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Biomass Burning in Tropical Ecosystems

An Analysis of Vegetation, Land Settlement, and Land-Cover Change to Understand Fire Use in the Brazilian Lower Amazon

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BIOMASS BURNING IN TROPICAL ECOSYSTEMS: AN ANALYSIS OF VEGETATION, LAND SETTLEMENT, AND LAND-COVER CHANGE TO UNDERSTAND FIRE USE IN THE BRAZILIAN LOWER AMAZON

DISSERTATION

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DEDICATION

To

Gerald F. Sorrensen,

who always told me "Don't give up,"

and

Jo Ann Sorrensen,

who always said "Hang in there, babe."

ABSTRACT

Research in global environmental change emphasizes that biomass burning significantly contributes to increased atmospheric trace gases and possible climate change. Analysis of what drives anthropogenic fire is less thoroughly examined because such study involves investigation the human and physical dimensions of biomass burning at local and regional scales. This dissertation uses a multi-scale approach to address fire use within local and regional contexts. It investigates dynamics and effects of fire use within four rural communities with different settlement histories, then expands these findings to understand burning patterns in a larger agricultural frontier south of Santarém, Brazil's third largest Amazon city. The aim of the dissertation is to understand how landscape environmental factors and land settlement shape land-use practices and the burning patterns associated to those practices.

The dissertation integrates analyses of biomass burning at three spatial scales: regional, ecological field, and local. At the regional scale, a model of biomass change is developed from remotely sensed data (Landsat TM images path/row: 227/62; dates: Oct. 1986, Oct 1995) and used in combination with household land-use information to infer extent of biomass burning in the study region over a nine-year period. At the field scale, physical evidence of slash-and-burn agriculture is examined through vegetation inventories and measure of post-fire fuel loads in 14 agricultural fields. At the local scale, in-depth household interviews on settlement history, land-use strategies, and present/historical burning practices compliment physical evidence, to provide a fuller understanding of the local causes and impacts of fire use. Throughout the dissertation a geographic information system (GIS) is used to assess temporal and spatial characteristics of human settlement; and a global positioning system (GPS) is used to link vegetation information and settlement findings to land-cover classifications derived from remotely sensed data.

This dissertation advocates the need for local and regional studies on environmental issues to inform global environmental change research and estimation. It provides a framework that links human dimensions of biomass burning to larger global change issues. Findings in the dissertation contribute to the discipline of geography in the area of human/environment interactions.

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CHAPTER 1

CONCEPTUAL CHALLENGES FOR GLOBAL ENVIRONMENTAL CHANGE AND BIOMASS BURNING

As we near the end of the century, we are constantly reminded that the last 150 years of human activity has altered the composition and chemistry of the Earth's atmosphere and biosphere at rates, which are unprecedented. These activities include: (1) burning of fossil fuels to support mechanized agriculture and industrial activity, producing carbon dioxide (CO_2), carbon monoxide (CO), nitric oxide (NO), and sulfur dioxide (SO_2); (2) burning of vegetation to facilitate land clearance and provide energy, which contributes to atmospheric CO_2, CO, NO, methane (CH_4), and hydrocarbons; (3) permanent conversion of forests, woodlands, and grasslands to agricultural fields, depleting carbon stocks and possibly shifting the natural carbon flux; (4) increase in livestock and rice paddies to feed world populations which, through microbial metabolic processes, produces methane; and (5) daily use of human-made chemicals such as those in aerosol spray cans and refrigerator and cooling systems, which are sources of chlorofluorocarbons and hydrochloroflurocarbons (Levine 1991).

Whether effects of these human actions are detrimental or harmless to the Earth underlies continuing debate on global warming and other global environmental change issues. This debate began largely in the physical sciences, where research monitors physical systems and processes to understand how they function and change, and to anticipate possible impacts of those changes (Houghton et al. 1996). It has more recently spread into the social sciences where researchers address social implications or human dimensions of such change in order to ameliorate local environmental degradation, understand societal impacts, and form effective abatement policies (Turner 1990; Sachs 1993; Meyer and Turner II 1994). In recognizing that local processes, as well as regional forces, affect global environmental change, global change research increasingly requires multidisciplinary and integrative efforts from biological, earth, and social sciences. As such, researchers are facing large conceptual, methodological, and theoretical challenges.

The first of these challenges is the regionalization of global climate change. Predictions of global warming indicate change would not occur evenly across the Earth and highlight this geographic variation along with its implications for inequality; there may be some who benefit and others who do not (Meyer-Abich 1993; Banuri et al. 1996). Seasonal changes may include droughts or heavy rainfall, colder or warmer temperatures. Some nations may gain economically through changed precipitation patterns and extended agricultural seasons (Rosenzweig and Hillel 1988; Kaiser and Drennen 1993). For other nations, loss may be extreme. For example, continued sea-level rise under a warmer climate regime may inundate island nations such as the Maldives, Fiji, or other South Pacific Islands, while nations with long coastlines, such as Chile, may loose valuable territory (Lanfredi et al. 1998; Mimura and Nunn 1998; Wang 1998). In still other regions, particularly those with Mediterranean climate regimes, a warmer global climate may instigate more extreme weather variability, causing increased chances of flooding, drought, and other natural disasters.

To complicate these regionalized physical impacts is the realization that even similar degrees of change may impact humans in different ways dependent on their vulnerabilities, and resiliency or ability to adapt to change (Liverman 1994; Scott 1996). Wealthier nations can better afford to monitor extreme weather conditions, implement natural disaster plans and withstand potential short-term economic losses from global climate change. Populations in countries with fewer resources to expend on such matters are more vulnerable to climate change. The mere implications of risk due to global climate change may negatively influence economic value and thus harm certain populations more than others (Meyer-Abich 1993). For example, coastal areas may depreciate in value due to impending risks of sea-level rise or increased change of hurricanes and tidal waves. While climate change may be a global phenomenon, the diversity of potential impacts at regional levels make it a highly politicized issue and a complex challenge that cannot be addressed in a single uniform manner.

A second challenge in global change research is to develop methodological frameworks that adequately address causes and effects of potential global climate change. These frameworks need to be capable of bridging spatial scales because of the regionalization challenge mentioned above (Levin 1992; Wessman 1992; Pickett and Cadenasso 1995; Root and Schneider 1995; Moran et al. 1998). For example, to understand contributing factors to potential global climate change, data collected at the local level must be extrapolated to regional scales then integrated into global models. Conversely, any prediction of global climate change must then be filtered down to the local scale in order to understand how regional impacts will affect local populations. These demands for a vertically integrated conceptualization of space highlight the complexity and interdependency of our world and remain one of the greatest challenges of global change research (Meyer et al. 1992).

A third challenge imbedded in both the two mentioned above is the need for more sophisticated theoretical frameworks that effectively link cultural and socioeconomic processes to the biogeophysical changes that are occurring. The belief that human activity, in all its variant forms, has and continues to drive global environmental change is fundamental to our assertions that such change is a serious threat or problem. Thus to deny the human factor in investigation of environmental causes and impacts of global climate change is to throw the baby out with the bath water. Certainly any investigation of regional impacts or causes must also undertake analysis of the human populations targeted by those impacts or causes. In addition, as human-environment interaction is a spatial process, it holds implications at local, regional, and global scales that must be dealt with methodologically. The challenge of global climate change is a fundamentally human-created phenomenon and must be regionally, methodologically, and theoretically addressed as such.

Where and to what extent change will occur, what spatial scales need to be bridged, and how we can develop methods and theoretical frameworks to link social and physical processes, causes and consequences are the major conceptual challenges of global environmental research today. These challenges require geographical analysis, in visualizing spatial scales at which changes occur, in highlighting geographic variation and inequality through regional study, and in linking human cultural and socioeconomic processes to physical environment processes to understand the nature of environmental degradation.

RESEARCH PROBLEM

Biomass burning, or the burning of live and/or dead vegetation to clear land, for use as fuel wood, as a management strategy in agricultural practices, or through natural wildfire activity, is a global environmental concern that embodies the challenges of regionalization, methodological application, and theoretical development facing the global climate change community. Global biomass burning is considered one of the major contributors to increased greenhouse, or trace gas emissions, accounting for 40% of total increased carbon emissions in the past century and a half (Levine 1991). Gases produced by biomass burning also include chemically active gases (nitric oxide, carbon monoxide, methane, and hydrocarbons) that lead to the photochemical production of ozone (or smog) in the troposphere, and other gases (methyl chloride and methyl bromide) that lead to destruction of ozone in the stratosphere which is critical is shielding Earth's life forms from dangerous ultraviolet solar energy (Levine 1985; Mano and Andreae 1994). Biomass burning has also been found to contribute to particulate emissions, or the miniscule solid particles that perturb the transfer of incoming solar radiation, further impacting the Earth's climate. By major Earth biome, fires in tropical forests account for 15–25% of total burning, in temperate and boreal forests, 6% of total, and in savanna ecosystems where annual fire activity is a dominant disturbance mechanism, fire accounts for ~70% of total burning (Brown et al. 1993; Houghton 1994; Andreae 1991). The anthropogenic component of global biomass burning, which is the topic of this study, is estimated at 15–35% of biomass burning's total contribution, but appears to be escalating with time (Levine 1991). This means that regionally, methodologically, and theoretically, estimates of global biomass burning must increasingly account for an often capricious variable, human behavior.

The extent and overall detriment of fire varies regionally, depending on biomass content present within the ecosystem exposed to fire. Biomass content in Savanna ecosystems, for example, is relatively small (in comparison to Tropical Moist Forest, Temperate Forest or Boreal Forest ecosystems), with the only significant accumulation occurring in open woodlands or gallery forests that are distributed on Savanna edges or in gullies along rivers. Fire is a natural disturbance mechanism, occurring annually, to encourage comparable vegetative regeneration after fire has passed. At the other extreme, Tropical Moist Forests and Boreal Forest, contain huge amounts of biomass and when burnt emit large amounts of carbon that will not be recuperated through new vegetation growth for an estimated 150 to 500 years. Fire damage in these ecosystems has much longer-lasting implications than in Savannas. With such regional variation in biomass, modeling of fire activity and estimation of actual biomass burnt requires meticulous study of fire behavior within each major vegetative biome on the Earth.

Vertically integrated conceptual models are also necessary in order to accurately estimate the contribution of anthropogenic biomass burning. Specifically, data necessary for estimation are collected at various spatial scales and must be integrated to calculate the overall contribution of biomass burning to atmospheric emissions that force climate change. Biomass content, or the total weight of biomass within a specified area, is the first of these variables. It is estimated through field surveying at the local level, then extrapolation to the size of area exposed to fire. Fire efficiency, the second variable, is usually a constant derived from observation of fire activity within local ecosystems. The third variable, total area exposed to fire is usually derived from remotely sensed data collected at regional 1 km x 1 km spatial resolution. To calculate the overall biomass-burning estimate and evaluate the contribution of anthropogenic fire to global emissions, the local variables of fire efficiency and biomass content are vertically integrated through extrapolation to be compatible with the remote sensing information.

Yet, because we are talking about fire purposely ignited by humans, analyzing the interaction of physical processes with human behavioral processes is critical to provide a fuller understanding of biomass-burning issues as well as increase accuracy of the three variables used in biomass-burning estimation. For example, humans select the vegetation to be burnt, and therefore, the biomass content that is exposed to fire. They decide how much land to burn and thus influence the total area exposed to fire. They then decide when and how to burn this vegetation, potentially influencing the fire efficiency. But, while humans make all decisions related to the burning of vegetation, once fire is set, the final outcome is a reflection of both human decisions and physical properties in place at the time of ignition. Microclimatic conditions on the day of ignition play a particularly important role in the impact of biomass burning. Specifically, precipitation levels, temperature and wind velocity influence the dryness of the vegetation, how thoroughly fire burns and how easily it then spreads to areas beyond that intended to be burnt. The implications of this interaction between human and physical processes is as complex as the plethora land-use decisions and clearance practices in place around the Earth.

Despite the efforts of leading scientists, anthropogenic biomass burning continues to present challenges at all spatial scales: from the accuracy of global estimates of biomass burning to analysis of regional burning patterns to what regionally and locally drives land-use decisions and fire use as a land management strategy. While regional estimates have been calculated and refined since the early 1980s, less attention has been paid to understanding the motives for burning in a systematic way that links human processes with physical ones, as well as local dynamics with larger scales.

This dissertation places a local face on global issues of biomass burning. It draws on nine months' fieldwork in the Brazilian Lower Amazon, a meso-region on the eastern flank of the state of Pará, and looks at human practices of biomass burning through the lens of how that practice is associated with the environmental consequences of fire. Terrain in this area consists of a dense tropical moist forest ecosystem, intermixed with landscapes sculpted by human agricultural practices (Figure 1.1).

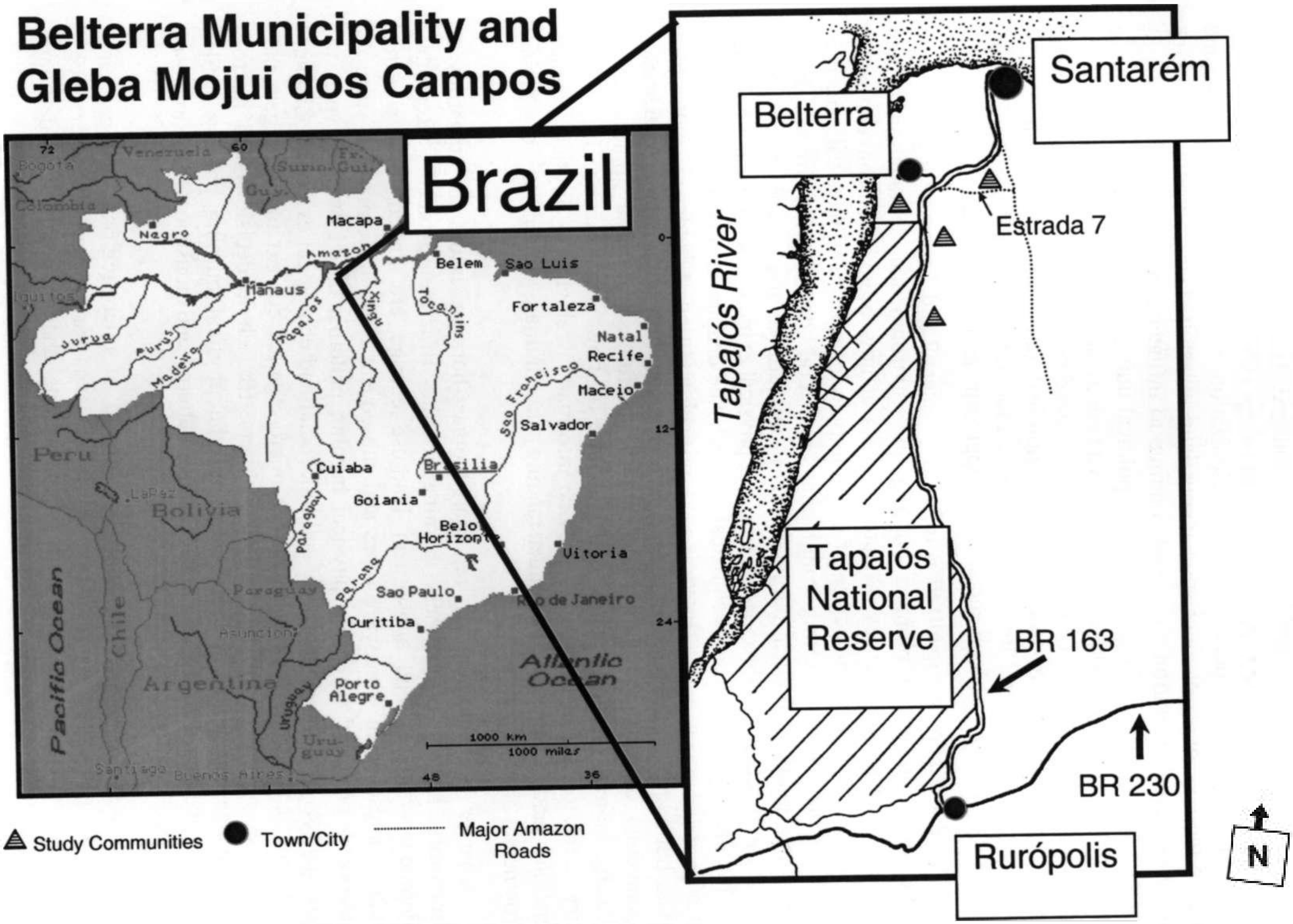

Figure 1.1: Map of Study Region

The spatial extent and degree of fire impact varies in this terrain, exemplifying the complexity of biomass-burning issues even at local scales. The region branches south and southeast of Santarém, Brazil's third largest Amazon city at the confluence of the Amazon and Tapajós Rivers. It comprises an agricultural frontier where settlement patterns are marked by federally planned colonization, recent land encroachment, and closer to the city, areas of older spontaneous land invasion. These settlement patterns have shaped past vegetation cover and continue to influence the frontier dynamics of the region, and thus, the fire activity. Two political units make up the region, Belterra Municipality, a recently incorporated county with administration centered in the town of Belterra, and Gleba Mojuí dos Campos, a neighboring area within Santarém Municipality. "Glebas" are usually frontier political units undergoing colonization administered by the Federal Institute for Colonization and Agrarian Reform. Together, the study region Belterra/Mojuí encompasses approximately 364,288 ha.

The dissertation is organized as follows. Chapters 2 and 3 review the substantive and theoretical issues on biomass burning and environmental degradation in the geophysical and social sciences. Chapter 2 looks at how biomass is conventionally addressed and emphasizes the degree of uncertainty in measurement, physical evidence, and causal mechanisms, resulting from human behavioral component of fire use. Here, variables that relate to physical burning patterns are outlined and provide a foundation to link social processes, anthropogenic fire, and physical evidence of landscape burning. While highlighting advances in ecological research, the chapter also points to the ways in which social science investigation is a critical addition. Chapter 3 approaches biomass burning from the opposite stance, by discussing how social science addresses environmental degradation. Here I evaluate the usefulness of these approaches in addressing biomass-burning issues, and elaborate on how social science theoretical inquiry needs to expand in order to provide information relevant to physical science estimations and contribute to understanding the human dimension of global environmental change.

Chapter 4 contextualizes regional biomass-burning issues by creating a contemporary history of biomass burning in the Brazilian Amazon. Regional development strategies and subsequent land-use change are linked to a shifting vegetative landscape in which fire types and subsequent trace gas emissions vary. A framework is proposed for using physical burning patterns, based on fire types, to analyze changes in anthropogenic fire and link social and ecological evidence. Chapter 5 places physical burning patterns within a micro-regional context to investigate the driving forces of fire use in agricultural frontiers. Household decisions and micro-regional change are linked to components of the physical burning pattern, while ecosystem properties directly influence burning patterns and household decisions on fire-use practice.

Chapter 6 provides an in-depth background of micro-regional changes and dynamics within four rural communities where fire use is part of agricultural practices and land invasion occurs in frontier areas. Micro-regional changes create the underlying pressures/incentives to resettle, which in turn creates specific burning patterns in the environment. Also discussed are the general physical characteristics of the study region, the nature of land tenure, and the agricultural system that includes fire-use practices.

Chapters 7 and 8 explore regional and local scales of biomass burning. Chapter 7 investigates biomass change through a regional analysis of land-use/cover change using satellite images taken in 1986 and 1995. Regional change analysis provides evidence of human intervention on the landscape and indicates fire types and frequency through the region. Attention focuses on forest cover change where burning implies larger loss of carbon stocks, and in younger succession change, where diversity indicates dynamics of agricultural practice. Chapter 8 looks at quantitative measures of biomass through analysis of 14 fallows sampled during fieldwork. These field sites provide information about physical change in biomass during the process of slash-and-burn agriculture. Specific measures are developed for pre- and post-fire biomass, fire efficiency, and area exposed to fire; and sites are classified by their biomass weights, structural characteristics, species composition, and diversity to form a base understanding of vegetation types farmers chose to burn.

Chapter 9, the final analysis chapter, explores linkages between regional and local physical evidence by bringing local household fire-use activity into a global environmental change context. It first looks at household decisions, burning practices, and land-use/cover change that have occurred in each study community. This information, in addition to the understanding of micro-regional development and change processes, illuminates both local and regional physical change and biomass-burning activity. Then, both physical and social information are integrated to estimate total biomass burning in the region in a form that can be comparable to other regional and global biomass-burning estimates.

Chapter 10 draws broader conclusions of the dissertation, discussing what local and regional analyses offer to global environmental change issues. Specifically, it discusses how analyses that mesh micro-regional change, physical landscape properties, and local rural community dynamics is necessary to more accurately understand global environmental change. It demonstrates how physical burning patterns are related to local, regional, and physical landscapes. It emphasizes the usefulness of viewing local fire-use practices in terms of physical burning patterns because social driving forces behind these patterns can then be placed in the context of larger global environmental problems. And last, it highlights local and regional level processes which are often masked at the global level, but which ultimately influence global changes.

CHAPTER 2

EXPLAINING THE ISSUES OF BIOMASS BURNING

Monitoring the emissions of carbon (CO_2) to the atmosphere is critical because CO_2 in combination with other trace gases, affects the heat balance of the Earth (Houghton 1991). Research documents a possibly alarming increase in the concentration of CO_2 in the atmosphere since the beginning of the twentieth century, with an estimated 250 parts per million (ppmv) in the pre-industrial era rising to an estimated 358 ppmv in 1994 (Houghton et al. 1996). Measurements from ice cores also suggest at least 15–26% higher CO_2 concentration levels in the atmosphere now than in the pre-industrial revolution era (Houghton et al. 1983; Siegenthaler and Oeschger 1987). In the last 30 years alone, continuous atmospheric monitoring in Hawaii indicates an increase of 11%. Whether the documented increase, and possibly altered climate, is detrimental or harmless underlies the continued debate on global warming and other global environmental change issues.

The largest form of carbon burning is fossil fuel use, the burning of liquefied organic carbon created from prehistoric carbon sources. Fossil fuel burning comprises approximately 60% of total atmospheric CO_2 (Houghton et al. 1996), and is attributed mostly to oil, gas and other petroleum products for industrial and mechanized agricultural purposes. These estimates are considered fairly accurate, to within < 15% (Houghton et al. 1983), due to the limited geographic distribution of regions that significantly use fossil fuel energy (the industrialized world) and the relatively detailed records these regions keep on energy use. In addition, burning of fossil fuel releases all gases in a single moment in time, making it easier to estimate the total impact of the burning (Fearnside 1997).[1]

Estimates from the burning of carbon matter in vegetation and soils, the second major contributor to total carbon burning, contain more uncertainty (Andreae 1991). Fire occurs naturally in many ecosystems, but burning increases are largely attributed to human land-use activities particularly land management strategies in agriculture, land clearance practices, and fuel wood use. None of these activities are fully understood nor documented because such knowledge requires thorough ethnographic study at the local scale. These practices usually take place in rural areas where records are not kept (Crutzen and Andreae 1990). They are widely distributed geographically across the world, even vary inter-regionally, and are subject to cultural variation at the local level. Many of these practices are considered traditional, becoming particularly susceptible to regional development. Last, as opposed to fossil fuel burning, the effects of vegetative and soil carbon burning are temporally expansive. While a burst of emissions occurs during the initial fire, decaying debris left over from the burn continues to emit gases for many years after. The natural decomposition rate becomes altered, often accelerating

[1] Other forms of burning, for example burning of vegetation, accelerate natural decomposition rates which continue long after the fire has subsided.

natural rates of decay and furthering overall biomass loss. Due to all of these circumstances, the task of accurately accessing carbon loss from fire in vegetation and soils is difficult and highly complex.

To model emissions from biomass burning, researchers extrapolate to the continental level from regional statistics on land-use change rates, ecosystems affected, and carbon storage rates in vegetation and soils. Yet, unfortunately the relative contribution of different human activities is poorly represented in these statistics as often activities overlap on the same land, are subject to distinct cultural practices, or are conducted within ecosystems that have natural fire regimes. In addition, vegetative regrowth occurs after most fires, the rate of which can depend on the ecosystem itself, the human intentions for the land, or a combination of both. New vegetation re-sequesters some of the carbon originally released to the atmosphere, making it difficult to measure how much atmospheric carbon actually remains and from what sources.

In this chapter, I elaborate on these biomass-burning issues whenever possible drawing from empirical studies of tropical forests, particularly, the Amazon Basin, and highlighting increasing uncertainty that emerges from continued human intervention in the environment. First, the role of vegetation in the global carbon budget and how it is critical to biomass-burning estimates is discussed. As vegetation becomes increasingly influenced by human land-use activity, complexity increases and uncertainties appear in natural or pristine forests. Next, general estimation procedures used in biomass-burning calculations are detailed. Variables used in biomass-burning estimation are all physical measures, yet, each is increasingly influenced by human activity, widening the gap of uncertainty in global estimates. Last, most recent estimates for the Brazilian Amazon are discussed to serve as the standards from which to evaluate estimates derived in the dissertation. Here, I re-emphasize the human element and the need for a more thorough investigation of the dynamics of anthropogenic fire that can only occur at the local level.

2.1 Vegetation and the Carbon Budget

Of basic importance in understanding the issues behind biomass-burning estimates is the global carbon flux. Actual models of the natural carbon flux in which carbon is cycled between the Earth and the atmosphere include oceanic and terrestrial biota, and have been thoroughly discussed elsewhere (Woodwell 1984; Trabalka and Reichle 1986; Post et al. 1990; Keller and Goldstein 1995). Here, I limit my discussion to the role of terrestrial biota, or vegetation, in the carbon flux as the uncertainties pertaining to vegetation are increasingly influenced by human land-use activity. For vegetation, the flux of carbon between the Earth's terrestrial biota and the atmosphere is represented by two types of processes: (1) rates at which carbon is released to the atmosphere from the terrestrial sphere through plant decomposition, burning, and oxidation of soil organic matter; and (2) rates at which carbon is absorbed by the terrestrial sphere from the atmosphere through the growth of live vegetation (photosynthesis) and the accumulation of soil organic matter (Houghton et al. 1987). Carbon absorption and release then make up the flux. The flux varies by specific ecosystem, implying an almost insurmountable task of analyzing carbon exchanges in each of the Earth's ecosystem types (the number of which is unknown). The flux also varies by land use as humans transform physical landscapes through deforestation, colonizing, logging, regional development, and agricultural activities.

Models of the global carbon flux are created with the assumption that there exists a natural balanced exchange of carbon between the Earth and the atmosphere. With this measure of balance in mind, researchers evaluate increases over and beyond the normal flux in atmospheric carbon content that is attributed to anthropogenic causes and considered unnatural. Such increase remains in the atmosphere, creating a radiative forcing, or the so-called enhanced greenhouse effect that absorbs long wave radiation emitted from the Earth's surface, warming the surface and lower atmosphere.

There are a variety of measures used for representing carbon emissions released from the environment. Net carbon flux, is the term used to describe the carbon concentration in the atmosphere which is not considered part of the natural carbon flux. Measuring it requires first estimating total carbon released at a particular time, termed the gross or prompt emissions, and subtracting an estimate obtained from a global carbon budget for what is natural to the atmosphere. More recent measures of net emissions account for delayed emissions as well, the emissions associated to a specific burn that enter the atmosphere in future years via decay of charred debris left from the original fire (Fearnside 1997).

In modeling the role of vegetation in the natural carbon budget to distinguish between net sources and gross sources of carbon from biomass burning, two underlying assumption are important: (1) that at some point in time, most likely pre-industrial revolution, the chemistry of the atmosphere was in some sort of natural steady balance; and once understood, this balance can shed light on the net carbon sources (the sources that are in addition to the natural steady state); and (2) that the terrestrial part of this natural steady balance exists because undisturbed forest vegetation is in a steady state as well, with as much carbon being respired as being fixed through photosynthesis; again once understood, net carbon sources as a result of unnatural forest conversion can be estimated (Lugo and Brown 1992).

Until recently, all forests and vegetation that make up the terrestrial biota, were considered carbon neutral or carbon sinks. Above and below ground biomass, organic matter in soils, and dead biomass within the forest ecosystem sequester carbon from the atmosphere, either neutralizing or actually "sinking" atmospheric CO_2. During natural fire and plant respiration carbon is re-released, but it was intuitively assumed that as forests grow, they take in larger and larger amounts of atmospheric carbon, balancing or neutralizing the global carbon budget by fixing carbon when necessary.

Current research challenges these assumptions about the global carbon budget. First, it is not clear that carbon content of the atmosphere was historically constant. Concentrations of carbon dioxide in ice cores demonstrate either that carbon concentrations have fluctuated over time or that the range of carbon dioxide constituting the natural balance is significantly wide. (Oeschger and Stauffer 1986). Second, this very wide range of atmospheric concentrations of carbon dioxide may be due in part to the "unsteady" state of the Earth's vegetation. Biomass content and accumulation rates in forests vary due to tree fall, natural gap dynamics and natural disturbance such as storms and fires (Salo et al. 1986; Brown and Iverson 1992).

Last, it is difficult to decipher exactly what are natural rates of biomass accumulation when the history of human intervention is extensive but not fully known. Many natural forest areas are now accepted as largely anthropogenic in origin, having been manipulated by indigenous populations in past centuries (Anderson and Posey 1989; Lovejoy 1991; Balée 1992; Coomes and Barham 1997). These forests evolve from burning and planting practices, species protection practices, and fortified soils that build up from human waste. Bamboo forests, Brazil nut forests, and Liana (vines) forests are a few of many forest types associated with ancient human settlement (Balée 1989). Other evidence leads to a new depiction of pristine forests as disturbance systems in which a combination of natural climatic perturbations and human settlement patterns shape forest structure (Piperno et al. 1990; Bush and Colinvaux 1994). Although whether ancient populations were initially attracted to these forest types and subsequently settled or human settlements actually created the forests cannot probably be proven. But in either case, human activity has been interacting with these forests for a substantial period of time. For example, Caatinga, a savanna-like forest covering over 200,000 km^2 in the Amazon Basin is thought to have developed as a result of repeated burning by indigenous groups over a 1,000 years ago (Smith 1980). Given recent ecological studies of forest ecosystem dynamics it is becoming increasingly unrealistic to assume a steady carbon state within forests and thus, a balanced atmospheric carbon concentration.

Yet, it is this very logic of a balanced global carbon flux which has lead researcher to predict that with rampant deforestation and fire activity, tropical forests are becoming atmospheric carbon sources. The encroachment of humans allows little room for vegetative regrowth after deforestation or fire and thus, suppresses the natural carbon re-sequestration process. Tropical forests are not only constantly trying to recover from degradation, logging and natural disturbance, but are also converted to permanent or shifting agricultural lands, and urban areas (Salo et al. 1986; Kurz et al. 1991). These disturbances affect forest composition and thus, the amount of existing biomass, and the rate of biomass regeneration. The history of land use prior to succession, cultural practices and societal pressures will also affect regeneration rates (Hecht and Cockburn 1989). As these very different vegetative landscapes cover more and more originally forested areas, it becomes very difficult to model a carbon budget. Given, the state of the environment now, it is probably most reasonable to think that there have been periods when forests were sinks and when they were sources (Lugo and Brown 1992).

The breakdown of the assumptions about the role of terrestrial ecosystems in the global carbon budget and the increasingly influential role humans are playing in transforming vegetation on the planet reveals a limitation to the underlying theoretical framework. Researchers rely on a baseline measure of an assumed natural system, the global carbon cycle. Measures of that baseline carbon flux are derived from models as well. While modeling remains the only feasible way to estimate the global effects of biomass burning on the atmosphere, it is important to identify where research at other spatial scales may highlight the uncertainties of assumptions necessary to form global estimates and provide information to refine global models.

2.2 Uncertainty in Global Biomass-Burning Estimates

Despite the aforementioned challenges to calculating the global carbon budget, the procedure for modeling biomass burning to derive CO_2 emissions is fairly straightforward. The total estimate of biomass burnt at a particular time is calculated using an equation with three variables. Depending on the inquiry of the research, the equation is applied by continent, region, ecosystem, and/or land-use activity. The results of individual calculations of biomass burnt (i.e., by region, continent, ecosystem, etc.) are then summed up to represent the global contribution. From here, CO_2 emissions from the total biomass burnt are calculated, usually as a ratio of 50% (Brown and Getson 1996). Last, the global emissions estimate is adjusted to account for natural levels of CO_2 in the atmosphere and the leftover portion is designated as the net atmospheric flux of carbon.

The general biomass burning equation is as follows:

$$B = f * l * c ,$$

where B = quantity of total biomass burnt, measured in grams of carbon per year (g C/yr); f = fuel load, an estimate of the total above ground biomass in a particular biome or vegetative cover, measured in dry mass per square meter (dm/m^2) or more commonly, metric tons per hectare (t/ha); l = total land area of the particular biome or vegetative cover that is exposed to fire, usually measured in hectares (ha); c = the combustion efficiency or completeness of the burn measured as the percent of initial fuel load lost in the fire (Seiler and Crutzen 1980; Brass et al. 1996).[2]

Using this basic equation, researchers search for ways to obtain more accurate values for each of the three variables: total land area affected, fuel load, and burning efficiency. In areas where little human intervention is assumed, values adhere strictly to physical measures of the particular biome. Researchers usually take the average of measures cited in a few reputable regional studies then extrapolate to the global level. In areas where human intervention is significant, the procedure for estimating emissions is still based on the general equation, but the derivation of variable values is a less direct process. For example, f as an indication of initial carbon content, is adjusted for carbon uptake in vegetative regrowth (Detwiler and Hall 1988). Population statistics, land-use change rates, and land requirements per capita are often used to derive values for the l variable (Seiler and Crutzen 1980; Detwiler and Hall 1988). Last, c is modified to account for land clearance practices, such as logging, which do not necessarily include burning (Detwiler and Hall 1988). With all variables the degree of uncertainty seems to increase with the degree of human intervention within a particular ecosystem

[2] In the literature on biomass burning, combustion efficiency, burn efficiency, and fire efficiency are all used interchangeably. I will use them interchangeably as well.

Fuel Load

The first variable, fuel load (f), is a physical measure of the initial density of vegetation in an area before the area is burnt. As density of biomass will vary between different types of vegetation, researchers modify the f value to reflect the Earth's major ecosystems or biomes in which the fire took place. The most common biome divisions are: boreal forests, temperate forests, tropical rain forests, tropical seasonal forests, humid savannas, dry savannas, and grassland (steppe). Most fuel load values are extrapolated to the global level from two extensive studies that systematically measure biomass density in various Earth biomes (Whittaker and Likens 1975; Myers 1980).

Fuel load is considered the most accurate of the three variables (Seiler and Crutzen 1980), yet uncertainties are widening. Within each major biome, a wide range of ecosystems exists making it difficult to accurately represent biomass density by a few major biome categories. For example, the range in biomass density for tropical rain forests in Latin America alone is 31–434 t/ha, depending on the openness of the forest (Brown and Lugo 1984; Fearnside 1997). Biomass estimates are also difficult in savanna areas which can represent diverse vegetative types such as, open woodlands, brush, grasslands or a combination of these three (Robinson 1991).

Uncertainties in the fuel variable corresponding to forests also exist due to discrepancies between average ecosystem biomass content and average biomass content in areas actually burnt (Detwiler and Hall 1988). This is particularly true in tropical ecosystems. Here, farmers and ranchers chose to burn portions of their forests that are denser than average, under the false assumption that thicker vegetation will contain richer soils for the intended cropland or pasture. Calculating overall biomass burning based on average biomass densities would lead to underestimation. Historically, forest conversion and subsequent burning was restricted to land with river access. These floodplain areas are often considered more fertile than upland areas, producing higher densities of vegetation than average for the ecosystem (Myers 1980). Biomass estimation can again be underestimated if higher biomass densities in floodplain areas are not accounted for. In addition, logging companies in their efforts to extract precious hard woods, often leave secondary and feeder roads that provide access to farmers and ranchers who apply fire management strategies within these logged forests. In this scenario, logged forests that are exposed to fire set by farmers and ranchers have already lost biomass and tend to contain lower than average biomass content for their ecosystem type. All of these circumstances highlight the connection between land-use history, local fire management strategies, and what vegetation actually gets burnt. In order to reduce uncertainty in biomass-burning estimation, the fuel load variable must be refined to account for human activity and decisions. The continued use of biomass density averages from general inventories weakens the accuracy of the overall estimate (Myers 1980).

Secondary succession is another recent addendum to vegetation categories considered in the fuel load variable creating complications and uncertainties in biomass-burning estimation. These areas represent previously deforested land that has been abandoned for a substantial period, such that the regeneration of vegetation has occurred at times attaining characteristic features of mature forests such as closed canopies and large biomass content. Shifting cultivation, an agricultural practice that slashes and burns land to plant crops and after a few years abandons the area as a fallow to regenerate naturally, increasingly burns secondary succession instead of primary forest. Biomass density of this secondary succession, is now under study. Estimates of biomass are significantly lower than in primary forests, ranging from 5 to 57.3 tons/ha (Uhl et al. 1988), and can vary by vegetation age and land-use intensification. (Fearnside and Malheiros Guimarães 1996). Human activity is increasingly manipulating ecosystems, exacerbating uncertainty and making the task of evaluating the fuel load variable ever more difficult.

Total Land Affected by Fire

The total land area affected by fire, *l*, is usually adjusted according to biome, human activity and continent. In areas where less degree of human intervention is assumed, such as, boreal and temperate forests, researchers extrapolate from previously published statistics. For example, statistics on total wood lost to forest fire available from the United States and the Canadian Forest Services, and are extrapolated to estimate total land area burnt in temperate and boreal forests, respectively, around the world (Seiler and Crutzen 1980). This has also been done in savanna areas with natural fire regimes using data available from forestry agencies in Australia. In areas specifically influenced by human activity, the *l* value is derived from statistics on population engaged in land-use activities with estimates of land required for each activity. These estimates usually involve extrapolating from the results published in one or two reputable regional studies to represent the whole continent in which the studies were conducted.

Deriving accurate values for total land area affected by fire contains many uncertainties. First, it is difficult to determine total land area affected by fire from agricultural surveys and population statistics. Debate exists over the quality of such data, particularly in remote rural areas where accurate head counts are difficult (Robinson 1989). For example, head counts of cattle are used in estimating forest conversion via burning to pasture (Seiler and Crutzen 1980). Yet, cattle ranchers often claim smaller herd sizes to avoid taxes. In addition, much overlap occurs in forest conversion to agriculture, pasture maintenance, road construction, logging, and permanent settlement (Robinson 1989). Area affected by biomass burning may be better understood by looking at combinations of land-use activities (Uhl and Buschbacher 1985).

Using statistics of population engaged in land-use activities is also of limited value in assessing the area affected by accidental fire which loses control, burning areas larger than the intended agricultural site. Swidden farmers in some parts of Thailand build fire lines to prevent fire escape. In places in the Amazon Basin, farmers use the bordering vegetation as a zone for the fire to die out. Total area burnt and area intended for burning may be very different. Tree mortality rates in secondary and logged forests adjacent to burnt agricultural fields have been found to range from 79–99% (Uhl and Buschbacher 1985). Estimating the degree to which biomass is burnt in these agricultural border zones is an added effect of fire-use practices not only remains overlooked in most biomass-burning estimates, but which depends both on microclimatic conditions of the day and cultural fire-use practice.

Combustion Efficiency

The third variable, *c*, is the ratio of total biomass density in an area exposed to fire to the actual quantity of biomass burnt during the fire. It is adjusted in a similar way as *l*; by biome in areas where human intervention is assumed minimal or by biome, land-use activity and continent in areas where human intervention prevails. In a setting unaffected by humans, combustion efficiency is dependent on the dryness and distribution of the fuel load, as well as, microclimatic conditions of the day, such as wind and precipitation. In a setting in which humans are actively using fire in land management strategies, this variable is difficult to obtain accurately as the influence of the human component layered over fuel load distribution and micro-climatic conditions creates complexity at even local scales.

To begin with, natural fires may have a human component. As mentioned earlier, most biomass-burning estimates of temperate and boreal wildfires extrapolate from statistics of burn loss per unit area available in the United States and Canada, respectively. This causes problems in that other countries with large temperate forests may deal with natural fires differently. For example, the Commonwealth of Independent States tends to let fires in remote regions burn themselves out, a fire management practice very different from the prescribed fire strategies used in the United States (Robinson 1989). Not much is known about fire strategies within China, another large country where boreal forests exist. In addition, statistics from Canada and the United States are averages taken from a predetermined number of years, but when used in biomass-burning estimates they are assumed to represent a specific year (Robinson 1989). Thus even seemingly natural fire disturbance often has a human element embedded within it.

In tropical regions where most fire activity is the result of human land-use practice burning efficiency is particularly complex due to the influence of cultural practices in combination with the physical landscape. Techniques of slash-and-burn agriculture vary tremendously within individual continents and throughout the world (Peters and Neuenschwander 1988; Fearnside 1991; Steenberg 1993). Some practices require re-burning leftover fuel from the initial burn, increasing the long-term combustion efficiency at the site. Other practices leave this material to decompose, or use it as domestic fuel. Crutzen et al. (1980), when they calculated what is considered to be the first thorough global biomass-burning estimates, overlooked the potential of human influence over fire efficiency. They assumed a 90% combustion rate for crop residuals across all biome categories in their 1980 seminal study. Yet, estimates from West Africa suggest that fire consumes only 37% of above ground crop waste, while wetness in some tropical areas may prevent burning of any agricultural waste (Robertson and Rosswall 1986; Robinson 1989). Uncertainty mounts even more in regions where there is a natural fire regime in combination with land-use practices. Here, efficiency depends on how much of the existing vegetation is resistant to fire as well as the human techniques of fire-use land management strategies. With such variation in the human component, it becomes difficult to derive a combustion efficiency value useful to extrapolate to continental scales (Robinson 1989).

Last, the time scale makes *e* particularly confusing as leftover charred wood from the original fire may continue to decompose for many years or be re-burnt in the next round of fires. Burning efficiency of the original fire does not account for accelerated decomposition or charred leftover debris both of which may actually serve to increase combustion efficiency in subsequent fires (Fearnside 1997; Schroeder and Winjum 1995). Yet, when calculating the overall impact of biomass burning, these issues must be addressed, for they accelerate natural processes and influence the outcome of further fire activity. An example of forest conversion to pasture makes this quite clear. Often large logs are left partially burnt after the initial forest fire. Grass seed is planted and pastures are maintained through subsequent more frequent fires (every other year or so) that continue to burn away at the original charred logs. Some researchers claim that subsequent burns triple the amount of carbon loss from initial forest fires (Fearnside and Malheiros Guimarães 1996; Schroeder 1996).

2.3 Current Biomass-Burning Estimates of Brazil

An estimated 50% to 70% of all biomass burning is associated with land-use practices by humans living in the Brazilian Amazon (Myers 1991). Estimates of biomass burning in Brazil have been calculated since the mid-1980s. The biomass burning equation discussed in the previous section underlies each study, though how values for equation variables are derived is not at all consistent. For example, how ecosystems are delineated, how area exposed to fire is determined, what overall time span or region is considered, and how fire efficiency is measured all vary by study. This makes direct comparison between studies virtually impossible. However, discussion of the underlying assumptions, results, methods, and uncertainties within each study is useful as it highlights the diversity in how one can define biomass burning and the areas where further understanding of human motives and resulting fire activity would be welcomed to refine estimates and minimize uncertainty.

Table 2.1 shows estimates from three recent studies. While results of all studies were published in the late 1990s, the base year used in each study is 1990. In Fearnside's study (1996, 1997), emission estimates cover the Brazilian Legal Amazon. This is a political delineation established by the Brazilian government and encompasses, not only the tropical moist forests bordering the floodplains of the Amazon river, but also the savanna and tropical dry forests that exist further out from the river. Results are calculated by vegetation cover within each state with an assumption that the percent of total state deforestation can be divided in proportion to the vegetation cover types within the state. In other words, if 40% of a state's vegetation cover was savanna and total state deforestation was 10%, 40% of that 10% would be assumed to have occurred in savanna. Considering human fire-use practices, there is no real logic to this assumption. Fire activity occurs where populations are present, and their presence is not likely in proportion to the state's various vegetation covers. It is also likely that those who use fire, bias their decisions toward certain types of vegetation cover over others. In addition, Fearnside's study uses a standard burning efficiency ratio of 33.2% through the whole Legal Amazon region. This too does not seem completely logical, because regardless of human fire-use practice, certain vegetation covers are more prone to total combustion than others.

Table 2.1 Recent Estimates of Biomass Burning in Brazil

*Fearnside, P. 1996, 1997	CO_2: 228 t x 10^6	Brazilian Legal Amazon	1990	33%
	CH_4: 1.39 t x 10^6			
	CO: 35.04 t x 10^6			
	N_2O: 0.16 t x 10^6			
	NO_x: 758 t x 10^6			
	NMHC: 1.26 t x 10^6			
Schroeder and Winjum 1995	CO_2-C: 174–233 x 10^6 Mg C	**Brazil**	1990	
	Tropical Moist Forests: 69–97 x 10^6 Mg C			27%
	Agriculture (re-burns): 62–93 x 10^6 Mg C			60%
	Fires in Degraded Forests: 75 x 10^6 Mg C			60%
	Savanna (Cerrado): 27–35 x 10^6 Mg C			100%
	Degraded Grassland: 10 x 10^6 Mg C			100%
Kauffman et al. 1995	No Estimate	No Estimate		42–57%

* Estimates are from the low trace gas scenario.

Schroeder and Winjum (1995a, 1995b, 1996), in a second recent study, come up with very different overall estimates. Their calculations are for the entire country, thus, including the industrialization and mechanized agriculture processes occurring in the south, and conclude that Brazil contributes between 4% and 5% of the global carbon emissions. Schroeder and Winjum subdivide their estimates by ecosystem and activity to produce estimates that are somewhat more easily comparable to Fearnside's estimates. Note the estimates for tropical moist forests, agricultural re-burns, and burning of degraded forests. Yet, Schroeder and Winjum's estimates remain lower than Fearnside's for a few reasons. First, Schroeder and Winjum are interested in presenting a model of annual carbon flux in Brazil and thus, account for carbon uptake in secondary forests. Fearnside's study does not account for such uptake. Instead, it attempts to measure total committed emissions from a single year and thus, tries to account for all carbon that eventually will be released from one year's activity. Schroeder and Winjum are also more sophisticated in their values for the fire efficiency variable by ecosystem, using 27.5% for tropical moist forests, 60% for secondary succession and 100% for savanna. There results dramatically show the impact of the combustion efficiency variable on the overall estimation of biomass burning.

Last, Kauffman et al., (1995), has a thorough study on biomass burning in Brazil. Unfortunately, they make no measure of total land exposed to fire, nor attempt to expand to other ecosystems in the Amazon other than the tropical moist forests that are the focus of the study. They do not extrapolate to larger scales to create regional biomass-burning estimates, but do present estimates of combustion efficiency in forests that are significantly higher than the estimates of Fearnside, or Schroeder and Winjum. Their results highlight the variability that may be occurring when those who set fires, continue to do so on a landscape with varying vegetation cover types. Evidence in the Kauffman et al. study claim that 42–57% of total above ground biomass of slashed primary forests is lost during the burning process.

2.4 CONCLUSION

In this chapter, I have discussed information on global biomass burning coming from physical scientific research. At the global level, climatologists and geophysicists have combined population, land-use change, and deforestation estimates to calculate overall biomass-burning activity that sheds light on the possible amount of CO_2 and other greenhouse gases released into the atmosphere. Knowledge we have at the landscape level has come from biologists, agronomists, and foresters who focus on developing biomass density estimates, understanding the effects of vegetation regrowth, and role of this growth as well as primary forest production in the global carbon flux. While echoing the contributions and uncertainties of global and landscape research, I have emphasized here the potential effects of transitioning landscapes in the natural carbon flux and the difficulty of differentiating natural from human-influenced vegetative covers.

In addition to these major issues in biomass burning, this chapter has highlighted the actual calculations of biomass burning in which uncertainties are increasingly arising due to human activity. For gross emission estimates, these are:

- The carbon stock as represented in biomass density
- The total land area affected by fire
- The combustion efficiency

In addition to the above variables, net emission estimates account for possible natural carbon fluxes due to biomass density in replacement vegetation.

While all of the variables of the biomass burning equations and estimates are physical measures, I imply in this chapter that *actual* values assigned to physical variables are increasingly dependent on nature-society interactions. Biomass density within an ecosystem is increasingly affected by historical land-use practice, changing land-use activities, as well as, the ecosystem's natural recovery capabilities. Size of land affected by fire reflects more and more on human decisions to burn land and population change, but also depends on the natural fire regime and the vulnerability of bordering vegetation to accidental fire from agricultural fields. Combustion efficiency depends, not only on the fuel loads and the dryness of the vegetation, but on how much a human has decided to slash, how many subsequent burns he/she chooses to do, and how he/she intends to use the area. Last, the uncertainties of the physical variables in biomass-burning estimates become even more complex when combinations of land-use practices overlap and transformed landscapes produce a mosaic of vegetation covers with varying carbon stocks. This increasing human facet is mentioned in biomass-burning estimates, but it is not adequately represented in global models. While certainly global modeling efforts are valuable and should continue, the problems mentioned above emphasize the need to understand burning patterns, as an interaction between physical and human elements at landscape levels across the Earth.

In the physical sciences the society-nature interaction focuses on the descriptive effects of human activity on the environment. It does not look thoroughly behind the social causes of such activities and thus, is limited in understanding human disturbances. The social science perspectives delve more deeply into the driving forces behind environmental degradation, but are weak in understanding the physical landscape patterns that evolve from land-use practices. These emerging landscape patterns are equally vital to understanding biomass-burning issues because of their abilities to re-sequester carbon. Both approaches to analysis are valuable in studying the role of biomass burning in global warming because only through understanding human causal forces in combination with the physical environment can we develop more sustainable practices.

In the following chapter I look more critically at social science perspectives of society-nature interaction to demonstrate the strengths these perspectives provide in analyzing human disturbance in the form of fire use. The social causes of biomass burning have not been empirically nor, theoretically examined in the nature-society literature. Instead focus remains on land degradation, deforestation issues, and general environmental destruction. Thus, I draw from these social science frameworks, keeping in mind the theoretical issues of the global carbon budget, and the physical variables necessary to quantify biomass-burning calculations.

CHAPTER 3

SOCIAL SCIENCE PERSPECTIVES OF ENVIRONMENTAL DEGRADATION

Whereas, physical scientists document human intervention upon the physical environment, the strength of social sciences is in providing explanations of why and how such intervention occurs. This information is particularly important in developing mitigation strategies, predicting future needs, and highlighting potential vulnerabilities, both social and biophysical. In this chapter, a discussion and critique of selected social science models is supplied with particular focus on broad nature-society explanations of environmental degradation. Until very recently, environmental degradation was theorized at local to regional scales without much acknowledgement of the linkage of local environmental change to global climate change. Social science perspectives reflect and have historically been limited by this oversight. Thus, issues such as global biomass burning have been reduced to studies of slash-and-burn agriculture, and little social scientific inquiry has been generated on the larger concern.

Aside from this oversight, the nature-society discourses on environmental degradation are an important starting point from which to expand to global environmental change issues such as biomass burning. In this chapter, two standard models, neo-Malthusian and neo-classical economic, are mentioned briefly along and their potential to evaluate biomass-burning issues is discussed. Then variants of human ecology and political ecology are addressed in more depth. The dissertation benefits particularly from these later two perspectives. To evaluate the effectiveness of these perspectives three questions are asked: (1) what are the key concepts of the model? (2) how do these concepts explain biomass-burning issues? and (3) what are the flaws in the argument when placed within the context of global environmental issues? In conclusion, a formulation of adjustments to contemporary social science theories is suggested in order to address biomass burning at a global level and set the stage for the methodological approach used my research presented here.

3.1 THE NEO-MALTHUSIAN MODEL

The neo-Malthusian model is a dominant perspective in discussions of environmental degradation. The model is rooted in the notion of carrying capacity first mentioned by Thomas Malthus in the early nineteenth century who observed that while human population increases exponentially, food production only increases arithmetically, periodically creating periods of over population with limited food resources. While ignored for a long time, Malthus' implication of finite Earth resources re-surfaced within the neo-Malthusian model in the 1960s just as accelerated population growth rates and environmental crisis hit developing countries simultaneously (Woods 1989). The reinvigorated theory saw population growth pressuring the Earth's natural limits to the point where the Earth would eventually lose ability to sustain its human population (Meadows et al. 1972; Daily and Ehrlich 1992). Within the developing world context, the argument was particularly focused on land-use change and saw accelerated population growth as prompting land scarcity, resulting in intensification or expansion of land under use both of which resulted in environmental degradation (Ehrlich and Ehrlich 1970; Brown 1987).

Further modifications of the population argument came from theories on agricultural change and rural peasant studies (Chayanov 1966; Boserup 1981). In these theories, local consumption demands as brought on by population increase, drive land-use change, particularly in the form of technological advancement. The argument was formed optimistically to imply that improved living standards occurred indirectly from these technological advancements as brought on by population increase. However, others utilized the argument to explain the connection between population and environmental degradation because it implied that country economic improvement required increased population and consumption. But as developing countries saw sharp rises in environmental degradation with population increase, the argument ended up reinforcing Mathusian claims. Agricultural change occurred with population increase, but environmental degradation still prevailed as the Earth natural limits were confronted.

Explaining Biomass-Burning Processes

The population perspective, as leading to land intensification or land expansion, has a variety of implications for altering regional biomass-burning patterns. Land intensification can lead to a shortening of crop/fallow cycles (Turner II et al. 1993). Fire occurs more frequently but the total biomass exposed to fire decreases as vegetative regeneration is limited by the shortened fallow length. Land intensification also leads to other forms of agriculture that eliminate fire use altogether, such as mechanized farming or certain permanent agriculture or agroforestry practices. Land expansion scenarios imply, new land invasion onto abandoned lands or primary forests. The range of biomass exposed to fire is much larger as both secondary succession and forest are targets for agricultural practice. A third, less visible explanation is that population pressure and land scarcity in one region is an impetus for land invasion in another region (Bilsborrow 1992). Thus, while on the frontier populations are sparse and land abundant, population pressure remains a driving force through migration. New land invasion brings similar burning patterns as those described above through the land expansion. Last, increased population can lead to increased political pressure to improve infrastructure, such as road building, that encourages others to migrate to the area, perpetuating the cycle of population pressure, land expansion and subsequent burning (Fearnside 1986).

Critique

Many researchers are critical of the carrying capacity argument. They claim that the definition of the carrying capacity is wrapped up in non-physical environment aspects such as, the system of land management, external demands and pressures, and the impacts of technology (Unwin 1988). It becomes difficult to measure what is sustainable for the environment from what is not, and thus the fine line between sustainability and destruction becomes arbitrary. In addition, many contend that the choice for a human to reproduce is a rational response to economic conditions, and thus, focus of analysis should shift from raw counts of population to the political and economic contexts that perpetuate poverty, influence reproductive choices and subsequent demographic processes (Stonich 1989; Olson 1994). The argument of land scarcity is further weakened by criticism revealing the unequal distributions of land (Hecht 1984). In this case, displacement of people is less a result of population pressure and more a legacy of inequitable land tenure systems. And last, land-use change and environmental degradation can arise in areas of low very population densities (Hecht 1993). In the Brazilian Amazon, the majority of deforestation comes from forest conversion to pasture, an agricultural strategy associated with very low population densities and usually not driven by local consumption needs. Ranchers tend to be wealthier business people who were never displaced from other regions. The connection between population and environment is not always direct when looking at a disaggregated level.

3.2 The Neo-Classical Economic Model

The neo-classical economic perspective is another standard social science model and approaches environmental degradation from the standpoint of resource use. It argues that market competition provides the best mechanism for natural resource use, allocation, and management. Under an ensuing private property system, each individual land user will act in her/his best interest by rationally managing resources to maximize profits. Idle land may continue to be brought under production, thus, extending the agricultural frontier, provided that costs of forest conversion undercut benefits of forest preservation (Southgate and Whitaker 1992). When land resources become scarce, land users begin to turn toward conservation measures such as, investments to improve present land holdings, enclosing the frontier region while continuing to use land resources in the most efficient manner (Southgate and Whitaker 1992).

Environmental degradation occurs when the mechanism of market competition is undermined, such as in common property resource use that results in the Tragedy of the Commons (Hardin 1968); or, when farmer ability to act rationally and maximize profits is circumscribed either through market distortions, such as occur with land scarcity and labor surpluses, or institutional constructions, such as, in certain frontier land tenure regimes (Hecht and Cockburn 1989; Ozorio de Almeida 1992). In the former case, the scenario is as follows. Open access to resources which occurs when property is commonly shared (as opposed to private or publicly regulated property), allows individuals to act selfishly, exploiting the resource base to the eventual detriment of themselves and every other user (Feeny et al. 1990; Roberts and Emel 1992). As resources become scarce, there is no competitive incentive to search for more efficient resource use, extraction, or management. Over use occurs because each individual user can externalize costs, passing part of total resource use cost onto others. Thus, resource use and management appears more efficient than it is.

Frontier land tenure regimes cultivated unique circumstances that further environmental degradation according to the neo-classical economic model. Under frontier conditions, environmental degradation occurs when maximization of profits is circumscribed by pressures placed on settlers to demonstrate land occupancy and secure usufructuary rights. The most visible and accepted method to demonstrate occupancy is to clear forested areas of the land which preempts any long-term resource development strategies using forest resources and can eventually lead to environmental degradation (Pichón 1996b). Because of the conditions of the informal tenure regime, settlers are forced to clear their land and cannot make the rational decisions to maximize profits. In addition, market distortions emerge when frontiers begin to close, land scarcity arises, but continued incoming immigrants create labor surplus. Wages are suppressed, diminishing labor's share of profit. This disproportionately benefits landowners who become more economically powerful, out competing smallholders who are forced off their land into more remote forested areas where they further the cycle of environmental degradation (Ozorio de Almeida 1992; Walker and Homma 1996).

Explaining Biomass-Burning Processes

The neo-classical economic perspective provides a number of insights to our understanding the persistence of fire use, but is problematic in providing adequate solutions. First, through the concepts of efficiency and rational decision making, neo-classical economics provides a very logical explanation as to why fire is used to clear land. To individual farmers in the Amazon, fire is a very efficient land management tool with few comparable substitutes. It requires little skilled labor and temporarily increases soil fertility without costly inputs such as fertilizers and insecticides (Dove 1983; Moran 1993b; Kleinman et al. 1995). In contrast, mechanized land clearance is very costly in terms of machinery rental, acquisition and maintenance, while the weight of machinery compacts soils, limiting their productive life (Toledo and Serrão 1982; Hecht 1984). Fire is also used as a maintenance technique to eliminate the persistently growing weedy materials of tropical areas. Other maintenance techniques are either more labor, such as weeding and composting the debris, or capital consuming, again convincing any rational minded farmer to use fire in his/her land management strategy. Last, fire use is a land management strategy to secure informal or formal usufructuary rights. Land clearance is an effective sign of occupation.

Environmental degradation resulting from fire use is also explained through the model's tragedy of the commons scenario and theory on external costs. Being a virtually free land management strategy, the practice of burning land passes the external costs of carbon emissions onto the atmosphere, a global commons that is particularly difficult to manage. Burning land also passes costs of lost biodiversity onto all other users. But while explanations are forthcoming, the solution seems overwhelming. How do we place a dollar value on the global implications of increased carbon emissions? How do we then break down this monetary number to establish policies that force and internalization of this cost? Dealing with regulation of global commons is overwhelmingly difficult.

There are still further frustrations with this model. The neo-classical economic model infers that improved land management strategies, which would potentially diminish the use of fire, will not occur until land becomes a scarce resource. In the Brazilian Amazon this implies privatization and occupation of an immense amount of rainforest area, which would lead to massive deforestation, the burning of these slashed forested, loss of biodiversity and a fragmented landscape. An alternative scenario would be to safeguard large areas as public property reserves to be regulated by government. Yet, because of the immensity and remoteness of the area, effective policing is virtually impossible.

Last, according to the argument, privatization would create an atmosphere in which land management strategies, such as fire use, would be utilized in the most efficient manner. Farmers would no longer feel pressured to burn their forests to establish use rights. Legal title and subsequent land security, would then encourage land owners to be more conservation oriented, perhaps allowing them access to loans for land improvements (often a legal title is prerequisite to obtaining a loan), and eliminating pressures to invade and burn other areas (Southgate and Whitaker 1992). In turn, burning patterns would shift away from primary forest areas and might be eliminated, if land improvements were substantial. If modernization continued, this could lead to mechanized farming or other technological innovation. Yet, this scenario is somewhat unsatisfying because it merely switches the form of burning from vegetation to fossil fuels. In the larger picture, carbon emissions still occur.

Critique

At the local level, in maintaining a neo-classical economic perspective, many researchers overlook the importance of how survival needs and desires are culturally molded; how resources may be socially constrained; and how even social factors may constitute resources (Wells 1991). Critiques that compliment these assertions emphasize the importance of external factors such as land tenure, government policies, and class position in the internal organization of resource management (Grossman 1984; Little et al. 1987; Collins 1988). Still other critiques of the neo-classical economic perspective focus on the rationality and adaptive strategies of small landholders, and point to the ecological sustainability of many more traditional land-use strategies (Dove 1983; Brush and Turner II 1987); or, on the potential sustainability of common property resources when informal regulations are employed (Bromley 1992; Ostrom 1992; Singh 1994). Last, according to the neo-classical economic perspective, land scarcity is the precursor to improved management strategies. The nature of many frontier areas is that land is abundant (Pichón 1996b). The implications of creating land scarcity are immense.

3.3 The Human Ecology Model

The human ecology approach marks a sharp contrast to the two model previously mentioned because it actually incorporates the physical environment into its theoretical perspective. In the human ecology approach, study is based within a particular ecological system. Obligatory relations, interdependencies, and causal relationships, between living and non-living entities within the ecosystem are fundamental, with the acknowledgement that the ecosystem structure itself will influence the nature of these relations (Moran 1990). When humans are viewed as part of the ecosystem, attention is paid to the ways in which they adapt physically, culturally, and behaviorally within their physical environment (Moran 1990). Analysis also looks to understanding the structural similarities of the human population and other biological populations within the ecosystem. Environmental degradation results when cleavages in the interdependent structures occur through human impact or disturbance that is exogenous to the initial system and considered not adaptable.

In the human ecology approach, the ecosystem or landscape is modeled, to understand how it functions, and then requirements for humans adaptability within the ecosystem are assessed (Moran 1993b). The landscape itself can be seen as a spatially heterogeneous area that is characterized as containing structure, function, and change (Turner 1989). Structure is the spatial distribution (or pattern) of energy, materials, and organisms as reflected in size, shape, number, and combinations within an ecosystem. Function is the flow or interaction of the energy, materials, and organisms within or between ecosystems. Change is depicted as disturbance or modification in the structure and functions through time. In biological terms structure, function and change can be viewed as environmental constraints, regenerative processes (death, birth, and dispersion of species), and disturbance, respectively (Urban et al. 1987). Each characteristic can be analyzed at varying temporal and spatial scales, and the interaction of the three characteristics makes the landscape more or less conducive to each one of its influences. Thus, the varying magnitudes of the characteristics simultaneously create the existing pattern and influence future pattern formation.

Explaining Biomass-Burning Processes

Those utilizing the human ecology approach have contributed greatly to our understanding of how indigenous land-use practices develop ethno-scientific knowledge of the environment to create elaborate and sustainable resource management strategies (Anderson and Posey 1989; Denevan et al. 1989; Dufour 1990). In terms of biomass burning, this work highlights the sustainability of slash-and-burn agriculture practices given land abundance and low population densities (Dove 1983). Relatively small areas are cleared and burnt. Fire temporarily transfers minerals stored in slashed vegetation back to soils, fortifying them for agricultural purposes (Kleinman et al. 1995). After a few years of agricultural use, which depletes soil fertility, these areas are left to fallow and eventually recuperate to their original vegetation cover. Carbon emissions released in the burn are theoretically re-sequestered as the replacement vegetation eventually returns to its original status in terms of biomass density and carbon stock.

Because of its specific understanding of how the ecosystem functions, the human ecology view also sheds light on situations where conditions for adaptability begin to break down, and burning practices become detrimental. During the burning process a portion of plant mineral content is oxidized, escaping into the atmosphere as trace gas emissions or as particulate matter which may either remain in the atmosphere or settle downwind of the burnt area. The remaining portion of original plant mineral content within vegetation is located in charred debris or is then transferred back to the soils via ash after a burn subsides (Ewel et al. 1981; Christanty 1986). Thus, due to the atmospheric loss, each recurrent burn has potential to transfer fewer and fewer nutrients back to the soils. The period of abandonment usually accommodates for this nutrient loss, but slash-and-burn agricultural strategies can become maladaptive within an ecosystem if fallow periods are shortened and fire frequency over the same area increases.

Critique

Human ecology is based on the assumption that an ecological system is in existence and as such, is subject to criticisms of all systems approaches. At the core of this system's framework is the assumption that the natural state of the system is in equilibrium, and thus, nature has a mechanical regularity and tends toward states of stability and homeostasis (Odum 1984; Moran 1990; Bryant 1992). This assumption homogenizes both time and space, and ignores the issue of how the system originated in the first place. It also denotes any system irregularity as a disturbance rather than part of the system and thus, provides no sophisticated means for further understanding of the disturbance.

Time, as seen through the systematic base of the human ecology perspective, is cyclical. Historical time with its emphasis on irregularity of environmental and ecological functioning is not easily placed with this cyclical perspective (Bryant 1992). Yet, historical time is particularly pertinent to the development of humankind and its interaction with the physical environment. For example, documented studies show increases in fire activity associated with increases in human settlement. In the same era, fire prone vegetative species gave way to fire resistant species, creating a new savanna ecosystem type. The context of the time period transformed the former ecosystem. To use an example more pertinent to this research, current global environmental change scenarios examine the accumulative effect of human action over time, and compare it to historical climate evidence (Blaikie and Brookfield 1987; Turner II et al. 1990). If examination of environmental degradation remains mired in a cyclical analysis, then any disturbance whether entirely nature induced or not will be considered foreign to the cyclical nature of the system. In order for human ecology to theoretically incorporate global environmental change phenomena, it must incorporate a conceptualization of time that accounts for historical change.

Spatially, the landscape is hierarchically oriented under the human ecology approach, which requires human intervention in conceptualizing the hierarchy. Spatial hierarchies constrain the notion of space to scale-dependent relations that can be decomposed into processes for quantitative study (Odum 1971). Yet, to decompose the systems requires some sort of prioritizing or limiting of aspects to be studied, without specific guidelines as to how such prioritizing should take place. As such, prioritizing is based on human perspectives. In addition, spatial and temporal contingencies often combine to form irregularities or patches of disturbance and systems approaches do not handle such contexts in a consistent manner (Zimmerer 1994). These changes are limited to being perceived as temporary instabilities within the system, which will eventually be overcome when balance of the system returns.

Even if equilibrium truly exists in the system, it is still very difficult to establish what that equilibrium is, for we do not necessarily understand where in time the equilibrium originated. As principles of equilibrium focus on the regularity of environmental variation, they do not account, nor analyze the unequal abilities of specific organisms to adjust to a changing environmental scenario, altering or creating a new system (Zimmerer 1994). Certainly, human populations can be characterized by differing capacities to adapt to environmental changes, especially taking into account human agency, cultural beliefs and societal values (Bryant 1992). In focusing on the adaptive abilities of human populations, human ecology overlooks cultural or economic situations that may favor some populations over other.

Last, and most importantly, the naming of a phenomena as a disturbance does not provide an adequate framework to study the disturbance. Instead it focuses on disturbance impact, which though certainly important, does not give us a means to analyze how the disturbance evolved or how to ease its effect. Some researchers who work within the ecosystems model classify disturbance based on frequency, duration, and spatial scale (Uhl 1990). While certainly disturbance is more likely to be addressed consistently using a classification, there is still no means for analyzing processes that create the disturbance, only for describing it. For example scientists are quick to imply that population increases have created disturbance in an ecosystem in the form of deforestation of new lands or decreases in fallow cycles. But, complexities of demographic change are not just manifestations of human reproduction. They can be tied to many social and economic processes. There is no place within the focus of the ecological system to thoroughly investigate these disturbance processes, when they reside outside of the system.

3.4 The Political Ecology Model

The political ecology approach represents a fourth theoretical framework to address environmental degradation. Central to this perspective is the argument that regional, national, and international political and economic systems influence local dynamics and land-use decisions. Aspects such as, farmer rationality, demographic conditions, and technological levels, become the background to understanding the unequal social relations that shape these aspects and allow one sector or entity to extract benefits or surplus from another (Blaikie 1994). In doing so, political ecology explicitly adds spatial scale to the analysis. Though the previous perspectives may incorporate information at different spatial scales, space is not inherent to the argument as it is in political ecology. Spatial distribution of resources, technology and economic growth are key as they emphasize inequality and highlight questions of why certain economic sectors have changed relative to others. In the last two decades, political ecology research has grown in sophistication to provide a wide variety of explanations to environmental degradation, but there are consistent themes: poverty, marginality, government policy, economic structural forces, and inequality. In this section, I discuss three variants of the political ecology approach: the pluralistic variant, the Marxist variant, and the development driven variant.

While the term "political ecology" dates to the 1970s (Bernstein 1972; Cockburn and Ridgeway 1979), if there is a seminal work on its theoretical framework, it would probably be Blaikie and Brookfield's *Land Degradation and Society* (1987). In it the authors try to explain a seemingly contradictory situation: why users of the land may act in ways that are destructive to the very land for which they are dependent on for survival. The authors' strategy is to examine the land manager or direct user of the land, his/her household needs and environmental constraints, and the regional pressures that impinge upon both these needs and constraints. A chain of explanation emerges in which the causes of degradation shift away from the direct user of the land, and are associated to the historical, economic, and political context in which the land user finds him/herself (Blaikie and Brookfield 1987). In answer, then, land users have no choice but to react to larger impinging forces through land-use activities that may harm long-term viability of their land.

This chain of explanation is considered pluralistic. Linkages between local and regional socioeconomic factors will exist, but which specific linkages are critical to explaining the environmental problem under study is contingent on the situation at hand. The justification for a pluralistic outlook instead of a single hypothesis approach comes from the complexity of three underlying characteristics of the nature-society relationship as it unfolds in environmental degradation. First, there exist interactive effects between the environment and society through time. The natural conditions of an environment can encourage or undermine social development and vice versa. Second, the spatial scale at which costs and benefits are allotted may differ from the scale at which land-use decisions are made. Thus, environmental degradation to one person may result in capital accumulation for another. Last, there exists debate between the criteria used for land degradation and that used for beneficial social change (Blaikie and Brookfield 1987). Different social groups hold competing definitions of environmental degradation, and, as such, plurality is inevitable.

In contrast, the Marxist variant of political ecology explains degradation through analysis of the structural economic forces of capitalism that create specific unequal social relations to production (Watts 1985). In many rural third world settings, unequal social relations to production result in a reproductive squeeze that local households experience as they increasingly rely on commodity production for their livelihood. The terms of trade for the rural products they sell perpetually weakens in comparison to market items deemed necessary for household consumption. This leads to intensification of production and/or reduction in household consumption, beginning the squeeze of the household trying to survive (Bernstein 1978 and 1979). Five environmentally degrading scenarios occur: (1) land-labor intensification forged by inequality and the reproductive squeeze increases the risk of ecological deterioration on the lands of poor households; (2) inequality also determines location of environmental problems: marginalized households are not only more vulnerable to environmental problems, but ecological problems occur in areas where humans are more marginalized; (3) surplus extraction often gets transmitted to the physical environment in that poorer households must extract the surplus in ecological terms from either their own lands or common property areas; (4) the increasing pressures of the reproductive squeeze can explain the disregard of more traditional strategies which could better adapt to the environment; and (5) high fertility among poorer households and its potential pressure on the ecosystem is a direct result of the persistence of high risk economic situations embedded in the social relations of production (Watts 1985).

The last variant of political ecology alludes to the role of government policy in providing incentives for economic development or production schemes and consequent push or pull forces that shift populations (Durham 1995). This variant looks more specifically at the historical context, but provides a consistent framework based in the regional development process, so is not pluralistic. Here inequality forms through two interrelated pathways, the first one being created by capital accumulation and the second by a basic cycle of impoverishment. On the upper capital accumulation pathway is a production scheme that is driven by foreign or domestic demand which is external to the local population, and is encouraged by government incentives to expand into frontier or unoccupied regions. Production schemes can range from cattle ranching to mineral exploration to logging and are usually lucrative in the short run, generating revenues which can then be invested in further expansion and further revenue generation. Consolidation of land is a by-product of the expansion and leads to displacement of any previous occupants. Short-term destructive land-use practices lead to immediate environmental degradation.

Operating simultaneously with this accumulation-expansion-accumulation pathway is the impoverishment pathway that initially is formed as a result of the displacement of the local population produced through the accumulation cycle. As these people lose access to resources necessary for their livelihood, they are forced to: (1) expand unto marginalized, less productive lands; (2) intensify activities on their own land perhaps by shortening the fallow cycle; and/or (3) incorporate cash crops into their land-use practices. Each of the three options ultimately leads to further degradation through soil erosion and a weakening of soil fertility, or deforestation. Continually declining yields on this land then reinforces this cycle. The outcome is either a cheap labor force that then supports the upper accumulation cycle or results in out migration to other areas where presumably the poverty cycle is re-established.

Explaining Biomass-Burning Processes

The political ecology perspective provides an explanation for biomass burning removed from the actual site of fire use. It therefore, is useful in explaining regional trends given specific development conditions. On a general level, environmental degradation is the consequence of population displacement and poverty. The displacement of populations encourages land expansion that usually involves burning of primary vegetation often on lands deemed fragile for the intended use. Poverty causes land intensification that eventually leads to land abandonment and encroachment onto new lands. Biomass burning is linked to the historical patterns of rural development. Scenarios would include: (1) government policy that neglects agricultural development in settled regions, encouraging out-migration toward the new frontier; (2) the failure of government to enforce access prohibitions to protected areas, making land invasion feasible; (3) lack of jobs outside of agriculture due to slow industrial growth; (4) government regional development which stimulates encroachment onto tropical forests, such as road construction, or other infrastructure development. Political ecology adds a dimension overlooked by the other perspectives as it is often focused on understanding processes underlying disturbance. It also brings into consideration that perceptions of environmental problems as espoused by different groups of people are as significant as the actual physical degradation.

Critique

One of the main critiques of the political ecology approach concerns the issue of pluralism and lack of a solid base in theory (Black 1990; Peet and Watts 1996). Without a clear guideline on how to select the linkages in the chain of explanation, there is no theoretical means to understanding why certain factors become links in the chain while other factors do not. Under such an approach, "degradation can arise under falling, rising, or stable population pressures, under an upswing or downswing in the rural economy, under labor surplus and labor shortage; in sum, under virtually *any* set of conditions" (Peet and Watts 1996:8).

A second criticism argues that while designed specifically to address ecological problems, political ecology does very little to incorporate the actual features of local social dynamics and physical landscape. Explanation is tied up in structural forces that impinge upon the local household, but neither the local household nor its physical environment are seen as having ramifications within the regional political economy (Black 1990; Painter 1995). "Any analysis that places total blame on structural or international forces is unappealing because it ignores the tremendous diversity of local initiatives and responses to external pressures, and because it falsely implies that those external pressures are exerted in a coherent way from an internally homogenous source" (Painter 1995:11). An analysis that weighs local dynamics and responses equally to exogenous forces would produce a multidirectional analysis, providing "an opportunity to express a dialectical relationship between the political economy and the environment, rather than simply observing the former on the later" (Black 1990:45).

Political ecology analyses also tend to bias environmental problems in specific sorts of contexts, which limits its potential as a universal theory. Context is most often a rural location within a third world, usually post-colonial setting, making the historical connection particularly palpable. The nature of political ecology is to look for causal mechanisms outside of the study region and in these contexts such mechanisms are more visible. This overlooks analysis of household evolution and frontier dynamics in a rural system itself, and how these dynamics uniquely articulate with specific regional urban forces.

In critique of the political ecology approach, many social scientists present convincing arguments as to the relevance of local level features. Yet, one such feature, the actual physical environment is not thoroughly investigated. While the environment can form part of the research problem, its structural properties and processes are not a part of the analysis. This is commonly the case in political ecology where researchers are concerned with social causes while the actual physical environment, its systematic properties and resiliency to perturbations, is often covered in a small descriptive background section. The land user is the smallest unit of analyses and research questions evolve around what influences his/her land-use decisions. Yet, when environmental problems are not at the scale at which land users make their decisions, such as in biomass-burning issues, appropriate research questions may never be asked.

There seems to be very little ecology in political ecology, and what exists, is limited to a simple discussion of the degradation and not a sophisticated understanding of how human practice results in measurable physical detriment, nor of how measurable physical detriment then conditioned certain human practice.

3.5 Summary

From the discussion above, a variety of social science explanations appear as to how environmental problems evolve from nature-society interactions. In summary, these are:

- population pressure
- unregulated, open access resource use and external costs
- disturbance or the application of environmentally maladaptive land-use strategies
- capital accumulation, marginalization of populations, and unequal distribution of wealth

Also in the discussion, I briefly explored the capabilities of these perspectives of addressing biomass-burning issues delineated in the first chapter. Population pressure is a nicely visible causal variable and expresses the implications of burning patterns associated with land expansion or land intensification scenarios. As shear numbers, the population variable can be easily aggregated to the global level, perhaps explaining why it is such a popular scapegoat for environmental crises. Numbers alone, however, do not express the less visible political and economic contexts that influence reproductive choices, migration patterns, and land/fire-use patterns that are not population driven. As we will see in the following chapter, the most detrimental land/fire-use patterns in the Brazilian Amazon are not population driven land expansion or land intensification, but are related to medium and large-scale cattle ranching operations (Hecht 1993; Faminow 1998).

The neo-classical economic perspective provides an ambivalent picture of fire issues because it addresses management strategies *only* in relation to resource use. This does not transfer well when the scale of the environmental problem does not match the scale of the resource use. At the global scale, biomass burning has large external costs that are extremely difficult to quantify, let alone internalize to each individual user. Within the neo-classical economic perspective, land expansion is acceptable and viewed as a precursor to resource scarcity. Yet, privatization of immense areas of land in frontier regions to combat rampant deforestation and forest burning is daunting. It is not always feasible at the time when that land and the atmosphere are most threatened. In addition, any chance for innovation or technological advance that would limit fire use merely leads to either a shift in the type of organic matter burnt, vegetation to fossil fuels, and in theory, still remains dependent on resource scarcity.

Human ecology shows us the role of fire within the landscape and when it can or cannot work in an ecologically sound manner. For this reason, it is an important layer in the understanding of biomass burning. It also places specific emphasis on local level human adaptability, where one can see individual decision-making processes.

Unfortunately, its focus on adaptive strategies can overshadow understanding of the larger changing environment in which those strategies play out. Causal mechanisms that lie outside of the region of study cannot be understood on a sophisticated level from this perspective alone. Frontier regions where most deforestation takes place, are often seen as resolutions to more congenital structural problems that lay outside the region (Pichón 1996). They are particularly susceptible to outside forces by their very nature of being highly dynamic, newly developing areas (Kasperson et al. 1995). In addition, through the local purview of human ecology, it is difficult to address environmental problems that are global in scope, but may not be visible at the local scale where adaptability exists.

Last, political ecology seeks to unmask the less visible historical, political and economic forces that impact local decisions. These forces broadly shape the nature of land-use change, and thus biomass burning associated with that change. The political ecology perspective also highlights the land user as the phenomena of study then branches out to question what influences each land user's decisions. Answers are historical, political and economic processes, explained largely through impoverishment and capital accumulation. The perspective does little, however, to credit ingenuity at the local level or provide quantitative linkages to the physical landscape, which is necessary for biomass-burning estimates.

3.6 Conclusion

In addressing biomass burning, each nature-society perspective seeks to understand the forces that propel environmental degradation. What is not as clear from these perspectives are the actual environmental effects at the local level. The physical environment forms the research problem but is rarely included in the research methods. Human ecology does make connections between land-use changes and landscape cover changes, but is limited in tapping into the influential positions of larger social and economic forces and in analyzing larger environmental problems dislocated from the local activity. Political ecology makes connections between social causes of land-use change and the actual environmental consequences of landscape changes, but often falls short in providing detailed information of landscape change and how it impacts future land-use decisions. Such detailed analysis is critical in assessing overall global danger and in developing appropriate mitigation strategies at the scale at which fire activity is occurring.

In the following pages, I create an analysis based in physical understanding of the landscape and prospects for human adaptability, while layering in an understanding of larger social forces that impinge on local dynamics to address specific environmental issues that hold local-to-global implications. While in political ecology the unit of analysis is the land user, and questions emphasize what forces impinge land-use decisions, I use the physical burning pattern as the unit of analysis, then question how regional change, household decisions, and landscape ecology influence this physical evidence. In this way, ecology becomes more central to political ecology without losing the thorough investigation into social causes that is its strength as a social science perspective. In addition, it affords an analysis critical to understanding larger global biomass-burning issues without impairing important local level knowledge.

CHAPTER 4

A CONTEMPORARY HISTORY OF BIOMASS BURNING: REGIONAL DEVELOPMENT IN THE BRAZILIAN AMAZON AND BURNING PATTERNS

To exemplify the usefulness of the approach proposed in the previous chapter, this chapter provides an overview of regional development within the Brazilian Amazon, and the consequent fire use and vegetation cover changes. While most of this information is not new, integration of both socioeconomic and physical landscape changes provides a picture of fire-use dynamics as a critical part of the contemporary environmental history of the Brazilian Amazon. It also puts ecology back into political ecology, the necessity of which I argued for in the previous chapter. Last, the intention of this chapter is to supply a meso-layer of information linking the local context of the study region to the larger issues of global biomass burning.

Since the early 1960s, regional development in the Brazilian Amazon has emphasized national integration, land occupation, and the attraction of private investment. The building blocks of development were the construction of major road corridors that transected the Amazon territory (refer to Figure 1.1), linking more prominent Amazon cities to the nation's southern more industrialized centers, while opening immense areas of unoccupied land along the eastern and southwestern flanks of the Amazon. Throughout the 1970s and mid-1980s, regional development plans moved away from emphasis on basic transportation infrastructure and shifted between medium to large-scale corporatist development, and fleeting attempts at populist social and agrarian reform. Cattle ranches, spontaneous land invasion, and planned colonization produced the largest and most spatially dispersed land-cover changes during this time period. Other large-scale projects, such as, mining and hydroelectric power were implemented in the 1980s, while logging persisted throughout this period as well.. Last, urbanization, a largely overlooked but predominant face of Amazon regional change, emerged as smallholders saw less and less possibility for survival in the agricultural frontiers.

Fire was present in almost all of these shifts of land occupation, use, abandonment, and re-occupation. The burning of primary forests was not only a precursor to initial road construction, but new roads encouraged human encroachment into bordering forest areas and further burning. The physical landscape began to exhibit a patchwork of younger vegetation covers that were much more vulnerable to natural or anthropogenic fire. Cattle ranches funded through corporate development projects required the deforestation and burning of large contiguous areas, while spontaneous and planned land occupation set into motion increased agricultural activity that utilized fire land clearance practices. Mining depleted carbon stocks through deforestation and the continuous burning of fuel woods to feed mineral processing. Logging indirectly influenced fire activity by creating openings in the forest canopy that increased forest vulnerability to fire, while providing human access via logging feeder roads to more remote areas.

In this section, I mesh regional development changes with subsequent fire use to establish a fire typology and conceptually link fire types to land use and regional landscape changes, keeping in mind the perspectives of political ecology and human ecology. I first consider the major trends that led to regional change in the Amazon, specifically colonization and spontaneous land invasion processes, the role of federal development of corporatist livestock practices, large-scale projects, logging, and urbanization. Next, I discuss the linkages of biomass burning to these regional changes by presenting a typology of fire and investigating the physical burning patterns associated to land-use change. I argue here that throughout regional development, fire use is central to regional change and has shifted as dramatically as land use itself.

4.1 Initial Road Construction, Planned Colonization and Spontaneous Land Invasion Processes

The Belém-Brasilia Highway was one of the first major corridors to be constructed as part of Brazil's concerted effort to develop the Amazon. This asphalted road transected the eastern flank of the state of Pará, connecting the major port and second largest Amazon city Belém, to the nation's capital. The intention was to attract private investment, by providing infrastructure. Few additional development projects were planned along the road to maintain capital within the region and promote true regional development. Instead, regional change was unguided and disorderly. As a consequence, spontaneous land invasions burgeoned, but smallholders received little technical assistance or land security measures from government agencies. Land speculation led to inflated land values and immense private landholdings, pressuring smallholders off their land. Approximately 5.4 million hectares of public property in the state of Pará shifted into private hands at this time (Browder and Godfrey 1997). In the following 20 years, 2 million people and 5 million heads of cattle settled along the highway (Moran 1993a; Mahar 1989). Patches of pasture land, small towns, and agriculture crisscrossed the landscape of eastern Pará, while displaced smallholders created a cheap labor force that eventually migrated to the Amazon's growing urban centers.

Continued infrastructure build up characterized development plans for the late 1960s. Transportation projects received 40.5% of the government promoted incentives, while 1.4% trickled down to small farmers (Milikan 1992). Policy was to be oriented toward the establishment of "development poles" with specific emphasis on the western Amazon states (Amazonas, Rondônia, Roraima, Acre) to counter the alleged earlier favoritism of eastern Pará (Mahar 1979). Construction of the Transamazon Highway, a major corridor running east-west across the Amazon was the hallmark of this period. Brazil's motives for construction of the corridor were also geopolitical. Many of the South American countries that border Brazil were developing their Amazon regions. Brazil sought to secure its territory by enticing landless populations from other parts of Brazil into the Amazon region (Mahar 1979; Hecht 1984).

Much of the planned roads were never paved, but left as dirt roads that became muddy and virtually impassable during the rainy season. Even paved portions were poorly maintained. Large potholes were common, travel became tediously slow, and many smaller roads deteriorated completely from the harsh environmental conditions. For many of the newly settled populations along these roads, particularly smallholders, transportation of agricultural produce became painstakingly difficult, market integration pointless, and agriculture as a commercial activity took second position to subsistence farming.

In the period 1970–74, the Brazilian government articulated a planned colonization project that sought for the first time to address social and agrarian reform (Moran 1981; Smith 1982). The program designed a colonization scheme that included a spatial hierarchy of settlements where 1 million families, mostly immigrants from Brazil's chronically drought stricken northeast, were to be settled along the newly constructed Transamazon Highway. Full settlement would be completed over the following the decade. Yet, by the mid 1970s only 7,500 families had been officially settled and few of the larger more service oriented settlements had been constructed (Browder and Godfrey 1997). The program's failure was largely blamed on the ignorance of regional planners to local tropical conditions. Basic environmental factors such as soil fertility and topography, as well as, environmentally adaptive subsistence strategies were overlooked. The program did serve to create a large cheap labor pool to be utilized in the next regional development phase, 1975–79, which returned to an emphasis on large-scale corporatist development with tax breaks and subsidies for large cattle ranching operations.

As opposed to the planned colonization along the Transamazon Highway, spontaneous settlement characterized land occupation in Rondônia, simultaneous to the construction of a third major corridor, the Cuiabá-Porto Velho Highway. With a total state population of 70,000 before 1968, the number of new immigrants averaged 28,500 per year in the following decade, then 65,000 per year between 1980 and 1983, and 160,000 per year from 1984 to 1988 (Moran 1996a). This last set of figures corresponded with the implementation of a second major agrarian-reform-oriented program, POLONOROESTE, from 1981 to 1985.

The informal rules of public land allocation also encouraged the clearing of forest by populations displaced from land consolidation processes. *Direito de posse*, the right of a squatter to unclaimed public lands through the demonstration of effective use, was commonly accepted. Government agencies, such as INCRA (Brazilian National Institute for Colonization and Agrarian Reform) and SUDAM (Superintendency for Development of the Amazon), granted titles to people based on the demonstration of effective land use for more than a year (Mahar 1989; Binswanger 1991; Milikan 1992; Stewart 1994). In some instances land titles were granted for up to three times the area supposedly in use. This gave individuals a major incentive to clear land even if they had no intention of directly using it. If actual use of the land was ever in question, inhabitants often would clear areas to create pastures.

4.2 Corporatist Livestock Practices and Government Policy

During the 1970s and into the early 80s, the Brazilian government provided subsidies and access to credit to medium and large landholders to promote livestock activity by privatizing large areas of previously open primary forest and converting them into ranches (Mahar 1989; Binswanger 1991). Pasture on these ranches averaged 25,000 hectares in size, in comparison to an average 100 hectares for smallholder farms, and thus, primary forest conversion to pasture was encouraged in large contiguous areas. In 1980, at the peak of these policies, 11.1% of total primary forest conversion went to pasture development and cattle ranching constituted the most extensive land-use activity in the Amazon (Mahar 1989). By 1983, 58% of all development projects approved by the Brazilian government's Amazon development agency, SUDAM, went to livestock projects (Browder 1988).

In addition to government subsidized corporate development projects, other government policies encouraged extensive forest land clearance to create pastures. First, the virtual exemption of agricultural income from income taxation made agriculture a tax shelter for large corporations and wealthy individuals. The burning of primary forests to create pasture became the optimal agricultural land use for these corporate interests because maintenance costs for pasture were much lower than for agricultural fields, and thus, profits conceivably higher. Corporate interests began to buy out smallholders in more settled areas, increasing land consolidation and displacing poorer households. (Lisansky 1990; Binswanger 1991; Hecht 1993). In addition, land taxes contained clauses that encouraged forest conversion to pasture. These taxes were higher on farms or ranches which encompassed land that was considered unused (Binswanger 1991). Primary forest fell into this category of unused land, while pasture fell into the used land category. This gave land owners further incentive to clear forested areas for seemingly useful pastures, regardless of whether they ever intended to raise cattle on the land.

4.3 Large-Scale Development Projects, Logging, and Urbanization

The 1980s period represented a shift away from road construction and colonization efforts toward large-scale, high-income-generating projects, such as, mining and hydroelectric power. This shift occurred for a number of reasons. First, the oil crisis of 1973 squeezed Brazil's financial resources for development. Since higher fuel costs impacted overall ground transport costs, any development strategies which relied on road construction to attract private investment seemed ever more unreasonable and unprofitable in the remote Amazon areas (Mahar 1989). Compounding this, Brazil's debt crisis was looming in the background, making large-scale, profit-making projects more appealing. Last, Brazil began to realize that populating the Amazon through planned colonization was not an easy answer to land and demographic pressures in other regions of the country. The harsh environmental conditions of Amazon living made extensive rural settlement much more difficult than anticipated and a general disillusionment emerged (Mahar 1989).

The new lucrative path to development focused on large multimillion dollar projects with international financial backing. These projects were to take advantage of the Amazon's tremendous natural resources, particularly mineral and hydraulic, while serving as dynamic economic sectors or "growth poles" that by their presence would boost other sectors of the local economy. Fifteen such areas were designated throughout the Amazon and were designed to control development much more carefully. Following their trail, however, uncontrolled settlement, informal gold mining, and logging have cropped up to take advantage of the infrastructure laid down by the larger projects(Thomson and Dudley 1989; Roberts 1995). In one mining project, nearly half the forest bordering a railroad was deforested within the first five years of the project (Anderson 1990). In another, 40,000 gold prospectors migrated onto Indian claimed territory in the first four months after the area was declared by the government to become a national mining project.

To complement the raw extraction of minerals, smaller projects are implemented or are in the process of being approved that require charcoal fuels for processing the raw materials. Eucalyptus plantations have been planted in anticipation of large charcoal demands, but they require eight to 10 years' growth before they can be harvested and there is doubt as to the ability of these plantations to fulfill needs. Some estimates put total demand for fuel wood at 14 million tons per year (Treece 1989; Anderson 1990). In the meantime, it is highly suspected that primary forests are fueling the projects' furnaces.

Besides the burning of large quantities of wood for fuels, hydroelectric dams have flooded forests to create reservoirs, some as large as 2,430 km^2. This has decreased standing carbon stocks and dislocated populations (Treece 1989; Fearnside and Barbosa 1996).

Logging operations flourished in the early 1980s when Brazil's export promotion policies were enacted to enhance international development and foreign trade. By 1983, nearly 35% of all tax credit financing by government policies went to industrial wood producers (Browder 1988). Government subsidization of export costs favored capital accumulation for small merchant class of trading companies, at the expense of local level timber producers (Browder 1987). This filtered financial resources away from the frontier regions where logging activity took place. Selected logging is considered one of the most economically viable land-use activities that does not directly use fire. Yet, the demands of international markets pressure overexploitation of certain commercial tree species, and the constant invasion into more and more remote areas. When hastily done, logging leaves many more trees damaged or fallen than the ones harvested.

The influence of urbanization is the last venue from which to discuss Amazon regional landscape change. Historically, urbanization in the region was subject to economic boom and bust cycles which left a scattered network of towns and cities poorly integrated with the national urban system. Trade focused on natural resource extraction that ignored sustaining regional development (Bunker 1985). By 1980, however, 51.6% of the region's total population was urban. The annual rate of population increase in urban areas averaged at 10.8% in 1960–80, compared to a 3.86% annual increase into rural areas (IBGE 1980). While most of this population increase was a result of migration from other regions in Brazil, a significant portion came from rural areas within the Amazon. Lack of substantive rural support led to land abandonment in rural areas and a movement to the cities in search of jobs. Rural absentee land ownership emerged or landowners left tenants to use and/or guard their properties. Though little research has investigated the influence of urban sectors on rural areas, absentee land ownership and tenancy may very well be shifting rural land-use strategies.

4.4 Fire Types, Vegetation Cover, and Land-use Transitions

Fire use is increasingly present, given the mixture of land uses spread throughout the Brazilian Amazon during this period of planned and spontaneous regional change (Kauffman 1991; Nepstad et al. 1991). Until the 1980s, global biomass-burning research often erroneously assumed that fires are homogeneous and therefore, the amount of trace gases emitted from those fires is consistent. However, vulnerability of live vegetation to fire, physical burning patterns in slashed areas, fire regimes, and replacement vegetation all vary to form a heterogeneous shifting fire landscape closely tied to land-use change, and the socioeconomic forces that propel such change. In addition, it is the combination of physical conditions and political economic forces that mold fire use in the landscape (Nepstad, Uhl and Serrão 1991). Associating different fire types with land use and vegetation-cover change, then, becomes very important to refine global estimates. Figure 4.1 represents a fire typology based on potential land-use transitions and resulting vegetation cover changes. Table 4.1 lists fire characteristics according to fire type.

There are four general fire types associated with land use in the Brazilian Amazon: (1) mature forest fires, linked to almost all initial clearance practices, as well as, some ongoing agricultural practices; (2) pasture fires, associated largely to medium and large-scale ranching projects; (3) cropland fires and secondary succession fires, both of which are common in spontaneous and planned smallholder settlement; and (4) logged forest and fuel fires. Within each fire type, biomass fuel load, fire efficiency, and size of area exposed to fire all vary to form the specific physical burning pattern that is extrapolated to calculate regional and global biomass-burning estimates (as discussed in Chapter 2). Fire regime, or degree to which each fire flames or smolders during combustion, indicates the proportions of trace gases emitted during the fire and is critical to understanding the contribution of the fire type to consequent atmospheric conditions. Last, live vegetation cover holds its own vulnerability to fire and represents capacity of replacement vegetation to re-sequester carbon from the atmosphere.

Land Clearance and Mature Forest Fires

The target of initial land clearance in frontier regions is native vegetation. In the Brazilian Amazon, this is predominantly mature tropical moist forests ((1) in Figure 4.1). When alive, tropical moist forests are considered to be minimally vulnerable to fire because high rainfall coupled with the closed canopy nature of these forests creates moist microclimatic conditions in the understory and combustion is difficult (Mueller-Dombois 1981; Kauffman et al. 1988). With a near to a complete absence of natural fire disturbance (fire frequency every 600 years or more according to Sanford et al. 1985), it is suspected that tropical moist forest species are not fire-tolerant, meaning they have evolved with little physical capability to survive after fire disturbances (Kauffman and Uhl 1990). Yet, when slashed, left to dry thoroughly, then burnt, carbon stocks in these forests can be significantly depleted, while the replacement vegetation is likely to contain considerably lower biomass loads and fewer plant species than the original forest. Ecological studies speculate it takes 190 to 500 years for burnt mature forest areas to regenerate to their pre-burn species composition and structure, though rates of biomass accumulation may reach mature levels in much shorter periods (Saldiarriaga 1988; Uhl 1988; Moran 1996).

Mature forests are burnt for agricultural crops, land colonization, pasture, or fuel. In the former three activities, they produce fires that are characterized by: (1) large biomass loads; (2) low burning efficiencies, an estimated 25–30% of the initial biomass load leaves the land during the initial fire (Fearnside et al. 1993; Carvalho et al. 1995); and (3) small to large land size exposed to fire, dependent on intended land use, the vulnerability of surrounding vegetation and the microclimatic conditions of the area. Such fires contain predominately flaming regimes that emit more nitric oxide and sulfur dioxide (Crutzen and Andreae 1990; Fearnside 1990; Lobert et al. 1991).

Table 4.1 Characteristics of Fire Types

Fire Type	Biomass Load	Burn Efficiency	Land Size	Predominant Fire Regime	Replacement Vegetation	Vegetation Vulnerability
(1) Mature Forest Fires	Large	Low	Small to Large	Flaming	Does not equal original vegetation	Low
(2) Medium- to Large-Scale Pasture Fires	Small	Low to Medium	Small to Large	Smoldering	Equals original vegetation	High
(3) Small Landholder Fires						
a) Agricultural Field Fires	Small	High	Small	Mixed	Equals original vegetation	High
b) Fallow Fires	Small to Medium	Medium to High	Small to Medium	Flaming	Eventually equals original vegetation	Medium to High
(4) Other Fires						
a) Logged Forest Fires	Large	Low to Medium	Small to Large	Flaming	Does not equal original vegetation	Medium
b) Fuel Fires	Large	High	Large	Flaming	Does not equal original vegetation	--

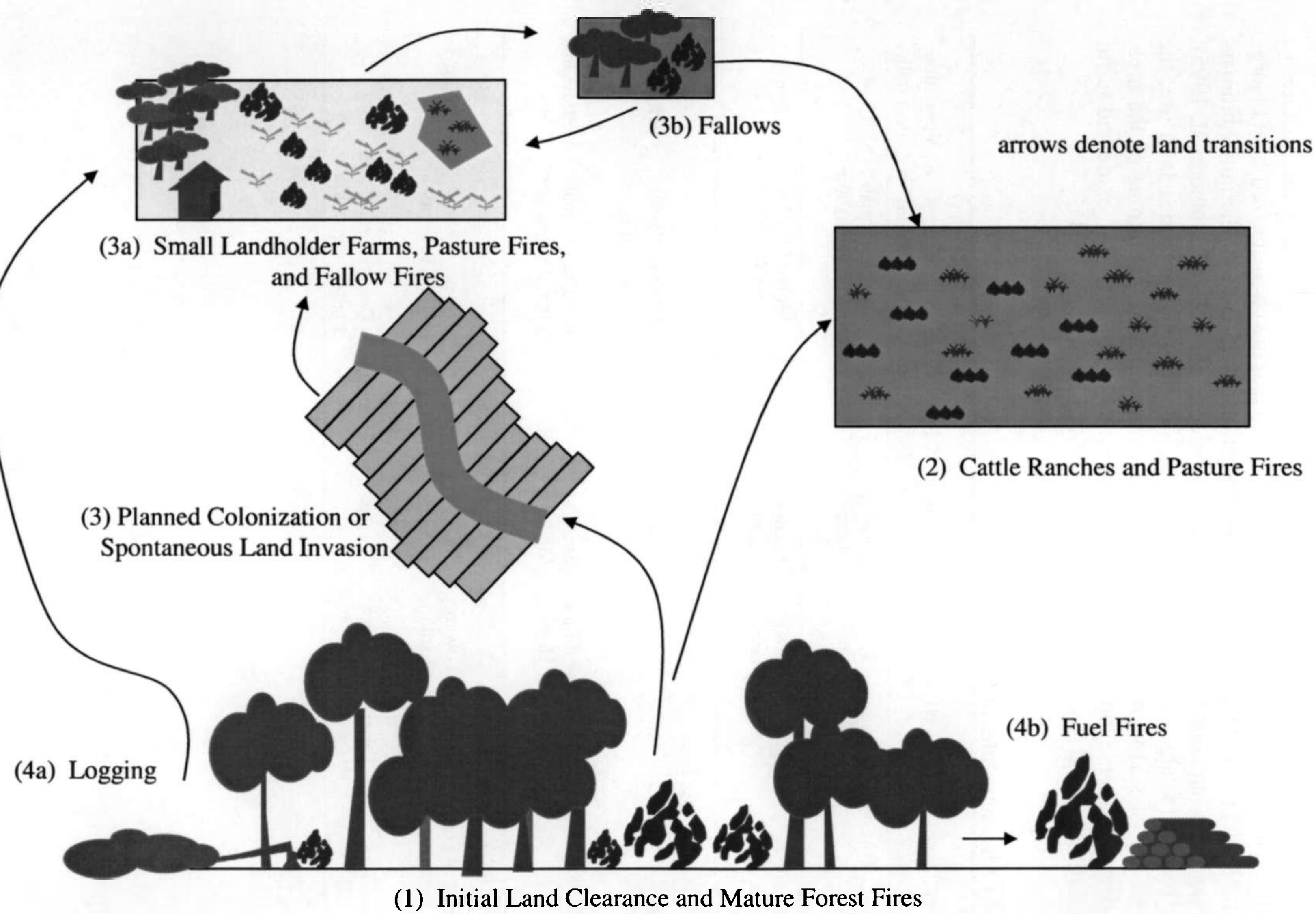

Figure 4.1 Fire Types and Land-Use Change in the Brazilian Amazon

Ranching and Pasture Fires

One of the main land transitions of forest vegetation cover is to pasture, a vegetation cover consisting largely of grassy land and extremely vulnerable to fire during the dry season. Often pastures are accidentally burnt when fire from neighboring agricultural fields passes easily onto them. An estimated 72% of total deforestation by 1980 was the result of cattle ranching activities (Browder 1989). Average ranch size was 25,000 ha thus, the potential extent of pasture fires or forest converted to pastures can be quite large. Others estimate that 60,000 km^2 of Amazon land is in pasture (Toledo and Serrão 1982).

Many environmental problems chronic to pasture areas are important to understanding biomass burning. Overgrazing destroys the long-term viability of pastures such that the average life span is under 10 years (Hecht 1984). As a consequence, pastures are abandoned relatively quickly meaning that large areas of Amazon land is now secondary succession on degraded pastures and highly vulnerable to fire (Uhl et al. 1988). Pasture maintenance strategies to limit further forest conversion are often inadvertently discouraged by government incentives. Subsidies make it more lucrative to convert forest rather than invest one's own money to recover a degraded pasture (Moran 1993a). In areas where ranchers are taking steps to upgrade their pastures, improvements are subsidized by the region's remaining forests; ranchers sell logging rights to forested areas of their properties to form the capital necessary for pasture maintenance. An estimated 3 ha of forest profit equals 1 ha of pasture upgrade. (Verissimo sited in Nepstad et al. 1991). Vegetative regrowth when pasture areas are eventually abandoned is relatively slow compared to agricultural fallows (Uhl et al. 1988; Fearnside and Malheiros Guimarães 1996). The implication for carbon re-sequestration is particularly critical. This replacement vegetation is estimated to absorb only 0.5% of the emissions from initial forest burning (Detwiler and Hall 1988; Uhl et al. 1988; Fearnside 1996).

Once the land becomes pasture, a second fire type emerges ((2) in Figure 4.1). In pastures, fire is often used on an annual or biannual basis to reinvigorate seeds and diminish weedy growth not suitable for cattle grazing. In contrast to fires in slashed forested areas, pasture fires are characterized by: (1) low biomass loads; (2) medium to high burn efficiencies; and (3) medium to large land size exposed to fire—both small landholders and large-scale cattle ranching projects contain pasture. They exhibit smoldering regimes that emit higher concentrations of methane, nitrates, carbon monoxide, and particulates (Crutzen and Andreae 1990; Ward 1990; Lobert et al. 1991; Fearnside 1997). Replacement vegetation after a pasture fire is considered to equal that of the initial pasture since the land use has not changed, however, pasture fires can continue to burn partially burnt logs left from original forest fires. In some studies, 12.3% to 28% of original forest remains were burnt during subsequent pasture fires (Fearnside 1996). This has lead researchers to speculate that pasture fires triple the amount of carbon released from the initial forest fire (Schroeder and Winjum 1995; Fearnside and Malheiros Guimarães 1996). In such cases, the initial biomass loads in the pasture are higher, but other characteristics of the fires remain consistent with most pasture fires. Last, pasture consists of grassland vegetation cover that comes extremely vulnerable to accidental fire during the dry season (personal observation). It can become water stressed and ignite after only a single rainless day (Uhl and Kauffman 1990; Nepstad et al. 1994).

Smallholder Settlement, Cropland and Fires in Secondary Succession

A second major transition of forest vegetation cover leads to human settlements (either planned colonization or spontaneous invasion) and smallholder agricultural activity. Two main fire types emerge from this transition. First, within cropland areas, fire can be used as a maintenance technique to eliminate weedy growth in the second and/or third year of cultivation ((3a) in Figure 4.1). Cropland fires contain relatively small biomass loads, but burn very efficiently as often crop debris is collected into piles for burning. The land area exposed to fire tends to be small, limited to the size of the agricultural field. The crops themselves can be very vulnerable to accidental fire particularly near the end of the dry season when vegetation has been without water for a few months. Their loss not only facilitates accidental fire but, represents an economic loss for the household, who relies on food or income generated from the field.

In addition, many smallholders have incorporated livestock activity into their land-use strategies. In such cases, some cropland is not fallowed after a few years of use, but is planted with grasses. Small landholder pasture sites exhibit many of the same fire dynamics in terms of fire frequency, smoldering regime, and grassland vegetation vulnerability as was discussed in the previous section. The spatial scale of burning is significantly smaller. The trend toward livestock practice is increasing within the small landholder group where livestock practice is perceived as a more secure agricultural strategy than food cultivation and a method of farm diversification that helps minimize farm risk (Hecht et al. 1988; Loker 1993; Faminow 1998). Livestock is a more liquid asset that can be exchanged for cash at any time of the year. It is not tied to a particular season, such as crops are to harvest time. Livestock provides a daily and ongoing food source, again not seasonally limited as produce often is.

After crop cultivation or pasture use, the land is fallowed and enters another land transition. This transition contains a second fire type predominant in settlement areas ((3b) in Figure 4.1). The fallow period can last up to 20 years before the area is slashed, re-burnt, and used for agricultural purposes. Fallows from abandoned agricultural fields often exhibit comparable biomass loads to natural secondary succession of similar age. Vulnerability to accidental fire in these areas is still fairly high, particularly if the dry season has been long. When farmers slash these fallows and burn them, the fires exhibit: (1) small to medium fuel loads, dependent on the length of the fallow cycle; (2) medium to high burn efficiency, again dependent on the length of the fallow cycle; and (3) small land size exposed to fire. In general fallow fires contain a mixed flame and smoldering regime, dependent on the age of the vegetation and overall biomass load. The replacement vegetation after the fire is likely to eventually equal that of the pre-fire biomass because of the nature of the cyclical fallow/use process.

Logging and Fuel Fires

The last fire scenarios within the Brazilian context begin with logging. There is increasing evidence in logged areas that remaining forest vegetation becomes more vulnerable to fire (Uhl et al. 1988; Uhl 1990). Logging creates openings in the forest canopy where warmer, drier conditions prevail. The estimated 80–90% canopy cover of mature tropical forests is diminished to 50% (Nepstad et al. 1991). Often many non-commercial trees are killed or damaged during logging practices, which then creates combustible fuel loads at the ground level (Fearnside 1996). In the drier conditions, these fuel loads combust easily. The proximity of vulnerable logged areas to people engaged in fire-use practices is often very close. Loggers build secondary and feeder roads to extract commercial timber. Smallholders wishing to take advantage of road access, invade these areas, bringing with them their fire-use practices (Detwiler and Hall 1988). In addition, many large-scale cattle ranchers hire logging companies to selectively log the forested parts of their properties. This places logged areas in close proximity to pasture areas where fire occurs on an annual or bi-annual basis (Uhl and Buschbacher 1985).

When fire from pastures, slashed fallows, or agricultural fields, reaches logged areas (Figure (4a)), it exhibits characteristics similar to fallow fires. Initial biomass loads are higher, but because live biomass is less combustible fire efficiency is lower. Area exposed can vary greatly, depending on the size and force of the fire. Studies on forest tree mortality due to fire show up to 80% mortality, but do not indicate the efficiency of the fires and how much biomass actually burnt (Uhl and Buschbacher 1985). Logged areas can also follow similar land-use transitions to agricultural fields or pastures. Replacement vegetation may equal or be less than the original pre-fire biomass.

Non-commercial logging is also practiced to create the fuel loads necessary for mineral extraction. Predictions of fuel requirements for mineral extraction and processing at the Greater Carajás Project in eastern Pará near 3 million tons of charcoal or 14 million tons of wood per year (Anderson 1990). Establishment of fast growing eucalyptus plantations is to eventually supply the brunt of this charcoal need, but currently industries are relying on native forests. Though at present I am unaware of research specifically addressing the characteristics of these Fuel Fire characteristics (Figure (4b)), much can be inferred by the nature of their purpose. Since charcoal is a major source of fuel energy, large amounts of biomass are burnt. This charcoal is burnt in controlled conditions where micro-climatic conditions have less impact, and thus most likely fires exhibit near complete burn efficiency. While fuel fires do not occur on the landscape and thus, land area exposed to fire is irrelevant, and they indirectly affect large areas of land when fuel is created through deforestation. In practice, areas deforested are *supposed* to be replanted with fast growing tree species that can be used for future fuel, when mature. There is little evidence however, as to whether this replacement vegetation will equal the biomass of the original forest cover.

4.5 Conclusion

From this chapter, it becomes obvious that the historical drives to clear land in the Brazilian Amazon are wrapped up in a variety of exogenous forces, such as, government biases toward specific land-use practices, large-scale development projects, and populist oriented settlement programs, as well as, population dislocation and spontaneous invasion. These forces acting upon the land result in diverse new land covers, increase the vulnerability of vegetative landscape to accidental fire, and shift the nature of fire upon the landscape. Fire types, and how each contributes atmospheric trace gas emissions, can be seen with each land-use transition.

In discussing the broad changes in land use since development of the Amazon became a national priority in the late 1950s, I utilized a political/landscape ecology perspective in which both the driving socioeconomic forces, as well as, the physical environmental changes were equally examined. A variety of conceptual features that interweave social with natural components are important to delineate biomass-burning issues.

Concepts about fire use are as follows:

- Fire use is both a frontier expansion issue and a land management strategy. Both are tied to regional development and are influenced by local level household dynamics.
- Fire use is temporally heterogeneous. Land users burn land for a variety of continuous and one-time purposes including shifting and permanent agriculture, cattle ranching, settlement and road building. Burning patterns (biomass density of vegetation, the amount exposed to fire, and the burning efficiency) and replacement vegetation types vary with the intended land use.
- The problems of global biomass burning go beyond the initial burn. The replacement vegetation is equally important to study because of its role in the global carbon flux and its greater vulnerability to future fires. Thus, patterns of biomass burning (the biomass load of vegetation, land area exposed, and efficiency), and subsequent land use are equally important as the processes that drive initial fire-use practices.
- The impacts of burning are spatially dislocated. The accumulative effect of biomass burning makes it a global environmental issue, but the burning of vegetation and the types of replacement vegetation occurs across the landscape in multiple local forms that vary locally and globally.

CHAPTER 5

A POLITICAL LANDSCAPE VIEW OF BIOMASS BURNING: CONCEPTUAL FRAMEWORK AND RESEARCH DESIGN

While the previous chapter described regional changes in the Amazon and corresponding shifts in fire type, this chapter develops a conceptual framework to look more closely at local level dynamics where decisions to burn land are made and actual physical burning patterns formed. Physical burning patterns can be conceptualized as specific values of biomass fuel load, fire efficiency, and area exposed to fire. In the conceptual framework discussed below, the combination of these values provides a link between local physical occurrences and global biomass-burning issues. These values also create a link between the physical environment and the socioeconomic context in which fire activity is taking place.

In political ecology perspectives of land-use change or deforestation, the base unit of analysis is the land user (Blaikie and Brookfield 1987; Bryant and Bailey 1997). Yet, questions and analyses very quickly jump up the spatial scale to highlight how political-economic forces or historical legacies impinge on household land-use decisions. This conceptual framework veers slightly from political ecology frameworks because it shifts the base unit of analysis away from the land user and places it in the environmental pattern. In doing so, the analysis addresses a broader range of local decisions and physical evidence that would be masked if analyses remained steadily focused on larger forces that influence land users' decisions. In addition, local agency is given equal weight to regional forces. Yet, this framework does draw on the theoretical discussion in Chapter 3 because it acknowledges that larger regional development strategies, overall settlement, and economic development within the study region affect local activity.

Only one of the major actors in land-use transitions described in the previous chapter is considered here, the smallholders that are a part of spontaneous and planned settlement. There are a few reasons for this. First, as a cumulative group, smallholders with fire-use practices are considered to be the largest contributing force to released trace gas emissions from biomass burning worldwide after fossil fuel burning (Hao et al. 1990). Yet, there is little thorough study into the ground level dynamics of their fire-use practices and the types of vegetation they chose to burn. Second an estimated 80% of Amazon produced food comes from over 400,000 smallholders who live on relatively poor soils (Serrão and Homma 1993). Their potential to feed the Amazon's growing urban population makes support and understanding of their activity important for regional economies. Third, this smallholder population makes up a heterogeneous group that is spatially dispersed. The task of detailed local studies is tremendous and often goes overlooked to more feasible aggregated analysis.

Considering this smallholder group then, their decisions to burn land form the most direct link to fire activity. Whether consciously planned or spontaneously made, these decisions determine what vegetation to burn, how large an area to clear, and where to establish agricultural fields or pastures. Once a farmer makes these initial decisions, however, the determinants of the actual burning pattern become less sequential and are contingent on a mixture of physical and social factors. These are outlined in Figure 5.1 and discussed in the chapter. The chapter begins with discussion of each household decision as connected to the physical burning pattern, then discuss regional factors that influence household decisions. Next, the double role of the physical landscape plays on the physical burning pattern is discussed. Last, a broad layout of the research design is provided that indicates the general methods used to integrate all data used in the research.

5.1 Household Decisions, Regional Pressures/Incentives, and the Physical Burning Pattern

The first of the household decision factors, resettlement choices/pressures, sets into motion land-use decisions that influence the type of vegetation to be burnt, and thus, the overall biomass fuel load exposed to fire. Reasons for resettling may include potential land tenure rights and access to infrastructure such as roads, schools, markets or towns. They may reflect personal tastes and neighbor disputes, or societal pressures, such as, displacement from other regions or population pressure. Relocation includes local moves as well as, regional in-migration. Regardless of these decisions to resettle, the move to a new locale, presents the household with a new vegetative landscape that may not initially fit the farming expectations the household carries with it. As such, initial burning practices associated to household establishment occur in addition to the more ongoing slash-and-burn agricultural techniques the households may practice. Settlement in new frontier areas often means that households have no choice but to burn primary forest to establish the house site and create agricultural fields. Settlement into previously established areas may mean secondary succession already exists around the house site and perhaps mature forest exists only on the outskirts of the property. Households then have different choices in the type of vegetation they wish to burn and the biomass fuel load exposed to fire.

Regional pressures, particularly as discussed in the previous chapter, greatly influence resettlement at the local level and thus, can be linked to the biomass fuel load exposed to fire. Promotion of colonization by offering land titles, opening land access, road construction, schools, medical facilities or other infrastructure influence the population influx to the region, as well as, the distribution of the region's original population if these people seek to acquire new land where such amenities are in place. Regional policies can also dislocate populations by making land illegal for settlement. These pressures are often unique to the specific context. But again, as these households move onto new vegetative landscapes, their initial burning practices change the face of these landscapes.

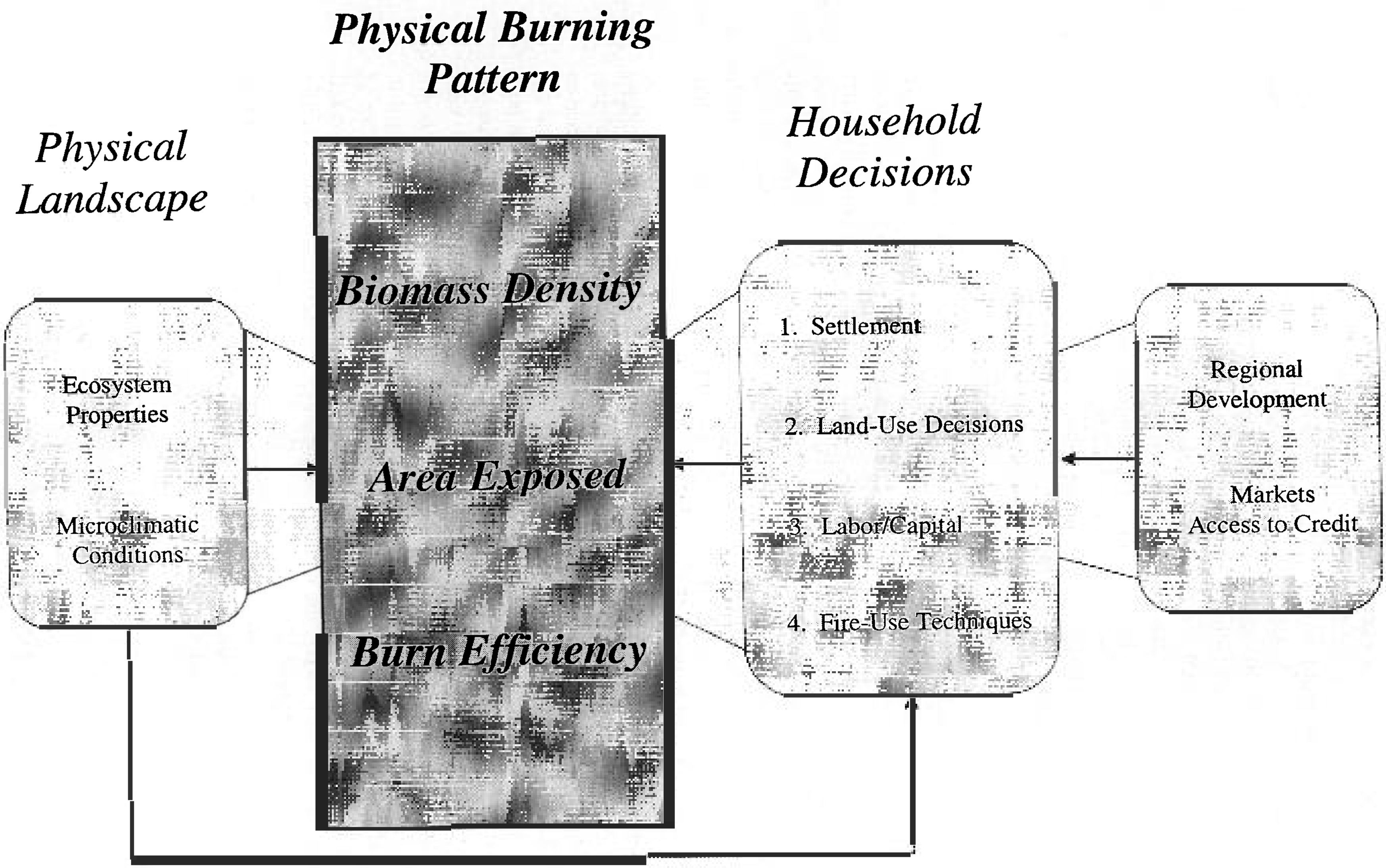

Figure 5.1 Conceptual Framework

The second household decision factor, land-use decisions, also influences the biomass fuel load exposed to fire. Farmers consider the intended land use when choosing an area to burn. Certain crops are better suited to soils where mature forests or older fallows with large biomass fuel loads were burnt. Other crops thrive in areas where younger vegetation once dominated and relatively small biomass fuel loads prevailed. Pastures for cattle raising may be placed on land abandoned for a short period of time and biomass loads have not built up at all. In addition, farmer preferences such as desire for a field to be near roads, the house site, or shacks where processing can be done, also informs the decision on where to establish the agricultural field, and thus, the biomass load to be burnt. This means that vegetation on land nearer to house sites or other built structures is often burnt on a more frequent basis and is not abandoned long enough to contain a large biomass load.

At the regional level, market integration and demand for commercially viable crops can influence farmer land-use decisions and thus, the biomass load exposed to fire. Households situated on major thoroughfares or nearer to urban centers may cater land-use decisions toward the commercial demands of those urban markets. Farmers in more remote areas or located along dirt roads which are impassible in the rainy season when crops would go to market, may make land-use decisions based more on subsistence needs. A second regional factor that influences land-use decisions is access to loans. Banks only lend to those households that have legal titles to their land. Automatically this eliminates a portion of the population who are either awaiting the long bureaucratic process to acquire their title, or who do not legally own land. For those who do chose to work with a bank, loans often come with stipulations as to what can be grown. Again, these factors influence farmer land-use decisions.

Fire-use techniques, the actual practices and tools used in preparing and burning areas, make up the third household decision factor linked to the physical burning pattern. These techniques most directly affect the efficiency of the burn and total area exposed to fire. Tools available to farmers for slashing can influence the size of area cleared and the thoroughness of the clearing. Farmer access to chainsaws, tractors or other machinery means large areas can be felled relatively quickly and easily. For farmers with manual tools, such as machetes and sickles, the clearing process is significantly slower, very labor intensive and time consuming. If farmers who work manually do not begin slashing early in the dry season, they may not be able to clear land quick enough for it to dry thoroughly before the rainy season begins. They may then be limited in the size of area to clear. They may also leave larger trees standing because they are difficult to fell with manual tools. In both cases, the overall efficiency of the burn decreases. Partially green slash or live green trees are less combustible. The length of time that farmers allow slashed areas to dry will influence the burn efficiency as well. Thoroughly dried areas will combust well, increasing the efficiency of the burn. Slashed areas still green in places, will not burn as well, often discouraging farmers from working in them during the following cultivation season.

When farmers ignite fires, a few techniques influence the burn and the extent of accidental fire. Farmers may construct fire lanes[3] that prevent fire from crossing into bordering vegetation, limiting the total area exposed to fire. Other farmers allow fires to die out in surrounding vegetation, increasing the area exposed to fire. Still other farmers wait to burn until after the first rainfall. The reasoning is that bordering live vegetation is likely to remain moist longer after a rainfall, than is the slashed area. When the fire is lit, it then burns the slash easily, but is less successful in penetrating into the bordering still wet vegetation. This vegetation serves as a buffer to suppress the fire. Farmers may chose to burn adjacent fields at the same time, minimizing the extent of accidental fire and increasing the burn efficiency. Last, some farmers increase the overall burn efficiency by making *coivaras*. In this technique the farmer collects charred debris left from the initial fire into mounds, then burns these mounds.

Household decisions over labor and capital allocation, affect the total area exposed to fire and the burn efficiency. These decisions are closely tied to the fire-use techniques mentioned above and influence both fire efficiency and total area exposed to fire. For example, households with extra money can hire workers to slash larger areas or can rent chainsaws to fell large trees, creating a larger slashed area more conducive to combustion. When money is not available, extra working hands within the household can lead to larger areas being slashed, increasing the size of land exposed to fire.

5.2 Physical Landscape, Household Decisions, and the Physical Burning Pattern

Within the physical landscape, factors encourage or discourage fires, but also influence farmer perception and thus, land-use decisions. Broadly depicted, two main categories are determinants for physical biomass-burning patterns, the terrestrial properties of the natural ecosystem, and the microclimatic conditions. The terrestrial properties of the ecosystem influence the type of vegetation that can grow and the capacity for biomass fuels to accumulate. Microclimatic conditions are particularly important in the efficiency of the burn and the total area exposed to fire. The number of rain free days and the temperature and humidity of those days will influence the dryness of the slashed vegetation and its ability to combust (Uhl and Kauffman 1990). Wind conditions on the day of the fire feed oxygen for the fire to thrive helping it to spread and increase the area exposed to fire and the chance for accidental fire.

The way the physical environment influences farmer fire-use decisions is a consideration often overlooked in work on biomass burning. The length of the dry season may give farmers a longer window of time in which they can slash vegetation and still have sufficient time for it to dry and be burnt before the rainy season starts. Precipitation and temperature can psychologically influence the farmer. If farmers perceive the summer to be extra hot, they may chose to slash larger areas, thinking there will be sufficient time for it to dry.

[3] Fire lanes are strips of bare soil completely cleared of vegetation that run along the edge of the slashed area. They are a preventative measure and make it difficult for the fire to pass out of the area intended to be burnt. They are usually constructed on the edge of the fallow down wind of the fire and are 1 m to 2 m in width.

5.3 Research Design

Understanding the local dynamics of biomass burning requires a physical assessment of the burning pattern, as well as, knowledge of the physical landscape conditions, household decision making processes and regional change. The conceptual framework discussed above provides a set of the *possible* linkages, while which particular linkages determine actual burning patterns are context specific. What is important to glean from study of local contexts is the type of burning patterns that emerge, and the regional changes and household decisions associated to these patterns. This information then becomes the building blocks for assessing the environmental detriment of the fire-use practices locally and globally, anticipating the nature of future burning, and perhaps providing steps toward appropriate mitigation policies if such need be the case.

The goal of this dissertation is to test the conceptual framework within a specific study area. In doing so, I provide local level information of burning patterns that can be transferred to regional estimation and at the same time, contribute to understanding global biomass burning and the larger issues of global environmental change. In using the conceptual framework, the study of local biomass-burning practices requires: (1) meshing data that are informative of the physical landscape with data representative of the human processes acting upon the landscape; (2) utilizing methods that effectively sample phenomena at varying spatial scales; and (3) applying technologies that can then bridge these scales to afford overall analysis.

The discipline of geography provides such methods and technologies, through global positioning systems (GPS), remote sensing capabilities, and geographic information systems (GIS). Specifically, GPS can link local geographic information on both physical landscape and human processes, to regional remotely sensed information that represents larger spatial and temporal land-cover changes. In doing so, local information informs larger regional patterns and processes. In addition, GIS layers information at one spatial scale and links aspatial information to spatial information at each scale. This allows for the integration of various types of information.

Complementing this technological base and equally important to it, however, is quantitative fieldwork and qualitative observation. Determining biomass-burning patterns require measures of biomass changes in vegetation during slash-and-burn processes, while micro level analysis requires interviewing household members on land and fire-use practices. Ground-truth observations increase accuracy and facilitate interpretation of remotely sensed data. Thus, quantitative and qualitative ground surveying information is another local level component to the research design.

Figure 5.2 maps the research design of the study. Data collection and analysis on three spatial scales are considered: (1) at the regional or landscape scale, remotely sensed data are used to understand regional land-use/cover change and fire-use activity involved in that change; (2) at the local scale farm/household, survey information collected from in- depth interviews is used to understand settlement history, land-use practice, and fire-use techniques; and (3) at the field survey scale, vegetation inventory data are used to estimate biomass changes due to fire-use practices in fallows. Details of methods used at each scale are placed within the following four chapters, which form the analysis of the dissertation.

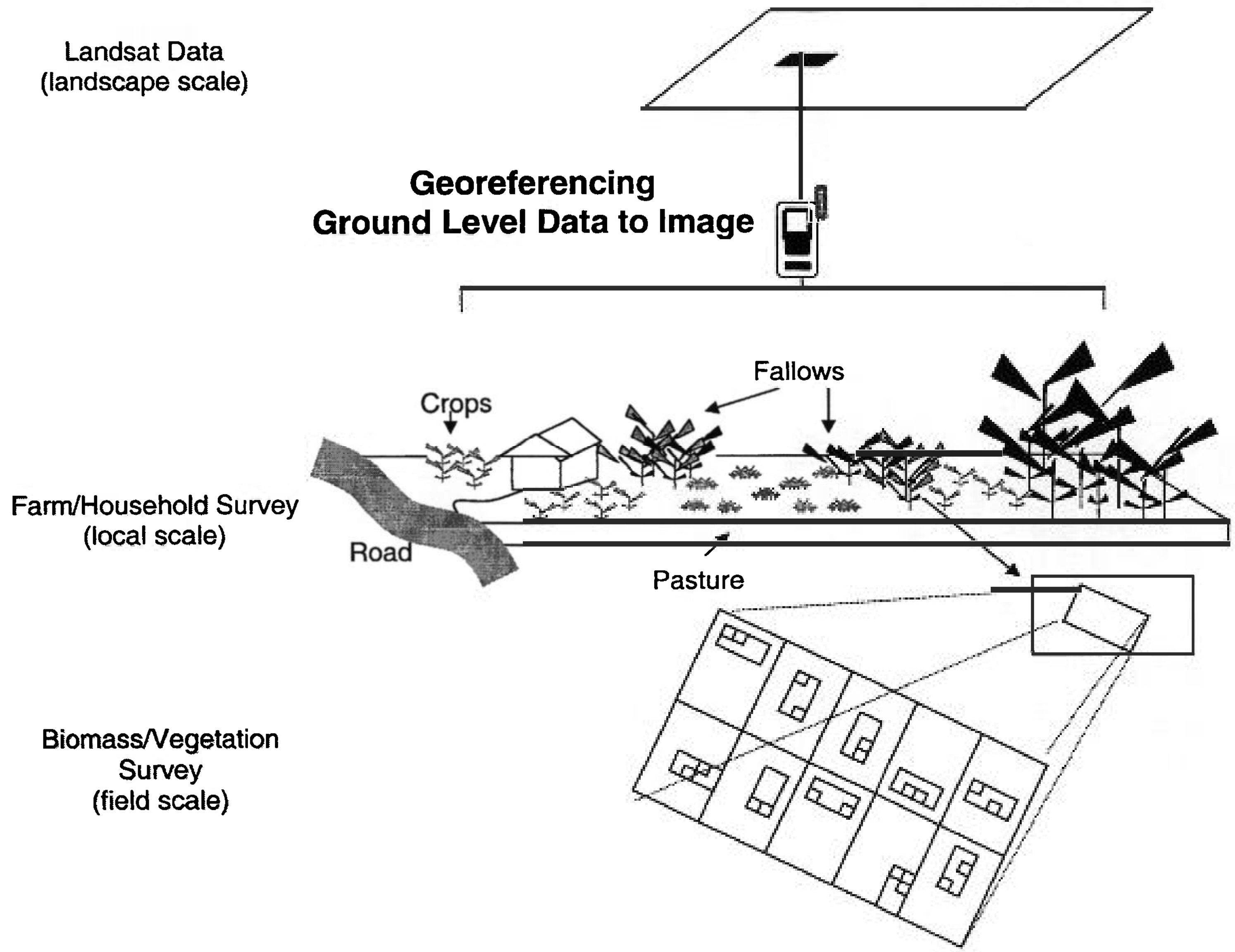

Figure 5.2 Conceptual Diagram of Methods

5.4 CONCLUSION

By conceptualizing how household decisions, regional processes, and ecosystem properties influence physical burning patterns, the framework presented in this chapter creates a body of information critical to understanding global biomass-burning issues. Not only does it capture the physical evidence that can be used to as variable values in the biomass equation to refine burning estimates, but it also provides a way of linking specific physical evidence to human practices that initiate fires. This then provides a more sophisticated understanding of the true causes of biomass burning, information that is paramount to decreasing overall biomass-burning emissions. A common ground emerges in which physical burning patterns are placed within the social context in which they evolve, as well as, can be linked to estimation and thus, larger biomass-burning issues. The framework does not however, provide a more definitive picture of actual burning patterns, nor does it provide a key as to which particular linkages are most influential. It merely provides an approach that begins from the variables important in understanding the atmospheric impact of biomass burning. Specific patterns and critical linkages are context specific and study of them can only be achieved through regional field studies and empirical information. The following chapters begin investigation into one micro-regional setting.

CHAPTER 6

THE STUDY REGION: REGIONAL CHANGE, RURAL SETTLEMENT, AND LAND-USE PRACTICE IN THE BELTERRA/MOJUÍ DOS CAMPOS AGRICULTURAL FRONTIER

Change in the Belterra/Mojuí dos Campos study region has been marked by a disregard for local rural development in state and federal development plans. Large development strategies have sought to link areas where industrialization processes have evolved and paid little attention to the "in-between" places, where the majority of local populations and immigrants flock to in hopes for a better existence. The study area is one such in-between place, left unnoticed and under supported.

Over the past 35 years, four main regional changes produced explicit consequences in terms of land use/cover in the micro-study region and have influenced land occupation: the construction of the Santarém-Cuiabá Road, the establishment of the Tapajós National Reserve, the delineation of Gleba Mojuí dos Campos and most recently, the incorporation of Belterra Municipality. The objective of this chapter is to describe in detail these changes and their corresponding landscape changes. After a brief description of methods and the physical environment, I discuss the major regional changes in the past 30 years. Then, I briefly describe four rural communities within the study region where fieldwork was conducted. Here I give background in terms of settlement patterns and tenure history, land cover and population. Last, I discuss community land-use practices with specific focus on agricultural calendar and common crops cultivated, and explain in detail slash-and-burn agricultural practices used by farmers.

6.1 Methods

Four rural communities with varying settlement histories were selected for the study. A sample population within each community was interviewed to understand land-use practices and characterize the corresponding burning patterns of these strategies (N = 45). Appendix I shows an English version of the interview form. The household farms that contained the 14 vegetative areas sampled in the biomass data are located within these four communities and the owners are a part of the sample population interviewed. The survey method consisted of in-depth interviews focusing on land-use strategies and history, crop/fallow cycles, present and historical burning patterns, and household history.

6.2 Physical Environment

The micro-study area resides largely in the municipality of Belterra, situated near the confluence of the Tapajós and Amazon Rivers, in the Brazilian Lower Amazon. Figure 6.1 shows the study region. The region is situated on the Tapajós Interfluvial

Plateau, locally referred to as *plano alto* and averages an altitude of 175 m. The climate is tropical with an annual rainfall of over 2000 mm and a distinct dry season of 2–3 months. Mean annual air temperature is 25° C. The native vegetation is classified as *terra firme* forest, an upland tropical moist forest cover that is not subject to periodic inundation by river systems (Olegario Pereira de Carvalho 1992). These forests are usually situated on well-drained plateaus with heights exceeding 40 m. As human settlement has persisted, vegetation cover is more varied now. Up to 50 year old secondary succession from rubber plantations encircles the town of Belterra, while in the long-established rural area east of Belterra, secondary succession is prominent. Further south along BR 163, mature forest cover still exists but is increasingly mixed with younger vegetation covers and agricultural fields.

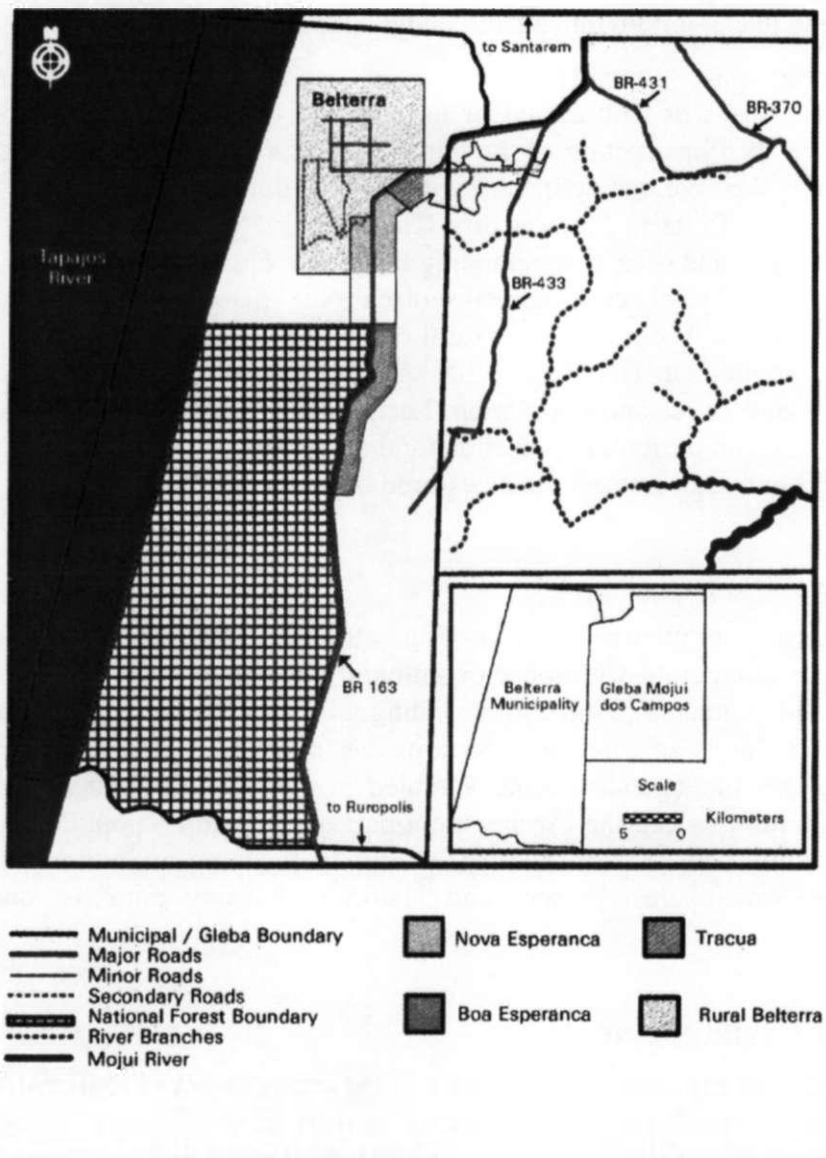

Figure 6.1 Map of Belterra/Mojuí dos Campos Agricultural Frontier

6.3 Regional Changes, Development and Land Tenure

The Santarém-Cuiabá Corridor

The eastern half of the Belterra/Mojuí dos Campos study region was opened up as an agricultural frontier in the early 1970s with the construction of the Santarém-Cuiabá Highway (abbreviated BR-163 on Figure 6.1). This 1,698 km road was initially planned as a larger regional transport corridor to distribute manufactured goods shipped from Manaus' export zone, via the Amazon River to the port of Santarém, then southward by road onto the more populated and affluent portions of the country (see Figure 6.1). Little attention was paid to populations that crept onto lands alongside the corridor. Focus was on the larger transport network potential. By 1990, only 640 km of the road had been paved north from Cuiabá. The rest remained dirt and virtually impassable during the rainy season (de Onis 1992).

In the 1980s, mechanized production of soybeans, rice, and corn, became possible along the southern savanna edge of the Amazon Basin, extending through the state of Mato Grosso and into the southern rim of Pará. With potential for increased crop yields, farmers and ranchers in these parts demanded improvement and maintenance of the road to create an efficient export route through Santarém. Their crops could then be distributed via the Amazon River to feed major urban centers in the entire Basin, as well as, be exported internationally. Both the states of Pará and Mato Grosso promised to complete pavement of the road, promoting it as a corridor of integration to ameliorate regional economic inequality. Again state development was envisioned in terms of linking two more industrialized processes, mechanized agriculture in the south of Pará to exportation, rather than attending to the crowds of people who claimed road side parcels, but had little assistance to improve their living standards.

Today, most of this corridor still remains dirt and distribution of commercial crops is not widespread. According to the 1990 agricultural census, 90% of all agricultural products consumed in Pará came from other states (Fernandes et al. 1996). Even those farmers who invaded land along the road and are in close proximity to Santarém, remain only partially integrated to urban markets. Most engage in a combination of both subsistence and commercial agriculture production.

At the very northern portion of the road, a 217 km dirt road runs north-south through the study region, connecting it north to the regional urban center of Santarém and south to the smaller city of Rurópolis where the Transamazon Road passes. To stimulate land occupation along this stretch, the Brazilian Institute for Colonization and Agrarian Reform (INCRA) surveyed 750 lots perpendicular to the road, each 100 ha, and offered land titles. For most of the stretch of road between Santarém and Rurópolis, lots are located only on the east side of the road, running 500 m along the road then 2000 m out from the road. This forms a two-kilometer band of land settlement parallel to the road.

Once land titles were issued, law prohibited the subdivision of the property and the selling of titles for smaller pieces. The purpose of this law was to counter land consolidation and further deforestation. In the eastern flank of the Amazon during earlier development, land speculators and corportist interests had gradually bought out many smallholders. This led to further deforestation as it pushed smallholders into more remote areas. Since the title could not be subdivided, it would be more difficult to sell off pieces of the initial property. This would then promote land security and stability.

In reality, the law exacerbated rural conditions. After the lots were surveyed, farmers were basically left to their own means. No other rural development strategies were planned, leaving the area somewhat stagnated. Lack of reliable infrastructure, technical and social assistance remain the principal factors to land abandonment (Santos 1996). Households that found rural life too severe and wished to move into cities, had to sell their lot as a whole for the title to be passed on. New incoming smallholders did not necessarily have the resources to buy a full lot. Inevitably, lots were subdivided, and new owners did not have titles. At most, the only seemingly legal document they had for the land was a receipt of purchase. Others did not even have this. To topple the confusion, jurisdiction for the lots transferred hands to INCRA's office in Rurópolis, meaning that new comers to the area who did buy whole lots had a much further distance to travel to transfer title names. Poor road conditions and bus access to Rurópolis discouraged many residents of the road from legally establishing their properties.

In addition, in order to be eligible for the very limited agricultural loans and technical assistance that did exist, smallholders had to show title to their land. The tenure structure created a process that left many farmers increasingly detached from rural development sources. Newcomers could not afford to buy full lots and settled for subdivisions, then without titles, they were unable to obtain agricultural assistance to improve their financial resources.

In 1974, the Tapajós National Forest was legally constituted, covering 600,000 ha of primary rain forest (13–60 km wide and 150 km long) along the Tapajós River. It is located 50 km south of Santarém and borders the West side of the Santarém-Cuiabá Road, restricting settlement in the last 24 years east of the road or north of the Reserve. The Brazilian Institute of Environment and Renewable Resources (IBAMA) manages the reserve with the combined objectives of extraction, research and tourism. Many Brazilians living within the National Forest boundaries prior to 1974 were displaced and most relocated to lots along the Santarém-Cuiabá Road.

Gleba Mojuí dos Campos

The southern and eastern portion of the study region remains in Santarém Municipality under the jurisdiction of INCRA. It developed spontaneously in an arc formation south and east from the city of Santarém and has a longer-established history of agriculture though remains a frontier of the city. It was first established as a Gleba in 1976 as part of INCRA's *Projetos Fundiários* (Tenure Projects), projects with the objective of surveying and titling land with demonstrated occupancy. In its first year, INCRA issued land documents to 1367 households for a total of 52,020 ha (de Miranda 1996). This first year's activity represents 41% of all land documents and 40% of all land surveyed in the Gleba through 1995, indicating that a substantial bulk of the area experienced land occupation prior to 1976. In the following 20 years, INCRA issued an additional 1848 land documents and total area occupied grew to 132,284 ha. The ultimate ten-year period, 1985–95, which coincides with change analysis detailed in the following chapters, evidenced 28% of land documents issued and 36% of new land occupied (de Miranda 1996).

From this information on land tenure, it is difficult to determine periods of rapid land invasion, because peak years in processing land requests do not necessarily coincide with actual land occupation changes in the Gleba. The process to acquire land titles is bureaucratic. Often households remain 10 or more years with Licenses of Occupation or Protocol Numbers that refer to INCRA documentation or entitlement in progress without an inkling of a notion as to when they will actually receive titles. In addition, the information masks land abandonment, a process that is common due to the difficulty of rural living and small prospects for rural farming. Regardless of these oversights, 83% of the allotted 158,870 ha established as the Gleba has been surveyed and some form of land occupation documented, indicating a dynamic frontier region with some what limited space for further growth.

Belterra Municipality

The northeast corner of the study area was originally cleared in the mid 1930s to create a rubber plantation owned by the Industrial Ford Company of Brazil, a subsidiary of the United States owned Ford Motor Company. The area was surveyed in 400m x 400m quadrants which remain and give the area its grid shape land settlement pattern. Dirt roads were constructed every four quadrants to make all areas of rubber relatively accessible to transport.

In 1945, the Brazilian Ministry of Agriculture (MA) appropriated the land when the Ford Motor Co. abandoned its business venture in Brazil. Under the jurisdiction of MA, the area could not be privately owned. In 1980, 231,000 ha were transferred to the jurisdiction of INCRA in Santarém Municipality, but minimal promotion of land occupation accompanied the transfer. By 1990, rubber had dwindled, MA completely downsized operations and allowed agriculture for the first time, in the remaining 50,000 ha still under its jurisdiction. Agricultural use rights were granted through a letter of solicitation to MA explaining how much land and for what purpose the land was to be used. With this virtual abandonment of the area by MA, an estimated 80% of the MA employees, living in Belterra on government owned land, established their own properties through land invasion (EMBRAPA, pers. com.). It was the hope of most, that a new municipality would eventually form, and land titles would be granted in the rural outskirts to those demonstrating occupancy. Proximity to schools, pharmacies, markets, and other infrastructural features situated within the town of Belterra, made the area particularly appealing to invasion. Seven years later, in January 1997, the Belterra Municipality was incorporated, has officially encouraged land occupation in rural areas and has promised to process land titles.

In addition to the 50,000 ha of the formerly MA-administered land, Belterra Municipality appropriated 210,000 ha back from INCRA and the municipality of Santarém, making the municipality total area 260,000 ha. The four study communities—Tracoá, Nova Esperança, Boa Esperança, and Rural Belterra—reside largely within Belterra Municipality, but overlap into Gleba Mojuí dos Campos. Table 6.1 shows basic characteristics of study communities and 1995 land use/cover to be discussed in the following section.

Table 6.1 Basic Characteristics of Study Communities

Community	Number of Households*	Date of Initial Establishment	Percent of Land Cover** Forest	Advanced Succession	Intermediate Succession	Young Succession/ Crop	Pasture	Total Size (ha)	Number of Households Surveyed
Tracoá	88	1924	9.5	30.7	**29.9**	**25.7**	4.2	3749	15
Nova Esperanca	46	1970	56.6	16.4	**12.2**	**12.0**	2.8	5230	11
Boa Esperanca	82	1970	36.3	25.2	**11.2**	**21.6**	5.7	3035	12
Rural Belterra	17	1990	36.36	27.2	19.1	15.7	1.6	11348	7

* Household numbers are based on population data provided by the Ministry of Health in Santarém who defines community boundaries as much larger than do community members.

** Data are based on 1995 land use/cover classification made from Landsat TM imagery.

6.4 Study Communities

Tracoá

Tracoá, the oldest of the study communities, has a history of over 70 years and is located closest to Santarém, along the dirt road Estrada 7. It resides in the larger Gleba Mojuí dos Campos. Before the construction of the Santarém-Cuiabá Road, Estrada 7 was the only road linking the town of Belterra to Santarém. Consequently, land settlement evolved in a spontaneous fashion along this road and the community of Tracoá established itself and thrived. Farmers in Tracoá were able to sell their produce both in Belterra, where government ownership of the land limited private agricultural activity, and in Santarém, where the large urban population created a substantial market.

In the early 1970s, INCRA surveyed property boundaries within Tracoá, and began issuing land titles according to who lived on the land at the time. INCRA adhered to the way in which property boundaries were already delineated and as such, property sizes are uneven, ranging from 10 ha to 180 ha, although they tend to be smaller than the standard, uniform lots of 100 ha surveyed in most INCRA-administered settlement areas. Because Tracoá was established pre INCRA involvement, titles are not legally associated to a specified sized area of land. Both title transference and land subdivision is therefore, easier. In addition, because of its close proximity to Santarém, Tracoá residents can more easily get to INCRA headquarters to submit applications for titles. As a consequence, most residents in Tracoá have titles to their land or some form of documentation, such as, a License of Occupancy, an Authorization or a Receipt of Purchase. All land is surveyed, most lots occupied, and land invasion has halted. Farmers feel secure and do not feel the need to demonstrate occupation, by deforesting areas.

Since the 1980s, Tracoá's commercial agricultural activity has slowed. The construction of BR-163 reduced traffic flow through Tracoá, making transportation to Santarém's markets more complicated. Demand in Belterra deteriorated too. Over the years, MA had gradually downsized its operations due to dwindling rubber production and allowed its employees land-use rights to grow their own food. Belterra's economy slowed to a near stop discouraging Tracoá's farmers who now began to focus on subsistence agriculture.

At present, Tracoá contains 88 households spread along Estrada 7 and the feeder road São Raimundo de Tracoá and covers 3749 ha. Population is evenly mixed between people born within the region and immigrants from Ceará, a state in the northeast of the country. Because of the relatively longer history of land occupation, land cover is predominantly secondary succession, with very little remaining mature forest, only 9.5% of total land cover in 1995. Of the four communities, Tracoá has the highest percent of land cover in each succession class, and inversely the least amount of forest. Because many of Tracoá's residents are more established and have been born on or at least have lived on their properties for the past 30+ years, there is a trend toward small-scale livestock practice and thus, pastures exist. In areas that have experienced many crop/fallow cycles and show signs of degradation, farmers have planted grasses and bought a few cattle. In addition, there is one abandoned *fazenda*[4] near the edge of the community bordering the Santarém-Cuiabá Road and another one, currently in operation, alongside the road. However, these pasture areas still only make up 4.2% of total land cover.

Nova Esperança and Boa Esperança

The next two oldest communities, Nova Esperança and Boa Esperança, are located south of Tracoá along the Santarém-Cuiabá Road at kilometers 45 and 68, respectively. Both communities were established in the 1970s, under an INCRA planned colonization project, and exhibit similar patterns of land settlement and clearance. The section closest to the road is cleared for the house site. Then, land is gradually cleared out from the road and behind the house site for agriculture. The pattern of gradually clearing out from the road leaves remaining forest cover on the back end of the lots, further and further from the house site and main road. Most properties are 100 ha, running 500 m along the road and 2 km perpendicularly out, forming a two-kilometer band of occupation parallel to the road.

Land tenure status of community members reflects INCRA policies. Households established early on, own lots of 100 ha and have legal titles or protocols which refer to INCRA documents. Newer community households tend to settle on subdivisions of the original 100-hectare lots, with only purchase receipts or no tenure documents at all. When whole lots change hands, those living in Nova Esperança have an easier time transferring titles because the community's boundaries are still under jurisdiction of INCRA in Santarém and bus access to the city is fairly good. More of Boa Esperança's residents remain without titles or documentation because the area is administered by INCRA's Rurópolis division, the distance to this city is substantially further and bus access poor.

While the settlement history of both communities is influenced by INCRA's activities in the 1970s, the populations are slightly different in origin. Households in Nova Esperança have a longer history in the region with stronger ties to the town of Belterra. Many of these farmers had been occupying land owned by MA on the West side of the Santarém-Cuiabá Road. With no prospect of legal ownership of this land, farmers saw opportunity to legally establish properties on INCRA-administered lots. In addition, the families dislocated from the Tapajós National Reserve relocated in this community. Boa Esperança, being further south from Santarém and not in proximity to other longer-established towns, represents the settlement pattern more common to areas where INCRA has been involved in colonization projects. Farmers here are a mix of local residents with immigrants from Northeast of Brazil and have come to the region within the last 30 years.

Community size and land cover also show variation. Nova Esperança contains 46 households all along both sides of the Santarém-Cuiabá Road, totaling 5,230 ha. Slightly over half of its land cover remains is forest because it borders the Tapajós National Forest and INCRA avoided surveying lots to minimize encroachment into the Forest. Advanced and intermediate succession covers another 28.6%, while only 12.2% of land cover is

[4] Fazenda is the Portuguese word for ranch, usually implying a medium to large-scale operation.

associated with either young succession or cropland. Very few farmers engage in livestock practices, with pasture grassland covering only 2.8%. Boa Esperança contains 82 households mostly located along the Santarém-Cuiabá Road, with a few households along the feeder road São Raimundo Mojuí. It is the smallest of the communities, area wise, with 3035 ha, but its total percent of cover deforested is greater than in Nova Esperança. Approximately two-thirds of its land cover has moved into some stage of succession or cropland. Areas under pasture are also higher in Boa Esperança, than in the other three communities, covering 5.7%. As in Tracoá, Boa Esperança contains households that are fairly well established on the land and are seeking ways to diversify their farming systems through livestock practice. Since they are located where the Tapajós Interfluvial Plateau begins to descend, construction of well is more feasible. With year round well water, livestock practice is easier and has become a recent farm diversification strategy.

Rural Belterra

The last and youngest area of interest, Rural Belterra, is located east of the Santarém-Cuiabá Road, north of the Tapajós National Reserve, and south of the town of Belterra. The area overlaps the town of Belterra and thus, shares its settlement history with the town. The area is significantly larger in size than the other communities, approximately 14096 ha. Because of its location, is experiencing rapid land invasion. Many of those invading the land have houses or other property within the town limits of Belterra and do not physically live on the land. Thus, community organization is minimal, and the area is more an extension of the town.

Slightly over a third of Rural Belterra is part of the area surveyed in quadrants by Americans during the rubber years and contains advanced succession interspersed with a few abandoned rubber trees. Citizens of the town of Belterra, petitioning for use rights are usually given one of these quadrants, and thus, much of the recent land clearance is close to the town limits and in grid shapes. Since up until 1997 when the municipality was incorporated, these petitions were granted on a one-year basis, there was a high degree of farmer mobility. Farmers cleared new areas every year and did not return to previously cleared and abandoned areas. Ongoing use rights were not granted to minimize continual occupation that at some point could be used by the occupant to legitimize land ownership.

South of plantation boundaries is primarily forest, covering 36.4% of the total area. Invasion has also occurred here, but in a less uniform fashion. No surveying has been done making invasion patchy, but most areas cleared are along small secondary roads. As all land in Rural Belterra is now legally under the jurisdiction of the Belterra Municipality, the extent and nature of land invasions including whether land titles will be issued, will change.

All communities are characterized by large fluctuations in the number of houses established, indicating that the study region is still very much a frontier with high rates of abandonment as well as, in-migration. Unfortunately, data on exact population flux are sketchy at best and can only be inferred by community members or public health officials. The former group defines community boundaries according to neighbor contact and thus perceives communities as much smaller than does the latter group who aggregates areas for administrative convenience. Both, however, experience the region as containing established households and population flux. According to public health officials who keep census counts in terms of houses constructed or abandoned, 40 houses were constructed in Tracoá during 1992–96, and eight houses abandoned. In Nova Esperança, 16 of the 17 houses constructed during the time period remain, implying a more stable community development. Further south, Boa Esperança showed the most fluctuation since 1990 with 57 new houses constructed and 15 abandoned. Last, all 17 houses in Rural Belterra were constructed in the last five years (pers. com. with SUCAM 1996).

6.5 Land Use, Slash-and-Burn Agriculture, and Crop/Fallow Cycles

Agriculture largely occurs during the rainy season that begins late November and runs through May, and thus, most crops are temporary, not perennial. Due to declining crop values in the regional Santarém market, farmers engage in subsistence agriculture with commercial crops being of secondary priority.[5] The main subsistence crops are manioc, which is toasted to make a coarse flour mixture called *farinha*, corn, beans, and rice. During the beginning of the rainy season, small vegetable gardens are also planted, and on some lots, fruit trees provide added food. Commercial crops harvested in the region include watermelon, pineapple, coffee, tomato, banana, pumpkin and a native colorant called *urucú*.

Almost all farmers in the region use variants of slash-and-burn agricultural techniques to prepare land for cultivation. In general this process begins with fallow selection and clearance during the first half of the dry season (July–Sept.). First a farmer or member of the household selects an area to cultivate during the upcoming rainy season. Most often the male household head makes this decision, but adult children may chose areas as well. The area selected may be either forest or secondary succession, dependent on intended crops to be planted, proximity to either roads or shacks for processing raw crops, perceived soil quality, future plans for farm use and layout, and estimated work required to clear the area. During slashing larger trees or palms are often left standing due to extensive labor required to fell these trees with hand axes. Households with access to chainsaws or financial resources to hire chainsaw operators usually fell these larger trees. Some households work cooperatively to slash areas, in a *mutirão*, a situation where a group of farmers work together to clear one farmer's plot, then work on another's plot the following day. The drying period may be as little as a week, for young succession areas, or two months for mature forest areas.

October and November are peak burning months. There are a various techniques used in the burning process to increase efficiency and minimize accidental fire. Farmers wait until after the first rains of the rainy season so that live vegetation bordering the slashed area remains moist and less vulnerable to passing fire. They do not let high fuel load fallows get too dry to minimize potency of fires and maintain better control. They

[5] According to one farmer, a 60-kilogram sack of farinha sells for approximately $5.00 in Santarém. It takes 3–4 days to process the manioc and roast the farinha, and $1.50 to transport it to Santarém produce markets. Similar conditions of low prices coupled with intensive labor efforts exist for other staples (corn, beans, rice) as well. This particular farmer would like to see a better export system so that his produce can reach beyond the Santarém markets, where prices are presumably better.

construct fire lanes, particularly on edges bordering other cropland or in the direction of the normal winds. These bands of bare soil are completely cleared of vegetation, impeding the ability of fire to pass beyond of the slashed area. They may leave bands of unslashed fallow vegetation around the slashed areas to act as buffers where fire will die out. Often the degree to which farmers are conscientious about their fire-use practice depends on the location of the slashed area. In remote areas farmers tend to take fewer precautions than if slashed areas border crops, pasture or house sites. Yet, a few farmers are careful regardless of location, wishing to protect their forest cover as reserve.

After the initial burn, some farmers practice a technique of forming *coivaras*, in which all charred leftover wood is collected into piles and re-burnt. Often decisions to make *coivaras* depend on the effectiveness of the initial burn and farmer intentions for the area. Additional clearance improves farmer mobility within the area, facilitating planting and harvesting of crops. In areas where farmer mobility is less a concern, such as, in pasture, charred logs are not likely to be re-burnt. However, often the decision to make *coivaras* has more to do with farmer preferences than actual crop yields and efficiency.

In January, crops are planted and follow a specific crop/harvest sequence dependent on the biomass of the fallowed, slashed-and-burnt area. If the area burnt was late intermediate or advanced succession, or forest, main crop planted is usually rice, though corn is a preferred option of some farmers. Secondary crops are beans and/or manioc. Rice and corn are harvested in March and April while beans mature in June. Manioc continues to grow through this first agricultural season and matures in the second and third years. Often after the second year's manioc harvest, farmers practice a technique called *stok*. Here, farmers will pull up and set aside all manioc stocks, slash-and-burn weedy up-growth, then replant the manioc stocks for a second harvest. Newly burnt fallows that contained younger succession are usually planted with corn and secondary crops manioc and/or beans, or with manioc alone. Manioc is the preferred crop on these young fallows because it is the major staple of the region. In addition, manioc does not require high nutrient soils and can thus, thrive in areas where soils that have been depleted by the previous year's crops or which have not gained nutrients from the burning of older vegetation.

The land is used for two to four years, until soils are depleted and crop yields begin to decline. This phase of abandonment is critical in the crop/fallow cycle, but time length by farmer and fallow area. Natural vegetative regrowth will provide soil nutrients in the following burning. Length of fallow periods ranges from a few years up to 20 years, before farmers slash the regrowth and the cycle begins again. However, most farmers use a fallow period of 10 years or less, with an occasional longer period of up to 20 years.

Poor water access in the region creates specific limitations for agriculture. There is no irrigation system and farmers must rely on seasonal rain for crops and trucked in, well, or cistern water during the dry season. Year round surface water sources, such as streams and lakes, do not appear until Km 83 of the Santarém-Cuiabá Hwy. Because cattle and other livestock herds require year round water sources, farmers do not engage in livestock practices. Thus, pasture, a dominant land cover in most of the Brazilian Amazon, is not common in the study region. Three of the communities, Tracoá, Nova

Esperança, and Rural Belterra are located on a plateau where well digging is extremely difficult. In some spots, one must dig over 100 m to reach underground water sources. Most farmers do not have the technical or financial resources to dig to such depth. During the dry season, these people travel up to 5 km to get water at community wells or rely on water trucks. The fourth community, Boa Esperança, is situated where the plateau begins to descend, making well digging more feasible. Boa Esperança is the farthest community from Santarém and no water trucks service it. Here, most farmers have wells on their own properties.

6.6 Conclusion

Regional changes in the past 30 years have induced broad shifts in land occupation throughout the agricultural frontier. The construction of the Santarém-Cuiabá Road in combination with land tenure restrictions in Belterra meant populations shifted out of the Tapajós National Forest and onto the Santarém-Cuiabá Road. More recently, with the incorporation of Belterra Municipality, new land occupation is rapidly occurring on the rural outskirts of town. Throughout, areas of settlement are abandoned and new land invaded. Because of early settlement history in Belterra and spontaneous settlement in Tracoá, a substantial population already existed in the study region such that the last 30 years of land settlement, invasion and abandonment involved local residents, second-generation residents, and immigrants unfamiliar to the region. This created a situation unique to most frontier settlement processes. Previous government promoted colonization schemes had focused largely on immigrants, moving landless populations from the northeast and south of the country to the Amazon. Circumstances in the Belterra/Mojuí dos Campos region meant that both local and immigrant populations participated in new frontier settlement.

These changes brought fire activity and vegetation cover change to new parts of the region and away from other areas. Fire became more frequent in the area bordering the Santarém-Cuiabá Road, and in agricultural activity throughout Gleba Mojuí dos Campos. Natural vegetation cover became interspersed with patches of secondary succession, cropland, and pasture encroaching into once forested land. The following chapter looks more closely at the physical responses to the broad frontier dynamics discussed in this chapter. Evidence of land invasion, occupation, and abandonment are examined using remotely sensed data.

CHAPTER 7

REGIONAL LAND-USE/COVER CHANGE, BIOMASS, AND FIRE ACTIVITY

Satellite images are static representations of the landscape that can be used to decipher physical patterns upon the Earth's surface at a fixed point in time. When collected in a time series, images are frequently used to detect physical change in the Earth's cover and can indicate areas of human intervention. However, this temporally spaced data do not provide understanding of the processes underlying physical changes nor why humans intervene in the ways they do. Ground level information, particularly substantive knowledge of land-use practice, ecosystem functions, and regional development trends addresses better driving forces of change. When integrated with satellite images, a fuller assessment of the nature and effects of physical landscape change is created.

This chapter uses remotely sensed data to describe a particular pattern of change in the study region, namely that of biomass change. Change in biomass present valuable information for biomass-burning issues. As a natural process, biomass change reflects potential for carbon stock sources to absorb trace gas emission. Changes in biomass that are counter to natural processes imply human intervention and hint at fire use and historical burning activity. While it is difficult to calculate exact biomass from spectral reflectance as modeled in remotely sensed data, variation in reflectance throughout the electromagnetic spectrum provides information that, when combined with knowledge of the local ecology, indicates areas of varying biomass content.

I begin this chapter with a basic discussion of spectral modeling as applied to detecting vegetation cover. Next, specific remote sensing methods used in the land-use/cover change analysis are detailed. Then, I discuss the general relationship of biomass change to fire frequency and type. This entails consideration of the ways in which biomass change is an indication of human intervention on the landscape and description of a simple model to visualize and discuss biomass change as it relates to fire activity. Last, I begin discussion of land-cover change between 1986 to 1995 in the Belterra/Mojuí dos Campos agricultural frontier, highlighting specific processes of land invasion, forest encroachment, and agricultural diversification. Within this section, more specific attention is paid to biomass changes in forest cover and agricultural activity within the study region.

7.1 Remote Sensing and Biomass Change

The Reflectance of Vegetation and Landsat Data

Spectral modeling is the use of remotely sensed data to record solar reflectance, or brightness level, of the Earth's surface at various wavelengths.[6] Brightness levels are recorded as numeric values (Digital Numbers [DNs]) in grid cells, or pixels, that represent a specified area on the Earth's surface. In Landsat Thematic Mapper Imagery, ranges of wavelengths correspond to bands of TM data and through comparison of DN values and band ratios, effective classification of data is possible. In modeling spectral reflectance of vegetation biomass, information in Bands 3, 4, 5, and 7 of TM data is useful.

A major component of vegetation is chlorophyll that absorbs extensively in the visible red portion of the spectrum, 0.63–0.69 μm. Band 3 models this range of the electromagnetic spectrum range and hence is useful in distinguishing vegetative from non-vegetative features. Vegetation absorbs visible red light and thus shows low brightness values in TM imagery. However, as all vegetation types exhibit low brightness values, it becomes difficult to differentiate well between vegetation types. While older vegetation will appear darker with lower pixel values, than newer vegetation, the degree of difference is minimal and difficult to visually decipher.

A second plant component, mesophyl, reflects brightly in the near infrared portion of the spectrum, at 0.76–0.9 μm wavelengths. At this wavelength range, vegetation reflects brightly, and DNs are relatively high. Band 4 of TM imagery is designed to model spectral reflectance in the Near Infrared spectrum portion and is useful in discriminating vegetation types, vigor, and biomass content. Higher DN values indicate newer, more vigorous vegetation, while lower values indicate older, higher biomass content vegetation or weaker vegetation.

Using Bands 3 and 4 together, one can infer relative biomass content. As biomass matures and increases, Band 4 DNs drop, while in Band 3 DNs remain relatively constant. This means that, as the DN range between the two Bands decreases, the biomass content of the vegetation tends to increase. Table 7.1 shows the band 3 to band 4 ratio for all the vegetation classes to be discussed in the following paragraphs. Higher biomass content classes have smaller ratios, further from value 1. Lower biomass content classes have higher ratios, closer to value 1.

In addition, closed canopy vegetation areas contain multi-layers of leaf vegetation and upper layers cast shadows further down. This shadowing tends to depress reflectance values that in essence now represent a mixture of leaf reflectance and shadow reflectance. The decrease is more pronounced in the near infrared than in the visible region of the electromagnetic spectrum. This again, makes the Band 3 to Band 4 ratio useful in assessing biomass content. Band 4 changes are more visible affecting the ratio by decreasing it as the pixel values in Band 4 lower.

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[6] Each pixel value recorded by the Thematic Mapper is not solely a record of the earth's reflectance of solar radiation. Pixel values are influenced by solar irradiance that reaches the satellite before reaching earth, the earth's own radiating energy, and backscattering that occurs as the earth's solar reflectance expands up through the atmosphere. These factors are often accounted for in a radiometric calibration process.

Table 7.1 Ratio of Band 3 to Band 4 DN Mean Values

Class	1986	1995
Burn/Bare Soil	0.85	0.99
Pasture	0.61	0.82
Old Pasture/Crop	0.49	--
Crop/Young Succession	--	0.61
Young Succession	0.30	0.51
Intermediate Succession	0.27	0.47
Advanced Succession	0.25	0.38
Advanced Succession/Lowland Forest	--	0.52
Lowland Forest	0.30	--
Forest	0.35	0.43

Moisture content and soil exposure are two more components of spectral modeling that are useful in deciphering vegetation. Vegetation with high biomass content and closed canopies will trap moisture, while in younger open vegetation cover moisture evaporates more quickly. During the dry season in the Brazilian Amazon, moisture differences are particularly pronounced among vegetation of varying biomass, making it a good characterization parameter. Both images used in the land-use/cover analysis were recorded in October, the peak of the dry season. The degree of soil exposure also indicates the density of the canopy, with open areas exposing more soil than closed canopies. Bands 5 and 7, representing the mid-infrared spectrum at 1.55–1.75 μm and 2.08–2.35 μm, respectively, are sensitive to these two components. Wetter areas exhibit lower DN values in Band 5, while soils exposure will increase Band 7 brightness values.

Methods

Two LANDSAT TM satellite images (path/row: 227/62; dates: Oct. 1986, Oct 1995) were used to assess the impact of land settlement upon the physical landscape over a nine-year period. All image processing was performed using ERDAS/Imagine computer software. A 1:100,000 topographic map of the study region (IBGE 1984) was used to geographically project images into UTM coordinates and register them to each other (Brondizio et al. 1994). UTM projection also made possible the association of ground-truth data to images through geographically positioning of information with a GPS.

A hybrid classification of land cover was performed on each image but procedures used varied slightly for each image. The 1995 classification was based on spectral signatures derived from ground-truth data collected during fieldwork. Since the image was recorded the year before fieldwork was conducted, the ground-truth data were sufficiently accurate. Ground-truth data were collected on two levels. First, 14 field sites were sampled, with measures of vegetation structure and composition recorded. GPS points were taken at each field site to locate site position on the image. Once positioned on the image, polygons surrounding the GPS points were constructed to serve as training samples. Spectral signatures were developed from mean band values of training samples, and were merged to create three succession classes: Young Succession, Intermediate Succession, and Advanced Succession. In addition, ground-truth data identifying vegetation cover not represented in field sites were also collected. This information was positioned on the images and training samples developed to create additional land-cover classes: Forest, Advanced Succession/Lowland Forest, Sand/Coastal Land, Cropland/Young Succession, Pasture, and Burns/Bare Soil.

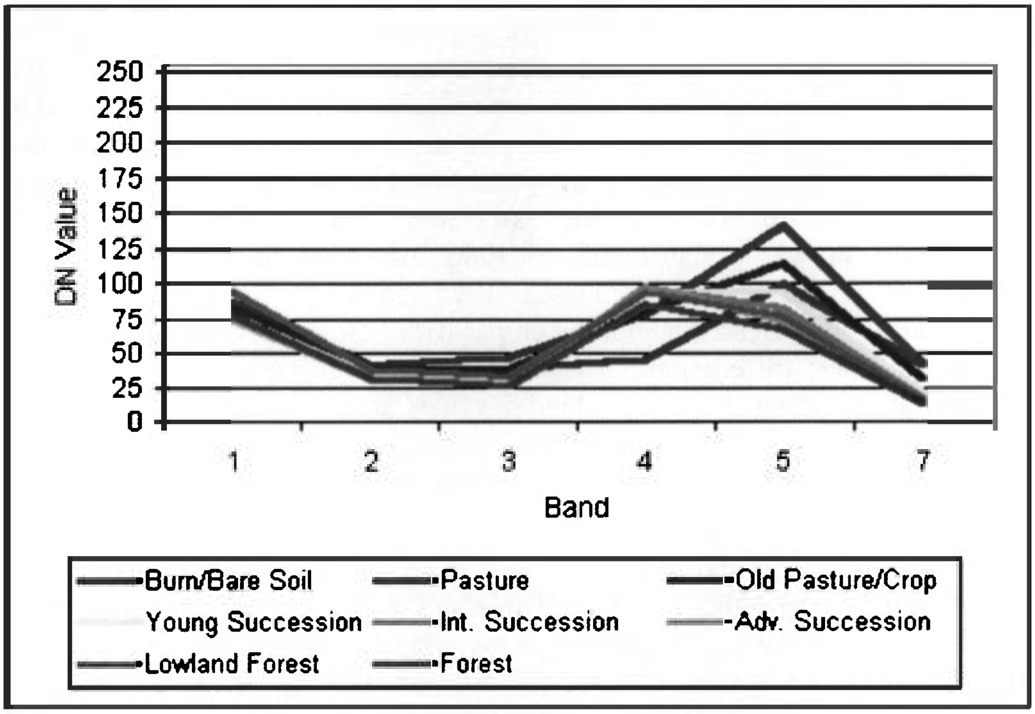
Since 1996 ground-truth data are not suitable to depict 1986 land cover, the 1986 classification relied on statistical procedures along with historical knowledge of the area. First, a Minimum Distance clustering algorithm was applied to generate a range of spectral signatures (Smith et al. 1994). Next, spectral signatures of each class were refined through comparison with the signatures generated in the 1995 classification. Final classes included Forest, Lowland Forest, Advanced Succession, Intermediate Succession, Young Succession, Old Pasture/Cropland, Pasture, and Burns/Bare Soil.

To represent rural boundaries of the communities surveyed in the research, subsets of both classifications were created. Determining community boundaries is not precise, because communities are not legally incorporated entities and while property grid maps exist for some communities, boundaries are not designated. With these limitations in mind, community subsets were designated in the following manner. Rural Belterra encompasses rural and urban limits of the town and extends to the National Forest border. Both Nova Esperança and Boa Esperança were formed by creating a two-kilometer buffer parallel to the Santarém-Cuiabá Road. To form an area unit representing the community of Tracoá, a property map of Gleba Mojuí dos Campos Section D was digitized, registered to classifications, and Tracoá properties were subsetted out.

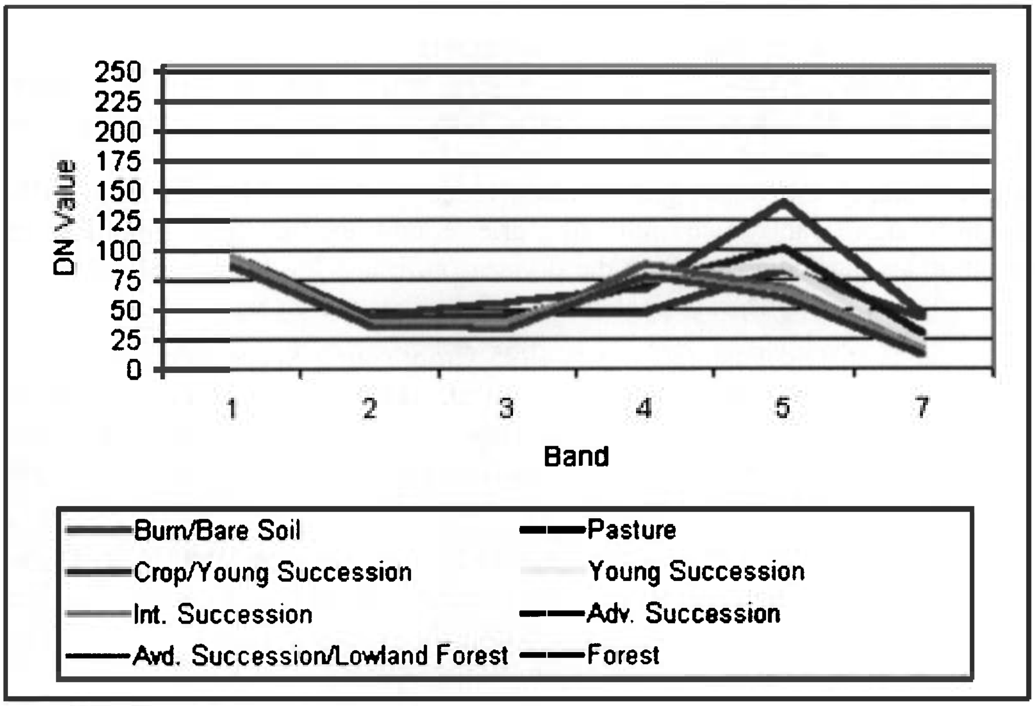
Land-Use/Cover Classification and Biomass

Figure 7.1 shows spectral DN means for each class in the 1986 and 1995 classifications by band. Because images were recorded on different days and in different years, DNs are not completely consistent. Atmospheric conditions on each day as well as solar radiation were not the same. For example, a pixel with a DN of 80 in the 1986 image would not necessarily show a value of 80 in the 1995. Thus, 1986 and 1995 classes are not directly comparable, but trends in relative shifts from band to band can be compared.

In both classifications, Forest classes show the smallest ratios between Band 3 and Band 4, indicating higher biomass content. They also show relatively lower values in Band 4 and Band 5. This indicates that shadowing may be suppressing Band 4 values, and that moist conditions suppress Band 5 values. Both of these characteristics are associated with closed canopy forests. Last, the Forest classes in both classifications show very low Band 7 DNs, again implying canopy cover and minimal soil reflectivity.



(a) 1986 Classification



(b) 1995 Classification

Figure 7.1 Spectral DN Means of 1986 and 1995 Land-Use/Cover Classifications

The Advanced Succession classes represent vegetation cover with the next highest biomass content after Forest. In 1986, Advanced Succession extensively covers the abandoned rubber plantations surrounding the town of Belterra. Its values in Band 4 average slightly higher than Forest values, indicating newer or younger vegetation, but drop in Band 5, indicating moisture and somewhat closed canopies. In 1995, there are two advanced succession classes, with one associated with Lowland Forest. 1995 Advanced Succession shows similar trends to 1986 Advanced Succession and also includes areas where rubber was once planted. 1995 Advanced Succession/Lowland Forest is lower on average in Band 4, and more on par with Forest classes. This class may be nearing the point where differentiation between advanced succession and forest are unreliable in spectral modeling. However, Band 5 values are slightly higher, indicating drier conditions than those usually seen in forests with closed canopies. The Band 3 to Band 4 ratio is also higher than is seen in the Forest or other Advanced Succession classes indicating less biomass.

Intermediate Succession and Young Succession classes are associated to the next levels of biomass content. In 1986, the Band 3 to Band 4 ratio in these two classes is similar to the Forest and Advanced Succession ratios. This can be partially explained by the higher Band 3 values that indicate less vegetation cover and bias the ratios toward the higher biomass classes. The overall trend in spectral means of 1986 Intermediate and Young Succession classes though, is indicative of young vegetation cover types. Band 4 and Band 5 values are relatively higher, indicating younger vegetation and possibly drier conditions.

In 1986, Young Succession is further differentiated by Old Pasture/Crop. This class is classified as such because it is commonly located on the outskirts of pasture areas. These areas may be abandoned pastures or they may be what in Portuguese is called "dirty" pastures, areas where perhaps farmers have no resources to upgrade or maintain the grass quality and weedy growth has invaded. Within Old Pasture/Crop, DNs in Band 5 begin to significantly rise, indicating drier conditions that are exemplified in open vegetation areas, particularly during the dry season. Band 7 values are also higher, indicating soil exposure or dryness, both characteristics of pasture areas.

Comparable 1986 Old Pasture/Crop is 1995 Crop/Young Succession. This class also has higher Band 3 and Band 4 DNs than the classes representing more biomass content, but it tends to form small patches that are not located on the outskirts of pasture. Since these patches are centrally located within agricultural areas, they are cropland, or areas very recently abandoned as fallows.

The last two classes in each classification are Pasture and Burn/Bare Soil. These classes represent the least amount of biomass. In Table 7.1, Band 3 to Band 4 ratios are the closest to 1, again signifying low biomass contents. In Pasture classes values in Band 5 are particularly high indicating new young vegetative growth, but dry conditions. In Band 7 values are relatively high as well signifying soil exposure, while in Band 4, values remain high enough to be considered vegetation. Band 3 values are also higher than the classes with more biomass content, also indicating minimal vegetation cover. The trends are somewhat different in the Burn/Bare Soils classes. Here values are uniquely low in Band 4 and rather high in Band 3. This trend implies minimal, if any, vegetation cover because it is contrary to how vegetation reflects solar radiation.

Types of Biomass Change and Implications for Fire Type and Frequency

Table 7.2 shows a change schema for discussing 1986–1995 land-use/cover change. Each land-cover class is numbered such that when subtracting 1995 from 1986, positive differences imply increases in biomass, while negative differences imply loss of biomass and a value of 0 indicates neutral biomass change, the later two of which imply fire activity. The change values are vaguely proportionate with extreme values, either very positive or very negative, representing more extreme changes in biomass. For the negative values, they also imply higher fire frequency. Values closer to 0 represent small amounts of biomass change and if negative, lower fire frequency.

Land-cover change is associated with three types of biomass change. Each is important in assessing the amount of fire activity within the region and the implications for biomass-burning issues. In the first, biomass change is *positive* as vegetation cover grows older from 1986 to 1995. An example would be if an area classified as Intermediate Succession in 1986 became Advanced Succession in the 1995 classification. To a large extent, the natural tendency of vegetation is the positive change case. It is expected that vegetation, in undisturbed conditions continues to grow and amass biomass. Hence, positive change implies that anthropogenic fire has not occurred to alter the landscape. It also indicates increased carbon stocks and the continued potential re-sequestration of carbon.

In the second change scenario, biomass change is negative as biomass decreases from 1986 to 1995. Forest in 1986, for example, becomes cropland in 1995. Negative changes are counter to the natural tendency of vegetation to grow and as such, imply human intervention or natural disturbance. These changes therefore, indicate fire activity, and shed light on the initial fire to occur during the change period. It is difficult to establish exactly when between 1986 and 1995 the fire occurred, but it must occur earlier enough within the change period for the vegetation to then have enough time to reach its 1995 class. Thus, the initial fire occurrence in the change period is in biomass comparable to the 1986 class or only slightly higher. Negative change also implies carbon losses as the land cover is moving from a higher biomass content cover to a lower one.

In the third change scenario, biomass change is termed neutral because vegetation cover remains constant when comparing 1986 to 1995. For example, Young Succession in 1986 remains Young Succession in 1995. In all classes except Forest, neutral changes imply human intervention because such change is counter to the natural tendency of vegetation to grow. Any undisturbed area would exhibit nine years' of growth during the time period and could not possibly be classified similarly in both 1986 and 1995. As in the negative change scenario, neutral change also indicates of the initial fire to occur during the change period. Neutral change, however, does not indicate carbon stock depletion but that the replacement vegetation equals the vegetation that was burnt. This is common in early succession from crop and pasture, and young succession up to nine years old.

Table 7.2 Land-Use/Cover Classes, Biomass Change Values, and Fire Scenarios

Change Type	Classification Value/ 1986 Land Cover	Classification Value/ 1995 Land Cover	Change Value	Initial Fire Type	Additional Possible Fires
~	1 Forest	1 Forest	0	No Fire	No Fire
-	1 Forest	2 Adv. Succession	-1	No Fire	No Fire
-	1 Forest	3 Int. Succession	-2	Fire in Forest	No Fire
-	1 Forest	4 Yng. Succession	-3	Fire in Forest	Fire in Yng. Succession
-	1 Forest	5 Cropland/Yng. Succession	-4	Fire in Forest	Fire in Yng. Succession or Multiple Pasture Fires
-	1 Forest	6 Pasture	-5	Fire in Forest	Multiple Pasture Fires
-	1 Forest	7 Burn/Bare Soil	-6	Fire in Forest	Multiple Pasture Fires
+	2 Adv. Succession	1 Forest	1	No Fire	No Fire
~	2 Adv. Succession	2 Adv. Succession	0	No Fire	No Fire
-	2 Adv. Succession	3 Int. Succession	-1	Fire in Adv. Succession	No Additional Fires
-	2 Adv. Succession	4 Yng. Succession	-2	Fire in Adv. Succession	Fire in Yng. Succession
-	2 Adv. Succession	5 Cropland/Yng. Succession	-3	Fire in Adv. Succession	Multiple Pasture Fires
-	2 Adv. Succession	6 Pasture	-4	Fire in Adv. Succession	Multiple Pasture Fires
-	2 Adv. Succession	7 Burn/Bare Soil	-5	Fire in Adv. Succession	Multiple Pasture Fires
+	3 Int. Succession	1 Forest	2	No Fire	No Fire
+	3 Int. Succession	2 Adv. Succession	1	No Fire	No Fire
~	3 Int. Succession	3 Int. Succession	0	Fire in Int. Succession	No Fire
-	3 Int. Succession	4 Yng. Succession	-1	Fire in Int. Succession	Fire in Yng. Succession
-	3 Int. Succession	5 Cropland/Yng. Succession	-2	Fire in Int. Succession	Fire in Yng. Succession or Multiple Pasture Fires
-	3 Int. Succession	6 Pasture	-3	Fire in Int. Succession	Fire in Yng. Succession or Multiple Pasture Fires
-	3 Int. Succession	7 Burn/Bare Soil	-4	Fire in Int. Succession	Fire in Yng. Succession or Multiple Pasture Fires
+	4 Yng. Succession	1 Forest	3	No Fire	No Fire
+	4 Yng. Succession	2 Adv. Succession	2	No Fire	No Fire
+	4 Yng. Succession	3 Int. Succession	1	No Fire	No Fire
~	4 Yng. Succession	4 Yng. Succession	0	Fire in Yng. Succession	Fire in Yng. Succession
-	4 Yng. Succession	5 Cropland/Yng. Succession	-1	Fire in Yng. Succession	Fire in Yng. Succession or Multiple Pasture Fires
-	4 Yng. Succession	6 Pasture	-2	Fire in Yng. Succession	Fire in Yng. Succession or Multiple Pasture Fires
-	4 Yng. Succession	7 Burn/Bare Soil	-3	Fire in Yng. Succession	Fire in Yng. Succession or Multiple Pasture Fires

(continued on next page)

+ positive change

- negative change

~ neutral change

Table 7.2 (continued)

Change Type	Classification Value/ 1986 Land Cover		Classification Value/ 1995 Land Cover	Change Value	Initial Fire Type	Additional Possible Fires
+	5 Old Pasture/Yng. Succession	-	1 Forest	4	No Fire	No Fire
+	5 Old Pasture/Yng. Succession	-	2 Adv. Succession	3	No Fire	No Fire
+	5 Old Pasture/Yng. Succession	-	3 Int. Succession	2	No Fire	No Fire
+	5 Old Pasture/Yng. Succession	-	4 Yng. Succession	1	No Fire	No Fire
+	5 Old Pasture/Yng. Succession	-	5 Cropland/Yng. Succession	0	No Fire	No Fire
-	5 Old Pasture/Yng. Succession	-	6 Pasture	-1	Pasture Fire	Multiple Pasture Fires
-	5 Old Pasture/Yng. Succession	-	7 Burn/Bare Soil	-2	Pasture Fire	Multiple Pasture Fires
+	6 Pasture	-	1 Forest	5	No Fire	No Fire
+	6 Pasture	-	2 Adv. Succession	4	No Fire	No Fire
+	6 Pasture	-	3 Int. Succession	3	No Fire	No Fire
+	6 Pasture	-	4 Yng. Succession	2	Pasture Fire	Multiple Pasture Fires
+	6 Pasture	-	5 Cropland/Yng. Succession	1	Pasture Fire	Multiple Pasture Fires
~	6 Pasture	-	6 Pasture	0	Pasture Fire	Multiple Pasture Fires
-	6 Pasture	-	7 Burn/Bare Soil	-1	Pasture Fire	Multiple Pasture Fires
+	7 Burn/Bare Soil	-	1 Forest	6	No Fire	No Fire
+	7 Burn/Bare Soil	-	2 Adv. Succession	5	No Fire	No Fire
+	7 Burn/Bare Soil	-	3 Int. Succession	4	No Fire	No Fire
+	7 Burn/Bare Soil	-	4 Yng. Succession	3	Fire in Yng. Succession	No Fire
+	7 Burn/Bare Soil	-	5 Cropland/Yng. Succession	2	Fire in Yng. Succession	No Fire
+	7 Burn/Bare Soil	-	6 Pasture	1	Pasture Fire	Multiple Pasture Fires
~	7 Burn/Bare Soil	-	7 Burn/Bare Soil	0	Pasture Fire	Multiple Pasture Fires

+ positive change

- negative change

~ neutral change

Together, biomass change values in combination with the length of the change period help understand fire frequency and additional fire types. Because the change period is nine years, all vegetation in the study region can at most, exhibit nine years of growth. This means that vegetation reaching Intermediate Succession by 1995, has only been burnt once during the change period since there is not enough time in nine years for the area reach Intermediate Succession 1995 after experiencing a crop cycle. Conversely, any changes leading to one of the younger 1995 vegetation classes, either Pasture, Burn/Bare Soil, Cropland/Young Succession, or Young Succession, leave the possibility of additional fires open. There is ample time during the change period for fire to occur more than once and still be sufficient time for regrowth to match the 1995 classification.

7.2 Land-Cover Change from 1986 to 1995

The Belterra/Mojuí Agricultural Frontier

In discussing land-cover change at an aggregated level, it is important to realize that change in one biomass class by 1995 does not always directly indicate vegetation change in the comparable 1986 class. Classes represent vegetation that is alive and thus constantly transitioning. Change in a 1995 biomass class can actually indicate a dynamic in the biomass class next youngest to 1995 class because during the nine-year change period this next youngest class would naturally grow to become the 1995 class. For example, change in Advanced Succession by 1995 reflects a dynamic in 1986 Intermediate Succession during the 1986–95 period. Change by 1995 in Intermediate Succession reflects a dynamic in 1986 Young Succession. However, direct loss within a vegetation class is also demonstrated. Change in Forest cover by 1995 signifies a change in 1986 Forest cover because it is assumed that Forest would remain consistently classified regardless of nine years of growth. Last, change in Young Succession and Pasture by 1995, is particularly problematic. Because both land covers represent young vegetation, a number of possible land covers could have been manipulated to create the change by 1995.

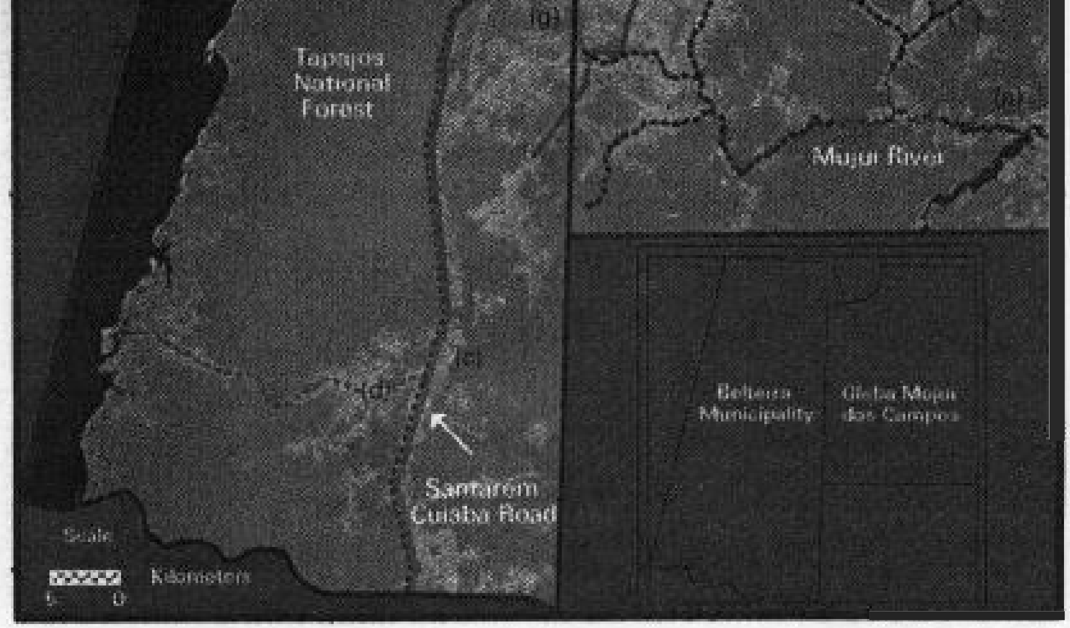
A variety of land-use processes underlie physical changes apparent during the period studied. Most evident are processes of land abandonment that lead to increases in biomass as areas are no longer utilized; new land invasion that increases forest loss which is related to two processes: (1) land consolidation processes that dispossess smallholders and push them into ever more remote forest areas coupled with in-migration processes and population expansion and (2) further forest encroachment on lands already occupied that is related to farm expansion or diversification. Table 7.3 shows percent of total land use/cover for each biomass classes, and percent of change. To simplify the scheme, percent of change represents the aggregation of classes as is noted in the table.

Table 7.3 Land Use/Cover and Change in the Belterra/Mojuí dos Campos Agricultural Frontier

1986 Land Use/Cover		1995 Land Use/Cover		1986–95 Change*
Forest	33.47%	Forest	35.25%	-1.15%
Lowland Forest	14.78%	Adv. Succession/Lowland Forest	11.85%	
Adv. Succession	16.71%	Adv. Succession	17.85%	+1.12
Int. Succession	15.86%	Int. Succession	13.75%	-2.11%
Yng. Succession	8.75%	Yng. Succession	8.61%	+7.72%
Old Pasture/Yng. Succession	5.52%	Crop/Yng. Succession	7.86%	
Pasture	4.22%	Pasture	4.32%	-5.58%
Burn/Bare Soil	.69%	Burn/Bare Soil	.53%	

* Forest = (1995 Forest + 1995 Adv. Succession/Lowland Forest) - (1986 Forest + 1986 Lowland Forest)
Adv. Succession = 1995 Adv. Succession - 1986 Adv. Succession
Int. Succession = 1995 Int. Succession - 1986 Int. Succession
Yng. Succession = (1995 Yng. Succession + 1995 Crop/Yng. Succession) - 1986 Yng. Succession
Pasture = (1995 Pasture + 1995 Burn/Bare Soil) - (1986 Pasture + 1986 Old Pasture/Yng. Succession. + 1986 Burn/Bare Soil)

Figures 7.2–7.5 show reference maps to be used in discussing land-cover change and land-cover/use classifications for 1986 and 1995. At the regional scale, large decreases occurred in Forest (-13.00%) and Pasture (-5.58%), combined with large increases in Young Succession (+7.72%) and Advanced Succession (+12.97%). Together these changes reflect the broad land-use change processes mentioned above. Changes in Forest cover and Young Succession are particularly linked to new land invasion and further deforestation on occupied land. As new areas are invaded and deforested, households are established and the first crops planted. Within the nine-year change period, these new areas experience one use/fallow cycle and then are abandoned to create the increased in 1995 Young Succession. Further deforestation on occupied land follows a similar path. Established households seeking to expand farm production gradually clear more forest portions of their properties. After a few years of cultivation, these areas are abandoned and show signs of young succession.



Municipal / Gleba Boundary
Major Roads
Minor Roads
Secondary Roads
National Forest Boundary
River Branches

(a) Mojui River
(b) North Santarem-Cuiaba Road
(c) South Santarem-Cuiaba Road
(d) Sao Jorge
(e) Belterra (town)
(f) Revolta
(g) Branches of Mojui River
(h) Northeast Gleba Mojui dos Campos

Figure 7.2: Refernce map of Belterra Municipality and Gleba Mojui dos Campos.

1986	1995
Cloud	Sand/Coast
Shadow	—
Lowland Forest	Adv. Succession/Lowland Forest
Int. Succession	Int. Succession
Adv. Succession	Adv. Succession
Old Pasture/Crop	Crop/Yng. Succession
Pasture	Pasture
Burn/Bare Soil	Burn/Bare Soil
Yng. Succession	Yng. Succession
Forest	Forest
Water/Shadow	Water

Table 7.3: Color legend.

Figure 7.3 Color Legend for Figures 7.4 and 7.5

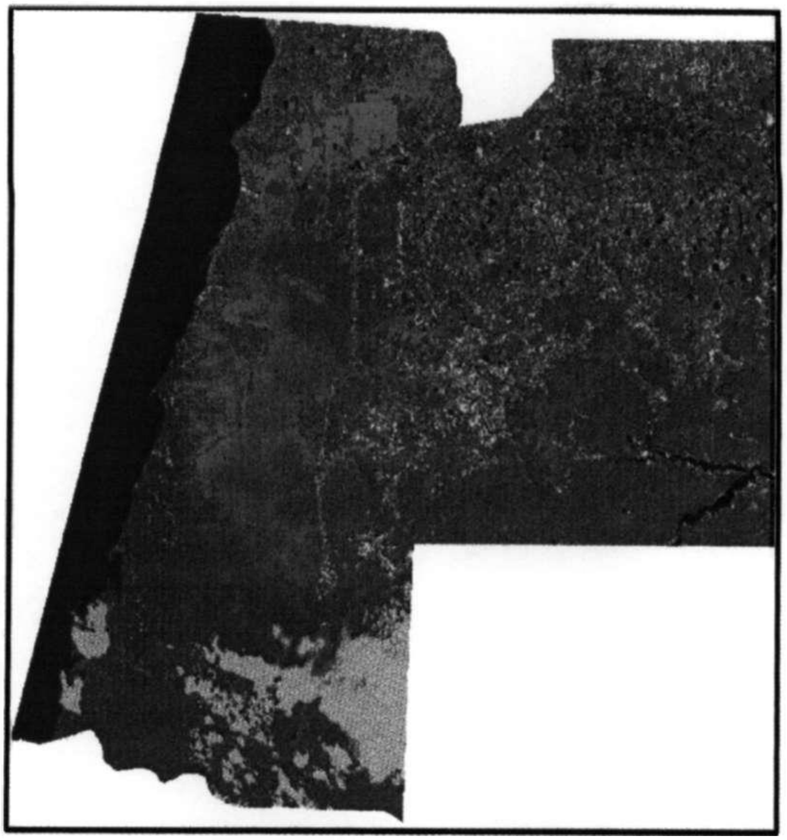


Figure 7.4: 1986 Land use/cover classification for Belterra Municipality and Gleba Mojui dos Campos.

Figure 7.5: 1995 Land use/cover classification for Belterra Municipality and Gleba Mojui dos Campos.

	1986	1995
	Cloud	Sand/Coast
	Shadow	—
	Lowland Forest	Adv. Succession/Lowland Forest
	Int. Succession	Int. Succession
	Adv. Succession	Adv. Succession
	Old Pasture/Crop	Crop/Yng. Succession
	Pasture	Pasture
	Burn/Bare Soil	Burn/Bare Soil
	Yng. Succession	Yng. Succession
	Forest	Forest
	Water/Shadow	Water

Table 7.3: Color legend.

Color Legend

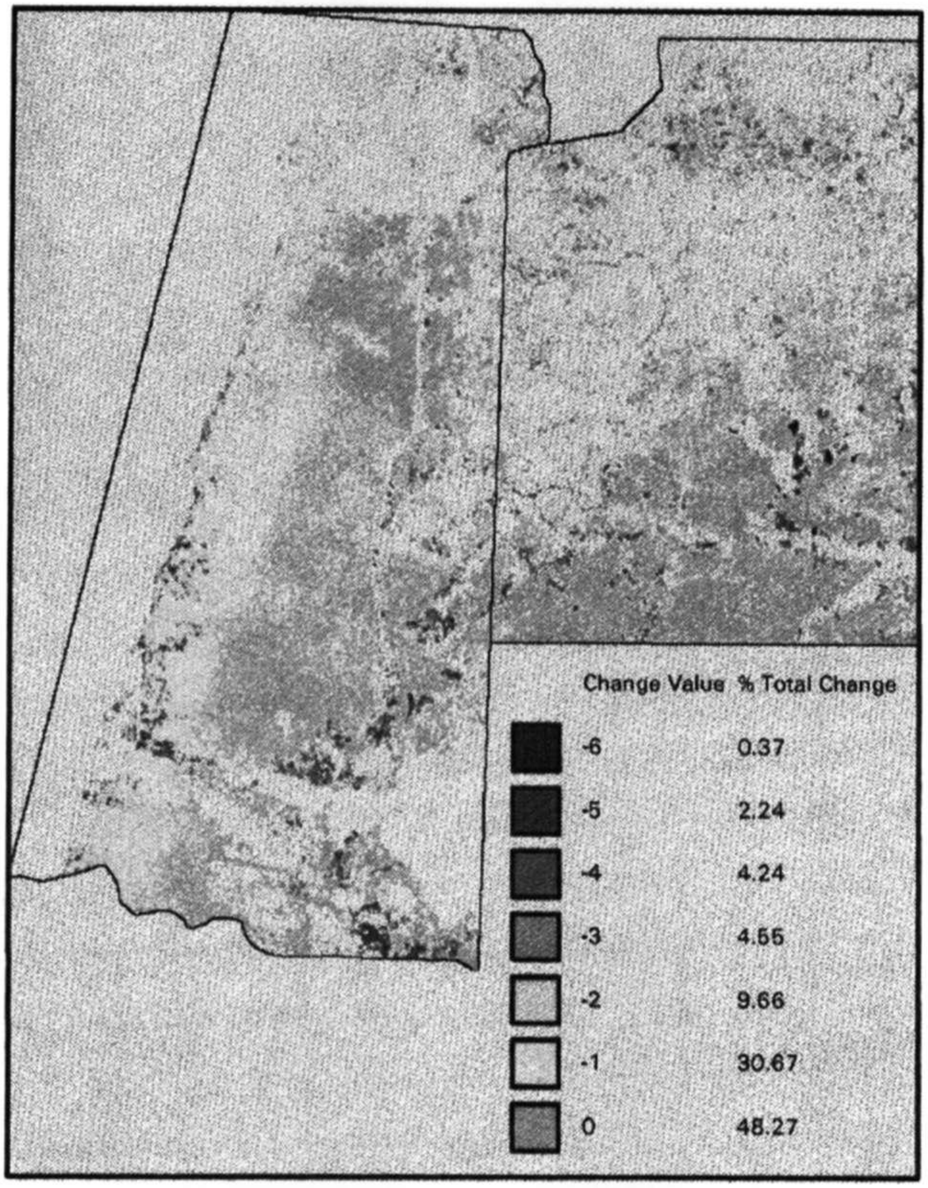
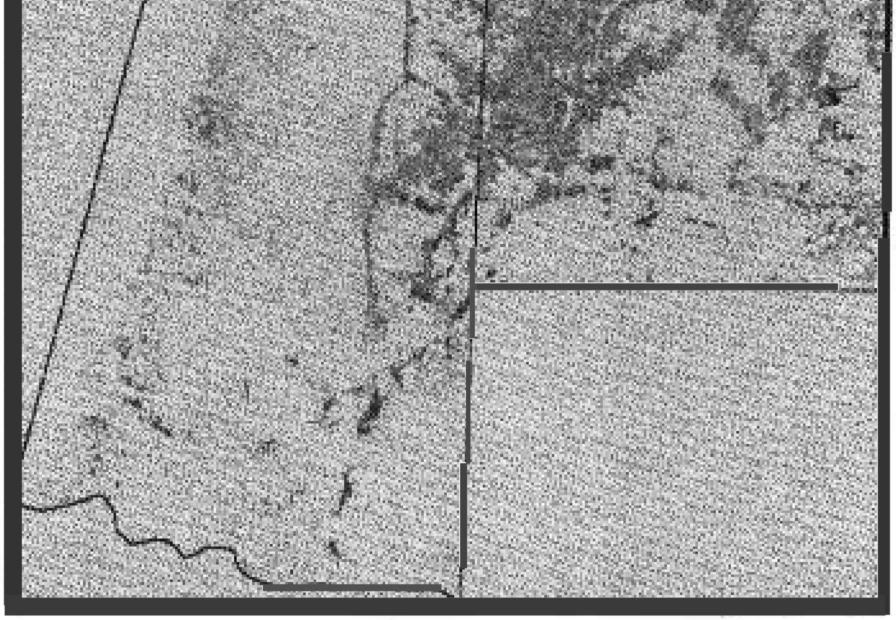


Figure 7.6: 1986-95 Forest cover change for Belterra Municipality and Gleba Mujui dos Campos.



Change Value	% Total Change	Change Value	% Total Change	Change Value	% Total Change
-4	.2	0	21.4	4	3.7
-3	2.2	1	26.7	5	1.4
-2	6.7	2	18.3	6	.2
-1	11.9	3	7.2		

Figure 7.7: 1986-95 Change in intermediate succession, young succession, and pasture cover for Belterra Municipality and Gleba Mujui dos Campos.

Changes in agriculture and land abandonment are largely seen through decreases in Intermediate Succession and increases in Advanced Succession. By 1995 Intermediate Succession decreased, signifying that Young Succession in 1986–95 was re-used and did not continue the regeneration necessary to reach Intermediate Succession by 1995. Fallow cycle lengths were shortened as farmers preferred to work in younger successional areas. Increase in 1995 Advanced Succession also implies two possible dynamics in existing agricultural system. First, farmers did not work in 1986 Intermediate Succession and thus, it remained abandoned and continued to grow into 1995 Advanced Succession. This implies that farmers utilize longer fallow lengths in some areas, in combination to the shorter fallow lengths mentioned above. Second, because the increase in 1995 Advanced Succession is large, actual farm abandonment is likely to be occurring in some areas.

Population statistics to substantiate land-use/cover changes in the study region are sketchy at best and sometimes nonexistent. No data were obtained for Belterra Municipality on population change. Considering that just over half of Belterra Municipality is within the National Forest and theoretically off limits to new invasion, the bulk of population change in the Belterra/Mojuí Region is concentrated peripheral to National Forest boundaries (though National Forest encroachment exists), and spread throughout Gleba Mojuí dos Campos. In Gleba Mojuí dos Campos, statistics on population were not obtained either, however, from 1986 to 1995, documents were issued in Gleba Mojuí dos Campos to 709 properties totaling 132,248.15 ha (de Miranda 1996). The total size of Gleba Mojuí dos Campos is 158,870 ha, signifying that in the change period, 21% of the land was titled. Land titling shows the portion of land invasion that was surveyed and documented with titles or licensees of occupation. Because it is a highly bureaucratic, time-consuming process, the statistic of land regularization is somewhat limited in reflecting actual population fluctuation during the time period. The 21% change could include long-established households that never bothered to regularize their land before or did not have the resources to do so. It could also exclude new land invasion into areas not surveyed or subdivisions on larger, surveyed areas. Yet, given these limitations, almost a quarter of the Gleba was surveyed within the nine-year period. This certainly hints to a dynamic frontier.

Through map comparison (Figures 7.3 and 7.4), land-cover changes occur throughout the study region. Along the banks of the Mojuí River (see Figure 7.2), new farm establishment and farm development is evident. Previously established pastures have increased in size and new pastures have been created. Here land clearance follows out from the river onto forested areas. Pastures tend to border the banks of the river so cattle have a water source. Other agricultural activity, as indicated by the intermediate and young succession classes, spread further from the riverbanks. These changes are the result of both new land invasion and further clearance on properties already established.

Along the Santarém-Cuiabá Road (see Figure 7.2), the area of land clearance has widened during the change period. Change is indicative of farm expansion and diversification coupled with further use of forested land on occupied properties. The northern portion of the road (b) is situated on the Tapajós Interfluvial Plateau where lack of streams makes livestock practice difficult. Hence land-cover change shows an increase in small patches of young and intermediate succession, and is an indication of crop cultivation. Further south (c), the plateau descends and the first natural water sources appear. The area immediately opens up into pasture, marked by more uniform rectangular shapes indicative of mechanized clearance and ranch development.

Land-cover change in the Tapajós National Forest is somewhat difficult to see because of the cloud cover in the southern portion of the 1986 image. However, forest clearance is related to expansion of agricultural activity outward from the town of São Jorge (see Figure 7.2), and along secondary roads which connect the town to the Santarém-Cuiabá Road, and the Tapajós River. This change is patchy and consists of extended cropland, young and intermediate succession, all associated to smallholder agricultural activity. There is also a large amount of consistent forest cover during the nine-year change period in the National Forest, indicating the extent of the forest as a reserve.

Land clearance in the town of Belterra is also particularly pronounced (see Figure 7.2). Here, encroachment means the loss of the advanced succession that grew up in the abandoned rubber areas. Whereas in 1986, thin lines of land clearance marked the grid shaped road system of the town, by 1995 clearance has spanned out from the roads. While most of this change is classified in the younger succession classes, it represents the beginnings of development within the town of Belterra and rural expansion, as people continue to build houses and establish small farm lots on the once government owned land.

Directly south of the town, land clearance in forest cover areas has led to increases in young and intermediate succession spanning out from the community of Revolta (f) and along the small roads that connect the community to the town of Belterra and the Santarém-Cuiabá Road. The patchy quality of the change again indicates crop cultivation and not large-scale pasture. While Revolta has a long-established history, much of the change along the small roads represents new land invasion as has been encouraged by both the Ministry of Agriculture and the pending incorporation of Belterra.

More subtle cover changes occur in the central portion of the study area indicating land abandonment and ranch consolidation. Much of the intermediate succession along branches of the Mojuí River (Figure 7.2, (g)), has grown to advanced succession by 1995 while 1986 Intermediate and Young Succession classes have shrunk. This can be seen in the overall increased light green color on the 1995 image and decreased yellows and browns. In addition, by 1995 pasture area is more concentrated and increasing. These changes are associated to each other and indicate that intermediate succession areas are not being used but continue to grow and reach the advanced succession stage by 1995, and, that cattle ranchers are consolidating land property.

Some of the new pasture area in this central portion of the study region is also small in size. Thus, while there may be some land abandonment occurring during the change period, smallholders who have remained in the area, are shifting their land-use practices toward livestock, and spend less time on other cultivation activities. This area is conveniently located near water sources so that livestock practice is feasible for both smallholders and corporate interests. An increase in livestock practice by smallholders again coincides with the increase abandonment of intermediate succession during the change period culminating in the increase advanced succession cover by 1995.

Last, there is further land clearance in the smaller patches of forest cover areas that are surrounded by land occupied in 1986. The forest cover in the northeast corner of Gleba Mojuí dos Campos (Figure 7.2 (h)), for example, is shrinking. Since these shrinking areas are interspersed with occupied areas, most likely they are the more remote portions of already established properties. There is less indication of new land invasion, then, and more a dwindling of forest cover on established properties.

Forest Cover Changes

Changes in forest cover represent the largest potential carbon stock changes and thus, imply more extreme consequences in terms of biomass-burning issues. To better visualize these biomass changes, Figure 7.6 shows the location of the 1986 Forest and the degree of biomass change (the change value) that occurred in them by 1995. Change values coincide with Table 7.2, such that values further from 0 represent extreme changes in biomass, negative values indicating biomass loss and positive values, biomass gain. The scale is not linear, but represents general change tendencies.

In the forest change map, the lightest colors correspond to change values 0 and -1. They indicate areas where minimal biomass change occurred and the forest basically remained intact between 1986 and 1995 without fire activity. These light colored areas are the largest change value categories in the region, over 78% of the total 1986 forest cover change. The large light area along the left flank of the region comprises the Tapajós Nation Forest, while the southeast area marks the edge of frontier expansion from Santarém.

Darker patches show where the most extreme negative biomass change occurred and imply fire activity in forest cover. In the Belterra/Mojuí dos Campos region, there are large patches of extreme biomass change within the Tapajós National Forest out from the community of São Jorge and south along the Santarém-Cuiabá until the boundary of the municipality. There are also patches along the edges of the Mojuí River and in the northeast section of Gleba Mojuí dos Campos. In the former two areas, 1986 forest cover changes are more concentrated, either along river branches and secondary roads, or at the frontier edges. These patterns indicate frontier expansion and new land invasion. A more dispersed pattern exists in the northeast portion of Gleba Mojuí dos Campos, where all degrees of biomass change are intermixed. Here, the overall pattern of forest cover change indicates further encroachment on land already occupied, rather than expansion and new land invasion.

The potential of additional fires in forest cover is important to biomass-burning issues because these fires speed up biomass loss. A significant portion of forest biomass does not burn in the initial fire, but gradually decomposes in the following years. Additional fires continue to burn this leftover forest debris and release trace gases at a faster rate than would occur in decomposition. Change values -6 through -3 represent the most extreme biomass decreases and imply ongoing fire activity. In these areas, the 1986 forest cover was classified as bare soil, pasture, young or intermediate succession in 1995. Because the vegetation by 1995 was relatively young, the original 1986 forest cover could have been slashed and burnt sometime in the late 1980s, used for a few years, abandoned for a few years, then burnt and used a second time. Thus, in addition to the original fire in forest cover, additional fires in Young Succession or Pasture are possible.

In the study region, more extreme negative biomass changes tend to be in areas indicative of new land invasion (Tapajós National Forest and the Mojuí River areas), rather than areas of further forest encroachment on established properties (northeast Gleba Mojuí dos Campos). Newly invaded areas do not have a wide range of vegetation covers and farmers have little choices in what they can burn. They either slash-and-burn forest cover, which is very labor intensive, or if they have lived on the land a few years and have young abandoned fallows, they re-burn these areas. Intermediate and advanced fallows are not as abundant on farm sites, because the land has not been occupied long enough for agricultural fields to reach older fallows. Young abandoned fallows in frontier regions are slightly unique from most young fallows in that they often remain full of charred trunks from the initial forest clearance fire. New land invaders have no choice but to burn these young fallows speeding the process of forest decomposition and actually burning more biomass than what is usually associated with young fallows. In older more established regions, farmers have more choices in vegetation covers. They do not need to continue working in a recently forest cover area and can allow it to fallow for more than a few years. Many of the younger fallows have experienced few crop cycles and contain less quantities of forest trunk debris.

Secondary Succession and Agricultural Activity

Biomass changes in younger vegetation classes demonstrate the possibility of ongoing fire activity, farm diversification and agricultural expansion. These changes hold less serious consequences for global biomass burning because biomass in replacement vegetation is usually comparable to that of the vegetation burnt. However, as indications land occupation and agricultural activity, farm failure or stability and accumulation holds consequences for future fire activity.

Figure 7.7 shows biomass changes of the five smallest 1986 biomass classes (Burn/Bare Soil, Pasture, Old Pasture/Young Succession, Young Succession, and Intermediate Succession) aggregated together. Again, the scale is not linear, but represents areas of varying biomass gain or loss. Approximately 57% of all biomass change in the young succession classes is toward positive change values, meaning increases in biomass. Considering that a fallow period is part of the agricultural practice in the region, this is not surprising in the younger succession classes. The positive biomass change also implies that approximately half of all land cleared for agriculture is not under immediate use. This leaves approximately 42% of the change in the younger biomass classes to negative and neutral change values, both of which imply ongoing fire activity.

The area covered by these classes is largely concentrated in the northern portion of Gleba Mojuí dos Campos on the outskirts of Santarém, and spans south, continuing concentration parallel to the Santarém-Cuiabá Road. All types of biomass change (positive, negative, and neutral) are interspersed. However, there is more negative change in the area between the Santarém-Cuiabá Road and the branches of the Mojuí River, than in the northeast corner of Gleba Mojuí dos Campos. These areas with more negative change have younger settlement history and are further from Santarém. They exhibit the tendencies of most newer settled areas: repeated burning of young fallows, because intermediate and advanced fallows are less available. Once young succession is available farmers will use it in their initial farm establishment. The northeast section of Gleba Mojuí dos Campos has a long-established history of agricultural activity and land use. Here the landscape contains a wide range of succession such that farmers have more choice.

7.3 Conclusion

In this chapter I used remotely sensed data to detect biomass changes from 1986 to 1995 throughout Belterra Municipality and Gleba Mojuí dos Campos. These changes are not direct measures of biomass quantity, but are signs of vegetation cover growth or loss. As such, they hint at human intervention in the landscape and provide a window into the frequency and nature of fire activity throughout the change period. A variety of land-use change processes, propelling biomass change, are evident within the study region. Most significantly are: (1) farm diversification and expansion leading to further deforestation in already occupied areas; (2) land invasion into more remote areas resulting in deforestation; and (3) land abandonment coupled with land consolidation leading to increases of biomass in fallowed areas and clearance for pasture.

These broad changes reflect the settlement history of the region and the nature of fire activity. In the first groups of changes, farm diversification entails shifts into pasture fires or ongoing land uses. These changes are seen in well-established areas of the study region. They usually minimize fire in secondary succession because land-use practice is moving away from rotational crop systems. Farm expansion, however, requires the burning of additional forest cover. Yet, because these fires occur on already established lots, forest lost is most likely small and occurring incrementally. Areas that exhibit new land invasion, as is grouped in the second set of changes, are likely to cause fire in primary forests. These tendencies are seen in remote newly established areas of the study region. Change occurs by small landholders who have few resources to clear large areas effectively. Fire in forest occurs incrementally in relatively small cleared areas. The last group of changes, land abandonment in combination with land consolidation, is occurring most visibly in the central west section of the study region. Here settlement history is mid-ranged and regional changes imply some increases in biomass, while fire activity increases in grasses associated with pastures.

In the following chapter, I discuss biomass change on a quantifiable level by analyzing vegetation inventories in 14 fallows, before and after they were slashed and burnt. Here the scale of analysis shrinks to the size of agricultural fields and sampling of individual trees is used to create estimates of living biomass. Yet, this information can be extrapolated to the larger regional scale where biomass-burning estimates are made because of the link between vegetation cover and land-use change. Chapter 8 then sets the ground for such extrapolation, and provides the physical values of biomass at various stages of secondary succession and forest which can later be integrated with land-cover change to estimate biomass burning in the Belterra/Mojuí dos Campos agricultural frontier.

CHAPTER 8

SECONDARY SUCCESSION, AND PRE- AND POST-FIRE BIOMASS IN THE BELTERRA/MOJUÍ DOS CAMPOS REGION

Because biomass burning is largely the result of human decisions and these decisions may reflect preferences for certain areas over others, comparing vegetation provides a method to link land-use decisions with physical burning patterns and biomass change. There are a variety of measures that can be used to compare vegetation areas, ranging from actual biomass weight estimations, to indications of vegetation maturity (species diversity, average tree heights and diameters, and average canopy depths), to estimations of age and land-use history. In a natural undisturbed setting, age alone may be sufficient to classify vegetative regrowth. However, as humans intervene in the landscape more and more, land-use history influences the ability of vegetation to regenerate (Uhl et al. 1988). Hence, in regions, such as agricultural frontiers, other structural and floristic parameters are useful.

While biomass is synonymous with vegetation, two measures of biomass are particularly important to biomass-burning issues; (1) biomass as a *dry* weight[7] of vegetation; and (2) biomass as a composition of minerals that when burnt emit specific proportions of trace gases. In the dissertation, I deal only with the former aspect, because there is an assumed correlation between weight and mineral composition (Brown and Getson 1996; Mackensen et al. 1996).

This chapter looks specifically at biomass in the study region through 14 vegetation surveys collected during fieldwork. I begin by reviewing the basic indicators of biomass maturation: weight, structure (canopy, total height, tree diameter), and species composition and diversity. Then, I detail methods used in site sampling. Next, I incorporate land-use history with these indicators to analyze biomass in 14 field sites. Together this information creates a picture of the pre-fire biomass loads for vegetation in the study region. Next, I present field site data of vegetation left after the areas have been burnt. This post-fire biomass includes charred debris, unburnt slashed vegetation, and trees that were left standing during the slashing period. I use the pre-fire and post-fire biomass loads to assess the amount of biomass change occurring during the process of slash-and-burn agriculture, and calculate burning efficiencies for each field site.

8.1 BIOMASS ESTIMATES, METHODS, AND COMPARISON

Estimates of Biomass Weight

Estimating the dry weight of the vegetation is a fundamental way to compare biomass in different areas. There are both direct and indirect approaches, and each has its advantages and disadvantages. Direct approaches calculates weight estimates based on

[7] A measure when all moisture has been accounted for.

destructive sampling, a process in which all vegetation in sampling units is cut and weighed, moisture content is accounted for, and overall weight is adjusted to represent *dry* weight (Higuchi et al. 1994; Overman et al. 1994). One then extrapolates to reach a uniform area measure, either metric tons per hectare or tons per acre. While destructive sampling produces accurate estimates of the immediate ecosystem sampled, the procedure is so laborious that sampling units tend to be small and sparsely distributed rendering them unreliable for estimating of biomass in larger-scaled ecosystems (Brown et al. 1989). For example, estimates of biomass weight in the Brazilian Amazon, using destructive sampling range from 143–666 t/ha for the same region (Klinge et al. 1975; Fearnside et al. 1993; Revilla Cardenas 1982, cited in Fearnside et al. 1993). In addition, sampling units tend to reflect what researchers consider mature forest which can result in biases toward larger biomass plots, while within larger forest system more variation is apparent (Brown and Getson 1996). Biomass estimates made from different ecological studies are not always easily comparable because the components measured and methods used vary tremendously (Fearnside et al. 1993). Wood density, moisture content, below-ground biomass, litterfall, and soil organic matter are all factors that influence the variation in biomass estimates. Last, the practice of felling mature forest trees is seen as counter to the purpose of research on deforestation in the first place.

Two indirect methods are commonly used to estimate biomass weight. The first uses regression analysis to construct allometric equations that fit biomass weight to other, more easily measured, dimensions of trees, such as height and diameter. Allometric equations can be species specific or averaged to be applied to all vegetation based on diameter classes. The second method utilizes large-scale forest inventories that include species counts and timber volumes. Indirect methods remain problematic as well. First, allometric equations are often developed from ecological studies that were designed to characterize local forest or vegetation structures, not necessarily to represent larger plant populations that require larger random sampling (Brown et al. 1989). For example, the total area covered by ecological studies of tropical forests is less than .00001% of the world's tropical forest cover, yet, biomass weight estimates rely on these studies (Brown and Lugo 1984). In the Brazilian Amazon, more than 80% of ecological studies on tropical forests have been conducted in only two states, Pará and Amazonas, and situated in three locales (Weaver 1993). Second, while regression models have been developed for many ecosystems, it is not always easy to select an equation appropriate for the ecosystem surveyed (Higuchi et al. 1994). Consequently, biomass weight estimates calculated from different allometric equations produce varying results. Third, forest inventories, when used, often record only harvestable timber, omitting non-timber species and small diameter trees that may be present in substantial amounts. In addition, forestry inventories are not available for all the threatened ecosystems in the world. Estimates using indirect measures range from 160–374 t/ha (Brown and Iverson 1992; Fearnside et al. 1993). However, allometric equations and forest inventory methods continue to be refined as they are efficient and hardly disrupt the ecosystem being surveyed, a major advantage to their use over destructive sampling.

Because no allometric equations exist for the study region, seven different equations derived from datasets spread throughout the Amazon Basin were evaluated and a combination of two equations used based on tree diameter classes. In addition, to validate the results, other indicators of biomass maturity were considered.

Methods

Vegetation field surveys were conducted to estimate biomass content of agricultural fallows before and after burning, and gain an understanding of vegetation properties in the forest and succession forming the study region landscape. Fourteen field sites were selected based on farmer recollection of vegetation age. Since verification of exact age depends on acuteness of farmer memory, ranges of age were aimed for in site selection. The total sample consists of five young sites (three to five years' growth), five intermediate sites (6–10 years' growth), four advanced sites (14–17 years' growth) and one mature forest. Each fallow was located on a different farm so that the total sample represented slash-and-burn agricultural processes on 14 farms.

To sample the pre-fire biomass load, 10 large plots, 10 x 15 m each, were randomly established along a central transect. Species name, stem height, total height, and diameter at breast height (DBH) were recorded for all trees with a diameter larger than 5 cm. Within each large plot, a medium plot, 5 x 2 m, was randomly established, while species name, total height, stem height, and DBH recorded for all saplings between 2 cm and 5 cm in diameter. In addition, all seedlings and saplings (diameter < 2 cm) were identified and counted.

Pre-burn biomass content within each fallow was estimated allometrically using the following equations:

For all medium plots (Saldiarriaga 1988)

$$Y = -.292 + (.369 * X12) - (.087 * X2)$$

For all secondary succession large plots (Saldiarriaga 1988)

If DBH < 20 cm, $\ln Y = -1.981 + (1.047 * \ln(X12) + (0.572 * \ln(X2))$

If DBH $\geq$ 20 cm, $\ln Y = (-1.086 + (.876 * \ln(X12)) + (.604 * \ln(X2)) + (.871 * \ln(X3)))$

For forest site (Overman et al. 1994)

If DBH $\leq$ 45, $\ln Y = -3.555 + (1.002 * \ln(X12 * X2))$

If DBH > 45, $\ln Y = -3.843 + (1.035 * \ln(X12 * X2))$

where Y = biomass measured (t/ha), X1 = DBH, X2 = total height, and X3 = wood density (g/cm3) = 0.53.

Data collected to measure post-burn biomass load occurred in 12 of the fallows only, while in the case of the remaining fallow and the forest, the owners elected not to burn their areas. Methods follow a similar plot strategy to the pre-burn assessments. Ten 10 x 15 m plots were randomly selected along a central transect. All partially burnt vegetation and debris was sorted into fine debris (< 2 cm in diameter and palm fronds), medium debris (2–10 cm in diameter) and large debris (> 10 cm in diameter), then weighed. The diameter and height of all trees left standing within the 1,500 m^2 areas were measured and a qualitative estimate of how much of each tree remained, was noted. If the diameter fell within one standard deviation of the mean DBH for the pre-fire fallow sample, biomass was allometrically measured for that tree, adjusted by an estimate of how much was burnt, and added to the post burn biomass total. Otherwise, the tree was considered to be older than the fallow and was left out.

Other Indicators of Biomass Maturity

Because biomass estimates using allometric equations contain uncertainty, other indications of biomass maturity were considered. These other indicators measure structure in the sites, floristic composition, and spectral reflectance.

Structural Indicators

The first of these other indications used to validate biomass weight estimates is basal area, the surface area of a tree trunk if a horizontal cross section is made. Basal area is a structural indicator as it characterizes the vegetation stand. It is assumed that the tree trunk is cylindrical and thus, basal area is calculated as the area of a circle (πr^2). When the basal area of all trees in the sample site is summed, total basal area represents the area of horizontal space occupied by trunk biomass. Trunk, by its shear size, density, and height, contains the largest amounts of biomass, compared to other above-ground biomass (branch, leaf, litter). Higher biomass areas are assumed to contain more biomass in trunks and thus, a larger percent of the total horizontal space is occupied by biomass and basal area is higher.

A second structural indication of biomass maturity is canopy depth. Here the difference between total height of each tree and height to the first major branching is calculated. Average for all trees represents the average depth of the canopy for the sampled area. Mature forests will exhibit higher tree canopies and broader depths while younger areas remain open with minimally wide canopies and shorter total tree heights.

Floristic Composition and Diversity

A third indicator of biomass maturity is floristic diversity and composition. Each stage of biomass maturity is likely to be characterized by its family and species composition and diversity, while stage duration is influenced by the extensiveness of historical land use.[8] Factors, such as, surrounding vegetation, seed bank, topography, and competition are also influential in the way vegetation will regenerate (Moran 1996b). In younger sites, where sunlight is abundant, opportunistic species thrive which are characterized by short life cycles. Most of these species emerge from sprouting off of slashed or burnt trunks, or roots, and are encouraged by repeated burning practices (Kauffman 1991). Herbaceous plants, grasses, and vines are the more common opportunistic species. Within the first few years, small shrubs and tree saplings (diameter of 2–5 cm) appear as well and can dominate the site, accounting for most of the basal area. Emerging tree species are usually pioneer species, which grow quickly in abundant sun light conditions. Species dominance at this stage is particularly linked to land-use history. Frequently burnt or machined cleared sites tend to favor opportunistic species that are fire-tolerant, rather than wood species that are more sensitive to fire (Uhl et al. 1988). This initial regeneration process is similar to the gap phase of tropical rainforest growth cycles where pioneer species, which germinate only in full sunlight, sprout up after natural tree fall creates openings in the forest canopy (Swaine and Whitmore 1988). As sites reach intermediate stages of growth, they are marked by the increased family and species diversity, number of individual tree seedlings (diameter < 2 cm) and saplings, and the gradual replacement of grass, vines, and shrubs that made up the understory.

[8] The following discussion of succession applies to tropical moist forests only.

Branching from continued sapling and small tree growth, begins to shade the ground, creating dimmer light conditions unfavorable for pioneer species which become replaced by other longer-lasting tree species (Nepstad et al. 1991). This replacement process is complex and again, related to land-use history. Differentiation between canopy vegetation (dominant tree species that branch over the site) and understory (smaller vegetation that exists at ground level and below the canopy) begins to emerge with shade-tolerant species in the understory (Silva et al. 1995). As a site reaches advanced succession, the number of tree families increases, while the number of individual species within a family may decrease. Tree canopy gets denser shading the understory, keeping in moisture, and making it difficult for herbaceous plants, vines and grass to thrive. This thinning of groundcover creates the "clean" conditions seen in the understory of mature forests.

Spectral Indicators

A last indicator of biomass maturity is the vegetation's spectral reflectance. The basic components of spectral modeling as represented in remotely sensed data are soil reflectance, moisture absorption, and plant chlorophyll absorption and mesophyl reflectance. All four of these parameters can be associated to structural changes in vegetation such as those mentioned above, and can thus, highlight stages of biomass maturation. Two overarching processes occur in biomass maturation that make remotely sensed data useful, the gradual increase of biomass over soil and the increase of shadowing both of which are associated to the density of the canopy. The visible spectrum highlights increases in biomass by depressed values in Band 3, while the mid infrared (Band 7) accents the contrast between soils and vegetation. The near and mid infrared (Band 4 and 5) are sensitive to vegetation structure and moisture conditions, both indications of canopy density and shadowing.

8.2 Field Sites and Land-Use History

Table 8.1 shows basic characteristics of field sites. All sites except site 07 were secondary succession (fallows) when vegetation inventories were collected. While the land-use history of these sites follows some sort of use/fallow cycle, the length of these cycles and the extensiveness of the history vary greatly. Some sites were initially cleared over 60 years ago, while others were cleared for the first time within the last 10 years. The extensiveness of land-use activity takes its toll on the ability of sites to regenerate naturally in the fallow portion of the cycle. Site 07 is a forest that was logged in the 1940s.

Table 8.1 Basic Characteristics of Field Sites

Site	Community	Date of Initial Forest Clearance	Number of Past Use/Fallow Cycles*	Most Recent Age (yrs.)	Dry Period (days)	Date of Fire
10	Rural Belterra	1930	2	3	28	2nd wk., Nov.
11	Tracoá	1940	~9	3	30	1st wk., Dec.
05	Boa Esperanca	Before 1981	At least 2	4	20	2nd wk., Nov.
13	Rural Belterra	1955	6	5	36	2nd wk., Dec
02	Boa Esperanca	1987	1	6	--	1st wk., Dec.
06	Boa Esperanca	Before 1981	At least 2	6	26	4th wk., Oct.
08	Nova Esperanca	1962	5	8	12	4th wk., Oct.
09	Nova Esperanca	1971	3	8	60	1st wk., Dec.
01	Boa Esperanca	Before 1985	At least 1	10	30	4th wk., Oct.
12	Rural Belterra	1930	1	14	34	3rd wk., Nov.
14	Rural Belterra	1975	1	14	--	--
04	Tracoá	Before 1981	At least 1	15	43	4th wk., Nov.
03	Tracoá	1973	At least 2	17	--	2nd wk., Nov.
07	Nova Esperanca	~1940[1]	Never Fallowed	Logged Forest	Was not slashed	Was not burnt

* A use/fallow cycle consists of one use period and one abandonment period. It also indicates one burning. The data here do not include the use/fallow cycle that began during field work.

[1] Site was selectively logged in 1940.

Young Sites

Sites 10 and 11 are the youngest sites, each having been abandoned only three years. Site 10 is located on land initially cleared in the 1930s for rubber and has experienced at least two use/fallow cycles. It was abandoned some time in the next 15 years, but its use history from 1945 until 1988 when the present owner acquired the land, is not known. It was a fallow similar to intermediate age when the present owners acquired the land indicating that it was cleared at least once since 1945. From 1991 to 1993, the owners cleared it and planted corn, rice, and manioc. From initial clearance then, Site 10 has experienced at least three use/fallow cycles of varying length, being cleared and burnt at the beginning of each cycle. Site 11 is located in Tracoá, the oldest established community and has a longer history of continual use with initial land clearance in 1940. Corn and manioc are the main crops planted and the site has been utilized in approximately nine use/fallow cycles of six years. Site 05 is a four-year fallow located along the Santarém-Cuiabá Road. Date of initial clearance is unclear, but most likely occurred in the 1970s when the area was first opened. The land was fallow when the current owner arrived indicating at least one previous clearing and burning. The present owner cleared the land in 1991 to plant corn, rice and manioc, and then abandoned it two years later, making the total known use/fallow cycles at least 2. Site 13 is a five-year site located in Rural Belterra on the West side where the plateau begins to descend to the Tapajós River. It was initially cleared in 1955 and has been under continual seven-year use/fallow cycles with the first year consisting of mixed crops, either rice or corn with manioc, the second year harvesting the manioc, then fallow for five years. This total approximately six use/fallow cycles.

Intermediate Sites

Site 02 is a six-year fallow located along the Santarém-Cuiabá Road that was initially cleared in 1987. It has only experienced one use/fallow cycle where rice, cotton, corn and manioc were planted in a three-year sequence. Site 06 is also a six-year fallow located in close proximity to Site 02. It was initially cleared previous to the establishment of the present household, but most likely clearing occurred in the 1970s. In 1989, the site was an eight-year fallow, indicating one previous use, and was cleared and burnt a second time to plan corn, beans, rice, manioc, pumpkin and watermelon. It was then abandoned for six years. Hence, it has experienced at least two use/fallow cycles. Site 08 has is a eight-year fallow located along the Santarém-Cuiabá Road and has been in use since 1962, planting rice, corm and manioc during a two-year use phase, and abandoning the area for six to eight years. This totals approximately six use/fallow cycles. Site 09 is an eight-year fallow also along the Santarém-Cuiabá Road and was first cleared in 1971 and used for rice, then abandoned. A second clearing occurred in 1983 and corn, manioc, then rubber were planted. Part of the site was abandoned for three years and then used a third time, before the most recent fallow period. This adds up to three use/fallow cycles. Site 01 is a 10 year fallow and is located along the Santarém-Cuiabá Road. Because present owners are new to the lot, the use history is not known. However, the site contains substantial amounts of decaying logs, implying that the area was cleared only once before field surveying.

Advanced Sites

Sites 12 and 14 are both 14 year old fallows located in Rural Belterra, with similar land-use histories. They were initially cleared in 1975, planted with rubber, and used for experimental purposes. In 1982, fire passed through the area, killing most of the young rubber trees and the sites were abandoned. In 1992 fire again passed through the sites, with more extensive damage in Site 12. They have only experienced one use/fallow cycle. Site 04 is a 15 year fallow located in Tracoá. The land-use history of the site is not known prior to 1982 when the present owners moved to the lot. However, since it is located in the oldest community, its use history is likely to be extensive. Site 03 is a 17 year fallow in Tracoá and was initially cleared in 1973. It was used once for rice in 1974, then abandoned five years and used a second time in 1980, totaling two use/fallow cycles. Site 07 is a mature forest, selectively logged in the 1940s.

Indications of Field Site Biomass and Vegetation Maturity

Figure 8.1 (a) shows biomass weight estimates of the field sites by total basal area. Age ranges are indicated by data point shading. With the exception of sites 10 and

12, both biomass weight and total basal area increase with age range, and both measures are significantly higher in the forest site (07). Site 10 fits the trend of increases in biomass with total basal area, however, it exhibits higher amounts of both than would be expected considering its young age. Site 12 is problematic because it was damaged extensively by fire in 1992. It has lower total basal area and biomass than would be expected considering its age. This reflects the extent of regrowth occurring after fire. Basal area in young sites ranges 4–8 m^2/ha, while biomass is 10–30 t/ha. Intermediate sites exhibit a broader range in basal area, 8–16 m^2/ha, with biomass ranging from 30–60 t/ha. Last, basal area in advanced sites ranges from 13–21 m^2/ha, and shows a sharper increase in biomass weight than the other two ranges.

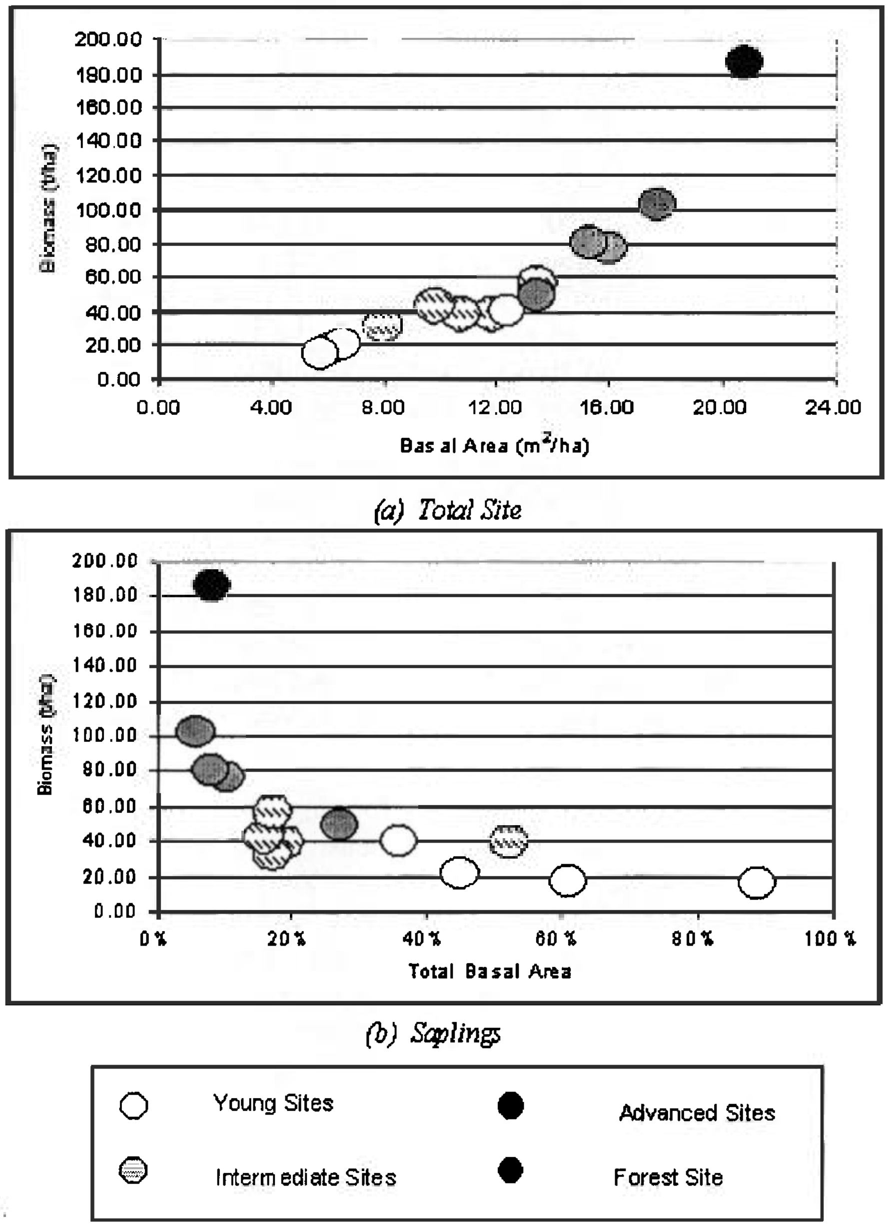


Figure 8.1: Basal Area and Biomass for Field Sites

The percent of total basal area represented in saplings (diameter of 2–5 cm) is shown in Figure 8.1 (b) and is an indication of understory density and openness of vegetation canopy. Younger sites do not have closed canopies, and sunlight infiltrates to the ground where young, small diameter trees grow and sapling basal area as a percent of total basal area is higher. Dense tree canopies as exhibited in mature forest and advanced succession, shade out sunshine, making it more difficult for younger vegetation to thrive. Ground cover and understory, where saplings exist, is minimal. From the data, canopy cover begins affecting the understory sapling growth at the intermediate stage of growth, and does not vary as much by biomass weight once a site has reached advanced growth.

As is expected, a general opposite trend appears where higher biomass weight is associated to smaller percent of total basal area in saplings. However, young sites exhibit a broader range of total basal area in saplings than do the other vegetation classes. Site 06, an intermediate site, is more characteristic of the young sites in terms of percent of total basal area in saplings, indicating that the site is still open and sapling vegetation dense. Site 02 is a six-year site and hence, is on the border between the two succession stages, though its biomass weight is comparable to the other intermediate sites. The rest of the intermediate Sites, 08, 06, 09, are more closely clustered near the 20% mark. The advanced sites and the Forest Site are also fairly clustered around the 8% mark, though the Forest Site is clearly marked by its biomass weight. This indicates that structurally advanced sites exhibit similar understory density as the Forest site. Site 12 again is less characteristic of advanced site trends, exemplifying that fire damage altered canopy structure and re-opened it to sapling and understory growth.

Figure 8.2 presents a picture of site mean canopy depth. The top of each bar represents site mean total height, while the bottom is placed at site mean stem height. Bar length reflects mean canopy depth. In general average canopies not only increase in depth with age, but canopy total height increases. Sites 12 and 14 seem to be considerably lower for their respective age ranges, but considering fire damage in these areas the data are plausible. Sites 03 and 04, on the other hand, contain average canopy depths wider than the Forest Site (07). Considering that Sites 03 and 04 also have percent of total basal area in understory saplings comparable to Forest, the depth of the canopies comes as no surprise.

In the young sites canopy is not truly forming and thus, the data show more the variation in sapling height than tree canopy density and depth. Both 13 and 11 have somewhat lower overall heights and shorter depths. They also have the highest percent of basal area in samplings (Figure 8.1 (b)). The two have the longest continued land-use histories of all of the sites, dating over 40 years, showing the toll taken on vegetation regeneration when land remains in an extensive use cycle. Site 10 and 05 are similar and are closer in height and depth to younger intermediate sites (02 and 06). Both have experienced fewer use cycles, and Site 10 in particular continues to exhibit traits more indicative of intermediate sites.

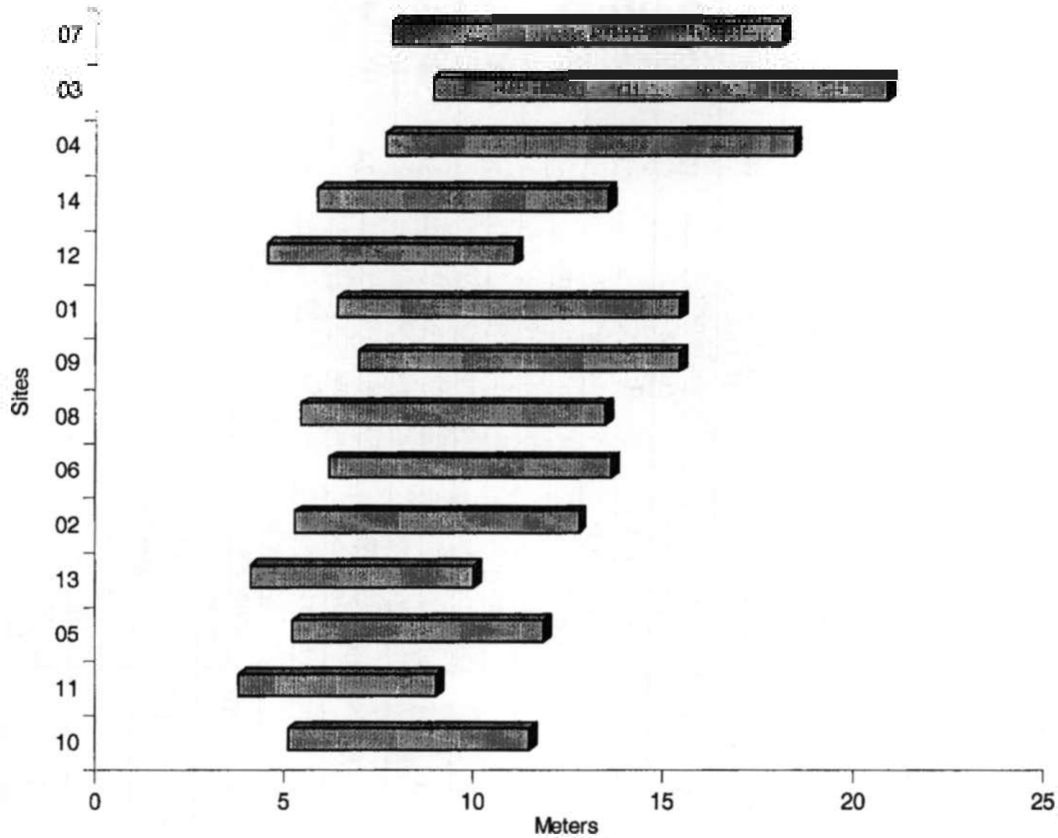


Figure 8.2: Average Stem Heights, Total Heights, and Canopy Depth of Field Sites

Species Diversity and Composition

Table 8.2 shows the species and family diversity of the sites, along with the two most dominant[9] tree (diameter > 5 cm) and sapling (diameter of 2–5 cm) families and species. In the intermediate and advanced sites, tree species are an indication of canopy composition while saplings represent understory vegetation. In young sites this distinction is less pronounced as there are significantly less individuals in the tree species category.

[9] Dominance is defined by the importance value for the species, a measure that combines the species average frequency, average density, and average basal area.

Table 8.2: Dominant Families and Species, Species Diversity for Field Sites

Site	Age	Dominant Saplings (Diameter = 2–5 cm) Family	Species	# of Species	# of Families	Count	Dominant Trees (Diameter > 5 cm) Family	Species	# of Species	# of Families	Count
10	3	Burseraceae	Protium sp.	42	30	154	Moraceae	Cecropia obtusa	18	14	214
		Verbenaceae	Aegiphilia sp.				Leguminosae	Inga sp.			
11	3	Annacardiceae	Tapirira guianensis	55	33	151	Moraceae	Cecropia obtusa	21	14	112
		Elaeocarpaceae	Sloanea sp.				Annacardiceae	Tapirira guianensis			
05	4	Moraceae	Cecropia obtusa	45	23	166	Moraceae	Cecropia obtusa	14	8	99
		Flacourtiaceae	Lindackeria paraensis					Vine - Not identified			
13	5		Vine - Not identified	36	23	165	Moraceae	Cecropia obtusa	12	10	34
		Guttiferae	Vismia sp.				Guttiferae	Vismia sp.			
02	6	Guttiferae	Vismia sp.	56	28	237	Leguminosae	Inga sp.	23	18	230
		Elaeocarpaceae	Sloanea sp.				Guttiferae	Vismia guianensis			
06	6		Vine - Not identified	48	27	168	Leguminosae	Cassia spruceana	28	17	251
		Flacourtiaceae	Lindackeria paraensis				Annonanceae	Guatteria poeppigiana			
08	8	Elaeocarpaceae	Sloanea sp.	43	22	135	Leguminosae	Inga sp.	29	20	142
		Lauraceae	Octoea sp.				Araliaceae	Didymopanax morototoni			
09	8	Euphorbiaceae	Hevea brasilensis	39	20	118	Euphorbiaceae	Hevea brasilensis	38	23	158
		Violaceae	Rinora macrocarpa				Annonaceae	Guatteria peoppigiana			
01	10	Flacourtiaceae	Lindackeria paraensis	50	25	144	Moraceae	Cecropia obtusa	24	18	221
		Tiliaceae	Apeiba echinata				Moraceae	Cecropia sciadophylla			
12	14	Elaeocarpaceae	Sloanea sp.	34	24	120	Elaeocarpaceae	Slonea sp.	28	20	199
		Rubiaceae	Coussarea racemosa				Guttiferae	Vismia guianensis			
14	14	Annacardiceae	Tapirira guianensis	41	26	101	Annacardiceae	Tapirira guianensis	39	24	244
		Rubiaceae	Coussarea racemosa				Bignoniaceae	Jacaranda copaia			
04	15	Elaeocarpaceae	Sloanea sp.	43	24	158	Annacardiceae	Tapirira guianensis	26	20	112
		Verbenaceae	Vitex triflora				Boraginaceae	Cordia bicolor			
03	17	Melastomataceae	Mourira plasscharti	50	26	194	Leguminosae	Inga sp.	30	21	140
		Monimiaceae	Siparuna dicipiens				Bignoniaceae	Jacaranda copaia			
07	Forest	Violaceae	Rinorea paussoua	52	29	153	Leguminosae	Piptadenia suaveolens	40	24	86
		Melastomataceae	Miconia sp.				Leguminosae	Crudia glaberrina			

In young sites (10, 11, 05, 13), only four species are dominant in tree composition, *Cecropia obtusa*, *Inga sp.*, *Tapiriria guinensis*, and *Vismia sp.* All are pioneer species that invade easily into newly opened areas and grow quickly under abundant sunlight conditions and minimal competition from larger trees (Silva et al. 1995). Once they reach small trees, they can act as cover, providing shade to slower-growing but longer-life-span forest tree species (Moran 1996a). The first two species are also characterized by short life cycles and tend to be replaced in later years of regeneration (Silva et al. 1995). *Vismia sp.* and *Tapiriria guinensis* are wood species, meaning they have longer life duration, can grow to more substantial proportions, and can be seen in later stages of succession (Uhl 1987). In addition, *Vismia sp.* is particularly common in areas that have experienced many burns, such as Site 13 where approximately six use/fallow cycles have occurred.

A larger diversity of species dominates the sapling composition of the young sites. It is common to have more diversity in the understory because of the range of plant types (herbs, shrubs, grasses, vines, and seedlings) that thrive under well lit conditions with minimal competition from larger trees (Uhl et al. 1988; Moran 1996b). However, both pioneer species *Cecropia obtusa* and *Vismia sp.* are present, as well as, wood species, *Tapirira guianensis*. Opportunistic vines are also dominant in two of the sites as is common in the initial stages of regeneration. Other light demanding pioneer species found in the saplings are *Sloanea sp.* and *Aegiphilia sp.* (Swaine and Whitmore 1988; Olegario Pereira de Carvalho 1992). One species, *Protium sp.*, is shade-tolerant, meaning it does not usually grow well under constant sunlight which characterizes young sites. However, it is dominant in Site 10, an exception to the young sites both in biomass weight and basal area. The dominant presence of this shade-tolerant species is yet another indication that the site is more exemplary of intermediate stage succession.

The intermediate stage is marked by gradual replacement of vines, grasses, herbs and shrubs, and emergence of more wood species within pioneering species. In the intermediate sites (02, 06, 08, 09, 01), there is more species diversity in the dominant trees and saplings, reflecting this shift toward more wood species. Two pioneer species, *Vismia sp.* and *Inga sp.*, are still present, while additional wood species include *Guatteria poeppigiana*, a currently non-commercial tree with logging potential, and the commercially logged, *Didymopanax morototoni*. These last two species are not only common in secondary succession, but have been noted in other succession studies of the Tapajós National Forest and succession in Belterra Municipality (Olegario Pereira de Carvalho 1992; Oliveira and Silva 1993). The dominance of rubber trees (*Hevea brasilensis*) in Site 09 saplings and trees particularly highlights the influence of past land use that included rubber cultivation.

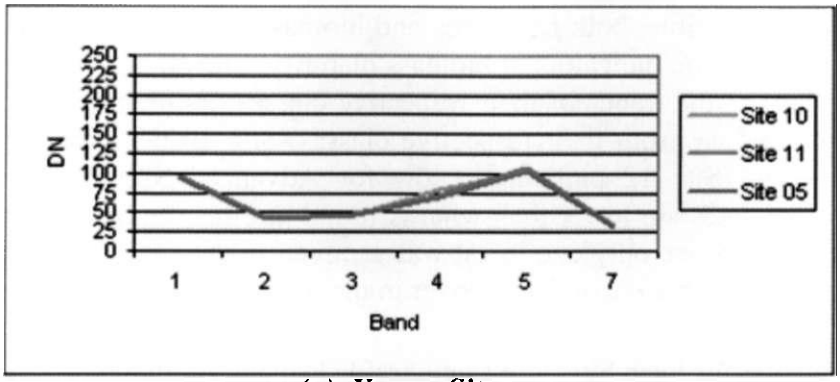
In the understory as represented by saplings, two shade-tolerant species are present, *Sloanea sp.* and *Rinora macrocarpa*. Their presence implies that canopy cover shading sunlight is occurring in some sites. *Rinora macrocarpa* frequently dominates understory of forests in the Tapajós National Forest region (Silva et al. 1995). The dominance of *Cecropia sp.* in Site 01, on the other hand, is unusual, considering the estimated age of the site. Complete land-use history of this site is not known by the present household, but the continued presence of a pioneer species could indicate extensive land use in the past. Last, vines in the understory are only present in one site indicating that overall the replacement of light demanding ground cover is occurring.

The gradual replacement of dominating pioneer species by slower growing longer-lasting wood species can take up to 20 years. Many of these new incoming wood species are considered climax species, which can germinate and grow under shaded light conditions, form the understory in mature forests, and when opportunity rises through natural tree fall gaps, they grow into the canopy (Saldiarriaga 1988). In the advanced sites (12, 14, 04, 03), all dominant tree species are wood species, with the exception of *Inga sp.* in Site 03. *Jacaranda Copaia* and *Cordia bicolor* are commercial species found in advanced succession and forests through the Belterra Municipality and Tapajós National Forest region, as well as, in Eastern Pará (Saldiarriaga 1988; Uhl 1988; Oliveira 1993). *Taparira guianensis* is a non-commercial wood species with harvesting potential also commonly found in the region (Oliveira and Silva 1993).

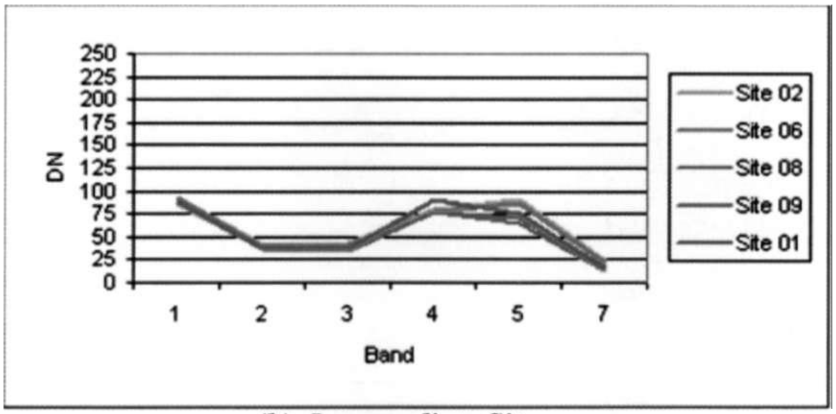
In the understory, *Coussara Racemosa* is dominant in both Site 12 and 14. It is a climax species, meaning it is usually found in mature forest canopies (Swaine and Whitmore 1988). That it is found in Site 12 mixed with a pioneer species, *Sloanea sp.*, reflects the patchiness of canopy cover in the site after fire damage in 1992. Shaded, more protected areas in the understory exist along side exposed sunlit spaces. In Site 03 understory, both dominant species are climax species unique to the site and not dominant in other sites. Both are rare species and reflects the broadening in species diversity that occurs as this stage reaches forest stature. They were identified in only two other sites, 14 and 07, the former begin an advanced site and the later, forest.

Spectral Means

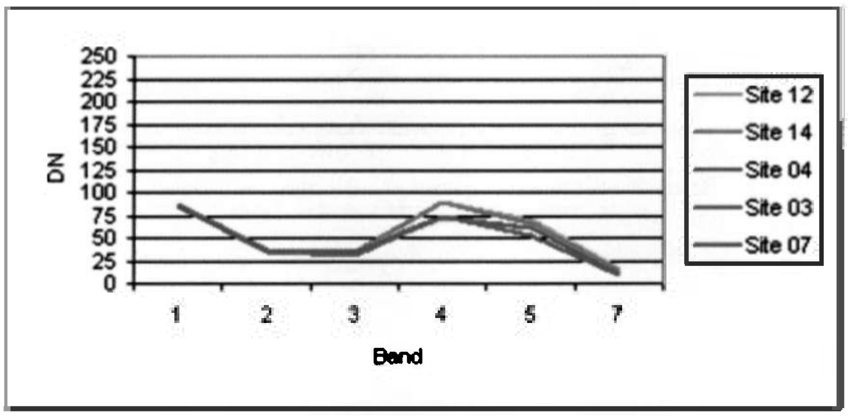
Figures 8.3 shows the mean DNs of the sites when located, by geographic coordinates taken with a GPS, on the 1995 TM image. Since fieldwork was conducted in the fall of 1996, sites were approximately one year younger on the image. Site 13 is not represented because it is situated within an area of mature forest making it difficult to obtain accurate geographic coordinates. Shifts of spectral means are consistent within each succession range. The young sites (Figure 8.3 (a)) exhibit a larger range in Bands 5 and 7 than do the intermediate and advanced sites, indicating the openness of the canopy, moisture evaporation, as well as, the reflectivity of soils. High values in Band 4 coupled with high values in Band 3 also indicate young vegetation, but low biomass content. The intermediate sites show two patterns (Figure 8.3 (b)). First Sites 02 and 06 show drier conditions (higher Band 5 DNs) and more evidence of soil exposure (higher Band 7 DNs) than do the rest of the intermediate sites. These are indications of fairly open canopy structure. Both Sites were five-year sites when the image was recorded and are situated between young and intermediate sites. Note the similar pattern in DNs with the young sites, though values are lower in Band 5 and 7. The second pattern, Sites 08, 09, and 01, are more in line with increases in biomass and the beginnings of canopy density as is expected in intermediate succession. Site 01 was a nine-year site slightly more biomass as indicated in lower Band 3 values. In the advanced sites and forest site (Figure 8.3 (c)), sites 12 and 14 are grouped, while sites 03, 04, and 07 are grouped. Again, the history of fire damage in Sites 12 and 14 opening the canopy to new young vegetation creates higher values in Band 4 and Band 5, but overall ratios are indicative of large biomass content. Band 7 values for all advanced and forest sites are characteristically lower indicating minimal soil reflectivity.



(a) Young Sites



(b) Intermediate Sites



(c) Advanced Sites and Forest Site

Figure 8.3 Mean DNs for Field Sites

Biomass Estimates

Table 8.3 shows dry weight estimates for all sites and estimates made from other ecological studies. Where possible, both basal area and biomass estimates are shown. In discussing structural and floristic indicators of biomass maturity, Site 10 and 12 stand out particularly as not following the trends of their respective classes. Estimates of biomass weight in these sites also vary from their respective classes, Site 10 being particularly high for Young Sites and Site 12 particularly low for Advanced Sites. In general, succession and forest estimates are lower than what is found in other studies shown, but basal areas are comparable. Since only one forest was sampled in the areas, it is difficult to speculate if site 07 is representative of forest cover in the region.

Table 8.3 Biomass Estimates for Field Sites and Comparable Ecological Studies

Site	Age	Biomass (t/ha)	Basal Area (m^2/ha)	Ave. Biomass (t/ha)	Ave. Basal Area (m^2/ha)
10	3	38.5	11.8		
11	**3**	16.8	6.1		
05	**4**	20.8	6.6		
13	**5**	14.6	5.8		
Young Succession				17.4	7.6
02	**6**	39.6	12.5		
06	**6**	39.1	10.7		
08	**8**	32.9	8.0		
09	**8**	42.9	9.8		
01	10	56.4	13.5		
Intermediate Succession				42.2	**10.9**
12	14	48.7	13.5		
14	**14**	70.9	16.1		
04	**15**	79.5	15.4		
03	**17**	101.8	17.1		
Advanced Succession				84.1	15.5
07	Forest	176.3	20.8	--	--

	Uhl et al. 1988		Fearnside 1991		Brown and Lugo 1992	
	Biomass	Basal	Biomass	Basal	Biomass	Basal
Yng. Succession	18.00–64.2	1.3–7.2	--	--	--	--
Int. Succession	53.2–57.3	8.2–9.1	--	--	--	--
Adv. Succession	--	--	--	--	--	--
Tropical Forest	--	--	188–271	--	175–289	--

8.3 Post-Fire Biomass and Fire Efficiency

Fire efficiency is the most difficult variable of the biomass burning equation to measure (Fearnside et al. 1993). As was discussed in Chapter 2, fire efficiency is subject to cultural practices, as well as, microclimatic conditions making efficiency rates spatially distinct across regions and even micro-regions. In the Brazilian Amazon, a 30% fire efficiency is typically used for forest while a slightly higher rate 40–50%, is used in succession areas (Fearnside et al. 1993; Carvalho et al. 1995). These rates are developed by surveying slashed areas before burning to calculate pre-fire biomass fuel load, weighing charred leftover debris to calculate post fire biomass, then taking the ratio of the difference of pre-fire and post fire biomass, with pre-fire load[10] (Brown and Roussopoulos 1974; Uhl 1990; Fearnside and Malheiros Guimarães 1996). A third study, conducted in Eastern Pará and Rondônia, measured fire efficiency significantly higher, claiming fires consume 42–57% of total above ground biomass (Kauffman et al. 1995).

Table 8.4 shows pre-fire biomass loads, post fire biomass, and fire efficiency rates. All sites except 07 were slashed and burnt by their respective landowners, and remaining charred vegetative debris was weighed according to the sampling scheme described at the beginning of the chapter. Site 10 is missing because the farmer began further cleaning and planting on the site before weighing could be conducted. All sites have higher rates than the typical 30% fire efficiency rate used in biomass-burning estimates for forests and most are higher than the 40–50% efficiency rates used to estimate succession areas. When averages are calculated, fire efficiency increases with biomass class. This response is contrary to evidence of previous studies where burning efficiency decreases with site age. However, in field sites, standard deviations also increase with biomass class, suggesting that fire efficiency ranges greatly and is not exclusively tied to pre-fire biomass load. For example, both the most and the least efficiently burnt areas are in the advanced succession sites. This increase in variation also suggests that as areas grow older, other factors, such as farmer practice and weather conditions may have more of an effect of fire efficiency.

Table 8.4: Fire Efficiency in Field Sites

Site	Age	Pre-fire Biomass (t/ha)	Post Fire Biomass (t/ha)	Percent Biomass Burnt	Average Efficiency	Standard Deviation
10	3	38.51	--			
11	3	16.80	9.57	43.02%		
05	4	20.79	11.43	45.03%		
13	5	14.57	7.01	51.91%		
Young Sites					46.65%	4.67%
02	6	39.62	20.82	47.45%		
06	6	39.05	19.82	49.26%		
08	8	32.90	10.41	68.36%		
09	9	42.93	20.77	51.61%		
01	10	56.43	30.42	46.10%		
Intermediate Sites					52.56%	9.07%
12	14	48.71	19.64	59.68%		
14	14	70.86	37.23	54.34%		
04	15	79.54	16.25	79.57%		
03	17	101.84	64.87	36.30%		
Advanced Sites					57.47%	17.80%
07	Forest	176.30	--	--	--	

There are a few other possibilities in discrepancies between efficiency rates calculated here and those used in other studies. First, the dataset is small and may not be

[10] (Pre-fire Biomass - Post Fire Biomass)/Pre-fire Biomass

extensive enough to represent larger common patterns for the area. Considering the many variables that affect overall efficiency of a burn, larger sample sets are more likely to minimize outliers. Second, measurement and estimation of biomass in sites was conducted while vegetation was still *alive*, a distinctly different procedure than measurement of *slashed* vegetation as used in the Fearnside et al. (1993) and Carvalho et al. (1995) studies mentioned above. Methods used in this study were designed specifically to capture change in biomass that occurs in the full process of slash-and-burn practice. Estimates of initial live vegetation more fully represent total change. In studies mentioned above, vegetation had already dried substantially and decomposition was in process.

8.4 Conclusion

This chapter presents the physical evidence of biomass burning at the local level by investigating the types of vegetation households in the study region use in their land-use decisions and fire-use practices. Vegetation chosen for burning varied in fuel load, structure, and floristic composition. While certain characteristics were associated to vegetation age and thus biomass was roughly classified, there were always areas that varied greatly from what would be expected due to past disturbance or land use. Even in a small sample such as that used in this research, such outliers were present.

Within these classifications, it would seem logical that fire efficiency, a variable that reflects the combustibility of the vegetation, would demonstrate a trend associated with other indicators of biomass. Certainly areas with higher pre-fire fuel loads have the potential to create hotter fires. Yet, efficiency did not show a clear relation to vegetation age, especially when considering the range of efficiency within each age group.

This lack of association, however, does not signify that no association exists, rather that conditions for the sites were not consistent, even within age classes. Each field site was slashed, dried, and burnt at different times during the 1996 burning season. The microclimatic conditions varied during this time period and no doubt influenced the combustibility of the vegetation. The process and timing of each burn also reflected a set of human land-use decisions and fire-use techniques. An important question in the efficiency of burning may involve why farmers chose the vegetation they do and why they burn when they do. The lack of clear association based on physical parameters alone opens the door to there being other influences, particularly human ones. With this information in mind, the following chapter looks specifically at household dynamics in four rural communities to understand what influences fire-use practices.

CHAPTER 9

FRONTIER DYNAMICS AND FIRE USE IN THE BELTERRA/MOJUÍ DOS CAMPOS REGION

To understand the forces that propel biomass burning across the landscape, I have consistently argued that connections between human activities and physical burning evidence must be made. These linkages involve understanding household land-use decisions, corresponding land-cover change, and how household actions are manifest in the physical burning pattern. Currently, social scientific inquiry addresses the beginning of these linkages through conceptualizations of land-cover change and investigation into resulting environmental responses. But this literature largely addresses the topics of deforestation or agricultural change, leaving only inferences as to the consequent fire-use choices and physical burning patterns resulting from land-use decisions. This chapter will layer analysis of fire use in the Belterra/Mojuí dos Campos agricultural frontier onto these conceptualizations of land-use/cover change to refine them theoretically and broaden their applicability.

At the local scale, land-use/cover change literature links frontier household structure, resource use or farm strategies, and resulting land-cover change (Netting 1993; Stonich 1993; Walker and Homma 1996; Godoy et al. 1997). Human agency and local processes are emphasized, but these can also be placed within the political economic conditions encompassing household farm development (Schmink and Wood 1987; Painter and Durham 1995; Peet and Watts 1996; Zimmerer 1996). Incorporating a regional economic perspective, price structures, public infrastructure, market distortions, and specific frontier economic characteristics also have been noted to play roles in production magnitudes, land consolidation and land-use decisions (Ozorio de Almeida 1992; Southgate and Whitaker 1992; Homma et al. 1994, cited in Walker et al. 1996; Pichón 1996b). Last, ecological constraints are also considered in the land-cover change literature, with particular focus on soil fertility (Moran 1993b; Pichón 1997). Without access to alternative farming technology that can improve soil conditions, gradual erosion and nutrient depletion forces households to clear new forest areas, the precursor to further land expansion, resettlement, and land-cover change (Oberai 1988; Pichón 1996a).

To layer the consequences of fire-use practices into these conceptualizations of land-use/cover change, it is necessary to place a human face onto the physical burning pattern through three questions: (1) the fuel load question: How do farmers select which biomass loads to burn and why? (2) the land exposed question: How do farmers choose the area of land to burn and, consequently, under what conditions do their actions lead to accidental fire that burns a larger area than intended? and, (3) the fire efficiency question: What fire-use techniques do farmers use when preparing their fields and subsequently burning them? Addressing these three questions highlights factors associated to fire use that influence land-use decisions and thus contribute to our understanding of land-use/cover change.

This chapter begins by discussing local level conceptualizations of land-use/cover change that focus on household evolution in frontier regions. I argue that when fire-use and biomass choices are placed within this conceptualization, other important aspects of frontier dynamics emerge that are overlooked by the framework. Next, a regional economic conceptualization of land-use/cover change is considered. Additional information on biomass choices is used to evaluate the ability of this framework to understand fire activity and land-cover change. Last, issues of fire efficiency are addressed. In this section, I argue that in addition to the more articulated analysis of land-use/cover change, farmer convenience, labor and time flexibility affect actual fire activity. These later variables emerge when analysis specifically addresses fire use and can expand the scope and understanding of land-use change conceptualizations.

9.1 Frontier Dynamics

Household Evolution, Land-Use Change, and Biomass Burning

In land-use/cover research at the local scale, household socioeconomic characteristics are viewed in phases related to household establishment length. Newly established households are equated to newly formed families and thus, show characteristics common in initial stages of family life. These characteristics include households with young children, small labor forces, and few resources other than parent labor power. These households have often exhausted their financial resources in buying land, making investment in long-term farm planning difficult. Initial resource endowments have been found to play a critical role in farm trajectories limiting initial farm establishment options (Bonnal et al. 1993, cited in Walker et al. 1996). In empirical studies of frontier settlement, young households show characteristics of *elasticity* in that they quickly adapt diversified economic strategies to meet livelihood needs (Stonich 1993). They pursue local off-farm employment, extractive activities, and may even migrate intermittently to keep their households afloat. This minimizes risk by spreading it geographically and through a variety of income generating activities (Collins 1988). Limited labor power is also an explanatory variable in farm strategies. With young dependent children, household consumption demands are high relative to labor force power, and first priority is to plant annual subsistence staples that will meet immediate caloric needs.

Established households show traits of more mature families with larger labor forces comprised of adolescent or adult children, farm accumulation, and increased resources. In place of elasticity, mature households are characterized by consolidation, with focus on farm diversification rather than reliance on off farm economic activities (Brasil and McCracken 1993). They often have developed local knowledge of effective land-use practices from extensive experiences. Households focus on specific profit generating activities, such as livestock. They may also diversify crop production, introducing perennials such as black pepper, cacao, rubber, coconut, banana, oranges, and other tropical fruits. Maintenance of these crops requires ongoing labor that mature households have and can afford to expend (Toniolo and Uhl 1994). Another common diversification strategy is agroforestry, where long-term plot production is maximized through the intermixing of tree crops that mature at different times. The time lag between planting and income generation makes this practice unfeasible to young households

(Walker and Smith 1993). This diversity serves as a buffer against market stresses, such as regional or international price fluxes, or ecological stresses, such as insect or fungus infestation (Smith et al. 1996). Measures of improved economic performance have been associated to agroforestry systems (Walker et al. 1994).

Land cover, burning options, and fire-use activity change in response to household developments and shifting farming strategies. Young households make land-use decisions to meet immediate needs. They plant subsistence annuals such as manioc, corn, rice, and beans that grow quickly and are reliable food sources. A rotation based subsistence farm strategy then emerges with successional vegetation cover surrounding house sites and fire activity is used within the rotational secondary succession system. In mature households, fire dynamics may become more complex. Ventures into livestock practices create grassland cover, which is highly vulnerable to accidental fire. If located near subsistence crop fields, where slashed areas create higher fuel loads and more intense fires, the potential of fire passing into pasture areas increases dramatically. Pasture maintenance also requires fire use every two to three years, increasing fire frequency in larger areas. Agroforestry systems, on the other hand, demand continual use of land and require fewer fires. Vegetation biomass continues to accrue and plot structure may eventually resemble advanced succession (Walker and Homma 1996).

Yet, other local dynamics that influence land-use decisions tend to be discounted within the continuum framework, because the spatial conceptualization of the frontier is not incorporated fully. Within this framework, time is prioritized with the major impact on land-use decisions being dependent on the establishment length and age of the household unit. The ecological and social evolution of frontiers is not solely influenced by the linear trajectory of the household, but constantly shifts due to other frontier dynamics that have spatial implications. Land-use history, farm abandonment, local resettlement, urban to rural extension, and second-generation farm establishment are all ongoing facets in frontier spaces. These additional frontier dynamics layer over the continuum of young to mature household establishment and influence land-use decisions.

Other Frontier Dynamics: History of Land Settlement and Abandonment, Household Resettlement, and Second-Generation Households

The first of these other frontier dynamics not accounted for within the household continuum literature on land-use/cover change is the influence of land settlement and abandonment (Walker and Homma 1996). Frontier settlement history is particularly important when considering burning patterns because the past occupancy of land leaves imprints upon the physical landscape that provide incoming households with different landscapes, than those households that abandoned frontiers had faced upon their initial arrival. New households moving onto land previously occupied make land-use decisions within a different mix of vegetation cover. In such instances, secondary succession exists close to the house site and forest is further off. Households are more likely to work in succession areas, than in forest because of its proximity. Older succession areas may be present as well, providing farmers with ample vegetation types necessary for common crops. Previously occupied land may also have internal paths or roads, and structures, such as processing shacks for rice or manioc. These features facilitate farm development and influence where farmers chose to slash-and-burn vegetation. Households prefer to work in areas close to shacks and roads because they can minimize labor extended to hand carry crop yields.

Households moving onto previously unoccupied land have different burning options. In the first year, they must burn native vegetation cover, usually forest cover, as it is all that exists. Forest cover is close to house sites and households burn area near the house site in the first years. After a few years, when initial clearance has been used, abandoned and begins to show signs of young succession, households have choices between slashing and re-burning this young succession and/or continuing clearance of more forest cover. The combination of these choices continues as households remain on land such that forest cover becomes ever more distant from the house site while, vegetation of varying successional stages begins to encircle the house site.

A second frontier dynamic neglected in the continuum framework is revealed in situations of household resettlement, creating a scenario in which newly established households are not necessarily young families. Regional resettlement, or migration to the area from other major regions of the country, is the most commonly expected dynamic of frontiers. The frontier is assumed empty and people are immigrating into it to populate it. The household continuum framework builds from this scenario, assuming that those who immigrate are young and desiring to establish the young families, which initiate the household cycle land-use dynamic. But local resettlement is also often at work and its impact shifts land-use decisions and burning patterns. Reasons for local resettlement vary from rural households repositioning themselves on better agricultural land, to urban households extending their properties into rural areas, to urban families wishing to relocate back to rural areas and escape urban poor neighborhoods. They may move to where road access is better, to where tenure is promising, to bigger lots that accommodate their growing extended families, or to areas where soil quality and water access is better. Though they are newly established on a lot, they show a mixture of the characteristics of both young and mature households breaking down the land-use expectations upheld in the continuum framework. They may have valuable local knowledge of ecological and climatic conditions, general region familiarity, and extra resources. They may have extended family and acquaintances that are valuable contacts in locating good available sites and helping to finance moves. They may maintain part time jobs in urban areas to see the household through initial farm start-up years. All of these factors influence their land-use decisions, allowing them to move more rapidly away from subsistence strategies into diversified farm strategies. Resettlement is an ongoing frontier dynamic, not fully addressed in the continuum framework, but which ultimately influences burning patterns.

Last, the continuum framework discounts the frontier dynamic of second-generation household establishment. New households frequently emerge on land in which one of the household heads was born. Though these second-generation residents may be starting their own new households, they have been established on the land for quite some time. As such they do not exclusively exhibit the characteristics associated to new households conceptualized within the continuum framework. They have extended family around them. They continue to work with their extended families, sharing tasks of clearing, maintaining and harvesting fields or pastures. They may even establish their households through land their parents have bought for them. Extended families then serve as buffers to the more difficult circumstances of new households as conceptualized within the continuum framework. As frontiers begin to reflect longer settlement histories, these second-generation residents modify the household cycle continuum, and thus, the land-use/cover change process.

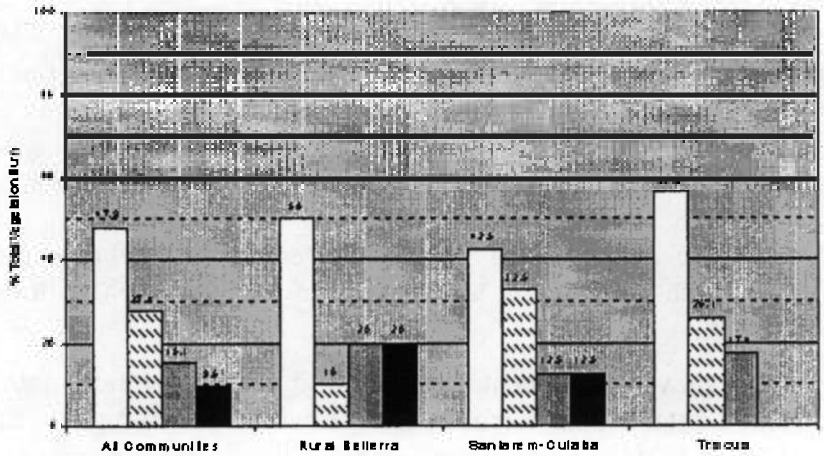
9.2 Frontier Dynamics in the Micro-Study Region

As settlement of frontiers persists, land-use/cover change and burning patterns not only result from household evolution, but are also influenced by settlement history, previous land occupation, resettlement, and second-generation household establishment. To understand the influence of these frontier dynamics, households in the study region were asked questions on establishment history, biomass load choices, total area burnt, farm diversification, land tenure status and history of burning choices. Verification of this information beyond farmer recollection is difficult. However, at the regional scale, basic land-cover trends can be confirmed through comparison with remotely sensed imagery, then using inference, land-use decisions can be evaluated given cover change. To evaluate the influence of household demographic dynamics on land-use/cover change, the analysis investigates current burning choices (by community and household establishment length) and types of land use/cover new households move onto. Also incorporated into the analysis is a comparison of household burning choices by establishment length.

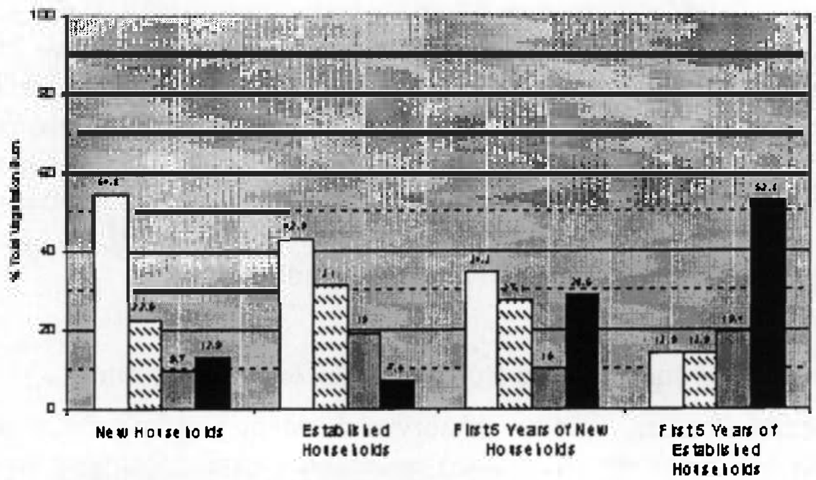
Figure 9.1 shows the percent areas burnt in each vegetation class by community and by household establishment length for the whole micro-region. Table 9.1 shows subsets of 1986 and 1995 land use/cover and change by community based on the classifications discussed in Chapter 7. These two sets of information combined shed light on the influences of settlement history, previous land occupation or abandonment, and existing cover which new households move onto. Overall, households chose to burn mostly Young and Intermediate aged fallows (Figure 9.1a). Just over 75% of all areas cleared were in these two smallest biomass load classes. The results seem odd considering the literature on slash-and-burn agriculture that argues farmers prefer to slash and work in older fallows or forest where nutrient transfer to soils is greater during the fire and thus, crop yields will be greater. However, as will be argued in the following discussion, biomass choice is tied up in a number of competing factors, which include existing land cover, resettlement, and farmer flexibility.

Land Cover and Biomass-Burning Choices by Community

In Rural Belterra, land-use history and recent political shifts create a frontier landscape in which newly established households exhibit burning patterns expected within the continuum framework, as well as, patterns that reflect the context of Rural Belterra's historical frontier dynamics. In Figure 9.1a, the choice to burn Young Fallows is second highest (50% of areas burnt) in all communities, while the decision to burn Forest cover is highest (20% of areas burnt). These patterns are expected within a recently opened frontier where households burn young vegetation nearest to their house sites, but also continue to burn forest cover to expand potential areas for farming. Young Fallows remain a preference, suggesting that households are beginning to re-burn younger successional areas to minimize the more resource demanding task of slashing advanced succession and forest areas. Land has only been legally available since 1990 and thus, there has not been sufficient time for Intermediate Fallows to develop and little is burnt in this vegetation age class. These burning patterns imply a relatively young frontier. However, the choice to burn Advanced Fallows is also higher than in any other community (20% of areas burnt). Normally this might imply an older frontier with ongoing land occupancy that accounts for the advanced successional growth of abandoned agricultural fields. In the case of Rural Belterra though, the existence of this vegetation is a direct result of historical land use in the area, the abandonment of rubber trees and the dominance of advanced vegetation regeneration in the area.



a. Burning Choices by Community



b. Burning Choices by Establishment Length

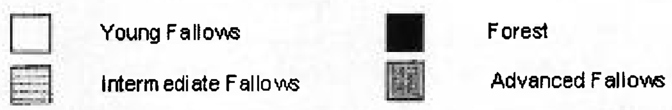


Figure 9.1: Biomass choices of households surveyed

Table 9.1: Land-Use/Cover Change in the Study Communities

	1986 Class	Boa Esperanca		Nova Esperanca		Rural Belterra		Tracoã	
		Ha	%	Ha	%	Ha	%	Ha	%
1986	Lowland Forest	3.3	0.1	28.7	0.6	134.0	1.0	17.8	0.5
	Forest	1373.9	45.3	3266.4	63.2	2819.9	20.0	861.3	23.2
	Advanced Succession	604.8	19.9	595.2	11.5	6136.8	43.5	497.2	13.4
	Intermediate Succession	543.6	17.9	658.4	12.7	2943.4	20.9	1160.9	31.3
	Young Succession	275.2	9.1	287.6	5.6	1027.3	7.3	616.1	16.6
	Old Pasture/Crop	133.8	4.4	170.2	3.3	559.0	4.0	369.0	10.0
	Pasture	91.1	3.0	145.0	2.8	414.4	2.9	176.4	4.8
	Burn/Bare Soil	6.9	0.2	16.4	0.3	61.7	0.4	8.1	0.2
	Total	3032.7	100.0	5167.8	100.0	14096.4	100.0	3706.8	100.0
1995	Forest	1101.5	36.3	2959.2	56.6	3727.3	25.8	550.4	14.6
	Advanced Succession/ Lowland Forest	4.1	0.1	441.7	8.4	140.8	1.0	1048.5	27.7
	Advanced Succession	761.3	25.1	414.4	7.9	5269.2	36.4	286.1	7.6
	Intermediate Succession	339.4	11.2	638.9	12.2	2103.8	14.6	739.8	19.6
	Young Succession	327.4	10.8	338.0	6.5	1457.4	10.1	449.1	11.9
	Crop/Young Succession	287.9	9.5	288.4	5.5	1245.8	8.6	434.3	11.5
	Burn/Bare Soil	40.9	1.3	2.6	0.0	59.1	0.4	4.1	0.1
	Pasture	172.5	5.7	147.1	2.8	453.2	3.1	270.0	7.1
	Total	3035.0	100.0	5230.2	100.0	14456.5	100.0	3782.3	100.0
Change*	Forest		-9.1		-7.2		4.8		-9.2
	Advanced Succession		5.3		4.9		-6.1		21.9
	Intermediate Succession		-6.7		-0.5		-6.3		-11.8
	Young Succession		1.7		0.9		2.8		-4.7
	Cropland/Pasture		8.9		2.0		4.8		3.8

* Forest = 1995 Forest - (1986 Forest + 1986 Forest/Lowland)

Adv. Succession = (1995 Adv. Succession + 1995 Adv. Succession/Lowland Forest) - 1986 Adv. Succession

Int. Succession = (1995 Int. Succession - 1986 Int. Succession)

Yng. Succession = (1995 Yng. Succession - 1986 Yng. Succession)

Cropland/Pasture = (1995 Pasture + 1995 Crop/Yng. Succession) - (1986 Burn + 1986 Pasture + 1986 Old Pasture/Cropland)

Land-use/cover change in Rural Belterra, as evidenced in the 1986 and 1995 remotely sensed data, reflects the burning patterns noted in the survey data as well, exemplifying a relatively new frontier area, but accounting for its historical land-use conditions. The combination of burning the oldest vegetation available along with the youngest vegetation is indicative of the frontier's expansion. From 1986 to 1995, the predominant abandoned rubber Advanced Succession decreased 6.11% while there were increases in Young Succession (2.8%) and Crop/Pasture (4.8%). Most of this change appears as increased clearance moving out from established roads networks. Also apparent are newly cleared areas along small feeder roads (see Figure 7.2 for reference map), all reinforcing the argument that smallholders whenever possibly, chose to work close to transportation routes. Also during the change period, Forest cover actually increased by 4.8%. This occurred mostly in the western portion of the image and does not actually reflect more forested areas. Instead advanced succession in this area has continued to grow such that its structure is comparable to forest and it is less decipherable by its spectral response.

In the communities along the Santarém-Cuiabá Road, both of which have mid range settlement histories, the frontier landscape reflects varying degrees of past human intervention and a balance of vegetation cover change not evident in Rural Belterra's landscape. Though new households move into the communities, burning choices and land-cover change along the Santarém-Cuiabá Road supports the trends of farm expansion and diversification, both of which are land-use strategies expected within the continuum framework for an area with an intermediate settlement history. Many households have been living on the land long enough to accumulate some capital and have a larger labor force with the additional help of teen or adult children. Overall, households surveyed along the Santarém-Cuiabá road show a higher preference for burning Intermediate Fallows than the other communities and a lower preference for burning Young Fallows, while together the two vegetation covers still represent 75% of all areas burnt. This combination of secondary succession burnt implies the use of medium ranged fallow cycles (7–10 years) in combination with short fallow cycles (three to seven years), allowing for various vegetation options to work in and the possibility of diversified farming strategies. Households also chose to burn Forest cover 12.5% of the time, implying they are still interested in expanding the potential area for farming.

Land-use/cover change during 1986–95 also supports the trend toward farm expansion and diversification. Forest cover in Boa Esperança and Nova Esperança, decreased 9.1% and 7.2%, respectively, between 1986 and 1995 and is particularly marked by further land clearance extending out from the Santarém-Cuiabá Road. This decrease is significant considering the amount of Forest cover present in 1986 (45.3% of the land cover in Boa Esperança and 63.2% of the land cover in Nova Esperança). The extension of potential farmland via this deforestation is coupled with an increase in Cropland/Pasture, particularly in Boa Esperança (8.9%), again emphasizing the trend toward increased land under direct farm use. Decreases in Intermediate Succession highlights the use of shorter fallow cycles, as young succession areas are re-burnt such that less of them reach Intermediate Succession by 1995. This is compatible with household survey data that show a utilization of different fallow lengths in farm diversification.

In Tracoá, the potential of incoming households to create burning patterns expected within the continuum framework is slim because of the area's spontaneous settlement history and more recent frontier development shifts. Land cover in Tracoá exhibits its extensive ongoing settlement history, comprising mostly of secondary succession at various stages and only miniscule forest remnants located at remote edges of farm properties. Newly established households move onto this landscape and immediately burn a combination of fallows near house sites, not forest. Tracoá households surveyed exhibit less of an even distribution of biomass burnt than do Santarém-Cuiabá households, and their preference is young succession (56.5% of areas burnt). This implies a landscape in which land-use decisions prioritize crops viable on young successional soils, in particular, the main subsistence crop manioc. Recent development strategies and economic downturn of the area further supports this trend toward subsistence manioc production. After the Santarém-Cuiabá Road bypassed Tracoá minimizing traffic flow through it, and Belterra Municipality weakened Tracoá's competitive edge by opening agricultural areas nearer to the town, the area became more focused on subsistence farming, particularly the production of farinha, which is processed from manioc. In addition, not one household surveyed during the fieldwork year burnt forest. Again, this is indicative of an old frontier area with extensive past deforestation, and would be expected within the continuum framework for the area, but does not bode well in characterizing land-use decisions and burning patterns of incoming households.

The burning patterns of an old exhausted frontier and its tendency toward subsistence agriculture are also exhibited in the land-use/cover change data. From 1986 to 1995, the community experienced increases in Cropland/Pasture (3.8%) and decreases in Intermediate and Young Succession (11.8% and 4.7%, respectively). These changes point to the continual use of land and re-burning of vegetation in younger successional stages. There is also an increase in Advanced Succession, a land-cover type that is often used in commercial crops. As residents of Tracoá have reduced their work with commercial crops, these more remote areas remain abandoned. Last, Forest cover loss is large in Tracoá, though this is deceiving. Tracoá contains minimal forest cover such that any clearing in forest creates a more dramatic change in total forest area.

Burning Choices by Household Establishment Length

With an idea of the influences of settlement history, the shifting frontier landscape, and the burning preferences within each community, Figure 9.1b shows the biomass preferences of individual households surveyed by establishment length, with New Households defined as living less than 10 years and Established Households as living more than 10 years on the land. Considering all communities, the expectations of the continuum framework hold well. Both new and established households burn in all ages of succession and forest, but new households burn more in the Young Fallows and Forest vegetation classes, while established households spread more evenly into the Intermediate and Advanced Fallows vegetation classes. Advanced Fallows is particularly small in the New Household group indicating the dearth of this vegetation within the first 10 years of household establishment if on new land.

While descriptively the trends in biomass load choice are visible in household surveys, using a rank order non-parametric statistic to evaluate the difference between newly established and established households shows minimal significance in their burning choices. The Spearmen's rho statistic produces a coefficient of -0.011 with very low significance (.929). This implies that the household continuum is not well associated to land-use decisions as reflected in actual biomass load choices. As frontier histories become longer, the influences of other frontier dynamics shapes landscapes, shifting the possibilities of land-use and burning decisions.

Differences between biomass choices of established households in their initial five years on the land and New households hint at the frontier landscapes that are present now as opposed to when Established Households first moved to the land. If the status of newness is influential in land-use decisions, then we can expect to see similar trends between the two groups. If not, we begin to see the workings of other frontier dynamics on burning patterns. For Established Households in their first five years, over half of all vegetation burnt was in Forest, while only 13.9% was in Young and Intermediate Fallows. The landscape showed less human intervention when Established Households initially moved to their lots. Often these households were the first known occupants of the land. New Households in their first five years on the land burnt slightly under half the amount of Forest than did Established Households in their first five years, while choices of Young and Intermediate fallows increased. These survey results exemplify the continually shifting frontier landscape and the changing options it provides for incoming households. New Households have moved onto a more diverse land cover. While they still have a propensity to burn young Fallows and Forest, they have more options to clear Intermediate and Advanced Fallows as well.

This trend is confirmed through non-parametric measures. The Mann-Whitney Test, which measures the central tendency of two independent groups, was applied to data on biomass choices during first five years on land, using the groups New Households and Established Households in their first five years. Again, the purpose of using data on biomass choice in the first five years is to depict Established Households when they were essentially new households on the land, and thus evaluate the influence of newness on burning choices. The results of the Mann-Whitney Test suggest there is a statistical difference in burning choices of New Households and Old Households in their first five years (p-value = 0.004). The mean rank of each group is different, suggesting that biomass choices of each group are not consistent, and that vegetation options provided in the landscape and varying frontier contexts may be part of this difference in choice. If status of being new were uniquely associated to biomass load choices, one would not see such a significant difference between group biomass choices.

A contingency matrix, shown in Table 9.2, also confirms that different patterns exist between current New Households and Established Households in their first five years on lots. In the matrix, the residuals measure the deviation in burning choice of a household group from what would be expected if choices were evenly distributed across biomass classes. While there is no reason to assume that biomass choice for either group of households would ever be evenly distributed across biomass classes, the standardized residuals in the matrix provide a way of comparing the behavior between the two groups. In the Young Fallow class, New Households burn more (1.1) than would be expected (standardized residual of 1.1), while Established Households in their first five years burn less (standardized residual = -1.5). In the Forest class, the opposite trend is shown with Established Households in their first five years burning more Forest than expected and New Household burning less than expected. The results of the contingency matrix again imply that choices of New and Established households in their first five years are different (P-value = 0.013). The burning patterns occurring under households with a status of newness shift as frontier settlement persists and different vegetation options become available.

Table 9.2 Standardized Residuals for Contingency Matrix of New Households and Established Households in Their First Five Years on Their Properties

Vegetation Class	New Households	Established Households in First Five Years.
Young	1.1	-1.5
Intermediate Fallows	0.8	-1.1
Advanced Fallows	-0.7	1.0
Forest	-1.1	1.6

The Nature of Settlement within the Micro-Study Region

The dynamic of resettlement, as households reposition themselves in hopes of fortifying their livelihood strategies, is another major frontier dynamic that is overlooked in the continuum framework, but which sheds light on burning patterns. Since land occupation within Rural Belterra has only been promised in the last eight years, all but one of the households surveyed are considered New Households.[11] Of New Households surveyed, 33% of New Households surveyed made local resettlements, either extending their total properties by acquiring land or repositioning themselves near to a future municipal seat through a move from within the Belterra/Mojuí region (Table 9.3). For Belterra residents, opportunity to own rural land is particularly compelling. Historically, the tenure regime administrated under the Ministry of Agriculture left Belterra citizens without legal access to land. With more recent changes in the municipality, Belterra residents now see chances to establish farms for themselves. The economic slowdown as MA ceased rubber production operations reinforced the need of residents to find new ways to be self-reliant and financially stable, both of which the prospect of land ownership promises.

The close proximity of frontier land to the town however, has allowed for household establishment, land-use options, and subsequent burning patterns that do not precisely fit the expectations of the continuum framework. Rural land acquisition has not always led to complete household establishment on rural land. Often Rural Belterra households maintain residences within town limits with income generating adjacent bars, pharmacies, stores, or government jobs, while venturing into agricultural production on their rural lots. This spreads economic risks over a wider range of activities, allowing

[11] The one household surveyed that is considered an Established Household according to the criteria I have put forth, is remotely located and was allowed use right in the 1950s under a MA retirement plan.

residents to invest in long-term farm strategies at the onset. Diversified strategies such as, the development of small coffee plantations, livestock practices, and establishment of perennial commercial crops, such as pepper or tropical fruits, require start up times before income generation begins. Under the continuum framework, most newly established households could not consider these land-use options. Belterra residents who invaded or bought rural land were able to move into these activities more quickly, and with these land-use options came varying burning patterns.

Table 9.3: Settlement in the Study Communities

	Community	Local Resettlement	Regional Settlement	Second-Generation
	Rural Belterra	33%	67%	0%
New Households	Santarém-Cuiabá	60%	40%	0%
	Tracoá	17%	67%	17%
	Rural Belterra	0%	0%	100%
Established Households	Santarém-Cuiabá	69%	8%	23%
	Tracoá	33%	33%	33%
	Rural Belterra	29%	57%	14%
Total	Santarém-Cuiabá	65%	22%	13%
	Tracoá	27%	47%	27%

The remaining 66% of Rural Belterra New Households originally came from other regions of the country. For all of them, the move to Rural Belterra was not direct. They all migrated to the Belterra/Mojuí region earlier on, then relocated once opportunity appeared. Many of them maintain residences within Belterra and exhibit the same tendency toward rural expansion as those who are originally from Belterra.

Both recent and past circumstances have induced local resettlement to communities along the Santarém-Cuiabá Road. First, in initial settlement during the 1970s, locals living within the Tapajós National Forest or on government MA property moved to INCRA surveyed lots. At the time, lots were virtually free, areas were completely surveyed, and legal ownership possible. An astonishing 69% of established households surveyed settled on lots as a result of local moves. In comparison to other INCRA-administered colonization programs, this percentage is unusually high. Initial colonization in Eastern Pará along the Transamazon Highway and in Rondônia, for example, mostly came from immigrant resettlement with little local resettlement.

More recent new land occupation by local Santarém-Cuiabá residents has come through purchase of whole properties from former owners or through purchase of lot subdivisions, either of which reflects the socioeconomic situation of incoming households and indicates that the household continuum is not the only link to land-use decisions and fire use. Households with sufficient resources purchase whole lots, indicating that their status as new households does not necessarily contain the characteristics associated to new households within the continuum framework. These households have the propensity to move more quickly into diversified farming strategies because of the combination of their resources with local knowledge and experience. Subdivisions, on the other hand, indicate two things. First, they reflect more limited resources of incoming households, who perhaps are more similar to new households within the continuum framework. Second, subdivisions indicate that farm and resource status of current lot owners is such that owners wish to contract farm size and operations, by selling off portions. Either they are leaving the land altogether, or cash received in subdivision purchase is more valuable to them than use of the subdivision. In both scenarios, local new households are moving onto land that has experienced some form of human activity, and the landscape exhibits the degree of this past activity. Resettlement for 60% of newly established households had been the result of a local move.

Local settlement into Tracoá is less pronounced, slightly over a quarter of Tracoá households surveyed. The community's extensive settlement history plays a role in this slower local rate. All lots have been surveyed. There is limited space for expansion or land invasion and hence, the acquisition of land can only be made through land purchase. In close proximity to Tracoá, the land within Rural Belterra is open for claim and at present one need only file for permission to obtain a parcel. This draws people with limited resources toward Rural Belterra and away from Tracoá. What little local relocation occurring in Tracoá is from extended family members of current property owners. In these cases, land owners live in Santarém, lots have been left unoccupied and daughters, or sons of landowners have chosen to return to the property to eliminate threat of invasion on an otherwise unoccupied lot. Incoming households may be from Santarém, may still maintain houses and/or jobs within the city, and have expanded economic activities by venturing into agriculture. As property ownership is within the extended family, these households have not actually purchased the land and thus, have not exhausted their resources in coming to the lot.

Interesting to note, 66.7% of newly established households in Tracoá came from outside the region. These newcomers have all come with resources to buy lots or subdivisions. They have chosen to buy land in Tracoá rather than establish lots within Rural Belterra. There are many reasons for this. First, purchasing land within Tracoá is secure legally, since all land has been surveyed. In Rural Belterra only the promise of land title acquisition exists. Second, the landscape within Tracoá is relatively well developed with roads, surveyed properties, various aged secondary succession, houses, and perhaps most importantly a communal well. Rural Belterra though in close proximity to the town of Belterra, is completely undeveloped. The terrain is mostly very advanced secondary succession. There are few roads and water sources, such as wells, have to be constructed. Thus, in general, incoming households with the resources to do so, purchase land within Tracoá.

Last, the households surveyed as presented in Table 9.3 show the beginnings of second-generation residents establishing their own households. This tendency is most apparent in Established Households throughout the communities, implying that many residents in the micro-region remain in rural areas and do not abandon their land. While in Rural Belterra, 100% of established households had a household member born within the community, Rural Belterra has very few established households. The land tenure regime that restricted settlement on government property was only recently been lifted. More interesting, are the percents of households formed by second-generation residents in Tracoá (33%) and the Santarém-Cuiabá communities (23%). Not only are households created by second-generation residents, but many of these households have remained long enough to become quite established. Some of the New Households in Tracoá also contained second-generation residents. In general, these trends found in only a sample of total community population indicate farming continuity and the continued possibility of livelihood in these areas.

Settlement, Farm Strategies, and Burning Patterns

Figures 9.2 and 9.3 compare farming strategies of New and Established Households, combined with local or regional moves that brought them to their present land. Both New and Established Households show different propensities for farming strategies and diversification, which do not entirely match the characteristics of young versus mature households within the continuum framework. This implies that resettlement is an important dynamic to understand in land-use decisions, land-cover change, and resulting fire use.

One farm strategy, which influences land-use/cover change and fire activity, is the expansion of land under production. This measure not only implies farm economic status and possible farming strategies, but also extent of property deforestation, potential fire frequency and its spatial distribution. In the survey data, land under production is measured as the percent of total property under production. Of locally resettled New Households, 60% have over 10% of total property under some form of agricultural production. They have quickly expanded farm operations since arrival, which typically is quite difficult for young households new to frontier areas. In contrast, only 8.3% of regionally resettled New Households have expanded farm operations over 10% of total property. This sharp difference between the two groups of New Households supports the argument that status of new is not the only defining factor in land-use options and burning patterns. Households who are new to the land but are merely repositioning themselves within the local landscape bring a variety of resources and experiences that support them in land-use decisions unavailable to those who migrate into the micro-region.

A second farm strategy influencing fire use and land-cover change is to diversify farm activities incorporating not only, subsistence annuals, but also perennials, livestock and/or agroforestry practices. As discussed previously in the chapter, farm diversification can create vegetation types more vulnerable to fire, increase fire frequency, or create more ongoing use patterns that reduce fire-use practice. In the New Household data, farm diversification shows only a slight variation between the two groups, supporting some basic common trends in New Household farm establishment. All New Households prefer subsistence annuals, with around 75% of all areas burnt in the 1996 burning season seeded with annual crops. This coincides well with the household continuum argument that associates initial farm establishment with subsistence crops and rotational farming systems. In addition both groups show diversification into both pasture and perennials, making up another 25% or so in the diversification variable. However, locally settled New Households are moving toward livestock practices (16.7% of areas burnt), while regionally resettled New Households prefer perennials (16.7% of areas burnt, but twice as much as locally settled New Households burn). These differences are only slight and do not show as statistically significant when subjected to non-parametric tests. Yet, if these trends continue, the implications in terms of fire tendency are potentially great. Livestock practice introduces the highly flammable grassland cover to the landscape, and requires frequent fire activity. Land cover planted with perennial crops reduces fire frequency on the land, but represents a great economic loss to households if exposed to fire.

Established Households (Figure 9.3) show similar patterns of farm diversification patterns to New Households, suggesting that farm strategies are not completely the result of household evolution, but may also reflect nature of settlement. Of the Established Households, 88.9% who had made local moves to present properties had over 10% of total property under production, expanding and diversifying into largely pasture, but also perennials. Regionally settled Established Households showed preferences for perennials in their diversification strategies. Approximately 66% of them had 10% or *less* of property under agricultural production. Again the locally resettled households expand farm sizes and engage in livestock practices while regionally resettled households diversify through perennial crops instead of pasture.

Farm diversification practices that entail livestock activities usually require larger contiguous areas for pasture. Hence it is not surprising that households of any establishment length engaged in this activity also have larger percents of their total property under agricultural production of some form. What is more important to highlight is the types of agricultural activity that households expand into and the implications of this for land and fire use. Locally settled households incorporate more of their land into agricultural systems that require both the burning of secondary succession and annual or semi-annual pasture fires. They also introduce highly flammable grassland cover onto the landscape, facilitating the spread of accidental fire. Regionally settled households are moving away from fire use by planting perennials that remain on the land for an extended period. Yet, these vegetation types remain highly vulnerable to fire in terms of economic loss. If orchids are exposed to fire, the long-term loss is greater than if subsistence crops or pasture is burnt accidentally. The burning patterns and potential fire threats vary among the groups based on their land-use decisions. These land-use decisions seemed to be influenced by the frontier dynamics of settlement and resettlement, in addition to the evolution of households.

A third strategy that influences land-use/cover change and fire activity is to supplement farm production with off-farm activities. The household continuum framework argues that new households are particularly prone to seeking outside employment, while more established households focus on on-farm activities. All the household's surveyed in the region, however, tend to work only on their lots. Only around 10% of new households worked off their farms during the year households were surveyed (Figure 9.2) and the pattern holds regardless of nature of resettlement. Off farm work included jobs within Santarém and paid work on other farm properties. In established households the percent was slightly higher in locally resettled households while no regionally resettled households claimed to work of their farms. Temporary work included contract work with logging companies, odd jobs on ranches, gold mining extraction, and migration of adult children for short periods of time. Most households seem to be trying to meet their needs through on farm activities, again, hinting the continuum considered in household evolution, land-use change, and resulting fire activity begins to break down when forces that encourage resettlement are layered over a landscape that has already experienced human intervention.

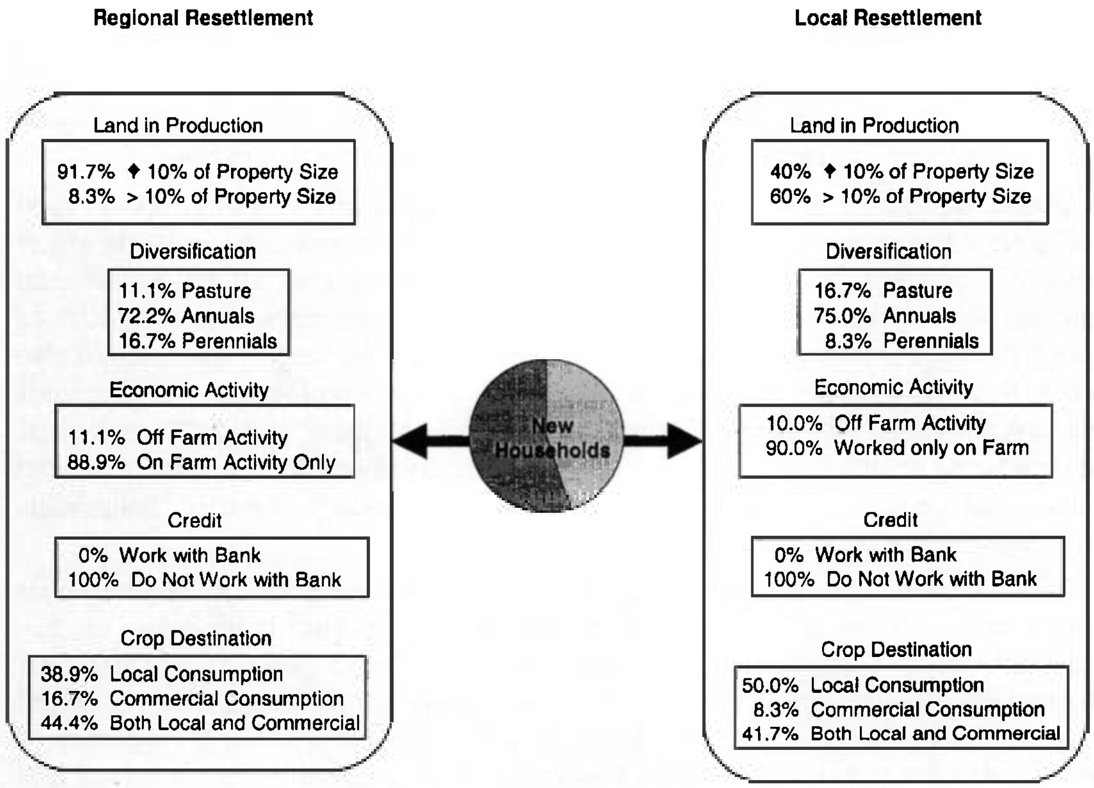


Figure 9.2: Survey Findings of Newly Established Households (establishment length ≤ 10 years)

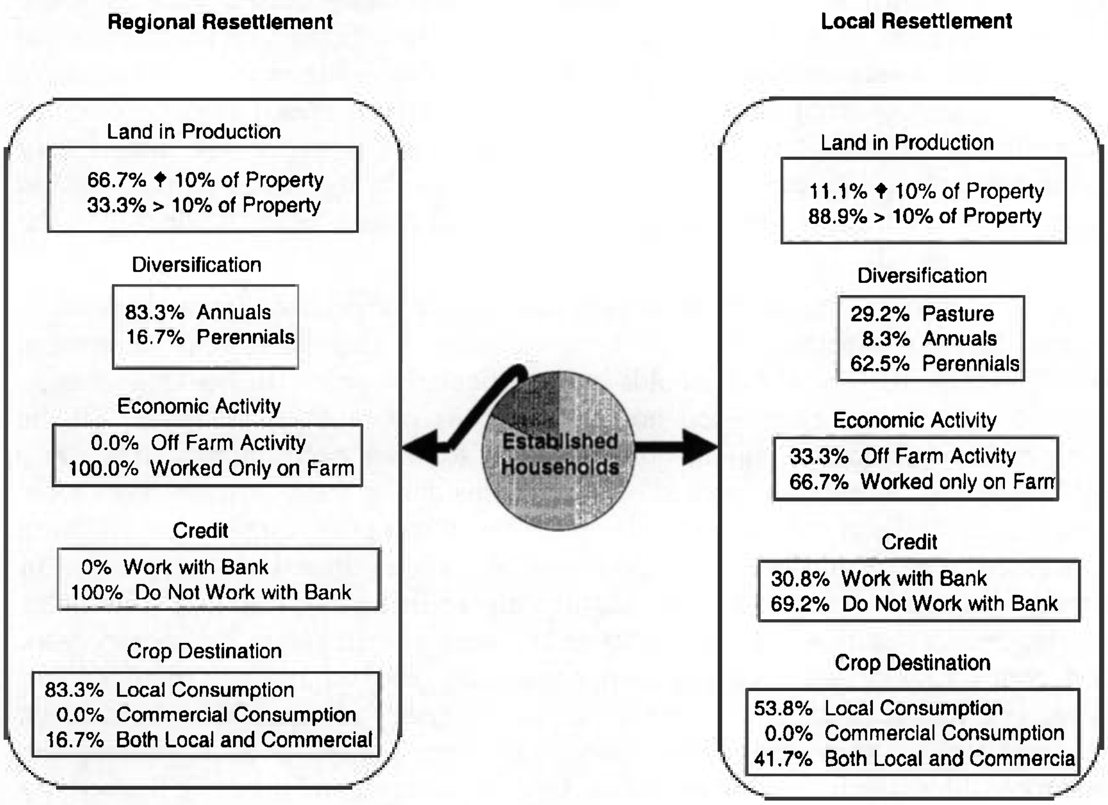


Figure 9.3: Survey Findings of Established Households (establishment length > 10 years)

A Kruskal-Wallis test was applied to data to substantiate the findings that nature of settlement may be associated with farm diversification strategies, land-use decisions and fire use, regardless of length of household establishment. The Kruskal-Wallis test is an extension of the Mann-Whitney Test to accommodate k > 2 groups. The test measures central tendencies of groups when ranked, and determines whether difference of these tendencies is statistically significant. For data shown in Figures 9.2–9.3, the test is used to determine if household tendencies toward farm diversification or expansion are significantly different when households are grouped by nature of settlement. Farm expansion is measured as the percent of total property under production. Farm diversification is a categorical variable containing dummy variables for subsistence annuals, perennials, pasture, and subsistence annuals going to pasture the following year. Three groups are used: locally settled, regionally settled, and second-generation households. Though only 45 households were surveyed, N varies in the results because data are organized by burnt fallow (total possible N = 73) and some data are also missing.

Table 9.4 presents the results of the Kruskal-Wallis test. Farm diversification is shown in part (a) of the Table and shows no statistical significance in the central tendencies of each group associated to types of agricultural production used. This is not surprising because any variation that exists is overshadowed by the strong propensity of all households to plant subsistence annuals (% of all areas planted by households surveyed went to subsistence annuals). However, if the Kruskal-Wallis test is applied to data when cases with subsistence annuals have been eliminated, a statistically significant difference between groups exists (p-value = .058 in Table 9.4b). How households diversify exclusive of their shared practices of planting subsistence annuals is associated to nature of settlement. The statistic significance is marginal because mean rank of locally settled households and second-generation households are very close, 12.96 and 12.5 respectively. This closeness of the rank seems logical because in essence, both groups represent residents with local backgrounds.

Farm expansion is shown in Table 9.4c. There is a statistically significant difference in tendencies of groups (p-value = .000). Those households that locally settled expand their farm production to a different extent than those households that regionally settled or are second-generation. It is interesting to note that closeness in mean ranks of locally settled and second-generation households does not hold for farm expansion as it does for farm diversification. In fact, distance of mean ranks is farther between the two groups, than between regionally settled and either of the groups. Because the Kruskal-Wallis test is a rank order association, this signifies that rank of percent of property in production is farthest apart between locally settled and second-generation households. It suggests that other variables beside nature of settlement may influence farm expansion.

Table 9.4: Kruskal-Wallis Test to Associate Resettlement with Farm Expansion or Diversification

a. Farm Diversification: Subsistence Annuals, Perennials, Pasture, or Subsistence Annuals to Pasture

Nature of Resettlement	N	Mean Rank
Locally Resettled	36	39.32
Regionally Resettled	24	34.46
Second Generation	13	35.27

p-value = .507

b. Farm Diversification: Perennials, Pasture, or Subsistence Annuals to Pasture

Nature of Resettlement	N	Mean Rank
Locally Resettled	12	12.96
Regionally Resettled	6	**6.33**
Second Generation	3	**12.5**

p-value = .058

c. Farm Expansion: Percent of Total Property in Production

Nature of Resettlement	N	Mean Rank
Locally Resettled	28	37.88
Regionally Resettled	18	21.39
Second Generation	11	18.86

p-value = .058

9.3 Economic Forces, Land-Use Decisions, and Biomass-Burning Choices

While extensive focus remains on linkages between household evolution, shifting farm strategies, and environmental response, a second focus of land-use/cover change research concerns the impact of regional economic structures on land-use decisions (Ozorio de Almeida 1992; Walker and Homma 1996). Farming strategies, deforestation, and subsequent land-use/cover change are explained as reactions to economic forces under specific frontier conditions. As such, this literature provides a better understanding of the socioeconomic frontier space and thus, fills in some of the gaps that are beyond the purview of the household continuum framework. For example, under frontier conditions characterized by land abundance, farmers respond to decreasing crop yields by expanding production, rather than intensifying it through technological upgrades (Southgate and Whitaker 1992). Production expansion then leads to further deforestation. Other studies suggest that modifications of cropping sequences and fallow cycles minimize labor costs and can become a household's best effort to maximize total farm production (Scatena et al. 1996). Here farm diversification is a result of profit maximization.

Deforestation and land-use/cover change is often explained as the result of frontier situations in which market forces are circumscribed. For example, insecure land tenure regimes, a common occurrence in frontier settings, limit farmer ability to maximize profits and thus, circumscribe market forces. In such instances, settler pressure to demonstrate land occupancy and secure use rights encourages further forest clearance or temporary crop production, both of which pre-empt any long-term resource management strategies that might be more profitable and sustainable (Loker 1993; Bedoya Garland 1995; Pichón 1996b; Schelas 1996). In addition, market distortions emerge when frontiers begin to close, land scarcity arises, but continued incoming immigrants create labor surplus (Ozorio de Almeida 1992; Walker and Homma 1996). Wages are forced down, diminishing labor's share of aggregate profits and disproportionately benefiting landowners who out compete smallholders, buying up their land and forcing them onto more remote forested areas. This then initiates a cycle of land consolidation, smallholder displacement and continued deforestation. Circumscription also occurs through non-productive means of securing profit, such as land speculation or securing advantageous institutional rents (i.e., governmental credits/subsidies). Under the auspices of livestock practice, forest conversion to grassland cover, was one of the most adept land-use strategies to facilitate such circumscription in the Brazilian Amazon (Hecht 1993).

This literature on land-use/cover change approaches land-use decisions with the assumption that households clear land and arrange farm activities to maximize utility and production. Crop types and destinations, cultivation techniques, and investment inputs, are all utilized in a fashion as best to maximize over all farming operations. Land degradation occurs when the unique conditions of frontier space circumscribe the mechanisms of the market.

Despite the glaring dearth of case studies applying an economic land-use/cover change analysis to fire activity, linkages between land-use decisions and fire use can be inferred. Any micro regional economic process that drives production expansion will likely require further forest clearing via fire use, or more frequent re-burning of fallowed areas. Labor cost minimization through crop modification also alters the fire regime, implying either extended use of land, less frequent fires, or increased burning in young fallow areas. When market distortions occur under specific economic conditions of frontiers, further forest clearing via smallholder displacement undoubtedly increases fire activity in slashed forest areas. Last, land speculation and acquisition of institutional rents through land clearance sets in place additional fire dynamics. Fires in slashed forest cover increase, annual maintenance of large pasture areas requires frequent grassland fires, and the development of large grassland pasture areas introduces a highly flammable vegetation cover onto the landscape, with consequences for accidental fire.

While adequately pinning down macroeconomic forces that impinge upon households, these regional land-use/cover change arguments often fall short in explaining why households would chose to work in ways that seemingly do not maximize profits. The often extremely precarious situations in which smallholder households find themselves in often makes them more interested in reducing risk rather than maximizing profit (Collins 1988; Pichón 1996). Empirical studies on tropical farming systems in frontier areas have documented cases where returns from livestock production are re-invested in subsistence, rather than more lucrative endeavors (Jones et al. 1995). Farmers have consciously chosen to burn young fallow areas knowing full well that such areas produce smaller crop yields. Labor and time flexibility, as well as logistics of burning in these young areas may out way the profit maximization. Farms may work under a threshold in that once overall production and risk minimization goals are met additional yield is welcomed with less attention to efficiency of land used. All of these aspects play into land-use decisions and thus burning patterns, but are not adequately factored into the economic land-use/cover change analysis.

Market Incentives in the Study Region

To understand market influences on farmer land-use decisions and corresponding fire activity, households were asked questions on crop destination, crop sequence, labor/capital allocation, and involvement with bank credit of agricultural extension. Answers to these questions where recorded for every area slashed and burnt by the 45 households surveyed during the 1996 burning season. This totals 73 areas. Figure 9.4 groups this information by vegetation class. The information implies there are trends between biomass of vegetation burnt and crop destination, sequencing, and labor allocation, suggesting that currently, larger economic forces play a role in land-use decisions and hence, fire activity and biomass loads exposed to fire. In addition to these forces, however, land-use decisions still reflect an individualized focus on farmer convenience, subsistence needs, and flexibility, factors that are not adequately dealt with under the economic land-use/cover change model. Unreliable infrastructure, especially during the rainy season when farmers need to bring crops to market, and low returns on produce are the main disincentives to produce solely for market demand. However, the farming behavior of new incoming households indicates a shift toward market orientation in the future and these circumstances may imply change in the near future.

Crop destination, indicates the primary purpose of crops planted in the areas cleared for agriculture during the 1996–97 agricultural calendar. That destination is for local household consumption, commercial consumption or some combination of both. Usually when a combination of the two is indicated, local consumption takes precedence while extras are sold if opportunity arises. Crop destination also hints at the extent to which households rely on markets to meet household needs, and consequently, the extent to which household activity centers on accumulation, in addition to subsistence needs.

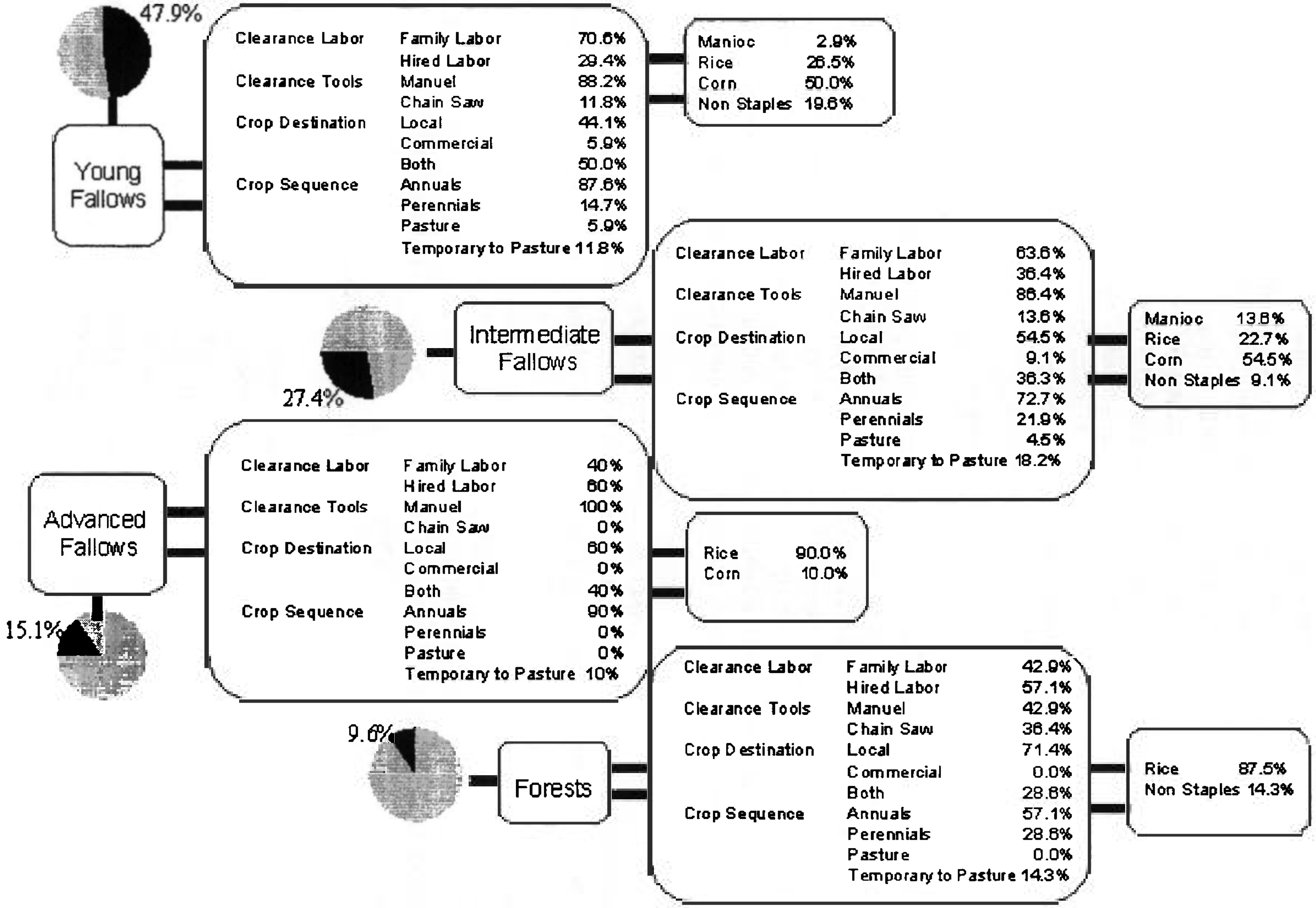


Figure 9.4: Survey Findings Grouped by Vegetation Age Class of Areas Burnt throughout the 1996 Dry Season

In looking at crop destination, it becomes clear that households surveyed are partially market oriented. Few areas cleared were planted with crops earmarked solely for commercial markets. In the smallest biomass class, young succession, the percent of crops designated for local consumption and for both commercial and local consumption is almost even. The gap between the two extends as biomass class increases, such that in the forest class, only 28.6% of crops are destined for both commercial and local use, while 71.4% are for local use only. Considering that 47.9% of all fallows burnt are in the smallest biomass class, young succession, households do seem to engage in market activity, but do not rely on it completely to meet livelihood needs. Their land-use decisions and fire use required to meet those decisions evolve around a combination of subsistence and commercially oriented activities.

Because market incentives are not strong enough to pull households into growing crops specifically for commercial demand, decisions to plant rice, corn, manioc or a mixture of both are based on farmer preferences and possible market potential. Clearly, specific crops are planted on specific types of burnt areas. 85.7% of the Forests and 90% of the Advanced Fallows burnt by households surveyed were seeded with rice. In the two younger vegetation classes, corn was dominant, while rice was only planted in almost a quarter of the areas only. Research has documented similar trends that rice requires nutrient rich soils as found in recently burnt, advanced fallows or forest cover, while corn can grow on more limited soils, and manioc can grow on the more depleted soils (Scatena et al. 1996).[12]

The absence of market incentives encourages farmers to invest more in subsistence agriculture and farm diversification minimizes risk on market reliance. This can be seen in the vegetation type demanding the largest resource investments to clear. Farmers invest more in terms of hiring labor to clear advanced succession and forest areas, but these areas are destined mostly for local consumption. This is not merely an indication of the immediacy of small landholders in the region, it is also an indication of lack of rural development which might motivate smallholders to be more market oriented. Over half of all Forest areas and 60% of Advanced Fallows utilized hired labor in the land clearance processes, while no crops in these areas were destined solely for commercial markets and between 28% and 40% were allocated to local consumption with possible selling of extras for commercial demand.

Few rural development strategies have been implemented to help households develop viable farming systems that can profit above meeting livelihood requirements and economic incentives are too weak to entice farmers into seeking loans. Again, these larger economic forces have less bearing on land-use decisions, biomass burnt, and fire use. Of the 45 households surveyed, only four said they had worked with agricultural loans from public banks, the only rural extension projects available. This low percent (8.9%) is, impart due to loan requirements that borrowers have legal titles to their land. However, there is also dissatisfaction among farmers about types of loans available and

[12] Manioc does not show strongly in data on crop type, although it is a major staple in the region, because the data reflects first crop harvested. Most often manioc is intermixed with corn or rice, but matures and is harvested in the second year.

stipulations involved in loads. Bank credit projects require farmers to grow specific crops and money borrowed is partially earmarked for fertilizers or other agricultural inputs specified by the Business of Technical Assistance and Rural Extension for the State of Pará (Empresa de Assistência Técnica e Extensão Rural do Estado do Pará [EMATER]). Farmers loose autonomy over farm decisions when they work with bank credit because of these stipulations.

At the time of fieldwork, two bank credit programs were functioning, both aimed at encouraging cultivation of crops with commercial potential. In the first program, loans were given only to plant manioc, that could then be processed into farinha, a marketable product. However, according to most farmers, time and energy spent to process manioc far outweighs Santarém's market price for the final product. This discourages farmers from applying for loans and farmers begin to focus solely on subsistence cultivation. A second program was recently initiated during the time of fieldwork. This project, funded by the Constitutional Fund for Financing in the North (Fundo Constitucional de Financiamento do Norte [FNO]), supplies EMATER technical support as well as, credit for the planting of two commercial cash crops, coffee and urucú. The program for the most part, operates in Belterra, and although Tracoá and Santarém-Cuiabá residents are eligible as well, few participate because of lack of information and distance. Because the program has recently been implemented, it remains to be seen how much it will influence overall land-use change and fire activity. Much will depend on using effective farming techniques to insure crop growth and also reasonable prices in commercial markets. Programs emphasizing monocropping of cash crops have had mixed results in other regions of the Amazon (Milikan 1992). However, by promoting agricultural activity that does not require annual fire clearance, future burning patterns within Belterra may be shifting.

9.4 Farmer Flexibility, Fire-Use Techniques, and Fire Efficiency

Land-use change research that focuses on household development or micro economic conditions suggests that farm trajectories evolve in response to changing household and socioeconomic conditions, and ecological limitations. Yet, another issue, household flexibility, becomes visible when the micro-climatic and biomass conditions necessary for a successful burn are considered. To farmers who use fire in their agricultural practices, an effective fire is one that thoroughly burns vegetation slashed such that: (1) nutrients from vegetation are redistributed to soils and enhance fertility; (2) farmer mobility within the area is facilitated; and (3) no extra labor is necessary to slash and pile up leftover charred debris for a second burn. Successful fires are critical to farming strategies. If a fallow burnt poorly, a farmer may chose not to plant in the area at all, deciding that loss in additional labor and eventual poor yield is greater than loss already expended through precious labor and time spent on preparing the area for agricultural production as loses. Further work is not worth it. While the efficiency of fire is largely determined by microclimatic conditions, farmers can minimize ineffective fires through the vegetation they chose to burn, the timing of the slash-and-burn process, and labor used.

The main way farmers have control over effective fires is by insuring a sufficient drying period for the slashed vegetation. Thoroughly dried slash combusts more efficiently. Control over this process is a logistical endeavor, the timing of which is critical for an effective burn. First, farmers must anticipate how long an area needs to dry to sufficiently burn. This depends on the amount of biomass within the area with slashed advanced fallows and forests requiring longer drying periods than abandoned pasture or slashed young succession. Second, farmers must calculate how long it takes to clear the area in terms of labor expended. If using hired labor with chainsaws, less time is necessary than if using family labor and manual tools. Third, farmers must plan the timing of the clearing task such that the job is finished with sufficient time for the area to dry, before the rainy season begins. Not waiting long enough risks that slashed areas are still green. Waiting too long risks the onset of the rainy season. Both circumstances produce inefficient burns. Fourth, burning in the hottest part of the dry season increases risk of uncontrollable fire as all surrounding vegetation is also dry and fires pass easily into it. Fire needs to occur at the end of the dry season perhaps after the first rains, but not too far into the rainy season, that vegetation is completely saturated with rainfall. Fifth, households must weigh the labor demands and timing for all the areas they wish to work in during a single agricultural year. This means starting the slashing process at different times during the dry season, and finding the labor power, either hired or familial, to help with clearing at the appropriate times.

While farmers do not necessarily plan the slashing process down to the hours and days spent in clearing and drying each area, flexibility of an area becomes a consideration and helps elucidate why farmers incorporate more younger fallows in their burning strategies. Younger fallows, because they are easier to slash and require less lengthy drying periods, provide farmers with both labor and time flexibility in the slashing process. Households can wait until late into the dry season before they begin to slash. Older fallow or forest, on the other hand, require a much more rigid scheduling, if a farmer wishes a successful burn. Timing flexibility is especially an asset when dry seasons are abnormally long and hot. If farmers perceive an extended dry season, they may slash young succession even after the first rains and it will still have time to dry sufficiently and burn well. In addition, resources and labor allocation play into the flexibility of decisions. With limited resources, farmers hire help to clear labor demanding vegetation cover, particularly advanced succession and forest. If resources later run too low or labor is scarce, farmers can clear younger succession areas by themselves or use unpaid family labor.

Figure 9.5, shows fallows burnt by fallow age and week of month burnt. Because not all households remember the date their areas were burnt, the data represent only 64 areas, rather than the full 72. All advanced fallows and forest areas were burnt in October or November, the end of the dry season. Slashing begins as early as July to utilize the hottest part of the dry season for the drying period. The burning of young and intermediate succession areas is distributed across a five-month period, from September into January. Over a third of the young fallows were burnt in December or January, signifying that slashing continues late into the dry season. Farmers were making decisions to slash and burn additional vegetation throughout the dry season. The time and labor flexibility of slashing young fallows makes them particularly appealing, and informs land-use decisions to use these areas.

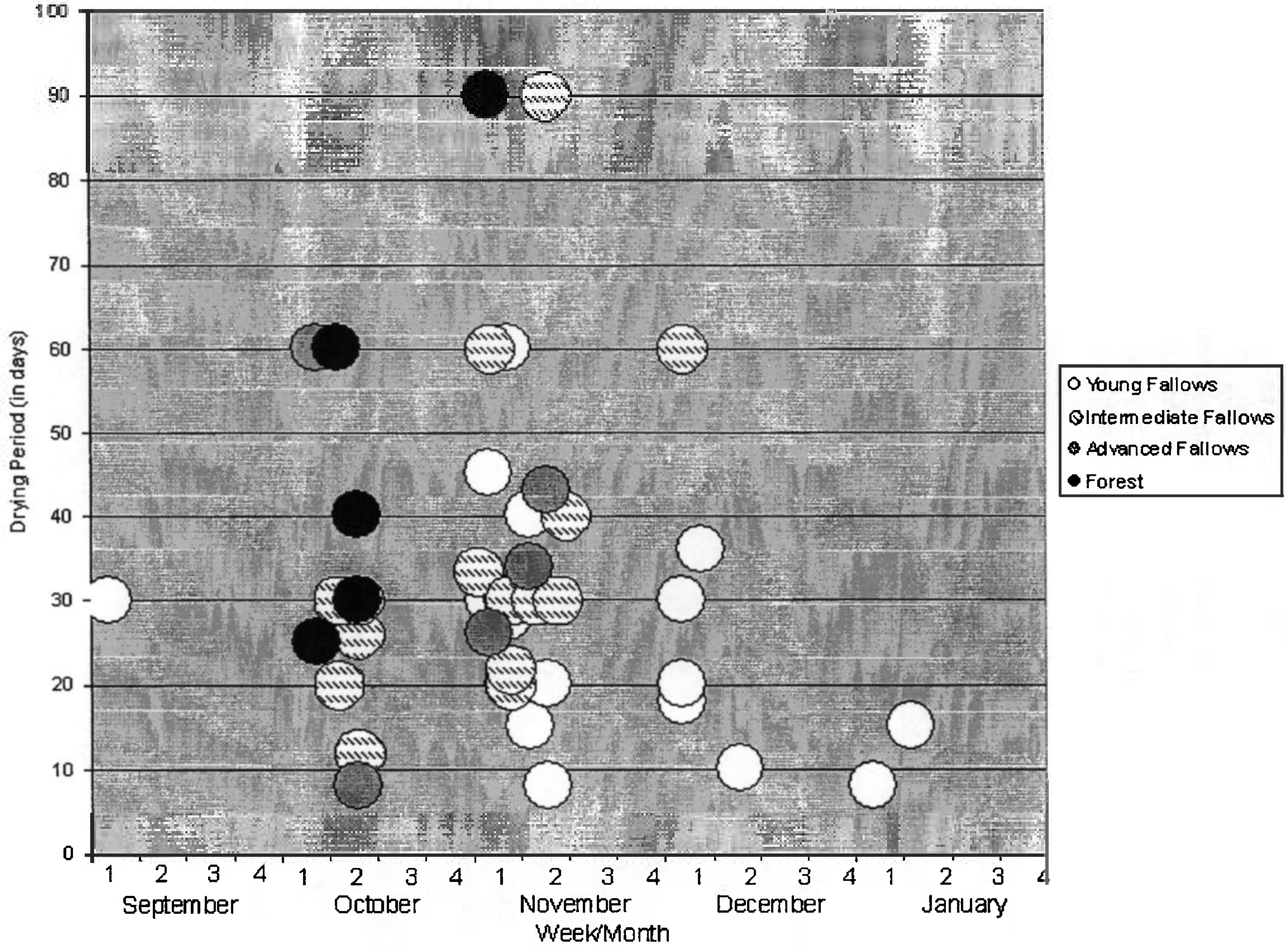


Figure 9.5: Length of Drying Period and Date of Burn for Areas Burnt throughout the 1996 Dry Season

To test whether length of the drying period and timing of burning are significant factors to farmers when choosing biomass for burning, a logistic regression model was developed and is shown in Table 9.5. The model predicts if burnt vegetation is young, based on the number of days it was dried and the calendar week in which it was burnt, ranked from the 1st week in September to the last week in January (k = 20). Overall, the results are good considering the variability of the data. Overall the model predicted 68% of the fallows correctly. The model predicted the intermediate through forest fallows better (70% correct), than the young fallows (65% correct). Since young fallows are more flexible vegetation to work in and can be burnt at anytime throughout the burning season, it seems logical that they would be more difficult to predict correctly.

Table 9.5: Logistical Regression Model to Predict Age of Burnt Vegetation

Observed	Predicted: Young Fallows	Predicted: Int. Fallows to Forest	Percent Correct
Young Fallows	21	9	70.00%
Intermediate Fallows to Forest	9	17	65.38%
		Overall	67.86%

Variables in the Equation

	B	S.E.	p-value	Percentage Change Parameter
Days Dried	-0.0406	0.0208	0.0513	3.98%
Week Burnt	0.2771	0.1368	0.0427	31.93%
Constant	-1.5439	1.5022	0.3041	

Correlation Matrix

	Constant	Days Dried	Week Burnt
Constant	1.00000		
Days Dried	-0.42030	1.00000	
Week Burnt	-0.87384	-0.02718	1.00000

The significance of the variables in the model supports the model assumptions that drying period length and timing of burning are predictive of the age of biomass burnt. The timing variable is clearly significant with a p-value of 0.042. The length of the drying period variable, however, had a p-value of 0.0513, which is borderline at suggesting actual significance. However, considering the likelihood of accuracy of farmers' responses in this question, the result can be argued. When farmers were asked how many days they left a slashed area to dry, the chance that they remembered the exact number of days was slim. More likely they made approximations such as one month or a month and a half, rather than more precise numbers. Thus, the information within the data was already generalized. A model with borderline significance still shows tendency.

Last, the percentage change parameter (EXP(Beta) - 1 * 100) produced some interestingly inferences that confirm the argument that timing and drying are considerations to farmers in their choices for burning. First, with every increase in week, the model shows that the likelihood that the burnt vegetation is young, increases by 32%, assuming the number of days dried remains constant. This confirms the argument that farmers are considering the timing of burns, and that young fallow areas are more frequently burnt at the end of the dry season. Second, the percentage change parameter for drying period is negative (-.0398), implying that with every increased day of drying, the likelihood that the vegetation is young decreases by 4%. Again, this is with the assumption that the week burnt remains constant. While the percent seems very small, the increment of the day is also small. If one considers the likelihood by week, the percent actually increases to 15%. Regardless, the negative percentage change parameter for the drying period variable infers that there is some sort of linkage between length of drying period and biomass choice. While the length of the drying period does not show a visual relation in the data in Figure 9.5, the model does exemplify the logic which farmers use in their burning practices.

A second manner, in which farmers affect fire efficiency is through the thoroughness of land clearance. In many agricultural fields larger trees are left standing either for lack of resources to fell them, or because a particular tree species is protected under law and cannot legally be felled. Standing trees, either alive or dead, do not burn as efficiently as trees that have been felled and dried for a substantial period of time. This means that the thoroughness of land clearance can vary hinging in part on farmer resources. To what degree these larger felled trees will completely burn also depend on the cumulative biomass load of the area. The smaller biomass loads in young succession may not be sufficient to fuel fire hot enough to entirely burn these felled trees. On the other hand, if felled trees are palms, a common vegetation within successional areas, felling them adds palm fronds to the fuel load. Palm fronds are highly combustible and can spread fire quickly. Regardless of the tree type, farmer decisions to felling all large trees will influence the process of decay and accelerate trace gas emissions.

The survey data reflect a tendency of households to insure efficient burns by thoroughly clearing their land. Chainsaws were used in over a third of forest areas cleared, almost three times as often as occurred in the two smallest biomass classes where only 11.8–13.6% were cleared with chainsaws. The percent of areas cleared using hired labor (Figure 9.4) also increases with vegetation age class, meaning that farmers tend to hire extra help when clearing higher biomass areas to insure a thorough burning. Often this involves hiring a chainsaw operator to fell large trees, thus supporting the trend in chainsaw use. Thoroughness of land clearance is largely influenced by tools used and labor allocated.

Last, the practice of a second burning (e.g., *coivara*) is common in the region and depends on farmer perception of its necessity after the initial burn. These second burns obviously increase overall efficiency, but to what degree is uncertain. Farmers pile up leftover charred branches to set the second fire. This technique is used to ease physical mobility within the area so that farmers can plant, weed and harvest crops easier. Thus, farmer decision to conduct a second burn depends on eventual land use. When intended land use is crops, the potential of *coivaras* is more likely. When intended land use is pasture, farmer mobility is less important and even poorly burnt areas will not be re-burnt, but seeded with grass as is. When practiced, the efficiency of coivara burning is uncertain. Fuel loads in *coivaras* are small, making it difficult to create hot enough fires to significantly burn large charred tree trunks. In addition, large felled trunks may be too difficult to pile up, particularly if farmers are without chainsaws that would separate the trunks into more manageable chunks. Regardless of these shortcomings, decisions to make *coivaras* increase to some extent overall burn efficiency for the area.

Given the logistics that farmers operate under and the techniques they use to insure to create successful burns, physical data from the 14 field sites were used to measure if farmer tactics actually had an influence on fire efficiency as measured in the field sites. Only nine of the 14 sites did not have missing values, thus the findings are limited. However, given these limitations, trends between farmer tactics and fire efficiency seem scarce. Figure 9.6 shows fire efficiency, by drying period length and age class. There is little overall direct correlation between length of drying period and burn efficiency. While the most efficiently burnt fallow had the second longest drying period, the fallow having the longest drying period shows a fairly average burn efficiency. On the other hand, the most common drying period was around 30 days and fire efficiency of fallows left to dry for this period clusters well, between 40% to 50% burning efficiency. In addition, if two outliers are discounted, the fallow with the longest and shortest drying periods, there seems to be a positive trend between drying length and burn efficiency.

The pattern between site age, dry period and fire efficiency adds more promise to understanding the influence of fire-use practice on burn efficiency. Advanced sites were among the most efficiently burnt, but their range is the greatest. Intermediate and young sites were less efficiently burnt on average, but the range in efficiency was tighter, suggesting more overall control. These trends suggest that farmers may have less control of efficiency as biomass load increases. Larger biomass loads are more difficult to burn fully. They also require longer drying periods and hence, there is more time for something to go wrong. There are more days in which fire set on a neighbor's property could accidental pass onto the land, more days in which unexpected heavy rains could fall. There maybe a threshold at which the length of the drying period becomes a risk factor to efficient burning as well, as a necessary factor to efficient burning. This threshold depends on the biomass amount and at what point during the dry season the area was slashed.

The tenuous correlation between actual fire efficiency and length of dry period does not discount the likelihood that farmers make land-use decisions based a perceived connections. If farmers do not use these tactics, the chances that their plots will burn poorly, is quite high. Vegetation that has not been thoroughly dried will combust poorly. Because of microclimate conditions, which include the possibility of unexpected rainfall or a chronically wet burning season, farmers may have less overall control of ultimate fire efficiency. But, they can at least minimize the risk of poorly burnt areas by engaging in the practices that they do.

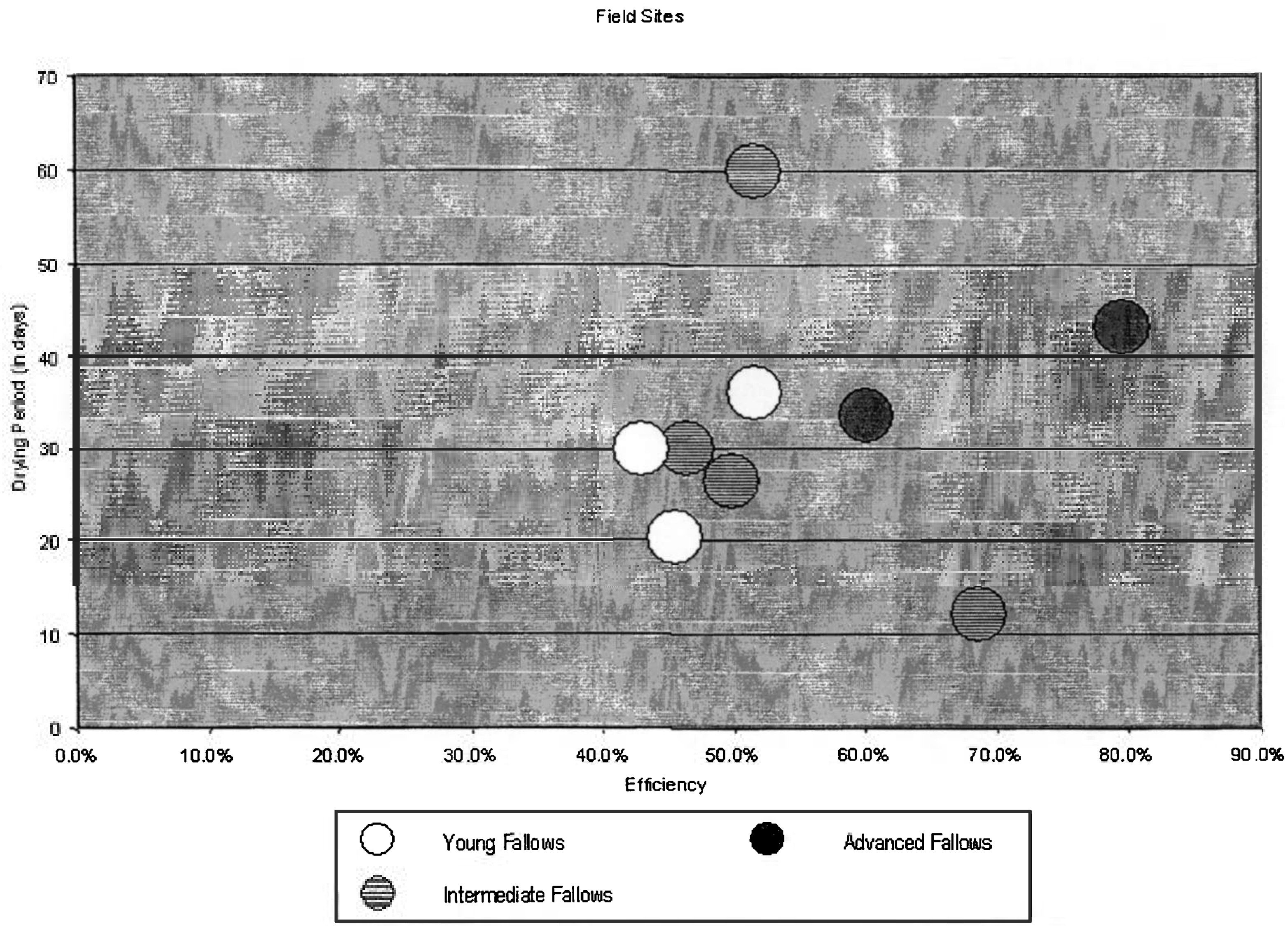


Figure 9.6: Fire Efficiency and Length of Dry Period for Selected Field Sites

9.5 Conclusion

In this chapter it becomes apparent that fire use as a farming strategy tied to land-use decisions is wrapped up in a variety of decisions that weigh household preferences, with land cover available and location, resettlement possibilities, economic forces, with household resources and logistics of the burning process. Local households exhibit similar patterns in land-use decisions regardless of household establishment length, suggesting that establishment length cannot exclusively be associated with land-use/cover change, particularly in older frontiers where population fluctuation is layered onto an already anthropogenic landscape. While certainly land-use decisions are individually made and influenced by market processes, issues of convenience, labor flexibility and timing are also influential. Farmers weigh these latter considerations with perception of environmental conditions.

CHAPTER 10

CONCLUSIONS

This dissertation advocates the need for local and regional studies on environmental issues to inform global environmental change research and estimation. Biomass burning significantly contributes to increased atmospheric trace gases and possible climate change, yet, analyses of what drives anthropogenic fire is less thoroughly examined because such study involves examining the human and physical dimensions of biomass burning at local and regional scales. This dissertation uses a multi-scale approach to address fire use within local and regional contexts. It investigates dynamics and effects of fire use within four rural communities with different settlement histories, then expands these findings to understand burning patterns in a larger agricultural frontier.

The dissertation integrates analyses of biomass burning at three spatial scales: regional, ecological field, and local. At the regional scale, a model of biomass change is developed from remotely sensed data and used in combination with household land-use information to infer extent of biomass burning in the study region over a nine-year period. At the field scale, physical evidence of slash-and-burn agriculture is examined through vegetation inventories and measure of post-fire fuel loads in 14 agricultural fields. At the local scale, in-depth household interviews on household history, land-use strategies, and present/historical burning practices compliment physical evidence, to provide a fuller understanding of the local causes and impacts of fire use.

This dissertation contributes to understanding of biomass-burning issues in a number of ways. First, in working from the local scale, the dissertation re-frames questions such that the base unit of analysis is not the land user as is often the case in political ecology perspectives or research that focuses on household dynamics and farming strategies. Instead the base unit of analyses is the physical evidence of biomass burning as seen through biomass loads chosen to be burnt, and fire efficiency. This roots the perspective in an analysis focused on environmental degradation, drawing from both physical measures and social processes. The physical pattern becomes a link between land-use processes that are influenced by household development, settlement, and farm strategies; and, the larger environmental responses to fire activity. More importantly, in utilizing this framework, the dissertation makes urgently needed social science analysis more accessible to global change research. The motives behind land-use decisions are reflected in physical measures that can be used in global estimates.

A concrete example of how the framework makes social science analysis accessible can be seen in the findings that households tend to burn young succession later in the burning season. Such information can help those who model biomass burning because it by indicates that there may be a temporal characteristic to burning within the burning season. This characteristic may be particularly important when dry seasons are abnormally long. Without knowledge of farmer logic used to obtain successful burns and to take full advantage of climatic conditions, global change research assumes the same types of vegetation are proportionately burnt throughout the dry season and thus, over or underestimate in a year where the dry season was extended. The findings of this dissertation indicate that more research should be conducted to investigate the extent of young successional burning in extended dry seasons. In this example, the social science expertise (used to understand farmer land-use decisions) is linked to a physical measure (the burning of young secondary succession). The tendency to burn young succession is a piece of information useful to those making estimates of biomass burning. This link was only made because the unit of analysis began with a physical measure: fire efficiency. Then questions were asked about human behavior connected to that measure: how farmers create successful burns.

Continuing along the lines of frameworks, a second contribution the dissertation makes is in the larger methodological approach. The dissertation exemplifies a method to address environmental degradation through the integration of data from the physical environment with information on human behavior. The task has been a challenge even though sophisticated scaling up and down techniques, via remote sensing, GPS, and GIS, were used. Regardless of the capabilities of the analyses to truly mesh physical and human data, discussion of both within the dissertation presents a fuller picture of biomass burning. A fuller understanding is critical to global change research to begin to address how to ameliorate fire use.

The use of remotely sensed data to detect biomass change, and the change scheme developed to interpret that change, is an example of this integration of data. By associating specific land-cover changes to the fire practices used to create those changes, a broader sense of burning activity within the study region was possible. Land-cover classes were developed based on the spectral reflectance of the physical environment. Information on land-use and fire-use practices was used to interpret spectral reflectance in a new way. It was used to model the degree of fire activity, in addition, to classify the physical landscape. In this more integrated model, inferences about initial fires were made, and the types of vegetation exposed in those fires. The possibility of additional fires was also detected and the nature of biomass loss in those fires discussed. Without knowledge of crop fallow cycles, and fire-use practices, both of which depend on human behavior, the biomass change scheme would not be able to estimate fire activity.

A third contribution of the dissertation is the analysis of fire efficiency, which was addressed from the perspective of the farmer and from the physical evidence in 12 of the 14 field sites. While it seems farmers play a role in this variable by extending drying periods, re-burning areas or thoroughly clearing areas, the data used in the dissertation did not produce clear connections between length of drying period, logistics of successful burns, and actual fire efficiency. In part, this may be overcome with further research and expansion of the dataset, which was limited (information of fire efficiency and length of drying period was collected for only nine of the field sites). The findings do call for more research into the logistics of fire use, and how farmers take advantage of flexible vegetation covers, such as young succession, when they perceive micro-climatic conditions extend the dry season. But regardless of the tenuous connections between farmer perception and fire efficiency, the findings of efficiency rates measured in 12 of the 14 field sites highlight that fire efficiency varies greatly and that variation is not necessarily correlated to vegetation age. In fact, variability in fire efficiency may be greatest in older succession areas. Global biomass-burning estimates often use a standard variable for fire efficiency that does not vary between vegetation types. The findings of this dissertation indicate, that fire efficiency may be much higher than the standard values used in estimation, especially as smallholder farming persists and secondary succession areas continue to be re-used in farming strategies.

A fourth contribution of the dissertation is that it specifically addresses the social forces driving fire use. In general, social scientific inquiry that operates within global change research has not done so in any depth. In the micro-study region, driving forces of fire use range from subtle but, influential economic incentives and regional land tenure regimes, to local factors such as, household establishment length, farmer flexibility, and convenience. Fire use emerges from the combination of these factors, making it very complex.

Yet despite this complexity, the findings of this dissertation indicate that burning patterns can be deciphered. Pattern recognition is important to global change research because we can use it to develop better estimates, detect where the most detrimental patterns exist, and understand why they exist. Once we get to this last step we can begin to develop strategies to change the situation. In the study region, newly established households chose different biomass loads than established households. In part these varying choices have to do with the condition of the land when they arrive on their properties. In part, choices have to do with intentions for farm expansion or diversification. Those who made local moves diversified and expanded farm operations in different ways than did households who made regional moves into the study area. Community biomass choices reflect settlement history. These patterns break down the presumption that fire is homogeneous and we can begin to incorporate variables in estimates that reflect the variability of patterns. In addition, with patterns, it is possible to target certain populations, anticipate where potential problems will arise based on those populations, and develop appropriate strategies to minimize the most detrimental patterns, based on the needs of households involved in those patterns. This is a very local approach to ameliorating the potential global threat of climate change.

Patterns also make individual practice generalizable. In doing so, the local context can be seen as part of wider trends that can be tested, deciphered, and evaluated in other setting. Questions that arise in comparison could include Do resettlement incentives promote the same sorts of burning patterns in other regions? Does household evolution more effectively determine fire-use patterns in other frontier settings than in the study area? To what extent is the changing vegetation cover in frontier regions more or less influential in household biomass choices? Answers to these questions become the building blocks to a theoretical framework that specifically addresses social dimensions of and environmental responses to biomass burning.

A fifth contribution of the dissertation is that it places analysis of the driving forces of biomass burning within conceptualizations of land-use/cover change both at regional and local scales. Land-use/cover change is a critical component to biomass-burning estimation and assessment because of the global biogeochemical fluxes, particularly that of carbon. In order to measure the increases in atmospheric trace gases, a model of the terrestrial side of the fluxes must be developed. The land-use/cover change models contribute to this because they conceptualize vegetation cover change. Social science perspectives, which are particularly adept at teasing out the social causes behind major cover changes, particularly deforestation and land-use change, have not looked thoroughly into fire use. Instead vague connections between land-use change and fire are implied or assumed. Where social scientific analysis has directly addressed fire use, in the slash-and-burn agriculture literature, emphasis has been on the sustainability of such practices under specific conditions. There are fewer conceptualizations of the actual change process within these studies. In general, land-use/cover change research conceptualizes fire as merely the outcome of land-use decisions. Little thought has been expended to investigate whether land-use/cover change conceptualizations adequately address the full consequences of fire use, or if fire-use strategies actually inform land-use decisions.

At the regional scale, a contemporary history of fire use was developed in the dissertation from evidence of land-use/cover change in the Brazilian Amazon over the last 30 years. This was more an exercise in integrating information on land-use change with knowledge of fire characteristics, than an actual research finding. However, it was an exercise well worth the effort. The result was a typology of fire for the Brazilian Amazon, based on land-use activity, actual fire regimes, and the types of trace gas emitted in those regimes. The link between trajectories of regional land use and consequent fire types is critical information for global change research. Too often estimates have assumed fire to be homogeneous with minimal regard for the various land-use decisions operating to create fire activity. Making the link between land use and consequent fire types provides a way to detect which types of land-use activity promote more detrimental fires. It also indicates why and where those activities are occurring.

At the local scale, the findings of the dissertation indicate that while fire is most certainly an outcome of land-use practice, fire-use strategies, particularly tactics to create successful burns, may inform and influence land-use decisions. In the micro-study region, farmers burn additional young succession to take advantage of flexibility of that vegetation. Findings such as these substantiate the argument that fire is a variable to be addressed in its own right and not hastily mentioned as an outcome without any further consequences. In addition, as land-use/cover change creates a physical environment where secondary succession and pasture become the primary vegetation covers, the issues of vegetation vulnerability to fire become quite serious. Accidental fire can be quite extensive in this more fire prone environment. One need only jog the memory a little to recall the monumental fires that spread across Brazil, South East Asia, Mexico, and Florida and to realize that the extent and damage of fire can reach far beyond intentional land clearance activities. Our conceptualizations of land-use/cover change need to account for the consequences of fire-use activity. The findings of the dissertation support expansion of these conceptualizations in such directions.

Last, by specifically studying smallholder fire-use practices, the dissertation gives voice to a social group that has often been thought of as homogeneous and overlooked. The 45 households in Rural Belterra, Nova Esperança, Boa Esperança, and Tracoá are not unique in their need to clear land, their ability to develop farming strategies and maintain livelihoods, and their desire to improve situations, provide for their families and plan for the future. They are part of a larger body of individuals across the world who, unbeknownst to themselves, have been targeted as the perpetrators of a serious environmental problem. This is not to say that culpability has been completely placed in the hands of these individuals. Political ecology arguments that highlight issues of poverty, landlessness, and economic pressures abound. But, these smallholders do ignite the fires and attention too easily falls on them. The truth of the findings in this dissertation is that for the most part households in the study region chose to work in successional areas. These areas are easier to slash, do not require hired chainsaw operators, are nearer to their house sites, and are a flexible land cover. The burning of young succession is the least harmful in terms of trace gas emissions because those that are released are eventually re-sequestered in the next fallow cycle. So long as these farmers are successful enough to remain on their properties, and provided that soil fertility hold up under utilization of short fallow cycles, these farmers may well be on a path toward fire-use practices that minimally contribute to global biomass burning.

The increasing complexity of fire issues within the Brazilian Amazon is such that it may pit local concerns against regional interests, and regional interests against national/international agendas. Conflicting social pressures are already present: those in ardent environmental movements oppose further burning while rural practice relies heavily on the burning of vegetation for continued livelihood. Determining the appropriate responses to this conflict is a social science question not consciously considered by environmental researchers. It is also a question that requires an analysis that merges social science methods with an understanding of physical processes. The frequency, efficiency, and areal extent of burning are dependent on human decisions influenced by local and regional pressures coupled with environmental conditions. By examining the relationship between settlement, land-use practice, and burning patterns, the dissertation has added micro- and meso-perspectives to the issues of global biomass burning. As well, because the dissertation focuses on land-use strategies of small landholders, it adds a level of understanding that is often overlooked or is, at times invisible, but which ultimately influences important larger environmental changes.

APPENDIX A: ENGLISH VERSION OF HOUSEHOLD SURVEY

Site ID:_________________________

Owner/Resident:_____________________

Community/Municipality:_____________

S-C Hwy/km:_______________________

UTM x:__________________________

UTM y:__________________________

Date:____________________________

Lot #:___________________________

Gleba:___________________________

Lot Characteristics

General relief: (<10 deg.)_______; rolling (10–20 deg.)_______; hilly (+20 deg)_______

Access to water: well________; stream________; cistern________; community well________; other________

Basic Information

Number of residents ________; Number over 14 yrs. old________.

Name	Birth Date	Relation	Origin

Year arrived on lot________; Year arrived in the area_______.

Where did you arrive from (state/municipal/community)?

Why did you move to this lot?

How did you acquire this lot?

Did you come with capital to invest in the lot?

If so, how much and how have you invested?

Did you clear forest to obtain the lot?

Have you augmented your lot since arriving?

Principal work activity of household head before arriving on lot:

Did you know other people in the area/community before moving here?

If so: who?

Where did they live?

Any family relation to your household?

Were you the first owners of this lot?_______; If not, who was the owner before?__________________

When did he/she arrive?

Size of property:

Do you own other lots?________; total areal size________

How much of the lot was forest when you arrived?

How much of the lot is forest now?

Did you receive financial support from government agencies when you arrived? (if so, for what, from who, when)

Since then? (if so, for what, from who, when)

Did you work off of your lot during the past year?

If so: In what work activities?

Where?

For whom?

Tenure situation: title____; occupation license____; receipt____; posse____; tenant_____

Information about Areas Burnt

Vegetation Age (before slashing/burning):

Surrounding vegetation:

Intended land use:

Preparation of Plots

Name of worker(s)	Relation to owner/tenant	Hired (yes/no)

Beginning date of slashing plot

Number of days used to slash plot

Tools used

Number of days for drying

Date of Burn

Information about Fire Use

Why did you choose this plot to slash/burn?

What factors do you consider when choosing a plot to slash/burn?

Do you make fire lanes or take any precautions against accidental fire?________;

explain precautions:

Do you have problems with accidental fire?_______; fire from neighboring lots?________

Explain some of the problems you have:

Are you burning more land this year than last?_______; Why?

Do you slash/burn more land now or in the first years that you lived here?

Was there a time when you burnt more or less land than you do now?

When was this and why?

How often do you burn your pasture?

Do you burn more fallow or pasture area?

Burning History (Start from present year and go back)

Year	Vegetation Age	Total Area Slashed/Burnt	Intended Land Use

Burning History (Start from first year and go forward)

Year	Vegetation Age	Total Area Slashed/Burnt	Intended Land Use

Other Land Use Information

Use	Area Used (ha)	Destination		
		Local	Commercial	Both
Perennials				
Annuals				
Fallows		N/A	N/A	N/A
Forest		N/A	N/A	N/A
Pasture				

How many years do you use a plot before leaving it to fallow?

Heads of Cattle:

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