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LAND HOLDING AND LAND COVER/USE ON AN
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LAND HOLDING AND LAND COVER/USE ON AN AMAZONIAN AGRICULTURAL FRONTIER

By

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ABSTRACT

LAND HOLDING AND LAND COVER/USE ON AN AMAZONIAN AGRICULTURAL FRONTIER

By

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Over the course of the past fifteen years, studies of land cover and land use change have become a major item on the global research agenda (Geist and Lambin 2001). Of the numerous potential land cover and land use changes, few have been as intensively researched as deforestation, especially in tropical areas such as the Amazon. However, research linking human agent interactions in the Amazon with their effects on the landscape is not yet complete.

This thesis investigates the link between smallholder cattle ranching and deforestation on a rapidly developing agricultural frontier in Uruará, Pará, Brazil by contrasting hollow frontier and household lifecycle processes. Many of the recent changes in household demographic and land cover and land use may indicate a hollowing frontier in Uruará. However, household lifecycle processes may also be at work in shaping this agricultural landscape.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

INCRA – Instituto Nacional de Colonizaçoa e Reforma Agrária

IPAM – Instituto de Pesquisa Ambiental Da Amazonia

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária

SUDAM – Superintendancy for the Development of Amazonia

POLOAMAZONIA – Programa de Pólos Agropecuários e Agrominerais da Amazônia

AEA – Association of Amazon Businessmen

LBA-ECO - Large-Scale Biosphere-Atmosphere Experiment in Amazonia

ESRI – Environmental Science Research Institute

FAO – United Nations Food and Agricultural Organization

MODIS - Moderate Resolution Imaging Spectroradiometer

SRTM – Shuttle Radar Topography Mission

TM – Thematic Mapper (Landsat 5)

ETM – Enhanced Thematic Mapper (Landsat 7)

GIS – Geographic Information System

SAD1969 – South American Datum of 1969

RMSE – Root Mean-Square Error

Kg - Kilogram

Cm - Centimeter

Km^2 – Square kilometer

Km – Kilometer

Ha – Hectare

INTRODUCTION

With the growing realization that global changes are occurring rapidly, land cover[1] and land use[2] change has become a topic of great interest in recent years (see e.g. Lambin et al. 2003 for a review). Large scale land cover and land use changes have been strongly associated with broad environmental impacts such as greenhouse gas increases, water quality and flow pattern change (Gentry and Lopez-Parodi 1980; Pontius Jr. et al. 2000; Schneider and Pontius Jr 2001; Wayland et al. 2002; Alsdorf 2003), the spread of disease and other health problems (Meade and Earickson 2000), global and local climate change (Meyer and Turner II 1992; Bounoua et al. 2002), biodiversity loss (Wilson 1999), and the degradation of land resources (Fearnside 1990; Lambin et al. 2003). Other, non-environmental impacts of land cover and land use changes are also observable in many locales, such as encroachment of settlers on indigenous lands (Simmons 2002) and the decimation of local social systems due to rapid environmental change (Endfield and O'Hara 1999).

One of the most extensively researched of these global change processes is deforestation[3], especially deforestation of tropical forest resources (Geist and

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[1] In this thesis "land cover" refers to the actual type of coverage (or lack thereof) of bare earth and is essentially resource-oriented (see e.g. Anderson et al. 1976).

[2] In this thesis "land use" refers to the actual human use of the earth and is essentially use-oriented (see e.g. Anderson et al. 1976).

[3] Though deforestation is a common term, it is often misunderstood and has widely varying meanings. In this thesis the word "deforestation" will indicate change in primary forest cover of any kind.

Lambin 2002). Nowhere in the world is the loss of tropical forest area as marked as it is in the Brazilian Amazon, the largest tropical moist forest on earth (Rand McNally 2000:101; Goulding et al. 2003). While the maintenance of forest resources is essential to regional and global environmental health (Wilson 1999), the importance of the forests in the Amazon is widely accepted, and the study of deforestation and its drivers comprises one of the most controversial and lively debates in academia. Among the deliberations regarding land cover and land use change, one of the most intense focuses on the three points of a complex triangle of interrelated landscape changes, involving (1) land cover and land use change (especially deforestation), (2) cattle ranching, and (3) the distribution of land ownership.

The purpose of this thesis is to investigate the relationship between land holding and cattle ranching and their respective influences on land cover and land use change in the Amazon in the recent past. The work will unfold as a comparative assessment of household lifecycle (founded in theories of peasant economy, see e.g. Ellis 1993) and hollow frontier processes (which consider multiple dimensions across time and scales, see e.g. Rudel 2002) and will examine the correlation between land holding change, smallholder cattle ranching efforts, and land cover and land use change on the relatively new agricultural frontier surrounding Uruará, Pará, Brazil (Perz and Walker 2002; Walker 2003). Because the household lifecycle and the hollow frontier are two of the most frequently cited theories used to explain the causes of land cover and land use change on *terre firme* agricultural frontiers in the Amazon, this thesis seeks to show which process is more evident in the area surrounding Uruará, Pará, Brazil (Figure 1). Though the frontier in the Uruará area does display some characteristics of a hollowing frontier (increasing cattle herds and a declining labor force), it is likely that household lifecycle processes are primarily responsible for land cover and land use change in this area. This thesis will test which of these two explanations for land cover and land use change processes is in evidence in Uruará, Pará, Brazil.

This thesis is organized into five chapters: chapter one consists of: (1) a brief history of development in the Brazilian Amazon, (2) a review of the literature investigating land holding and colonization, (3) cattle ranching, (4) land cover and land use change in Brazil, and then (5) concludes with a statement of the problem this thesis will address. Chapter two reviews the methods I use to address my research problem, and then discusses the difficulties and criticisms of land cover and land use research and some preconceptions of smallholder agriculture. Chapter three discusses land holding change in Uruará, how these changes are distributed spatially, and their implication for land cover and land use in the area. Chapter four discusses farm system changes, both on their own and in relation to property size, and discusses some specific instances of change between 1996 and 2002. Chapter five contains the conclusions of this work and its implications for the future land cover and land use of the area surrounding Uruará.

CHAPTER 1: REVIEW OF EXISTING LITERATURE

A BRIEF HISTORY OF AMAZONIAN DEVELOPMENT

Most estimates on deforestation in the tropics place current deforestation at very high levels, including some ominous predictions of a global tropical moist forest loss of over 50 percent[4] by the year 2022 (Wilson 1999). There are many different estimates, however, and some of the most alarming regional deforestation in all of the globe is presently occurring in Central and South America (Buschbacher 1986; Rudel 1997; 2002). Recent FAO (2000) estimates put annual deforestation loss for Latin America in its entirety at 4.4 million hectares per year between 1990 and 2000. Though 4.4 million hectares is an enormous amount of forest land to clear per year, an estimated 63 percent of the total tropical forests in Latin America remain (FAO 2000).

Because of the extent of deforestation, the development impacts on indigenous cultures, and the environmental importance of the area, the Amazon has become one of the most researched tropical forests. The Amazon River basin encompasses nearly 6,915,000 km^2, and is the largest river basin in the world (Rand McNally 2000:101; Goulding et al. 2003:18). Contained within is also the world's largest tropical moist forest (Rand McNally 2000:101; Goulding et al.

[4] Many estimates of the extent of future deforestation (such as those in Wilson 1999) do not establish a baseline. For instance, if 50 percent of forest is to be cut by 2022, is this 50 percent of the forest we see today, 50 percent of forest when Europeans arrived, or 50 percent of forest from Neolithic times?

2003). It is no coincidence that most land cover and land use change research on tropical moist forests targets this region of the earth. As mentioned above, the colonization and land holding of this region have a significant impact on the landscape, but the history and methods of settlement in the Amazon are complex.

In the past, the Amazon basin[5] (Figure 2) was often considered an endless 'virgin' forest ripe for use and improvement (for an example see: Delson and Dickenson 1984). However, authors such as Denevan (1992), Balée (1992), and, in a less direct way, Zinn (2001) have called the 'pristine myth' (the idea of a completely forested, virgin, and sparsely populated *new world*) into question. Adding to this debate, recent research has begun to show there was a much larger Native American population in the *new world* than previously assumed. In fact, Denevan (1992), Balée (1992), Smith et al. (1995), and Erickson (2000), claim that most of the forests (and other environments) in the Amazon Basin were selectively manipulated by humans and eventually became what we see today: human created landscapes (Williams 2000; Mann 2002). Many of these supposedly 'pristine' landscapes are, if the traditional 'pristine' view is accepted, inexplicably dominated by vegetation useful to humans. Whatever their potential for sustainable use under traditional technologies, it is certain Amazonian countries will continue to make their vast forested areas available to development, often espousing policies that encourage extractive uses of the land

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[5] The "Amazon basin" is the area that naturally drains into the Amazon river or its tributaries. This includes much of Brazil, and portions of Colombia, Ecuador, Bolivia, and Peru. Also, the Tocantins River Basin is often included in the definition of the Amazon basin in Brazil.

and the degradation of environment, potentially with global ramifications (Meyer and Turner II 1992).

Though humans have been inhabiting and using the forests of the Amazon for centuries, much of our present historical knowledge of the area begins with European "discovery." Early exploration in the Amazon had two origins: (1) Jesuit (Christian) missions and (2) agricultural colonies granted directly by the King of Portugal (James 1969; Santos 1984). While the inland penetration of missionaries was significant, especially from an epidemiological perspective (James 1969), major agricultural development in the Amazon basin moved forward more rapidly through large land concessions made by the Portuguese Monarchy (Santos 1984). Santos (1984) argues the historical basis for the large landholder-tendencies we see today in the Amazon started early in Brazil, with large land concessions by the king and the simultaneous evolution of bourgeois property rights. However, large *and* small land concessions were made, and it could be argued that the foundation for smallholder agriculture was laid simultaneously (Santos 1984).

After the rubber boom ended in the early 20th century, at the end of the Second World War, the military government pushed areas in the Brazilian Amazon into development in a suitably militaristic fashion with "Operation Amazonia" (Mahar 1979). Government leaders viewed the Amazon as an enormous area with large amounts of unused land, free for exploitation and development. This "empty" land was considered a solution for land shortage problems in the agriculturally developed south and northeastern parts of the country (Schneider 1995). Successive government-sanctioned settlement programs had essentially the same goal: economic development of Amazonia, and the alleviation of an acute land distribution problem evident in the more densely settled areas of Brazil. However, some research has shown the alleviation of a land crunch has not occurred, and frontier colonization in the Brazilian Amazon did not complete its objective (Wood and Wilson 1984; Simmons 2004).

During the 1970s and 1980s the Instituto Nacional de Colonização e Reforma Agrária (INCRA) began new programs to colonize parts of the Amazon. These colonization programs were placed along newly opened highways (such as BR-230, the "Transamazon" highway) which were created by the government to promote economic development of the Amazon. INCRA frequently built colonization roads spaced 5 kilometers apart and perpendicularly situated to a development highway. Land along each of these roads was typically divided into 100 hectare plots and given to new colonists under the condition that they use it productively as a family enterprise (Perz and Walker 2002; Walker 2003). INCRA led colonization projects exist throughout the Brazilian Amazon, with many of the more recent settlements occurring along BR-230 in the state of Pará (Walker 2003) and along BR-364 in the state of Rôndonia (Browder 2002). The settlement project surrounding Uruará, Pará, Brazil is shown in Figure 1.

From the early stages of Amazonian colonization programs, each settled area has, to a greater or lesser extent, followed a similar progression of events. At the point of initial settlement, a frontier area is typically isolated and inaccessible because road networks are non-existent or of poor quality (Wood 1983). Transportation is very difficult and integration with regional and national markets is impossible. Later, as the initial settlers establish themselves, agriculture becomes commercial in nature and the frontier area slowly integrates with regional and national networks of social and economic interaction (Wood 1983). Eventually, as individuals with capital are attracted to the frontier due to the establishment of defensible property rights and local government, poorer settlers may be forced out and will either move to an urban area or to another agricultural frontier (Wood 1983; Brown et al. 1994; Walker and Homma 1996; Rudel 2002).

During the 1990s, Amazonian colonization became predominantly unofficial and is presently driven primarily by private companies and other individuals with an incentive to develop certain areas. While spontaneous and unofficial colonization has occurred in the Amazon for quite some time (Moran 1984), individuals with economic interests (especially loggers) are inadvertently promoting new colonization by extending existing colonization roads (or creating new roads) in their quest for valuable timber species (Perz and Walker 2002; Simmons 2002; Walker 2003). The expansion of logging operations could accelerate present rates of deforestation, and future road building is likely to intensify both colonization and deforestation. According to the Instituto de Pesquisa Ambiental Da Amazonia (IPAM) 75 percent of the deforestation occurring between 1978 and 1994 was within 50 kilometers of an official development road (Nepstad et al. 2002). Additionally alarming is the fact that 90 percent of the logging that has occurred within the Brazilian Amazon is illegal (Nepstad et al. 2002). New, government-sanctioned, colonization programs have been largely put on hold due to pressures from the international community for environmental reasons. However, when it comes to concerns involving global capital, environmental and social trepidations take a back-seat to international investment in 'valuable' projects such as hydroelectric power (Ciccantell 1999). Frontier colonization, both old and new, has given rise to the present land holding regimes and land cover and land use changes evident in the Amazon basin. I will now briefly outline the problems concerning land holding commonly experienced in settlement areas.

LAND HOLDING AND COLONIZATION

Much of the land made available to settling small farmers in the Amazon consists of 100 hectare lots, though many large areas, called "glebas" (large land holdings often greater than 3,000 hectares) were set aside by the Brazilian government and devoted to the development of a large cattle ranching industry (James 1969; Mahar 1979; Hecht 1984; 1985; Buschbacher 1986; Hecht 1993; Walker 1993; Schneider 1995; Walker and Homma 1996; Walker et al. 2000; Perz and Walker 2002; Rudel 2002). Many of the smaller plots are devoted to small scale agriculture, typically both commercial and subsistence in nature (Buschbacher 1986; Rudel 2002). However, in a trend that is occurring in all parts of the Amazon, small land holders can find their holdings in jeopardy due to the confused nature of tenure relations in frontier areas, which can lead to conflict.

Land conflict has become a daily occurrence in some parts of the Amazon basin. Smallholders are often in a tenuous social and financial situation and find themselves at odds with largeholders, commercial agriculture operations, loggers, and some government development projects (Santos 1984; Coomes and Burt 2001). The concentration of small holdings into commercial properties has become more pronounced, which increases the potential for land-related conflict in many areas (Simmons 2002). Also a factor in consolidation of land resources is the widespread adoption of cattle ranching (Margulis 2004), which has been shown to influence land conflict (Simmons 2004). Although it may be difficult to conceptualize a land shortage in an area as large as the Amazon, scarcity-driven land conflict has begun to affect the Amazonian landscape (Simmons 2004). A notable outcome of land concentration is the encroachment of land holders close to, and even onto, indigenous reserves, a serious problem impacting both biological and cultural diversity (Simmons 2002).

Although smallholders dominate the Amazonian landscape, frontier areas in most parts of Brazil experience chronic rates of land holder turnover, even in areas where productivity is high (Schneider 1995). In some areas, up to 60 percent of colonists sell their land to largeholders (Schneider 1995). Rapid land turnover has been observed since the early development of the Amazon, and was first attributed to environmental degradation of extraordinary proportions (Myers 1981; Hecht 1984; Hecht 1985; Browder 1988b). The hypothesis of many early Amazonian researchers was that because land owners sought to maximize profits by farming in an extractive manner, productivity rapidly decreased with increased environmental degradation (Myers 1981; Hecht 1984; Browder 1988b). Researchers began to question not only the validity of one of the most prevalent agricultural strategies in the Amazon, cattle ranching, but also the viability of Amazonian agricultural development in general (Schneider 1995; Faminow 1998). Subsequent studies of colonization and agriculture in the Brazilian Amazon suggest that the early condemnations of colonist agricultural efforts may have confused environmental degradation with the early phases of colonization, which can be unavoidably destructive (Hecht 1984; Hecht 1985; Browder 1988b; Hecht and Cockburn 1990). Moran (1989a) emphasizes that all colonization efforts move through a process of learning from various mistakes and that early researchers too quickly criticized frontier areas which had not been given time to complete a "learning period."

The notion that all Amazonian development efforts are completely unprofitable has been further eroded by studies that have found frontier settler incomes are relatively high compared to other regions of Brazil (Schneider 1995). Schneider (1995) considers previous studies and concludes that there are more subtle reasons for the high rate of land ownership turnover than solely declining agricultural production. According to his argument, early settlers move away from a developed frontier for "fundamental demographic and economic" reasons (Schneider 1995: 22). As a frontier matures and becomes less "frontierish," property rights emerge with an increasingly visible and active government. After some time, the enforcement of property rights opens the area to what Schneider terms "urban capitalists," who can afford to buy land in a frontier area as the risk of losing their land to squatters diminishes. Urban capitalists are those that own agricultural operations, but reside in town, away from their properties. Forced out or voluntarily displaced by these urban capitalists, the original colonists make the decision that benefits them most: sell their land and move to a new frontier or find employment in an urban area (Schneider 1995). A more recent argument is that high land turnover rates, even on highly productive plots of land, are due less to environmental factors and more to an evolving land market and a geographically advancing economic and social frontier (Walker and Homma 1996; Rudel 2002). The argument that economic and social factors lead to change in land ownership is not, in and of itself, a new idea. However, it is interesting to note that in many frontier areas land holdings remain very dynamic, most likely due to changes in household demographics and regional economics that make buying, selling, or subdividing lots more attractive to many small farmers.

The rapid change in land holding control, coupled with the continuing maturation of frontier areas, manifests itself in the landscape through both subtle and blatant changes to land cover and land use, among other things. Research on land cover and land use changes in Brazil has been highly varied in location, time, scope, and result. A brief overview of this work will be covered in the next section.

LAND COVER AND LAND USE

Land cover and land use change literature exists in such abundance the field is nearly its own discipline. This abundance is probably attributable to an increased environmental awareness globally, though most concerns are expressed by people in the more developed nations of North America and Europe (Buschbacher 1986; Hecht and Cockburn 1990; Walker 1993; Ciccantell 1999). Nevertheless, much of the early research found significant correlation between land cover and land use change and an increasing concentration of atmospheric greenhouse gas, water quality/flow changes (Gentry and Lopez-Parodi 1980), and, most notably, global climate change (Meyer and Turner II 1992; Houghton et al. 1999). Major impacts on the biosphere have caused significant interest in and support for new research surrounding land cover and land use change simultaneously in more and less developed nations (Smith et al. 1995).

Due to rapid forest loss, especially tropical moist forest, deforestation has become a significant focus of much of the existing literature on land cover and land use change. Presently, high rates of deforestation are observed in the Amazon Basin of South America, various forests in Central America, parts of Africa, and many areas in Asia. Consequently, all of the above regions have been, and continue to be, the subject of many land cover and land use change studies (for examples see: Gentry and Lopez-Parodi 1980; Hecht and Cockburn 1990; Harrison 1991; Houghton et al. 1999; Messina and Walsh 2000; Coomes and Burt 2001; FAO 2001; Geist and Lambin 2001).

While the issue of deforestation has been regularly covered by both the popular press and academic journals, deforestation today is comparable in many ways to lesser known deforestation processes of the past. In fact, historic deforestation events in North America and Europe were just as dramatic in areal scope and environmental impact as recent tropical deforestation (for European examples see: Marsh 1864; Johnson 1980; for examples of North American deforestation see: Whitney 1987; Williams 1989; Howarth et al. 1996; Verheyen et al. 1999; Williams 2000; 2001). North American temperate forest loss was significant, but today many temperate areas are experiencing a restoration of forest cover (Johnson 1980; Walker 1993; Williams 2001). This fairly recent trend is commonly referred to as a "forest turnaround." In fact, in much the same way as the "pristine myth," there is mounting evidence that neolithic deforestation events were much more expansive than previously thought (Williams 1989; Williams 2000; 2001).

The occurrence of "forest turnaround" is occasionally used as a justification for continued deforestation in tropical regions. Some researchers and government officials argue that once tropical deforestation ends, forests will reestablish themselves and a "forest turnaround" may occur in tropical regions (Walker 1993; Rudel 2002). Proponents of a forest turnaround in the tropics often point to the increasing presence of secondary forest, often referred to as 'capoeira' in the Brazilian Amazon, that many researchers have noted in the Amazon (Smith et al. 1999; Sorrenson 2000; McCracken et al. 2002; Perz and Walker 2002; Walker 2003) as proof for the existence of this phenomena.

However, there are many reasons why a forest turnaround in tropical regions is unlikely in the short-run, but the most significant are (1) the high cost of protecting forests, (2) increasing demand for agricultural land, and (3) the availability of labor saving agricultural strategies such as cattle ranching (Walker 1993; Rudel 2002).

Considering the difficulties associated with understanding forest cover changes in the tropics, "forest turnaround" arguments may disappear as forest resources in developed nations begin to experience increased use (Johnson and Beale 1998; Williams 2001). Rural areas in developed countries (especially those of North America) where forest resources have seen a sharp increase over the past century are now experiencing slowly declining forest cover, a process catalyzed by nostalgia for rural areas coupled with widespread urban sprawl (Johnson and Beale 1998).

At this juncture, few would debate the importance of land cover and land use change research, especially research focused on deforestation, in tropical regions around the world. However, there is presently a great deal of debate about the causes of these land cover and land use changes. In their influential report, Geist and Lambin (2001) summarize over 150 cases of land cover and land use change and list the causes of deforestation in each case. They separate causes into two categories: (1) proximate causes, which "constitute (near-final or final) human activities that directly affect the environment" (similar to: Turner II et al. 1990; Turner 1993), and (2) underlying causes, which are "fundamental forces that underpin the more obvious or proximate causes of tropical deforestation"

(Geist and Lambin 2001:7-8). Geist and Lambin (2001:23) found 96 percent of all cases of deforestation have multiple causes, displaying the complex nature of human-environment interactions. However, after simplifying cases of deforestation into two-cause "tandems" Geist and Lambin (2001) find two important tandems explain the cause of nearly half the case studies; 37 percent of the case studies were caused by an "infrastructure-agriculture" tandem (mostly in South America), and 10 percent were explained by the 'logging-agriculture" tandem (mostly in Asia).

The infrastructure-agriculture tandem follows a commonly described set of events in which transportation infrastructure improvements lead to increased deforestation. Transportation infrastructure, in turn, opens access to land for crops and cattle ranching (Geist and Lambin 2001). Many authors have described this process, or processes much like this (Fearnside 1979; Hecht 1993; Faminow 1998; Walker et al. 2000). The logging-agriculture tandem is similar to the infrastructure-agriculture tandem except that instead of infrastructure improvements, logging activity opens land for agriculture. It could be argued, however, that the logging-agriculture tandem would not be possible without a previous infrastructure-agriculture tandem due to limited forest access before transportation infrastructure enhancements. The logging-agriculture tandem can be seen in the Amazon, though most often it occurs after an infrastructure-agriculture tandem begins the land cover and land use change process.

From studies on land use patterns of households (Pichón 1997; Coomes and Burt 2001; Perz and Walker 2002; Walker 2003), to the social and economic processes driving the conversion of forests to pasture (Fearnside 1979; Myers 1981; Buschbacher 1986; Browder 1988b; Hecht 1993; Mattos and Uhl 1994; Walker et al. 2000; Porro 2002), research on Amazonian deforestation continues to be varied. A common and popular image of deforestation in the Amazon is that of a large-scale logging operation, complete with logging skids, specialized trucks, and huge sawmills. In fact, much deforestation in the Amazon may be attributable not to large commercial logging ventures, but to smallholders, who are often attempting to establish their own cattle ranching operation (Walker 1993; Faminow 1998; Walker et al. 2000; Coomes and Burt 2001; Walker et al. 2001; Browder 2002; McCracken et al. 2002; Porro 2002; Walker 2003). To date, studies of deforestation have shown cattle ranching, roads, markets, labor power, and a multitude of other factors are at least partially responsible for deforestation. Though cattle ranching is only one of many influences on deforestation, no understanding of land cover and land use change in the Amazon would be complete without its description.

CATTLE RANCHING

Cattle ranching is by no means a new topic of research in Amazonia. Mahar (1979) points out that as of 1970 there were already close to six million cattle in the legal Amazon[6], and that sixty million hectares of the basin were likely to be suitable for livestock husbandry. In the late 1970s, researchers and policy makers thought cattle would be a viable and desirable use of the 'wild' lands in Amazonia, and much of the research of this period was focused on improving cattle production (Fearnside 1979; Mahar 1979). Actually, in dramatic contrast with later perspectives, many researchers felt that cattle production was *good* for environmental integrity in the Amazon, frequently citing an EMBRAPA study that made that claim (Falesi 1976). Even so, the optimism surrounding cattle ranching was tempered with the knowledge that without government subsidies cattle ranching was supposedly not profitable, except in the most extraordinary circumstances (Fearnside 1979; Mahar 1979; Schneider 1995; Arima and Uhl 1997).

As the environmental movement awakened the world to the possibility of irreparable environmental damage during the late 1970s and early 1980s, the idea that cattle ranches were environmentally beneficial to the Amazon rapidly became passé (except for, possibly, research in livestock management). By 1984, the prevalent argument was that cattle ranches were counterproductive for sustainability and development reasons. In a highly influential article, Susanna Hecht (1985) argued that the costs associated with the development of Amazonian cattle ranches, both in terms of environmental degradation and economic development, were too great to encourage ranching. From a sustainability perspective, cattle ranching came under fire because of its

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[6] The Legal Amazon contains the Brazilian States of Roraima, Rôndonia, Pará, Acre, Amazonas, Mato Grosso, Tocantins, and Maranhão.

infringement on indigenous agricultural methods and excessive subsidies, which were encouraged by the World Bank and other international development agencies (Redclift 1987). Various highly controversial claims focused on the negative aspects of cattle ranching were also made during the 1980s.

One such claim was the much touted 'hamburger connection' that was supposed to have created North American fast food hamburgers from hectares upon hectares of Central American tropical moist forest (Myers 1981). In his article outlining the "hamburger connection", Myers (1981:1) implies that beef production had turned forests in all of Latin America into fast food hamburgers. Myers goes on to paint a dramatic picture and claims that Costa Rican beef production is environmentally harmful and economically unsound. While the comparison Myers (1981) makes may or may not be spurious, conditions are very different in the Amazon than in Costa Rica. Though the "hamburger connection" was sensational at the time, and may have been an accurate assessment of Costa Rican beef production, very little, if any, Brazilian beef was sold during his study period in North America, and most Brazilian beef was sold domestically (Smith et al. 1995). In fact, Browder (1988) estimates that in 1982 (shortly after Myers "hamburger connection" research) Amazonian beef accounted for 0.007 percent of beef consumed in the United States, an insignificant amount by any standard. Low international export levels for Amazonian beef were due to herd health concerns such as hoof and mouth disease and further reduced by the mad cow disease scares of the 1990s. Though Brazilian beef was not commonly exported to the United States, domestic markets for Brazilian beef are not insignificant and absorb much of the beef produced in Brazil. Beef is a major protein source in much of the Amazon, though some researchers claim that Brazil could claim more protein from the Amazon River itself through fishing endeavors, as the Amazon has 8 times more fish species than the Mississippi River (Pearce & Meyers 1990). Even so, cattle ranching in the Brazilian Amazon has a bad reputation because the global environmental impacts of cattle ranching are negative, even if the economic and cultural benefits for ranchers are quite the opposite (Mattos and Uhl 1994).

In the late 1980s and early 1990s researchers still disparaged cattle ranching in the Amazon, though most (including Hecht herself) thought that Hecht's early assessments of the inability of the Amazonian environment to support ranching were excessive; some areas of the Amazon could profitably support cattle ranching (Hecht 1993; Mattos and Uhl 1994; Toniolo and Uhl 1995). Indeed, for many small land holders, who primarily engaged in subsistence agriculture, cattle ranching is the standard next step in the economic development of their household (Hecht 1993; Walker 2003). Cattle ranching was supposedly unprofitable, but large and smallholders alike continue to strive to establish ranching operations, even after government subsidies have disappeared (Walker et al. 2000; Porro 2002; Walker 2003). In fact, the cattle herd in the state of Pará has increased greatly between 1996 and 2002 with 6,182,000 head in 1990 and 10,271,000 head in 2002 (Margulis 2004). Ranching appears profitable when more than just income per head or the amount of beef sold is considered (Faminow 1998). A frequently cited reason settlers move toward ranching is that cattle provide a mechanism to invest surplus funds without using a bank (Hecht 1993; Faminow 1998). Cattle can also provide household food services such as milk and meat products, and, given a large enough herd, are self-reproducing. Many Amazonian households use cattle as a risk aversion strategy and appreciate their addition to diversity of agricultural options and financial security in times of hardship (Hecht 1993). The useful lifespan of cleared land can be increased by cattle which can be raised on land that might otherwise be left to fallow (Hecht 1993). Cattle also incur lower labor costs (Hecht 1993; Faminow 1998; Walker 2003) than many other agricultural strategies, and offer additional incidental services such as haulage ability and manure production (Faminow 1998).

Even today many new studies on land cover and land use change in the Brazilian Amazon focus on ranching as the primary land use outcome of deforestation efforts (Walker et al. 2000; Porro 2002; Rudel 2002). Though cattle ranches are not now regarded as a totally inefficient and irrational use of land, they are still held responsible for much of the deforestation presently occurring in the Amazon. Because of the numerous services a herd of cattle can provide both small land holders and large land holders, many people in frontier areas continue to include cattle in their production strategies. In fact, as of 1990 over 85 percent of the cleared forest area in the Brazilian Amazon was converted to cattle pastures (Hecht and Cockburn 1990). Indeed, cattle ranches account for the largest land use class in the entire basin, but the commonly held belief that this land use is universally negative seems to stem from a stereotypical reaction to deforestation of tropical moist forests; deforestation, in all its forms, is often held as detrimental to environmental health and socially irresponsible.

Whether environmentally sound or not, no one would deny that cattle ranching and the forces that drive it are among the most important factors impacting Amazon forests today. Many claim that ranching is the outcome of a social process; ranching is the result of an abandonment of cropping systems by subsistence farmers and a conversion to pasture owned by wealthy ranchers. This process is evident as a driving force behind much of the deforestation in the Amazon, both old and new (Casetti and Gauthier 1977; Buschbacher 1986; Schneider 1995; Rudel 2002). This staging of land uses, with agricultural systems changing from subsistence agriculture to cattle ranching creates what is referred to as a 'hollow frontier' after research by James (1969), Taylor (1973), and Casetti & Gauthier (1977).

THE HOLLOW FRONTIER

Historically, the most common references to the hollow frontier thesis are in description of coffee production in Brazil, which is where the process was first described (James 1969; Taylor 1973; Casetti and Gauthier 1977). Preston James (1969) described the hollow frontier as a smallholder agricultural frontier slowly being consolidated into large agricultural holdings with few inhabitants. Recently, a hollow frontier-like process has been observed in the Ecuadorian Amazon (Messina and Walsh 2001; Rudel 2002). Though no research has described this process in the Brazilian Amazon, there is a distinct possibility that the hollow frontier could exist in Uruará. A stylized version of the hollow frontier, as applied to a frontier area such as Uruará, begins with colonization (promoted by government initiatives or spontaneous in nature) by poor farmers practicing subsistence agriculture consisting of staple food crops (Casetti and Gauthier 1977; Rudel 2002). The colonization process often results in successive deforestation events which result in a smallholder dominated landscape used for subsistence agriculture. Eventually, as subsistence crop yields drop, land becomes unproductive and is abandoned (Rudel 2002). Many of the small land holdings are sold to speculative interests (often urban capitalists) or to wealthy cattle ranchers who typically convert them pasture and consolidate land into large ranches. Frontier colonists, forced out by an emerging land market, either move on to "unused" forest resources and begin the deforestation process anew, or depart to work in urban areas (Wood 1983; Brown et al. 1994; Rudel 2002).

Discussing the expansion of frontier areas, Wood (1983) describes the hollow frontier process (he does not, however, name it as such), and mentions that this series of events may lead to increased formal and informal economic activity. Framing his discussion of the relation between smallholders and largeholders in frontier areas of the Amazon in Marxist terms, Wood (1983) points out that the informal activities of small subsistence farmers creates cheap seasonal labor for the formal economy. Wood insists that formal and informal activities, which are typically studied as separate entities, are essential and complementary parts of the regional economic system (Wood 1983:263). Furthermore, he suggests that these two classes of economic activity enable each other to grow, but that in its expansion the formal economy forces a hollow frontier-like series of events (Wood 1983).

Hollow frontiers could be considered a manifestation of forces of differing types and scale on the landscape. Because a hollow frontier occurs due to tensions between large wealthy land holders (which in many parts of the Amazon are frequently cattle ranchers) and smallholder farmers and ranchers, a complex interrelationship is established. Each class of land holder influences the actions of the other (Wood 1983), and the landscape is affected at widely differing scales. The hollow frontier process may be interpreted as an explanation of land use and land cover change with a theoretical basis easily applied to political ecology frameworks.

Using Campbell and Olson's (1991) "Kite" model, the forces shaping a hollow frontier can be easily recognized (Figure 3). Starting at the local level, declining environmental quality increases the difficulty of smallholder farming on a frontier (Figure 3). In turn, the political influence of large property holders changes the ability of smallholders to reach their goal of ranching cattle (Figure 3). This desire to ranch cattle reinforces the frontier ethic of the area, further increasing environmental damage, and making it easier for large holders to purchase (degraded) land at a cheaper price (Figure 3). The influence of these processes is not linear, and multiple interactions can take place between these "points of the kite" and can influence interaction at multiple scales ranging from local to global (Campbell and Olson 1991). National policies influence local actions, and global opinion, political climate, and economic situation can influence national and local events as well. The influence can also move the other way; local events can shape national policy, which can then impact global opinion as well.

For instance, global events have historically had an impact on local landscapes in the case of cattle ranching and tropical deforestation. National development policies in Brazil encouraged large numbers of people to settle to the Amazon over the last fifty years (Browder 1988a; Moran 1989a; Hecht and Cockburn 1990; Porro 2002). Of these national development policies, many focused heavily on ranching cattle, such as the programs of the Superintendency for the Development of Amazononia (SUDAM) and Programa de Pólos Agropecuários e Agrominerais da Amazônia (POLOAMAZONIA) (Simmons 2002). These development policies were, in turn, dictated or influenced by international aid organizations touting Amazonian beef as a solution to global hunger and national organizations such as the Association of Amazon Businessmen (AEA) which also encouraged ranching (Simmons 2002). In this manner, global food needs and development policies have influenced the national policies of Brazil, especially with regard to Amazonia, creating the conditions for a hollowing frontier in some parts of the Amazon.

The power structure inherent in any global to national to local (and conversely local to national to global) interaction is quite frequently biased toward national and global influence (Ciccantell 1999). In fact, historically the Amazon has been viewed as a vast deposit of natural resources to be used for exploitation (Mahar 1979), a view that has not necessarily changed to any great extent (Ciccantell 1999). Because this use-focused view of the Amazon has little to do with those who inhabit the region, the structure of power can have a significant influence on frontier inhabitants and their actions.

The presence of the hollow frontier process in some areas has contributed to the popular notion that agriculture in the Amazon basin is universally extractive in nature, for perennial crops, annual crops, and cattle ranching. While the hollow frontier is mentioned in passing quite frequently in much of the land cover and land use literature, the process is not often explained in great detail.

Though the hollow frontier tells a striking story of the development and abandonment of frontier areas by smallholders, another process can also have a significant impact on the landscape, resulting in a similar terminus. However, this process, the household lifecycle, differs greatly in its explanation of the change to frontier landscapes. In the next section, I will outline this process, its theoretical origins, and its effects on local landscapes.

HOUSEHOLD LIFECYCLES

An alternative explanation, also mentioned frequently in much of the research focused on smallholder influences on land cover and land use change in the Amazon, is the household life cycle. This theory is based on the work of A. V. Chayanov on peasant economics, and states that household demographic change can translate into land cover and land use change, specifically increased cultivation land area (Perz and Walker 2002). Though the effects of household demography on agricultural frontier expansion are highly varied, many investigations of the household lifecycle have observed a similar series of events. The lifecycle of a colonist household begins with a young family settling and beginning to use the land on a newly opened frontier. At first, their agricultural strategy will focus solely on survival, and annual subsistence crops will be their primary agricultural activity (Walker and Homma 1996). However, a constant progression of deforestation will occur due to the household's need for fertile land, which, in turn, results in artificial land scarcity as formerly fertile lands fall out of active use (Perz and Walker 2002). After some time, farmers gain knowledge of how to farm successfully, and potentially have greater available labor power as their children grow (Moran et al. 2003). At this stage, with surplus labor power, households often begin to plant perennial, commercially oriented crops due to their elevated potential for profit (Walker and Homma 1996). These expansions in perennial crop area often lead to more labor intensive agricultural practices and amplified land cover and land use change (Walker and Homma 1996; Walker 2003). Alternatively, households with a smaller labor pool often choose to use their less fertile land to ranch cattle, a land use requiring much less labor than the cultivation of perennials (Pichón 1997).

As a colonist household continues to mature, children or other relatives may move off the property to start their own household. Alternatively, they may move to another part of the same property (Walker 2003; Browder et al. 2004). This, in turn, may lead to further deforestation, either in another area of the same land holding, or in a completely different location (possibly close to a newly opened frontier). This sort of property division has been noted in the state of

Rondônia, a part of the Amazon that has been intensively settled (Browder et al. 2004). When this property fragmentation occurs, original colonists may begin to change their agricultural strategy due to decreased labor power. Often, if the capital is available, households at this stage will either hire temporary labor power or adjust by adopting a less labor-intensive land use, commonly cattle ranching (Edelman 1985; Hecht 1993; Mattos and Uhl 1994; Faminow 1998; Walker et al. 2000; Porro 2002; Rudel 2002). In this way, the population and age of lot residents can significantly influence the land cover and land use of a property in agricultural frontiers in the Amazon (Perz and Walker 2002; Walker 2003). Regardless of the final agricultural strategy employed, the cause of property-level land cover and land use change, according to household lifecycle theory, is a logical progression of events: (1) colonization, (2) deforestation, (3) cultivation and/or ranching, (4) resettlement, and (5) repeat deforestation.

The explanation of land cover and land use changes through the use of household lifecycle processes is essentially an approach founded on the principles of peasant economy. Though a collection of individual households each impact their local environments collectively, they operate as independent entities. Each household[7] is under a constant process of transition, closely connected to its land, earning its subsistence through a nearly complete reliance on household labor (Ellis 1993). This theoretical foundation does not stress the

[7] A household, in this case, is the group of people sharing the same home after the definition set forth by Ellis (1993).

multiple scales each action by smallholders can influence, and instead focuses on local impacts.

Both household lifecycle and hollow frontier processes shape the landscape in similar ways, and new literature suggests deforestation in the Amazon may occur due to interactions between poor colonist holders and wealthy ranchers (Rudel 2002). Rudel et al. (2002) show that much of the land cover and land use change in the Ecuadorian Amazon may be caused by the hollow frontier process. Though the economic, social, and political contexts of deforestation the Ecuadorian Amazon are distinctly different than in Brazil, some of the same processes that Rudel et al. (2002) observed in Ecuador are also occurring in the Brazilian Amazon (Walker and Homma 1996; Simmons 2002). Because the hollow frontier involves land cover and land use changes, it seems a significant gap exists in the literature in connecting the hollow frontier process to these changes in the wider Amazonian landscape. The connection between colonist's land consolidations into large holder cattle ranching operations (the apparent result of the hollow frontier process) and land cover and land use change has not yet been addressed. Walker (2003), among others, has pointed to agent complexity in many critical logical tandems such as the relationship between logging and agriculture and agriculture and infrastructure as important to studies of deforestation. This thesis will explore the relationship between cattle ranching, land holding change, and deforestation by focusing on the complexity of the agents driving these processes and contrasting hollow frontier and household life-cycle explanations.

PROBLEM STATEMENT

As discussed, land cover and land use change is an increasingly important field of research, and as such is constantly under revision. As land cover and land use change research has matured, its explanations have progressed from oversimplifications to the complex and intricate studies we see presently (Lambin et al. 2003). The study of land cover and land use change came to the forefront of geographic research with the realization that human actions were having an effect on regional climates and, now, is moving on to include a much wider interdisciplinary viewpoint. Research about these important changes has begun to synthesize environmental, social, and economic themes and attempts to provide the scientific community and policy makers with a more complete picture of change worldwide (Lambin et al. 2003).

Like any field of research, our knowledge of land cover and land use change and associated drivers is far from complete; many aspects of land cover and land use change remain to be studied. With the increasing recognition of complexity in human environment interactions comes a seemingly infinite number of explanations for environmental change. In an effort to bring the number of proximate (direct human action) and underlying (influencing social and economic factors) causes of land cover and land use change to a manageable level, Geist and Lambin (2001) reduce the causes of change in 95 journal articles to a generalized set of logical tandems. Of these, two logical proximate cause tandems are most likely to impact deforestation in the areas surrounding Uruará, Brazil; the infrastructure-agriculture tandem and the logging-agriculture tandem explain over 40 percent of all land cover and land use changes in Latin America according to Geist and Lambin (2002). The same study draws attention to the complexity inherent in land cover and land use changes across Latin America; nearly 20 percent of the tropical deforestation in the region can be explained by a three-factor logical chain of infrastructure, logging, and agriculture (Geist and Lambin 2002).

Much of the literature pertaining to tropical deforestation in the Amazon focuses on the impact of swidden farmers[8] and large land holders, such as ranchers, commercial agriculturalists, and loggers, have on land cover and land use (Hecht 1984; Hecht and Cockburn 1990; Mattos and Uhl 1994; Smith et al. 1999; Nepstad et al. 2002; Porro 2002). Researchers have long known that, in both the low-lying floodplains along the Amazon river and on the *Terra Firme* in the interior of the Amazon basin, a significant portion of land cover and land use change in the Amazon occurs through the activity of small land holders (Dean 1995; Walker and Homma 1996; Pichón 1997; Rudel 1997; WinklerPrins 1997; Sorrenson 2000; Browder 2002).

Though large holder (cattle ranchers, loggers, and commercial agriculturalists) and small holder (swidden agriculturalists, small ranchers, subsistence settlers) land use strategies are well documented, our knowledge of the interaction between these two distinct, though geographically interspersed, groups remains skeletal. The important, and highly volatile, relationship between

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[8] For a discussion of swidden (shifting) agriculture see page 49.

small and large holders changes with time, and is an important research topic (Wood 1983). The hollow frontier process, frequently mentioned in literature dealing with frontier areas, may be apparent in the consolidation of land holdings and the creation of properties with land uses requiring large areas, such as cattle ranching. However, these processes may not be in evidence on smaller land holdings such as the 100 hectare one-lot properties created through many INCRA colonization projects. Instead, on these small lots, land cover and land use changes may be governed by household lifecycle processes.

In the Amazon basin, many farmers choose to raise cattle due to their obvious food uses, cultural significance and their many economic benefits (Hecht 1993; Faminow 1998; Walker et al. 2000). While large ranches are common in the Amazon, smallholders also control a significant number of the total cattle in the basin (Faminow 1998; Walker et al. 2000). The controversy concerning the effects of forest to pasture land cover/land use change continues, with pasture often considered environmentally detrimental. (Fearnside 1979; Hecht 1984; Buschbacher 1986; Browder 1988b; Hecht 1993; Futemma and Brondízio 2003). Regardless of the effects of pasture on the quality of global and local environments, it remains one of the most common land covers/uses in deforested areas of the Amazon; both largeholders and smallholders raise cattle on large pasture areas.

This thesis seeks to investigate the between link small holder cattle ranching and deforestation in the Brazilian Amazon by contrasting hollow frontier and household lifecycle processes. Land concentration, leading to large cattle ranches, may cause what might be termed a hollow frontier in Uruará, Pará, Brazil. However, cattle ranching efforts of small farmers, frequently driven by necessity of household demographic composition, are significant in their contributions to land cover and land use change in the Uruará area. These competing processes leading to land cover and land use change show how two different series of results can yield similar landscapes. This work will attempt to describe which process, and therefore which theory, best accounts for the land cover and land use change processes in Uruará, Pará, Brazil.

CHAPTER 2: STUDY AREA, METHODS, AND METHODOLOGY

STUDY AREA

Uruará is situated directly on BR-230, a federal road commonly referred to as the Transamazon highway. The municipio[9] and town of Uruará (located at S3°42'54", W53°44'24", Figure 1) are located between the cities of Altamira, 180 kilometers to the east, and Itaituba, 260 kilometers to the west. Uruará is situated between the Amazon River, which is 175 kilometers to the north, and the Iriri River, which is 80 kilometers to the south. Due to its relatively land-locked location, transportation in Uruará is mostly by vehicle on roads of widely varying condition.

The area surrounding the town of Uruará, Brazil, shown in Figure 1, comprises a relatively young agricultural frontier. This area opened to colonists in the late 1970s with the creation of the Transamazon highway, and a government sanctioned settlement project administered by INCRA (Perz and Walker 2002; Walker 2003). Before the colonization of the area through INCRA's settlement efforts, populations in Uruará were sparse (Censo-Agropecuário 1995/1996). The initial push to settle in Uruará started by the opening of the Transamazon, was legitimized by INCRA splitting the landscape into over 3,000 lots averaging 135 hectares per lot (mode 96.64 hectares).

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[9] A municipio is roughly equivalent to a North American county.

Land holding[10], which is ever-changing in much of the Amazon (Schneider 1995), is also variable in Uruará, though many small property holders have stable land holdings (see page 58). Population, livestock production, and the cultivation of some crops are increasing in the area, and land use regimes are gradually shifting away from solely subsistence agriculture to more commercially focused crops (see page 63).

Though the Amazon is often referred to as a "tropical rain forest" many of the forests in the basin do not, in fact, possess rain forest climates. Much of the Amazon could be more correctly classified as a "tropical savannah" climate (Aw) according to the Köppen-Geiger climate classification system (Strahler and Strahler 1992; Christopherson 1997). Tropical savannah climates experience mean year-round temperatures exceeding 64.5° Fahrenheit, and have a strong dry season with at least one month with below 6 cm of rainfall (Strahler and Strahler 1992), and because area around Uruará has a pronounced dry season, local climate is suggestive of tropical savanna. Even so, much of the vegetation of the Amazon basin *is* tropical rain forest, which means it experiences a year-round mean temperature greater than 64.5° Fahrenheit, and annual rainfall generally exceeds evaporation in these areas (Strahler and Strahler 1992).

The terrain in Uruará is mildly undulating, and does not exhibit drastic relief changes (Figure 4). Though elevation differences are exaggerated in Figure

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[10] The term "land holding" is used throughout this thesis in place of "ownership" to indicate the nature of Amazonian land possession. Because many landholders do not legally own the land they live on, it is important to refer to the control of land as holding and not owning. A land holding can be conceptualized in the same way as land owning, however, in the sense that land holdings are used in much the same way.

4, it is easy to see how BR-230 follows less rugged terrain, and how the town of Uruará itself is located in a relatively flat area. Average elevation in the area is 197.35 meters, though the range in elevations is wide, with a minimum elevation of 16 meters and a maximum elevation of 471.82 meters (σ = 66.84 meters). Because of the relative flatness of this part of the Amazon basin, small variations in topography can have a large impact on land cover and land use changes due to widely varying transportation costs (Arima 2004). However, the impact of terrain in Uruará is minor when compared with other areas around the globe, or even other areas of the Amazon, especially those far to the west of Uruará in Colombia, Peru, and Ecuador.

LAND CONCENTRATION / GINI COEFFICIENTS

Though the representation of land distribution change primarily reports results from other research in this thesis (especially results from Censo-Agropecuário 1995/1996) it is beneficial to briefly overview how the Gini coefficient is calculated. The Brazilian national agricultural census (Censo-Agropecuário 1995/1996) collects information on land holding size and divides land holdings into classes. Using this information, it is simple to calculate Gini coefficient values for the distribution of land resources in an area using the following equation:

$$GI = (X_i Y_{i+1}) - (X_{i+1} Y_i)$$

where "X_i" is the cumulative percentage of land area divided into land holdings in class "i", "Y_i" the cumulative percentage of the quantity (number) of land holdings in class "i", and "i" is the class of land holding (after Porro 2002).

Once Gini coefficients are calculated the relative distribution of land holdings is easily deduced. A Gini coefficient value close to one indicates more concentrated land resources, while a Gini coefficient value close to zero indicates evenly distributed land resources.

PANEL DATA

A socio-economic and household attribute dataset was collected during the summers of 1996 and 2002 as part of a collaborative project between researchers at Virginia Polytechnic Institute and Michigan State University (Browder et al. 2001). The study is an ongoing project (set to expire in Spring 2005) seeking to compare the processes of land cover and land use change in similar study areas along BR-364 in the state of Rondônia and BR-230 in the state of Pará. Because of constraints of time, resources, and knowledge I have opted to use this dataset as an alternative to collecting my own data. However, during the summer of 2003, I was able to work in some of the areas along BR-364 in Rondônia, Brazil giving me some idea of the hardships experienced by colonists and the social, economic, and physical structure of a developing frontier very similar to Uruará.

While the two socio-economic property-level surveys are not in complete agreement, and some properties changed significantly between surveys, properties surveyed during the two years are generally comparable. In order to characterize the change in land use systems at the property-level, in addition to tracking the change in household attributes, these two survey datasets were combined into one panel dataset in order to facilitate inquiry into the types and extent of change in Uruará over a six year period.

Because of the arrangement of each survey and the nature of land holdings in Uruará, this panel dataset can be divided into many different datasets with different units of analysis, all of which may overlap with other datasets. The ability to easily arrange the data in different ways makes the use of this data more difficult to conceptualize, at least initially. Because both the 1996 and 2002 surveys interviewed property holders by asking about each individual lot they controlled, the most basic level at which the panel could be analyzed is what I term a "lot panel." This panel compares individual INCRA delineated lots (property parcels, cadastral map units) regardless of their owner or location. The lot panel is useful to characterize how varied lot land cover and land use can be, but is not useful to illustrate land market forces or household demographic change.

In order to more accurately characterize changes in household demographics, the panel dataset can be divided in order to create what I term a "household panel." This panel dataset compares individual family units (more accurately termed "households" due to the fact that multiple families could conceivably live in the same housing unit) across the area regardless of the land resources they control or their location. As mentioned above, this data arrangement makes it easy to detail the demographic and agricultural changes households experience and the differences between individual households, but does not necessarily make it easy to characterize changes in land holding.

A "property panel" groups data according to owner, not household or lot, making it simple to compare changes in land holding over time. In addition, the property panel illuminates the effects of differing property sizes on land cover and land use in the area. Because the property panel groups lot-level data according to owner, it makes the comparison of farms across size categories possible in a way that the lot panel cannot. Further differentiating the property panel from the household panel is the possibility for multiple households on each property (though this is not in evidence in Uruará). Each of these panel datasets is distinct but has significant overlap with the others. However, the panels listed above stand on their own and do not rely on one another for their use in specific analyses.

As mentioned above, the lot panel breaks the landscape into observable units at the cadastral level (typically 100 hectare INCRA lots in this case). In this sense, the lot panel is, for all practical purposes, the most fine-scale unit of analysis collected in this survey. The lot panel, consisting of data collected in 1996 and 2002, covers 183 lots (91 lots in 1996, 92 lots in 2002[11]). As discussed previously, this dataset does not consider ownership; instead it compares variables on a lot to lot basis only.

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[11] One property in the lot panel dataset increased its lot holdings by 2002.

The household panel is an aggregation of lots into units consisting of land controlled by a household, commonly (though not necessarily) a single family unit. When unmatched data[12] is discarded, however, the household panel consists of only single family households of a similar demographic composition (Table 1). The household panel consists of 76 households over two surveys for a total of 152 observations.

The property panel, though not different from the household panel at this stage, is conceptually distinct from both the household panel and the lot panel. This dataset is based on property units, which are distinct from lots because a property can consist of multiple lots. The property panel also differs from the household panel as a property can actually house multiple households. Though properties can consist of multiple lots, providing multiple households with a place to live, the typical property in Uruará is actually a one-lot property with one household. This is not always the case, however, and many properties in the property panel consist of more than one lot. All together there are 76 properties in the property panel in both 1996 and 2002.

PANEL DATA METHODS

Though the data collected through the 1996 and 2002 surveys is similar, there are still some significant changes in certain variables between years. In this thesis I asses the statistical significance of these changes through standard t-

[12] Unmatched data includes properties that were sold between 1996 and 2002, lots that were vacant, or missing lot identification data.

tests, which compare the means of different variables and quantify their difference statistically. This statistical significance can enable a researcher to discuss the actual significance of changes over time. Comparing the difference between means is an efficient way to characterize the average differences between properties in the 1996 and 2002 surveys. Because the panel dataset contains information on the same properties during both time periods I have opted to perform t-tests on much of the data collected during both time periods.

A standard t-test is actually a test of the hypothesis that the mean of variable1 is equal to the mean of variable 2 (Khazanie 1997). The test of the hypothesis that the means of two variables are equal using the Student's *t* is as follows:

$$t = \frac{(X_1 - X_2)\sqrt{n}}{s}$$

where X_1 is the mean of variable 1, X_2 is the mean of variable 2, n is the number of observations, s is sample variance, and there are $n - 1$ degrees of freedom (StataCorp 2001).

Because the land cover and land use data and household attribute information is contained in respective panel datasets, I use a pairwise t-test to quantify the difference between the mean values for a variety of variables (Singleton Jr. et al. 1993; Khazanie 1997). This method of comparison enables me to characterize the typical land use and land cover systems on properties in the 1996 and 2002 surveys and to quantify the change between survey years.

Though the panel data sets are versatile, there are some limitations to their use, and a few biases may be apparent. For instance, larger properties were not typically surveyed in 1996 or 2002 as part of the survey effort due to the project's focus on small farmers. Therefore, even though there are a few larger properties (those having significantly more lots than is typical of properties in the area) in the total dataset, they are not actually part of the panel. Agricultural strategies in the Amazon are highly varied, including various combinations of subsistence and commercial agriculture, a potentially complicating trend that holds true for Uruará (though the most out-of-the-ordinary strategies are not captured as part of this survey, e.g. land holders farming only coffee). However, these initial biases were mitigated through survey design by implementing a significant random component to survey site selection (Browder et al. 2001). Also, because of the nature of the panel dataset's identical observations and variables over time, the results of each survey will not be completely independent of each other; a property surveyed as part of the property panel growing 10 hectares of coffee cultivation in 1996 is more likely to have 10 hectares of coffee cultivation in 2002 (Khazanie 1997). However, this interdependence of observations between time periods can be compensated for by conducting a pairwise analysis which considers only "in-pair difference (Khazanie 1997)."

While this analysis will focus on results derived primarily from the panel datasets, at times I will differentiate between the data I use to report results. Unless explicitly mentioned as being "outside the panel" all results are acquired from panel analysis. Specifically, some instances of land holding change, particularly examples of land consolidation, which I report on in this work, consider properties outside the panel dataset. In other words, these properties experienced such drastic changes between 1996 and 2002 that they were practically unrecognizable by the 2002 survey.

LAND COVER AND LAND USE CHANGE METHODS

Land cover and land use information, such as measurement of the amount of primary and secondary forest cover (capoeira), pasture, and the cultivation area of many specific crops, was collected as part of the 1996 and 2002 field surveys conducted in Uruará. Using this information, and simple t-tests (described above) I was able to define the average land cover and land use on small properties in Uruará (see Table 2), and draw conclusions on the potential for future changes (see pages 89 & 100). Though some might argue self-reported land cover/use areas collected via survey may not be as accurate as classified remotely sensed data, recent research has concluded that there is often no statistically significant difference in accuracy between the two methods of collection (Caviglia-Harris and Harris 2003). Due to constraints of knowledge and time, I have opted to use the self-reported land cover and land use information from the survey data to quantify land cover and land use change in Uruará over the time period, though a method integrating both sources of data would be most desirable. However, for display and explanation purposes, a geographic information systems and remote sensing database was established as part of this work. Images in this thesis are presented in color to better show differences in land cover and land use and to emphasize certain aspects of specific areas.

Using Landsat imagery acquired on a variety of dates by the Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) sensor, survey data from 1996 and 2002, and geographic information systems (GIS) data outlining the original official INCRA delimited lots, it is easy to identify areas of interest in Uruará and the surrounding area. This combination of data sources allows me to identify which lots have changed hands, characterize how the agricultural system on certain properties may be different from others, and then identify how much of the area controlled by each property has been deforested.

Land parcel information was acquired from INCRA in the form of a paper map without a projection (a spherical geographic coordinate system) and the South American 1969 datum (SAD1969). This map was scanned at high spatial resolution, and then digitized in Environmental Science Research Institute's (ESRI) ArcMap 8.1 using a heads-up process. This digital data, now in digital GIS format, was then georeferenced and projected to match the Universal Transverse Mercator projection (Zone 22 Zouth, World Geodetic System 1984 datum). These projection parameters match the Landsat ETM scenes I acquired from the Tropical Rain Forest Information Center's Landsat data archive (Landsat.org 2004). After georeferencing and projecting GIS data, the Landsat ETM satellite imagery and GIS data are co-registered and share the same projection and datum information. Careful visual inspection indicates that the GIS data are in spatial agreement with Landsat ETM imagery (acquired in June 1999).

However, older Landsat TM imagery, collected on the Landsat 5 platform, are not delivered rectified. Due to gross geometric errors, Landsat ETM imagery can be misregistered by up to 250 meters, though pre-release processing mediates this error in many cases (EROS 2004). Because GIS data and Landsat ETM imagery were in agreement, I rectified Landsat TM imagery, using ESRI's ArcMap 8.3, to the already georectified and projected ETM dataset (RMSE = 4.93 meters). Landsat TM imagery (acquired August 1986, July 1988, and July 1991), ETM imagery (acquired June 1999), and GIS data (digitized from original cadastral maps) were in complete spatial agreement at this stage.

In order to link survey data from 1996 and 2002 to the GIS data a common field (as mentioned earlier) must exist. The paper map of land parcels in the Municipio of Uruará made available to the "Patterns and Processes of Landscape Change in the Brazilian Amazon" project by INCRA contained the official lot number of each lot (Browder et al. 2001). However, instead of recording this lot number in the questionnaire and then matching survey and GIS data using INCRA lot numbers, the INCRA lot number was matched to questionnaire identification number in the field to eliminate further data processing steps. The questionnaire number was subsequently added to the digitized INCRA lot boundaries in the GIS and this questionnaire number field was used to link the survey data to GIS data.

As mentioned above, this dataset was assembled primarily for visualization purposes, and also to identify areas of interest in Uruará. However, although there are many areas displaying potentially interesting land cover and land use changes, due to the large area considered around Uruará and the necessarily limited number of properties surveyed, most of these areas were not surveyed during field data collection.

Though many potential areas of interest were not covered by the 1996 and 2002 surveys, there were some properties displaying significant changes that are characteristic of typical properties in Uruará. Some of these properties are discussed in detail in "CHAPTER 4: PROPERTY-LEVEL CHANGES" starting on page 93. These particular properties were selected because they display characteristics and changes that closely match the average land cover and land use for farms of similar size in the study area.

At first glance, land cover and land use change research using data collected via remote sensing seems to be a fairly non-invasive, but therefore somewhat superfluous, form of data collection. Compared with survey based research, it seems that many of the potential pitfalls survey data collectors have to work carefully to avoid can be circumvented by collecting data on land cover and land use using remote sensing. Nevertheless, as with any new technology and concurrent shift to new methods, some researchers have raised questions surrounding the ethical, gender, and data accuracy issues remotely sensed data can raise.

POTENTIAL ISSUES IN LAND COVER AND LAND USE CHANGE RESEARCH

Land cover and land use change encompasses a plethora of potential changes in the status of the land. Even "environmentally sensitive" changes to the environment, such as selective logging, alter the cover and/or use status of an area. On the one hand, strictly speaking, selective logging (as an example) is a land use change. However, on the other, actual land use change of the area after selective logging may not be measurable by conventional means of remote sensing. Much of today's land cover and land use change data is collected through a combination of remote sensing and survey data (for selected examples see: Edelman 1985; Harrison 1991; Geoghegan et al. 1998; Brown et al. 2000; Walker et al. 2000; Irwin and Geoghegan 2001; Messina and Walsh 2001; Bell and Irwin 2002; Walker 2003). The launch of new earth-resource observing remote sensing technologies, such as the Landsat satellite series during the 1980s, became a driving force behind the ascension of land cover and land use change research. However, due to the frequent reliance on relatively small spatial-scale remotely sensed data (often of Landsat TM or ETM origin), in some studies significant land cover and land use changes may be unnoticed (Meyer and Turner II 1992). A good example of a case where remote sensing may not sufficiently record vital change to land cover/use regimes is the differentiation between secondary forest cover and small holder agroforestry; this difference in land use does not significantly alter the way many Amazonian environments appear from space at a spatial resolution of 30 meters. Even with the potential pitfalls involving accuracy and data sources, land cover and land use research has become possible largely due to rapid advances in remote sensing and computing technology, as well as the recognition of the need for frequently updated data covering large portions of the globe.

The complexity of the real world versus the inherent generalization of remotely sensed information is a potentially serious problem in land cover and land use change research. In addition, many social and economic theories are not as spatially explicit as they need to be, causing the gathering of useful and clear information from remotely sensed data to be quite difficult at times (Geoghegan et al. 1998). Seasonality and other natural cycles can be incredibly important in using remotely sensed data to monitor both the extent and cause of land cover and land use changes as phenology may hide significant human impacts on local or even regional environments (Geoghegan et al. 1998).

Litfin (1997) raises another objection to new technology for earth observation; she argues the source of the technology itself should be questioned. Because science has historically been dominated by affluent males from wealthy western nations, Litfin (1997) insists that we question the goals of remote sensing as they exist in an unequal world. Furthermore, she criticizes global change science (including land cover and land use change research) because, as she claims, human actions are frequently considered only as an afterthought or cause of some otherwise thoroughly documented natural phenomena. Litfin's criticism of land use change research and the use of satellite remote sensing is another link in a debate surrounding the ability of those who have power (especially males) to be in control of those who do not. However, as technological innovation spreads and some of the less developed countries begin to launch earth observing satellites of their own (e.g. India's space program) this critique may fall out of favor. Regardless of its potential validity, this critique is not an issue this thesis will address.

Another shortfall of land cover and land use research is the focus on the effects of largeholders on generalized land covers and land uses. This is especially the case in the Amazon, as many researchers have held large land holders such as ranchers and loggers responsible for a large proportion of the deforestation occurring there (Hecht 1984; Nepstad et al. 2002). However, smallholders are also responsible for a large proportion of deforestation occurring in the Amazon, as Walker et al. (2000) illustrate. Given the shared responsibility of large and small land holders it is interesting to note the confusion surrounding small, "shifted" land holders who practice standard fallow agriculture, and small "shifting" land holders practicing swidden agriculture. This difference needs to be briefly considered in any work focusing on colonists and smallholder agriculture in the Brazilian Amazon.

A BRIEF DISCUSSION OF SWIDDEN AGRICULTURE

Because swidden, or slash-and-burn, agriculture is a passionately debated topic in many academic circles, it requires a brief explanation. To the lay person, agricultural methods on Amazonian frontiers are often thought of as being solely swidden in practice. While this may be true in some cases, such as agriculture practiced in many indigenous reserves (Simmons 2002), in most of the frontier areas set up through government sanctioned development projects and new settlement, swidden is only a transitory agricultural strategy at most (Perz and Walker 2002; Walker et al. 2002; Walker 2003). However, because it does occur in specific instances in Uruará, I will briefly discuss the process and its implications for the landscape.

Swidden agriculture is the most common indigenous[13] form of agricultural practice in the Americas (Beckerman 1987). Swidden methods of clearing the land to prepare it for agriculture have been practiced for thousands of years in the *new world* and old world alike (Conklin 1961; Beckerman 1987; Balée 1992; Denevan 1992). In order for swidden systems to work well in the moist environs of a tropical forest such as the Amazon, swidden agriculturalists, or "shifting cultivators," must clear the under story growth in an area, let the area sit during a drying period, and then cut and burn the area (Beckerman 1987; Denevan 2001). After this the newly burned area is planted, in Amazonia the crops are often manioc, banana, maize (corn), beans, or plantains, cultivated continuously for a period of 2 to 6 years (Beckerman 1987; Balée 1992). Following this cultivation period, crop yields begin to decline, weeds typically take over, soil fertility declines, and insect pests and fungal growth become major problems. Because of the difficulty in maintaining the area's cover to be suitable for agriculture, it is left to fallow for a number of years. After some time, secondary forest eventually

[13] In this case the term "indigenous" refers to persons of Native American descent and not persons who have settled in the area since the encouragement of Amazonian settlement by respective government initiatives.

replaces swidden cultivated varieties and the process of slash-and-burn agriculture can be repeated again (Beckerman 1987).

There are many estimates as to how much time it takes for swidden fields to fallow out to 'mature' Amazonian forests, but most estimates range between 20 and 100 years (Beckerman 1987; Uhl 1987; Southworth et al. 2002). A typical swidden cycle would let the recently cultivated land sit in fallow for up to 20 years, or possibly even longer, before the cultivators cycle back through the area to reestablish temporary agriculture again (Alcorn 1989). Swidden production systems are extensive, requiring huge areas of land and large amounts of labor, and because of their extensive nature have been disparaged in the past as unsustainable (Alcorn 1989).

Swidden agriculture has been under intense criticism for its unsustainability and the long-term harm it supposedly causes to the local environment, especially forest biomass and long-term species biodiversity (Southworth et al. 2002). Though the transition to permanent agriculture can cause fallow periods to become much too short (Conklin 1961; Beckerman 1987), and there is mounting evidence that many agricultural systems can create an artificial land constraint (Simmons 2004), some studies show that practiced in a more traditional system with enough available land, swidden agriculture can be a sustainable agricultural practice if practiced 'correctly' (e.g. when fallow periods are long enough, see: Colchester and Lohmann 1993). Some studies even point to the biosphere services that swidden plots, sufficiently separated, provide for an area. After forest is cut into fields, planted, and subsequently abandoned, the resulting secondary growth often exhibits a higher diversity of under story plants, trees, and animals (Kunstadter 1987; Denevan 2001; Southworth et al. 2002). Conklin (1961) warns that researchers who have severe criticisms of swidden agriculture are usually scientists of temperate zone origin exhibiting a sort of hemispheric-centrism; the idea that temperate agricultural practices should work equally well in the tropics appears to be pervasive in some fields.

As Conklin (1961) briefly mentions, researchers have to be careful, and avoid discounting any and all local knowledge, such as swidden agriculture practices, because valuable information about an area can be permanently lost when this knowledge is ignored (Alcorn 1989; Scott and Walter 1993; Sandor and Furbee 1996; Warren et al. 2003). In fact, in some soil quality and cultivar-diversity based studies, researchers have found that indigenous knowledge of soils and human influenced geophysical processes such as erosion are valuable in the remediation of local environmental damage and the preservation of genetic diversity in cultivars (Scott and Walter 1993; Sandor and Furbee 1996; Warren et al. 2003). It seems that, more often than not, modern agricultural strategies imported from the developed world do not work well in many tropical areas (Zimmerer 1992; Scott and Walter 1993; Zimmerer 1993). In addition to being wary of an anti-swidden bias in agricultural research, researchers should also be aware that shifting cultivation is often blamed for more deforestation than it actually causes. In fact, permanent cultivation and cattle ranching are responsible for at least as much (if not more) deforestation as shifting cultivation (Geist and Lambin 2001).

Regardless of the sustainability and viability of swidden agriculture, the fact is that most frontier colonists in the Amazon do not practice “shifting” cultivation, and are in fact “shifted” cultivators (Perz and Walker 2002). “Shifted” cultivators differ from “shifting” cultivators in that shifted cultivators practice standard small holder agriculture in stationary areas (including fallows) but are displaced from their original location (Myers et al. 2000). Along the Transamazon swidden agriculture is typically used only as a land clearing strategy or by indigenous peoples (Moran 1981). In Uruará, small farmers only practice swidden agriculture when they first arrive on a property to clear their land (Walker et al. 2002; Walker 2003). Though disparaged by environmentalists as unsustainable, farmers in Uruará have adopted swidden methods to their advantage, often establishing their land claims through its use (Moran 1984; Perz and Walker 2002; Moran et al. 2003; Walker 2003). Despite the benefits of swidden agriculture, most farmers in Uruará focus on more permanent cultivation, typically a combination of annual subsistence crops, cattle pasture, and a limited number of commercially oriented cultivars (Walker 2003).

CHAPTER 3: PROPERTY DYNAMICS IN URUARÁ

This chapter addresses the hollow frontier thesis by considering property dynamics in Uruará with household panel data. It first considers land distribution (derived from the 1995/1996 national Agricultural Census) nationally in Brazil, in the state of Pará as a whole, and the Municipio of Uruará over multiple time periods. From there, the chapter includes information that details land holding change in the Uruará area using information from the property panel dataset. Finally, this chapter concludes with a brief description of the spatial pattern of land holding changes and why this pattern may be evident.

LAND CONCENTRATION

The Gini coefficient indicates how evenly a variable is distributed over its range (Millimet and Slottje 2002; Porro 2002). In many geographic studies, this measure of equal distribution is frequently employed to illuminate the land concentration of properties in an area. If a location has more large holdings than small holdings, the Gini coefficient value for that area will be a value close to one, indicating an unequal distribution of land (Anh Tuan 2002; Porro 2002; Simmons 2004). If an area has many small properties the Gini coefficient value for that area will be a value close to zero.

Internationally, according to literature addressing development themes, Brazil is known for its unequal distribution of wealth (Peet and Hartwick 1999). This inequality also extends itself to the distribution of land resources, and especially with the colonization of the Amazon this distribution has remained unequal despite the best hopes of the proponents of colonization projects (Wood and Wilson 1984; Hoffman 1998, as cited in Simmons 2004.; Simmons 2004). Even so, many of the colonization projects throughout the Amazon have provided land for farmers from areas where there is a dearth of land resources and little interest in land reform programs. For some, it may be surprising to observe how the national property distribution has not improved drastically in Brazil over time, even though Amazonian land resources are so abundant. However, given the history of land reform globally, and the political climate of Brazil during many of the settlement pushes, it is not as shocking that the trend to unequal property distribution remains (Simmons 2004).

Land distribution in the state of Pará consolidated slightly between 1985 and 1995 according to Gini coefficients derived from INCRA data and the 1995/1996 Censo Agropecuáro (agricultural census), with Gini values changing from 0.71 in 1985 to 0.82 in 1995. The increased property consolidation experienced in Pará is also evident nationally; in Brazil, Gini coefficients for the entire country rose from 0.85 in 1978 to 0.89 in 1995 (Censo-Agropecuário 1995/1996; Simmons 2004), even with the continuing development of many agricultural frontiers in the Amazon, covering vast amounts of land. However, land distribution in the municipio of Uruará during the mid-1990s was more equal than the rest of the state of Pará and the nation, with a Gini coefficient of 0.18 – a nearly completely equal distribution of land (Censo-Agropecuário 1995/1996).

If land distribution over the entire state of Pará is skewed toward larger land holdings why does Uruará display the opposite trend? While there are many potential reasons, the most significant for the relative equity in land distribution for the area in 1995/1996 is the initial settlement project administered by INCRA in the 1980s. This area, as mentioned previously (page 9), is, for the most part, divided into 100 hectare lots which were made available to new colonists one lot at a time. Property is distributed more evenly in Uruará than the rest of Brazil because the time since initial settlement has not been sufficient for settlers to accumulate enough capital to acquire more lots or to clear enough land for their lots to be attractive to "urban capitalists" who may want to establish ranching or other commercial operations in the area. The initial, artificially imposed, property structure was very even in its allocation of properties and this even distribution has remained since the beginning of colonization in the area. A quick inspection of the property structure in the area overlain on Landsat ETM imagery from August 1999 shows that the majority of the lots in the Uruará area are small (not much more than 100 hectares, Figure 5). In addition, there is not a great amount of deforestation, and consequently (usually) colonization, beyond the boundaries of the original INCRA lot structure (Figure 1, Figure 5).

However, across the remainder of Pará the equity of land distribution is not nearly as evident. In fact, the average number of hectares per property in Pará has increased every year since 1970, which may indicate a continuing land consolidation already apparent in much of the state (Simmons 2004). Property consolidation issues aside, land ownership in Pará is much higher than it is in Maranhão, where only 32 percent of lot holders own their lots (Censo-Agropecuário 1995/1996). The low lot ownership rates in Maranhão have made land consolidation more frequent and has lead to increased conflict between small farmers and large ranchers. Low rates of ownership and consolidating forces are partially responsible for the inequity in the distribution of land resources and the violent land-related conflict evident there (Porro 2002). This consolidation and dearth of land resources could create similar problems in the areas surrounding Uruará if the distribution of land becomes skewed toward larger land holdings. Indeed, other areas of Pará not far from Uruará, have seen instances of intense land conflict involving indigenous populations, smallholders, ranchers, and loggers (Simmons 2002; 2004).

Nonetheless, properties in Uruará are still very equitably distributed, and though there seems to be an active land market, census data do not indicate strong property consolidation forces in the region. Even so, the farmers who have acquired more lots tend to focus on commercially oriented production and over time may require increased access to land resources. If commercially oriented agriculture such as coffee, pepper, cacao, and cattle ranching continue and increase, property consolidation may begin to take hold as farmers begin to accumulate capital and acquire more land. This, in turn, could lead to land conflict and land cover and land use changes that will have significant impact on local, regional, and global environmental health.

LAND HOLDING CHANGE

Land holdings on Amazonian agricultural frontiers tend to change hands frequently, leading to property turnover rates many researchers have found puzzling since the early 1980s (Schneider 1995). Uruará is no exception; like the rest of the Amazon, land holdings are highly variable among small farmers. In 1996, the average lot holder in the surveyed area controlled 1.21 lots, with a standard deviation of 0.62 (n=76, Table 1). In 2002, this average decreased slightly to an average of 1.20 lots per lot holder (σ=0.57, n=76, Table 1). The average number of lots per property is greater than 1.0 in both surveys because occasionally respondents control more than one lot. However, in order to do so, most colonists must first establish themselves and amass enough capital to acquire another lot. Due to the difficulties of frontier life, most colonists in the Uruará area control only one lot (see pages 9 & 17).

During 1995/1996, 16.5 percent of farmers leased, sharecropped, or occupied their property without a title in the state Pará, while 83.5 percent of farmers owned their lots (held with a formal title), the highest rate of land ownership on record in the state (Censo-Agropecuário 1995/1996). This contrasts with agricultural land ownership rates nationally where 26 percent of farmers lease, sharecrop, or occupy their lot without a title and 75 percent of farmers own the land they cultivate (Censo-Agropecuário 1995/1996). However, a comparison of Pará with the rest of Brazil considers widely varying agricultural strategies and includes states where land resources are scarcer than in Pará.

Comparing lot ownership in Pará with the rest of the Legal Amazon, one can see that lot ownership rates are higher in Pará than the rest of the Amazon basin. This higher rate of ownership contributes to a more even land distribution, helps solidify property rights, and aids those with sufficient capital in expanding their holdings. In Uruará, the rate of land ownership is quite high even compared to rates for the entire state of Pará, with very few farmers leasing or sharecropping the land and only 5 percent of farmers occupy their land with no legal documentation such as a land title (Censo-Agropecuário 1995/1996).

While the climate of lot ownership in Pará, and Uruará especially, may make it easier for property owners to expand their holdings, between 1996 and 2002 there was no significant change in the number of lots controlled by property owners in the study area (Table 1). Both losses and gains of lots were minor, though some specific cases of large expansions and losses exist, between 1996 and 2002, there were impressive gains with the largest of seven lots, and the largest loss being six lots. In the property panel, in which land holdings are nearly identical, the only change was a loss of one lot (Figure 6). Although there are definite changes between the surveys, and there is slightly less variation in the number of lots owned ($\sigma = 0.62$ in 1996, $\sigma = 0.52$ in 2002), the difference between the averages is not significant at the 95 percent level for the panel (Table 1). However, outside the panel there is significantly more variation, and it appears that lots are changing hands more frequently. Another interesting phenomena to note is that in the surveys the same number of lots were gained by properties as were lost, though these gains and losses were not solely to or from properties that were surveyed.

Small changes in the average number of lots each property holder controls may indicate the emergence of an active land market, where land holdings change hands frequently depending on many internal and external social and economic factors. Though the land market seems to be active in Uruará (see Figure 7), there is not any direct evidence of extensive land holding consolidation or fragmentation (Figure 8). Because levels of property fragmentation and concentration are equal, they even each other out (Figure 8). This result may be due to the survey data used, which is collected considering primarily small-holder lots, but the magnitude and proportion of gains and losses in land holdings are very consistent with other parts of Amazonia (Browder et al. 2004). In addition to the development of a land market, the gradual change of land holdings in Uruará may be also be influenced by variations in the demography of the surveyed area. Small changes in land holdings may signify the beginning of a gradual shift toward greater land consolidation, which is frequent in the rest of the state of Pará (Walker and Homma 1996), though not in evidence in Uruará (Walker 1993).

Even though the average number of lots controlled by properties is not significantly different between the 1996 and 2002 surveys (both for the panel and for the full dataset), individual instances of change are remarkable. Of the 76 properties in the property panel for 2002, 18 farmers claimed they had not been interviewed before, including one settler who arrived in 1997 and now owns five lots. Even if land holders are not accumulating new property or fragmenting their old property, an land resources change hands frequently, pointing to the existence of an active land market in Uruará. Given this land market, certain areas exhibit more rapidly changes in land holdings.

LOCATION OF LAND HOLDING CHANGES

Gains and losses of lots loosely follow a spatial pattern, as can be seen in Figure 9. Upon inspection, Figure 9 makes it appear that property lot gains tend to happen closer to town and closer to the Transamazon (the red line in Figure 9) while properties lose lots further from town or the highway. Nevertheless, because of the human tendency to see patterns in places where none actually exist, this may not be the case (O'Hear 1989). Also, due to the intricacies and problems associated with conducting field research in a remote area such as Uruará, especially in regards to transportation, lots closer to town were more likely to be surveyed than lots further away. This is especially true of lots further out on the colonization roads, which are often nearly impossible to get to because roads are often not well maintained. The pattern of lot gains near town is logical, however, because they are more desirable for development. This desirability might lead one to expect properties along BR-230 to see the greatest turnover due to land market effects. Indeed, increases in lot holdings do seem to occur closer to BR-230, though this is not a fixed outcome (lot losses can also be seen close to the highway, Figure 9). In a general sense, lot losses seem to occur further from BR-230 where land market forces and transportation issues may make it harder to maintain practicable settlement.

While property land holdings change frequently both close to and far from BR-230, there are many more farmers who did not gain or lose lots between the surveys (Figure 6). Because lot holders who retain the same number of lots (often only one lot) are spread more or less evenly throughout the landscape and far exceed the number of properties that experienced lot changes, it appears that the majority of land holdings in Uruará are stable over the six years between surveys (Figure 6). This stability is not surprising, as acquiring lots is expensive and often beyond the financial means of many colonists and the reasons for decreasing land holdings are more pressing in areas with more advanced agricultural frontiers, such as the colonization along BR-364 in the state of Rondônia (Browder et al. 2004).

CHAPTER 4: PROPERTY-LEVEL CHANGES

This chapter considers the changes occurring on properties by considering household and property level changes on properties in Uruará. The analysis in this chapter was simplified by the fact that at this stage the household panel and property panel are in fact identical datasets, therefore from this point on I will make no distinction as to which dataset was used. This chapter begins with an outline of the changes in labor power over the households in the study area and the implications these changes may have for agricultural production and land cover and land use. Next, the chapter details the average change in property-level production of annual subsistence and perennial crops (which are typically commercially oriented), and outlines the changes in the production of cattle that many properties exhibit. This chapter then outlines the typical land cover and land use strategy of properties in Uruará and how this strategy changes as property sizes increase. The chapter then concludes with a brief description of a few properties which display changes in agricultural production and land cover and land use strategies which closely match what is typical on properties of similar sizes.

In order to envision the conversion of a frontier area from primary forests to an explicitly human landscape it is often helpful to assume a series of events must occur. Though the process behind deforestation and agricultural development in the Amazon is not normally as linear as this progression, and does not follow a prescribed recipe, most observations of property-level changes note some sort of pattern. This pattern often starts with a change from forest to subsistence agriculture, followed by another change from subsistence-focused agriculture to commercially oriented crops, at both regional (Wood 1983) and local (Perz and Walker 2002; Walker et al. 2002) levels.

This process, with a few exceptions, can be seen in Uruará as well; early efforts by colonists were primarily focused on subsistence agriculture, and as time has passed have become increasingly commercially oriented. Uruará, Brazil, is therefore an example of a rapidly changing agricultural frontier displaying a trend toward more commercially oriented crops over a surprisingly short time span. Between 1996 and 2002, Uruará and the surrounding area have experienced a significant decrease in the planting and production of some key subsistence crops, while, at the same time, experiencing a slight increase in the production of some commercial cultivars (Table 3, Table 4).

Average property population has decreased, though these decreases are of mixed significance (95 percent level, Table 1). These population decreases may indicate a gradual shift in average property demographic is occurring in the area, which is typical for a developing agricultural frontier over time. A change in farming system orientation toward commercially valuable crops and low-labor agricultural strategies such as cattle ranching is noticeable in the typical land use properties in the area exhibit (Table 2, Table 5). These gradual changes point toward continuing development in the Uruará area and may indicate an eventual change to a more urbanized than agricultural frontier area.

Land cover and land use, agricultural strategy, and population change, many properties in the Uruará area are changing rapidly. With planned and impromptu improvements to the transportation network in Uruará along the Transamazon and into settlement roads (such as seasonal repairs of necessity), it is likely the commercialization of agriculture will continue in the future. As more remote areas become increasingly accessible, land values may rise near roads and more densely settled areas and agricultural goods will become easier to bring to marketplaces. These changes may lead to further deforestation in areas that remain forested due to their isolation.

LABOR

Of late, one of the most persuasive explanations of Amazonian deforestation at local and sub-regional (county-level) scales is the household life-cycle. According to this theory, deforestation and other land cover/use changes can be explained by the progression of a household's demographic structure through time, often framed within a common series of household events (discussed on page 17). Regardless of household demographic situation, labor power availability is often a driving force behind the selection of frontier agricultural strategies (Zimmerer 1993; Walker et al. 2000; Coomes and Burt 2001).

In Uruará, the location of farming households along the household life-cycle continuum can have a noticeable impact on the land cover and land use of both individual properties and the greater landscape (Perz and Walker 2002;

Walker et al. 2002). Changes in the demographic structure of individual households in the Uruará area are important to consider when observing concomitant change in agricultural strategies and land cover and land use regimes. The panel survey, which collected data in 1996 and 2002, gathered information on property populations and, through simple change analysis and t-tests, can illuminate the significance of demographic change in the area.

Recognizing that property population and other household attributes can have a significant impact on land cover and land use, in addition to agricultural strategy, it is important to place properties in Uruará along the continuum of the household life-cycle. In 1996, there were a total of 509 people living on properties surveyed as part of the panel dataset. Average total property population at the time was 6.70 people with a standard deviation of 4.3 from a total of 76 properties (Table 1). In 2002, there were 407 people on the surveyed properties, with an average total property population of 5.36 and a standard deviation of 3.93 (Table 1).

In Uruará, average total property population change between 1996 and 2002 is significant at the 95 percent level (Table 1), with a total decrease of 102 persons on properties between the two surveys. The significant decrease in overall population between the panel surveys would be expected of a "hollowing" frontier; as older children move to their own properties, the elderly may pass away, or parents age and are unable to have children, lots will gradually consolidate under fewer owners. This process may be due to household demographic changes, or an evolving land market. In either case, population decreases can be an indicator of frontier consolidation and maturation.

Traditionally, researchers across the globe studying phenomena in many fields have considered male populations as the most important for continuing agricultural viability (James 1969; Wood 1983 refers to labor in almost completely male terms). Recently, however, studies have shown that female and child labor are often at least as important for household survival as male populations (Carney 1996; Rocheleau and Edmunds 1997). Regardless of the proportion of labor females contribute, the elderly and young children are often a drain on household resources. Taken together, changes in the populations of the very young and very old can have an impact on the production of properties as increases in their populations change the ability of the property and available labor to meet subsistence needs. These changes, coupled with population change in other categories (female and male populations) can have serious implications for both property livelihood and land cover and land use in a frontier area such as Uruará.

In 1996, the average male population on each property was 2.42 males with a standard deviation of 1.79 from a total of 76 properties (Table 1). Of the 76 surveyed properties surveyed in 2002, there was an average of 1.79 males per property with a standard deviation of 1.36 (Table 1).

Over the properties covered by the panel there was a decrease in total male populations between 1996 and 2002, comprising the largest proportion of the total population loss during this period. The lower number of males between panel surveys is interesting, as the loss may indicate a significant decrease in available labor on the surveyed lots. However, a supposed loss in labor resources is debatable, as women and children often perform key agricultural tasks (Carney 1996; Rocheleau and Edmunds 1997). Regardless of the decline in male populations and their implication for labor in the area, the decline of males is an interesting phenomenon and quite significant at the 95 percent level (Table 1). This decrease in male labor may precede a noticeable decline in the clearance of forest cover on many farms, though this has yet to be evaluated.

Average female population was 1.63 females per property in 1996, with a standard deviation of 0.96 (n = 76). In 2002, the average number of females per property was slightly lower at 1.37 females and a standard deviation of 1.09 (n = 76).

The female populations (like male populations) also experienced declines on many properties, and the overall trend was a slight decrease between 1996 and 2002 from 124 females to 104 females. Though a change in the female population by 20 persons seems like a significant decline, especially given the low total number of females on surveyed properties, the average female population on properties did not change significantly between 1996 and 2002 at the 95 percent level (Table 1).

The average number of children (people 0 – 15 years of age) on the surveyed properties in 1996 was 2.47 (n = 76) with a standard deviation of 2.79 children. In 2002, average child populations on the surveyed properties (n = 76) decreased slightly to an average of 1.97 children per lot and a standard deviation of 2.45 children (Table 1).

Similar to female populations in the area, there was also a slight total decrease in the population of children; Uruará experienced a decrease from 188 children in 1996 to 150 children in 2002. This decrease indicates that households in the Uruará area may be maturing beyond the point of optimal labor force, though this remains to be seen. The majority of properties, however, retained the same number of children. The average number of children on each property was not significantly different between 1996 and 2002 at the 95 percent level of confidence (Table 1). If children are moving out of the area, it is interesting to note where they may be moving to. While the 1996 and 2002 surveys did not focus on where children have moved, some researchers have directly addressed this question in other parts of the Amazon. The link between urban and rural sectors is very strong in the Amazon, and in floodplain locations near Santarém, Pará, Brazil, many households send their children to school in urban areas, while the rest of the family remains in rural areas (WinklerPrins 2002; 2004). While this does occur in the areas surrounding Santarém, this is not necessarily the case in Uruará. In other parts of the Brazilian Amazon, as children mature they seek jobs in urban areas, or move to other lots along the agricultural frontier (Browder 1997; Browder et al. 2004).

On all the properties surveyed for the panel, the number of elderly persons (greater than age 65) per property is generally quite low. In 1996, the average number of elderly persons per property was 0.19 with a standard deviation of

0.61 (n = 76), and in 2002 the average elderly population per property remained the nearly same at 0.21 (σ = 0.57, n = 76, Table 1).

Elderly populations, which would, in addition to child populations, increase the dependency ratio between years (and drain labor power), remained almost exactly the same over the time period. By 2002, the total elderly population increased to 24 people, a slight gain of 4 people in 1996. This slight increase also conforms to a household lifecycle explanation of changes in the area, as elderly family members may move to the frontier as a colonist household establishes itself and life on the frontier becomes more stable. However this is not usually the case in Uruará, as most properties had no elderly population in 1996 and maintained no elderly population in 2002. The average number of elderly persons on each property did not change in any significant way between surveys (α = 0.05, Table 1). Again, research has shown that many elderly people in the Amazon move away from the frontier as they age, living in urban areas yet remaining closely tied to their families in rural areas (WinklerPrins 2002; 2004).

Dependent populations, those who are old and very young, did not change significantly at the 95 percent level during the six years between surveys (Table 1). However, the stability of dependants together with a decrease in male and female working populations could mean a failing labor force with an increasing dependency ratio for the Uruará area. In fact, the dependency ratio did increase between 1996 and 2002 for the properties surrounding Uruará (Table 1), though not significantly at the 95 percent level.

FARMING SYSTEMS

In the Uruará area farming systems are highly diverse, and include subsistence-oriented annual crops, commercially-oriented perennial crops, and multi-purpose cattle ranching (Walker 2003). Though commercially-oriented crops are grown primarily for profit, a certain proportion of these crops may be consumed on the farm for subsistence purposes. Likewise, subsistence-oriented crops are grown primarily for consumption on the property, though some may be sold at a profit, used to barter with neighbors, or as gifts.

Because of the high level of diversification and the large number of crops grown in Uruará[14], I will only talk about the three most ubiquitous of these crops which fall into two categories: (1) crops of which most of the production is consumed on the property, i.e. subsistence crops and (2) crops of which most of the production is sold or exchanged, i.e. commercial crops. Cattle are addressed separately because of their multi-faceted presence on the frontier of Uruará and fall into both categories at different stages of frontier life.

SUBSISTENCE CROPS

The surveys conducted in 1996 and 2002 collected information concerning the agricultural strategies of a large number of colonist farmers. Among the information collected, subsistence agriculture (crops consumed primarily by

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[14] The 2002 panel data survey asked respondents specifically about 19 different crops and also had an open-ended component for respondents to discuss other crops. For each perennial and annual crop respondents were asked to estimate how much of each crop was consumed on the property, how much was sold at market, and the price received per unit for each crop.

persons on each property) is among the most varied between the two surveys. Because an evolving agricultural frontier is not an easy place to maintain a viable farming establishment, certain crops are essential for a household's survival. Much of the food consumed by people on properties in the Uruará area is grown on the property itself, which means that subsistence crops are very important. In the study area there are many different subsistence crops of varying importance to the livelihood of small farmers, the three most important being corn, rice, and beans. As mentioned above, these crops are not necessarily used solely for subsistence (see page 71).

CORN

Throughout the world, corn is among the most important subsistence crops. In Brazil this is no exception; the national yield of corn exceeded 3,000 kilograms per hectare in 2002 which is an increase over yields in 1996, and more than double the yield of the entire continent of Africa (Table 6). In Uruará, the situation is similar to the rest of Brazil and corn is considered one of the more important food crops. However, the use of corn is different in many areas of the Amazon than in much of North America; corn is grown for feed purposes, and most corn production is fed to chickens and pigs in the Uruará area (Arima 2004).

In 1996, the average property area to dedicated to corn cultivation was 2.34 hectares per property with a standard deviation of 2.97 hectares (n = 76, Table 4). The average property area planted in corn decreased to 1.11 hectares per property in 2002, with a standard deviation of 1.70 hectares (n = 76, Table 4).

As would be expected considering average area decreases, the total area dedicated to corn cultivation also declined between the 1996 survey and the 2002 survey. The overall decline of land planted in corn between surveys is 93.18 hectares, nearly the size of an entire INCRA lot. While more properties decreased their corn cultivation area than increased it by 2002, there were still a fair number of corn cultivation increases as well (48 instances).

Corn production in both surveys was recorded in 60 kg sacks. Average property corn production in 1996 was 28.88 sacks (or 1,732.8 kg) with a standard deviation of 39.72 sacks (2,383.2 kg), while in 2002 average property corn production declined to 14.99 sacks (899.4 kg) with a standard deviation of 27.56 sacks (1,653.6 kg, Table 3, Table 4). In general, most properties decreased their corn production, though the decreases are not much more than the number of properties maintaining no corn production between surveys. A total of 48 properties increased their corn production, with most production increases being 3,000kg or less between 1996 and 2002. Corn production displays a significant overall decrease, totaling 63,330 kg (Table 3), and may indicate the beginning of a transition from subsistence agriculture to commercially oriented agriculture. This trend in agricultural strategies supports previous research by many authors showing a ramping-up of commercial integration as a common step in the development of a frontier area such as Uruará (Walker 1999; Coomes and Burt 2001; Camagni et al. 2002; Rudel 2002). However, though an increasing number of properties grow commercial cultivars in Uruará, decreases in corn planting and production could also be explained by local and regional environmental conditions, including events such as drought, excess rain, heat, pest invasion, etc.

RICE

Rice, in much the same way as corn, is an important subsistence crop in much Brazil. In fact, and quite surprisingly, rice yields in Brazil are almost as high as rice yields in Asia, at 3,326 kilograms per hectare in 2002 (Table 6). In Uruará rice is a staple part of the colonist's diet, which makes it a vital subsistence crop.

Average property area planted in rice was 2.30 hectares ($\sigma = 2.44$) per property in 1996 and 0.87 hectares per property in 2002 ($\sigma = 1.06$, Table 4). The decline in total rice cultivation area over all the properties surveyed between 1996 and 2002 is even more impressive than the loss of area planted in corn, covering 108.8 hectares. The majority of properties decreased their cultivation of rice (Table 4), though some properties did increase their rice areas (most expansions less than two hectares).

Average rice production (also recorded in the number of 60kg sacks) over surveyed properties was 44.54 sacks (2,672.4 kg) per property with a standard deviation of 43.09 sacks (2,585.4 kg) in 1996 and 16.70 sacks (1,002 kg) per property with a standard deviation of 27.71 sacks (1,662.6 kg) in 2002 (Table 3). Total overall rice production decreased by 126,960 kg over the surveyed properties, as would be expected from the decline in areas planted in rice between surveys. Between surveys, most properties decreased their rice production with most decreases being small (2,400 kg or less), though increases in rice production were not unimportant, and some properties increased their production (though most increases were small at 2,400 kg or less). Even with greater production on some properties, average rice yields experienced a significant decrease by 2002 ($\alpha = 0.05$, Table 3).

BEANS

Beans are another highly popular and ubiquitous subsistence crop in much of Brazil. Though there are many ways to cook beans and a great many specific bean varieties, this is an aggregated category with one exception: soybeans are not included[15]. National bean yields increased between surveys from 571 kilograms per hectare in 1996 to 735 kilograms per hectare in 2002 (Table 6). To illustrate the substantial nature of bean production, Brazil's bean yields were higher than either the continent of Africa or the continent of Asia in 2002. In Uruará, bean production covers less area than corn or rice, but still remains a very important subsistence crop.

In 1996, the average property area planted in beans was relatively minor when compared to the typical areas dedicated to corn and rice. Bean cultivation, on average, covered only 0.64 hectares per property ($\sigma = 0.84$, Table 4). In 2001, average bean cultivation decreased to 0.25 hectares per property in 1996 ($\sigma = 0.46$, Table 4). As would be expected given the decline in average area, total bean cultivation decreased between 1996 and 2002 by 29.88 hectares. Only 29 properties increased their bean cultivation area, which was not enough to counter balance the 47 properties that decreased their bean cultivation area. With the

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15 Soybeans are a growing land cover/use in Brazil, though on this part of the Transamazon they are not yet in great evidence.

number of properties decreasing bean cultivation area and the relatively small decrease in total area dedicated to bean cultivation it is apparent that most properties are moving away from bean production. Average property bean cultivation area is significantly lower between 1996 and 2002 surveys at the 95 percent level (Table 4).

Individual property bean production (measured in 60 kg sacks) averaged 4.06 sacks (243.6 kg) with a standard deviation of 5.59 sacks (335.4 kg) in 1996 and 2.18 sacks (130.8 kg) with a standard deviation of 5.59 sacks (335.4 kg) in 2002 (Table 3). Of all the properties surveyed, most decreased their bean production by 300 kg or less. On the other hand, increases in bean production were not uncommon, with typical increases being of the same magnitude (300 kg or less). The overall decrease in bean production between 1996 and 2002 was 1,792.8 kg, which is not a large amount when compared to the decreases in corn and rice production. However, the difference in average property bean production is still significant at the 95 percent level between 1996 and 2002 (Table 3).

SUBSISTENCE CROP SUMMARY

As subsistence crops rice, beans, and corn show a clear overall decrease in both average lot area and average lot production (Table 3, Table 4). These decreases are puzzling at first, as one would expect the population's need for sustenance would remain fairly constant over time. This stability in needs would be even more likely as decreases in the area under cultivation and production of subsistence oriented crops seem to outweigh the decreases in population. While there are many explanations for this trend of subsistence crop declines, a main reason could be the potential transition from subsistence oriented agriculture to a more commercially oriented agricultural outlook. An agricultural strategy displaying a decrease in subsistence crops coupled with a stable population would also be consistent with a household lifecycle explanation; properties have more labor power, due to more children, and can focus on more intensive agricultural practices and commercially oriented production. In turn, households may choose to purchase some of their food with funds they may have earned through commercially oriented crops or cattle ranching. Household lifecycles are not the only explanation for a shift in farming strategies, however, and other factors such as environmental conditions, culture, and an increase in beef consumption may have lead to the decrease in crops that are mostly subsistence oriented (corn, rice, beans).

COMMERCIAL CROPS

Though many properties in the region surrounding Uruará are primarily oriented toward subsistence crops, property owners also dedicate a portion of their cultivation area to crops that can be sold in markets for profit. These crops are a key way for farmers to diversify their agricultural strategies to include more flexible crops, increase earnings and, often, begin to raise livestock. In fact, as mentioned above, cattle ranching is a common end goal for farmers in much of the Amazon and commercial cultivars are often the small holder's best chance at gaining enough capital to purchase livestock or hire additional labor in order to realize this goal. As mentioned above, some of these crops may be consumed on the property they are grown on, but most of the production is sold (see page 71).

COFFEE

Coffee is a major revenue generating crop in rural Brazil, with an annual production of 399,000,000kg for the North region of the country (USDA 2002). Coffee can be quite profitable for large and small producers alike, but is also quite susceptible to global price fluctuations. One such price change occurred shortly after World War II when coffee prices were so low railroad lines in Brazil used raw coffee beans as combustible fuel for steam engines (Peet and Hartwick 1999). In 1996 and 2002, Brazil's coffee yields outranked much of the rest of the world, contributing to Brazil's fame as a leading coffee producer (Table 7). However, much of the Amazon's coffee production is not used for export purposes, instead being consumed at local and regional levels.

In the Uruará area, average coffee cultivation was 1.62 hectares per property, with a standard deviation of 4.48 hectares (Table 4) in 1996. In 2002, this average area changed to 1.31 hectares per property (σ = 3.30, Table 4). Between 1996 and 2002 there was an overall decrease of 23.91 hectares dedicated to coffee in Uruará, though average decreases are insignificant at the 95 percent level (Table 4).

In Uruará, it appears that coffee cultivation has become more profitable, potentially due to increased national, regional, and global market integration, coupled with a slight rise in coffee prices over the past two years (Lee 2002). Coffee production in 1996 averaged 6.46 60 kg sacks (σ = 21.43 sacks or

1,285.8 kg) per property for an average production of 387.6 kg (Table 3). In 2002 this average production for coffee increased to 9.82 sacks (589.2 kg) per property, with a standard deviation of 18.82 sacks (1,129.2 kg, Table 3). Coffee production has obviously increased on properties in Uruará and these increases in production are quite high, though quite variable (Table 3). Of the relatively few properties that produced coffee in 1996, 12 decreased their production by 480 kg or less between 1996 and 2002. However, 36 properties increased their production, accounting for the overall increase in coffee production of 15,295.2 kg between 1996 and 2002. Most increases were fairly small at the individual property level (60 kg or less), though a handful of properties increased their production by more than 6,000 kg between the two years. Regardless, the differences in average property coffee production between the surveys are not significant at the 95 percent level (Table 3).

CACAO (AND COCOA)

Cacao, the tree from which cocoa beans are derived, can yield uncertain benefits for smallholders with limited monetary resources. Similar to coffee, cacao prices are highly variable and the crop takes more time than most subsistence crops to grow to maturity. This does not stop small farmers from growing cacao, however, because when prices are high, profits from cacao are a powerful incentive to grow this perennial. Considering other parts of the globe, it is easy to see that Brazil is among the leading cacao producers. However, cacao yields are not as impressive as some other crops (such as coffee) and the Amazon does not produce the majority of Brazil's cacao (Table 7).

During the 1996 survey (n = 76), the average cacao area was 2.35 hectares per property, with a standard deviation of 4.94 hectares (Table 4). In 2002 this changed to an average of 1.74 hectares of cacao planted on each property (n = 76), with a standard deviation of 4.11 (Table 4). Cacao is another example of a slight decrease in total cultivation area over the panel dataset between 1996 and 2002, with a decrease of 45.89 hectares during (insignificant at 95 percent level, Table 4). Most increases in cacao cultivation area on properties were small in size, at 11 hectares or less, though a few properties decreased their cacao area by more than 11 hectares. Most properties did not increase their cacao planted areas, however, and many properties did not have cacao planted at all during both surveys.

Cacao production averaged 565.66 kg per property in 1996, with a standard deviation of 1,199.59 kg (Table 3). During the 2002 survey, average property cocoa production increased slightly to 567.37 kg with a standard deviation of 1,288.81 kg. The increase in cocoa production in the area was minor at only 109 kg between 1996 and 2002, and was not a significant increase at the 95 percent confidence level (Table 3). Whatever influences the production of cocoa in the area, it appears that a major shift to commercial cacao production is not in evidence in the area surrounding Uruará.

PEPPERCORN

Peppercorn production is not often considered to be a major agricultural crop, but in Brazil that perception is certainly spurious. In 2002, Brazil's yields of pepper were double that of North & Central America's, and far exceeded production in Africa and Asia (Table 7). Pepper is a high-yield commercially oriented crop, which might be quite attractive to small holder agriculturalists attempting to begin small-scale commercial agriculture. However, pepper production in the Amazon has had a different historical basis than many of the other frequently grown cultivars. Introduced as a plantation crop by Japanese immigrants in the years leading up to the Second World War, pepper plantations were highly profitable especially as Indonesian exports of the crop declined (James 1969:554).

During the 1996 survey, the average area planted in peppers on properties was small at 0.65 hectares and a standard deviation of 0.85 hectares (Table 4).This average area declined to 0.44 hectares per property with a standard deviation of 0.83 hectares in 2002 (Table 4). Peppers do not cover a significant area on each property, and this area does not change greatly between surveys (Table 4). However, many properties (36) in the 1996 survey did not have peppers planted at all.

Total pepper production over the surveyed properties decreases noticeably from an average of 917.99 kg per property (σ = 1,337.06 kg, Table 3) in 1996 to 340.04 kg per property (σ = 740.30 kg) in 2002 (Table 3), for a total overall decrease of 35,924 kg pepper production. This means that most smallholders in the panel are not focusing their agricultural efforts on the production of pepper for commercial purposes.

The decrease in pepper production may be due to opportunities lucrative crops such as coffee and cacao offer many of the small scale commercial agriculturalists in the area. In addition, coffee and cacao have on-property uses as most household members drink coffee and juice made from cacao fruit is frequently prepared. Another explanation for decreased pepper production could be environmental conditions were such that yields were lower than normal in 2002. Yet another possibility is that many farmers have decided to decrease pepper cultivation, due to its high labor costs, in favor of pasture creation and cattle ranching as these strategies are often a more fiscally attractive use of available land resources.

COMMERCIAL CROP SUMMARY

Commercial crops have not changed significantly in production between 1996 and 2002 with the exception of pepper, which experienced a noticeable and significant decrease in production (Table 3). On the other hand, between 1996 and 2002, property production and planted area decreases are significant with regards to subsistence crops (Table 3, Table 4).

Commercially-oriented crops yields are likely to continue to increase as the frontier in Uruará matures. Another positive influence on the continued production of commercially-oriented crops is the fact that the Uruará area is becoming increasingly integrated with the rest of the region as transportation networks improve. This could be creating a larger market area in Uruará, further influencing the area and production of these commercial crops. However, the average total cultivated area decrease between the surveys is interesting and may be due to changes in growing conditions or the prices growers can get for their products. Another potential explanation for area differences between the surveys concerning commercially oriented crops could be differences in data collection methods between the two surveys. Because the 1996 survey collected an estimated number of plants of each of these crops and all subsequent 1996 area estimates are interpolated from these, estimates for the area of these cultivars may be slightly biased. Furthermore, many smallholders in the Uruará area may finally be acquiring enough capital to start raising more cattle, a common goal of many smallholders.

CATTLE RANCHING

As an agricultural frontier matures and labor power on properties decreases, smallholders frequently convert from subsistence agriculture to more commercially oriented agriculture, including cattle ranching (Walker et al. 2000; Walker et al. 2002). However, many frontier colonists acquire livestock very early in their agricultural decision making process as the benefits of ranching cattle are many and often hard for smallholders to ignore (Faminow 1998)[16].

In 1996 the average cattle heard was 27.45 head per property with a standard deviation of 27.24 head, while in 2002 the average was 51.95 head per property with a standard deviation of 45.13 (Table 3). Total survey head counts were 2,089 head in 1996 and 3,948 head in 2002. This near doubling of cattle populations in the surveys speaks strongly of the benefits (see footnote 14) cattle may offer the frontier colonist, and is a statistically significant increase in cattle numbers at the 95 percent level (Table 3). This increase may have substantial

[16] For further discussion on the potential non-monetary benefits of cattle ranching see page 17.

implications for property land use patterns and the orientation of agricultural production in the area (whether production is commercial or subsistence in nature) and mirrors the expansions in cattle herds throughout the Brazilian Amazon (Walker et al. 2000; McCracken et al. 2002; Porro 2002).

Cattle ranching is widely variable in Uruará, and comprises a major part of the rural agricultural economy in the area. Many farmers manage cattle that are not their own in order to gain more capital, which they often use to establish their own cattle herd. If the trend toward increasing cattle herds continues in Uruará as it did in Rondônia during the 1990s (see: Margulis 2004), significant land cover and land use impacts, especially with respect to forest cover, will occur in the near future on this rapidly developing frontier.

CATTLE RANCHING SUMMARY

The farming system of the average colonist in Uruará changed slightly between the two surveys. As would be typical of a maturing agricultural frontier, lot holders in the area are growing fewer subsistence-oriented crops, and slowly switching their agricultural production system to commercially oriented cultivars and cattle ranching. This changing strategy is not surprising due to the decline in population on most properties, which in turn means that property labor power has decreased. Cattle ranching is a good, low labor, option for maturing households.

A farming system change from subsistence to commercial orientation would be expected of a maturing frontier and a maturing household (Walker et al. 2002). As accessibility and transportation networks improve in many remote areas, households increase their labor power, and farmers realize an improved financial situation. As this occurs in Uruará, the area will probably experience increased deforestation, increased pasture (discussed on page 86), and an increase in areas dedicated commercial crops.

PROPERTY LAND COVER AND LAND USE

CULTIVATED AREA FOR ANNUAL AND PERRENIAL CROPS

Average area planted in annual and perennial cultivars obviously varies among properties, but in 1996 the average cultivated was 9.90 hectares (σ = 8.66, n = 76, Table 2) per property. Over all the surveyed properties in 1996, the total cultivated area was 752.45 hectares. By 2002, the average area in cultivation was 5.72 hectares (σ = 6.70, n = 76) per property (Table 2). Over all surveyed properties, 434.86 hectares of land in the Uruará area was under active annual or perennial cultivation in 2002.

The change in areas dedicated to subsistence (primarily annuals such as beans, rice, and corn) and commercially oriented (mainly perennials like cacao, coffee, and peppers) crops between 1996 and 2002 is significant at the 95 percent level. It is clearly evident that less land is being converted into active cultivation over the surveyed properties, and that properties are not increasing areas under cultivation. This is not surprising, and is a commonly noticed phenomenon; as the frontier ages, more forest is cut down, but this area is typically converted to pasture (Hecht 1993; Faminow 1998; Pfaff 1999; Brondizio et al. 2002). However, the decline in cultivated area and the concomitant decline in crop production seems to indicate that agricultural efforts are not intensifying. Instead, it appears that other agricultural strategies are being pursued.

FOREST AREA

Average primary forest cover changed from 74.29 hectares per property (σ = 58.31) in 1996 to 56.52 (σ = 35.31) hectares per property in 2002 (Table 2). Forest cover over all surveyed properties (*n* = 76) was 5,646.3 hectares in 1996, while in 2002 the total forest cover decreased (4,295.39 hectares). Similar to the decreases in average cultivated area on properties between 1996 and 2002, there is a significant decrease in the amount of average property primary forest cover in 2002 (α = 0.05, Table 2).

No Amazonian researcher debates the fact that deforestation is occurring in the Amazon, and the trend over the six years between surveys is in no way surprising. Primary forest must be cleared for the increase in pasture land and the slight increases in perennial agriculture which are evident in Uruará. However, on average as of 2002, smallholders in the Uruará area had not yet exceeded the legal limit to land clearance at 50 percent of land holdings (assuming a 100 hectare lot average, see Table 2), though the average amount of cleared land is quite close (Walker 2003).

PASTURE AREA

As mentioned above, cattle herds in the surveyed area experienced a marked increase between 1996 and 2002 (Table 3), which, in turn, is likely to have an influence on pasture in the area. Average pasture area was 27.94 hectares per property in 1996, with a standard deviation of 18.59 hectares (n = 76, Table 2). In 2002 (n = 76), the average pasture area on each property was 28.76 hectares with a standard deviation of 21.27 (Table 2). Total pasture on the surveyed properties in 1996 was 2,123.4 hectares, while in 2002 the total pasture was 2,186.0 hectares.

The property average for pasture area did not increase significantly (α = 0.05) between 1996 and 2002, and appears to be highly variable (Table 2). A slight average increase in property pasture area is consistent with other research, though in other areas it has been greater, often occurring due to increased demand for beef (Walker et al. 2000). These small expansions are an indication that the small holder agriculturalist in Uruará often focuses on establishing a cattle ranching operation, and most farmers are succeeding at this. However, because forests are difficult to clear, it is likely that many properties are not expanding their cultivation of perennial or annual crops or their pasture area to any great extent.

CAPOEIRA

Capoeira, or secondary forest growth, is common throughout the Amazon (Smith et al. 1999; Sorrenson 2000; McCracken et al. 2002; Walker 2003), and has been observed in Uruará (Perz and Walker 2002; Walker 2003). In fact, capoeira can be a significant land cover on many agricultural frontiers as areas planted in crops lose their fertility and pastures become overrun with weeds or pests. In Uruará, capoeira is a significant land cover, and in 1996 it covered an average of 6.82 hectares on each property (Table 2). In 2002, capoeira covered, on average, more of each property than crop cultivation at 12.05 hectares per property (Table 2). Capoeira areas increased significantly between 1996 and 2002 at the 95 percent level (Table 2), which is consistent with observations of the area conducted by Perz & Walker (2002).

SUMMARY

The average 100 hectare, one-lot property surveyed in 1996 consisted of nearly 75 hectares primary forest cover, almost 28 hectares of pasture, nearly 10 hectares cultivated area, and almost 7 hectares of capoeira (Table 2). This land use system is typical of a frontier area; most of the property is still forested, lot food supplies are grown on a small area, a portion of the property is covered by land that has fallen out of use, and the less labor-intensive cattle ranching is practiced on a small scale (Faminow 1998; Walker et al. 2000). However, six years later, in 2002, the typical small holder land use system is arguably more mature. The typical 100 hectare property in the 2002 survey has 56 hectares of primary forest, 29 hectares of pasture, 12 hectares of capoeira, and 6 hectares of cultivated area (Table 2). Again, this land use pattern is typical of a maturing frontier moving toward a greater integration with commercial activities, more disused land, and an increased focus on cattle ranching (Faminow 1998; Walker et al. 2000). These trends may indicate many small properties in the area are moving toward less labor-intensive agricultural solutions, possibly because of the decrease in male populations and increase of the dependency ratio in the area (Table 1).

Even though the land use system is changing as the agricultural frontier in Uruará matures, and average forest area on lots is significantly different between the 1996 and 2002 surveys, pasture has not experienced a significant increase ($\alpha = 0.05$) since 1996. This is interesting because average cultivation area and primary forest cover have both experienced significant decreases, while only capoeira has experienced a significant increase (Table 2). These small inconsistencies are likely due to the way inter-cropping (raising two or more crops on the same area of a property simultaneously) was handled as part of the 1996 survey. Regardless, the property land use strategies will continue to change as Uruará continues to mature as an agricultural frontier, and if studies in other areas of the Amazon are any indication, pasture land will continue to increase rapidly (Hecht 1984; Schneider 1995; Walker et al. 2000; Rudel 2002). One potential issue for further research in this area is the impact of government subsidies, use of technology, and other support. Though very few of the properties included in the property panel received aid of this sort (19 properties in 1996 and 11 properties in 2002), the impact of technology and financial assistance could be substantial.

PROPERTY SIZE AND LAND COVER AND LAND USE STRATEGIES

Larger properties in the 2002 survey (those controlling more than a single lot) often have a distinctly different land use strategy than smaller, single-lot properties. As would be expected, average property size increases with the number of lots held (Table 1), potentially impacting the landscape in different ways due to the special strategies largeholders have when using the land (e.g. large cattle pasture areas). However, taking land holding size and land cover/use into account, two general trends can be observed in Uruará: (1) as properties increase in size, the percentage of the property covered in primary forest decreases slightly, and (2) as properties increase in size up to three or four lots the proportion of total property area covered by pasture and cultivars remains fairly stable (Table 2, Table 4, Table 5, Figure 10).

Figure 10 displays the average proportional land cover and land use by the number of lots controlled by individual farmers in the Uruará area in 1996 for the entire survey. For this analysis, lot holdings are used in place of actual property area due to inaccuracies in the self-reporting of respondent lot holdings. I believe this is a reasonable approach because, in general, lot sizes are highly uniform within the study area (see Figure 5, Figure 6, Figure 9). In 1996, land holdings spanning up to three lots have very similar land cover/use regimes. These smaller properties tend to be about 60 percent primary forest, 10 percent cultivated area, and 30 percent pasture land (Figure 10). This land cover/use regime begins to change subtly on four-lot properties, which often have proportionally more primary forest cover and less pasture (Figure 10). Things become radically different on five and six lot properties, which appear to possess different land cover/use strategies, in particular more cultivated area, greater proportions of capoeira and less pasture (Figure 10)[17]. These differences on larger properties are interesting because they run counter to the hollow frontier thesis and, when taken at face value, seem to indicate that larger holdings do not typically move toward cattle ranching. This may not actually be the case, however, because there are very few five and six lot properties in the survey (in fact, there is only one example of each in 1996) and these few instances misreported land cover/use, tallying only land cover/use for only one lot out of many.

In 2002, these land cover and land use regimes are noticeably different. Proportional property land use is not nearly as similar across property sizes, and there seems to be more varied land cover/use strategies. Single-lot properties, which comprise the most significant portion of the survey, have much the same land cover/use strategy as single-lot properties in 1996; they are about 75 percent primary forest, 5 percent cultivated area, and 20 percent pasture (Figure 11). However, the similarities between the 1996 and 2002 surveys end with single-lot properties. Two, three, and four-lot properties are similar to each other, but have far more pasture and much less primary forest cover than two, three, and four-lot properties in 1996 (Figure 11). The larger properties, spanning from six to eight lots, have drastically different land use regimes than large properties

[17] For the 4 and 6 lot properties shown in Figure 10 total hectare counts are not accurate because missing hectare count data. However, this information was included anyway because the respondent's proportional estimation of each land cover/use class was nearly identical to this proportional display. Also, there are only on example of a 4-lot and 6-lot farm in 1996.

surveyed in 1996. Pasture is the dominant land cover/use on larger properties in 2002, when in 1996 the dominant land cover was primary forest (Figure 11). In addition, proportionally, cultivated area declined drastically by the time of the 2002 survey, further highlighting the focus on pasture land, especially on the one eight lot property, which is completely dedicated to pasture (Figure 11). These trends on larger properties are not surprising, especially when labor considerations are taken into account. Because the few larger properties in this study have the land resources for extensive agricultural operations, strategies requiring less labor, such as cattle ranching, are attractive.

While there are a few general trends in land cover and land use on properties as land holdings increase, there are some substantial differences between surveys as well. In general, considering the differences between the 1996 and 2002 surveys, there is a shift in land use regimes from a highly diversified farming system toward a greater focus on pasture land, especially on larger properties in Uruará (Figure 11). There are a lot of potential driving forces behind this land use strategy change, but among the most significant is the fact that Uruará and the surrounding area are beginning to become more regionally integrated. This change supports both the hollow frontier and household lifecycle theories, though it is not certain which of these processes (or if other processes) drive land cover and land use change in the area. Farmers in Uruará may be increasing their focus on cattle ranching in order to store any capital they may have accumulated, or as a solution to waning farm labor power if their children have moved off the property. On average, properties seem to be focusing more on cattle ranching than the cultivation of crops, a phenomena that can be found on many properties in the area.

DETECTING CHANGE WITH THE AID OF REMOTELY SENSED DATA

To illustrate the changes that are commonly evident in a property's land cover and land use over time I will now briefly describe four small properties of different sizes in the Uruará area. These properties are, in general, very similar to properties of similar size in the study area in their demographic composition, land cover and land use, crop production, and cattle ranching activities yet show surprisingly varied agricultural strategies.

PROPERTY ONE

Individual properties differ greatly in the Uruará area, even among the few properties that cover larger land area. This 325 hectare property included in the panel survey, covering 4 lots, has some particularly interesting characteristics (Figure 12). One of the most striking changes between 1996 and 2002 on this particular property is the decline in population. Total property population decreases from 13 in 1996 to 6 in 2002, with the biggest loss in population being males. Coupled with this change in the demographic composition of the property is a rapid change in land cover/use strategy. Total primary forest decreased from 300 hectares to 240 hectares coupled with a decrease in area of the property under cultivation, from 13.95 hectares in 1996 to 6.5 hectares in 2002 (Table 8).

According to the survey data, pasture area supposedly declined between the surveys as well, from 75 hectares in 1996 to 55 hectares in 2002, but given the decrease in property size without any property disaggregation occurring, this is probably due to errors in the self-reporting of the property owner (Table 8). On this property, capoeira covered 5.5 hectares in 1996, with secondary growth present on only two of the four lots. In 2002 capoeira doubled to cover 11 hectares, with secondary forest growth in evidence to some extent on all four lots (Table 8). Regardless of capoeira and pasture area changes, the number of cattle on this property has increased from 82 animals in 1996 to 122 animals in 2002 (Table 8). It is interesting to note that cultivated area has decreased for most cultivars excepting cacao, and the number of cattle on the property has increased between the surveys, which may be related to the significant declines in property population and the concomitant increase in capoeira growth. As people have left the property, owners are often forced to change to less labor intensive agricultural strategies (Pichón 1997; Walker et al. 2000), in this case cattle ranching. In fact, this particular farmer plans to maintain the same area of the property in subsistence crops and pasture, but increase the area of the property dedicated to perennial (commercial) crops and the number of cattle.

On this same property there were significant changes in agricultural production between the panel surveys. Corn production increased, while other annuals such as rice and bean production decreased (Table 8). However, commercial cultivars were a slightly different case; the production of perennials such as coffee and cacao increased greatly between the surveys, while pepper production greatly decreased. This trend is puzzling, especially considering the decline in property population. However, the increase in corn, cacao, coffee, and the cattle herd is not so puzzling when hired labor is taken into account. In 1996, this farmer did not hire any off-property labor, but by 2002 this farmer had begun to hire labor for a daily wage. This increase in labor daily wage hire provides made it easier for this particular farmer to increase the output of perennial crops even while the on-farm labor power decreased. In addition, the cattle herd increase can provide income and capital storage for this smallholder using only available labor.

These substantial changes in production, land cover and land use, population, and cattle herd aside, it is impressive to view the change occurring on this property on satellite imagery. Figure 12 shows the change that has occurred through the use of unclassified Landsat TM and ETM imagery in a 5,4,2 band combination. With this particular band combination heavily disturbed areas are shown in magenta and white. This property was mostly covered by primary forest in 1986, with most clearing occurring in the southeast corner of this property, which is, not coincidentally, closest to the road and town. By 1991, some of this cleared land had been revegetated, but land cover changes penetrate further into the lot. These changes continue in 1999, and it becomes clear that the extent of clearance and how farmers in more remote locations (northern part of figure) are rapidly converting forest cover to other intensive uses. Seeing this simple imagery time-series of a fairly small property it is easy to understand why land cover and land use change is such an important topic of research in Amazonian environments.

PROPERTY TWO

This property, larger than most in Uruará (over 300 ha), is shown in Figure 13. This particular property covers three lots, and is a much more stable property as far as land cover and land use and population are concerned. Property population decreased by one person, a child, and property area has remained the same between the surveys, covering two lots. Land use is also more even over time, at least with respect to cultivation area, when compared to the property discussed above. In 1996, 4.8 hectares of the property were dedicated to cultivation, while there were 178 hectares of primary forest, about 100 hectares of pasture, and only 5.7 hectares of capoeira. The property's land cover/use changed by 2002 to 4.3 hectares of cultivated area, 75 hectares of primary forest, nearly 50 hectares of new pasture, and an incredible 89 hectares of capoeira (Table 8). The changes in the agricultural production of this property varied: corn, coffee, and pepper production declined between 1996 and 2002. Cacao production increased slightly, as did rice production, but cattle declined over the six years between the surveys (Table 8). Similar to the four lot property mentioned above (Figure 12), this farmer planned to increase the property's cattle herd and the property's area dedicated to commercial (perennial) cultivars.

PROPERTY THREE

Small properties differ from large properties in more than just area. One small property, shown in Figure 14 covers one 100 hectare lot. This property has nearly as many people as the larger properties in the area with eight people in 2002, though one male left the property and an elderly person moved to the property between 1996 and 2002. Land use strategy is more variable on this small property than some of the larger properties, and changed greatly between surveys. In 1996, the property' had 6.75 hectares of cultivars, 67 hectares of primary forest, 25 hectares of pasture, and 2 hectares of capoeira (Table 8). By 2002, this lot land use had changed with 3.5 hectares of cultivated area, 54 hectares of primary forest, 40 hectares of pasture, and only 1 hectare of capoeira (Table 8). What is interesting is that even though the pasture on the property nearly doubled between 1996 and 2002, cattle actually declined. This may be due to speculation on the part of the farmer or a desire to start ranching other people's cattle on the property. This sort of pasture increase without a concomitant increase in the property cattle heard has been noticed elsewhere in the Amazon, and may be associated with land clearance in anticipation of cattle heard increases (Faminow 1998; Walker et al. 2000).

As would be expected from this property's decline in cultivated area, most crops experienced a decline in production between the two surveys. Corn, rice, coffee, and pepper production decreased in 2002 (pepper saw the largest decrease of over 1,280 kg, Table 8). Of all cultivars, only bean production increased between the two surveys. The Landsat TM and ETM imagery in Figure

14 show the land cover and land use change activity on this lot over the years, and is quite impressive, especially considering that this property has been active since 1974. In 1986 only a small portion in the lower left corner of the property had been deforested, but by 1991 this disturbed area increased along the lot boundary (Figure 14). By 1999, just before the 2002 survey, nearly half of the property had been deforested, most of which was turned into pasture land, according to the survey (Table 8, Figure 14).

PROPERTY FOUR

Another small property in the area, this one covering two lots and spanning across one of the colonization roads in the area (Figure 15), was also highly variable between 1996 and 2002. Total property population remained stable, though there were more children and fewer men in 1996 than in 2002. The real changes by 2002 on this 203 hectare property were realized in its agricultural strategy. Cultivation area increased from 18 hectares in 1996 to 20 hectares in 2002, while primary forest area supposedly increased by four hectares (from 50 hectares in 1996 to 54 hectares in 2002, Table 8). Pasture area increased by 10 hectares to cover 110 hectares of the property by 2002 and capoeira experienced a decrease of 5 hectares to cover 20 hectares of the property by 2002 (Table 8). It is interesting to note that the land cover and land use on this property are quite close to the averages for two lot properties in 2002, shown in Figure 11.

This property's production did not change significantly between the two surveys (with the exception that cacao and coffee production and areas seemed to switch between surveys, Table 8), which puts this particular property in a category with many others in Uruará. For many farmers the main objective is property maintenance; the farmer will make no major changes in agricultural strategy but instead will focus on maintaining production and diversifying agricultural production enough to cope with problems as they arise. This stability can easily be seen on the satellite imagery of this property, as the land cover does not change to any great extent between 1986 and 1999, though there may be more secondary forest and disturbance further into the lots (Figure 15).

Because the 1996 and 2002 panel surveys focused on smallholders and ignored larger land holders such as loggers, large ranchers, and commercial agriculturalists, there are few lot holders in the dataset who have more than one or two lots (Table 1). However, even over the six years between surveys there does appear to be an active land market and properties are slowly changing. Some land fragmentation, observed in other parts of the Amazon (Browder et al. 2004), does occur in Uruará, but it is not widespread (Arima 2004). While changes are equally distributed between gains and losses of lots, it seems that property fragmentation is not prevalent in the panel (Figure 8), and there may be a slow consolidation of properties. Land concentration can cause conflict, and runs counter to many of the Brazilian government's reasons for the development of many Amazonian agricultural frontiers (Wood and Wilson 1984; Smith et al. 1999; Porro 2002; Simmons 2002; 2004).

CHAPTER 5: CONCLUSIONS

With the growing recognition of the significant impacts local land cover and land use changes have on regional and global environmental integrity, researchers have begun to assemble a more complete picture of land cover and land use processes (Lambin et al. 2003). This work is not complete, and many competing explanations for land cover and land use change are presently being tested.

Among the plethora of competing theories, two of the most frequently cited causes of deforestation (and other land cover and land use changes) in Amazonia are the hollow frontier thesis, and household lifecycle theory. Interestingly, both of these explanations for land cover and land use changes often result in a similar agricultural landscape; a frontier with larger land holdings, very little forest cover, and a property-level emphasis on perennial crops of a commercial nature or cattle ranching. Many of the agricultural areas of the Amazon display this pattern of land cover and land use, as the result of a high rate of deforestation spanning many years.

A variation on the hollow frontier has been documented in the Ecuadorian Amazon, and outside of the Amazon in the region surrounding São Paulo (James 1969; Taylor 1973; Delson and Dickenson 1984; Dean 1995:233; Messina and Walsh 2000; Rudel 2002). Also apparent in much of the Amazon is the effect of a household's demographic change on the land cover and land use of a property

(Walker and Homma 1996; McCracken et al. 2002; Perz and Walker 2002; Walker et al. 2002; Walker 2003). Both of these processes, or a variation on them, may be in operation in Uruará, but which of the two best captures the actual process driving the widespread land cover and land use change in this area? This thesis has discussed the political ecologic forces that may be driving the development of a hollow frontier in Uruará, and the forces behind the impact of household lifecycles on the landscape.

Household lifecycles influence agricultural frontiers in most developing areas to some degree, but in the Amazon they are a highly significant force shaping agricultural landscapes (McCracken et al. 2002; Perz and Walker 2002; Walker 2003). In Uruará, household lifecycle processes have driven substantial land cover and land use changes, especially with regard to secondary forest (Perz and Walker 2002). The findings presented by Perz and Walker (2002) do not necessarily translate into a direct impact of household demographics on agricultural strategy. Changes in the frontier may indicate the development of a hollow frontier and not a maturing frontier changing due to maturing colonist households.

As mentioned above, a hollow frontier is an agricultural frontier where small farmers have moved away from the frontier they originally opened, either of their own will or through force. On a hollow frontier large land holders dominate and agricultural tasks are frequently performed by daily laborers (James 1969; Taylor 1973; Casetti and Gauthier 1977; Rudel 2002). A hollow frontier typically has very few on-property residents, and instead property holders live off-property in nearby towns (Rudel 2002). In most cases, property consolidation must occur for a hollow frontier to develop, a process which has yet to occur on any significant level in Uruará (see page 54).

Properties are not consolidating very rapidly in Uruará, and land resources are more evenly distributed in this area than most other parts of the Amazon (see page 54). This fact does not support the hollow frontier theory, though on its own the lack of land consolidation does not completely eliminate the possibility of the development of a hollow frontier in Uruará. Specifically, if land owners started moving to urban areas (such as the town of Uruará itself), running their properties remotely or by hiring permanent help, a hollow frontier would be likely to develop in Uruará. Indeed, significant population decline did occur in the panel between 1996 and 2002 (Table 1), and average daily workers hired per year on properties has increased significantly from 30 per year in 1996 to 61 per year in 2002 ($t = 3.12$, $n=76$). Specific land cover and land use changes seem to indicate a gradual hollowing of the frontier as well. Properties tend to have more area dedicated to pasture, and decreasing (though insignificantly) areas dedicated to cultivation of commercially valuable crops, primary forest cover, and subsistence crops (Table 3, Table 4). The decline in property populations and increased daily labor hire, coupled with trends in property land cover and land use, could be construed to indicate the presence a hollowing process on the frontier in Uruará.

However, I would argue these changes are not drastic enough to hollow the agricultural frontier in Uruará in the near future. In fact, the land cover and land use changes that could indicate a hollowing of the frontier in this area are not significantly different among panel properties; average property pasture land only increased mildly, primary forest and cultivated area declined greatly (Table 2, Table 5). If pasture did not increase significantly, and primary forest cover and cultivated area decreased significantly, in what way are farmers using the remainder of their deforested land in Uruará? One explanation would be that farmers may be abandoning production of any sort on parts of their property, leaving land fallow for a period before restarting production. Indeed, capoeira (secondary forest growth) increased significantly between 1996 and 2002 (Table 2, Table 5) indicating many farmers are letting areas become reforested.

If active use of the land on properties moved through a progression of use and abandonment, which was suggested by some researchers in the 1980s and early 1990s (Hecht 1984; Fearnside 1990; Hecht and Cockburn 1990), the land cover and land use strategies of farmers would be of great concern to anyone interested in the health of local and global environments (Morello et al. 2000; Gerbens-Leenes and Nonhebel 2002). However, there is not, at this time, evidence suggesting this consumption of land resources is occurring any more in Uruará than in other locales in Amazonia beyond what is normally attributed to what many researchers term "the frontier ethic" (Walker et al. 2000:687). In all actuality, secondary forest re-growth does occur in Uruará, but its existence is not necessarily attributable to use and discard practices and is instead related to household lifecycles (Perz and Walker 2002; Walker et al. 2002).

In fact, much of the land cover and land use change in Uruará could be attributable to property household demographic progression. For instance, as a household matures children are likely to move off lots to work in urban areas or to establish their own property (Browder et al. 2004). As the younger property inhabitants move away, populations decline and labor power becomes more limited (Pichón 1997; Walker et al. 2000; McCracken et al. 2002). At this point a farmer has few options to maintain the property; the farmer can either hire labor power if he or she has the capital, or can leave cleared land to fallow and eventually return to forest.

In Uruará we see a slight, yet insignificant increase in pasture land on properties, significant decreases in the production and planted area of all major crops (except coffee), and a significant decrease in forest cover (Table 2, Table 3, Table 4, Table 5). In addition, cattle production increased significantly between 1996 and 2002 (Table 1). Keeping in mind the significant decrease in property population, the land cover/use and agricultural activities on these properties are adequately explained by household lifecycle theory. As labor has moved from lots, in the form of children or adults (Table 1), many farmers in Uruará may have been unable to maintain previous levels of agricultural production (Table 3). Because of the lower labor requirements of cattle ranching (Hecht 1985; Mattos and Uhl 1994; Faminow 1998; Walker et al. 2000), many farmers have left their crop production land to fallow, choosing instead to ranch cattle (Table 3).

Between 1996 and 2002 there have been many changes to properties and their demographic composition, socio-economic status, land holdings, and land cover and land use strategy in Uruará. Though some of these changes seem to indicate the development of a hollow frontier, this is not the case with small farmers in the area. In fact, the household lifecycle is the more likely explanation of these changes. The knowledge that land consolidation and large scale agriculture are not very common in the Uruará area makes it difficult to say with any certainty that a hollow frontier is developing. Instead, household demographic change is beginning to yield a terminal landscape that appears quite similar to a hollow frontier, but without the widespread land consolidation.

Though hollow frontiers have been observed in many areas, there does not appear to be a hollowing of the agricultural frontier surrounding Uruará. Indeed, in areas of Rondônia, a part of the Amazon quite similar to Uruará in its history but more advanced in its development, a hollow frontier has not yet developed. Instead a combination of increasing regional integration and property fragmentation has been observed, with cattle ranching as a common land use (Browder et al. 2004). The development of this sort of landscape is highly likely in Uruará, and as time passes by there will continue to be a focus on cattle ranching and a continuing of the deforestation already so frequently observed.

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APPENDIX A

Variable	1996		2002		Difference of Means	
	$\bar{X}$	σ	$\bar{X}$	σ	t	α
Number of Lots Owned	1.21	0.62	1.20	0.57	-0.14	0.05
Total Population	6.70	4.30	5.36	3.93	***-2.01***	0.05
Male Population	2.42	1.48	1.79	1.36	***-2.73***	0.05
Female Population	1.63	0.96	1.37	1.09	-1.57	0.05
Child Population	2.47	2.79	1.97	2.45	-1.17	0.05
Elderly Population	0.19	0.61	0.21	0.57	0.14	0.05
Dependency Ratio	0.70	0.71	0.74	0.80	0.37	0.05

n = 152, 150 dof, critical t = 1.97

Table 1. Changes in property land holdings and property population in Uruará, 1996 – 2002. Statistically significant changes are represented in boldface.

Property Area	1996		2002		Difference of Means	
	$\overline{X}$	σ	$\overline{X}$	σ	t	α
Cultivars	9.90	8.66	5.72	6.70	***-3.33***	0.05
Forest	74.29	58.31	56.52	35.31	***-2.27***	0.05
Pasture	27.94	18.59	28.76	21.27	0.25	0.05
Capoeira	6.82	8.07	12.05	15.37	**2.63**	0.05

n = 152, 150 dof, critical t = 1.97

Table 2. Changes in average hectares of land uses on properties in Uruará, 1996 – 2002. Statistically significant changes are represented in boldface.

Crop	1996		2002		Difference of Means	
	$\bar{X}$	σ	$\bar{X}$	σ	t	α
Corn	28.88	39.72	14.99	27.56	***-2.50***	0.05
Rice	44.54	43.09	16.70	27.71	***-4.73***	0.05
Beans	4.06	5.59	2.18	5.59	***-2.07***	0.05
Coffee	6.46	21.43	9.82	18.82	1.03	0.05
Cocoa	565.66	1,199.59	567.37	1,288.81	0.01	0.05
Pepper	917.99	1,337.06	340.04	740.30	***-3.30***	0.05
Head of Cattle[1]	27.45	27.24	51.95	45.13	***4.05***	0.05

n = 152, 150 dof, critical t = 1.97

[1]a property with 700 cattle removed. *n = 151, 149 dof, critical t = 1.97*

Table 3. Agricultural production for selected crops of subsistence and commercial nature in Uruará, 1996 – 2002. Units in 60kg sacks for all variables except cocoa and peppers (in kilograms) and cattle (in number of animals). Statistically significant changes are represented in boldface.

Crop	1996		2002		Difference of Means	
	$\bar{X}$	σ	$\bar{X}$	σ	t	α
Corn	2.34	2.97	1.11	1.70	***-3.13***	0.05
Rice	2.30	2.44	0.87	1.06	***-4.70***	0.05
Beans	0.64	0.84	0.25	0.46	***-3.59***	0.05
Coffee[1]	1.62	4.48	1.31	3.30	-0.49	0.05
Cacao[1]	2.35	4.94	1.74	4.11	-0.82	0.05
Pepper[1]	0.65	0.85	0.44	0.83	-1.52	0.05

n = 152, 150 dof, critical t = 1.97

[1] interpolated from number of plants according to measurements from Walker et al. 2002 (p. 194).

Table 4. Area in hectares dedicated to selected crops of subsistence and commercial nature in Uruará, 1996 – 2002. Statistically significant changes are represented in boldface.

Lots	Properties in Category	Average Property Area	Forest Area	Agriculture Area	Pasture Area	Other
1	63	94.92	48.61 *51.21%*	4.73 *4.98%*	24.90 *26.23%*	16.68 *17.57%*
2	7	183.67	90.50 *49.27%*	11.07 *6.03%*	48.50 *26.41%*	33.60 *18.29%*
3 or More	6	300.83	170.67 *56.73%*	11.50 *3.82%*	60.17 *20.00%*	58.49 *19.44%*

Table 5. Average area of major land covers and land uses on large and small holdings in Uruará during 2002. Units in hectares.

Yield in Kilograms / Hectare	**1996**	**2002**
Corn		
Africa	1,703	1,632
Asia	3,853	3,876
Europe	5,087	5,781
North & Central America	6,485	6,777
Brazil	2,697	3,011
Rice		
Africa	2,310	1,989
Asia	3,854	3,977
Europe	5,090	5,693
North & Central America	5,421	6,074
Brazil	2,657	3,326
Beans		
Africa	588	641
Asia	600	579
Europe	1,222	1,380
North & Central America	903	1,046
Brazil	571	735

Table 6. Brazil's production of key subsistence crops compared to other major agricultural regions. Source: FAOSTAT (FAO 2004)

Coffee		
Africa	469	365
Asia	743	961
North & Central America	630	581
Brazil	713	1,055
Cacao		
Africa	476	374
Asia	830	929
North & Central America	421	423
Brazil	388	300
Pepper		
Africa	629	596
Asia	541	673
North & Central America	1,009	1,214
Brazil	1,939	2,465

Table 7. Brazil's production of key commercially oriented crops compared to other major agricultural regions. Source: FAOSTAT (FAO 2004)

	Property One		Property Two		Property Three		Property Four	
	1996	2002	1996	2002	1996	2002	1996	2002
People	*13 people*	*6 people*	*7 people*	*6 people*	*9 people*	*8 people*	*10 people*	*19 people*
Cattle	*82 head*	*122 head*	*120 head*	*96 head*	*23 head*	*15 head*	*171 head*	*171 head*
Area								
Corn	*0.00 ha*	*0.75 ha*	*1.50 ha*	*2.00 ha*	*1.50 ha*	*1.00 ha*	*0.00 ha*	*0.00 ha*
Rice	*3.00 ha*	*0.00 ha*	*2.00 ha*	*1.50 ha*	*1.50 ha*	*1.00 ha*	*0.00 ha*	*0.00 ha*
Beans	*1.00 ha*	*0.00 ha*	*0.50 ha*	*0.00 ha*	*0.00 ha*	*0.00 ha*	*0.00 ha*	*0.00 ha*
Coffee	*0.63 ha*	*0.25 ha*	*0.48 ha*	*0.00 ha*	*2.03 ha*	*1.00 ha*	*0.00 ha*	*20.00 ha*
Cacao	*4.05 ha*	*5.00 ha*	*0.23 ha*	*0.80 ha*	*0.00 ha*	*0.00 ha*	*18.00 ha*	*0.00 ha*
Pepper	*5.27 ha*	*0.50 ha*	*0.16 ha*	*0.00 ha*	*1.70 ha*	*0.50 ha*	*0.00 ha*	*0.00 ha*
Production								
Corn	*0 kg*	*600 kg*	*2,400 kg*	*0 kg*	*60 kg*	*0 kg*	*0 kg*	*0 kg*
Rice	*2,920 kg*	*1,800 kg*	*3,000 kg*	*1,500 kg*	*3,300 kg*	*1,800 kg*	*0 kg*	*0 kg*
Beans	*120 kg*	*0 kg*	*0 kg*	*0 kg*	*0 kg*	*360 kg*	*0 kg*	*0 kg*
Coffee	*110 kg*	*600 kg*	*500 kg*	*0 kg*	*600 kg*	*0 kg*	*0 kg*	*6,000 kg*
Cacao	*0 kg*	*1,060 kg*	*40 kg*	*60 kg*	*0 kg*	*0 kg*	*5,000 kg*	*0 kg*
Pepper	*3,850 kg*	*170 kg*	*400 kg*	*0 kg*	*1,400 kg*	*120 kg*	*0 kg*	*0 kg*
Land Use								
Cultivation	*13.95 ha*	*6.50 ha*	*4.8 ha*	*4.3 ha*	*6.75 ha*	*3.5 ha*	*18 ha*	*20 ha*
Forest	*300 ha*	*240 ha*	*178 ha*	*75 ha*	*67 ha*	*54 ha*	*50 ha*	*54 ha*
Pasture	*75 ha*	*55 ha*	*100 ha*	*59 ha*	*25 ha*	*40 ha*	*100 ha*	*110 ha*
Capoeira	*5.5 ha*	*11 ha*	*5.7 ha*	*89 ha*	*2 ha*	*1 ha*	*25 ha*	*20 ha*

Table 8. Attributes for specific properties in the Uruará area.

APPENDIX B

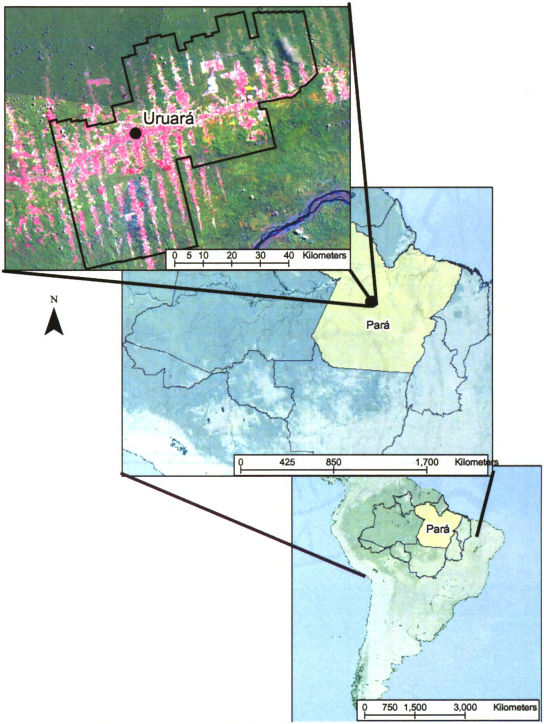

Figure 1. Location of Uruará and study area within the Brazilian Legal Amazon. The bottom graphic displays the location of the Legal Amazon within all of continental South America, the middle graphic displays the location of the Legal Amazon within a regional context, and the top graphic shows the location of Uruará and the extent of the study area. Source data varied, including MODIS data obtained in 2001, and Landsat 7 ETM Imagery dated August 9, 1999 (bands 5,4,2).

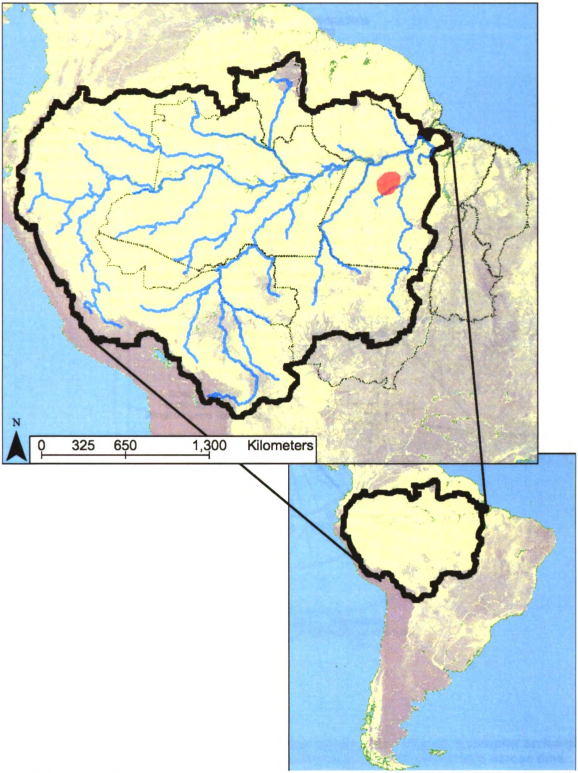

Figure 2. The Amazon basin with hydrologic network. The Brazilian Legal Amazon is shown as a dotted line. Though the Tocantins river basin, directly to the east of the Amazon basin, is often considered part of the Amazon, especially in Brazil, it is not shown here. Source data: MODIS imagery obtained in 2001, Hydrologic network and basin boundary from LBA-ECO project.

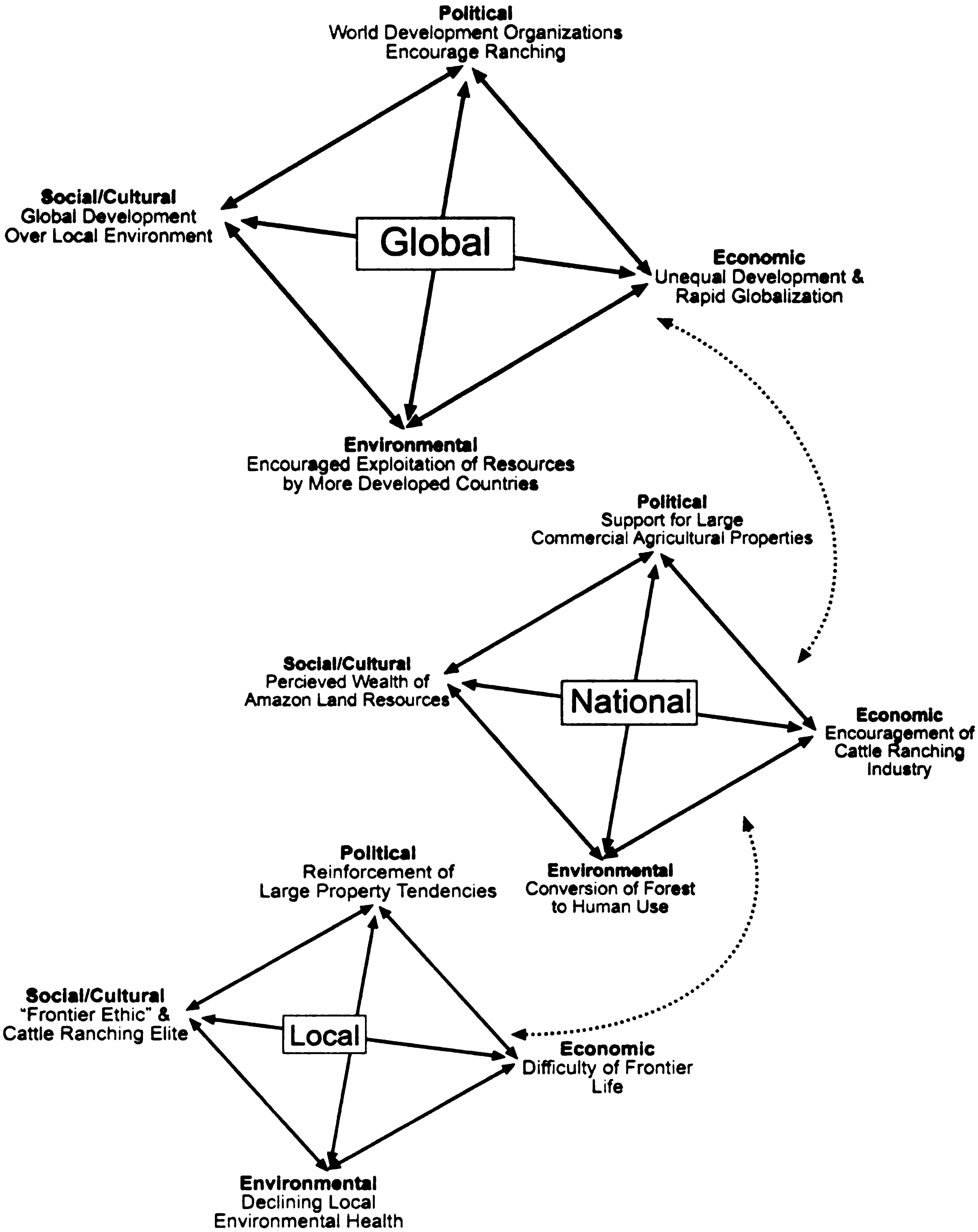

Figure 3. An illustration of how a Hollow Frontier comes about through a complex series of cultural, political, environmental, and ecologic interactions at varying scales across time. Based on the Kite model, from Campbell and Olson (1991:18).

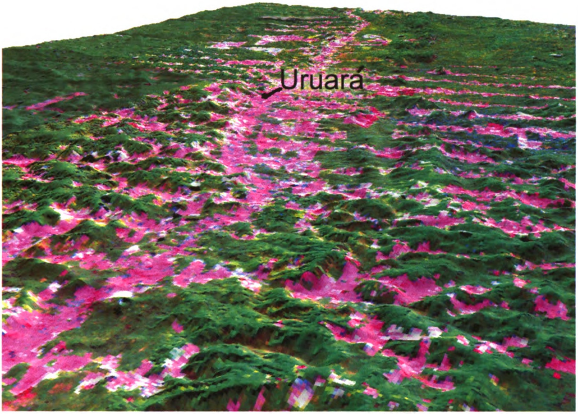

Figure 4. Relief of the Uruará area, looking Eastward toward Uruará along the Transamazon (BR-230). 5x vertical exaggeration makes the terrain variation more obvious. Source: Terrain information from SRTM data at 90 meter spatial resolution resampled to 30 meters for visualization purposes. Imagery data from Landsat ETM imagery dated August 9, 1999 (5,4,2 band combination).

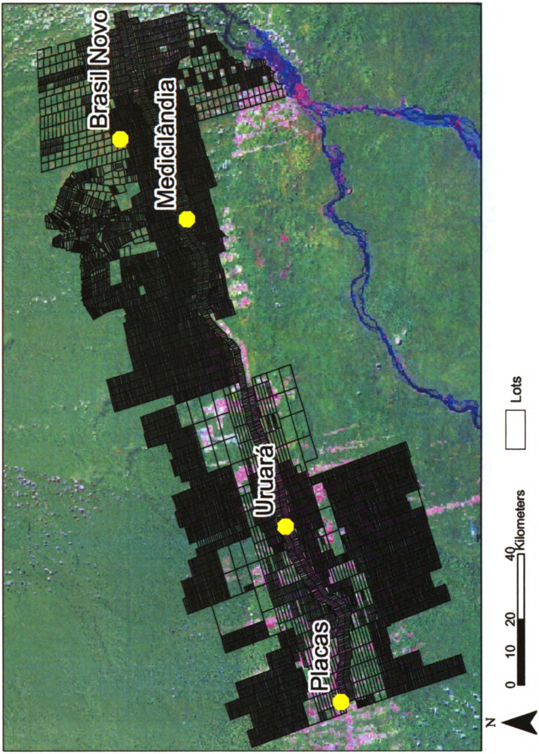

Figure 5. Lots in the Uruará area (between the towns of Placas in the West and Brazil Novo in the East), shown on satellite imagery. Source: Imagery data from Landsat ETM sensor dated August 9, 1999 (5,4,2 band combination). Land parcel information digitized from paper INCRA lot map.

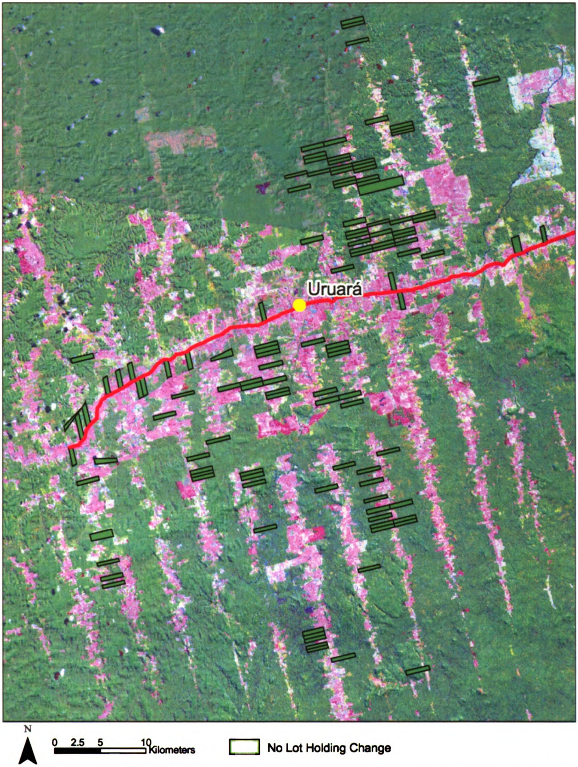

Figure 6. Location of stable land holdings in Uruará, shown in green. Stable land holdings occur both close to Uruará and far out on the colonization roads. Source: Land parcel location digitized from INCRA lot map. Parcel status collected as part of survey (Browder et al. 2001). Imagery data from Landsat ETM imagery dated August 9, 1999 (5,4,2 band combination).

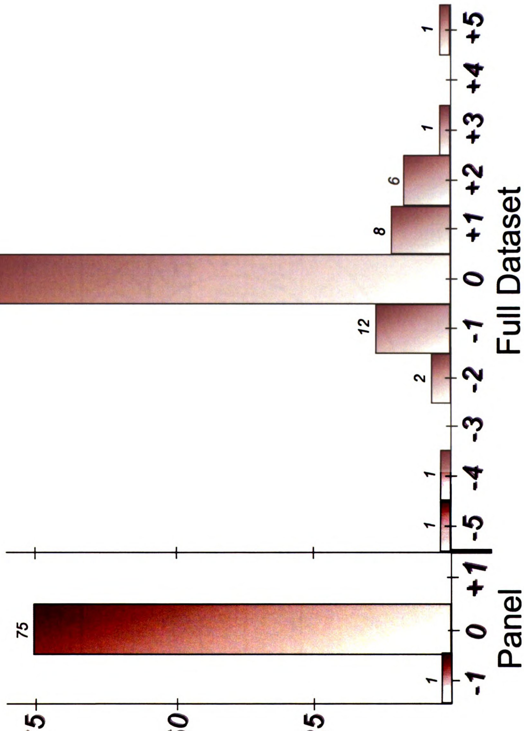

Figure 7. Histogram of property change between 1996 and 2002. Panel data changes are shown on the left, on the right property changes for the entire dataset are shown. Source: Data collected via survey (Browder et al. 2001).

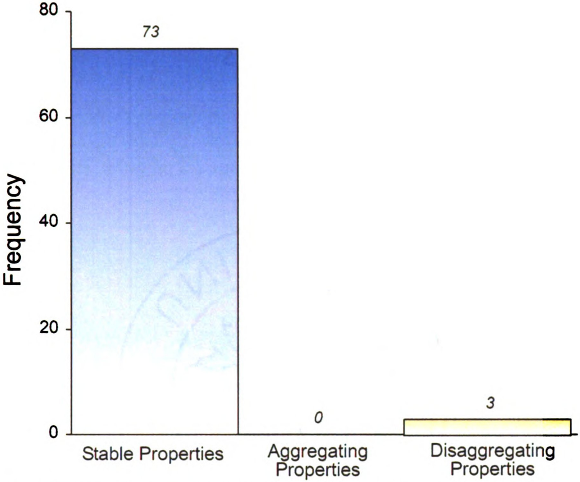

Figure 8. Property changes in Uruará property panel, 1996 – 2002 Source: Parcel status collected as part of survey (Browder et al. 2001).

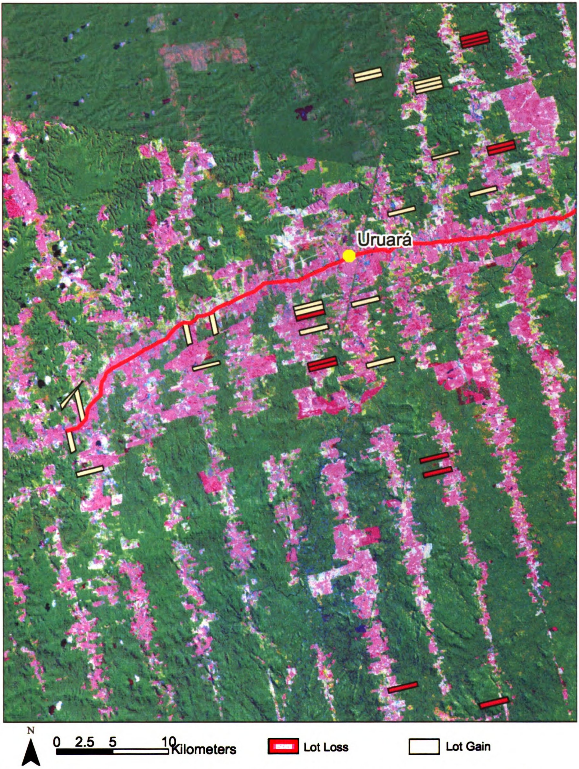

Figure 9. Multiple lot gains and losses between 1996 and 2002 in the Uruará area. Lot gains, displayed in blue, occur slightly more often close to the town of Uruará. Lot losses, shown in red, occur in more remote areas. Source: Land parcel location digitized from INCRA lot map. Parcel status collected as part of survey (Browder et al. 2001). Imagery data from Landsat ETM imagery dated August 9, 1999 (5,4,2 band combination).

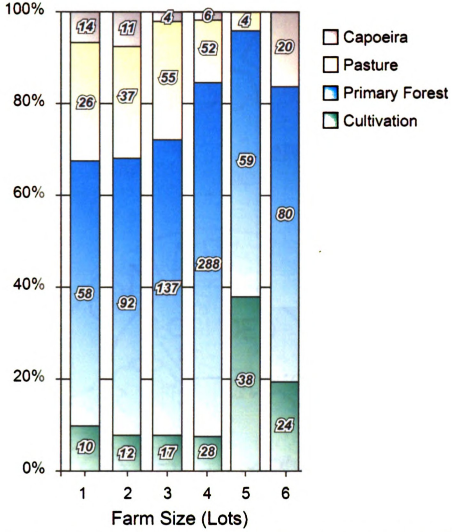

Figure 10. Average proportion of land covers and land uses by property size in 1996. Numbers within bars indicate average number of hectares per property in each land cover/use category. Source: Parcel status collected as part of survey (Browder et al. 2001).

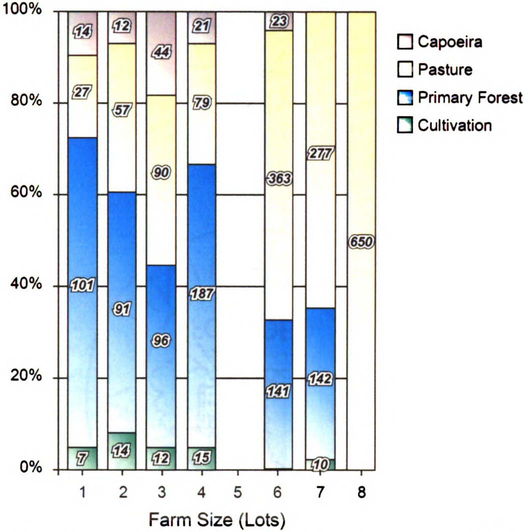

Figure 11. Average proportion of land covers and land uses by property size in 2002. Numbers within bars indicate average number of hectares per property in each land cover/use category. Source: Parcel status collected as part of survey (Browder et al. 2001).

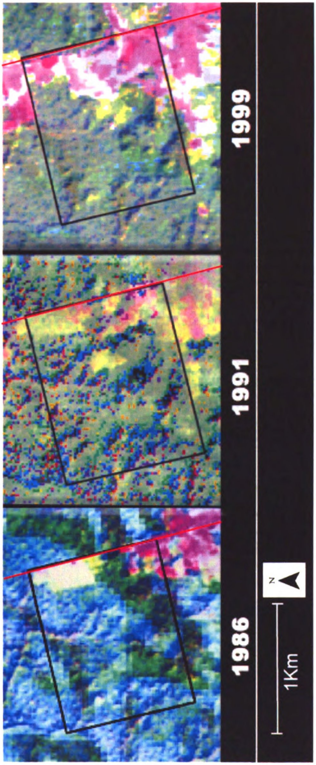

Figure 12. Property one, shown in 1986 (on the left), 1991 (middle), and then 1999 (on the right). Colonization road shown in red. Source: Land parcel location digitized from INCRA lot map. Parcel status collected as part of survey (Browder et al. 2001). Imagery data from Landsat ETM imagery dated August 9, 1999 (5,4,2 band combination).

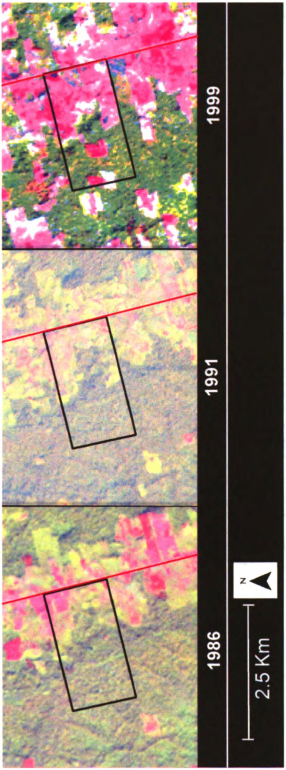

Figure 13. Property two, shown in 1986 (left), 1991 (middle), and 1999 (right). Colonization road shown in red. Source: Land parcel location digitized from INCRA lot map. Parcel status collected as part of survey (Browder et al. 2001). Imagery data from Landsat ETM imagery dated August 9, 1999 (5,4,2 band combination).

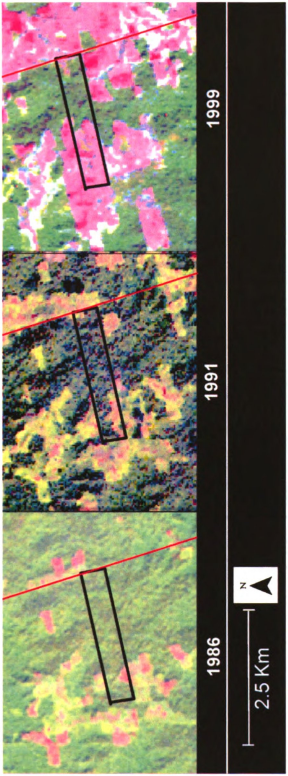

Figure 14. Property three, shown in 1986 (left), 1991 (middle), and 1999 (right). Colonization road shown in red Source: Land parcel location digitized from INCRA lot map. Parcel status collected as part of survey (Browder et al. 2001). Imagery data from Landsat ETM imagery dated August 9, 1999 (5,4,2 band combination).

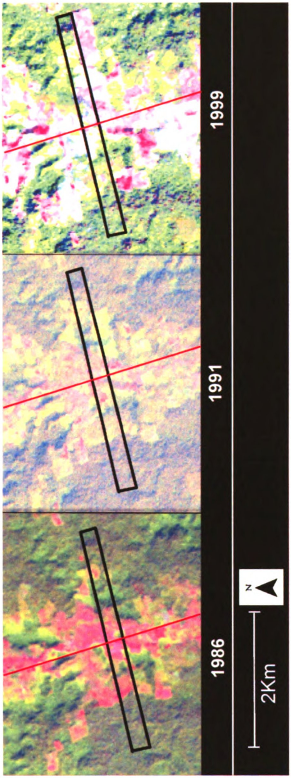

Figure 15. Property four, shown in 1986 (left), 1991 (middle), and 1999 (right). Colonization road shown in red. Source: Land parcel location digitized from INCRA lot map. Parcel status collected as part of survey (Browder et al. 2001). Imagery data from Landsat ETM imagery dated August 9, 1999 (5,4,2 band combination).