
< 0	Very bad
0 – 0.2	Bad
0.2 – 0.4	Moderate
0.4 – 0.6	Good
0.6 – 0.8	Very Good
0.8 – 1	Excellent

4.4 Fourth Stage - Clusters Analysis

A number of empirical analysis techniques like factor analyses, canonical analyses, cluster analyses and regressions have been proposed to explore land use and land cover data. The diversity in data structures, research questions and specific study cases demands a careful analysis of the requirements of the method necessary for each specific case study (Lesschen et al. 2005). In the fourth stage, households with similar land use and land cover characteristics were grouped based on cluster analysis. This kind of analysis groups observations based on the similarity between them. The groups are determined in a way to obtain homogeneity inside the group and heterogeneity between them (Doni, 2004). The objective was to investigate the relations between groups with similar land use and socio-economic characteristics and spatial deforestation patterns.

In general terms, the cluster analysis consists in clustering observations by computing the similarity between any pair of observations through a distance coefficient (Sokal, 1977). This distance coefficient between two samples can be expressed as a function of the distance between two representative points of this sample in a n-dimensional space. There are some methods to calculate the distance between two points, the most usual being the Euclidian distance (x_{ab}):

$$x_{ab}^2 = \sum_{j=1}^{n} \left(d_{aj} - d_{bj} \right)^2$$

For LUCC (Land Use and Cover Change) research, two methods are usually used to group similar land use types or farming systems: hierarchical cluster analysis and K-means cluster analysis (Lesschen et al. 2005). K-means is the most applied method (Pichón, 1996; Lambin, 2003; Browder, 2004). The K-means clustering algorithm attempts to identify relatively homogeneous groups of cases based on selected characteristics, using an algorithm that can handle large numbers of cases. In this procedure, the variables must be quantitative and homogeneous in terms of scale. Distances between observations in the feature space are computed using a simple Euclidian distance (Lesschen et al. 2005). The K-means is a non hierarchic cluster algorithm, which has been developed to group elements in K groups, where K is the number of groups defined a priori (Doni, 2004). It is often necessary to apply the method a few times for different values of K, choosing the results that allow for the best interpretation of the groups or the best graphical representation (Bussab, 1990). The main idea of this method is to choose an initial number of partitions of the elements and then to modify successively this number to get the best partition (Anderberg, 1973). In general terms, the K-means cluster analysis uses the steps of a standard algorithm described in the Figure 4.9.

In : The number of groups, ***K***, and the data-base with ***N*** elements;
Out: A set of K groups.

1. To choose an arbitrary number of ***K*** elements in the data-base as the initial center of the groups ;
2. Repeat;
3. (Re)attribute each element to a more similar group in accordance with the mean value of the elements of this group;
4. To renew the means of the groups calculating the mean value of the elements for each group;
5. Until that does not make changes in the elements between groups.

(Source: Doni, 2004)

Figure 4.9 K-means cluster algorithm

4.4.1 Clusters Analysis – procedure

The analysis by clusters was performed using the K-means algorithm and considering two different types of data: the socio-economic data from the household survey and the land use and land cover data from satellite images. The aim of this analysis was to investigate the set of households interviewed in search for subgroups that could be related specifically to some of the spatial patterns of deforestation. For the analysis using data from the household survey (questionnaire), first all questionnaires had been standardized and organized in the same Excel sheet to make quantitative analysis possible. Then, the data related only to land use and economic activity were isolated and analyzed. The sampling unit was the household and the variables analyzed were: average area subsistence crops (ha), average production of subsistence crops (kg), average area of commercial crop (ha), average production of commercial crop (kg), area of pasture (ha), average number of animals (livestock), and average production of NTFP (kg). All households were analyzed together and the clusters most representative were isolated and the localization of their households in relation to the spatial patterns was observed. If the cluster was formed by households associated with a specific spatial pattern, then the socio-economic attributes of this cluster could be attributed to this spatial pattern.

For the analysis using land use and land cover data from satellite images, the general approach was the same. In this case the variables analyzed were: area of forest (ha), area of secondary forest (ha), area of crops (ha), and area of pastures (ha). However the spatial data from the satellite images needed to be related to the households which posed some technical challenges, already described in this chapter, section 4.1. The main question was how to link spatial information from the satellite images with each property visited in the field. Fortunately, for the study area, the property grid was available in digital format. After being imported to the database and overlaid on the land use and land cover data from the satellite images, this information could be attributed to each household interviewed.

4.5 Fifth Stage - Analysis of variance (ANOVA)

To verify the differences observed in the previous section, an analysis of variance ANOVA was applied. This analysis was conduced as a way to verify whether there are significant differences within and between spatial patterns. In relation to the variables analyzed before. The analysis of variance (ANOVA) is a statistical test for heterogeneity of means between three or more groups based on the analysis of variances. This method was developed by Fisher (1925) initially to work with agricultural data, and has been applied to a vast array of other fields for data analysis (Bower, 2000).

In general terms the method calculates the variance between groups (mean square between groups-MSB) and within groups (mean square within groups-MSW). If the variance between groups is greater than the variance within groups, then the null hypothesis can be rejected. In this case, the null hypothesis will be the equality between population means and, the alternative hypothesis is that at least one mean is different. To apply the ANOVA test, some conditions must be met. The population distribution must be normal or approximately normal, the samples must be independent and the variance of the population must be equal. However, according to Box et al. (2005), whether the size of the samples is balanced (or almost balanced), the difference between the biggest and the minor variances can be up to 9 times and thus the results of ANOVA will be essentially trustworthy. The basis of ANOVA is the partitioning of sums of squares into between-class (SSB) and within-class (SSW). It enables all classes to be compared with each other simultaneously, rather than individually (Shutler, 2002). The one way analysis is calculated in three steps: first the sum of squares for all sample (SST), second, the sum of squares between classes (SSB) and then, the sum of squares within class (SSW) cases. For each stage, the degrees of freedom (*df)* are also determined. The degree of freedom is the number of independent pieces of information that go into the estimate of a parameter (Shutler, 2002). With the variances between and within groups calculated it is possible to evaluate the null hypothesis using Fisher statistics or simply *F* statistic. If $F >> 1$, then differences between class means exist (Shutler, 2002). All of these ANOVA information in general are presented in a summary table (Table 4.2) (Shutler, 2002).

Table 4.2 ANOVA summary table

	Sum of Squares	Degree of freedom	Mean of Squares	F-statistic
Between	SS(B)	k-1	SS(B)/k-1	MSS(B)/MSS(W)
Within	SS(W)	N-k	SS(W)/N-k	
Total	SS(W)+SS(B)	N-1		

These results can also be analyzed through a statistical significance test or P-value, where the P-value is the probability that a variable would assume a value greater than or equal to the value observed strictly by chance. If the P-value is small (e.g. $P<0.01$ or $P<1\%$) then the null hypotheses (the groups are equal) can be rejected.

The data used in this analysis were the same as used in the cluster analysis. The sampling unit was also the household and the variables analyzed were, firstly, from the questionnaire: average area subsistence crops (ha), average production of subsistence crops (kg), average area of commercial crop (ha), average production of commercial crop (kg), area of pasture (ha), average number of animals (livestock), and average production of NTFP (kg); and, secondly, from satellite images: area of forest (ha), area of secondary forest (ha), area of crops (ha) and area of pastures (ha). The analysis was performed for each variable separately (7 variables from household survey and 7 variables from satellite images), considering four groups (four spatial patterns). The test is performed automatically for between groups as well for within groups.

To verify the statistical significance of the ANOVA results, a Bonferroni test was applied. The Bonferroni test or Bonferroni correction is a mathematical correction originally utilized to reduce falsely significant results in a statistical analysis. This test consists in multiplying the *p* value by the number of tests carried out. The corrected value is then compared against the level of 0.05 to decide if it is significant. If the corrected value is still less than 0.05, only then is the null hypothesis rejected.

Chapter 5

Results and Discussion

This chapter presents the results obtained through a methodology structured to analyze spatial patterns of deforestation. For this study, changes in land use and land cover from an area of the Brazilian Amazon were analyzed in relation to the spatial patterns of deforestation observed by satellite images. Quantitative and qualitative analyses were applied using socio-economic data from household surveys, and land use and land cover data from satellite images, with the objective to find specific characteristics related to the different spatial pattern present in the study area. The methodology was divided into five stages and the results are presented below for each stage. Section 5.1 presents the results of the first stage, where the spatial pattern of deforestation were determined and delimited and their deforestation rates were calculated. Section 5.2 presents the results of the second stage dedicated to the field survey. A general analysis based on the socio-economic data is presented in this section. In section 5.3 are presented the results of the land use and land cover classification based on satellite images. This classification process allowed to quantify the area of two land covers (primary and secondary forests) and, two land use classes (crops and pastures), and to calculate the changes between these classes. Section 5.4 presents an analysis based on the characteristics of the groups formed by clustering analysis. This stage aimed at finding homogeneous groups related to the spatial pattern analyzed. The last section 5.5 presents the results of an analysis of variance ANOVA, applied to the same data used in the cluster analysis.

5.1 First Stage - Identification of spatial pattern of deforestation

The identification of spatial pattern of deforestation present in the study area, was based on the typologies of deforestation visualized in forest/non forest classifications derived from satellite images. The results of this approach were complemented by a second analysis based on a visual image interpretation (Fiori and Soares, 1976, Veneziani, 1984). Auxiliary data were used to decide which spatial pattern to analyze and to determine the exact border of each spatial pattern analyzed. Figure 5.1 shows the main spatial patterns found in the study area, considering the two spatial segmentation methods.

Spatial pattern A – fishbone. This configuration consists in a main road with transversal roads that cut the first in regular points, like the "fishbone" typology. In the Brazilian Amazon, this kind of spatial pattern is generally related to small and medium farms in a colonization planning area. In this area, this spatial pattern is composed by properties around 80 to 100 ha, dedicated mainly to cattle ranching.

Spatial pattern B – In this case, as there is no correspondent typology for this spatial pattern, it was identified and classified using the visual interpretation method. In function of the level of organization and directions of expansion, it was classified as "multidirectional ordered" and consists in a square with lines that start in the border of the square and converge to the same point in the center of this square. This spatial pattern is composed by properties around 80 to 100 ha, dedicated mainly to cattle ranching.

Spatial pattern C – as the spatial pattern B, the spatial pattern C doest not have a corresponding typology in the main method, thus it was interpreted using the complementary method. According to this method, this spatial pattern can be classified as "bi-directional preferential", due the direction of its roads. In this case, this spatial pattern can also be classified as a small scale fishbone. This spatial pattern is related to a specific colonization project, composed of small farms between 4 and 10 ha, allocated to small production activities and small amounts of livestock.

Spatial pattern D – diffuse. This spatial pattern consists in small open points in the forest, with a random appearance. However, in the area, this kind of spatial pattern is related to a planned colonization based on the old roads (tracks) used by the previous rubber extractors. The properties of this spatial pattern are dedicated mainly to the family agriculture and extraction of NTFP (Non Timber Forest Products).

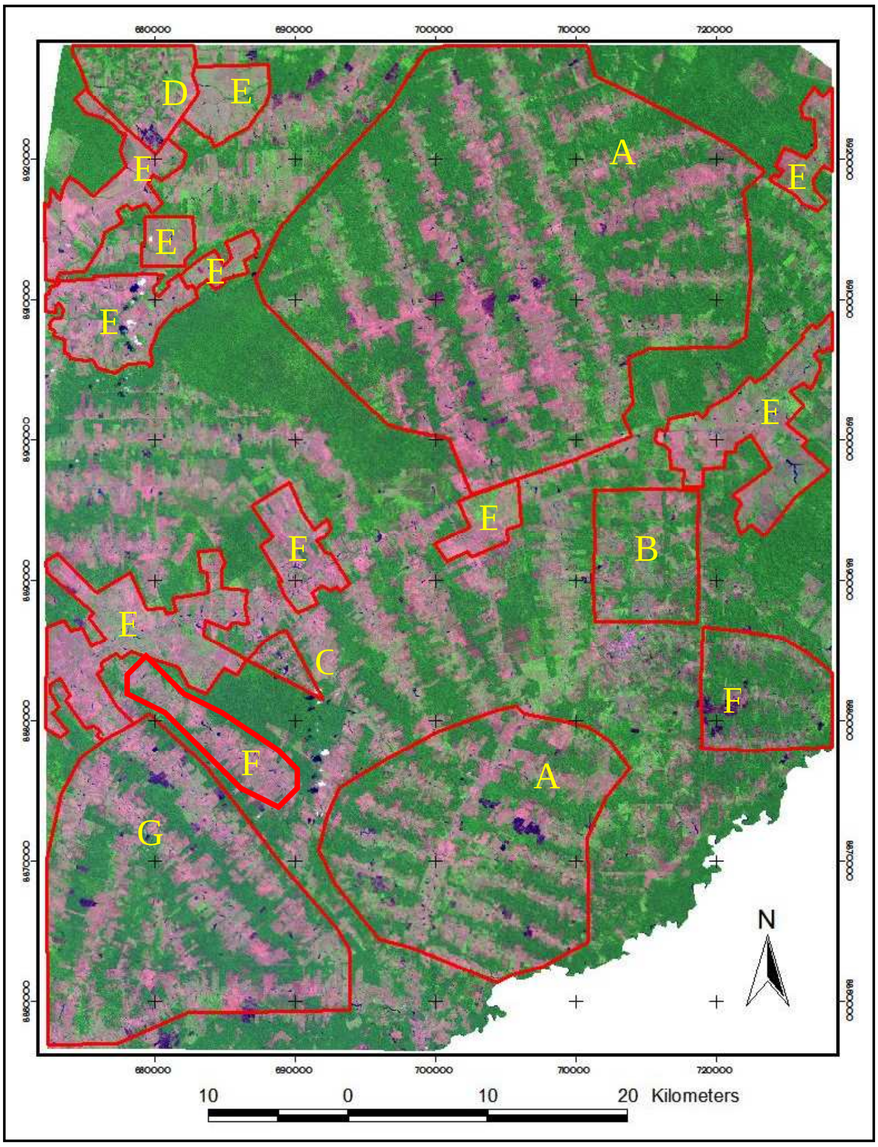

Figure 5.1 Spatial pattern of deforestation presents in the study area

Spatial Pattern E – geometric. It consists in large geometric forms, normally squares or rectangles, related in the Amazon Basin to large farms of extensive cattle ranching or plantations. The properties related to this spatial pattern often have 500 ha of area.

Spatial pattern F – corridor. This spatial pattern consists in a single line in the forest, frequently related to spontaneous colonization. In the study area, there are some roads opened, to link roads that already exist in the area. This is enough to begin spontaneous colonization in the Amazon Basin. The properties of this spatial pattern can vary in area, but are normally dedicated to familiar production.

Spatial pattern G – This spatial pattern, like the spatial patterns B and C, do not have correspondence in the main method. In this case, due to the organization of the lines and multitude of directions, this spatial pattern is also classified as "multidirectional ordered". The structure of this spatial pattern is a triangle and the roads that form the triangles converge to the center in a way to create minors triangles inside one of the other. Is not a spatial pattern frequently observed in the Brazilian Amazon.

5.1.1 Auxiliary data

The identification of spatial pattern of deforestation based on the typologies identified in forest/non forest interfaces of satellite images, and complemented by a method of visual image interpretation, have demonstrated their efficiency in identifying spatial pattern of deforestation in satellite images. However, after this stage of identification, two questions had to be addressed: which patterns would be analyzed and which criterion to use to delimit the chosen patterns ? The first question is relevant because many different patterns had been found and to study each one, would require too much time and resources. Some spatial pattern like "Geometric" and "Patchy", were not included in the analysis because they specifically include large farms of extensive cattle ranching (geometric) or periurban areas (patchy). Second, the history of colonization was analyzed with the objective to find some details that could be used as a reference to choose the spatial pattern for the analysis.

The second question is also important because the limit of the spatial pattern is not always clear, and its determination requires some reference. In this case, the agrarian map of the settlement projects was available. This auxiliary data was used only to help choose which spatial pattern to analyze. In addition, all spatial patterns identified were part of the same government settlement project. This presupposes similar historical and land uses. However, the analysis of the settlement history revealed that some spatial pattern present in the study area had been elaborated following a specific purpose. Aimed to compare different spatial pattern with different sizes and purposes, four different spatial pattern of deforestation were selected and delimited for the analysis and are presented as follows:

a) Spatial pattern A - Ramais do Peixoto – 1977 (fishbone)

The settlement project “Pedro Peixoto” was implanted in 1977 with the opening of the first four roads, perpendicular to the main road (BR 364) following a standard conception of forest settlement: small and medium properties distributed along parallel roads, perpendiculars to a main road. The “Ramais do Peixoto” (Roads of Peixoto – Figure 5.2) as it is known is the first spatial pattern determined, formed mainly by 4 roads nominated (from west to east) “Granada, Bigode, Oco do Mundo and Nabor Junior” perpendicular to the BR 364. The area of this spatial pattern is around 718 km² and is basically composed by properties with 80ha of area on average, where the occupant has the right to deforest up to 50% of the primary forest present in the property, according to the Brazilian forest code.

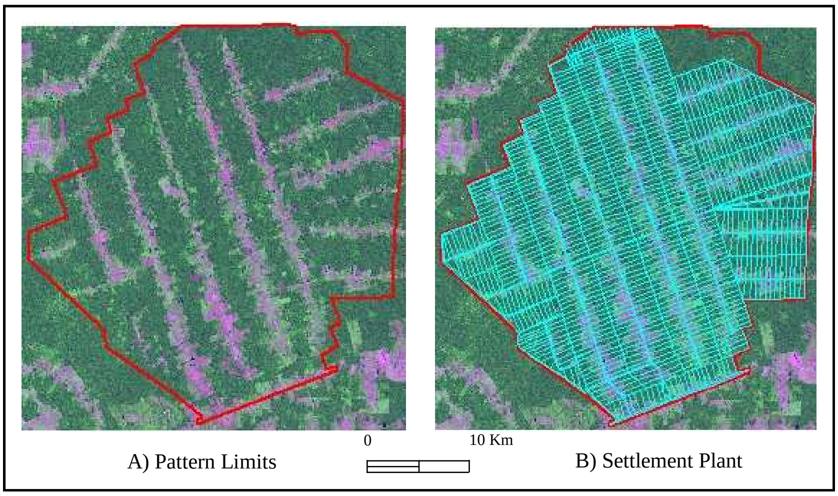

Figure 5.2 Spatial pattern A - Ramais do Peixoto

b) Spatial pattern B - Redenção – 1982 (Multidirectional ordered)

In 1982, the National Institute for Colonization and Agrarian Reform tried to implement a concept of settlement based on the Israeli kibbutz, aiming at stimulating social contacts between inhabitants of the area. In this spatial pattern with area around 174 km², the properties with an area between 80 to 100 ha, are disposed in a radial pattern, inside a square with a common area in the center, where (in the original idea) a school, a market, health and social centers were planned. In accordance with the Brazilian forest code, the occupants also have the right to deforest 50% of the area (Figure 5.3).

Figure 5.3 Spatial pattern B - Redenção

c) Spatial pattern C – Campinas – 1991 (bi-directional preferential or small scale fishbone)

The settlement project called "Campinas" (Figure 5.4) represents a smaller spatial pattern, representing just 0.2 % (10.61 km²) of the whole study area . This spatial configuration is similar to the fishbone pattern, however with property sizes up to 10 ha, compared to the traditional fishbone with 80ha on average. This settlement was conceived to receive a large number of families in a relatively small area. The property sizes varied between 4 and 10 ha, which allow working only with small crop production and small scale livestock holders. In accordance with the Brazilian Forestry Code, properties up to 10 ha have the permission to exploit the entire primary forest present in the lot.

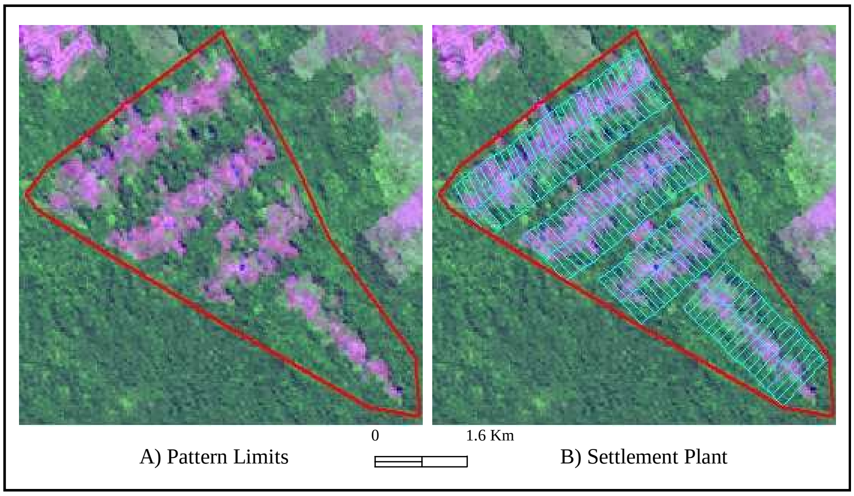

Figure 5.4 Spatial patter C - Campinas

d) Spatial pattern D – Caqueta – 1997 (diffuse)

One of the current concepts of colonization projects in the Amazon tries to integrate families and forest as a way to diminish the impact on the forest caused by the presence of colonists. In the Caqueta project, with an area around 46.62 km², the property sizes vary from 15 to 25 ha. The spatial distribution of its properties, visualized by satellite images, seemed to be random and without organization. However, this spatial pattern was conceived to respect the old "*seringal*" roads. These roads in fact, are much more similar to a track in the forest than a road. In the old "seringais" (area occupied by native "Seringuerias" – *Hevea Brasilienses*) the tradition was to link every "Seringueria" (tree of latex) by a track, forming a network where the responsible for the extraction passed in the morning (around 4 or 5 am) wounding the trees and returned in the afternoon (around 3 and 4 pm) to collect the latex. In this spatial pattern, the properties were disposed in relation to these old tracks, and the inhabitants were stimulated to adopt old land uses which were less aggressive towards the forest, such as rubber extraction. In this spatial pattern, the occupants had the right to deforest only 20% of the entire area (Figure 5.5).

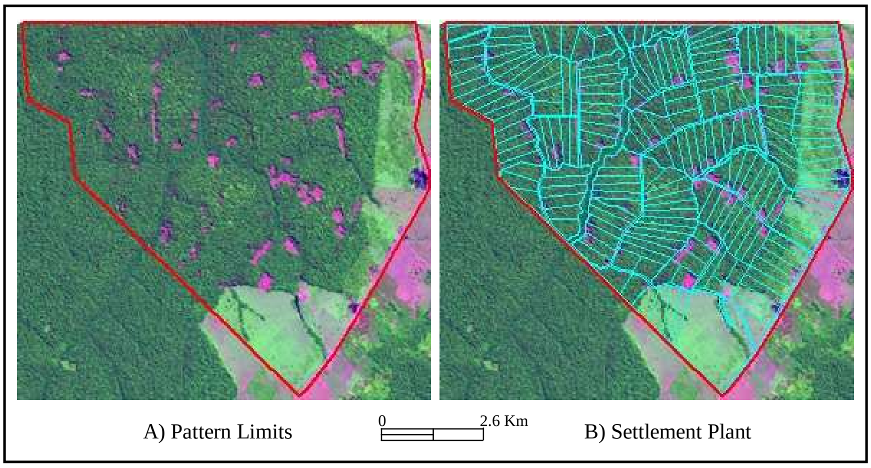

Figure 5.5 Spatial pattern D - Caqueta1

5.1.2 Deforestation analysis

Besides the identification of spatial patterns of deforestation, the forest/non forest classification also allowed quantification of deforestation rates for the study area between 1990 – 2004, for each spatial pattern of deforestation, and for each household interviewed in the field survey. The study area suffered from rapid deforestation during the study period. Up to 1990, only 16% of the primary forest present in the area had been deforested. In 1999, this value increased to 45% and, by 2004, attained 62 % of the entire study area (Figure 5.6). These results are consistent with the study by Sant'Anna et al. (2001) using the same methodology. They calculated 16% for 1984 and 50% for 1998. This suggests that the deforested area had changed very little between 1984 and 1990 and that rapid changes took place from the 1990s onwards. It is probably related to the pavement of the BR 364 that links Rio Branco (AC) to Porto Velho (RD), which occurred in the early 1990s (Scouvart, 2006). Before its pavement this area was considered very isolated and distant from markets. After the renovation on this road, the economic interests in this land grew fast and many people, amongst whom small, medium, and large farmers, decided to settle in this region.

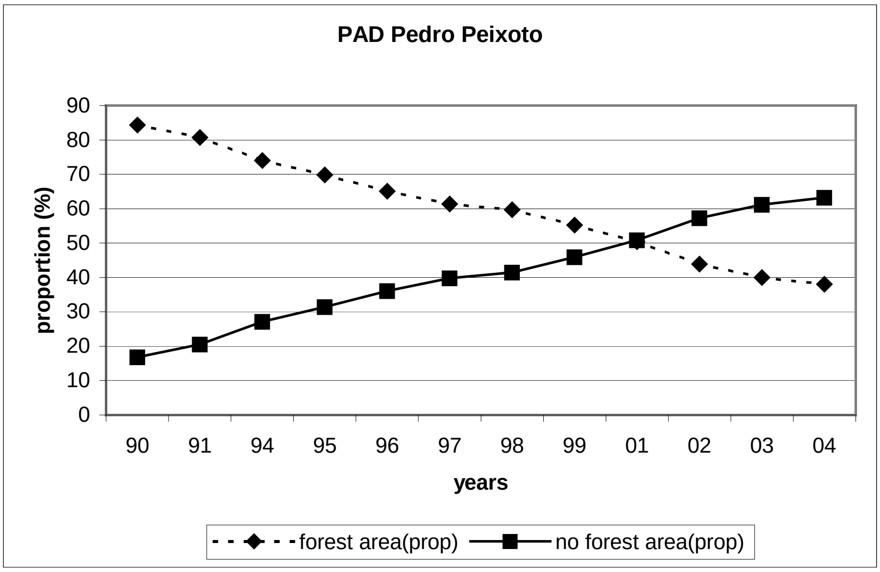

Figure 5.6 Relative increase of deforested area and decrease forest area in relation to the total surface of the study area.

Figure 5.7, presents the area deforested by year in km² for the entire study area between 1990 and 2004 (less 1992, 1993 and 2001). It can be observed that there are low values between 1990 and 1994, followed by a period of increases from 1995 to 1997, 1999 and 2002. The low values observed between 1990/1994 are also observed in the dynamics of deforestation for the Acre State and the Legal Amazon in general. This period, as explained before (section 2.3.2), is related to a few years of economic contraction (Fearnside, 1993, Escada, 2004) with rural producers without means to invest in forest clearing. It also denotes the influence of the RIO-1992 conference where the reduction of the Amazon deforestation was discussed. The increase of the deforestation mainly in 1995 and 2002 also corresponds to the sequence of deforestation in the Acre State and Legal Amazon. The increase from 1995 is related with the availability of capital for new investments due to the rapid recovery of the economy. The increase in 2002 is probably related with investments in infrastructure (mainly in terms of road quality) through the Avança Brasil project. However, the increase observed in 1999 does not correspond to the pattern of deforestation in the Acre State and the Legal Amazon. It is probably associated with a flow of migrants that arrived in the same period, with similar land uses and rates of deforestation (Escada, 2004). Brondízio et al. (2002) and MacCraken et al. (1999 and 2002) also attribute this increase in deforestation in specific areas and periods to local political and economic factors.

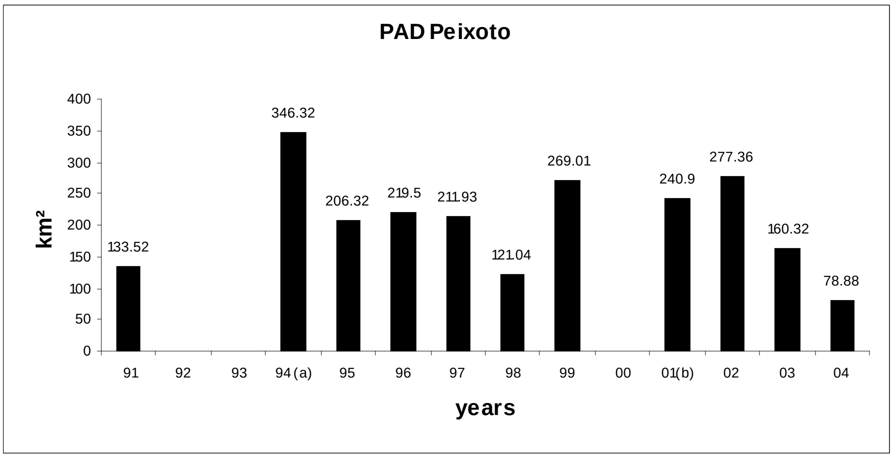

Figure 5.7 Deforested area by year between 1990 and 2004 (a-area deforested between 1991 and 1994; b-area deforested between 1999 and 2001)

Moreover, beyond the federal investments through the “Avança Brasil” program, the Acre State government called “Governo da Floresta” (forests’ government) had stimulated a forest occupation in an organized way in the period between 2000 and 2004, through actions like the creation of the “Instituto de Terras do Acre” (Acre Land Institute) in March 2001, or the INCRA (National Institute for Colonization and Agrarian Reform). These two institutions are together responsible for the execution and promotion of the regularization, ordinance and utilization of public lands. In this same period, investments in terms of road infrastructure and electricity distribution are also notable. The BR 364 road that links Rio Branco (Capital of Acre State) to the rest of the country in the east and to the isolated west of the State, and the BR 317 that links Rio Branco and Porto Acre to the north and Rio Branco and Assis Brasil to the south, had been paved or re-paved to facilitate the traffic in the region. Despite the notable advance in terms of traffic, these investments in road infrastructure had certainly contributed to the deforestation once isolated areas had been reached and previously cleared areas had been reactivated thanks to their greater accessibility.

The investments in the distribution of electricity also played a role in the deforestation during this period. The State Government had assigned a contract with the Federal Government for the energy distribution to rural families. From 2000 to 2004, around 720 km of transmission lines were installed and more than 1300 km were expected by 2008. This investment improved the quality of life in rural areas. Television, radio, DVD, electric hot water, electric water pump and other goods were not accessible until a few years ago. This should contribute to decrease deforestation once it stabilizes families in the area. However, the absence of other factors such as technical assistance, fertile soil, market and financial assistance end up contributing to deforestation. Actuallly, with infrastructure (e.g., roads and electricity) but without credit and knowledge, farmers clear 1 or 2 ha of primary forest per year in search for soil temporarily suitable for farming.

5.1.2.1 Deforestation in spatial pattern A (Ramais do Peixoto)

The spatial pattern A, "Ramais do Peixoto" (Roads of Peixoto), with 718 km² is the larger spatial pattern analyzed in this study, representing 20% of the entire area. Despite having been launched late in the 1970's, in 1990 only 12 % of its area was deforested. However, in 1997, the deforested area already represented 33 % of the entire area of spatial pattern A and 59 % in 2004, (Figure 5.8). As observed in the deforestation of the entire study area, it was only after 1990 that significant changes in this area have occurred.

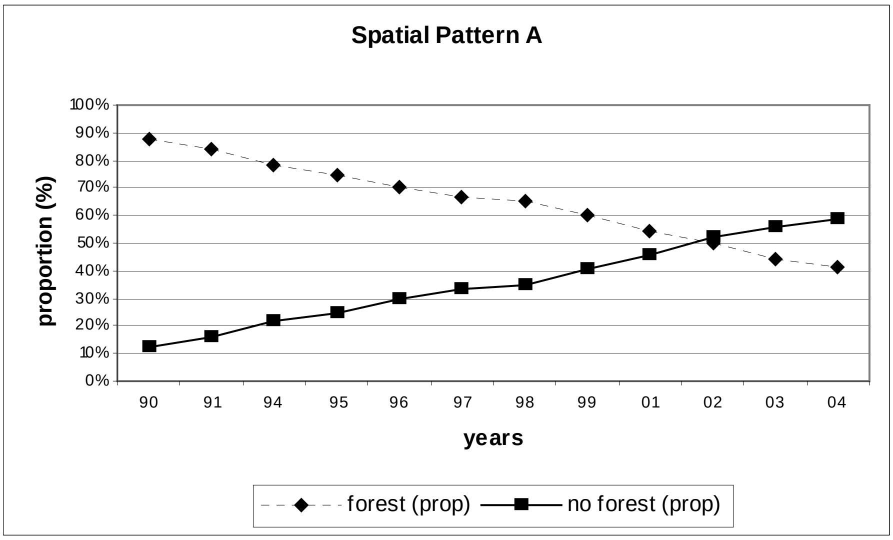

Figure 5.8 Relative increase of deforested area and decrease of forest area in relation to the total surface of the spatial pattern A.

Furthermore, the deforestation of this spatial pattern evolves through time similarly to the deforestation of the entire study area. It presents low values between 1990 and 1994, followed by an increase between 1995 and 1997, 1999, and 2002 (Figure 5.9). This evolution suggests that deforestation in this spatial pattern is influenced by the same causes that drive deforestation in the entire study area, such as the improvement of road infrastructure (BR 367), the implementation of electric networks and the investments in migration projects.

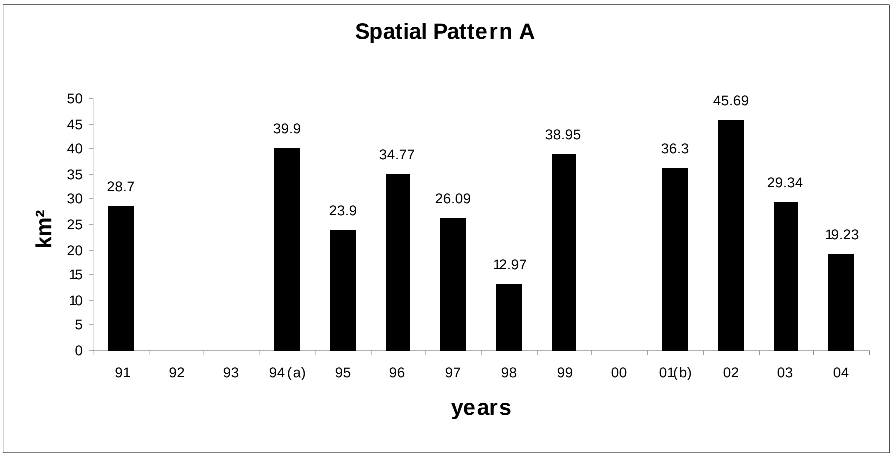

Figure 5.9 Deforestation rate of Spatial Pattern A

5.1.2.2 Deforestation in spatial pattern B (Redenção)

The second spatial pattern analyzed in terms of deforestation rates was the spatial pattern B (redenção), which occupies an area of about 174.55 km² or 4.7% of the entire study area. Similar to the spatial pattern A, the spatial pattern B started in the early 1980's. However, in 1990 the deforested area already represented 20% of the entire area of spatial pattern B, 52 % in 1997, and 71% in 2004 (Figure 5.10). This difference in the dynamic of deforestation may be related to the difference in area between spatial patterns A and B. However, considering that the properties have a similar size and that both spatial patterns have started in the same period, other factors can also be influencing this situation. According to Lira et al. (2006), 72% of spatial pattern B occupants are from the south of the country, being cattle ranchers in their majority. As cattle ranching are practiced in an extensive way in this region (one animal *per* hectare in average), it can explain the fact that, in 1997, the area of no forest was already larger than the forest area.

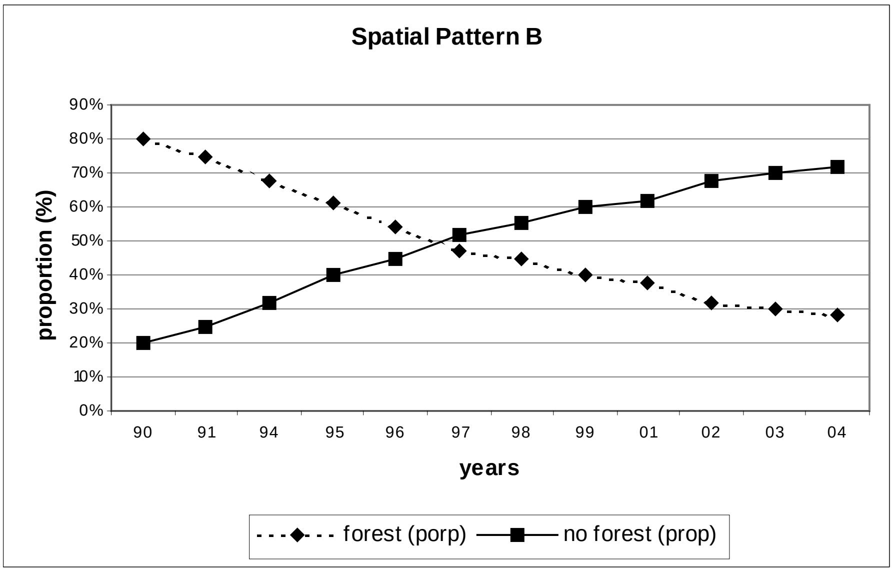

Figure 5.10 Relative increase of deforested area and decrease of forest area in relation to the total surface of the spatial pattern B

The deforestation in this spatial pattern, like in spatial pattern A, has a trajectory that resembles the deforestation of the entire study area, with low values between 1990 and 1994 followed by a growth between 1995 and 1997, 1999, and 2002 (Figure 5.11). Despite presenting a smaller area than spatial pattern A, spatial pattern B is composed of properties with similar sizes compared to the properties of the spatial pattern A. It is also located along the BR 364. This suggests that the deforestation of this spatial pattern is influenced by the same causes as spatial pattern A and the entire study area, as well.

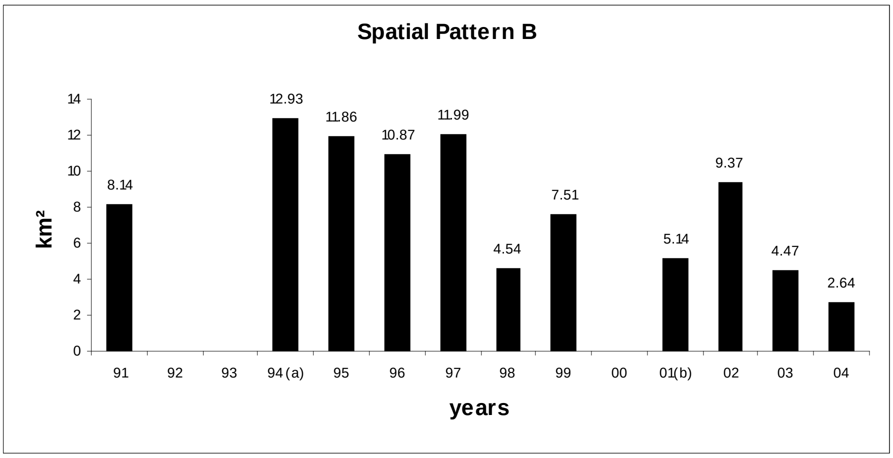

Figure 5.11 Deforestation rate of Spatial Pattern B

5.1.2.3 Deforestation in spatial pattern C (Campinas)

The third and smaller spatial pattern analyzed in this study, was defined as a "small fishbone" pattern, occupying an area of about 10.69 km² or only 0.2% of the entire area. In this spatial pattern, formed by properties around 4 to 10 ha, the occupants have the right to cut all the primary forest present in the property. As this spatial pattern was set up in 1991, it was not deforested in 1990. However, in 1997, the deforested area represented 40% of the entire area of spatial pattern C and 76% in 2004 (Figure 5.12).

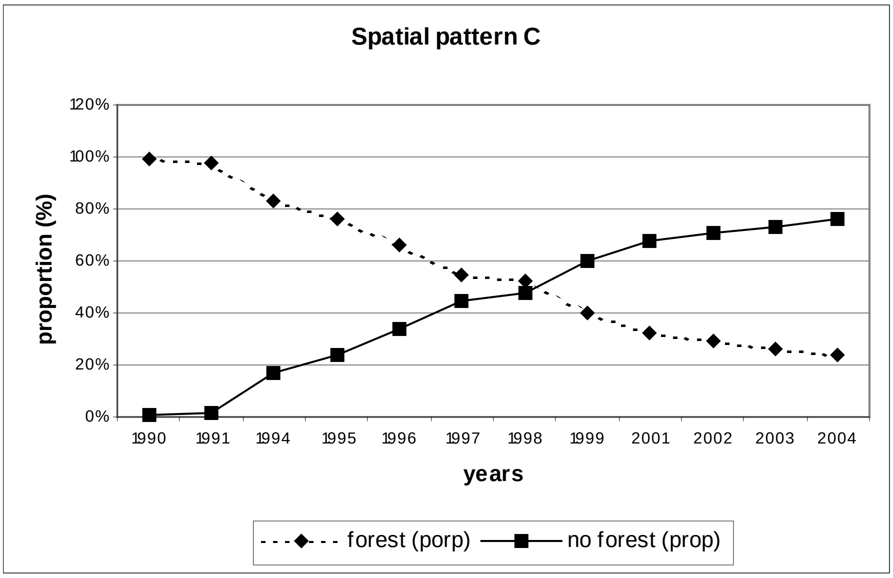

Figure 5.12 Relative increase of deforested area and decrease of forest area in relation to the total surface of the spatial pattern C

Figure 5.13, shows that deforestation in this spatial pattern shows a constant increase from 1991 to 1997, followed by a decrease in 1998 and increase in 1999. This was also observed in the deforestation of spatial patterns A and B. Deforestation between 1991 – 1997 is probably related the period of initial colonization, with the constant need for land for crops and pastures. The decrease in 1998 and increase in 1999 already observed in spatial patterns A and B is probably related to exogenous factors, such as political or economic factors. However, there is a strong decrease followed by a stabilization in the deforestation rate from 2000 onwards, compared to the high value presented by the other spatial patterns. It is probably related to the singular characteristics of this spatial pattern, such as, the reduced surface area and the possibility to exploit the whole primary forest present on the property. In function of this, some properties of this spatial pattern do not hold any remaining area of primary forest. In addition, certain properties of spatial pattern C had been transformed into a summer property (weekend property) without any primary vegetation.

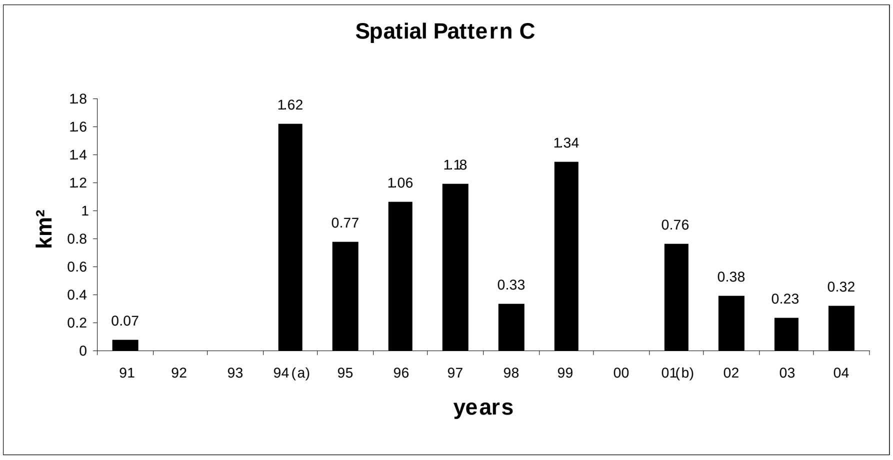

Figure 5.13 Deforestation rate of Spatial Pattern C

5.1.2.4 Deforestation in the spatial pattern D (Caqueta)

The fourth spatial pattern of deforestation analyzed in this work was the “Caqueta”. Its spatial pattern occupies an area of about 47 km² or 1.2 % of the entire study area. It was conceived to follow the old rubber tracks and to simulate the old land use practices, such as the extraction of latex. This area presents a different dynamic of deforestation compared to the other spatial patterns. Despite having started only in 1997, the area was already occupied before this date. In 1990, around 3 % of the entire area of spatial pattern D was not forest. In 1997, this area represented 22 % and in 2004 the deforested area already covered around 80 % of the entire area. This demonstrates the intense process of deforestation affecting this spatial pattern after the implementation of the settlement project in 1997 (Figure 5.14).

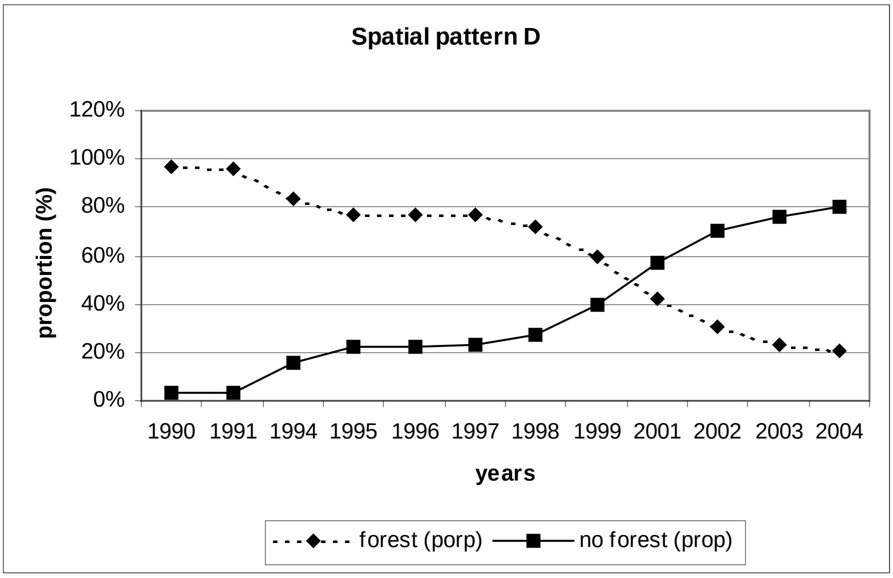

Figure 5.14 Relative increase of deforested area and decrease of forest area in relation to the total surface of the spatial pattern D

The deforestation of this spatial pattern presents three distinct presents, with different characteristics (Figure 5.15). First, from 1990 to 1995, before the creation of the settlement, the deforestation is probably related to the occupation of the first farms along the road. These farms had been added to the Caqueta project when it was created. Its corresponds to the analyses made by Alves (2001) about the deforestation in the Legal Amazon for the period 1991-1996, that showed a trend of deforestation occurring along main roads and in pioneer areas. In the second period, between 1996 and 1997, deforestation almost stopped. This can be considered as a transition period between the old concept of land division and the new colonization project, presenting low values of deforestation. The third period of deforestation started in 1997 with the first clearings related to the new colonization project. It can be speculated that, during this period, this spatial pattern indicates the "effect of migrants" on deforestation described by Brondízio et al. (2002) and MacCraken et al. (1999 and 2002). This effect is associated with the migrant groups that arrived in the same period and found different conditions compared to the other groups established before (Escada, 2004). In general, most of the colonists arrived together, with similar land use strategies and causing high rates of deforestation, typical of the beginning of farm establishment (MacCraken, 2002; Walker et al, 1997). From this time, the deforestation in this spatial pattern evolved in a way similar to spatial patterns A and B as well as to the entire study area, presenting increases in 1999 and 2002 and a decrease from 2003. It suggests that this spatial pattern, conceived to preserve the forest more than the other spatial patterns, ended up like the other spatial patterns - probably given the absence of conditions to support this new concept of colonization.

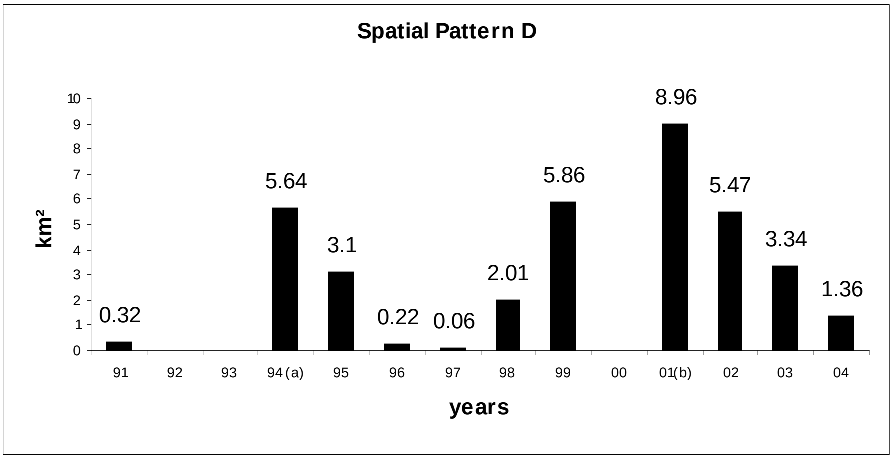

Figure 5.15 Deforestation rate of Spatial Pattern D

5.1.2.4 Summary of the Deforestation Analysis

The analysis of deforestation based on satellite images provided interesting information about the spatial patterns of deforestation. The analysis of the deforestation rate *per* year for each spatial pattern revealed that the large spatial patterns A and B, with similar sizes and both composed of medium properties, evolved in time in the same way. By contrast, spatial patterns C and D, composed of small properties, are characterized by different deforestation behaviours, related mainly to the availability of space in the spatial pattern C and the history of the spatial pattern D. In addition, while the spatial pattern A lost 53 % of its primary forest area, spatial pattern B lost 64 % (Figure 5.16). The difference in area between spatial patterns can partially explain the above differences. However, the intense process of land concentration observed in spatial pattern B could also be another important influence. On the other hand, while spatial pattern C lost 76 % of its primary forest, spatial pattern D lost 79 %. In relation to spatial patterns A and B, the property size and area are certainly important explanatory factors. In addition, the possibility to deforest the entire property in the spatial pattern C also contributes to this situation. However, spatial pattern D which is younger than the other ones was conceived to promote forest conservation with permission to cut only 20 % of the primary forest present on the property. Nevertheless, it lost more primary forest in the same period than the other spatial patterns. This is an important fact because this spatial pattern was conceived to preserve the forest. In addition, spatial pattern D is served by dirt roads and is located 40 km from the main road, while the other spatial patterns are located along the main road. This is important evidence against the hypothesis that roads determine rates of deforestation in a simple and exclusive way.

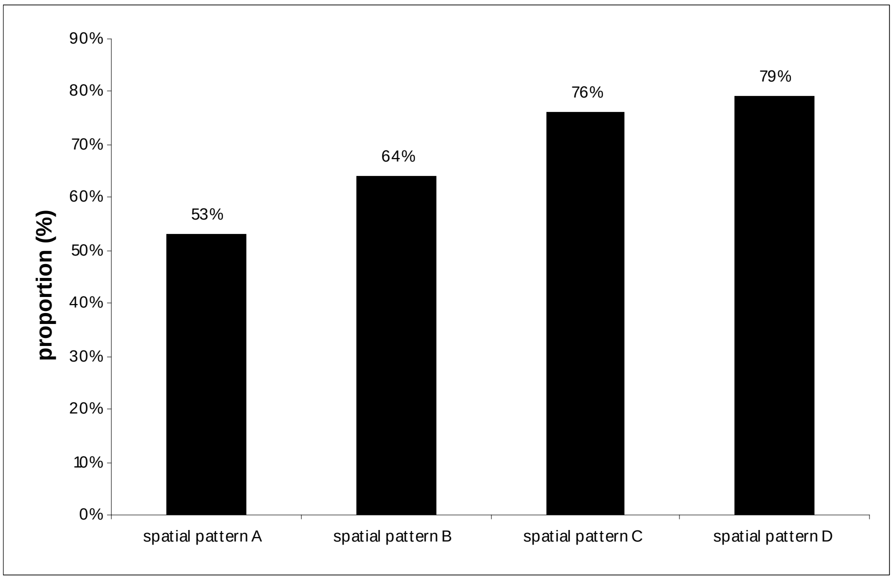

Figure 5.16 Proportion of forest lost in relation to the area of the spatial pattern

5.2 Second Stage - Field Survey

The field survey took place between June 10th and August 04th 2005, the main objective being to collect socio-economic data at the household level trough a questionnaire. Other activities were carried out during the field survey, such as GPS survey, data mining in the INCRA historical archive, and informal conversations with key informants. Supported by INCRA in terms of transport (vehicle) and driver, the interviews with the inhabitants of the study area occurred in two missions, one of about 15 days, complemented by another of about 5 days. The division of the field survey in two missions was decided given the availability of the car and drivers in the institution. Considering both missions, 119 questionnaires were completed and distributed according to the following spatial pattern: spatial pattern A = 39 (around 4 % of the families occupying this spatial pattern); spatial pattern B = 31 (around 6 % of the families); spatial pattern C = 26 (around 15 % of the families) and spatial pattern D = 24 (around 10 % of the families).

5.2.1 General household characteristics

With the information derived from the questionnaires made in the household surveys and the data on deforestation derived from satellite images, it was possible to draw a general profile of land use activities for the entire study area, as well as for each spatial pattern analyzed (Table 5.1). Taking into account the whole study area and all households interviewed it was observed that, in general, households are composed on average of four people with a male head around 45 years old with a low level of education (two years of school maximum). In relation to the origin of the family, 40% of the interviewed households came from different regions of the Acre State and the other 60 % from other 16 Brazilian States. The Acre State was colonized in the 1970s mainly by people from the northeast and south of the country and, today, the territory is apparently occupied by descendants of these first inhabitants. Around 48 % of those interviewed arrived in the region after 2000, 36% in the 1990s and only 17% in the 1980s. This demonstrates that, while some spatial pattern as A (Ramais do Peixoto) and B (Redenção) started in the 1980s, many of the original occupants already left they properties, suggesting difficulties in stabilizing themselves in the region. There is an intense process of land transference. It is confirmed by the item “first occupant” in the questionnaire, where 77 % of interviewed answered “no”.

This also demonstrates the problem of land tenure in the region. In the study area, 80 % of those interviewed declared to be landowners with some document to prove it. However, “some document” does not guarantee land ownership in the Amazon. In the INCRA-sponsored Amazon settlements, there are only two categories of land ownership rights: households with only the use rights (card) and households with property rights (title). In general, the households with only the use rights are colonists who recently arrived, with the right to exploit but not to sell the property. The households with the property rights are in general colonists that have been established for a long time, with the right to exploit and sell the property. The use right system is expected to stabilize colonists to the land until they receive the title, ten years after establishment. However it is observed that 50% of the declared proprietors have only the rights of use and arrived between 1995 and 2005. This suggests the presence of an intense process of land transference, stimulated by a black market for land, where many of the colonists with only the use rights sell their property against the law, often at a low price. This influences directly the deforestation in the region because, as a tradition, each family who arrives in a property cuts around 1 or 2 ha of primary forest in the first years, just for subsistence crops.

Table 5.1 General characteristics of the households interviewed

Variables	PAD – Peixoto	Variables	PAD - Peixoto
Family Origin: (per region)	%	**Date of occupation**	%
North	47	80 – 84	8.5
Northeast	11	85 – 89	7.5
Southeast	19	90 – 94	11
South	19	95 – 99	25
Center west	4	00 – 05	48
First occupant:	%	**Gender (head)**	%
Yeas	23	Male	85
No	77	Female	15
Age (head)	%	**Education (head)**	%
20 – 29	9	Primary	87
30 – 39	21	Secondary	10
40 – 49	32	Over	2
50 – 59	20		
60 and over	17	**Number of lots**	%
		1 – 2	90
Documents:	%	3 – 8	8
Card (use rights only)	50	8 and over	2
Title (property rights)	33		
Other (not official)	4	**Number of wage**	%
Without	13	1 – 3	74
		4 – 6	16.5
Number of people living	%	7 and over	9.5
1 – 4	59		
5 – 9	38	**Equipments**	% (yes)
10 and over	3	Manual tools	98
		Chainsaw	40
Number off farm used	%	Tractor	6
0	32	Inputs	6
1 – 2	61		
3 and over	18	**All season roads**	%
		Yeas	20
Cooperative	5%	No	80
Association	47%		
Coop. + Assoc.	3%		
Not participant	45%		

In relation to the process of “land concentration”, currently observed in the Amazon colonization settlements, 77% of those interviewed have only one lot, generally characterized by the presence of subsistence crops, pastures (both active and abandoned pastures), and primary and secondary forests. This does not mean that there is no process of land concentration in the study area. There are some areas, mainly in spatial pattern B (Redenção), where the property disposition forms a square (16 lots) and some squares could not have been accessed because they were totally surrounded. This suggests a massive land concentration in this spatial pattern.

Related to the labor force and available equipment in the household, it is observed that, in average, between 1 and 3 persons *per* household have an external income (74%), 43 % of the farms contract on average 1 off-farm worker to help in the property. In terms of equipment, the majority of the settlers work only with manual tools (hoe, cutlass, axe). Even though 40% of the interviewees have declared to possess a chainsaw, only 6 % have access to a tractor and only 6% use inputs (fertilizers). Its gives an idea about the level of agriculture practiced in the area. About the community associations, while 47% of the households make part of an association, only 5 % are associated to a cooperative. Its demonstrate that the cattle ranching practiced in the area is much more for beef than for milk. Actually, cooperatives are linked only and directly with the milk production. Associations give possibility to have access to equipment, such as chainsaws, tractors or resources such as financing. In relation to the roads, 80% of the interviewees consider the roads impracticable during one season. It's demonstrated how much the circulation in this region is precarious. Finally, concerning land use (Table 5.2), the households are characterized on average by 3 ha of planted area with a production of around 1,000 kg/season (subsistence and commercial crops). The properties have around 50 heads of cattle on 26 ha of pasture and extract around 8 kg of non timber forest product (NTFP). This number suggests an environment dominated by cattle activities, given the small cultivated area and the high number of animals and large pasture area. However, this observation is based on mean values for the entire study area. This is very general and could hide some intrinsic variability and specific land use attributes associated with some of the spatial patterns of deforestation. To uncover this, an analysis considering each separate spatial pattern of deforestation was required.

Table 5.2 Characteristic of the land use activities

Variables	**PAD Peixoto**	
	Average	Std
Subs. Crops (average area - ha)	3	4
Subs. Crops (average production - kg)	572.5	1436
Production per hectare	190 kg	
Comm. Crops (average area - ha)	0.8	1.8
Comm. Crops (average production - kg)	562	2023
Production per hectare	702 kg	
Average number of animals	53	72
Pasture (average area – ha)	26	31
NTFP (average production – kg)	8	28

a) Spatial pattern A – Ramais do Peixoto (fishbone)

In spatial pattern A, formed by medium properties around 80 ha, 82% of the households are composed on average by four inhabitants, with a male head between 40 and 50 years old with 2 years of education maximum. Around 38 % of the families come from the Acre State (North); 10 % from Paraná State (South); 10 % from Ceará State (Northeast); and 10 % from Espirito Santo State (Southeast). In relation to the "date of occupation", 23% arrived between 1982 and 1986, 33% between 1990 and 1998, and 41 % arrived between 2002 and 2005, demonstrating a situation similar to that presented by the general analysis in relation to the difficulty in establishing in the region (Table 5.3). This observation is also supported by the fact that around 85% of those interviewed were not the first occupants. The labor force is composed in average by 3 residents, complemented by the aide of 1 to 3 off-farm workers in general. Between 1 to 3 residents are also off-farm workers in other farms. Actually, in some places there a system of exchange favours, where the neighbours help each other without necessarily to dispend money. Relating to the equipments, beyond the manual tools (almost 100%), around 85 % of the households' posses a chainsaw, 7.5 % have access a tractor and around 10 % use inputs in the crop fields. It suggests that the occupants of this specific area have better conditions to work the land in comparison with the rest of the study area. The are no many cooperatives in this area given the meat-orientation of cattle. The majority of the households are associated to some association to have access to a tractor and financing. Finally, 77% of the interviewees consider that roads impracticable during one season, confirming the absence of road infrastructure in the region.

In relation to land tenure, 45% of households had the land title, which means that they have real land ownership and can sell the property; 40% have only the use rights (called "card"), 5% only have a "contract of sale", not official but tolerated given the difficulty to monitor this type of land transaction. It is less complicated to regularize the situation of those who are on the property than to put other families there. The large number of families with a land title indicates a certain stage of maturation of this spatial pattern. However, the considerable number of families with only the use rights also suggests a high dynamic of this spatial pattern related to land transference. Finally, it is observed that 10 % of the interviewees do not have any document. Its also supports the idea that there is an intense (and irregular) process of land transference, given that the official settlers have always some document.

Table 5.3 General characteristics of the households interviewed – spatial pattern A

Variables	spatial pattern A	Variables	spatial pattern A
Family Origin: (per region)	%	**Date of occupation**	%
North	38.5	80 – 84	10
Northeast	20.5	85 – 89	15
Southeast	25	90 – 94	18
South	10	95 – 99	15
Center west	5	00 – 05	41
First occupant:	%	**Gender (head)**	%
Yeas	13	Male	87
No	87	Female	13
Age (head)	%	**Education (head)**	%
20 – 29	7.5	Without	1.5
30 – 39	13	Primary	87
40 – 49	30.5	Secondary	10
50 – 59	26	Over	1.5
60 and over	23		
		Number of lots	%
Documents:	%	1 – 2	92.5
Card (use rights only)	40	3 – 8	7.5
Title (property rights)	45	8 and over	-
Other (not official)	5		
Without	10	**Number of wage**	%
		0	18
Number of people living	%	1 – 3	56.5
1 – 4	51	4 – 6	23
5 – 9	45	7 and over	1.5
10 and over	4		
		Equipments	% (yes)
Number off farm used	%	Manual tools	97.5
0	36	Chainsaw	84.5
1 – 2	45	Tractor	7.5
3 and over	19	Inputs	10
Cooperative	-	**All season roads**	%
Association	54%	Yeas	23
Coop. + Assoc.	2.5%	No	77
Not participant	43.5%		

The properties of this spatial pattern have on average 3 ha of planted area with around 1.400 kg of production, 116 heads of cattle on 42 ha of pasture, and around 9 kg of NTFP in average, related mainly to the Brazilian chestnuts (Table 5.4). These values suggest a tendency towards cattle activity, given that the cultivated area is small in comparison with the pasture and property area. Analyzing the deforestation rate for each property visited in this spatial pattern, it was observed that most of the properties had deforested more than 3 ha/year, arriving up to 17 ha/year in some cases. This confirms the importance of cattle in spatial pattern A. Deforestation for subsistence cultures reaches normally a maximum of 2 ha/year. As there are no large commercial cultures in the study area, it is supposed that lay forest openings are related mainly to pasture areas.

Table 5.4 Characteristic of the land use activities spatial pattern A

Variables	**spatial pattern A**	
	Average	Std
Subs. Crops (average area - ha)	2.80	3.36
Subs. Crops (average production - kg)	900	1833
Production per hectare	321kg	
Comm. Crops (average area - ha)	0.5	1.1
Comm. Crops (average production - kg)	479	1758
Production per hectare	958 kg	
Average number of animals	116	117
Pasture (average area – ha)	42	47
NTFP (average production – kg)	9	15

b) Spatial pattern B – Redenção (radial)

Spatial pattern B (Redenção) is also composed of medium properties between 80 ha and 100 ha, inhabited on average by 4 people, with a male head around 40 years old, and with maximum 2 years of education. In relation to the origin of the families, 26% came from the Paraná State (South), 16% from Minas Gerais State (Southeast), 10 % from Amazonas State (North), 10 % from Acre State (North) and 10 % from São Paulo State (Southeast) (Table 5.5). This demonstrates the utility of the analysis by spatial pattern. While the general analysis indicated that most of the families present in the region came from the Acre State, this analysis by spatial patterns suggests that some specific areas were colonized and are inhabited mainly by people from other regions of the country. It also confirms the important presence of people from other states (especially from the south) in the colonization process of this region.

Concerning the date of occupation, it is observed that around 33% of the families arrived between 1980 and 1986, 37 % arrived between 1992 and 1998 and 30% arrived after 2000. This suggests certain stability in terms of land transference. It is supported by the percentage of properties with titles, where it is observed that around 72 % of the properties have a land title and only 28 % have just the use rights. The land title gives the right to commercialize the land, which explains the high degree of land concentration in this spatial pattern: 83 % of the properties visited were composed by a minimum of 2 lots, 7% have 6 lots, 7% 10 lots and 3 % 18 lots. Each property of this spatial pattern reaches at least 150 hectares of area.

Table 5.5 General characteristics of the households interviewed – spatial pattern B

Variables	spatial pattern B	Variables	spatial pattern B
Family Origin: (per region)	%	**Date of occupation**	%
North	26	80 – 84	10
Northeast	3	85 – 89	15
Southeast	32	90 – 94	18
South	35	95 – 99	15
Center west	3	00 – 05	41
First occupant:	%	**Gender (head)**	%
Yeas	31	Male	87
No	61	Female	13
Age (head)	%	**Education (head)**	%
20 – 29	26	Without	10
30 – 39	42	Primary	71
40 – 49	16	Secondary	13
50 – 59	16	Over	6
60 and over			
		Number of lots	%
Documents:	%	1 – 2	74
Card (use rights only)	22.5	3 – 8	16
Title (property rights)	61	8 and over	10
Other (not official)	3		
Without	13	**Number of wage**	%
		0	13
Number of people living	%	1 – 3	64.5
0	13	4 – 6	22.5
1 – 4	45	7 and over	-
5 – 9	39		
10 and over	3	**Equipments**	% (yes)
		Manual tools	93.5
Number off farm used	%	Chainsaw	64.5
0	32	Tractor	13
1 – 2	64	Inputs	39.5
3 and over	3		
		All season roads	%
Cooperative	9.5	Yeas	29
Association	51.5	No	71
Coop. + Assoc.	3		
Not participant	35.5		

The properties have on average 5 ha of planted area with around 400 kg of production per season. There are around 70 heads of cattle distributed in 40 ha of pasture on average. Despite the significant values of cultivated areas and crop production, the number of animals and the size of pastures give to this spatial pattern a character dedicated to cattle activities. Moreover, the analysis of deforestation by property revealed that 50 % of the properties (formed in general of 2 lots, with 80 ha each) deforested on average less than 3 ha/year, probably due to the opening of areas for subsistence cultures. Moreover 50 % of the farms (formed in general of more than 3 lots) deforested more than 4 ha/year, arriving at 30ha/year in some properties composed of more than 5 lots, certainly related to pasture expansion in this case (Table 5.6).

Table 5.6 Characteristic of the land use activities spatial pattern B

Variables	**spatial pattern B**	
	Average	Std
Subs. Crops (average area - ha)	5	5.7
Subs. Crops (average production - kg)	50	66
Production per hectare	10 kg	
Comm. Crops (average area - ha)	2	3
Comm. Crops (average production - kg)	326	923
Production per hectare	163kg	
Average number of animals	70	75
Pasture (average area – ha)	41	54
NTFP (average production – kg)	3.3	14

c) Spatial pattern C – Campinas (Campinas - small scale fishbone)

Spatial pattern C – Campinas is composed of small scale farmers, with an average area of 10 ha. The properties of this spatial pattern were inhabited in general by 4 people (60%) with a male head of around 35 to 45 years old and a maximum of 2 years of study. Most of the families, around 70%, came from the Acre State (North) and arrived mainly after 2000 (60%). Others, from the South of the country, mainly from the Paraná State (16%) (South), arrived before 2000. As a young colonization project, the majority of its occupants (90%) have only a card for document (use only) (Table 5.7). This may prevent a process of land commercialization and consequently land concentration in this spatial pattern, where more than 75 % of families have only one lot. Despite this, and the fact that the occupants with only the use rights are forbidden to sell the property, 85 % of the occupants declared not to be the first occupant. This strengthens the feeling that there is a chronic situation of irregular transference of properties, already observed in the analysis of the spatial patterns A and B.

Table 5.7 General characteristics of the households interviewed – spatial pattern C

Variables	spatial pattern C	Variables	spatial pattern C
Family Origin: (per region)	%	**Date of occupation**	%
North	73	80 – 84	-
Northeast	-	85 – 89	-
Southeast	4	90 – 94	8
South	19	95 – 99	32
Center west	4	00 – 05	60
First occupant:	%	**Gender (head)**	%
Yeas	15	Male	69
No	75	Female	31
Age (head)	%	**Education (head)**	%
20 – 29	12.5	Without	8
30 – 39	31	Primary	77
40 – 49	31	Secondary	15
50 – 59	18.5	Over	-
60 and over	12.5		
		Number of lots	%
Documents:	%	1 – 2	96
Card (use rights only)	73	3 – 8	4
Title (property rights)	11	8 and over	-
Other (not official)	-		
Without	15	**Number of wage**	%
		0	8
Number of people living	%	1 – 3	88
0	4	4 – 6	4
1 – 4	65	7 and over	-
5 – 9	31		
10 and over	-	**Equipments**	% (yes)
		Manual tools	80
Number off farm used	%	Chainsaw	20
0	27	Tractor	-
1 – 2	73	Inputs	-
3 and over	-		
		All season roads	%
Cooperative	0	Yeas	19
Association	36	No	81
Coop. + Assoc.	0		
Not participant	64		

The properties of this spatial pattern have on average 2 ha of planted area, with 370 kg of production/season, 2 heads (maximum) of cattle on 1,5 ha of pasture, without NTFP production. Beyond the subsistence crops of cassava, rice, beans and maize, Spatial Pattern C also produces bananas, coffee and lemons (Table 5.8). Moreover, the production of cassava in this spatial pattern is not only for subsistence, but also to produce cassava flour which is very appreciated in the region. This denotes a trend in the agriculture of this spatial pattern. This trend is supported by the results of the deforestation analysis by lots, where an average deforestation rate of around 0.36 ha/year was observed with a maximum of 0.58 ha/year.

Table 5.8 Characteristic of the land use activities spatial pattern C

Variables	**spatial pattern C**	
	Average	Std
Subs. Crops (average area - ha)	1.5	2.15
Subs. Crops (average production - kg)	216	570
Production per hectare	144 kg	
Comm. Crops (average area - ha)	0.4	0.8
Comm. Crops (average production - kg)	150	537
Production per hectare	375 kg	
Average number of animals	1.6	3.4
Pasture (average area – ha)	1.6	3.4
NTFP (average production – kg)	5	16

d) Spatial pattern D – Redenção (diffuse)

Spatial pattern D – Redenção, is the most recent of this study and is formed by small properties with areas between 15 and 25 ha. These properties are inhabited on average by 4 people (64%) with a male head around 30 to 40 years old and 2 years maximum of education (Table 5.9). There are also some properties without occupants. Around 20 % of those interviewed declared that they just work on the land but live somewhere else - probably in the city. This is a situation observed only in some properties of spatial pattern C, where the property was transformed into a weekend getaway without economic activity. Its reveals another interesting situation because the land occupants of the INCRA settlements are obliged to live in the property. Finding some properties without inhabitants suggests not only the absence of monitoring but also, in some cases, the complicity of inspectors and/or responsible for the land tenure verification.

Table 5.9 General characteristics of the households interviewed – spatial pattern D

Variables	spatial pattern D	Variables	spatial pattern D
Family Origin: (per region)	%	**Date of occupation**	%
North	62.5	80 – 84	-
Northeast	17	85 – 89	-
Southeast	12.5	90 – 94	-
South	4	95 – 99	46
Center west	4	00 – 05	54
First occupant:	%	**Gender (head)**	%
Yeas	29	Male	75
No	71	Female	25
Age (head)	%	**Education (head)**	%
20 – 29	20.5	Without	-
30 – 39	25	Primary	83
40 – 49	2	Secondary	17
50 – 59	17	Over	-
60 and over	12.5		
		Number of lots	%
Documents:	%	1 – 2	96
Card (use rights only)	75	3 – 8	4
Title (property rights)	-	8 and over	-
Other (not official)	4		
Without	21	**Number of wage**	%
		0	4
Number of people living	%	1 – 3	87.5
0	4	4 – 6	8.5
1 – 4	75	7 and over	-
5 – 9	17		
10 and over	4	**Equipments**	% (yes)
		Manual tools	96
Number off farm used	%	Chainsaw	46
0	17	Tractor	-
1 – 2	83	Inputs	4
3 and over	-		
		All season roads	%
Cooperative	0	Yeas	12
Association	35	No	88
Coop. + Assoc.	4		
Not participant	61		

Half of the occupants came from the Acre State (52%) (North) and arrived in the area before 2000. The remaining families arrived in general between 1997 and 1999, and came mainly from Clara State (18%, Northeast) and Minas Geris State (9%, Southeast). As in spatial pattern C, this spatial pattern is also recent and consequently 75 % of the occupants have only the use rights and 4 % have “a no legal contract of sale", as already observed in the spatial pattern A. As explained before, this kind of "non-official" document is tolerated given the difficulties of monitoring land transference in this region. The number of inhabitants without any document is also high, around 20 %, confirming the intense dynamic of land transference. Despite the recent implementation of this spatial pattern and the massive presence of farmers with only use rights, more than 75 % of the inhabitants were not the first occupants. This confirms the same trends observed in the other spatial patterns in relation to the land tenure. Actually, there is a difference compared to what is observed in other regions of the Brazilian Amazon: land tenure does not apparently play an important role in this region, maybe given the absence of a monitoring scheme and also given the complicity of inspectors and/or land monitoring responsible.

The properties of this spatial pattern hold on average 2.5 ha of planted area with 100 kg of production/season, 12 heads of cattle on 7 ha of pasture, and 7 kg of NTFP production (Table 5.10). These average values suggest an intermediate situation in terms of land use in relation to the other spatial patterns analyzed. In general, it seems that the occupants of this spatial pattern do not have a primary activity and try to survive investing a little in each activity. It can be related to the age of the settlement and consequently to its level of development. It can also be related to the isolated condition of this spatial pattern given the distance from the main road and the very poor condition of the road that serves this spatial pattern. The deforestation rate by property is around 1.5 ha/years, which also suggests openings related to subsistence crops. However the average area of pasture in the lots indicates that deforestation in this spatial pattern also occurs for pasture expansion.

Table 5.10 Characteristic of the land use activities spatial pattern D

Variables	**spatial pattern D**	
	Average	Std
Subs. Crops (average area - ha)	2	2.58
Subs. Crops (average production - kg)	180	490
Production per hectare	90 kg	
Comm. Crops (average area - ha)	0.5	0.9
Comm. Crops (average production - kg)	7.2	17
Production per hectare	14.4 kg	
Average number of animals	12	18
Pasture (average area – ha)	7	8
NTFP (average production – kg)	7	11

5.2.2 Summary of field survey

This first analysis considering the socio-economic data from the field survey and the deforestation data from the satellite images has provided a land use description of the area. It also showed the utility of linking "people to pixel" where information from the field survey could be combined with information from satellite images, for the same area on the ground. Summarizing the results presented above, it can be observed that spatial pattern A is occupied mainly by people from the Acre State, who arrived after 2000. These families, in general, possess one lot where subsistence crops are practiced. However, cattle ranching are the main activity for the properties when considering the number of animals and the pasture area. The analysis of deforestation also suggests cattle as a main activity, given the average area deforested *per* property. Spatial pattern B (Redenção) is occupied mainly by people from the south of Brazil, despite the significant presence of people from the center and the north of the country. These families in general possess more than one lot, where subsistence and some commercial crops in small areas (5 ha average) are also cultivated and with cattle as a main activity, given the number of animals and the pasture area. The deforestation analysis by lot also confirms cattle as the main activity. Mainly people from the Acre State occupy spatial pattern C. The average value of subsistence and commercial production combined with low number of animals, small pasture area in a small property, suggest a "crop cultivation" character for this spatial pattern. This is confirmed by the deforestation analysis where most of the occupants cut around 0.36 ha per year. This certainly relates to openings for crops. Finally, Spatial pattern D is occupied mainly by people from the Acre State. This pattern revealed an intermediate situation in relation to land use, where the presence of crops (only for subsistence), pasture areas, a greater number of animals than observed in spatial pattern C (considered "crop-based") and less than spatial patterns A and B (considered "cattle-based") can be observed. The deforestation analysis by lot of this spatial pattern suggests the presence of forest openings for crops. However, the pasture area presented by the lots also suggests forest openings for pasture.

5.3 Third Stage - Classification of land use and land cover based on satellite images

A process of image classification using satellite images was applied with the objective of quantifying the extent of land use and land cover classes. The following classes composed the map's legend: primary forest, secondary forest (regeneration), crops field, pasture, burned area, exposed soil, and water (Annex B). The process of classification was supported by GPS data acquired in 2000 and complemented by direct field observations and GPS points collected during the field survey that occurred in 2005. These classes are described in terms of satellite response and in relation to their structure and main species. The physical description of the primary forest and secondary forest was based on transects made in a previous study (Lorena, 2001). First the thematic classes that composed the maps produced are presented and characterized. Then the results of the accuracy assessment to evaluate the maps produced are reported. At last, the analysis of land use and land cover change based on the maps produced is presented.

5.3.1 Characteristics of thematic classes

a) Primary forest

Despite the fact that the study area presents signs of intense human activity, the remaining primary vegetation is still significant and can be easily identified in the Landsat TM images by the strong green coloration in the color composite 3(B), 4(G) and 5(R). This class includes all existing forest formations in this area, such as the open forest with occurrence of lianas and bamboos as well as the dense forest. In accordance with data obtained through transects made in a field survey in 2000, the area of primary tropical forest is structurally characterized by an “average diameter” DAP = 19 cm, “average height” H = 14 m, with 400 individuals per hectare. The vegetation is composed mainly of species like: *Tetragastris altíssima* (breu vermelho), *Pseudomedia laevis* (pama preta), *Bertholletia excelsa* (castanheira), *Theobroma microcarpum* (cacaurana), *Celtis sp* (farinha seca), *Leonia glycicarpa* (gogó de guariba), *Brosimum alicastrum* (inharé), *Guazuma sp* (mutamba branca), *Altophilus sp* (seringueira), *Virola multiflora* (ucuuba preta).

b) Secondary forest (Regeneration)

Generically called « Capoeira Latifoliada » by the RADAMBRASIL project (1976), this class is related to the vegetal formation that was established mainly after the agrarian activities and including different structural stages and varying densities. In relation to the spectral response of this formation on the satellite images (composition 3(B), 4(G) and 5 (R)), the variation of density and structure in this class generally presents an intermediate green coloration between the primary forest and the response of some crops, mainly with a shrub structure. Structurally, this formation corresponds to an intermediate stage presenting individuals with an “average diameter” DAP = 10 cm, “average height” H = 8 m, with 500 to 600 individuals per hectare. The most frequent species in this formation were: *Ochroma pyramidale* (algodoeiro bravo), *Zanthoxylum rthoifolium* (limãozinho), *Metrodorea flavida* (pirarara), *Heliocarpus sp* (malva branca), *Acacia pollyphilla* (espinheiro preto), *Schizolobium amazonicum* (fava canafistula), *Solanum sp* (jurubeba).

c) Crop Fields

The crop fields' class is formed by any type of crop present in the region: perennial and annual crops, for subsistence or commercialization. The principal crops are: rice, beans, maize, cassava, coffee and banana. During the field survey, it was observed that the textural and spectral response of some cultivated parcels in the region presented some spectral similarities with stages of "secondary succession". The absence of extensive cultivated areas in the region was also observed.

d) Pasture

This class includes implanted pasture areas, including areas of activity pasture and abandoned pasture. The pastures present in the region are formed mainly by two species of grass: Brachiara and Brizantão that are very common in the Amazon region. The Pueraria species is also found as a pasture in the region, however at a minor scale and used mainly to fatten the cattle and to increase the fertility of the soil, given the greater amount of protein in this grass. This type of grass is also used as an additional source of income for farmers, who commercialize its seeds. In relation to the satellite response, this class presents pink tones that vary in function of the stage and structure of the grass and the soil response.

e) Burned area

This class concerns the areas that have been burned in the field and appear in the satellite image in general as a geometric dark stain. These areas can be related with the traditional practice of slash-and-burn, or with the process of land "cleaning", where areas already deforested, exploited and abandoned after a few years, are cleaned through fire and prepared to receive another culture in the case of crops or pastures in the case of the change in land use. The minimum area mapped of this class was 9000 m² or 0.9 hectares.

f) Exposed soil

The class "exposed soil" concerns the areas where the spectral response of the soil is much more important that any vegetation cover present in this area. Normally it relates to the urban areas, roads and other surfaces with a low presence of vegetation. In the satellite images (composition Landsat 3(B) 4(G) and 5(R)), it is represented by saturated pixels with a rose coloration.

g) Water

It represents any water body present in the area of more than 1800 m² or 0.2 hectares. It is represented in the satellite images by an area with blue coloration, where the tonality can vary in function of the sediments in suspension in the water body.

5.3.2 Evaluation of classification

Using the training samples, the supervised classification by region was realized for images from 1990, 1995, 1997, 1999 and 2004. The samples sought to represent the variability of each class, and to characterize the homogeneous areas as best as possible. Based on the results obtained for each image (Annex 2, 3, 4, 5), it was possible to proceed with the evaluation of the classification using an error matrix, with sample tests defined and georeferenced in the field for the images from 1999 and 2004. As field data to evaluate the classifications for 1990, 1995, 1997 were not available, it was assumed that the Kappa value for 1999 (estimated at 0.7) could be used to infer the performance of the images from 1990, 1995 and 1997, given the small number of classes studied and the same methodology used.

The Kappa values were considered significant, and it was demonstrated that there was a good agreement between the classifier and the reference data collected in the field. According to Landis & Koch (1977), a Kappa value of 0.7 represents a "very good" level of agreement between the thematic map and the ground truth. During the process of evaluation, it was verified whether certain thematic confusions occurred between classes. This can be explained by the fact that some targets present similar spectral responses. The error matrix for the classified image of 1999 is presented in Table 5.11. This matrix compares the reference data (field) with data from the classified images. Correctly classified pixels are found in the main diagonal line of the matrix (Congalton, 1991).

Table 5.11 Error matrix for the image classification – 1999

Class	P_forest	S_ forest	Crops	Pasture	Exp Soil	Total
P_ Forest	13	1	0	0	0	14
S_ forest	2	15	3	1	0	21
Crops	0	0	18	0	0	18
Pasture	0	1	1	15	0	17
Exp Soil	0	0	0	1	4	5
Total	15	17	22	17	4	75

Analyzing the error matrix of the images from 1999 shows that the major confusion occurred between the classes "Crops" and "Secondary forest". This confusion was expected because the areas of secondary forest in their initial stage, despite the presence of very strong photosynthetic activity, also present a strong soil response similar to certain cultivated areas with open canopy. There is also some confusion between crops with scrub structure (e.g. coffee) or arboreal structure (e.g. seringa) and some stages of secondary forest. The Table 5.12 shows the errors of *omission* and *commission* estimated from the Table above. Errors of *omission* occur whenever the classification does not recognize pixels that should have been identified as belonging to a particular class. Errors of *commission* result when the classification incorrectly identifies pixels associated with a class as belonging to other classes.

Table 5.12 Omission and Commission errors of the error matrix, image 1999

Classes	Omission	Commission	Mapping Accuracy
Primary forest	7%	14%	81 %
Secondary forest	28.5 %	9.5 %	65 %
Crops	0	22 %	81%
Pastures	7.5 %	7.5 %	80 %
Exposed soil	20 %	0	80 %

The evaluation of the classification for 2004 was made based on field data collected in 2005. Some targets may have changed between 2004 and 2005. Table 5.13 presents the error matrix for the classification of 2004. As is observed in the evaluation of the classified image from 1999, the classified image from 2004 presented confusions between some stages of secondary forest and some crops with shrub structure, as well as with pastures in a stage of abandonment.

Table 5.13 Error matrix for the image classification – 2004

Class	P_forest	S_forest	Crops	Pasture	Exp Soil	Total
P_Forest	13	0	0	0	0	13
S_forest	0	3	0	0	0	3
Crops	0	2	10	3	0	15
Pasture	0	0	0	3	0	3
Exp Soil	0	0	0	0	3	3
Total	13	5	10	6	3	37

Despite all this, the evaluation process of the images from 2004 presented a Kappa value of 0.8, which according to Landis & Koch (1977) can be considered “excellent”. Note however that the number of reference GPS points used was small compared to the evaluation process applied to the image from 1999. Table 5.14 shows the commission and omission errors of the error matrix.

Table 5.14 Omission and Commission errors of the error matrix, image 2004

Classes	Omission	Commission	Mapping Accuracy
Primary forest	0	0	100 %
Secondary forest	0	66 %	60 %
Crops	33 %	0	50 %
Pastures	0	100 %	50 %
Exposed soil	0	0	100 %

5.3.3 Land use and land cover change analysis

The land use and land cover change analysis aimed at detecting the changes during the selected time period, and to measure the areal extent of these changes for each spatial pattern, and at a household level. From the quantification of the thematic classes for the years 1990, 1997, 1999 and 2004, it was possible to detect significant changes in land use and land cover in the region. Table 5.15 presents the area in square kilometers (and the percentage of this area in relation to the total area) for each thematic class analyzed in this study and its percentage in relation to the total area, for the years 1990, 1997, 1999 and 2004.

It can be observed that the area of primary forest had a strong area reduction with an average rate of deforestation around 120 km^2 per/year between 1990 and 1997, and 143 km^2 per/year in the remaining period (1997 to 2004). With the development of the colonization project, there was a rapid and considerable growth (around 600%) of the cultivated area (specially identified as subsistence crops of cassava, rice, beans and corn and some small crops of coffee and banana) in the first years of the colonization project and until 1997. This was followed by a stabilization period between 1997 and 1999 with an average area of about 300 km^2 and followed by a strong decrease during the remaining period, between 1999 and 2004.

Table 5.15 Area (in km²) of the main thematic classes – PAD Peixoto (AC)

PAD Pedro Peixoto	1990 km²	1997 km²	1999 km²	2004 Km²
P. Forest	3029.25 (80.95%)	2422.60 (64.74%)	2173.54 (58.08%)	1453.86 (38.85%)
S. Forest	81.22 (2.17%)	35.29 (0.94%)	198.7 (5.31%)	638,05 (17.05%)
Pasture	558.26 (14.91%)	915.10 (24,45%)	1018.79 (27.22%)	1470,02 (39,28%)
Crops	62.1 (1.65%)	332.08 (8.87%)	290.50 (7,76%)	41,47 (1,10%)
Exp Soil	6.62 (0.17%)	6.74 (0.18%)	13.8 (0.36%)	10.03 (0.26%)
Water	0.91 (0.02%)	1.176 (0.03%)	1.88 (0.05%)	15.91 (0.42%)
Burn area	2.72 (0.07%)	28.82 (0.77%)	44.43 (1.18%)	112.54 (3.00%)

This trend of increase, stabilization and decrease of the cultivated area some years after the establishment of the colonization project is observed not only in this colonization project, but in almost all colonization projects in the Amazon basin. The problem is that there are "colonization projects" but there are no "projects for colonization" (planning) (Henrique Sanntana[1]). In general, colonization projects (in the Amazon region[2]) consist in dividing a forested land (without owners) into parcels and giving these parcels to poor families of the region, as well as from other Brazilian regions. In the beginning, the families recently given a lot by the INCRA through the "Agrarian Reform Program" received a modest financial support and some technical assistance to begin the activities on the lot. This support is enough only to construct a small wooden house and to start the first subsistence crops, but not to develop the agricultural exploitation. Given the limited fertility of the soil (Wood, 2002) and the absence of technical assistance, the cultivated parcel becomes unproductive after 2 or 3 years and the farmer is obliged to open a new area of primary forest to continue producing. This activity of opening forest, plant 2 or 3 years and cut the forest again, is a labor intensive activity and has a low productivity in financial terms. The farmer ends up abandoning the area and starts to plant pasture, to ranch cattle or to rent to those who have cattle. The cattle are easier to keep and generate a guaranteed income. The evolution of the classes is presented in the Figure 5.17.

[1] Agronomist Engineer from INCRA.
[2] The Brazilian Institute for Colonization and Agrarian Reform INCRA is responsible for all colonization projects on the Brazilian territory.

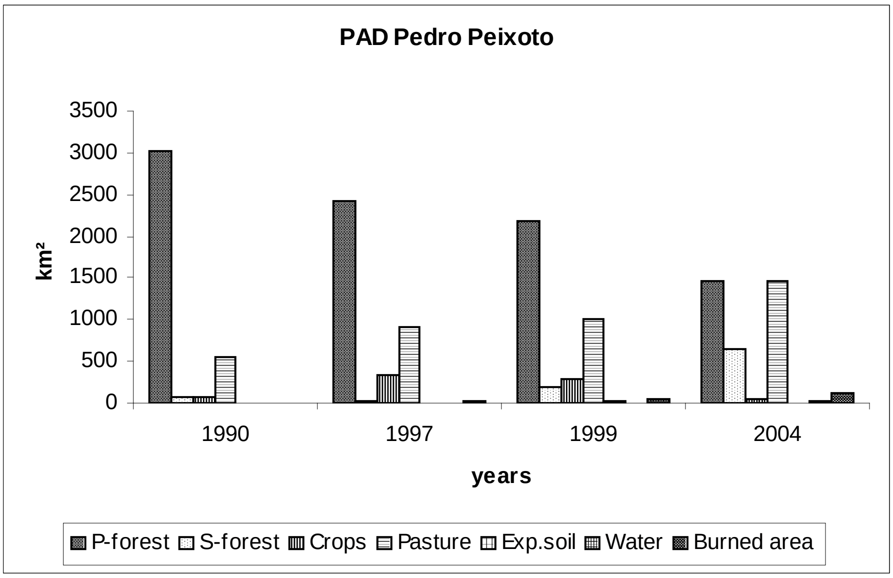

Figure 5.17 Evolution of the classes of the PAD Pedro Peixoto

The pastures, continuously increased between 1990 and 2004 representing currently around 1400 km². They occurred in all properties, to a greater or lesser extent depending on the origin and condition of the landowner. Some farmers are originally from old areas of rubber extraction in the Amazon and some others are from the extensive agriculture areas of southern Brazil. This difference of origin influences work habits on the land. In general (but not exclusively), the properties managed by old rubber extractors from the Amazon region present an abandoned appearance. This is related to factors such as the absence of agricultural tradition and consequently absence of knowledge about soil and agrarian techniques. They have a tradition of forest preservation given the long contact with the activities inside the forest, such as rubber extraction or Brazilian chestnut exploitation. However, with land division, some properties stay with no or few trees that can be exploited for non timber products extraction. As a consequence, the landowner who does not have experience in agriculture is obliged to plant pastures and ranch some cattle to guarantee a minimum income.

The colonists from the south of Brazil in general have different work habits on the land. They come from a region with a strong tradition in agriculture and cattle. With this experience, they start the property with traditional subsistence crops of cassava, rice, beans and corn together with the opening of pastures. With the knowledge of more advanced agricultural techniques and the financial resources earned from cattle, they keep soil productivity 2 or 3 years longer than others. However, after some years it is impossible to maintain the soil productivity in the same area and they, like the other colonists, are obliged to cut 1 or 2 ha of primary forest in search for temporarily fertile soil. The abandoned area of crop is rapidly transformed into pasture and this process is repeated until reaching the forest limit allowed[1]. As there is no strong field surveillance, this forest limit is often overtaken, up to the limit of the property. Independent of the reached limit (forest or property) the colonist from the south of the country in general does not abandon the unproductive areas and ends up transforming everything into pasture.

The class “Secondary Forest” presented a constant growth during the study period, with a significant increase over the last years. In some cases, this growth of secondary forests can be related to the temporary abandonment of the property, due to the absence of investments and consequently low financial returns. In other cases, the cultivated parcel is abandoned given the low soil fertility soil and another parcel is opened in the area of primary forest. Actually, independent of their age, secondary forests can be found everywhere in the study area. In general the properties most distant from the main road present a more advanced stage of abandoned pasture and secondary forest than the properties near the main road. This happens because the properties distant from the main roads have many difficulties to develop production due to their low accessibility. Landowners end up abandoning the property or parts of it.

5.3.3.1 Land use and land cover change analysis - spatial pattern A

As already observed in the analysis of deforestation for each separate spatial pattern, spatial pattern A presents a very similar evolution, in terms of land use and land cover during the period studied, to the situation present in the overall study area. Table 5.16 presents the area in km² for each thematic class and the percentage that it represents in relation to the area of spatial pattern A, for the years 1990, 1997, 1999 and 2004. Despite the difference in area, the analysis of the relative percentage of each class shows an evolution in land use and land cover that is very similar to observed in the study area. As described above, spatial pattern A (Ramais do Peixoto) is formed by the first roads opened in the region (1977), with an area of about 718 km² representing 20% of the entire study area. These two factors, history and size of the spatial patterns, are probably related to this similar behaviour.

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[1] Depending of the settlement project, by law, the agriculturist can cut only 50% of primary forest present in the property.

Table 5.16 Area of classes in km² and percentage related to the total area spatial pattern A

spatial pattern A	1990 km²	1997 km²	1999 km²	2004 km²
P. Forest	618.65 (86.16%)	497.38 (69.27%)	446.89 (62.24%)	303.62 (42.28%)
S. Forest	7.96 (1.10%)	8.48 (1.18%)	53.15 (7.40%)	118.82 (16.54%)
Pasture	6.31 (0.87%)	60.95 (8.48%)	65.48 (9.11%)	5.42 (0.75%)
Crops	84.58 (11.7%)	149.07 (20.7%)	152.08 (21.18%)	262.3 (36.53%)
Exp Soil	0.59 (0.08%)	0.19 (0.02%)	0.19 (0.02%)	0
Water	0.030 (0.004%)	0	0.06 (0.009%)	2.29 (0.32%)
Burn area	0.34 (0.04%)	2.27 (0.31%)	0.70 (0.09%)	25.74 (3.58%)

This spatial pattern began in 1977 and, in 1990, the area of primary forest represented still almost 90 % of the entire area of the spatial pattern A, with a small area of pastures corresponding to 10 % of the entire area. This indicates an absence of activities during the first 10 years of the colonization project, probably related to an absence of economic interest in this isolated area of the Amazon region and consequent absence of financial and technical support. In the first period (1990 – 1997) a decrease is observed of around 20% of the primary forest area, given the increase of the pasture and crop area, with a small increase of secondary forest, suggesting a beginning of settlement with the arrival of new colonists. This characteristic is described by Brondízio et al., (2002), MacCraken et al. (1999 and 2002) as a "migration effect". Despite beginning in 1978, the period after 1990 is marked by government incentives for forest occupation and consequently new colonists arrived in the region. This is confirmed by the data acquired in the field survey, where almost 40% of the interviewed households arrived between 1990 and 1998. The increase in crop and pasture areas is a consequence of the establishment of new agriculturists in this period. The small increase of secondary forests can be related to some areas of primary forest opened in the early 1990s for subsistence crops, that subsequently evolved into pasture and were finally abandoned, following the trends explained above. These evolution of the classes can be analyzed through Figure 5.18.

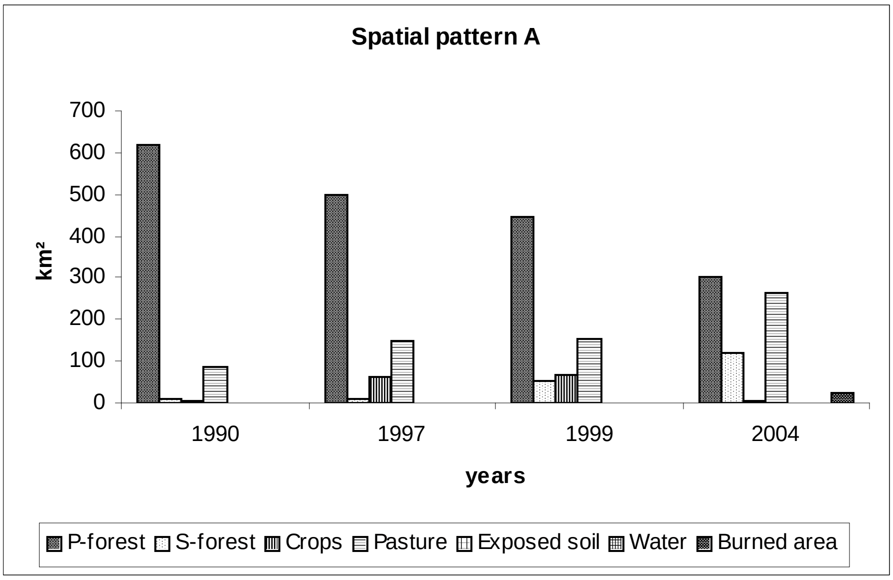

Figure 5.18 Evolution of the classes of the spatial pattern A

In the second period (1997 – 1999), a decrease of around 10 % is observed in the primary forest area with a relative stabilization of the crops and pasture area and a strong increase in the secondary forest. The stabilization of the crops and pasture area suggests a period when the agriculturists try to maintain the production while exploiting the temporary fertility of the soil. However, the reduction of the primary forest and increase of the secondary forest in a short period of time, also suggests a very dynamic period when part of the crops and pastures were abandoned given the low fertility of the soil after two or three years of production and evolved into a secondary forest. Then, the deforestation in this period is probably related to the opening of new areas of crops and pasture to substitute the abandoned areas. The increase of the secondary forest in this short period can also be related to some confusion between classes in the classification process. In this period of establishment, the spectral behaviour of some crops is very similar to the behaviour presented by some stages of secondary forest.

The third period (1999 – 2004) is characterized by the abandonment of the crops, an increase in pastures and secondary forest areas and continuous deforestation. The increase in the secondary forest is probably related to the abandonment of the crop areas and part of the pastures, despite the increase of this class in this period. Following this logic, the deforestation in this period is probably related to the direct opening for pastures, which accounts for the visible increases of this class after 1999.

5.3.3.2 Land use and land cover change analysis - spatial pattern B

Spatial pattern B started in the early 1980s. In 1990 (as for the spatial pattern A), it already had large areas of pasture, crops and secondary forest as witnesses of the activities of the 1980s (Table 5.17). However, in 1990 the area of primary forest still represented around 80% of the total area of spatial pattern B, suggesting the same absence of interest in this region observed in the spatial pattern A. In this period, pastures corresponded to 15 % of the area of spatial pattern B, suggesting a trend of this spatial pattern towards cattle activity.

Table 5.17 Area of classes in km² and percentage related to the total area spatial pattern B

spatial pattern B	1990 km²	1997 Km²	1999 km²	2004 km²
P. Forest	138.79 (79.76%)	83.0 (47.71%)	70.90 (40.75%)	49.31 (28.34%)
S. Forest	6.29 (3.62%)	15.6 (9.00%)	33.31 (19.14%)	54.92 (31.56%)
Pasture	26.29 (15.11%)	52.38 (30.10%)	44.92 (25.81%)	59.96 (34.46%)
Crops	2.493 (1.43%)	20.50 (11.78%)	23.28 (13.38%)	3.52 (2.025%)
Exp Soil	0.03 (0.02%)	0.19 (0.11%)	0.04 (0.02%)	0
Water	0.04 (0.02%)	0	0.07 (0.04%)	0.54 (0.31%)
Burned area	0.27 (0.15%)	2.35 (1.35%)	1.53 (0.87%)	5.89 (3.38%)

Between 1990 and 1997 a significant reduction is observed in the area of primary forest (around 30 % of the total area of this spatial pattern) associated with the increase of pastures and crops areas. This period is characterized by the “migration effect”, already observed in spatial pattern A. It is probably related to the beginning of the settlement. Although it was initiated in the early 1980s by the federal institution INCRA, the management of this spatial pattern was transferred from the Federal to the State Government in 1990 and the process of colonization started again with new colonists and incentives. This explains that the period is characterized by an increase in crops and pasture areas followed by a period of establishment between 1997 and 1999, where stabilization of the crops and pasture area is observed with an increase in secondary forest. The results presented in the last table, can also be analyzed through the Figure 5.19.

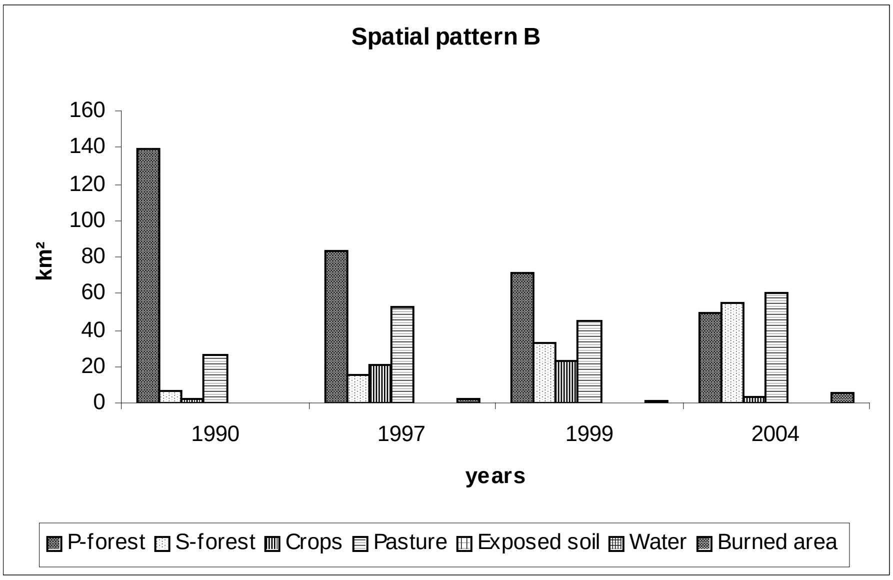

Figure 5.19 Evolution of the classes of the spatial pattern B

The third period between 1999 and 2004 goes through a continuous decrease in primary forest following the increase of pastures and secondary forest. Between 1999 and 2004, it is possible that some parts of the deforested area were abandoned and evolved into secondary forests. However, it is most probable that the increase in secondary forest in this period is related to the abandonment of cultivated areas. It is observed that a significant reduction in this class occurred in the same period and the continuous deforestation of primary forest is probably related to the openings for direct pastures expansion.

5.3.3.3 Land use and land cover change analysis - spatial pattern C

Spatial pattern C, characterized by small properties around 10 ha, and destined mainly to small scale plantations and small scale livestock, presents an evolution of land cover (Table 5.18) with some similarities to the spatial patterns A and B. Despite its beginning in 1991, it can be observed that, in 1997, almost 50 % of the primary forest area was lost to the increase in the pasture areas. It can be speculated that the rate of deforestation during this period (1990 – 1997) is characterized by the effect of migration waves as described by Brondízio et al. (2002) and MacCraken et al. (1999 and 2002). This effect is associated with groups of migrants arriving in the same period, with the same land use strategies and high rates of deforestation, typical of the period of property establishment (Escada, 2004). In the area of spatial pattern C, property size and the possibility to eliminate all primary forest present on the property can also influence the strong decrease in primary forest, in relation to the deforestation observed in spatial pattern A (20%) and spatial pattern B (30%) for the same period.

Table 5.18 Area of classes in km² and percentage related to the total area spatial pattern C

spatial pattern C	1990 km²	1997 km²	1999 km²	2004 km²
P. Forest	10.60 (100%)	5.90 (55.69%)	4.21 (39.76%)	2.59 (24.48%)
S. Forest	0.06 (0.56%)	0.71 (6.70%)	1.49 (14.14%)	1.87 (17.69%)
Pasture	0.02 (0.28%)	3.34 (31.55%)	1.89 (17.85%)	4.87 (45.97%)
Cultures	0	0.73 (6.90%)	3.08 (29.08%)	0.69 (6.52%)
Exp Soil	0	0	0	0
Water	0	0	0	0.11 (1.04%)
Burn. area	0	0	0	0.49 (4.62%)

The significant presence of pastures in 1997 relative to the other classes suggests a trend towards ranching activities. However, this spatial pattern was conceived mainly to favor agricultural production, and the major presence of pastures in this first period could be related to errors in the classification. In this period of establishment, there were many recently opened areas for crops. Depending on the type of the crop and its development, the spectral response can be very similar to the response of pasture. The results are also presented through the Figure 5.20.

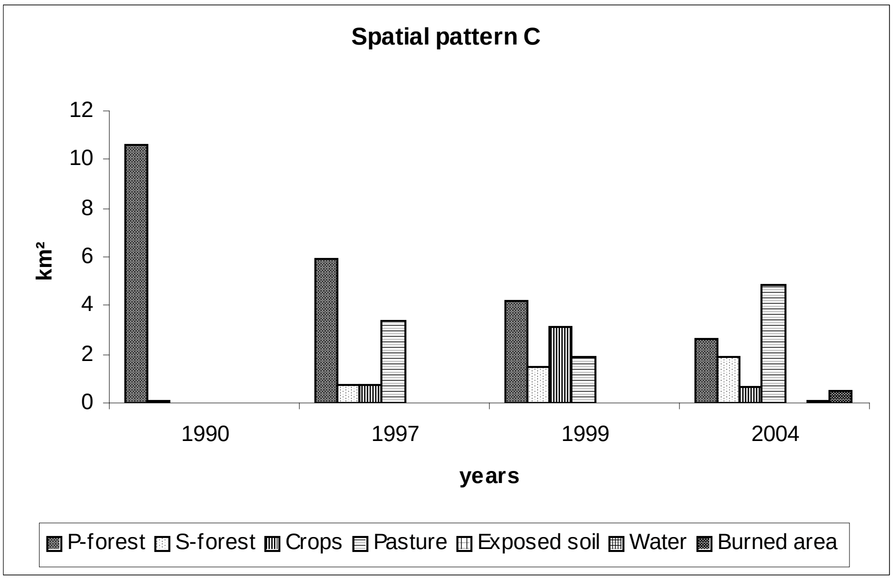

Figure 5.20 Evolution of the classes of the spatial pattern C

The land cover classification of 1999 supports the hypothesis that the area experienced a reduction in pasture area and an increase in crops area. However, the results observed for 2004 confirm the trend presented by the other two spatial patterns analyzed before. It can be observed that a decrease in crop area and an increase of pasture and secondary forest areas are related to the abandonment of the cultivation and increase in ranching activities. Despite the small area of the properties, the limited cattle activity in this spatial pattern became more interesting than cultivation because of the difficulties in maintaining soil productivity. In this case, this difficulty is the same as that observed for the other spatial pattern, such as low fertility of the soil, the absence of financial and technical support, the absence of market for the products, the absence of transportation and the road condition.

5.3.3.3 Land use and land cover change analysis - spatial pattern D

Although it was initiated officially in 1997, the analysis of the deforestation, land use and land cover changes based on satellite images has detected the presence of activities in this area previous to this year. It can be observed in the Table 5.19 that in 1990, the area of pastures represented 2.5% of the surface of spatial pattern D. This presence of pastures is probably related to the occupation of the first properties along the road before the creation of the settlement. With the establishment of the settlement in 1997, these properties were incorporated into the “Caqueta project” and many of them were donated to new colonists. This explains the presence of pastures as well as the presence of crops and secondary forest in the beginning of this settlement project.

Table 5.19 Area of classes in km² and percentage related to the total area spatial pattern D

spatial pattern D	1990 km²	1997 km²	1999 km²	2004 km²
P. Forest	45.63 (97.09%)	36.20 (77.02%)	28.34 (60.31%)	9.71 (20.67%)
S. Forest	0.17 (0.36%)	3.36 (7.16%)	2.00 (4.26%)	10.11 (21.52%)
Pasture	0	2.03 (4.33%)	6.32 (13.46%)	22.10 (47.03%)
Crops	1.18 (2.52%)	5.44 (11.57%)	8.86 (18.86%)	2.06 (4.40%)
Exp Soil	0	0	0	0
Water	0	0	0	0.27 (0.58%)
Burn. area	0	0	1.37 (2.92%)	2.79 (5.94%)

The evolution of the classes between 1997 and 1999 is characterized by the “migration effect” observed in the other spatial patterns. The areas of crops and pastures display a significant increase while the areas of primary and secondary forest show a decrease. The decrease in the secondary forest especially can be related to the expansion pastures. The classification of 2004 confirms the trends observed in the other three spatial patterns analyzed in terms of abandonment of crop areas and consequently an increase of secondary forest and pasture areas.

The significant decrease in primary forest and the strong increase in pasture areas observed in 2004 (also observed in the other spatial patterns for the last period) indicates that deforestation in the last period is related mainly to the implementation of new areas of pasture. Despite the forest conservation principles of this spatial pattern it ends up evolving just like the other spatial patterns. This confirms the difficulty to maintain the soil productivity using the same cultivated parcel, due to the low fertility of the soil and the absence of financial and technical support. This forces the farmer, independent of the spatial pattern, to cut up to 2 ha per/year to keep up subsistence crops. Finally the colonists end up preferring cattle, because of the ease in terms of labor compared to crop activity. This explains the continuous reduction of the forest and crops areas, as well as the increase in pasture area. The results presented in the last table can also be analyzed through the Figure 5.21.

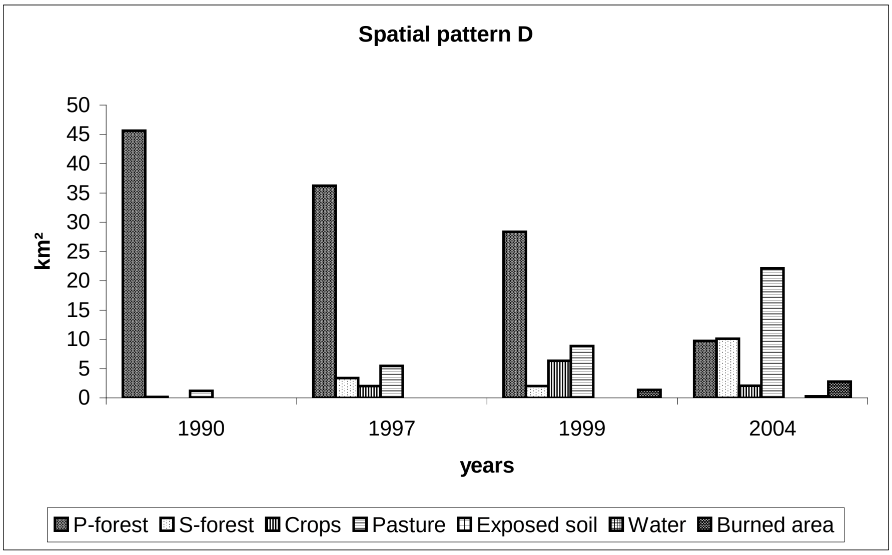

Figure 5.21 Evolution of the classes of the spatial pattern D

Despite the forest conservation principles of this spatial pattern, it ends up for losing more primary forest than the others spatial patterns. Independent to be for crops or pasture, this situation confirms the difficulty to maintain the soil productivity using the same cultivated parcel, due the low fertility of the soil and the absence of financial and technical support. This forces the farmer, independent of the spatial pattern, to cut up to 2 ha per/year to keep up subsistence crops.

5.3.4 Summary of land use and cover change analysis

This analysis of land use and land cover change based on satellite images suggests that the different spatial patterns of deforestation analyzed in this study end up following the same trends, independent of the size and the land use planning. All spatial patterns present a continuous decrease of the primary forest area during the three periods analyzed. Despite some differences in terms of land use evolution between spatial patterns, in general the first period (1990 – 1997) is characterized by an increase in the crop and pasture areas. The second period is characterized by a stabilization of these activities in terms of surface, and in the third period (less for the spatial pattern D) there is a reduction of the crop areas and an increase in pastures and secondary forests. The different behaviors presented by the secondary forests, mainly in the second period, are not clear. It is always related to some abandonment, however potential errors in the classification need to be considered. On the other hand, the similar increase in secondary forests linked to the decrease in crops area in the last period suggests that, for the most part, the cultivated areas were abandoned and transformed into secondary forests while the decrease in primary forest is related to the direct implementation of new areas of pasture.

It is also observed that, proportionally, spatial patterns C and D, despite starting on average 10 years after the other two, lost more primary forest during the period analyzed than spatial patterns A and B. Certainly, the difference in terms of spatial pattern area and property size plays an important role in this case. Spatial pattern C is 70 times smaller than spatial pattern A and 13 times smaller than spatial pattern B. In addition, the property size of spatial pattern C is 9 times smaller than the properties of spatial patterns A and B and the occupants possess the right to clean all primary forest present on the property. This can explain the relative high loss of primary forest in spatial pattern C compared to spatial patterns A and B. However, spatial pattern D (with a total area 15 times smaller than spatial pattern A and 3 times smaller than spatial pattern B, and properties 3 times smaller than those in spatial patterns A and B) lost almost 80 % of its primary forest in 7 years of occupation and displayed a rapid increase in the crops area in the last period analyzed. As explained above, this is interesting because this spatial pattern was conceived to promote forest conservation, stimulating its occupants to practice activities linked to the exploitation of non timber forest products (NTFP), mainly the extraction of latex. In addition, the occupants of this spatial pattern can eliminate only 20% of the primary forest present on their property. According to the old inhabitants of this spatial pattern (Edilson Fernado Araújo[1]), in 2005 (8 years after its beginning), 50 % of the first occupants already left their properties. This is confirmed by data from the questionnaires where it is verified that 48 % of the occupants arrived after 1999. This can explain a good part of the deforestation in this period, once each family arrived in the area, it was obliged to cut more than 2 or 3 ha of primary forest present on the property to guarantee the family production. Finnaly is noted the increase of the burned area in the last period presented by all spatial patterns, indicating the intensification of the activities from this period.

5.4 Fourth Stage - Cluster Analysis

The fourth stage of this research aimed to search for homogeneous groups in terms of land use and land cover that could be related to the spatial patterns analyzed. The analysis was conduced using the K-means algorithm and considering two different types of data: socio-economic data from field survey and land use and land cover data from satellite images. The first run, using the socio-economic data from the household survey, produced two main clusters corresponding together to 89% of the households analyzed. These two clusters were isolated and analyzed separately and the results are presented in Table 5.20.

[1] One of the first inhabitants of this Spatial Pattern arrived before the colonization project (1992). Worked only with cattle

Table 5.20 Frequency, participation and main characteristics of the clusters produced by the first run of the K-means algorithm, (household data)

Cluster	Freq (t=118)	Main representation (spatial patterns)	Subsistence Crops Average area (ha)	Subsistence Crops Average production (kg)	Commercial Crops Average area (ha)	Commercial Crops Average production (kg)	Livestock Average number	Pasture Average Area (ha)	NTPE Average Production (kg)
1	16 (13.5%)	A(62%) B(38%)	0.75	46.87	0.38	540.80	111.49	86.18	7
2	89 (75%)	A (28.5%) B (21.5%) C (25 %) D (25%)	0.70	776.56	0.10	85.96	14.47	15.69	2.9

Cluster number 1, composed exclusively of households from spatial patterns A and B, presents characteristics of cattle ranching because of the number of animals and pasture area present in this group relative to cluster number 2. On the other hand, cluster number 2, with a higher frequency and composed of households from all spatial patterns, presented more general characteristics, with a more significant production of subsistence crops but less animals and smaller areas of pasture. Given its general composition, the households of cluster number two were isolated and a second run was made considering only these households. This time, the process produced four main clusters corresponding together to 86 % of the households present in this second run. Table 5.21 shows the composition and the characteristics of these clusters.

Table 5.21 Frequency, participation and main characteristics of the clusters produced by the second run of the K-means algorithm, first approach (household data)

Cluster	Freq (t=89)	Main representation (Spatial pattern)	Subsistence Crops Average area (ha)	Subsistence Crops Average production (kg)	Commercial Crops Average area (ha)	Commercial Crops Average production (kg)	Livestock Average number	Pasture Average Area (ha)	NTPE Average Production (kg)
1	39 (44%)	C (49%)	0.59	60.57	0.08	17.98	1.57	2.05	1.15
2	17 (19%)	A(41%) B(35%)	0.90	144.85	0.07	0.35	25.38	30.70	1.35
3	9 (10%)	D(78%)	0.8	120.83	0.37	3.27	3.33	11.66	26.33
4	9 (10%)	A(89%)	0.54	47.22	0	0	96	21.66	10

First, it can be verified that each cluster is related to one or two spatial patterns in particular, as indicated by the percentage of participating households from a specific spatial pattern in the clusters' composition. It is observed that, while clusters 1 and 3 are related to spatial patterns C and D, clusters 2 and 4 are related to spatial patterns A and B. Moreover, it is also observed that cluster 3 is largely composed of households from spatial pattern D and cluster 4 is almost exclusively composed of households from spatial pattern A. Up to here, as the data used in clustering analysis is about the economic activities practiced by the household, and each cluster is related specifically to one or two spatial patterns, it would be logical to think that each spatial pattern is related to a specific economic activity.

The analysis of the characteristics of each cluster supports this observation. Cluster number 1, composed mainly of households from spatial patterns C (in particular) and D, is characterized by reduced pasture areas and a reduced number of animals in comparison with the other clusters. Moreover, although it is characterized by an area and production of subsistence crops smaller than clusters 2 and 3, the production of commercial crops is greater than in other clusters, indicating an influence of spatial pattern C and suggesting an “agricultural” character to this cluster. Cluster number 2, composed mainly of households from spatial patterns A and B and with a minor presence of households from spatial patterns C and D, has characteristics that suggest that “cattle ranching” is the main activity of this cluster because of the number of animals and size of pastures compared to clusters 1 and 3. Cluster number 3, composed mainly of households from spatial pattern D, is characterized by an NTFP production greater than that of the other clusters. Furthermore, this cluster presents reduced pasture areas and number of animals in relation to clusters 2 and 4. Despite the presence of subsistence crops, this cluster shows no presence of commercial crops. The aggregation of these characteristics suggests and confirms the importance of NTFP exploitation in this cluster, as well as in spatial pattern D. Cluster number 4, composed only of components from spatial patterns A (mainly) and B, is characterized by a large number of animals and pasture areas and, similar to cluster 2, is also composed mainly of households from spatial patterns A and B. In addition, despite the presence of subsistence crops, the cluster does not include areas of commercial crops, suggesting a character “cattle ranching” of this cluster.

A second test was made using data from the satellite images. The first run of this test also produced two main clusters, including together 89 % of the households analyzed. These two main clusters were isolated and analyzed separately and their results are presented in Table 5.22.

Table 5.22 Frequency, participation and main characteristics of the clusters produced by the first run of the K-means algorithm, (satellite data)

Cluster	Freq (t=118)	Main representation (Spatial pattern)	Primary Forest (km²)	Secondary Forest (km²)	Active Pasture (km²)	Abandoned Pasture (km²)	Crops Area (km²)	Water Area (km²)	Burned Area (km²)
1	9 (7.5%)	A(100%)	13.41	9.10	6.90	5.59	1.11	0.14	1.31
2	88 (75%)	A(28%) B(20%) C(27%) D(25%)	21.08	7.18	60.20	2.63	0.49	0.65	1.19

Cluster number 1, despite presenting a lower frequency than cluster number 2, is composed exclusively of households from spatial pattern A. The characteristics presented by this cluster have indicated that it is probably related to the farms placed far from the main road. These farms, in general, are smaller than those placed near the main road, with an average area between 40 and 60 ha. The isolation of these properties and the absence of infrastructure (financial and technical), gives an "abandoned" look to these properties, also because of the presence of secondary forest and abandoned pastures. As can be observed, these two classes were more representative in this cluster than in cluster 2. Cluster number 2, composed of 88 % of the households analyzed, is divided almost equally between spatial patterns, thus presenting more general characteristics. Given their general character, the households of cluster number two were isolated and a second run was made considering only these households. Table 5.23 presents the composition and the characteristics of each cluster produced.

This second run produced five clusters with a high frequency. Each cluster was related to one or two spatial patterns in particular concerning specific characteristics of each spatial pattern. Cluster number 1, composed mainly of households from spatial patterns C and D, has characteristics related to these two spatial patterns. The small area of primary forest is maybe related to the properties of spatial pattern C where this class is particularly small. The secondary forest area similar to the area of primary forest is probably related to the properties of spatial pattern D, as there is no secondary forest of this size in spatial pattern C. The pasture area is probably related to spatial pattern D, where the pasture area are larger than in spatial pattern C. Finally, the crop areas are very small and similar to the area of subsistence crops observed for these two spatial patterns. However, this class presents an area larger than the other clusters, which suggests the character "cultivation" for this cluster.

Table 5.23 Frequency, participation and main characteristics of the clusters produced by the second run of the K-means algorithm, first approach (satellite data)

Cluster	Freq (t=88)	Main representation (Spatial pattern)	Primary Forest (km²)	Secondary Forest (km²)	Clean Pasture (km²)	Abandoned Pasture (km²)	Crops Area (km²)	Water Area (km²)	Burned Area (km²)
1	49 (55%)	C(51%) D(43%)	3.57	2.99	2.51	2.46	0.96	0.05	0.34
2	8 (9%)	A(100%)	46.18	10.67	4.71	5.78	0.01	0	1.10
3	8 (9%)	A(100%)	30.58	7.71	28.50	4.91	0.12	0.17	2.72
4	7 (8%)	A(57%) B(43%)	23.89	18.91	4.81	5.75	0.32	0.18	3.60
5	7 (8%)	B(86%)	4.78	27.81	3.64	9.96	0.05	0.35	1.21

Clusters 2 and 3 were composed exclusively of households from spatial pattern A. These two clusters present distinct characteristics possibly related to the differences between the farms located away from the main road and the farms placed near the main road. Cluster number 2 presents the characteristics of the properties located away from the main road. The large presence of primary and secondary forest, abandoned pasture area larger than the active pasture and absence of crops, giving an abandoned appearance to these properties locate away from the main road. On the other hand, cluster number 3 shows a group with less primary and secondary forest, a large presence of clean pastures compared to the other clusters and the presence of crops. These characteristics suggest a more dynamic group, dedicated mainly to cattle and probably located near the main road. Clusters 4 and 5 were composed exclusively of households from spatial patterns A and B. The cluster number 4 was composed almost equally of households from spatial patterns A and B. This cluster has the same characteristics of abandonment presented by the cluster number 2, which is composed exclusively of households from spatial pattern A. Cluster number 5, composed mainly of households from spatial pattern B also presented a characteristic of abandonment, however with less forest area. From the field survey, it was observed that the large farms visited in spatial pattern B, resulted from the land concentration process. In the beginning of the establishment, these farms lost much primary forest mainly to pasture expansion and to a lesser scale to subsistence crops. The area of crops was quickly abandoned and generally became pasture. The area of pastures is enormous and a large part of this start to regenerate before it is exploited for cattle.

5.4.1 Summary of cluster analysis

The analysis by cluster was applied to find homogenous groups in terms of land use and land cover that could be related to the spatial patterns analyzed. The analysis was made considering two different types of data separately: socio-economic data from the household survey and land use and land cover data retrieved from satellite images.

The k-means cluster algorithm produced results that support the hypothesis of this work. Using socio-economic data from the household survey, the cluster algorithm formed homogeneous groups in terms of land use, composed in its majority by households from a specific spatial pattern. The main differences found between spatial patterns were related to the size of pastures, number of animals, production of commercial crops and production of NTFP. The clusters related to spatial patterns A and B presented areas of pasture and a number of animals larger than the cluster related to spatial patterns C and D. The cluster related to spatial pattern C presented a larger production of commercial crops than the other spatial patterns and the cluster related to spatial pattern D presented a larger production of NTFP than the others. This suggests that spatial patterns A and B are both dedicated to cattle activity in general. Spatial pattern C is dedicated to agriculture. Spatial pattern D, despite the high production of subsistence crops compared to the other spatial patterns, can be classified as agriculture and dedicated to NTFP exploitation.

The analysis using data from satellite images also suggested some differences between spatial patterns. However, in this case, the differences are more related to the size of the spatial patterns than to land use activities. While the clusters related to spatial patterns A and B presented larger forest (primary and secondary) and pasture (active and abandoned) areas than the clusters related to spatial patterns C and D, the clusters related to the spatial patterns C and D, presented more areas of crops. This is not strong evidence, but it also suggests that spatial patterns A and B are dedicated to cattle activity and spatial patterns C and D are dedicated to subsistence production.

5.5 Fifth Stage - Analysis of Variance ANOVA

The analysis of variance ANOVA was applied as a way to confirm the differences observed between the spatial patterns, using both types of data. Assuming that the distribution is balanced and the difference between the greater variance does not exceed 9 times the minor variance, the null hypothesis was that there is no difference between the spatial patterns. In the Table 5.24 is presented the p-value for each variable analyzed, the respective Bonferroni test for each p-value and the spatial patterns considered different in relation to each variable. The coefficients calculated for each factor show that the null hypothesis is rejected for the factors average area of subsistence crops (ha), average area of commercial cultures (ha), average number of animals and average area of pastures (ha). This indicates significant differences between the spatial patterns relating to these factors. It confirms the differences already observed in terms of pasture area and number of animals. However, the difference in terms of subsistence and commercial crops areas was not clear, given that in the cluster analysis the main difference in terms of crops was related only to the production of subsistence crops.

Table 5.24 P-value, Bonferroni test and different patterns for each field survey variable analyzed

Factors	P-value	Bonferroni test	Different Patterns
Average area of subsistence crops (ha)	0.0048	0.018	b ≠ c, b ≠ d
Average area of commercial crops (ha)	0.0044	0.017	a ≠ b, b ≠ c, b ≠ d
Average production of subsistence crops (kg)	0.2168	0.867	-
Average production of commercial crops (kg)	0.4099	1.636	-
Average number of animals	<.0001	<.0004	a ≠ c, a ≠ d, b ≠ c, b ≠ d
Average area of pastures (ha)	<.0001	<.0004	a ≠ c, a ≠ d, b ≠ c, b ≠ d
Average production of NTFP (kg)	0.4375	1.748	-

The Bonferroni test confirmed the rejection of the null hypotheses for the same variables (average area of subsistence crops, average area of commercial cultures, average number of animals and average area of pastures) and identified the patterns that are different in relation to these variables. It is observed that, for the area of subsistence crops, the spatial patterns that are different are: B ≠ C, B ≠ D. There are no significant differences between spatial patterns A / B, A / C, A / D, and C / D. For the area of commercial crops, one observes statistically significant differences between A ≠ B, B ≠ C, and B ≠ D. For the production of subsistence crops and commercial crops, there are no significant differences observed. Finally, for the variables “number of animals and pasture area” the same differences are observed: A ≠ C, A ≠ D, B ≠ C, B ≠ D, confirming the differences already observed in the cluster analysis relating to these variables and these spatial patterns.

An analysis of variance ANOVA was also applied using land use and land cover data from satellite images. In this case, the variable analyzed was the average area of primary and secondary forest, active and abandoned pastures, crops area, burned area and water bodies (Table 5.25). The coefficients calculated for each factor show that the null hypothesis is rejected for the variables: average area of primary forest (km^2), average area of secondary forest (km^2), average area of active pasture (km^2), average area of abandoned pasture (km²), average area of crops (km²), and average area of water bodies. The burned area is the only variable that does not present a statistically significant difference between spatial patterns.

Table 5.25 P-value, Bonferroni test and different patterns for each satellite image variable analyzed

Factors	P-value	Bonferroni test	Different Patterns
Average area of primary forest (km²)	0.0018	0.012	a ≠ c, b ≠ c
Average area of secondary forest (km²)	<.0001	0.007	a ≠ b, a ≠ c, b ≠ c, b ≠ d
Average area of active pasture (km²)	0.0006	0.004	a ≠ c, a ≠ d,
Average area of abandoned pasture (km²)	<.0001	0.007	a ≠ b, a ≠ c, a ≠ d, b ≠ c, b ≠ d, c ≠ d
Average area of crops (km²)	0.0035	0.023	a ≠ b, b ≠ c
Average area of burned area	0.056	0.392	-
Average area of water buddies	0.0018	0.012	a ≠ c, b ≠ c

These differences observed in terms of class areas derived from satellite images are probably related with the difference in surface area between spatial patterns. However, no difference was detected in terms of crop area between the spatial patterns A and C. The difference in terms of secondary forest between spatial patterns A and B, considered both as being influenced by cattle ranching with similar property size, suggests a different role for secondary forests, which are always related with abandoned areas. The ANOVA summary tables for every variable analyzed is presented in the Annex C.

5.6 General household profile of each spatial pattern

a) Spatial pattern A (fishbone)

Composed of families of five from the Acre State, who arrived after 2000. The property is formed in general for one lot (80 ha) with 3 ha of planted area and 1400 kg of production, 40 ha of pasture and 116 heads of cattle. They produce around 10 kg from NTFP, and deforest 3ha per year on average, arriving at up to 17 ha in same cases.

b) Spatial pattern B ((Multidirectional ordered))

Composed of families of four from the south of the country, mainly from Parana State and who arrived between 1980 and 1996. The property is formed of 2 lots (80 each) minimum with 6 ha of planted area and around 370 kg of production, 40 ha of pasture and 70 heads of cattle. They produce around 4 kg of NTFP and deforest 4 ha per year on average, arriving at up to 30 ha in some cases.

c) Spatial pattern C (bi-directional preferential or small scale fishbone)

Composed of families of four from the Acre State and who arrived after 2000. The property is composed of 1 lot (10ha) with 2ha of planted area and 370 kg of production, 1.5 ha of pasture and 2 heads of cattle. They produce around 3 kg of NTFP and deforest around 0.36ha per year.

d) Spatial pattern D (diffuse)

Composed of families of four from the Acre State and who arrived between 1997 and 2005. The property is formed of one lot (25ha) with 2.5 ha of planted area and 100 kg of production, 7 ha of pasture and 12 heads of cattle. They produce in general 16 kg of NTFP and deforest around 1.5 ha per year.

Chapter 6

Conclusions

6.1 Synthesis

Changes in land use and land cover are associated with many environmental issues observed on the earth's surface. In the last decades, these changes were unprecedented, mainly in tropical forest areas. The Brazilian Amazon, the world's largest tropical forest, lost around 200,000 km² of primary forest in the last ten years (INPE, 2005). Considering this, and the consequences caused by this deforestation, it is important to know and define correctly the responsible agents, aiming at better public policies that can help preserve the forest. Searching for indicators that could help to identify the deforestation agents, some studies, such as Mertens and Lambin (1997), suggest that every deforestation process shapes the forestland in a specific way, producing a spatial pattern that can be interpreted as indicative of the role of a set of agents with specific economic activities. Based on this hypothesis, the objective of this study was to contribute to a better understanding of land change processes in the Amazon forest, investigating the linkages between spatial patterns of deforestation, as visualized in satellite images, and different agents and their specific economic activities. To reach this objective, our methodological approach was based on socio-economic data acquired at a household level combined with data from satellite images. First, different spatial patterns of deforestation were identified on the satellite images, based on the typologies proposed by Husson et al. (1995). Then, some of the identified spatial patterns were isolated and analyzed for specific aspects, with the objective to find indicators that could differentiate the spatial patterns in terms of main economic activities and main agents. Each spatial pattern was analyzed in relation to its deforestation rate calculated through satellite images;

socio-economic characteristics based on household survey data; and evolution of land use and land cover based on thematic maps derived from satellite images. In addition, cluster analysis was applied using the socio-economic data (household survey) and land use and land cover data (satellite images) in a search for homogeneous groups related to the spatial pattern. In the end, an Analysis of Variance (ANOVA) was applied to confirm the differences between spatial patterns.

6.1.1 Deforestation analysis

The first stage of spatial pattern analysis focused on the evolution of deforestation. Using remote sensing data, the evolution of deforestation was studied over the period 1990 to 2004. The changes were analyzed for the entire study area at the spatial pattern and household levels. At a regional level, the study area presented an evolution of deforestation similar to the deforestation presented by Acre State. As the study area occupied a large portion of the most deforested area of the Acre State, its deforestation behavior is probably one of the main contributions to the deforestation behavior of the State. Concerning spatial patterns, the analysis of deforestation demonstrated that, while spatial patterns A and B presented an evolution of deforestation similar to the behavior of the entire study area, spatial patterns C and D presented a particular behavior, indicating differences in land use strategies. The analysis at a household level demonstrated that, while in spatial patterns A and B the deforested area per lot varied from 4 ha to 30 ha per year - suggesting direct openings for pasture expansion - in spatial patterns C and D the deforested area per lot varied between 0.36 (spatial pattern C) and 1.5 ha (spatial pattern D) - indicating openings only for subsistence crops. At last, comparing the proportion of forest lost inside each spatial pattern, it was observed that, while spatial patterns A and B respectively lost 53 and 64 % of their primary forest during the period studied, spatial patterns C and D respectively lost 76% and 79% of their primary forest during the same time. Despite the difference in area (and considering that spatial patterns A and B started around 10 years earlier than spatial patterns C and D), these results suggest that the spatial patterns with medium size properties (between 80 to 100 ha) that did not suffer an intense process of land concentration were more stable in terms of primary forest lost than the spatial patterns composed of smaller size properties, dedicated mainly to family production.

6.1.2 General characteristics of households based on household survey data.

The second part of the spatial pattern analysis was based on socio-economic data acquired in the field survey through a questionnaire. From this information it was possible to build a general profile of the main agents and their activities for each spatial pattern analyzed.

a) Spatial pattern A consists mainly of families from the Acre State, of five members on average and arrived in the region after 2000. Around 85 % are not first occupants and only 50% having a land title. This suggests an intensive rate of land transfer and the presence of a black market for land, since only the properties with a title can be legally exploited. In general, these families possess only one lot, where the presence of crops is observed, but with cattle as the main activity given the number of animals and the pasture area.

b) Spatial pattern B (Redenção) consists mainly of families from the south of Brazil, who arrived between 1980 and 1996. Around 72 % have a land title and 83% possess more than 2 lots, and up to 18 lots in some cases. Despite the presence of subsistence crops and in some cases also commercial crops, the large pasture area and high number of animals suggests that this spatial pattern is dedicated mainly to cattle breeding. This is confirmed by the deforestation analysis, where it was detected that some properties composed of more than 5 lots had deforested around 30 ha per year.

c) Spatial pattern C, formed by small properties of around 10 ha, is occupied mainly by people from the Acre State, who arrived after 2000. Despite starting in 1991, 85 % of the occupants in 2005 declared not to be the first occupant and 90 % do not have a land title. This justifies the low level of land concentration, where it was observed that the majority of the occupants (75%) possess only one lot. Despite the presence of subsistence crops, the significant production of a small property combined with the presence of small pasture areas and a small number of animals suggest a “cultivation” character for this spatial pattern. This is confirmed by the deforestation analysis where most of the occupants cut around 0.36 ha per year, which certainly relates to openings for plantations.

d) Spatial pattern D is composed mainly of families from the Acre State that arrived at the beginning of the settlement, between 1997 and 1999. However, 75 % of the inhabitants declared not to be the first occupants, suggesting a fast process of land transfer that started in the beginning of the settlement. The analysis of land use data revealed an intermediate situation. It was observed that the planted area, the pasture area and the number of animals were higher than in spatial pattern C (considered “cultivation”) and smaller than in spatial patterns A and B (considered “cattle”). The analysis of the deforestation showed that, on average, families cut around 1.5 ha per year, probably for crop expansion. However, the area of pastures present in the lots also suggests openings for ranching.

6.1.3 Evolution of land use and land cover

The land use and land cover change analysis based on the thematic classification of satellite images was not conclusive in terms of differentiation between spatial patterns. However, it revealed a situation where the different spatial patterns of deforestation analyzed in this study, independent of size, planning and main activity, ended up evolving following more or less the same trends. In general, it was observed that in the first period, there was a decrease in primary forest in response mainly to the increase in crops and pasture areas. In the second period, there was a stabilization of the primary forest, crops and pasture areas. And in the third period, there was a strong decrease in the crops and primary forest areas, following the increase in secondary forest and pasture areas. The increase in the secondary forest is related mainly to the abandonment of the cultivated parcels while the decrease in primary forest is related mainly to direct openings for pasture expansion. This suggests the absence of good conditions (infrastructure, financial and technical) to keep the original design of each spatial pattern - compelling occupants to follow a livelihood scheme where 1 or 2 ha of primary forest is cut per year to keep the subsistence crops and the cattle. This played an important role as a guarantee of income for households. This absence of "conditions" is confirmed by the questionnaire answers, where more than 80 % of all households interviewed declared working the land without any financial or technical aid. They also declared that the roads are impracticable in the rainy season, where many of them stay isolated in the forest. The presence of pastures and cattle can also be observed (to a greater or lesser extent) in all spatial patterns analyzed, confirming the role of cattle. The deforestation analysis per lot showed that, in general, each lot visited cut around 1 or 2 ha per year of primary forest for subsistence crops. Some properties in spatial patterns A and B were cutting much more, indicating direct openings for pasture expansion.

6.1.4 Cluster analysis

The analysis by cluster aimed at finding homogeneous groups in terms of economic activity related to the spatial patterns. The analysis was made considering two different types of data: socio-economic data from the household survey and land use and land cover data from satellite images. The main results were produced using the socio-economic data from the household survey, where specific groups related to the spatial patterns were formed.

Independent of the spatial pattern, all groups presented areas and productions of subsistence crops at the same scale. The main differences detected between spatial patterns were related to the size of pastures, number of animals, production of commercial crops and production of NTFP. The clusters related to spatial patterns A and B were characterized by a combination of large areas of pasture with a high number of animals, greater than the clusters relate to spatial patterns C and D. On the other hand, while the cluster related to spatial pattern C presented a greater production of commercial crops than the others, the cluster related to spatial pattern D presented a greater production of NTFP than the others. The analysis using land use and land cover data from satellite images was not very conclusive, but also detected some differences between spatial patterns. The clusters related to spatial patterns A and B presented larger forest (primary and secondary) and pasture areas, than the clusters related to spatial patterns C and D, while the clusters related to spatial patterns C and D presented a larger area of crops. Considering the difference in size between the spatial patterns, these results suggest that, while spatial patterns A and B are both dedicated to cattle activities in general, spatial pattern C is dedicated mainly to agriculture and spatial pattern D, following its original concept, is dedicated to subsistence crops the exploitation of NTFP.

6.2 Main findings

The main question of this research was: Is there a linkage between spatial patterns of deforestation visualized by satellite images and specific economic activities? The results obtained through the proposed methodology directly address this question, suggesting that the different spatial patterns of deforestation found in the study area can be related to specific economic activities. Table 6.1 shows the main economic activities of each spatial pattern and the information about deforestation related to each area. Nevertheless, the results have indicated that the spatial configuration is not a consequence of its main economic activity. They suggest that the spatial configuration is linked to the settlement project. The main economic activity in the spatial patterns is a consequence of a set of factors such as: size of property, location and disposition of the property, presence or absence of infrastructure (road, market, transportation, economic and technical). The four spatial patterns analyzed were part of the same government settlement program, each one with a specific history and purpose. However, due to the unsuitability of the soil to support permanent agriculture without adequate management and without infrastructure to keep the proposed activity for the settlement going, cattle became an important activity, thanks to its financial guarantees and easiness compared to plantations - independent of the spatial pattern and the property size.

More than 80 % of the households visited declared not receiving any financial support and more than 90 %, any technical assistance. More than 90 % declared that the roads are impracticable during the rainy season. Colonists located far from the main road declared not having transportation or some way of delivering their production. More than 90 % of the households visited, including on small and medium properties, declared to be obliged to abandon the cultivated parcels because of the low fertility of the soil and consequently the low agricultural productivity, and also to be obliged to cut up to 2 ha per year of primary forest to keep up the productivity of the subsistence crops. The abandoned parcels in general are directly transformed into pasture or left to evolve into a secondary forest. This behavior is confirmed by the land use and land cover change analysis using satellite images, where an increase in cultivated parcel areas in the first years was observed, followed by an abrupt decrease in primary forest area in the last years along with a strong increase in pasture and secondary forest area.

Table 6.1 Main activity and deforestation information for each spatial pattern of deforestation

Spatial pattern	Main economic activity	Secondary activity	% of forest lost between 1990 - 2004	Deforested area *per* lot, *per* year
Spatial pattern A	Cattle ranching	Subsistence crops and exploitation of NTFP	53	from 3 up to 17 ha
Spatial pattern B	Cattle ranching	Subsistence and commercial crops	64	from 4 up to 30 ha
Spatial pattern C	Subsistence and commercial crops	Small scale livestock	76	from 0.36 up to 0.48 ha
Spatial pattern D	Subsistence crops and exploitation of NTFP	Small scale livestock	79	up to 1.5 ha

There are indications that the land concentration also played a role in the land change of this area. The concentration of land influenced the increase of extensive activities due to the availability of land and thus accelerated the deforestation. Some spatial patterns are apparently more subject to land concentration than others. For example, spatial pattern B, with a singular configuration presented a strong concentration of land compared to the other spatial patterns. The properties of this spatial pattern are disposed in a radial configuration that may influence this trend. Another possibility is the origin of the household that composed this spatial pattern. Differing from other spatial patterns analyzed, spatial pattern B is composed in its majority by households coming from the south of the country. However, this linkage is not clear. Despite presenting a different configuration, spatial pattern A having similar property sizes also presented indications of land concentration, however less than for the spatial pattern B and with less forest lost. This can be an indication that settlements with property sizes around 80 ha, with a traditional configuration (fishbone) and low land concentration can be more stable in terms of primary forest loss than other spatial configurations and small settlements. The analysis of deforestation showed that spatial pattern A with properties sizes similar to those in spatial pattern B, but with less land concentration, lost less primary forest than the other three spatial patterns. In this case, the colonization projects should be monitored intensively. Colonization projects without monitoring can easily deviate from their original goal and thus increase and accelerate deforestation. In addition, the results suggest that the settlements composed of small properties, between 10 and 30 ha, can lead to more deforestation than medium properties (80 to 100 ha). Spatial patterns C and D, composed of small properties had lost, in the same period, more primary forest and faster than in spatial patterns A and B, with medium properties. In the case of spatial pattern C, is may be related with the very small property sizes and with the permission to cut the entire area of primary forest present in the property. On the other hand, it is important to note that spatial pattern D lost more primary forest (79%) than the other spatial patterns in the same period. Comparing with the other spatial patterns, spatial pattern D is the most recent (1997) and the only one conceived with conservation objectives. However, given the total absence of infrastructure (roads quality, technical and financial support) and monitoring, this spatial pattern presents high rates of land transference (50 % of households are not the first occupants and around 50 % arrived after 2000) and continuous growth of pasture areas. Furthermore, this spatial pattern is served by a dirt road, which is impracticable in the rainy season and is located 40 km from the main road (BR163). This is evidence against some conclusions from researchers (Laurence, et al., 2001; Nepstade et al., 2001; Fearnside, 2002; Kirby et al., 2006) that identify roads as the greatest vector of the Amazon deforestation.

At last, these conclusions should be considered only for this region. Extrapolating these observations to the entire Amazonian basin would be a mistake. The Amazon tropical forest is a huge area and is very heterogeneous in terms of deforestation processes, agents involved, infrastructure conditions (transport networks, road conditions, markets, schools, water and electricity supply). Further investigations will be required to generalize these conclusions to other regions of the Amazon Basin.

6.3 Methodological discussion

This study combined spatial information from satellite images with socio-economic data from a household survey to explore the linkages between different spatial patterns of deforestation and specific economic activities as a way to gain a better understanding of the changes in the Amazon forest. This combination between socio-economic and remote sensing data seemed to be the most effective approach to understand land use and land cover changes (Hostetler, 2007). Furthermore, socio-economic data can be used to improve interpretation of remotely sensed data (Rindfuss and Stern, 1998). However, linking people (socio-economic data) to pixels (satellite images) raises some methodological challenges that this study tried to address. The critical question is where to georeference the individuals or other social units and which unit of study to use (household, community, village, region). Rindfuss et al (2003) argue that the link between people and land has to be designed differently in different settings. According to these authors, there are no universal theories or formulas to determine the link needed. The methods for linking people to land should be responsive to the needs and conditions of the research at hand. This study aimed at analyzing spatial patterns of deforestation, thus the unit adopted was the household that composes the spatial patterns. To link the household visited in the field survey with the information from satellite images, the GIS technology was used. First, the satellite images and the property grid (available in the National Institute for Agrarian Reform - INCRA) was georreferenced and registered in the same spatial database. Then each household visited and georreferenced with GPS coordinates in the field survey was associated to its respective lot on the property grid. As a consequence, the socio-economic information from the household survey data and the land use and land cover information from the satellite data were associated to a specific area on the ground.

The link between people and pixel provided much information about the households. To explore this information, a multivariate statistical technique was used. A recent article (Lesschen et al., 2005) reviews the multivariate techniques as most useful to explore data for land use and land cover change. In search for homogeneous groups inside the data, we used a cluster analysis, testing the K-means algorithm. Interesting research about tropical deforestation was carried out based on cluster analysis (i.e. Pichón, 1996; Lambin, 2003; Browder et al. 2004), most of them using the K-means algorithm. For this work, this cluster algorithm produced good results, finding homogeneous groups in terms of land use that could be related to the spatial patterns.

6.4 Methodological limitations

Due to the importance of the field survey for this type of study and the lack of experiences in linking people to pixel at a household level, we highlight here some limitations affecting this study. At a household level, a land use and cover change study needed to be supported by a well conducted field survey. However, as was reported in the methodology, given that linking "people to pixels" is a relatively new scientific method, still without standards about the necessary requirements for an ideal field survey, we designed the survey on our field experience, counting mainly on the aide of local contacts to complete the mission. Although we have produced an important set of field data, including more than a hundred interviews, GPS points for the land use classification, and discussions with key persons, it is difficult to evaluate the precision of the data acquired in the field survey. Given the absence of a sufficient financial support, trained people, and time, it was not possible to apply procedures to evaluate systematically the precision of these data.

Another methodological issue is related to the accuracy of the property grid used. Despite being an "ideal" view of the landscape and the properties, and providing an entirely new capacity to observe the land cover change at a household level, the accuracy of the property grid in relation to the disposition and shape of the properties is a challenge. Some factors such as natural features (topography, rivers) and neighbour relationships are not considered by the property grid and influence directly its accuracy. This problem was minimized considering that there are no great topographic variations or other natural features that could influence the disposition or size of the properties. We also used GPS points at strategic places in the property, such as the lateral borders, plantations, pastures and dwellings. However, to guarantee an optimum precision between images, grid property and ground data, a very large GPS survey would be required to determine exactly the borders of properties.

At last, besides these methodological issues, the main limitation of this study was that it was carried out only for one site in the huge Amazon basin. The intent of this study was to analyze spatial patterns of deforestation that can be identified in many tropical forests in the world. However, studying only one site, the results and derived conclusions cannot be extrapolated to other sites. Attributing these conclusions to other sites would not be valid without specific data and field knowledge.

6.5 Perspectives for further research

It is imperative that further works investigate other sites. The same spatial patterns needs to be observed in different sites and contexts. Only after knowing the dynamic of these spatial patterns in other regions, we will be able to address specific characteristics for determined spatial patterns in a more general sense.

The sensitivity of some spatial patterns to particular configurations of land concentration needs to be better investigated. Spatial pattern B, with a radial configuration, presented strong process of land concentration relative to the other spatial patterns. The situation suggests a relationship between the disposition of the properties and land concentration. However this relation was not clear and future investigations are required to better understand this linkage.

Some questions remain to be answered for future research. Why spatial pattern D, while younger and conceived with a specific forest conservation goal, and more distant from the main road, lost more primary forest than the other spatial patterns during the same period? Certainly the absence of infrastructure observed in the field survey, plays an important role.

Finally, this kind of study has also applications for deforestation modelling. Once land use associated with these spatial patterns is understood, further studies involving modelling could use the spatial patterns as a spatial indicator of specific land use and rates of deforestation. It could facilitate the interpretation of the spatial data through a modelling approach and perhaps improve the precision of model-based projections.

6.6 Scientific contribution

Despite the large amount and variety of land use and cover change studies, many of them investigating spatial patterns of deforestation, this is the first time that spatial patterns of deforestation, were analyzed from socio-economic data acquired at a household level and combined with land use and land cover change data from satellite images. Before, scientists could only suggest such linkages (spatial patterns vs. land use). With the methodology adopted in this research, it is now possible to investigate this linkage in depth. Specifically, the integration of land use and land cover data derived from satellite images and socio-economic data from a household survey for a specific area has demonstrated the applicability of this method to provide a broader picture on land use and deforestation for an specific area. As argued above, these results have also implications for deforestation modelling. Based on these results, modelling techniques could improve the representation and prediction of colonization trajectories.

Moreover, some of our results have other scientific implications. The hypothesis about the role of roads in deforestation is questioned. The discussions about the predominant influence of roads on rates of deforestation have increased after researchers suggested that the opening of new roads and the improvement of the quality of old roads drastic increase the rate of deforestation in the Brazilian Amazon. Linking exclusively deforestation with roads would be a mistake. The results demonstrated that the low quality of roads and general infrastructure, and the absence of conditions (financial and technical) to stabilize the households on the property and to maintain agricultural production at a certain level have an important impact on deforestation in the area. A significant number of people live in the Amazon region. Depriving them from development opportunities and access to markets will certainly worsen their socio-economic conditions.

6.7 Policy implications

If these results can be confirmed in other sites, they will have implications for policy. With the perspective of recognizing specific land uses and other spatial indicators through the analysis of spatial patterns of deforestation visualized through satellite images, policy makers will be able to generate different diagnostics of the causes and dynamics of deforestation for different regions and then address adequate occupation policies for these specific areas. Moreover, better understanding the relationships between spatial patterns of deforestation and land use activities will help to comprehend how each specific area will be affected by an economic or occupation policy. Calibrations or adjustments of the policies to specific local situations could then be considered. Furthermore, understanding the role of the spatial configuration and the size of the property on the settlers' development process will help to better design future settlement projects in the Amazon region.

Finally, the results suggest that colonization or settlement projects without financial and technical aide will increase deforestation and poverty. Future occupation policies for the Amazon basin should respect the original purpose of the settlement and the occupants need to be assisted until they develop a sustainable land use. Only with investments in infrastructures (e.g. transport, market, energy, water), aid (e.g. financial and technical assistance) and field monitoring, will it be possible to stabilize the families in the field with dignity, to control the process of land concentration and thus better control deforestation rates.

Annex A

Field Questionnaire

Questionário de Campo – Acre 2005

1- Informações Básicas

- Código do Padrão Data da entrevista

- Travessão_____________________________Municipio

- Latitude

Graus	Minutos	Segundos

- Longitude coordenadas da frente do lote

Graus	Minutos	Segundos

- Entrevistado

Sexo (_____) Idade(_____) Escolaridade (_____)

- Responsável pelo lote

Sexo (_____) Idade(_____) Escolaridade (_____)

Origem: (   ) Acre (onde?)_______________ (   )outro estado

Procedencia: (   ) Acre – 1-cidade, 2-zona rural (   )outro estado – 1-cidade, 2-zona rural

(   )outro lote – 1-mesma região, 2-outra região, qual?

- Porque deixou o lote anterior?

- Qual a localização do lote anterior?

- Quando chegou no lote, quanto dele ainda era floresta?
(   )todo, (   )mais da metade, (   )metade, (   )menos da metade

- Atividades do lote hoje:

- Agricultura: (   ) familiar (   ) renda
- Pecuaria (   ) Corte (   ) leite
- Extrativismo (   ) sim (   ) não

2 - Histórico do Lote

- A propriedade é: (   )comprada   (   )alugada   (   )arrendada
(   )adquirida   (   )invadida   (   )outros

- Quando chegou ao Lote:_______/_________/_____________

- Valor, forma de pagamento e data :

- Tempo: (alugou, arrendou, recebeu o lote por quanto tempo ?)

- Observações:

3 – Pessoal e Força de trabalho   ENS= Entrevistado não sabe

Pessoal e Força de trabalho	Número em 2005	Em 1999 era: 1. mais importante, 2. menor, 3. o mesmo, 4. ENS comparado à 2004	Em 1995 era: 1. mais importante, 2. menor, 3. o mesmo, 4. ENS comparado à 1999
Nùmero de pessoas que moram no lote			
Número de trabalho assalariado usado			
Número de parentes usados			
Numero de pessoas de fora do lote			

4 – Insumos e equipamentos agrícolas

Insumos	2005	1999	1995
Fertilisante			
Herbicidas			
Inseticidas			
Fungicidas			

Equipamento Agricola	2005	1999	1995
Enxada			
Foice			
Trator			
Pulverizador			
Serra Elétrica			

Código de insumos equipamentos 1= sim 0 = não

5 - Agricultura

- Vocês cultivaram algo em 2005 ? (sim) (não)

- Vocês tem cultivado continuamente desde a aquisição do lote ? (sim) (não)

- Vocês possuem algum tipo de financiamento ? (sim) (não)
Qual:____Valor:

- Vocês recebem alguma orientação de plantio de alguma instituição ou ONG ?
(sim) (não) Qual ?

- Esta orientação teve continuidade nos anos posteriores? (sim) (não)

Quais as principais culturas do lote hoje	Area e n° do sketch map	Em relação a 1999: 1maior, 2 menor, 3 igual, 4 cultura não cultivada	1-Renda 2- Subsistencia

- Vocês tiveram algum tipo de financiamento em 1999 ? (sim) (não)
Qual:____Valor:

- Vocês receberam alguma orientação de plantio de alguma instituição ou ONG em 1999 ? (sim) (não) Qual ?

- Esta orientação teve continuidade nos anos posteriors? (sim) (não)

Quais as principais culturas do lote em 1999	Area e n° do sketch map²	Em relação a 1995: 1maior, 2 menor, 3 igual, 4 cultura não cultivada	1-Renda 2- ubsistencia

- Você poderia nos estimar qual foi a produção para as culturas do lote ?

Culturas	2005	Em relação a 1999: 1maior, 2 menor, 3 igual, 4 cultura não cultivada	Em relação a 1995: 1maior, 2 menor, 3 igual, 4 cultura não cultivada

- Indique a proporção de sua produção que foi vendida durante os seguintes periodos

Cultura	2005	1999	1995

Código: 1=nehuma
2=menos que a metade
3=metade
4=mais que a metade
5=tudo
6= ENS - Entrevistado não sabe

- Você faz rotação de culturas ? (sim) (não) – Tempo ?

- Qual a ordem das culturas ?

- Você costuma abandonar as areas de culturas ? (sim) (não) ?

- Se sim, após quanto tempo de uso ?

- Qual o principal motivo ?

- Quando uma área é abandonada, uma outra de floresta virgem é aberta (sim) (não)

- Qual o tamanho médio da nova area aberta?

- Qual o tempo que se leva para abrir uma área destas ?

- Áreas que ja foram abandonadas (floresta secundária), voltam a ser utilizadas ? (sim) (não)

- Após quanto tempo uma área abandonada volta a ser utilizada ?

- Oque te incentiva a plantar ?

( ) bom negocio	( ) proteção do lote
( ) terra disponivel	( ) financiamento
( ) rendimento	( ) outros

- Que culturas você gostaria de plantar no futuro, dado o contexto atual ? Porque ?

6 - Pecuária

- O lote possui cabeças de gado? (sim) (não) Corte ( ) Leite ( )

- Oque te incentiva a criar gado ?

( ) bom negocio	( ) proteção do lote
( ) terra disponivel	( ) financiamento
( ) rendimento	( ) outros

Qual o numero de cabeças hoje	Em relação a 1999: 1maior, 2 menor, 3 igual	Em relação a 1995: 1 maior, 2 menor, 3 igual

Qual a área de pastagem hoje	Em relação a 1999, a area era: 1-maior 2- menor 3 – igual	Em relação a 1995, a area era: 1-maior 2- menor 3 – igual

- Que tipo de forrageira você costuma usar como pastagem ?

- È feita a rotação (sim) (não). A cada quanto tempo ?

- Você costuma abandonar as áreas de pastagem ? (sim) (não) Após quanto tempo ?

- A área abandonada volta a ser reutilizada? (sim) (não) Após quanto tempo ?

- Qual a frequência que se broca a floresta para criar mais pasto ?______Quanto ?

- Vocês possuem algum tipo de financiamento ? (sim) (não)
Qual:____Valor:

- Vocês recebem alguma orientação de criação de alguma instituição ou ONG ?
(sim) (não) Qual ?

- Esta orientação teve continuidade nos anos posteriors? (sim) (não)

- Você possui algum espécie de auxilio para vender sua produção (sim) (não)
Qual:

- Como:

7- Extrativismo (NTFP)

- Seu lote colheu NTFP em 2004 ? (sim) (não)

- Distância ou Tempo gasto para acessar os produtos :

Produtos NTFP	Distancia ou tempo entre o lote eo local de colheta	Em relação a 1999: 1maior, 2 menor, 3 igual, 4 produto não extraido	Em relação a 1995: 1maior, 2 menor, 3 igual 4 produto não extraido

- Quantidade

Produtos NTFP	Quantidade coletada em 2004	Em relação a 1999: 1maior, 2 menor,3 igual 4 produto não extraido	Em relação a 1995: 1maior, 2 menor, 3 igual, 4 produto não extraido

- Venda

Produtos PFNM	Quantidade vendida em 2004	Em relação a 1999: 1maior, 2 menor, 3 igual, 4 produto não extraido	Em relação a 1995: 1maior, 2 menor, 3 igual, 4 produto não extraido

- Onde é feita a colheita de PFNM ?

( )dentro do proprio lote. Qual a distância/tempo?
( )outro lote. Onde e distância/tempo

- Vocês possuem algum espécie de auxilio para vender sua produção
(sim) (não) Qual:

- Vocês recebem algum tipo de incentivo para praticar o extrativismo ?
(sim) (não) Qual:
- Atualmente, oque te incentiva a praticar o extrativismo ?

( ) bom negocio ( ) proteção do lote
( ) terra disponivel ( ) financiamento
( ) rendimento ( ) outros

- Vocês costumam plantar arvores (sim) (não)

- Qual o motivo :
( ) comercio ( ) proteção do lote
( ) consumo ( ) outros
( ) comércio e consumo

Espécies plantadas	Quantidade e/ou área plantada em 2004	Em relação a 1999: 1maior, 2 menor, 3 igual, 4- produto não extraido	Em relação a 1995: 1maior, 2 menor, 3 igual, 4- produto não extraido

- Vocês possuem algum tipo de incentivo para plantar árvores ?
(sim) (não) Qual e que tipo

-Vocês recebem alguma orientação de plantio de alguma instituição ou ONG ?
(sim) (não) Qual ?

-Esta orientção teve continuidade nos anos posteriors? (sim) (não)

8 - Extração Seletiva de Madeira

-Vocës costumam fazer a extração seletiva de madeira (sim) (não)

- Esta madeira é comercilaizada ? (sim) (não)

Quantidade extraida em 2004	Em relação a 1999, a quantidade: 1maior, 2 menor, 3 igual, 4- produto não extraido	Em relação a 1995, a quantidade: 1maior, 2 menor, 3 igual, 4- produto não extraido

- Qual o principal motivo que o leva a extrair Madeira da floresta ?:
( ) bom negocio ( ) proteção do lote ( ) combustivel
( ) madeira disponivel ( ) financiamento ( ) outros
( ) rendimento ( ) necessidades

- Quem faz a derrubada e extração da madeira de seu lote ?
( ) pessoas que moram no proprio lote ( ) funcionários da madeireira interessada
( ) funcionários da madeireira e pessoas do lote

- A areas de seu lote onde você retira a madeira, costumam se transformar em área para cultura ou pastagens ? (sim) (não)

9 – Cooperativa e associação

- Você participa de alguma cooperativa ? (sim) (não). Qual ?

- Qual a natureza da cooperativa : ( ) publica ( ) privada
( ) colonização ( ) produção

- Qual o papel da cooperativa?

- Para você, quais as vantagens em participar de uma cooperativa ?

- Você acredita que esta cooperativa realmente contribui com os colonos? (sim) (não) Porque ?

- Além da cooperativa, existe alguma outra instituição ou sindicato que auxilia os colonos ? (sim) (não) Qual ?

- Como funciona ?

- Você conhece alguma ONG que atua na Região ? (sim) (não). Qual ?

10 - Infraestrutura

- O lote é servido de água encanada (sim) (não). Qual a procedencia?

- Vocês tem problema de falta de água em algum periodo do ano?(sim) (não).
Qual ?

- Este problema afeta de alguma maneira a produtividade do lote ? (sim) (não)
- Como ?
- Nas épocas de seca, você faz irrigação ? (sim) (não). Como ?

- O lote possui energia elétrica ? (sim)   (não)
- De onde vem a energia elétrica?

Na sua opnião, em que condições estão as seguintes estradas da região

Estradas	estado da estrada	Em relação a 1999, o estado era 1melhor, 2 pior, 3 igual, 4 estrada não existia	Em relação a 1995, estado era 1melhor, 2 pior, 3 igual, 4 estrada não existia

Código do estado das estradas: 1=excelente 4=ruim
2=boa 5=pécima
3=regular 6= ENS - Entrevistado não sabe

- Distancia do lote a via principal:

- A região é servida de posto de saude (sim)   (não). Qual ?

- Qual a distância do lote ao posto de saude mais próximo ?

- A região é servida de escola (sim)   (não). Qual ?

- Qual a distância do lote a escola mais próxima ?

- A região é servida de algum mercado ou venda (sim)   (não). Qual ?

- Qual a distância do lote a venda ou mercado mais próximo ?

- SKETCH MAP (Croqui)

Annex B

Land Use/Land Cover Maps

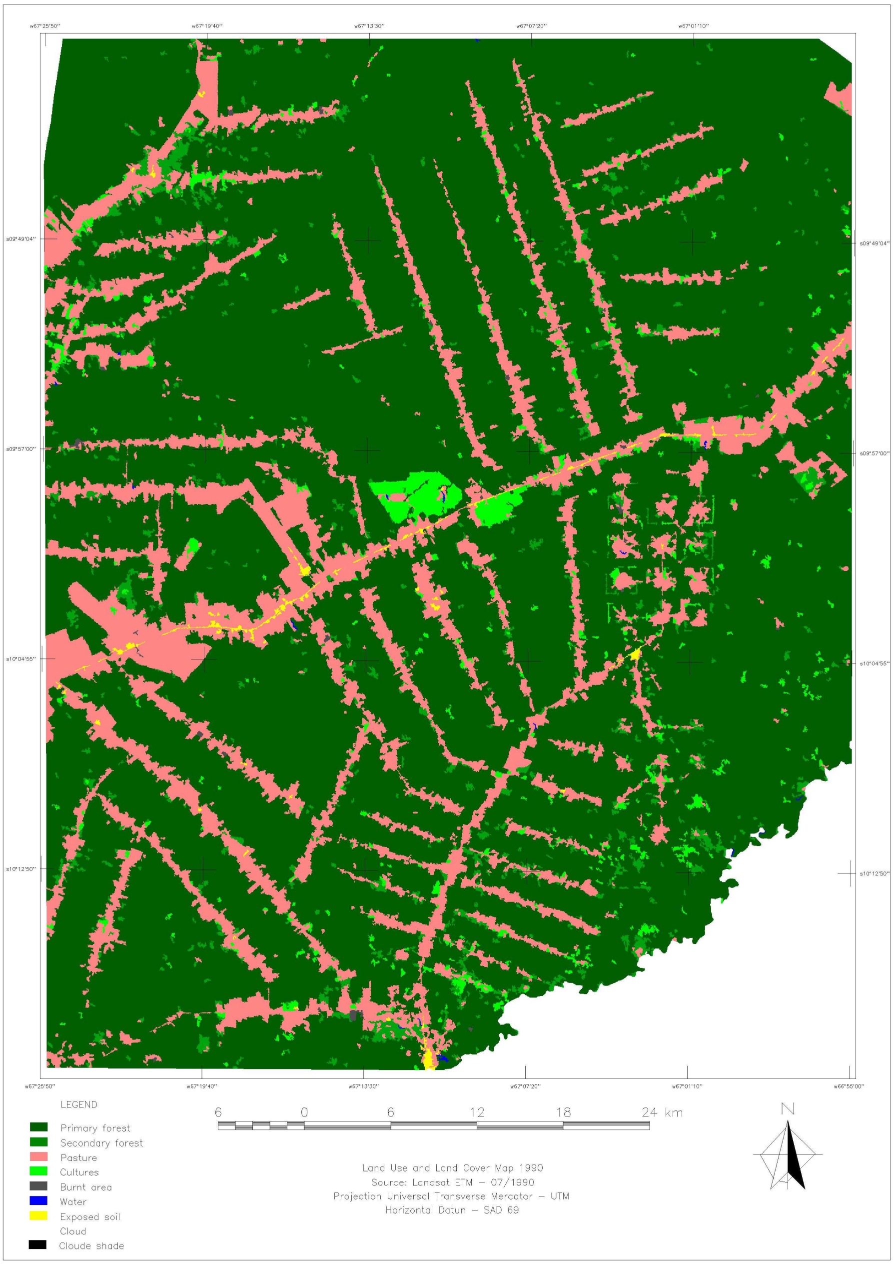

Figure annex 2.1 Land Use / Land cover Map 1990

Figure annex 2.2 Land Use / Land cover Map 1997

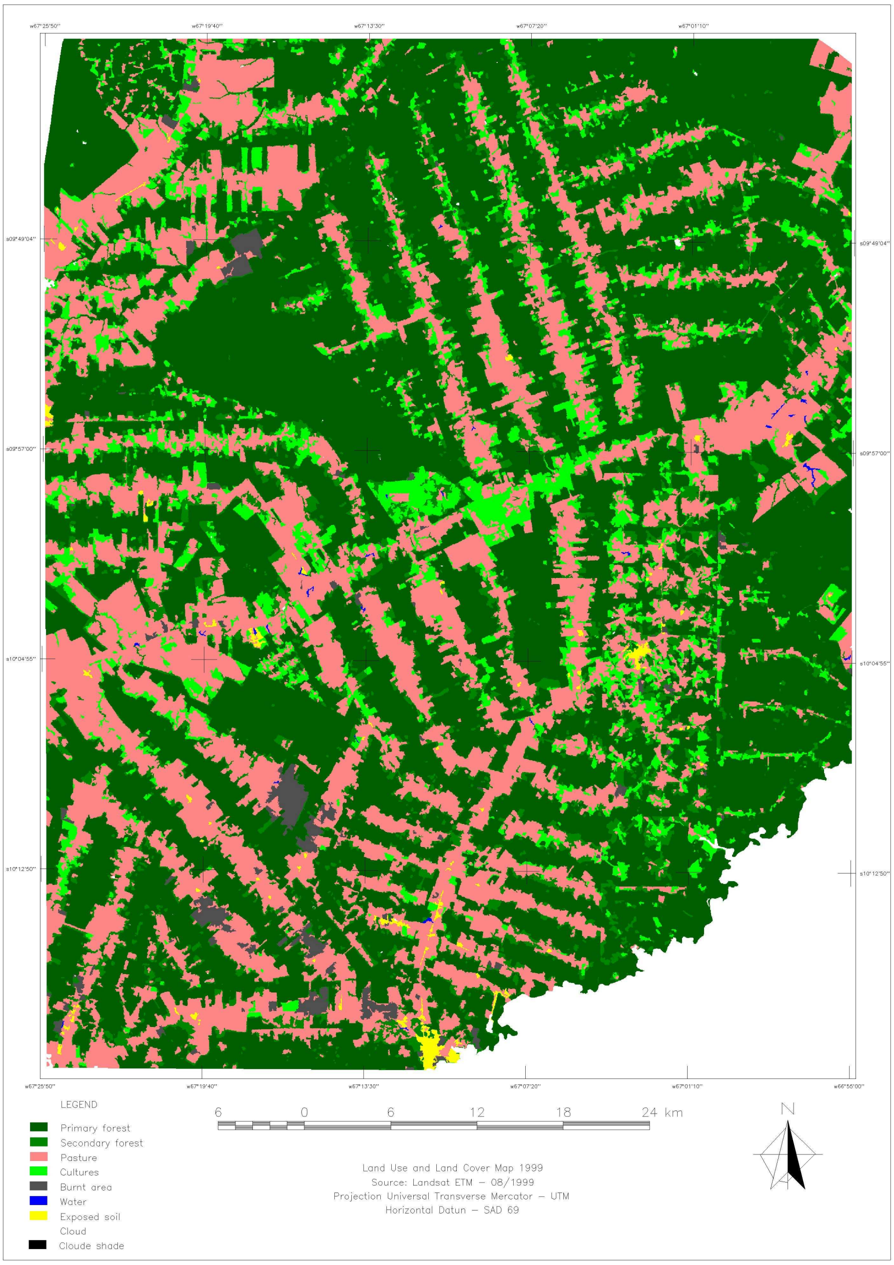

Figure annex 2.3 Land Use / Land cover Map 1999

Figure annex 2.4 Land Use / Land cover Map 2004

Annex C

ANOVA Tables

1 – Subsistence crops area (ha)

	Sum of Squares	Mean of Squares	F-statistic	Pr-value
Between	31.3466	10.4488	4.55	0.0048
Within	259.5045	2.2965		
Total	290.8511			

2 – Commercial crops area (ha)

	Sum of Squares	Mean of Squares	F-statistic	Pr-value
Between	104.37872	34.792905	4.61	0.0044
Within	860.99676	7.5526031		
Total	965.37547			

3 - Subsistence crops production (kg)

	Sum of Squares	Mean of Squares	F-statistic	Pr-value
Between	389920710	129973570	1.51	0.2168
Within	9.839E+09	86309752		
Total	1.023E+10			

4 – Commercial crops production (kg)

	Sum of Squares	Mean of Squares	F-statistic	Pr-value
Between	98093196	32697732	0.97	0.4099
Within	3.846E+09	33737427		
Total	3.944E+09			

5 – Average number of animals

	Sum of Squares	Mean of Squares	F-statistic	Pr-value
Between	207242.25	69080.749	13.83	<.0001
Within	569609.18	4996.5717		
Total	776851.43			

6 – Average area of pastures

	Sum of Squares	Mean of Squares	F-statistic	Pr-value
Between	40152.76	13384.253	8.66	<.0001
Within	173060.02	1545.1788		
Total	213212.78			

7 – NTFP average production (kg)

	Sum of Squares	Mean of Squares	F-statistic	Pr-value
Between	3078.5214	1026.1738	0.91	0.4375
Within	128254.9362	1125.0433		
Total	131333.4576			

8 – Primary forest area (km²)

	Sum of Squares	Mean of Squares	F-statistic	Pr-value
Between	3.4744643	1.1581548	5.37	0.0018
Within	22.444561	0.2158131		
Total	25.919025			

9 – Secondary forest area (km²)

	Sum of Squares	Mean of Squares	F-statistic	Pr-value
Between	19899.442	6633.1473	10.22	<.0001
Within	67514.094	649.17398		
Total	87413.536			

10 – Crops area (km²)

	Sum of Squares	Mean of Squares	F-statistic	Pr-value
Between	204.65763	68.21921	4.84	0.0035
Within	1466.5424	14.101369		
Total	1671.2			

11 – Active pasture area (km^2)

	Sum of Squares	Mean of Squares	F-statistic	Pr-value
Between	20541.456	6847.1519	6.29	0.0006
Within	113279.48	1089.2258		
Total	133820.93			

12 – Abandoned pasture area (km^2)

	Sum of Squares	Mean of Squares	F-statistic	Pr-value
Between	14984.65	4994.8832	15.97	<.0001
Within	32523.3	312.72404		
Total	47507.949			

13 – Burned area (km^2)

	Sum of Squares	Mean of Squares	F-statistic	Pr-value
Between	264.89952	88.299841	2.59	0.056
Within	3541.0009	34.048086		
Total	3805.9004			

14 – Water (km^2)

	Sum of Squares	Mean of Squares	F-statistic	Pr-value
Between	3.4744643	1.1581548	5.37	0.0018
Within	22.444561	0.2158131		
Total	25.919025			

Annex D

List of Abbreviations

AC - Acre State
AM - Amazonas State
ANOVA - Analyze of Variance
CIFOR - Centre International de Recherche sur les Forêts (Center for International Forestry Research)
CVRD - Compania Vale do Rio Doce (Vale do Rio Doce Company)
ENIDs - Eixos Nacionais de Intergração e Desenvolvimento (National Axes of Integration and Development)
ETM - Enhanced Thematic Mapper
FAO - Food and Agriculture Organization of the United Nations
FRA - Forest Resource Assessment
GIS - Geographical Information System
GHG - Greenhouse gases
GPS - Global Position System
IBAMA - Instituto Brasileiro de Meio Ambiente (National Institute for Environment)
IBGE - Instituto Brasileiro de Geografia e Estatística (National Institute for Geography and Statistics)
IGBP - International Geosphere-Biosphere Program
IHDP - International Human Dimension Programm on Global Environmental Change
INCRA - Instituto Nacional de Colonização e Reforma Agrária (National Institute for Colonization and Agrarian Reform)
INPE - Instituto Nacional de Pesquisas Espaciais (National Institute for Space Research)
IPCC - Intergovernmental Panel on Climate Change
LBA - Large Scale Biosphere and Atmosphere Experiment in the Amazon
LUCC - Land Use and Cover Change Program
NET - Neoclassical Economics Theory
NGO - No Governmental Organization
NTFP - No Timber Forrest Products
PBA - Programa Brasil em Ação (Brazil in Action Program)
PIN - Progama de Integração Nacional (National Integration Program)
PND - Plano Nacional de Desenvolvimento Econômico e Social (National Plain for Socio-economic Development)
PPG 7 - Pilot Program for Brazilian Tropical Forest Protection
PRODES - Programa de Monitoramento do Desflorestamento Bruto da Amazônia (Monitoring the Brazilian Amazon Gross Deforestation)
PROTERRA - Programa de Redistribuição de Terras (Land Redistribution Program)
RD - Rondônia State
SIVAM - Sistema de Monitoramento da Amazônia (Amazon Monitoring System)

SPRING - Sistema de Processamento de Informação Georreferenciada (Georeferenced Information Processing System)
SUDAM - Superintendência de desenvolvimento da Amazônia (Superintendence for the Amazon development)
TM - Thematic Mapper
UNCED - United Nation Conference on Environment and Development
UNFCCC - United Nations Framework Convention on Climate Change
ZEE - Zoneamento Ecológico Econômico (Ecological Economic Zoning)

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