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SECONDARY VEGETATION DYNAMICS ASSOCIATED WITH CATTLE RANCHING LAND-USE SYSTEMS IN PARÁ STATE

Raquel Carvalho de Lima

Doctorate Thesis of the Graduate Course in Earth System Science, guided by Drs. Ana Paula Dutra de Aguiar, and Silvana Amaral Kampel, approved in September 24, 2018.

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São José dos Campos, 24 de setembro de 2018

“And no one showed us to the land
And no one knows the where's or why's
But something stirs and something tries
Starts to climb towards the light”

(Echoes, Pink Floyd)

(In Portuguese)

A minha mãe Lucia Carvalho, melhor mãe e amiga de todos os tempos.

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(In Portuguese)

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ABSTRACT

The increasing human intervention on the land surface has impacted climate stability and biogeochemical cycles, putting land-use and land-cover change (LUCC) in evidence as a key field of investigations in global environmental change. Considering that LUCC is to a great extent the outcome of human decisions (e.g. of actors and institutions), research in this field has used different methods and tools of investigation to go beyond the identification of drivers of LUCC, but also to focus on how human decisions operate as underlying causes of the changes observed in the physical space over time. In the Brazilian Amazon, during the last three decades, the rapid expansion of large-scale mining and agricultural activities, and especially cattle ranching, implied conversion of at least 19.55% of total primary forests, making deforestation the main process investigated in the LUCC field. However, cattle ranching is not only a main driver of deforestation but is also behind the historical accumulation of secondary vegetation which, as a result of the conversion of forests into pastures often implemented with no technical concerns, are rapidly degraded and abandoned, allowing plant regeneration and forest regrowth. In the Brazilian Amazon, until mid-2000s estimates for secondary vegetation indicated a progressive increase of this cover, however following 2010, only 1,197 km^2 of additional secondary vegetation was generated, while 42,040 km^2 were converted into other land-covers. Meanwhile, deforestation rates progressively decreased, being currently around 6,000 km^2 in contrast to the 27,772 km^2 peak in 2004, largely as a consequence of various legal and alternative coercive measures being implemented since 2004. Considering that, in this thesis I investigated the heterogeneity of processes underlying secondary vegetation dynamics in cattle ranching systems in Pará, with a particular focus on the potential impacts of changes in the strategies of actors to cope with pasture degradation. I began by investigating on a regional scale the spatial-temporal patterns of secondary vegetation cover, and how they related to spatial-temporal patterns of different land-covers in Pará. Following that, based on a field-work investigation, I aimed to understand how increased law enforcement to halt deforestation could have stimulated actors to change practices and techniques to cope with pasture degradation. Besides describing motivations, beliefs and strategies of actors, I classify the systems they operate by quantifying the practices and techniques used in pasture management and discussed how practices and techniques might have impacted secondary vegetation cover based on accumulated knowledge of its dynamics. Finally, I spatialized cattle ranching systems and performed a spatial-temporal analysis of the representativeness of clusters of secondary vegetation and pastures in each system, followed by an exploratory analysis of the associations between different categories of drivers and clusters of high and low values of secondary vegetation in different cattle ranching systems in both pre-law enforcement (i.e. 2000-2004) and post-law enforcement (i.e. 2010-2014) periods. I have found that clusters of high values (hotspots) of secondary vegetation per deforested land prevailed in the north, while clusters of low values (cold spots) prevailed in the South of Pará, a pattern explained by the distinct regional stories of occupation and deforestation dynamics, but also by differences in the prevalence of specific land-covers. As evidenced by transitions and clusters analysis, small-scale agriculture and pastures under regeneration contributed to the concentration of high values of secondary vegetation in the north, with clean pastures being relevant to the concentration of low values in the south. Cattle ranching was in this way an important driver of change, both through conversion of secondary vegetation into clean pastures in the south and of dirty pasture and pasture under regeneration to secondary vegetation in the north. With respect to the adoption of practices and techniques to deal with pasture degradation, changes were restricted to regions where farming background of actors and nearness with market favored the emergence of the Professional system. In other regions, although practices and techniques with high impact in precluding pasture degradation were adopted, management is still done with low impact techniques which, in addition to other characteristics, describe the Traditional, Medium Scale and Subsistence systems. The analyses of spatial-temporal responses of secondary vegetation in each system, showed important associations between cattle ranching and secondary vegetation, especially concerning the representativeness of secondary vegetation and clean pastures. Notwithstanding, with respect to law enforcement, although observed associations between agriculture adequacy, price of bare land, and expansion of herds with clusters of high and low values of secondary vegetation can be connected with law enforcement, regardless the scale, cattle ranching operations follow decision making processes much more complex, which go beyond legal norms.

Key-words: Secondary vegetation, cattle ranching, law enforcement, pasture degradation, Pará, Brazilian Amazon.

DINÂMICA DE VEGETAÇÃO SECUNDÁRIA ASSOCIADA AOS SISTEMAS DE USO DA TERRA PELA PECUÁRIA

RESUMO

A crescente intervenção humana sobre o sistema terrestre tem alterado o clima e os ciclos biogeoquímicos, colocando as mudanças de uso e cobertura da terra em evidência como um campo de investigação central para as mudanças globais. Considerando mudanças de uso e cobertura da terra como o resultado de ações humanas, diferentes métodos e ferramentas de investigação têm sido empregados para entender como tais ações levam às mudanças no espaço físico. Na Amazônia Brasileira, ao longo das últimas três décadas, a rápida expansão particularmente da pecuária, além de mineração e agricultura em larga escala, levaram à perda de pelo menos 19,55% do total de florestas primárias. No entanto, a pecuária não representa apenas um importante vetor de desmatamento, mas também de acúmulo de vegetação secundária, como resultado da conversão de florestas em pastagens. Frequentemente implantadas sem cuidados técnicos, as pastagens entram em processo de degradação e, uma vez abandonadas, permitem a regeneração e o acúmulo de vegetação secundária. Até meados dos anos 2000, as estimativas de vegetação secundária para a Amazônia Brasileira indicavam um progressivo acúmulo, no entanto, após 2010, apenas 1.197 km^2 de vegetação secundária foram detectados, enquanto 42.040 km^2foram convertidos em outros usos da terra. Neste mesmo período, como consequência de várias medidas legais e alternativas contra o desmatamento, implementadas a partir de 2004, as taxas de desmatamento também sofreram redução, estando atualmente em torno de 6.000 km^2, em contraste aos 27.772 km^2detectados em 2004. Neste contexto, esta tese investigou a heterogeneidade dos processos subjacentes à dinâmica da vegetação secundária em sistemas de pecuária no Pará, analisando os impactos potenciais das estratégias contra a degradação de pastagens sobre esta cobertura. Inicialmente, na escala regional, foi feita uma análise dos padrões espaço-temporais e de agrupamento (clusters) de altos e baixos valores de vegetação secundária e de diferentes tipos de coberturas da terra no Pará. Na sequência, tendo como base uma investigação de campo, buscou-se entender como o aumento da pressão legal contra o desmatamento pode ter estimulado os atores a mudar práticas e técnicas para lidar com a degradação de pastagens. Além das motivações, percepções e estratégias dos atores, é apresentada uma classificação dos sistemas de pecuária por eles operados, quantificando-se as práticas e técnicas empregadas no manejo de pastagens.Tendo como base o conhecimento acumulado sobre a dinâmica de vegetação secundária, é apresentada também uma discussão sobre como tais práticas e técnicas podem ter impactado esta cobertura. Por fim, os sistemas de pecuária foram especializados para possibilitar uma análise da dinâmica espaço-temporal da representatividade dos clusters de vegetação secundária e pastagens em cada um dos sistemas, seguido de uma análise exploratória das associações entre diferentes vetores e clusters nos diferentes sistemas de pecuária nos períodos pré (2000-2004) e pós-pressão (2010-2014) legal contra o desmatamento. Como principais resultados destaca-se que clusters de altos valores de vegetação secundária prevaleceram ao Norte do Pará, enquanto clusters de baixos valores prevaleceram ao Sul, um padrão explicado por histórias de ocupação e dinâmicas de desmatamento distintas, mas também pelas coberturas da terra predominantes nas diferentes regiões. A pecuária foi um importante vetor de mudanças, seja pela conversão de áreas de vegetação secundária em pastos limpos, ou contribuindo à concentração de altos valores de vegetação secundária ao Norte. Com relação às práticas e técnicas contra a degradação das pastagens, o padrão é de que a adoção de técnicas e práticas de impacto negativo sobre a regeneração nas regiões se restringiu às regiões nas quais a experiência prévia dos atores com atividades produtivas e inserção em conexões de mercado com frigoríficos industriais favoreceram a emergência do Sistema Profissional. Nas demais regiões, embora práticas e técnicas com alto impacto sobre a degradação tenham sejam adotadas, as pastagens são ainda predominantemente manejadas com técnicas de baixo impacto negativo sobre a regeneração, as quais juntamente com outras características como perfil dos atores definem os Sistemas Tradicional, Média escala e de Subsistência. A análise das respostas espaço-temporais da vegetação secundária em cada sistema evidenciou relações importantes entre pecuária e dinâmica da vegetação secundária, particularmente em se tratando da representatividade de clusters de altos e baixos valores dessa cobertura e também de pastagens. No entanto, com respeito ao controle do desmatamento, embora associações observadas entre aptidão agrícola, preço da terra nua e expansão de rebanhos com clusters de altos e baixos valores de vegetação secundária possam estar conectadas com o cumprimento das normais legais, independentemente da escala, as operações de pecuária seguem processos de tomada de decisão bem mais complexos que vão além da pressão contra o desmatamento.

Palavras-chave: Vegetação secundária, pecuária, normas legais, degradação de pastagens, Estado do Pará, Amazônia Brasileira.

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ACRIPARÁ	Associação de Criadores do Pará
APRONOP	Associação dos Produtores de Novo Progresso
CAR	Cadastro Ambiental Rural
EMATER	Empresa de Assistência Técnica e Extensão Rural do Estado do Pará
FAEPA	Federação da Agricultura do Estado do Pará
IBGE	Instituto Brasileiro de Geografia e Estatísticas
MDIC	Ministério da Indústria e Comércio
PPM	Pesquisa Pecuária Municipal
PPCDAM	Plano de Prevenção e Controle do Desmatamento na Amazônia
SIF	Serviço de Inspeção Federal
SIE	Serviço de Inspeção Estadual
SNUC	Sistema Nacional de Unidades de Conservação
INCRA	Instituto Nacional de Reforma Agrária

CONTENT

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1 INTRODUCTION

As the importance of local and regional spatial dynamics to the functioning of the earth system emerged, showing that modifications in the land surface were connected to global climate stability, more attention was given to processes of change on the land surface (FOLEY et al., 2005; LAMBIN, GEIST, LEPERS, 2003; TURNER et al., 2007). Through water pollution, soil depletion, and deforestation, the increasing human intervention on the land surface has impacted climate stability and biogeochemical cycles, putting land-use and land-cover change (LUCC) in evidence as a key field of investigations in global environmental change (FOLEY et al, 2005; LAMBIN; GEIST; LEPERS, 2003).

Although changes in land-cover and land-use can be hardly discernible, at least in theory these concepts are fairly distinct: being the former the attributes describing the land (i.e. soil, infrastructure, vegetation, biodiversity, slope), and the later the assemblage of practices, techniques and objectives managing it (LAMBIN; GEIST, 2006; LAMBIN; GEIST; LEPERS, 2003; LAMBIN et al, 2001). Hence, while changes in land-cover can be detected in satellite images, for instance (ALVES, 2002; DOS SANTOS et al., 2008; ESPINDOLA; AGUIAR, 2012; RINDFUSS et al. 2004) changes in land-use are processes, subtle or drastic, whose investigation requires interdisciplinary tools (RINDFUSS et al, 2004, 2013; ROUNSEVELL et al, 2012; VERBURG et al, 2009). Adding even more complexity, changes can be direct or indirect, or the result of feedback mechanisms (RINDFUSS et al 2004; VERBURG, 2006). Direct causes of change mean direct human actions, very often local, and that can be perceived by analyzing spatial patterns, while indirect causes, on the other hand, refer to background processes, whether social or political, acting at regional and global levels, stimulating changes (GEIST; LAMBIN, 2002; VERBURG, 2014).

LUCC is to a great extent the outcome of human decisions (e.g. of actors and institutions) thus research in this field has used different methods and tools of investigation to “move from simplistic representations to a much more profound understanding that involves situation-specific interactions among distinct factors at different spatial and temporal scales” (in LAMBIN, GEIST; LEPERS, 2003, p

207). Therefore, besides the identification of biophysical, demographic, economic and political factors as potential drivers of LUCC, investigations focus in understanding how human decisions operate as underlying causes of changes observed in the physical space over time (ALVES et al., 2010; GEIST; McCONNELL, 2006; RINDFUSS et al., 2004; ROUNSEVELL et al., 2012). In this context, integrative approaches that capture for resources use and management choices are useful for a better comprehension of how indirect drivers affect direct drivers thus determining patterns of LUCC (VERBURG, 2014; YOUNG; KING; SCHROEDER, 2008).

Considering actors either as entities that through their actions intentionally make things happen (BANDURA, 2001) or as human active forces of land change (MEYFROIDT, 2013), in approaching the perspectives of actors, research questions focus on “the motivation behind and the external factors influencing decisions about land-use” (LAMBIN et al. 2003, p. 231). Values, understood as beliefs, desirable goals, standards or criteria to guide actions, play an important role in this context, as they can be used to characterize cultural groups, societies and individuals, trace changes over time and explain the motivational basis of attitudes and behavior (SCHWARTZ, 2012). As an example, the frontier expansion in the Brazilian Amazon was found to be largely influenced by dominant types of actors (i.e. smallholders or medium- or large-scale landholders) who, despite the widespread adoption of cattle ranching[1], make different decisions with respect to deforestation, and intensification (PACHECO, 2012). By the same token, the adoption and diffusion of new agricultural practices and techniques rely on a combination of social, economic, and cultural factors influenced by household preferences, resource endowments, market incentives, biophysical factors, and perceptions of risk and uncertainty (MERCER, 2004; SOUZA-FILHO et al., 2011).

[1] Cattle ranching is used in reference to cattle raising operations in properties of any size.

During the last three decades, as the rapid expansion of cattle ranching, large-scale mining and agricultural activities implied the conversion of at least 19.55% of forests in the Brazilian Amazon (PRODES, 2017), deforestation became the main process investigated in the LUCC field (AGUIAR et al., 2007; HECHT, 1985, 1993; KAIMOVITZ et al., 2004). In this regard, the expansion of cattle ranching that occupies 62.1% of all deforested lands in this region, has been particularly important to this process (ALMEIDA et al., 2016; BOWMAN et al., 2012; WALKER et al., 2009a).

Although cattle ranching operations in the Brazilian Amazon date back to the 17th century, when the first herds were brought to the Marajó Island (HOMMA et al., 2006; VALVERDE, 1967), the expansion of this land-use over lowlands began only in the 60s when, stimulated by the implementation of roads, public credit and subsidies, and prospects of facilitated acquisition of public lands, large areas of forest started to be converted into pastures (HECTH, 1993; 1985; WALKER et al., 2000).

Seen as a crucial strategy to integrate the Amazon region during the dictatorial regime, the expansion of cattle served national and international purposes: occupy a large and unknown region, supply an increasing demand for beef in Brazilian urban centers, and as a means to diversify Brazilian exports by supplying utility or cutter (cheap) beef to the United States(HECTH, 1985). Moreover, cattle ranching easy implementation, lower demands of less skilled labor, and prospects of enormous capital gains in land speculation during a period of high inflation were features that favored it as the best strategy to open Amazon frontiers (HECTH, 1985; 1993). Despite celebrated as a promising development and integrating strategy, less than one decade after first ranches were implemented, expected financial gains were not met (HECTH, 1985; 1993). In addition, concerns arose about large-scale deforestation, public land appropriation and alienation, and land conflicts (COSTA, 2008; MARTINS, 2014; NEPOMUCENO, 2007; PEREIRA, 2013). Land concentration as a result of cattle expansion has led to severe, and sometimes, permanent land conflicts, as described, for instance, in Southeast Pará (NEPOMUCENO, 2007; PEREIRA, 2013; SCHMINK, 1982).

Besides low land prices, land availability and prospects of land rent capture, environmental conditions found in most regions of the Brazilian Amazon favor a higher productivity, making cattle ranching an attractive land-use (ARIMA et al., 2005; BARROS et al., 2002; BOWMAN et al., 2012; WALKER, 2009a). In comparison to other Brazilian regions, factors such as higher luminosity, shorter dry periods and favorable rain regimes could make pastures in the Amazon on average 10% more productive, therefore exempting nutritional supplementation, especially in areas under 1,600 a 2,200 mm/year (ARIMA et al., 2005; BARROS et al, 2002). Notwithstanding, in less than 20% of grasslands stocking rates exceed 1.38 herds per hectare, a reality often attributed to poor implementation and management of pastures (ARIMA et al, 2005; BARROS et al, 2002; DIAS-FILHO, 2011; DIAS-FILHO; FERREIRA, 2011).

Implementation without any technical concerns and in inappropriate lands (i.e. lacking agricultural aptitude) are pointed out as responsible for reduced productivity and carrying capacity of pastures in the Brazilian Amazon (ARIMA et al, 2005; BARROS et al, 2002;). During pasture implementation, factors that contribute to low productivity include inappropriate land preparation prior to sowing (locally called “tree stump” or “ashes” pastures), poor quality of seeds, and inadequate use of these grazing lands, with herds being introduced too early or too late in newly implemented areas, for instance. Excessive stocking rates, lacking of chemical fertilization and use of fire also respond for rapid decreases in productivity, while several biotic (diseases and pests), and abiotic factors (low fertility, and poor soil drainage) also lead to or accelerate the process of pasture degradation (DIAS-FILHO, 2011; 2015).

Pasture degradation is the progressive decline in forage and animal productivity, as a result of soil degradation or invasion by weeds (DIAS-FILHO, 2011; 2015; OLIVEIRA et al., 2004). In soils where, either as a result of impoverishment or compaction, pastures lose their capacity of sustaining plant biomass production, there is biological degradation (DIAS-FILHO, 2011). On the other hand, when soil properties are preserved and the capacity of sustaining plant biomass production is not affected but, as a result of invasion by weeds and changes in their botanical composition, pastures lose their capacity to maintain a minimum grass biomass, there is agricultural degradation (DIAS-FILHO, 2011; 2015). Therefore, agricultural degradation (hereafter referred simply as pasture degradation) basically represents the starting point of plant ecological succession or regeneration, a reversible process through which a cleared area is colonized by a new assemblage of secondary species (CLEMENS, 1916, DIAS-FILHO, 2011).

Either as a result of inadequate implementation or management, pasture degradation is estimated to affect 50% of pastures in the region (DIAS-FILHO, 2015) which will, depending on their different pathways of regeneration, accumulate as secondary vegetation cover: between 2010 and 2012, for instance, 13% (or 2.4 million ha) of secondary vegetation cover mapped in the Brazilian Amazon were the result of regeneration in cattle ranching areas (TERRACLASS, 2014).

At the beginning of the decade, estimates of secondary vegetation for the Brazilian Amazon indicated a progressive increase in this cover (CARREIRAS et al. 2006; LUCAS et al. 2000; NEEF et al 2006). Lucas et al. (2000) estimated that between 1991 and 1994, 157,973 km^2 (or 35.8% of the total deforested area in 1992) was under regeneration, with 48% having been abandoned for less than five years. For 2000, estimates were that secondary vegetation covered 140,000 km^2, being particularly concentrated to Pará and Maranhão (CARREIRAS et al., 2006). Covering a larger period of time, Neef et al. (2006) showed that, between 1978 and 2002, secondary vegetation cover increased from 29,000 to 161,000 km^2. By mid-2000s, new studies provided more detailed but quite similar estimates. Almeida (2009), for instance, using a statistical regression model to predict the spatial distribution of secondary vegetation, estimated that in 2006, from 121,722 to 145,608 km^2 of the Brazilian Amazon was covered by secondary vegetation, being hydrography and land tenure structure the factors positively influencing this dynamics. This pattern of accumulation of secondary vegetation was also detected in 2008 when 21.2% (or 150,815.31 km^2) of the total deforested land was detected as covered by it (ALMEIDA et al., 2016), and between 2008 and 2012, in particular the conversion of forests and pastures generated additional 21,374.47 km^2 of secondary vegetation.

During the two following years however, only 1,197 km^2 additional secondary vegetation cover was generated, with at least 42,040 km^2 of it being converted to other land-covers, in particular pastures (28,488 km^2) and mechanized agriculture (1,884 km^2) (ADAMI et al., 2015). Despite restricted to a short period of time (i.e. the second half of the last decade) these figures suggest that, after 2008, the historical pattern of accumulation of secondary vegetation have changed, being this my first topic of investigation in this thesis: ***Did the historical pattern of accumulation of secondary vegetation change in the last decade?***

In 2004, the Brazilian Government started conceiving and implementing PPCDAM, a comprehensive set of measures to control deforestation in the Brazilian Amazon region (ARIMA et al., 2014; BORNER et al., 2014; 2015; DALLA-NORA et al., 2014; GIBBS et al., 2016; GOLNOW, LAKES, 2014; LAPOLA et al., 2013; PACHECO; POCCARD-CHAPUIS, 2012; RUDEL et al., 2009). Among several measures to halt deforestation, increased command and control operations, restricted access to credit, and purchasing conditioned to registration in the Rural Registering System (CAR) are said to have reduced the impact of cattle ranching in terms of deforestation that, as a consequence, reached in 2012 its lowest rate since 1988 (ARIMA et al., 2014; LAPOLA et al., 2013). The PPCDAM was also strengthened by sector agreements that forced major slaughterhouses and retailers to commit to zero deforestation in the beef production chain (GIBBS, 2015, 2016). Therefore, in this period, several forces potentially affected and changed cattle ranching operations which, even in a context of reduced deforestation, exhibited a steady expansion in terms of pastures, herds, slaughtering and exports (PACHECO; POCCARD-CHAPUIS, 2012; PPM/IBGE, 2016; COMEX-STAT/MDIC, 2016).

In spite of the few detailed investigations on how and where such processes took place, some studies suggest that concomitantly to law enforcement, actors not only effectively responded to disincentives (i.e. fines and embargo) (BORNER et al., 2014; 2015), but also improved pasture and herds management (PACHECO; POCCARD-CHAPUIS, 2012), being these processes particularly strong in regions with better infrastructure. In Pará, for instance, clusters of reduction in deforestation coincided with a concentration of law enforcement operations, and field-based enforcement reduced large-scale deforestation, being deterrence effect estimated in 9.9 ha/inspection of avoided deforestation (BORNER et al., 2015). Effectiveness of command and control measures however is potentially higher in more accessible areas where both probability of law enforcement operations and opportunity costs of legal environmental compliance are also higher (BORNER et al., 2014).

With respect to improved pasture and herd management, in agreement with Pacheco and Poccard-Chapuis (2012), between 1996 and 2006, pastures expanded only 3.4 million ha (50.4 to 53.4 million ha), what in a scenario without increased productivity the recorded expansion of herds in this period would require more 20 million ha of pasture. Moreover, these authors present a set of parameters indicating improvements in cattle herd management in medium and large-scale properties, although this may not apply to small-scale systems. ***Following that, the second topic I investigate in this thesis regards whether and how increased law enforcement led actors in cattle ranching to adopt more intensive practices and techniques to cope with pasture degradation.***

Cattle ranching is not only a main driver of deforestation but is also behind the historical accumulation of secondary vegetation that represents in this context a by-product of the conversion of forests into pastures which, following degradation, are abandoned allowing plant regeneration and forest regrowth (COSTA, 2004; 2007; 2008; NEPSTAD et al., 1996; MESQUITA et al., 2001; 2015; UHL et al., 1988). Cattle ranching and secondary vegetation are in this way intertwined and, as pastures expanded over forests, large areas were also degraded and/or abandoned being left to regenerate. More recently however, concomitantly with increased law enforcement, while pastures, herds, slaughtering, and exports steadily increased, deforestation and accumulation of secondary vegetation were reduced, suggesting that these dynamics may be related through the process of pasture management (i.e. degradation and recover). ***In this context, my third topic of investigation in this thesis refers to whether law enforcement against deforestation which, after 2009 targeted the beef production chain, is also related with the observed reduction in secondary vegetation in the same period.***

1.1 Hypothesis and goals

In this thesis I explore the hypothesis that after increased law enforcement over the beef production chain to halt deforestation, the historical pattern of secondary vegetation accumulation, observed until the beginning of the 2000s, changed. In a scenario of increased pressure against deforestation, unable to keep expanding pastures over newly deforested lands, actors were forced to adopt more intensive practices and techniques to cope with pasture degradation which, as a consequence, negatively affected regrowth and secondary vegetation. These changes however were restricted, being connected to a concentration of major slaughterhouses, and stronger law enforcement. On the other hand, in regions where law enforcement was lower or prevailing market connections were not restrictive, traditional or less intensive practices and techniques to cope with pasture degradation allowed the historical pattern of secondary vegetation accumulation.

Based on this hypothesis, the overall objective of this thesis was to explore changes in the dynamics of secondary vegetation in distinct cattle ranching systems in pre and post-law enforcement. Hence, my main goals in this thesis were:

1. Analyze the spatial-temporal patterns of secondary vegetation in Pará during the last decade and identify how these dynamics were related to

prevailing land-uses including small-scale agriculture, mechanized and industrial agriculture, and cattle ranching.

2. Based on a field-work investigation, acquire data to understand whether increased law enforcement against deforestation stimulated actors to change practices and techniques to cope with pasture degradation. Besides describing the motivations, beliefs and strategies of actors, I classify the systems they operate and quantify the use of practices and techniques in pasture management. At the end, I discuss how such practices and techniques have potentially impacted changes in secondary vegetation based on the accumulated knowledge about its dynamics.

3. Spatialize cattle ranching systems and perform a spatial-temporal analysis of the representativeness of clusters of secondary vegetation and pastures, followed by an exploratory analysis of the associations between different drivers and clusters of low and high values of secondary vegetation in different cattle ranching systems in pre-law enforcement (i.e. 2000-2004), and post-law enforcement (i.e. 2010-2014) periods.

To achieve these goals, I have structured this document in five chapters. Chapters 2, 3 and 4 present the context, methods and results regarding the accomplishment of each specific goal. Then, in Chapter 5, I conclude connecting main findings of this investigation to my hypothesis, also discussing some of the limitations and implications of methods adopted, and pointing out opportunities for future research in this field.

2 CHANGES IN SECONDARY VEGETATION DYNAMICS FOLLOWING LAW ENFORCEMENT AGAINST DEFORESTATION IN PARÁ

2.1 Introduction

Tropical secondary vegetation is of particular interest as carbon sinks (AGUIAR et al., 2016; NEEF et al., 2005; ORIHUELA-BELMONTE et al., 2013), potential lands for agriculture and livestock expansion (PEREIRA; VIEIRA, 2001; STRASSBURG et al., 2014), biodiversity conservation and ecosystem services (BENAYAS et al., 2009; CHAZDON et al., 2009; KLEMICK, 2011; SMITH et al., 2003). Ultimately the result of land-use and abandonment, the regeneration and permanence of secondary vegetation are largely influenced by environmental factors, and directly connected to land-use decisions (CHAZDON, et al., 2009; 2012; GUARIGUATA; OSTERTAG, 2001; HOLL, 1999; LAUE; ARIMA, 2014; LU et al., 2002; MORAN et al., 2000; MESQUITA et al., 2001; 2015; PERZ; SKOLE, 2003). Among environmental factors determining regeneration, emphasis has been given to soil degradation, heavy rains, steeper sloped topography and less primary forests (BENTOS et al., 2013; CHAZDON, 2009; 2012; MESQUITA et al., 2001; 2015). In this respect, exception made to less primary forests, all other environmental factors affect regeneration both directly, as determinants of ecological pathways of regeneration, and indirectly, as determinants of land-abandonment (BENAYAS et al., 2007; LAUE; ARIMA, 2014; PERZ; SKOLE, 2003; MESQUITA et al., 2015; SPERA et al., 2014).

Soil depletion and changes in physical structure were found to negatively impact the initial stages of regeneration, in particular where heavy rains, constantly high temperature and frequent use of fire accelerate soils degradation (GUARIGUATA; OSTERTAG, 2001; LU et al., 2002; MORAN et al., 2000). Over time, higher investments in agricultural inputs required to deal with soil degradation is a condition that, if not met, may lead to land abandonment (PERZ; SKOLE, 2003). Heavy rains and accelerated soil degradation increase the propagation of plant and animal diseases, also stimulating land abandonment (LAUE; ARIMA, 2014; PERZ; SKOLE, 2003). Steeper sloped lands, in addition, reduces the growth of seedlings (BENTOS et al., 2013) and it also increases chances of land abandonment (BENAYAS et al., 2007; LAUE; ARIMA, 2014; SPERA et al., 2014).

In the Brazilian Amazon, Costa (2004; 2009) emphasizes that regeneration and persistence of secondary vegetation are the result of three main land-use decisions: integration into a land-use system (e.g. swidden agriculture), land abandonment (e.g. degraded pastures), and intensification through conversion of secondary vegetation areas into perennial or semi-perennial land-uses (e.g. industrial agriculture). Swidden agriculture and cattle ranching are the main land-uses related to regeneration (UHL et al., 1988; NEPSTAD et al., 1996; COSTA, 2004), while the recent expansion of industrial agriculture has been pointed out as a driver of secondary vegetation reduction (BUTLER; LAURANCE, 2009; LAMEIRA et al., 2015; LEES; VIEIRA, 2013; VIEIRA et al., 2001).

In swidden agriculture, secondary vegetation is an asset, providing important ecosystem services (e.g. protect soils and increase fertility), and also timber and non-timber resources (COOMES et al., 2000; SMITH et al., 1999; 2003). As part of "nature-friendly" landscapes, regeneration and persistence of secondary vegetation in these areas is primarily dictated by land and labor availability, and market conditions as well (COOMES et al., 2000; MEYFROIDT; LAMBIN, 2011; PRATES-CLARK et al., 2009; SCATENA et al., 1996; SMITH et al., 1999). In addition, the dominance of small properties was found to be related with less deforestation (AGUIAR et al., 2007; PACHECO, 2009) what has a potential positive aspect for secondary vegetation concentration. Moreover, as identified by Almeida et al. (2010), a prevalence of small properties was found to positively affect the accumulation of secondary vegetation, hence where small properties prevail, more secondary vegetation is to be found.

In cattle ranching systems, secondary vegetation is a by-product of forest clearing and the establishment of pasture which, following rapid degradation, are eventually abandoned (COSTA, 2004; 2009; NPESTAD et al., 1996; MESQUITA et al., 2001; 2015; UHL et al., 1988). Notwithstanding, investigations on regeneration in abandoned pastures show that some practices adopted in pasture management (e.g. intensive grazing, use of fire, continued cutting, and reduction of primary forest stocks), on the contrary, slow or even preclude regeneration (MESQUITA et al., 2001; NEPSTAD et al., 1996; UHL et al., 1988). Intensive grazing degrades soil through compaction, and destroys emerging tree shoots, negatively impacting seed banks and seedling recruitment (GUARIGUATA; OSTERTAG, 2001; NEPSTAD et al., 1996; PRATES-CLARK et al., 2009). Negative impacts on seed banks can also result from frequent use of fire which precludes regeneration and depletes soil properties (UHL et al. 1981, MESQUITA et al., 2001). Intensive use of bulldozers in pasture recovery was found to delay or completely preclude forest regrowth after pasture abandonment (UHL et al., 1981; NEPSTAD et al., 1996). In addition, dominance of large properties implies more deforestation (PACHECO, 2009) which can affect regeneration because less primary forest stock reduces seeds availability and dispersal (MESQUITA et al., 2001; CHAZDON, 2012).

Until mid-2000s, absolute figures on secondary vegetation in the Brazilian Amazon indicated a progressive increase in this cover, with estimates being that around 140,000 km^2 to 161,000 km^2 of already deforested lands were under regeneration (CARREIRAS et al., 2006; LUCAS et al., 2000; NEEF et al., 2006). In 2004, TerraClass Initiative (TERRACLASS, 2008) estimated that secondary vegetation covered 100,674 km^2. Between 2004 and 2008, more 50,141 km^2 of this cover were detected, but soon after 2008 increments in secondary vegetation were progressively reduced from 14,414 km^2between 2008 and 2010 to 1,197 km^2 between 2012 and 2014. Moreover, in the same period, at least 42,040 km^2 of secondary vegetation was re-converted into other land-uses, in particular to pasture (28,488 km^2) and mechanized agriculture (1,884 km^2) (TERRACLASS, 2014). Meanwhile, following a 27,772 km^2 peak in deforestation rates, legal and alternative coercive measures targeted the aggressive, and seemingly uncontrolled process of deforestation, and as pressure of industrial agriculture and pasture expansion over newly deforested lands was reduced (GOLNOW; LAKES, 2014; MACEDO et al., 2012;

RUDDORF et al., 2011, 2012) deforestation rates reached their lowest levels ever, currently around 6,000 km^2 per year (PRODES, 2018).

These figures suggest that the historic pattern of progressive accumulation of secondary vegetation in the Brazilian Amazon is changing; hence, in this paper we explore the hypothesis that, over the past decade following increased pressure to halt deforestation, re-conversion of areas under regeneration into other land-uses has reduced areas of secondary vegetation. Our focus in this work was then to investigate on a regional scale the spatial-temporal patterns of secondary vegetation with respect to different land-uses in Pará. The diversified contexts of occupation, deforestation, and land-use as a result of facilitated access to land and expansion of a network of infrastructure (roads, ports, slaughterhouses and other facilities) stimulating rapid expansion of cattle ranching and industrial agriculture makes Pará an ideal region to explore our hypothesis. To achieve our purposes, we combined two complementary spatial-temporal analyses: (i) a quantitative analysis of transitions between land-uses; and (ii) detection of clustering patterns of secondary vegetation cover with respect to clustering patterns of different land-uses including pastures, small-scale, mechanized and industrial agriculture.

2.2 Methods

2.2.1 Study area

Since the 70s, Pará has being transformed by the rapid expansion of cattle ranching and industrial agriculture, particularly stimulated by the construction of roads, ports, slaughterhouses and other processing facilities in conjunction with facilitated access to lands (BOWMAN et al., 2012; LAMEIRA et al., 2015; WALKER et al., 2009b). In 2014[2], pastures covered 61.35% (or 12.5 million ha) of the total deforested lands in Pará, followed by secondary vegetation which

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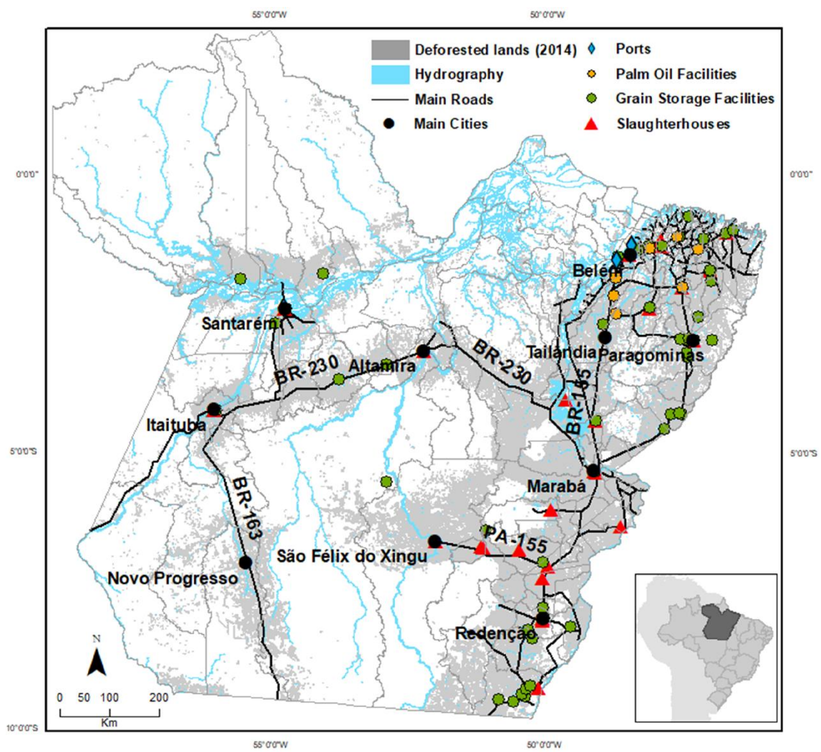
[2]Absolute figures presented here may differ from raw non-processed data provided by TerraClass project as a result of masks applied (see Data processing for more details on masks application).

occupied 25.44% (or 5.2 million ha) of these lands (TerraClass, 2014). Industrial agriculture (mechanized agriculture and palm oil), and small-scale agriculture, represented by the mosaic of occupation covered 1.3% (or 265,640.7 ha), 1.06% (219,000 ha), and 2.21% (452,613.3 ha) of total deforested lands respectively, while areas of pasture under regeneration represented 7.76% (or 1.59 million ha) of total deforested lands.

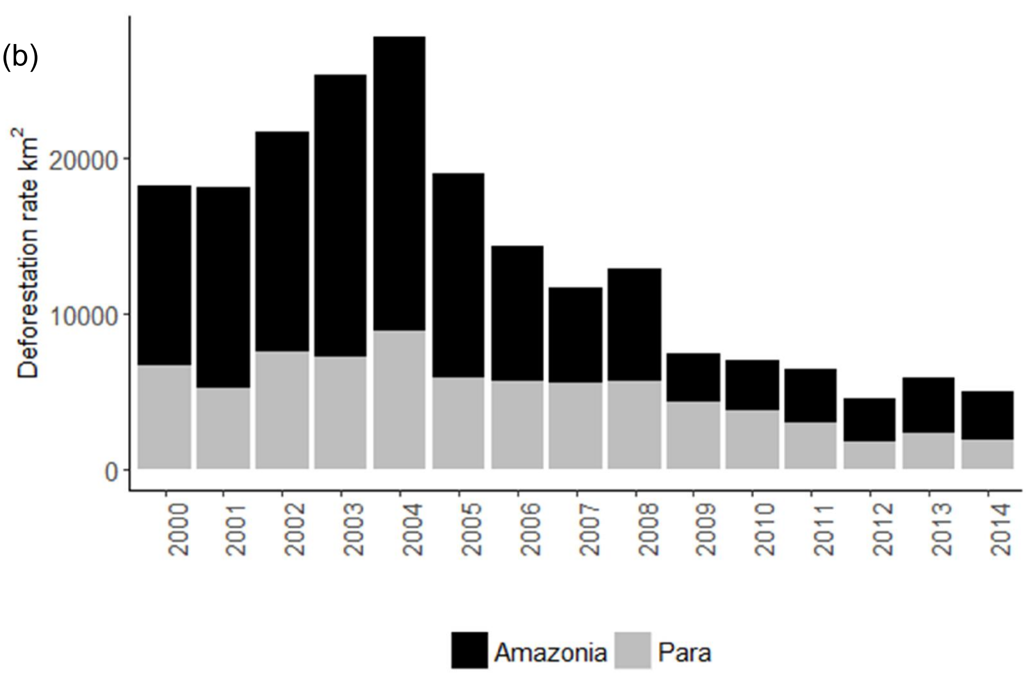
Figure 2.1 presents the study area and shows the quantitative evolution of deforestation rates between 2000 and 2014. Until the beginning of 2000s, Pará was considered a hotspot of deforestation with rates between 5,237 and 7,510 km^2. Following a peak of 8,870 km^2 in 2004, the several legal and alternative coercive measures put in place to halt deforestation progressively led to a reduction in rates, with lowest being recorded in 2012 when 1,741 km^2 were lost.

Figure 2.1 – Study area (a) Pará limits and infrastructure network; (b) Deforestation rates in Pará and Brazilian Amazon between 2000 and 2014.

(a)



(b)



2.2.2 Data processing

We used data provided by the TerraClass Initiative to build a geographical database for 2004, 2008, 2010, 2012 and 2014. The TerraClass Initiative (TC) is a long-term project that uses a combination of deforestation vector data (i.e. deforested polygons > 6.25 ha detected by PRODES) and satellite orbital images (Landsat-5/TM, MODIS and SPOT-5) which are classified using visual and semi-automatic techniques in 15 different classes (TERRACLASS, 2008; ALMEIDA et al. 2016). Description of land-use classes provided by the TerraClass Initiative was rigorously observed (TERRACLASS, 2008), being classes used in our analyses (i) secondary vegetation, (ii) mechanized agriculture, (iii) clean, dirty and under regeneration pasture, (iv) mosaic of occupation and (v) annual deforested land. Besides data provided by the TC Initiative, we accessed data on palm oil areas >9 ha as detected in LANDSAT images in agreement with Benami et al (2018) which in this study comprises data on palm oil areas identified by 2012.

From these data sets we obtained masks which were applied to the whole data set to exclude: (i) ‘not observed’ areas (i.e. areas covered by clouds and their shadows); (ii) ‘reforestation’ areas (i.e. planted forests), and (iii) palm oil areas in order to avoid double counting of these areas as secondary vegetation cover. After masks were applied, processed data was organized as attributes in a database of 10 km x 10 km cells using the FillCell Plugin (TerraME), an add-on plugin to calculate attribute values for the cellular space using attribute tables of layers. Fill Cell Plugin allows information coming from different geometries (vector, raster, or cellular) to be homogenized and aggregated in a single spatial-temporal layer, providing a database for modeling and statistical analyses.

All cells having less than 100 hectares of accumulated deforested land until 2004 were excluded from the dataset. Land-use classes used as attributes in our analyses are described in Table 2.1.

Table 2.1 - Attributes in the 10 km x 10 km grid cells.

Attributes	Variable	Description [1]
Secondary vegetation	SeVe	Percentage of secondary vegetation (SeVe) in each cell. Secondary vegetation cover is characterized by an advanced progress of regeneration and high plant species diversity.
	SeVe/De	Percentage (%) of secondary vegetation (SeVe) in relation to the deforested (De) area in each cell.
Pasture	PaClean/De	Percentage (%) of clean pasture in relation to the deforested (De) area in each cell. Clean pasture is a productive pasture with 90% to 100% of herbaceous vegetation cover (grass species).
	PaDirty/De	Percentage (%) of dirty pasture in relation to the deforested (De) area in each cell. Dirty pasture is a productive pasture with 50% and 80% of herbaceous vegetation cover (grass species) in association with 20% to 50% of sparse shrub cover.
	PaRe/De	Percentage (%) of regeneration with pasture in relation to the deforested (De) area in each cell. Regeneration with pasture is a non-productive pasture with 30% to 60% of herbaceous vegetation cover (grass species) in association with 40% to 70% of shrub cover and eventually occurrence of trees (0% to 15%).
Industrial Agriculture	MecAg/De	Percentage (%) of mechanized agriculture in relation to the deforested (De) area in each cell. Mechanized agriculture covers areas with large-scale annual agriculture with indications of high technological standards.
	PaOil/De	Percentage (%) of palm oil in relation to the deforested (De) area in each cell. Areas cultivated with palm oil crops in agreement with Benami et al. (2018).
Mosaic of Occupation (Small-scale Agriculture)	SmAg/De	Percentage (%) of mosaic of occupation in relation to the deforested (De) area in each cell. Mosaic of occupation represents areas in which an association of diverse land-uses is found but, given the spatial resolution of satellite images these different land-uses cannot be isolated. In this land-use class, family agriculture is developed together with subsystems of pasture for traditional cattle ranching.
Deforestation	De	Annually detected deforested areas.

2.2.3 Spatial-temporal analysis of secondary vegetation dynamics

In order to understand changes in the secondary vegetation dynamics between 2004 and 2014, we performed two complementary spatial-temporal analyses:

(i) Spatial-temporal analysis of secondary vegetation transitions - To uncover broad temporal trends we quantified and analyzed the overall changes in area for all different land-uses classes between 2004 and 2010, and 2010 and 2014. We used polygons and a spatial analysis tool to compute the geometric intersection of features from different spatial data sets.

(ii) Cluster analysis - To identify spatial-temporal clustering patterns of secondary vegetation and different land-uses we used the cluster technique Getis-Ord Gi*. The Getis-Ord Gi* allows the identification of cold spots and hotspots, corresponding respectively to clusters of cells with low and high values of a given attribute when compared to the whole study area. The local sum of a selected cell attribute and neighboring attributes (defined by a threshold distance) are compared proportionally to the sum of all features. If the local sum differs from the expected local sum, and this difference is too large to be the result of randomness, statistically significant Z-scores and confidence levels (Gi-Bin) are returned. When local sum is significantly lower than expected local sum, cold spots are detected, and when local sum is significantly higher than the expected local sum, hotspots are detected (GETIS;ORD, 1992; ORD; GETIS, 1995).Getis-Ord Gi* hotspot and cold spot detection was chosen because, in opposition to other clustering analysis: (1) the number of clusters is not defined beforehand, better fitting to our purpose of an exploratory analysis of secondary vegetation cover throughout time; and (2) all features in a given distance band are included instead of neighbor features only, which would eventually lead to spurious results especially when using short distance bands.

Getis-Ord Gi* was processed as follows (1) calculation of Moran´s Global index at different distances to identify the distance band where the clustering phenomenon was expected to be maximized (threshold distance) which in this paper refers to a window of 20,000 meters; (2) performing the analysis for each year using the identified threshold distance, and (3) elimination of clusters with p values < 0.05.

We identified and compared clusters using the following attributes (Table 2.1) in 2004, 2008, 2010, 2012, and 2014.

(i) Secondary vegetation - we compare hotspots and cold spots following two alternative perspectives of secondary vegetation (i) percentage of area secondary vegetation in each cell (SeVe), and (ii) percentage of area of secondary vegetation per total deforested area in each cell (SeVe/De). Section 3.2.1 presents the results of these analyses.

(ii) Land-uses - we perform an analysis of hotspots and cold spots of pastures (clean and dirty), regeneration with pasture, large-scale agriculture (mechanized agriculture and palm oil crops) and small-scale agricultural (swidden agriculture). Focus was given to an understanding of where and to which extent these clusters overlap with hotspots and cold spots of secondary vegetation in different periods of time.

Following the detection of clusters, we used the level of overlapping between clusters to explore the associations between hotspots and cold spots of secondary vegetation and of the different land-uses. For that, values of Gi_Bin (coefficient of confidence level) were returned to a new square grid with same cell size (10 km x 10 km) to allow a comparison between cells throughout the years. The level of overlapping was calculated as follows:

$$\frac{\textit{Number of cells of variable X in a given year + Number of cells of variable Y in a given year}}{\textit{Number of cells of variable X in a given year}} \times 100$$

2.3 Results

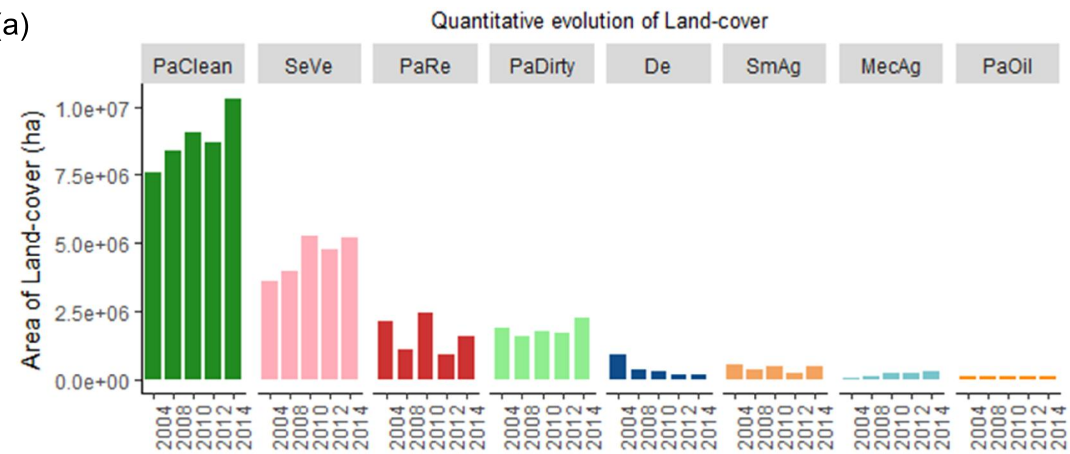
2.3.1 Spatial-temporal analysis of secondary vegetation transitions

Figure 2.2.a illustrates changes in all land-use classes analyzed between 2004 and 2014, and Figure 2.2.b shows the percentage of each class relative to the total land deforested until 2014. The most prevailing land-use classes were

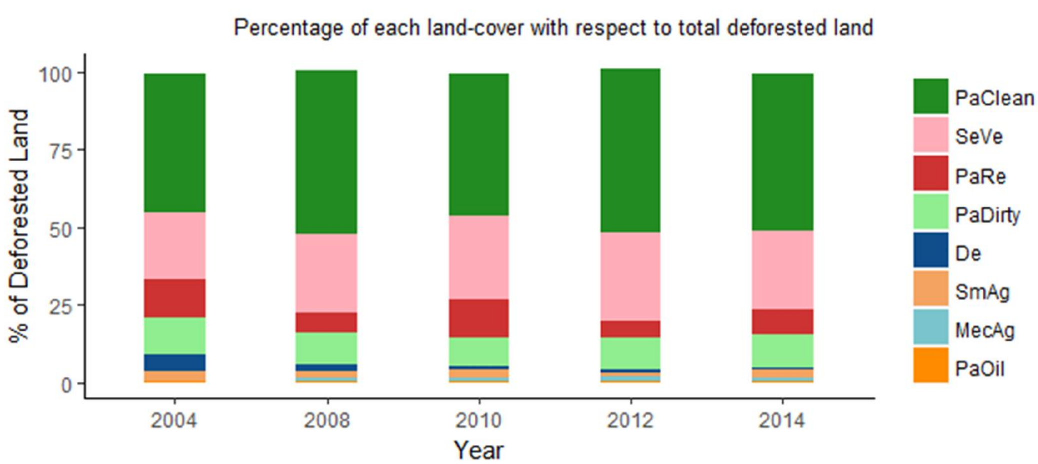
clean pastures (PaClean), and secondary vegetation (SeVe), being small-scale agriculture (SmAg), mechanized agriculture (MecAg) and palm oil (PaOil) the least representative. PaClean (16.5%), MecAg (259.7%), and PaOil (28%) were the only classes expanding in the period, while land-use classes related to forest regeneration i.e. SmAg (-29.4%) and PaRe (- 44.84%) had areas reduced. PaDirty exhibited no clear tendency for increases or decreases in area, and SeVe showed a slight decrease during the 2010 and 2014 (-2.8%).

Figure 2.2 - Quantitative evolution of different land-use classes between 2004 and 2014: (a) total area of each class; (b) percentage of total area of each class relative to the total land deforested until 2014.

(a)



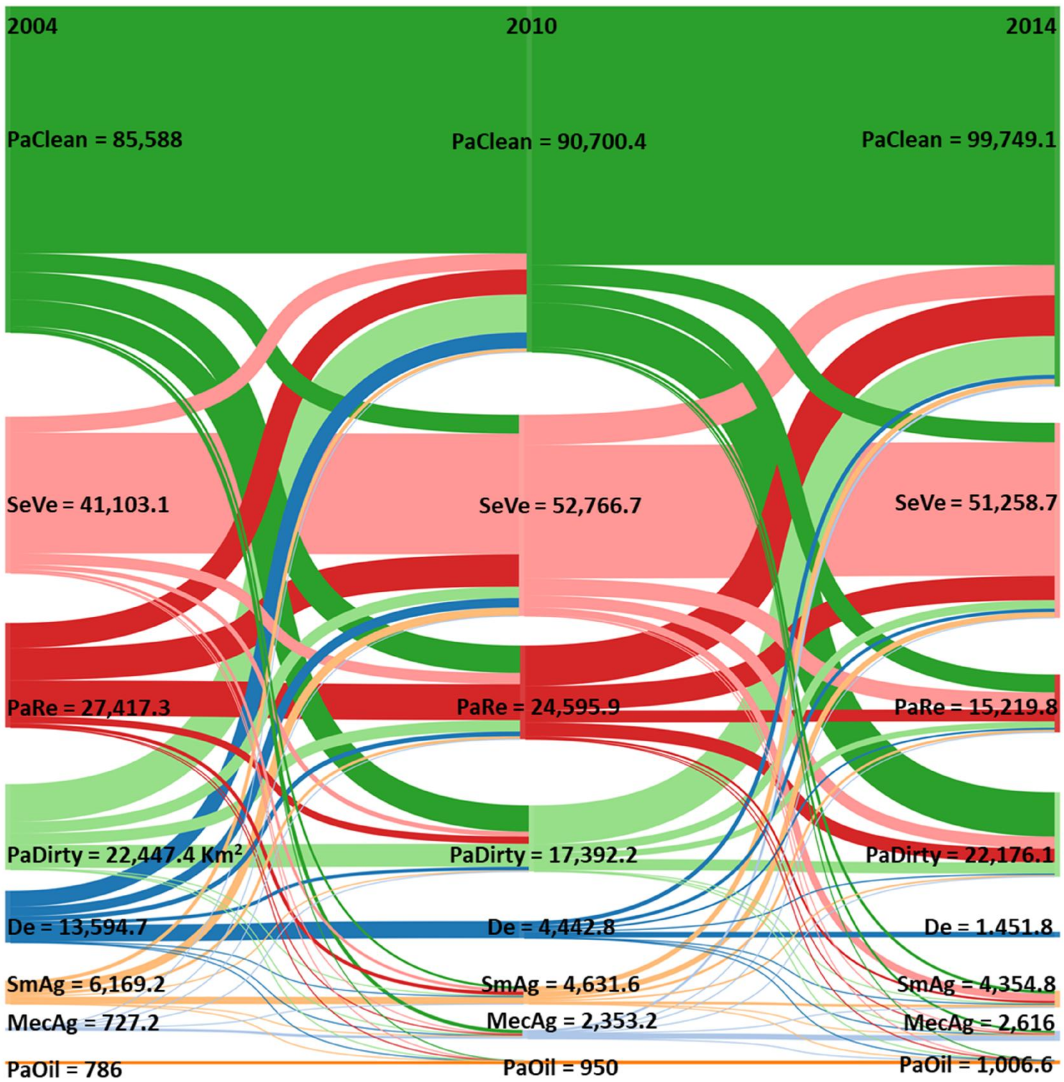
(b)



Clean pasture (PaClean), Secondary vegetation (SeVe), Pasture with regeneration (PaRe), Dirty pasture (PaDirty), Annual deforestation (De), Small-scale agriculture (SmAg), Mechanized agriculture (MecAg), Palm oil (PaOil).

In Figure 2.3 uncovers transitions between different land-uses in Pará between 2004 and 2014. The flows from SeVe to PaClean, MecAg, and PaOil, the only land-uses that expanded in the period, show that in face of increased pressure against deforestation, the re-conversion was the primary source of increases in area. On the other hand, the flows to SeVe indicate that more SmAg was converted into this cover (from 4.15% to 2.89%) before 2010. The same applies to flows from PaDirty (5.69% to 4.37%) and from PaRe (16% to 12.4%) to SeVe, showing that regeneration in areas of pastures was reduced over time. Reinforcing that, there are increases in observed flows from PaRe into PaClean (7.2% to 10.6%) after 2010.

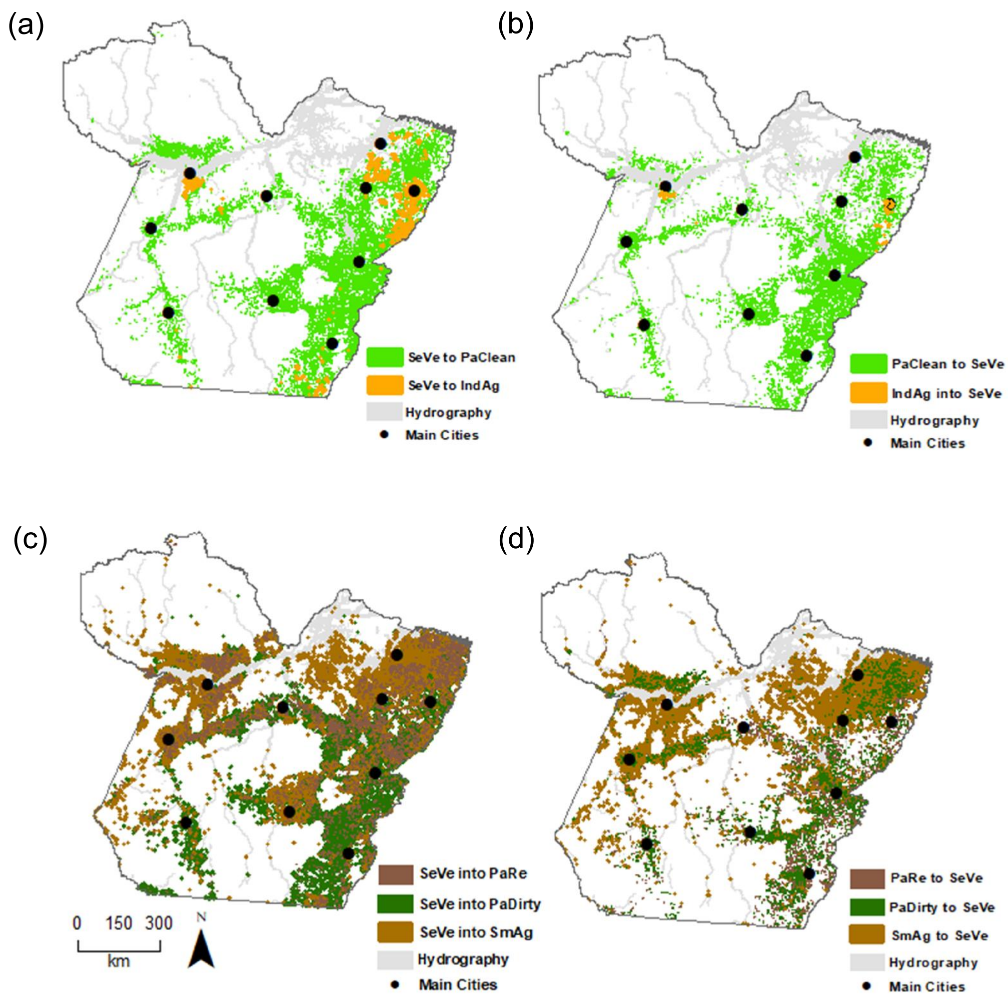
Figure 2.3 – Transitions between land-uses between 2004 and 2010, and 2010 and 2014 in km ^{2}.



Clean pasture (PaClean), Secondary vegetation (SeVe), Pasture with regeneration (PaRe), Dirty pasture (PaDirty), Annual deforestation (De), Small-scale agriculture (SmAg), Mechanized agriculture (MecAg), Palm oil (PaOil).

Figure 2.4 presents the spatial distribution of transitions between SeVe and different land-uses. Conversions from SeVe into pastures were widespread, while conversions into PaClean were particularly evident in the Southern region (Figure 2.4.c). Conversions from pastures into SeVe, on the other hand, were concentrated in the Northeast and Northwest, where PaDirty and PaRe were the primary classes transitioning to SeVe. Conversions from SeVe into and from different types of agriculture were mostly concentrated to the Northeast and Northwestern regions (Figure 2.4.c and 2.4.d), where SmAg was the primary source of conversion of agriculture into SeVe (Figure 2.4.d).

Figure 2.4 - Spatial distribution of transitions between 2004 and 2014 (a) Secondary vegetation into classes that expanded (PaClean - clean pasture; IndAg - mechanized agriculture and palm oil); (b) Classes that expanded into secondary vegetation; (c) Secondary vegetation into classes that were reduced in the period (SmAg – small-scale agriculture; PaDirty – pasture dirty; PaRe – regeneration with pasture; (d) Classes that were reduced into secondary vegetation.

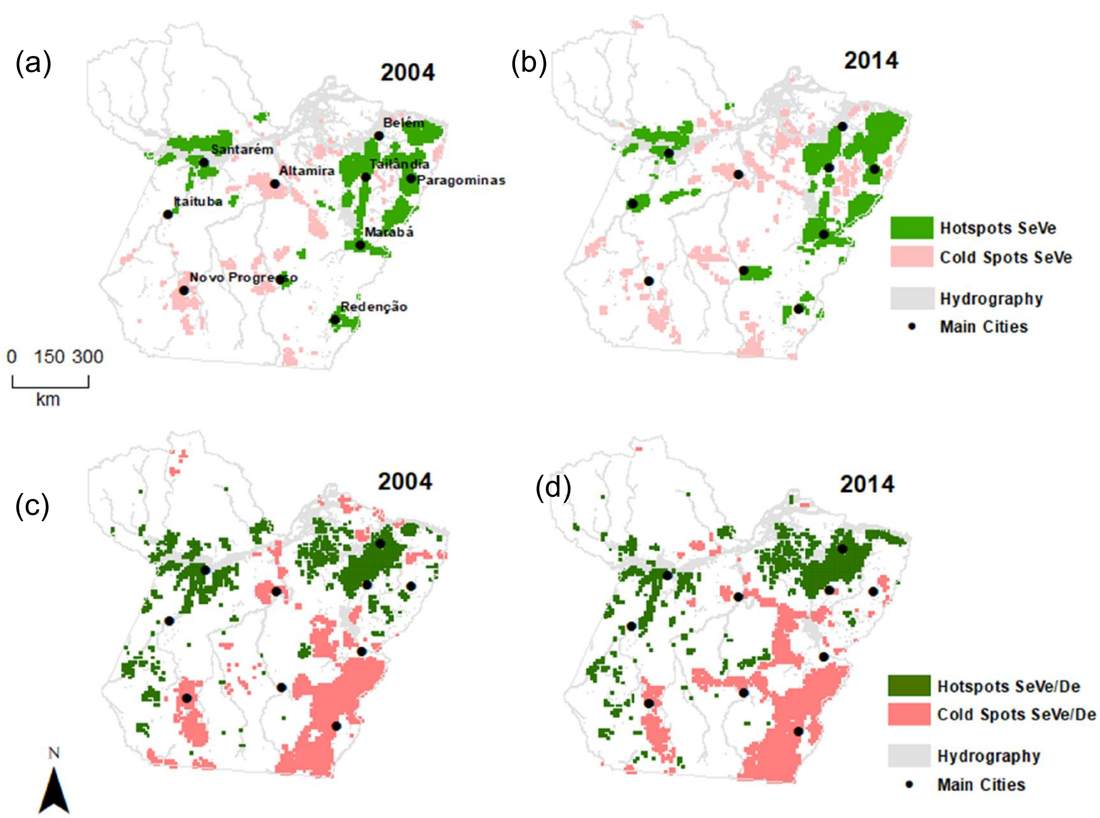


2.3.2 Cluster analysis

2.3.2.1 Clusters of secondary vegetation between 2004 and 2014

Figures 2.5.a and 2.5.b illustrate the hotspots and cold spots identified using total area of secondary vegetation in cells (SeVe) in 2004 and 2014, respectively. Figure 2.5.c and 2.5.d represent the hotspots and cold spots identified when using the attribute SeVe/De in 2004 and 2014, respectively. For Hotspots and cold spots identified between 2008 and 2012 see APPENDIX A.

Figure 2.5 - Clusters of secondary vegetation secondary vegetation (SeVe) in (a) 2004 (left) and (b) 2014 ; Clusters of secondary vegetation per deforested area (SeVe/De) in (c) 2004 and (d) 2014.



Hotspots of SeVe predominated in the Northern portion of Pará (Figures 2.5.a and 2.5.b), with cold spots more widespread. North/south differences in the distribution of hotspots and cold spots of SeVe are highlighted when the percentage of deforestation is considered (Figures2.5.c and 2.5.d). In this case, hotspots also prevailed in the northeast and northwest, and cold spots of SeVe/De markedly predominated in the southwest and southeast. Table 2.2 summarizes the temporal evolution of cold spots and hotspots´ area for both variables.

Table 2.2 – Quantitative evolution of cold spots and hotspots of secondary vegetation (2004 and 2014).

Year	Cluster	Variable			
		SeVe (ha)	Change(1)	SeVe/De(ha)	Change(1)
2004	Cold spots	71,300	NA	1,687,400	NA
2008		110,400	1.54	2,319,500	1.37
2010		123,200	1.11	2,408,500	1.0
2012		203,900	1.65	2,697,000	1.11
2014		174,300	0.85	2,118,700	0.78
2004	Hotspots	2,061,400	NA	6,934,500	NA
2008		2,691,400	1.30	8,549,300	1.23
2010		2,789,600	1.04	8,906,000	1.0
2012		2,917,900	1.04	9,380,600	1.0
2014		2,700,600	0.92	7,844,200	0.83
Change (2004/2014)	Cold spots		2.44		1.25
	Hotspots		1.31		1.13

NA - Not applicable

Results in Table 2.2 show that, from 2004 to 2014, while hotspots of SeVe 30% increase (1.3 times increase), the area of cold spots of SeVe more than doubled (2.4 times increase). For SeVe/De, differences between hotspots and cold spots were more restricted, but even so, the area occupied by cold spots increased1.26 times, more than that of hotspots which increased 1.13 times.

The quantitative evolution of hotspots and cold spots reinforce the reduction in SeVe cover shown by absolute values (Figure 2.2.a), as a result of their conversion into other land-uses (Figure 2.3). Also noticeable is that hotspots of SeVe and SeVe/De prevailed in the Northeast and Northwest of Pará, the same regions where transitions into SeVe predominantly took place (Figure 2.4.c).

2.3.3 Clusters of secondary vegetation and other land-uses between 2004 and 2014.

2.3.3.1 Secondary vegetation and pastures: clean (PaClean), dirty (PaDirty) and regeneration with pasture (PaRe)

Figure 2.6 illustrates hotspots and cold spots of different classes of pasture detected using percentage of each class in relation to the deforested area in cells, superimposed over hotspots and cold spots of secondary vegetation shown in the previous section.

Hotspots of PaClean/De are clearly discernible in the south, overlapping cold spots of SeVe/De (Figures 2.6.a and 2.6.b). Throughout time, the identified pattern for these hotspots was similar, although, by the end of the decade, they were larger and more concentrated around Novo Progresso, São Félix do Xingu and Redenção. On the other hand, cold spots of PaClean/De are seen overlapping hotspots of SeVe/De in the northwest and northeast, in an inverse relation with hotspots.

PaDirty/De hotspots and cold spots show the same pattern identified for PaClean/De, with cold spots in the north, overlapping hotspots of SeVe/De, and hotspots in the south, overlapping cold spots of SeVe/De. Especially towards the end of the analyzed period cold spots in the northeast, near Tailândia and Paragominas, and hotspots near Marabá are larger (Figures 2.6.c and 2.6.d). For PaRe/De, no clear pattern was identified although by the end of the decade, a more prominent concentration of hotspots is seen in the northeast (Figures 2.6.e and 2.6.f).

Overlapping between hotspots of PaClean/De and PaDirty/De with cold spots of SeVe/De ranged from 40% (in 2004) and 74% (in all other years). Overlapping of cold spots of PaClean/De and PaDirty/De with hotspots of SeVe/De was also high, ranging from 51% (in 2004) and 66% (in 2012). Given that PaRe/De clusters were smaller and more widespread; overlapping between these clusters and clusters of SeVe/De was always less than 40% regardless of the year. Table 2.3 summarizes the quantitative evolution of the area detected as cold spots and hotspots of classes of pastures in different time intervals.

Figure 2.6 - Clusters of pasture superimposed over clusters of secondary vegetation in 2004 (on the left) and 2014 (on the right). Clean pasture (PaClean/De) in (a) 2004 and (b) 2014; Dirty pasture (PaDirty/De) in (c) 2004 and (d) 2014; and Regeneration with pasture (PaRe/De) in (e) 2004 and (f) 2014.

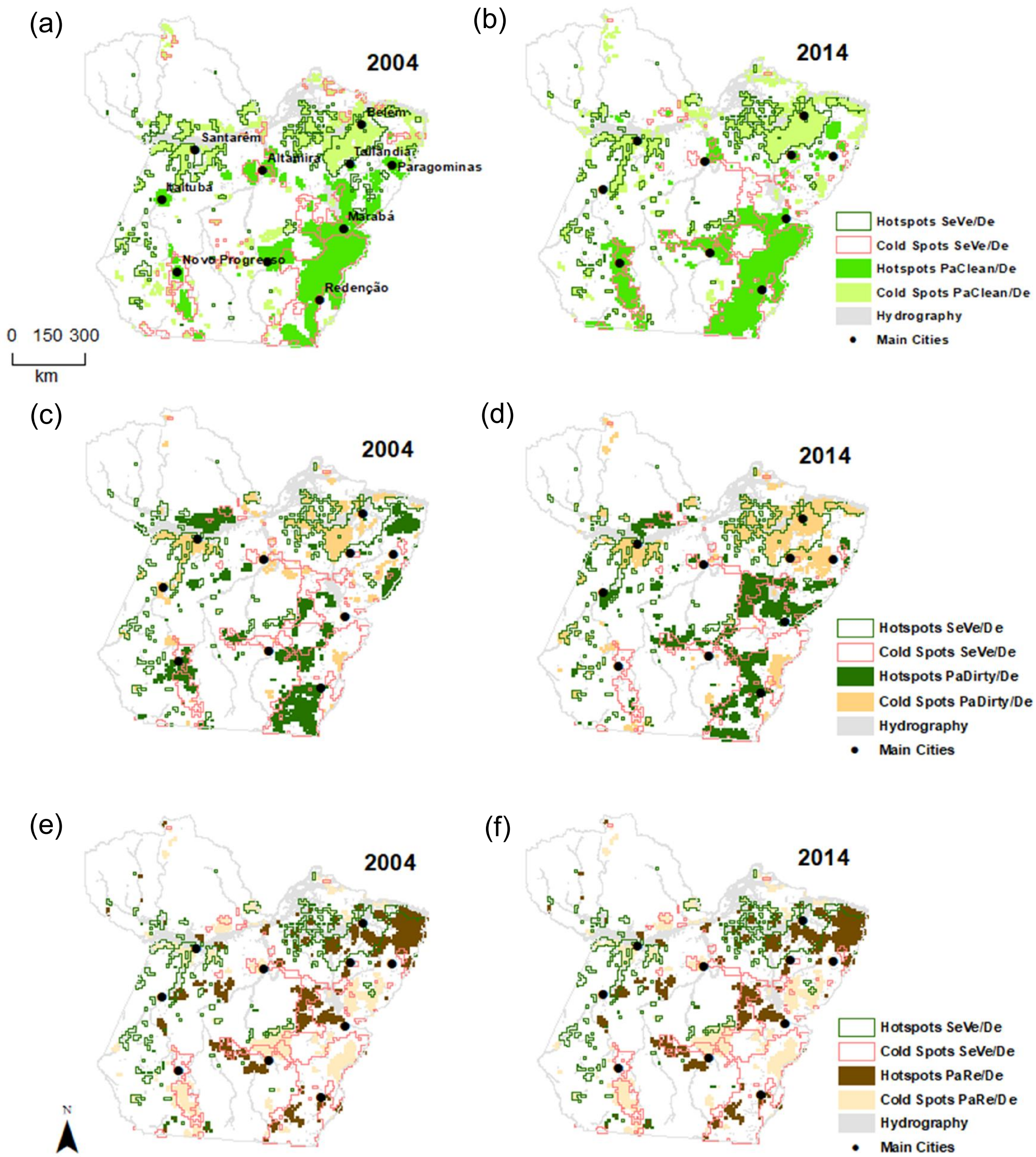


Table 2.3 – Quantitative evolution of cold spots and hotspots of pasture (2004 and 2014).

Year	Cluster	Variable					
		PaClean/De (ha)	Change(1)	PaDirty/De (ha)	Change(1)	PaRe/De (ha)	Change(1)
2004	Cold spots	543,000	NA	55,500	NA	143,200	NA
2008		720,600	1.32	74,300	1.33	23,876	0.16
2010		693,700	0.96	40,000	0.53	159,521	6.68
2012		848,400	1.22	56,400	1.41	5,175	0.03
2014		992,100	1.16	127,800	2.26	55,888	10.79
2004	Hotspots	8,959,600	NA	2,457,200	NA	2,604,800	NA
2008		10,716,200	1.19	2,341,000	0.95	2,133,200	0.81
2010		11,504,000	1.07	2,028,700	0.86	3,135,700	1.35
2012		12,018,400	1.04	2,054,300	1.01	1,327,157	0.42
2014		10,916,300	0.90	2,248,800	1.09	1,955,069	1.47
Change (2004/2014)	Cold spots		1.22		0.92		0.75
	Hotspots		1.83		2.30		0.38

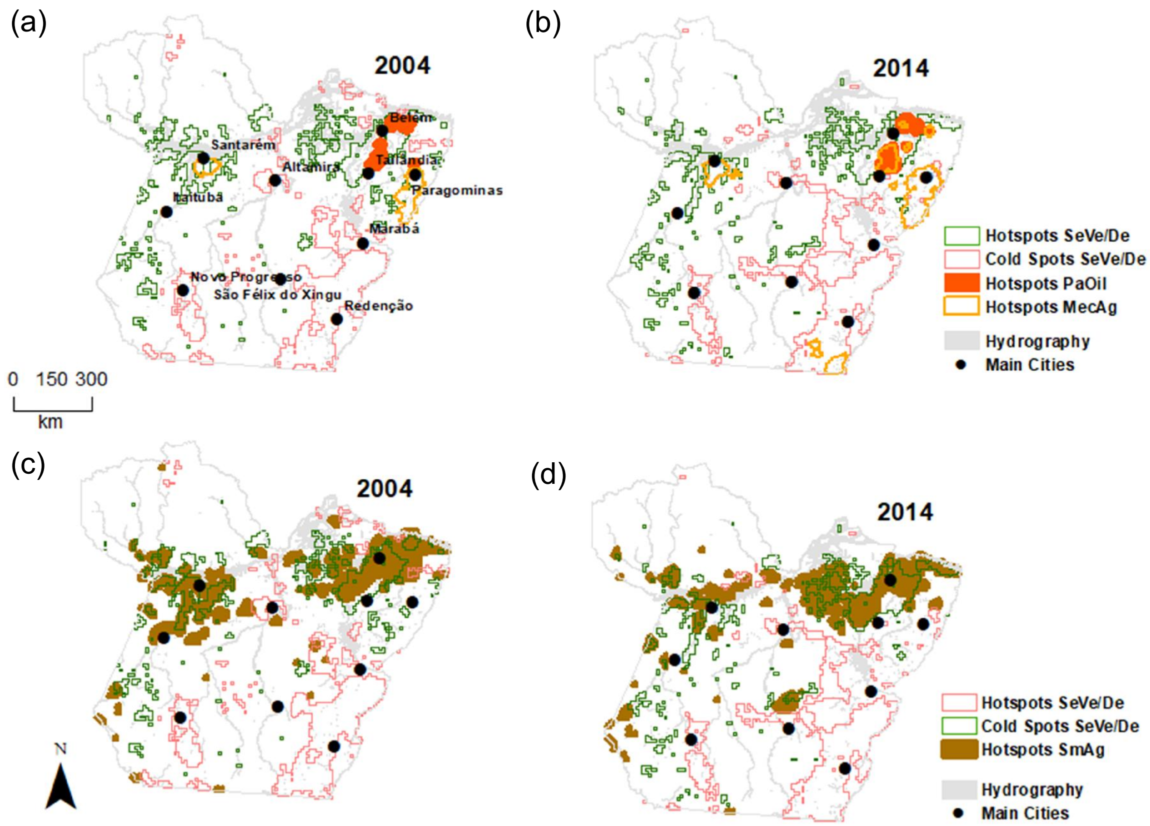
(1) Changes in area with respect to the previous period. NA - Not applicable

Throughout the decade, changes in the size of hotspots and cold spots of the different classes of pasture were variable, with clear trends being seen only for hotspots of PaClean/De that decreased over time (1.19-0.90), and for hotspots of PaDirty/De that increased in the same period (0.95-1.09). Variations in the size of clusters of pastures are in agreement with absolute values previously shown (Figure 2.a) which indicated that, in particular for PaDirty, changes in area were dynamic. It is noticeable that, although absolute values showed increases in PaClean, decreasing rates of change in the size of hotspots indicate that pasture expansion decelerated, possibly because, as seen in transitions in the period, increases in this cover were mostly the result of re-conversion of other land-uses instead of its expansion over newly deforested lands (Figure 2.3).

2.3.3.2 Secondary vegetation and agriculture: mechanized agriculture (MecAg), palm oil (PaOil) and small-scale agriculture (SmAg).

Figure 2.7 illustrates hotspots of different classes of agriculture detected using percentages of each class in relation to the deforested area in cells.

Figure 2.7 - Clusters of secondary vegetation and agriculture in 2004 and 2014. (a) and (b) Hotspots of industrial agriculture i.e. mechanized agriculture (MecAg/De) and palm oil (PaOil/De); (c) and (d) Hotspots of small-scale agriculture (SmAg/De).



Hotspots of MecAg/De were detected in the Northeast, Northwest and Southern regions of Pará (in 2014), and hotspots of PaOil/De were detected in the northeast (Figures 2.7a and 2.7b). In all years, hotspots of SmAg/De were detected in the Northeast and Northwest Pará, and southeast in 2014 (Figures

2.7.c and 2.7.d). Given that both small-scale and industrial agriculture are land-uses concentrated to specific regions of Pará, no cold spots were detected. Table 2.4 summarizes the quantitative evolution of the area detected as hotspots of mechanized agriculture, palm oil, and small-scale agriculture.

Table 2.4 – Quantitative evolution of hotspots of mechanized agriculture (MecAg/De), palm oil (PaOil/De) and small-scale agriculture (SmAg/De) (2004 and 2014).

Year	Cluster	Variable					
		MecAg/De	Change(1)	PaOil/De	Change(1)	SmAg/De	Change(1)
2004	Hotspots	104,000	NA	299,700	NA	1,752,700	NA
2008		362,800	3.48	309,100	1.03	2,030,000	1.15
2010		541,200	1.49	380,300	1.23	1,526,500	0.75
2012		600,400	1.10	397,300	1.04	1,002,000	0.65
2014		594,400	0.99	406,300	1.02	1,375,100	1.37
Change (2004/2014)	Cold spots		-		-		-
	Hotspots		5.71		1.35		0.78

(1) Changes in area with respect to the previous period.
NA - Not applicable

The quantitative evolution of clusters shows that both MecAg/De and PaOil/De hotspots increased throughout the decade, although increases in hotspots of MecAg/De were higher (5.71 times) in comparison to hotspots of PaOil/De (1.35 times). For hotspots of SmAg/De, on the contrary, in spite of a considerable variation, rates of change agree with absolute figures that showed a decrease over time.

Overlapping between hotspots of SeVe/De and industrial agriculture ranged from 35% (for MecAg/De) to 94% (for PaOil/De), being identified in all regions where these land-uses are found, except for a hotspot in the southeast near Paragominas (Figures 2.7.a to 2.7.d). Overlapping between hotspots of SmAg/De and hotspots of SeVe/De was mainly identified in the Northwest and Northeastern of Pará, ranging from 32% (in 2004) to 64% (in 2008).

The quantitative evolution of clusters of agriculture are in agreement with absolute figures previously shown (Figure 2.3), and while industrial agriculture expanded, the area under small-scale agriculture tended to decrease over time, being such losses the result from their conversion into different land-uses, as indicated by spatial-temporal transitions (Figure 2.3).

2.4 Discussion

After a peak in deforestation rates in 2004, legal and alternative coercive measures started to be reinforced In the Brazilian Amazon what reduced pressure of industrial agriculture and pastures over primary forests, as shown by the progressive decrease in deforestation rates in this period (ARIMA et al., 2014; DALLA-NORA et al., 2014; GIBBS et al., 2015; RUDDORFF et al., 2011; 2012). Reduced deforestation, together with the expansion of pastures and industrial agriculture indicate that somehow dynamics in already deforested lands had changed to accommodate the continuous expansion of such land-uses. As our results show, particularly after 2010, this new dynamics implied in that more secondary vegetation was re-converted into pastures and industrial agriculture. Small-scale agriculture, dirty and under regeneration pastures proved to be also relevant to increase the area occupied by land-uses that expanded, while pastures were, on the other hand, an important driver of changes in secondary vegetation cover, not only due to the expansion of clean pastures over these areas in the south, but also as a result of conversion of regeneration with pasture into secondary vegetation in the north.

The spatial distribution of hotspots and cold spots indicated that high values of secondary vegetation were concentrated in the Northeast and Northwest of Pará, regions characterized by a longer history of occupation, and where deforestation intensity is low. On the contrary, particularly when deforestation was used in the analysis, a concentration of low values was detected in the southeast and southwest, more recently occupied regions, where deforestation is still intense, or has just been reduced. These north-south differences are in agreement with previous investigations showing similar patterns for secondary vegetation in the Brazilian Amazon (MELLO; ALVES, 2011; PERZ; SKOLE, 2003). For instance, less forest regeneration was found on active frontiers of deforestation and occupation (3%), while regions with a longer history of occupation had more forest regeneration (25% of regrowth) (PERZ; SKOLE, 2003). Similarly, in Rondônia, Alves et al. (2003) found an increase in deforestation and concurrent decline of secondary vegetation, a pattern that the authors suggested was related to land-use intensification that precluded land abandonment and reduced forest regeneration. Almeida et al. (2010), estimating secondary vegetation cover for the Brazilian Amazon, showed that increases in deforestation were also related to reduced secondary vegetation.

North-south differences in the spatial distribution of hotspots and cold spots of secondary vegetation in Pará found in this work must however be also understood as an outcome of the dynamics of prevailing land-uses, in particular, those that progressively expanded during the last decade. In Northwest and Northeast Pará hotspots of secondary vegetation not only coincided with regions with less deforestation and a longer history of occupation, but also with a prevalence of small-scale agriculture (swidden agriculture), and of dirty and under regeneration pastures. Moreover, transitions and overlapping of hotspots in these regions showed that these classes were the main being converted to secondary vegetation. In this regard, prevalence of small properties and nature-friendly landscapes are the factors which explain more regeneration and persistence of secondary vegetation in regions where small-scale agriculture prevails. In the Brazilian Amazon, the predominance of small properties (<100 ha) was found to be related to lower rates of deforestation (<15% of deforestation), while forest conversion was higher in regions dominated by large-scale land-uses (> 1,000 ha) (AGUIAR et al., 2007; PACHECO, 2009). In addition, as a general rule, smallholders tend to diversify land-use strategies, integrating different productive activities with primary and secondary forests, configuring nature-friendly landscapes (COOMES et al., 2000; KLEMICK, 2011; MEYFROIDT; LAMBIN, 2010; PRATES-CLARK et al., 2009; SMITH et al., 1999; 2003). In the Peruvian Amazon, Coomes et al. (2000) found that in small properties (< 45.21 ha), half of the lands were occupied by fallow forests, aging from 1 to 9 years which were differently managed, according to previously cultivated crops, and labor, capital ad land availability. In the Bragantina region, Northeast of Pará, Smith et al. (2003) attributed the persistence of secondary vegetation to the fact the landholders had diversified income sources i.e. annual crops non-farm income, perennials and secondary forest products.

Secondary vegetation and pasture dynamics have been shown to be intertwined, and as a result of specific local conditions (e.g. technical, market and infrastructure), differences in cattle ranching strategies had opposite effects when north and south are compared (BOWMAN, et al., 2012, PACHECO; POCCARD-CHAPUIS, 2012). With respect to conversions from secondary vegetation into clean pastures, these were discernible in the south, in contrast to the north, particularly the Northeast that, on the contrary, concentrated transitions from dirty and under regeneration pastures into secondary vegetation. In addition, overlapping between hotspots of clean pastures and cold spots of secondary vegetation were detected in the south, while the opposite pattern i.e. overlapping between cold spots of clean pasture and hotspots of secondary vegetation was detected in the north. While the Northeast and Northwest Pará are regions dominated by small properties where diversified land-use strategies might eventually include small to medium scale herds, the Southwest, and the Southeast in particular are, in contrast, characterized by large-scale cattle ranching properties and large herds where more intensive pastures management should be expected, especially considering that most industrial slaughterhouses operating in Pará are concentrated in this region (PACHECO, 2009; PACHECO; POCCARD-CHAPUIS, 2012). Therefore, conditions such as larger stocks of primary forest, smaller herds and less intensive pasture management favored the prevalence of large secondary vegetation areas in the north, while less forested surroundings, frequent use of fire, bulldozing, and larger herds reduced or even preclude forest regeneration in the south (CHAZDON, 2012; MESQUITA et al. 2001).

Different authors have already reinforced the fact that secondary vegetation cover is heterogeneous both in space and time, particularly as a result of distinct trajectories of land-use (AGUIAR et al., 2016; ALMEIDA, 2009; ALMEIDA et al., 2010; PERZ; SKOLE, 2003). Our results show that, following increased pressure of law enforcement to halt deforestation, expansion of clean pastures and industrial agriculture was mostly the result of changes in the dynamics in previously cleared lands which involved a reduction in secondary vegetation but also affected other land-uses, especially small-scale agriculture and dirty and regeneration with pasture. Although evidence of the intertwined dynamics of secondary vegetation and pastures is new, previous studies have approached the ongoing process of secondary vegetation re-conversion into industrial agriculture in Pará (PEREIRA; VIEIRA, 2001; VIEIRA et al., 2014). In this context, the observed losses of secondary vegetation, the overlapping of secondary vegetation hotspots with hotspots of mechanized agriculture and palm oil crops, and the spatial distribution of transitions from secondary vegetation into these land-uses indicate that, in a near future, the identified pattern of concentration of high values of secondary vegetation in Northwest and Northeast Pará may change as the expansion of industrial agriculture land-uses is eventually favored by market and infrastructure conditions.

2.5 Concluding remarks

Following increased law enforcement to halt deforestation in the Brazilian Amazon areas in process of regeneration were progressively converted to clean pastures, mechanized agriculture and palm oil in Para. As a most pervasive land-use in the Brazilian Amazon, cattle ranching was particularly important, either because of re-conversion of secondary vegetation and pastures under regeneration into clean pastures in the south, or through the progressive incorporation of dirty and under regeneration pastures into secondary vegetation in the north.

The prevalence of clusters of high values of dirty pasture, regeneration and secondary vegetation in the north indicate that pressure of herds has been lower, and management of pastures less intense in comparison to the south, where a concentration of industrial slaughterhouses and larger herds suggest more intensive pasture management is taking place. Therefore, although North/South differences in the spatial distribution of clusters of low and high values of secondary vegetation can be explained by the distinct histories of occupation and deforestation frontiers, differences in clustering patterns of distinct land-uses were also important in explaining North/South differences.

3 CATTLE RANCHING AFTER LAW ENFORCEMENT AGAINST DEFORESTATION: ACTORS, SYSTEMS AND POTENTIAL IMPACTS ON SECONDARY VEGETATION

3.1 Introduction

Roughly 62.1% of all deforested land in the Brazilian Amazon is covered with pasture, making cattle ranching the most pervasive land-use system in this region (LAPOLA et al 2014; BOWMAN et al, 2012; WALKER et al., 2009a;ARIMA et al 2005). Housing around 30% of Brazilian herds, the Brazilian Amazon concentrated 83% of the expansion of herds in Brazil, during the last two decades (BOWMAN et al. 2012, IBGE, 2018). As a result of this rapid and aggressive conversion of forests into pastures, between 2003 and 2004, deforestation rates reached alarming 27.7 km^2, which forced the Brazilian Government to conceive and implement several command and control measures (GIBBS et al, 2015; BORNER et al. 2015; 2014; ARIMA et al., 2014; DALLA-NORA et al 2014; LAPOLA et al. 2013; PACHECO; POCCARD-CHAPUIS, 2012; RUDEL et al. 2009; GOLNOW; LAKES, 2014). Legal measures such as embargo of properties due to deforestation and mandatory registration of properties in the Rural Properties Environmental System (CAR) were imposed over the beef production chain, and major slaughterhouses were obliged to suspend non-qualified supplying properties (PACHECO; POCCARD-CHAPUIS, 2012; BORNER et al., 2014; 2015; GIBBS et al., 2015). Despite these measures, cattle herds and pastures continued to expand, with a temporal decoupling between deforestation and cattle expansion being detected in specific regions, suggesting that expansion over previously cleared lands and/or gains in productivity took place (MACEDO et al., 2012; RUDDORF et al., 2011, 2012; GOLNOW; LAKES, 2014). Therefore, command and control measures, together with other incentives, are believed to have stimulated the recovery of degraded pastures or a transition to more intensive systems (PACHECO; POCCARD-CHAPUIS, 2012; GOLNOW; LAKES, 2014).

Although no characterization of actors or classification of systems can be found regarding cattle ranching operations in the Brazilian Amazon, the size of holdings is frequently used to distinguish both actors and systems (WALKER et al., 2000, CAVIGLIA-HARRIS, 2005, SANTOS et al., 1999). In this respect, Walker et al. (2000), classify actors as "*fazendeiros*" (landholdings > 1,000 ha) or small producers (<100 ha), mentioning differences in wealth positions and cultural backgrounds as explanations behind decisions to adopt cattle ranching. Santos et al (1999) also distinguish actors as small and large-holders, emphasizing their differences with respect to the adoption of practices and techniques in pasture and herds´ management. In small properties, the cow-calf stage predominates, while large-scale operations focus mostly the full-cycle or fattening (finishing) (BOWMAN et al., 2012; CAVIGLIA-HARRIS, 2005; MERRY et al., 2004; SANTOS et al., 1999; POCCARD-CHAPUIS, 2004).

Regardless the system adopted, cattle ranching is predominantly a large-scale land-use based on low productivity pastures and reduced use of agricultural inputs, with less than 3% of herds being finished under intensive and high productivity systems (Associação Brasileira das Indústrias Exportadoras de Carne, 2011; CEZAR et al, 2005; ESCADA et al., 2005; MERRY; SOARES-FILHO, 2017). Supposedly, as a result of increased solar radiation, temperature and favorable rain regimes, productivity of pastures in the Amazon were to be higher, however less than 40% of grazing areas present a stocking rate of around 0.5 herds per hectare, while in less than 20%, stocking rates are above 1.38 herds per hectare (ARIMA et al., 2005; BARROS et al., 2002; WALKER, 2009a). In this respect, low stocking rates are largely related to pasture degradation that affects 50% of grazing areas with primary causes being inappropriate establishment and management of pastures, excessive stocking rates, soil compaction and low fertility, together with low levels of technification and technical assistance (ARIMA et al., 2005; BARROS et al., 2002; DIAS-FILHO, 2011; DIAS-FILHO; FERREIRA, 2006).

With respect to secondary vegetation, land management practices and techniques affect this cover which, in general terms, represents the outcome of three basic decisions: incorporation in a land-use system, abandonment or intensification (COSTA, 2004; 2009; PRATES-CLARK et al., 2009; MESQUITA et al. 2001; 2015). While in swidden agriculture systems, for instance, secondary vegetation cover represents a strategy to recover soil fertility, eventually being a source of forest and non-forest products, in large-scale cattle ranching systems it is a by-product of inadequately established and poor managed pastures (COSTA, 2004; 2009; NEPSTAD et al., 1996; MESQUITA et al., 2001; 2015; UHL et al., 1988). Historically, expansion of cattle ranching in the Brazilian Amazon involved clearing forests, implementing pastures and their abandonment to regrowth as a result of degradation, a dynamics that made cattle ranching one of the primary drivers of secondary vegetation cover in the Brazilian Amazon (COSTA, 2004; 2009; DIAS-FILHO, 2011; 2013). However, more recently, especially where market connections privilege major industrial slaughterhouses, increased law enforcement against deforestation had the potential to change this dynamic. This is corroborated by estimates of secondary vegetation cover: in the early 2000´s, from 140,000 km^2 to 161,000 km^2 of secondary vegetation covered already deforested lands, but after 2012 only 1,197 km^2 additional secondary vegetation was generated, with at least 42,040 km^2 of this cover being re-converted into other land-covers, particularly pastures (28,488 km^2) and mechanized agriculture (1,884 km^2) (ADAMI et al., 2015; CARREIRAS et al. 2006; LUCAS et al., 2000; NEEF et al., 2006).

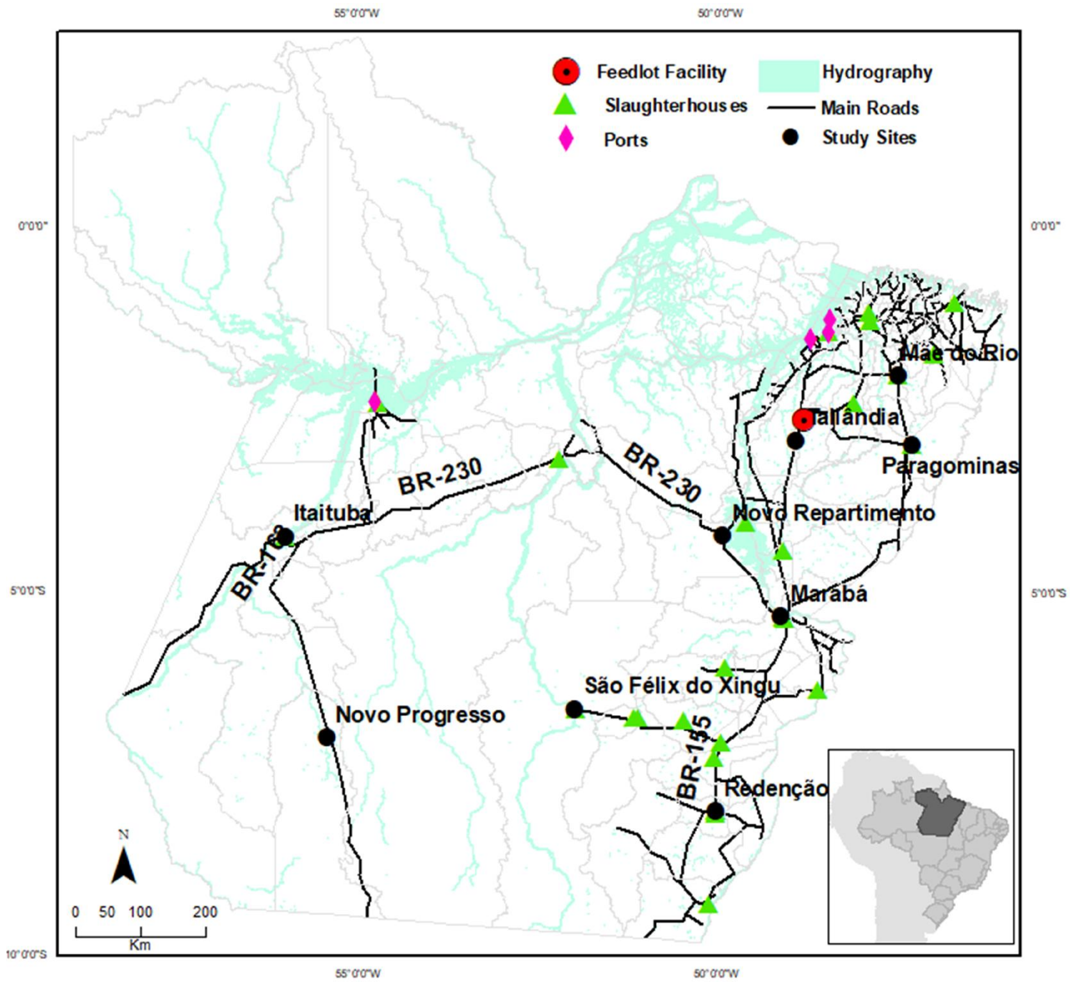
In this chapter, our primary focus was then to investigate how increased law enforcement against deforestation could have worked as a stimulus for actors in cattle ranching systems to change practices and techniques in pasture management to preclude degradation or recover already degraded pastures, thus impacting secondary vegetation dynamics. We focus on Pará, because besides concentrating the fifth largest herd in Brazil, it is also a hotspot of deforestation. As a consequence, Pará has been strongly targeted by law enforcement measures to halt deforestation which, since 2004, and more strongly since 2009, have put the beef production chain under scrutiny. In this context, our main objectives were (i) characterize actors involved with cattle ranching operations, (ii) classify cattle ranching systems with respect to practices and techniques of pasture management, and (iii) discuss how eventual changes impacted secondary vegetation dynamics. To achieve our purposes, we relied on field work and discourse analysis methods, structuring our work as follows: the second section presents an overview of the study area, bringing a historical analysis of the unfolding dynamics of cattle ranching in Pará, followed by a description of methods applied in this research. In the third section, we characterize actors, and present cattle ranching systems. At the end of this section we also summarize the potential impacts of these practices and techniques over secondary vegetation, considering the accumulated knowledge on its dynamics. Finally, in the last section we discuss our findings with respect to the regional dynamics of secondary vegetation in Pará.

3.2 Methods and study area

3.2.1 Study area: land-uses and cattle ranching in Pará

With 1.24 million km^2, the second largest State in the Brazilian Amazon, Pará has experienced rapid changes in land-use and land cover in the past three decades (Figure 3.1). In this period, low land prices together with improved access to markets following the implementation of roads, ports and slaughterhouses stimulated the expansion of cattle. In 2014, for instance, pastures covered around 14.6 million ha or 11.7% of the State; by the same token during last 15 years herds doubled from 10.2 million to 20.2 million heads (WALKER et al, 2009b, BOWMAN et al., 2012; ALMEIDA et al., 2016). Notwithstanding, due to intra-regional diverse historical contexts and connectivity to other Brazilian regions, different processes coexist in space and time (BECKER et al., 2005, 1989. AGUIAR et al., 2007).

Figure 3.1 - Study area showing infrastructure network and study sites chosen for field work.



In Northeast Pará, cattle ranching expanded between the end of the 60s and beginning of the 70s connected to timber extraction along BR-010 and PA-150, connecting northeast and southeastern regions. Emerging as a secondary activity and as strategy to consolidate occupation in already cleared lands, cattle ranching was a driver of violent conflicts involving large landholders and settlers, particularly during the 80s and 90s, which after expropriation and declaration of official settlements, have diminished or completely ceased. The Arch of Fire operation launched on February 2008 is viewed as a turning point for the activity because, following the collapse of the timber businesses, financial resources for cattle ranching were reduced, and operations were restricted to a few properties or completely ceased in others, leading to the abandonment of lands, which were soon occupied by palm oil, and more recently by mechanized agriculture.

In southeast Pará, following inauguration of BR-010 in 1959, cattle ranching expanded initially to the south, by the end of the 60s, and later to the west, by the beginning of the 80s. Expansion to the south was particularly led by actors in traditional cattle ranching and private companies, giving birth to a “culture of cattle” that made of south Pará one of the most important cattle ranching regions in the Brazilian Amazon. Concomitantly to large-scale operations, Brazilian nuts collection and swidden agriculture were important economic activities until mid-80s but the expansion of pastures over native Brazil nuts populations (“castanhais”) and difficulties experienced by smallholders to trade perishable products stimulated small scale cattle ranching operations.

Until the beginning of the 80s, the primary economic activities in the western portion of the Southeastern region were gold and cassiterite mining, timber and “jaborandi” leaves (*Pilocarpus jaborandi*) extraction. After becoming connected to the rest of the southeast, migrants with farming background from South, Southeast and Center Brazil started acquiring lands to establish cattle ranches, while Northeast migrants brought the labor force to support its expansion. Timber companies also invested in planting pastures which were implemented after burning, sowing seeds by plane in areas already cleared by timber extraction. After timber business collapsed, by the mid-90s, cattle ranching became the primary economic activity in large and small properties.

The BR-230 inauguration was also an important vector for cattle ranching expansion to the west of the Southeastern region and to Southwest Pará as well. To the west of the Southeast Pará, as migrants initially involved with Brazil Nuts extraction and swidden agriculture, particularly rice crops, progressively exhausted lands which were then converted from swidden agriculture into pasture. The decline of rice crops cultivation was followed by other unsuccessful initiatives of fruit crops cultivation (e.g. passion fruit and coffee beans), but high debts of smallholders stimulated cattle ranching expansion in these smallholdings. Despite some smallholders were able to expand properties and increase herds, main actors in medium and large-scale operations are individual entrepreneurs with diversified background (i.e. local businessmen, public officers, and migrants from other regions) or migrants from mining and timber extraction operations.

Along BR-163, the rapid expansion of timber extraction and a boom of mining, from the 1970s until the 90s, provided the financial resources to implement large ranches. Migrants with farming background coming from southern Brazil initially focused agriculture, but as happened along the BR-230, dirt roads also precluded trading. Hence, these actors adopted cattle ranching as their primary productive activity stimulated by the demand for food in gold mining camps. Increasingly profitable, cattle ranching expanded to medium and large properties as a result of actors´ abilities to acquire and accumulate land. Following improvements in BR-163, southwestern Pará became connected to Mato Grosso, which was determinant not only to secure a cattle market but also to improve genetics of herds.

3.2.2 Research design

3.2.2.1 Process of investigation

From August through December 2016, nine study sites located in the Northeast, Southeast and Southwestern regions[3] of Pará were visited (Figure 3.2). These regions were chosen to maximize data collection and cover the heterogeneity of operations and actors in lowlands cattle ranching. Sites were defined based on (i) dynamics of herds between 2000 and 2015 which are represented by a ratio that gives a dimension of the quantitative evolution of herds, and (ii) insertion in

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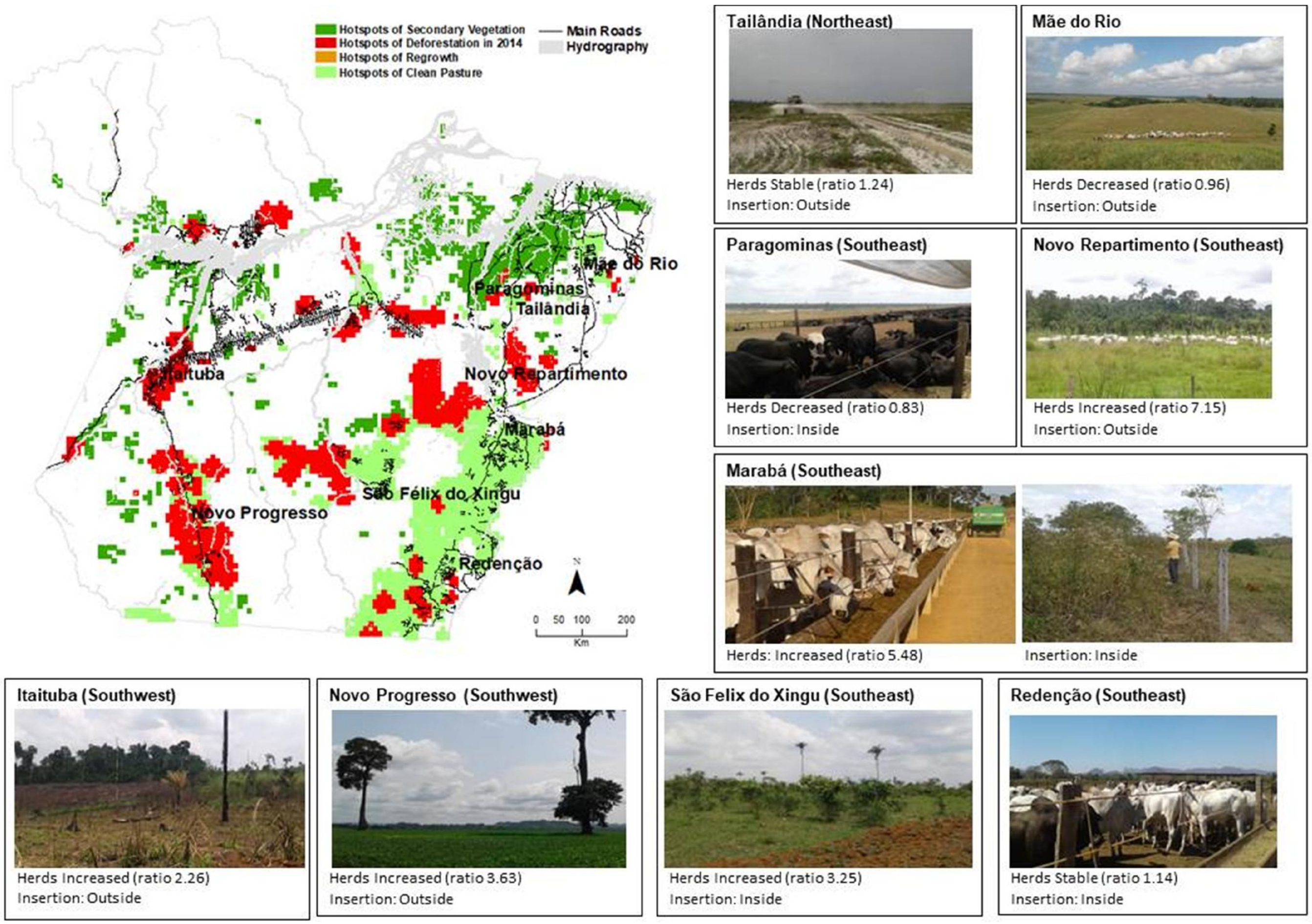
[3] Belém Metropolitan region, the Marajo Island region and the Lower Amazon river region were excluded from our fieldwork investigation. The metropolitan region of Belém, with a high level of urbanization presents different land-use dynamics in which cattle plays a restricted role. In the Marajo Island and the Lower Amazon river cattle ranching is largely developed following tidal influence and exploitation of fertile periodic flooded areas configure a completely different dynamics in comparison with lowland areas. In addition, infrastructure and settlement policies of occupation in place since the 60s in lowland areas differ from those implemented in these regions.

the network of industrial slaughterhouses. The dynamics of herds was determined based on the PPM (Monthly Cattle Inventory) data from IBGE. Insertion in the industrial slaughterhouses network was based in a database covering purchasing operations traceability data from three major industrial slaughterhouses operating in the Brazilian Amazon since 2013. Figure3.2 brings these data for each study site.

Figure 3.2 - Study sites, hotspots of deforestation, secondary vegetation, and clean pastures in 2014. Itaituba: Degraded pasture; Novo Progresso: Pasture under renovation using mechanized agriculture (soybeans); São Félix do Xingú: pasture under renovation; Redenção: Semi-confinement; Marabá: Semi-confinement in large property (left) and degraded pasture in a small property (right); Paragominas: Semi-confinement; Novo Repartimento: pasture under degradation; Tailânida: Abandoned pasture under conversion to mechanized agriculture; Mãe do Rio: Renovated pasture (Ratio = Number of heads of cattle in 2015 divided by number of heads of cattle in 2000; Herds increased = ratio > 1.5, Decreased (Ratio < 1), and Stable (1< Ratio <1.5); Insertion = Inside – Supplied at least two major industrial slaughterhouses, Outside – Site did not supply any major industrial slaughterhouses.



3.2.2.2 Approaching and interviewing informants

Data was obtained in personal semi-structured interviews following guiding questions synthesized in Figure 3.3 (HOELLE, 2011; 2015; BERNARD, 2006; PIKETTY et al., 2005; KELLEY et al., 2003; BARRIBALL; WHILE, 1994). This method was chosen because interviewees were able to talk freely, which facilitates accessing particularities about actors and operations at each site (BARRIBALL; WHILE, 1994). In addition, semi-structured interviews are more flexible, ensuring that adequate terms and expressions are used, thus respecting local particularities of language (BARRIBALL; WHILE, 1994). Also, focus is given to relevant issues as they come up, so time spent in interviews depends more on the knowledge and 'eagerness' of the interviewee to talk (BARRIBALL; WHILE, 1994; BERNARD, 2014; 2017). A primary disadvantage however regards securing high response rates which in this method are hard to control (BARUCH, 1999; KELLEY et al., 2003).

The interviewees were non-randomly selected following the snow balling method in which interviewees are identified as field investigations progress (KELLEY et al., 2003; BERNARD, 2006). First, we approached technicians at official agencies because they were more accessible, providing further contacts, and eventually introducing the investigator to other potential interviewees. Second, we performed pre-scheduled interviews with key informants following interviewees´ recommendations in each site. When approaching potential interviewees we clarified the purposes of the investigation, emphasizing that the work was purely academic. We chose language carefully avoiding too technical terms and too much specifics that could confound or make informants feel unprepared to participate. All questions were presented beforehand to interviewees, followed by clarifications on how the data obtained was to be published, being reinforced that information would be used anonymously. Notes were taken instead of voice recording.

From four to eight days were spent in each study site, and on average four informants were interviewed each day. After interviews, we requested to visit properties for detailed information about practices and techniques, footages and pictures. All field visits were done together with owners or with someone indicated by him/her. Visits were always scheduled in advance, and footages and pictures were done with the permission, and in the presence of interviewees.

3.2.2.3 Data processing and results

Figure3.3 summarizes the methodological steps through which data obtained from transcribed interviews were organized to classify actors and systems. Firstly, we tabulated responses about actors and classified them with respect to the size of properties (small< 100 ha; medium>100 and <1,000 and large> 1,000 ha), farming background (farming or no farming), education (formal and no formal education), and profile (traditional ranchers[4], diverse background, private companies). The reconstruction of actors´ trajectories was done based on the time-line of historical events describing the unfolding dynamics of cattle ranching in each study site. Secondly, we interpreted discourse of interviewees (BERNARD, 2006) to have a broader contextualization of their beliefs, motivations, perceptions and responses with respect to increased law enforcement after 2004. This data is presented in Section 3.1 with actors being classified as:

(i) Migrants with no farming background.

(ii) Migrants with farming background.

(iii) Private companies

Thirdly, responses were tabulated and data was organized to cover beef cycle (cow-calve, finishing, full cycle), market connections, practices and techniques used in pasture management, and strategies to deal with environmental norms i.e. the Forest Code and secondary vegetation suppression. This information was quantified and expressed in percentage of use and supports the

[4] Rancher is used throughout this document to designate actors in large-scale cattle ranchingoperations.

classification of cattle ranching systems presented in Section 3.2. In this vein, as previously mentioned, semi-structured interviews are limited with respect to standardization of samples as data is obtained through a flow of information using guiding questions instead of a closed questionnaire with pre-defined categories. Therefore, we use response rates (RR) (BARRIBAL; WHILE, 1994; BARUCH, 1999; KELLEY et al., 2003) as a strategy to standardize data quantification by giving in terms of percentage, an idea of the universe of responses (samples) from which data was extracted. Our choice for this method is justified by the fact that data quantification of responses provides a better comprehension about the similarities and differences among actors and systems.

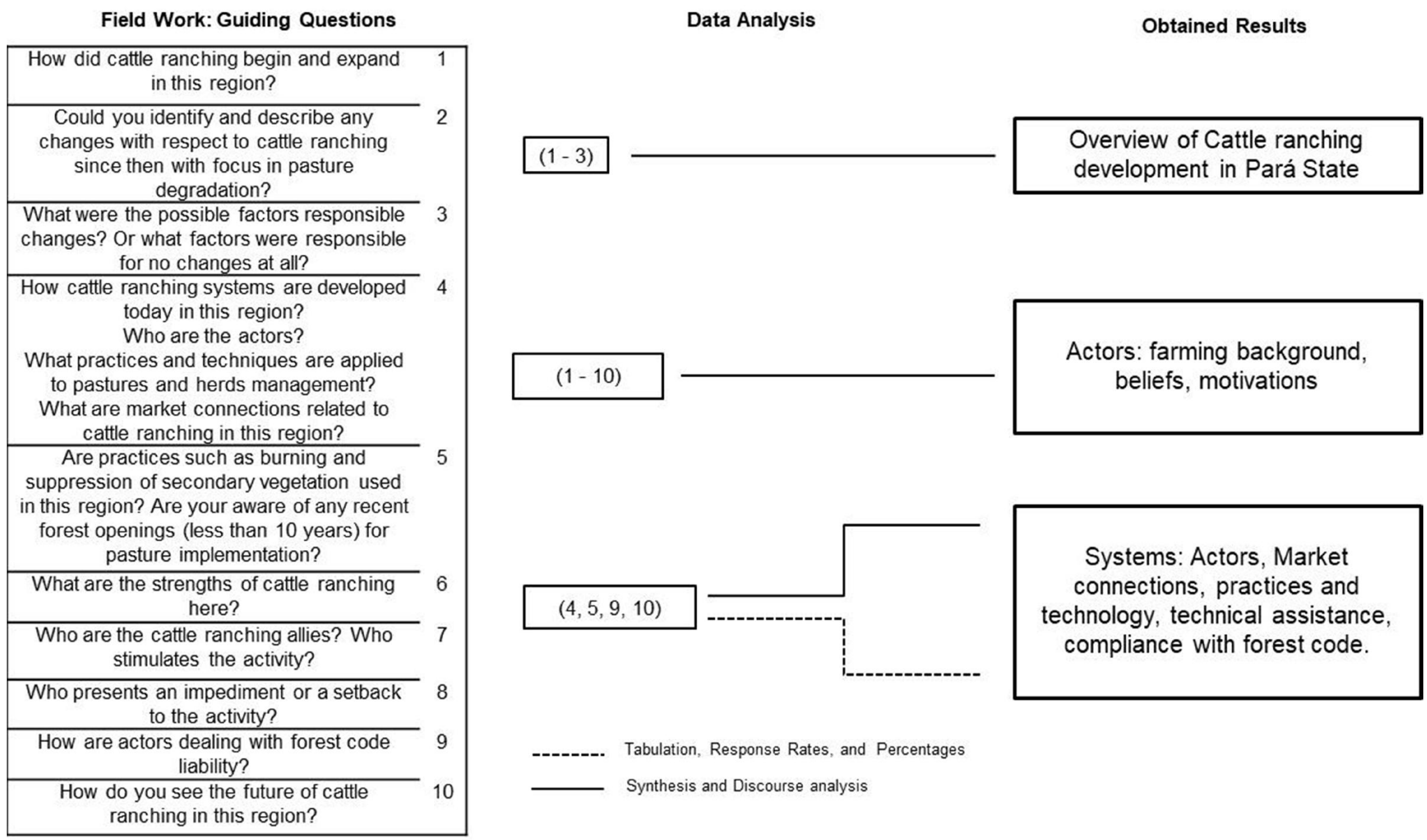
3.2.2.4 Analysis of practices and techniques across cattle ranching systems and potential impacts on secondary vegetation

Finally, based on accumulated knowledge on the dynamics of secondary vegetation, we summarize the potential impacts of practices and techniques adopted in pasture management over secondary vegetation having the percentage of use of practices and techniques as a reference as follows:

(i) For data having response rates < 50%, the potential impacts of practices and techniques were defined as LOW when percentages of adoption were< 60%, MODERATE when percentages of adoption were between 60-90%, and HIGH when percentages of adoption were >90%.

(ii) For data having response rates > 50%, the potential impacts of practices and techniques were defined as LOW when percentages of adoption were< 40%, MODERATE when percentages of adoption were between 40-60%, and HIGH when percentages of adoption were > 60%.

Figure 3.3 – Methodological steps from data analysis to classification of actors and systems based on semi-structured interviews.



3.3 Results

3.3.1 Actors in cattle ranching systems

In this section, we describe the actors in cattle ranching systems with respect to their trajectories and farming background, also disclosing the relationships between these features and different systems currently found in Pará as summarized in Table 3.1.

3.3.1.1 Actors with no farming or livestock production background

Migrants with no farming background: these actors came to the Amazon region during the 70s and 80s, attracted by gold mining, timber and free land. In this group, two main trajectories were identified: actors with rural and urban jobs able to settle in or acquire smallholdings, and actors involved with mining who achieved the financial means to acquire large properties. Actors whose trajectories led to the acquisition of smallholdings are currently involved in the Subsistence system found in Marabá, Itaituba and Novo Progresso, while those whose trajectories led to acquisition of large properties relate to the Medium scale and Traditional systems identified in Tailândia, Novo Repartimento, and Itaituba.

Actors whose trajectories relate to the Subsistence system had short to medium-term stays in different locations, having urban and rural jobs, acquiring a diversified background. After occupying or buying lands in different tenure status, they developed “roças”[5] and small poultry. Stimulated by cattle ranching expansion, facing difficulties to trade agricultural products, and following incentives of INCRA to raise cattle, they started implementing pastures in previously deforested and fallow lands. Security and facilitated trade are primary motivations to raise cattle that is seen improvement in life conditions: ‘*Cattle ranching works like that, if you need health assistance, a medicine, and you have nothing to sell, cattle is easy to trade*’. Because cattle is easier to trade and

[5] “Roça” is used to identify the land use based on techniques of slash-and-burn/shifting cultivation agriculture whose list of species is diversified, including annuals, and eventually semi-permanent crops.

labor demands are lower, actors implement pastures and raise cattle, even if expected financial results are not met: "*Today you have no other option, you raise cattle or raise cattle*".

Increased law enforcement affected these actors, with deforestation reported as having been reduced in smallholdings: "*They are really aware they can´t deforest. I don´t know who programmed that in their minds, but they do".* Either because forests stocks are already reduced, or as the result of intimidation by law enforcement operations, actors in Subsistence system are now suppressing secondary vegetation to secure pasture availability.

Actors with no farming background whose trajectories relate to land and wealth accumulation, started with mining and/or timber extraction, and acquired land for speculation. Motivations to adopt cattle ranching include social and political status, and to be seen as producer', instead of an 'extractivist'. Being a secondary activity, herds and pastures are poorly managed. Following pressure of law enforcement, properties were sold or partially leased to other land-uses, particularly palm oil in the Northeast of Pará, and mechanized agriculture in Northeast and Southwestern regions.

Individualistic and poorly associated, flow of information among these actors is restricted, and despite the existence of Unions of Rural Producers in all study sites, these institutions are seen as ineffective in defending their interests: "*They* (the Union) *are good only for making '*arraial' (a traditional Brazilian party celebrated in June). *The sector is annihilated because there is no organization representing it*".

Table 3.1 – Background and trajectories of actors related to different cattle ranching systems in Pará.

Background	Motivation	Trajectories and Strategies: Beginning	Pre-cattle	Cattle	Current Stage	System
No farming	Gold mining and free land	Mining camps (miners, managers, suppliers)	Acquisition of forested lands to extract timber	Investment in cattle	Wealth, political or social status	Traditional
		Urban or rural jobs	(i) Settling or acquisition of small lands (ii) Development of agriculture (iii) Exhaustion of forest stocks (iv) Unviable trading of staple products	Investment in cattle	Pastures are limited and/or degraded, and actors are unable to diversify land-use	Subsistence
Farming and cattle ranching	Free land and financial incentives to develop agriculture	No initial financial resources	(i) Settling or acquisition of small properties (ii) Development of agriculture (iii) Unviable trading of staple products	Investment in cattle	(i) Dairy processing and/or diversification of land-use	Mixed dairy-beef
					(i) Expansion of pastures and herds	Medium and eventually large-scale systems
	Prospects of large-scale operations	Had initial financial resources	(i) Acquired large areas	Investment in cattle	(i) Extract timber, expand properties and profit from a network of roads and slaughterhouses	Traditional and Professional
Private companies	Financial incentives and tax deductions	Profit from facilitated access to public lands	(i) Investment in cattle (ii) Extract timber		(i) Poor resultsand exposure of deforestation and slavery practices (iii) Pressure of land conflicts	Cease operations
	Increased land prices, and prospects of foot-and-mouth disease free area	Facilitated access to loans and public credit Foreign financial resources	(i) Invest in cattle (ii) Profit from a network of roads and slaughterhouses			Traditional and Professional

Environmental norms were frequently defined as bureaucratic by these actors, and labor norms as permissive, particularly in Itaituba, where labor conditions were described as choking: '*If you take a walk around these properties here, you won´t find a single employee registered. These people* (employees)*, you would be ashamed of the conditions they live in; they work because they need. A registered employee means security, but not here. Here, it is not the standard to give any security to employees. Cattle ranchers here* (in Itaituba) *are different from other regions".*

In Itaituba, actors in the Traditional system openly expressed their contempt for labor norms: "*We never heard it here that an employee was expected to be paid for extra labor hours!*" On the contrary, in other study sites such as Tailândia and Marabá, either as a result of their insertion in the palm oil chain (e.g. Tailândia), or in the beef production chain (e.g. Marabá), pressure for compliance with labor norms was said to have improved housing infrastructure and labor conditions in properties.

Although these actors recognize that deforestation and the use of fire are illegal practices, they are still adopted: "*Our practice was to get everything from pastures, but today we know we are exposed* (referring to law enforcement operations), *so an adequacy is necessary to secure profits*'. Environmental and land tenure agencies bureaucracy is usually used a justification for illegal practices: "*Here, you won´t find an IBAMA office to give you a license, or an INCRA office to give you a land title. These legal norms came only to muddle everything*". These environmental legal norms are frequently defined as a "*setback*", in particular deforestation regulation.

However, in general terms, law enforcement had little or no impact over all actors, either in small and large properties, with respect to practices and techniques in pasture management. Compliance with the Forest Code, when applicable, is still seen as problematic as actors have not envisioned any strategies so far: "*Nobody is considering that* (compensation of legal reserves)*, because this is up to the government to define. The government has to deal with that*". In Tailândia, an important palm oil area, actors showed great expectation around the acceptance of exotic species in reforestation of illegally deforested areas[6].

3.3.1.2 Actors with farming or livestock production background

Migrants with farming or cattle ranching background who came to the Amazon region during the 70s and mid-80s, were attracted by facilitated access to land and financial incentives propaganda. In this group, two main trajectories were identified: actors who had agriculture as their primary focus, and actors with initial financial resources attracted to the region by prospects of large-scale cattle ranching operations.

Actors with no financial resources who had agriculture as their primary focus present trajectories that included agriculture, mining and timber exploitation, and acquisition of land, being currently related to the Mixed dairy-beef, medium scale and large-scale systems identified in different sites of Pará. Although agriculture was their primary focus, dirt roads made trading of staple food difficult, leaving cattle ranching as the only alternative. Profiting from their farming background, actors started working with dairy production, and diversified activities by including cultivation of semi-perennial and perennial crops. Currently involved in the Mixed dairy-beef system found in São Felix do Xingu, Mãe do Rio, and Tailândia, their focus is the cow-calf stage, with the weaned male calves sold to medium and large ranches, being their connection with the beef production chain.

Actors with initial financial resources had trajectories involving both timber extraction and mining, and supplying beef to gold mining camps[7], being these the activities that allowed them to acquire land and accumulate wealth. Currently behind Medium, Traditional or Professional systems, they represent the "culture

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[6] So far the Forest Code allows compensation through reforestation cannot be based only on exotic species crops, and must include native species as well.

[7] At the beginning, mining camps alongside BR-163 were supplied by actors from small-scale cattle farming in Novo Progresso. Later, herds started to be anesthetized and taken by plane to reproduce and supply these camps. In the mid-80s, after the Transgarimpeira, a road connecting gold mining camps, was built these camps started to be supplied by the nearby site Castelo dos Sonhos.

of cattle" seen in Redenção, Marabá, São Felix do Xingu, and Novo Progresso where second and third generations of traditional cattle ranchers are found. Commonly, these actors have a formal education in Veterinary medicine, Agronomy or Zootechny, which represents an important aspect considering the adoption of more intensive practices and techniques to manage pasture and herds hence defining the Professional system.

Also defined as "individualistic", the expression "*Every man for himself*" is often used to define how the sector operates. Individualism is pointed out as a primary reason for isolation and non-associative behavior: "*Cattle ranchers are isolated, they are not associative. They think they have money to work and produce"*. As a result, the sector is poorly organized and fragile in face of market and legal constraints. The inability of Unions and FAEPA to negotiate sector demands was frequently criticized: "*The Union* (in Marabá) *is trying to organize* (our demands) *following the law, but it is fragile, and without money* (to pay for legal assistance) *you can´t do anything. It comes from ranchers´ culture to be like that*". Individualism is also related for the low information flow between actors who, in general, have no idea about how other ranchers are coping with pasture degradation, with some of them seeming indeed reluctant in sharing experiences: "*I won´t leave my property to teach my neighbors how to do produce*".

Following increased pressure of law enforcement and public campaigns exposing the beef production chain, poor sector organization is perceived as a weakness, and a stronger representation is seen as crucial: "*While NGOs are organized, ranchers only get together when pressure is extreme*". Exclusively focused in cattle ranching, new organizations are then emerging in Marabá (ACRIPARÁ), Novo Progresso (APRONOP) and São Felix do Xingu to deal with land conflicts, environmental and land tenure regularization among other relevant issues which, in agreement with actors´ perception, have been neglected by the institutions currently representing the sector.

Particularly in the Professional system being in the Amazon is perceived as a weakness because as it means being involved with deforestation: "*The name Amazon is too strong* (and) *nobody wants to buy beef from deforested areas*". Deforestation is eventually recognized as wrong in comparison to intensive pasture management: "*Is your area producing or becoming* 'juquira' (popular name for secondary vegetation)? *If I have a degraded land, shall I advance over forests? No, because it is cheaper to increase pastures productivity, and it is politically correct. Society pressured us, cattle ranchers and the agribusiness sector understood the message*". Even so, actors still argue that deforestation was a governmental guidance: "*We came to put the forest down; that´s why the government brought us here*".

Compliance with environmental norms is frequently criticized: "*Every day there is a new legal norm, but enforcement is weak"*. Although not strongly reinforced outside more accessible areas, the legal norms regulating secondary vegetation suppression and environmental licensing of rural properties[8] are also criticized: "*In Brazil, they had put us in a very restricted context for production, there are too many criteria*". With respect to the Forest Code, preservation of forest remnants and regrowth in consolidated livestock areas is seen as out of question: "*To accept it* (the Forest Code) *is unfeasible*". Hence, compensation would be the best strategy: "*The best option is to compensate but forested remnants are unclaimed lands* (terras devolutas) *which cannot be used for compensation*". However, outside consolidated areas actors have no strategies either, and only two actors operating in São Felix do Xingu mentioned having acquired land for compensation. In this respect, expectations are that the government would respond by defining strategies: "*If the problem is only yours, you are alone, and this is worrying but when many have the same problem, a solution will pop up*". In this scenario, compliance would imply a monitoring

[8] In agreement with Normative Instruction 02/2014 any suppression of secondary vegetation must be authorized by the State Environmental Agency. Today, increased risk of been blocked forced agents to renovate previously abandoned pastures which are now in advanced stages of regeneration. This has imposed an additional setback because even though agents caught suppressing such areas without appropriate licensing will not be blocked in the supply chain, they will be fined.

mechanism of forest credits (CRA)[9] and improvement in land tenure conditions which today in Pará is quite chaotic. Moreover, pressure for land occupation, especially in the southeast, is also a weakness regarding compensation.

The lack of control of productivity indexes and financial accounts are also distinguishing features of actors in large-scale systems, with the statement *"Ranchers don´t do the math*" being frequently heard. Actors have a poor idea of how their businesses are doing: "*Financial and production control are crucial but these are not ranchers´ characteristics. Ranchers are afraid of doing the math, they are afraid of seeing how much money they are losing*". Seen as particularly risky for those intending to remain in business, especially in a scenario of increased law enforcement in which more than changes in practices and techniques, a whole change of mind with respect to properties management is seen as necessary. Indeed, only one interviewee systematically recorded productivity indexes and expenses, and even those investing heavily in pastures renovation don´t keep a track of their expenses: "*Now I am walking in the dark*", quoting an actor in the Professional system with respect to resources invested in pastures renovation so far.

3.3.1.3 Private corporations

Cattle ranching operations by national and international private corporations began in the 70s, following financial incentives and tax deductions provided by the military government to boost the Amazon region occupation. Here, two main trajectories were identified: private companies that pioneered cattle expansion during the 70s but failed and ceased operations, and private companies that were attracted by rising land prices and recent prospects of Pará becoming a foot and mouth disease free zone.

In spite of considerable governmental investments to support cattle ranching

[9] CRA (literally environmental reserve shares) is a legal mechanism previewed in the New Forest Code (Law 12651/2012) through which owners whose properties exceed 50% of forest reserve can transfer these shares as compensation of forest reserve of other properties in the same biome. Primary and secondary forests are eligible, except when biophysical conditions do not supporting regrowth.

operations of pioneer private companies coming during the 70s, expected financial results were not met. Moreover, national and international exposure of the environmental and social impacts related to their operations, and increased pressure of social movements for land occupation were primary reasons leading many of these corporations to cease their activities and either selling their lands, or having them expropriated, and later declared as settlements.

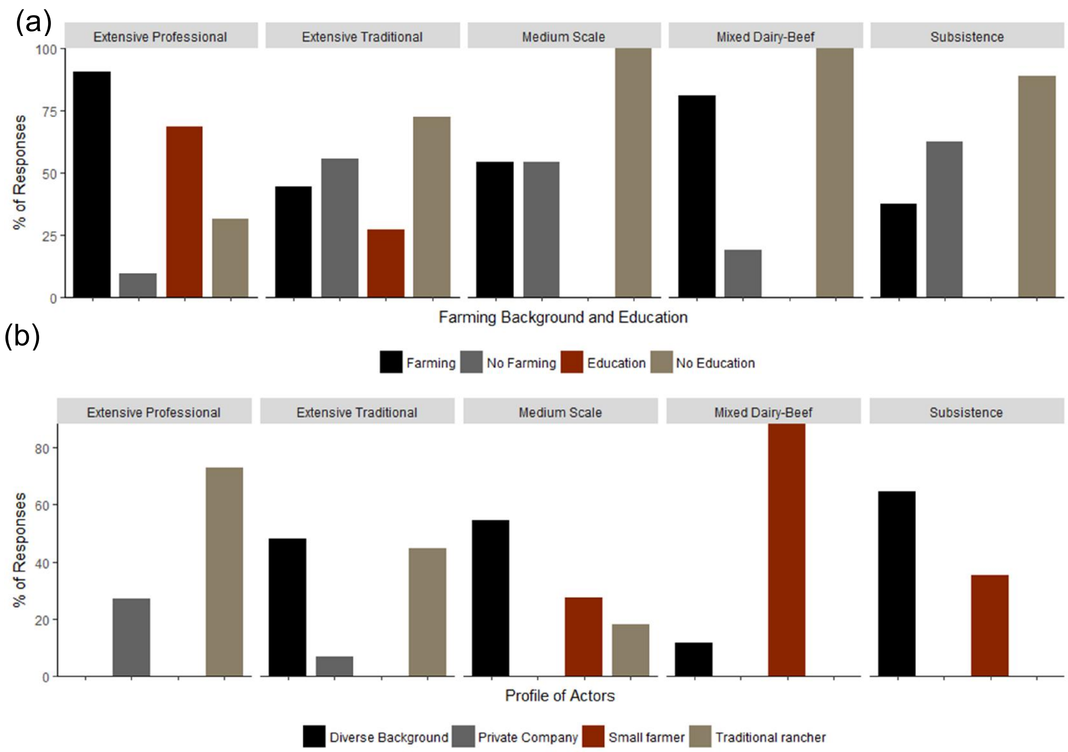
By the end of the 90s, particularly in the southeast, attracted by increased land prices, and efforts of Pará State Government to eradicate the foot-and-mouth disease, new private corporations started operating: "*Cattle ranching has attracted private companies whose extra money has been invested in cattle. Also, there are family companies, such as the* (…) *Group, who profited from cassiterite and amethyst mining, and later started investing in cattle. This is because cattle is profitable, and the slaughterhouse is just around the corner*".

By attracting technicians and input suppliers, and stimulating investments in cattle ranching operations, private corporations contributed to the emergence of the "culture of cattle" and of the Professional system. On the other hand, there are still private companies strictly focusing on land accumulation and loans with low interests to be invested in other activities, instead of in cattle operations: "*The* (…) *Group, for instance, did not come here to work with* cattle*, but instead because of financial incentives*". In addition, criticism abounds concerning these groups and suspicious operations of money laundry: "*They are not a reference in cattle ranching, they never were, their operations focus on money laundering*". Money laundering by private companies operating with cattle was reported in Novo Progresso, Redenção, and Mãe do Rio.

3.3.2 Cattle ranching systems

In this section we classify cattle ranching systems identified in Pará. We begin by relating the profiles and background of actors presented in the previous section with different systems. As illustrated in Figure 3.4.a and 3.4.b, farming background is a distinguishing feature of Professional and Mixed dairy-beef systems in which more than 75% of actors had this profile, contrasting with all other systems in which less than 50% of actors had such background. Formal education was found in Traditional and Professional systems, although in this last one, the percentage of actors with formal education was higher than 60% in comparison with 25 found for in the Traditional system.

Figure 3.4 - Actors in different cattle ranching systems: (a) Farming background and formal education; (b) Profile of actors.



The remaining of this section is organized as follows. Sections 3.2.1 to 3.2.5 present a description of the five cattle ranching systems with respect to market connections, practices and techniques applied in pastures management. Response rates for these data were included in Appendix B.

3.3.2.1 Subsistence system

Exclusively associated with small properties, the Subsistence system was identified in official settlements and outside these areas. Land-use is not diversified and dairy, when produced, supplies only household demands. With properties ranging from 5 to 336 ha (RR=100%), herds from 29 to 200 (RR =

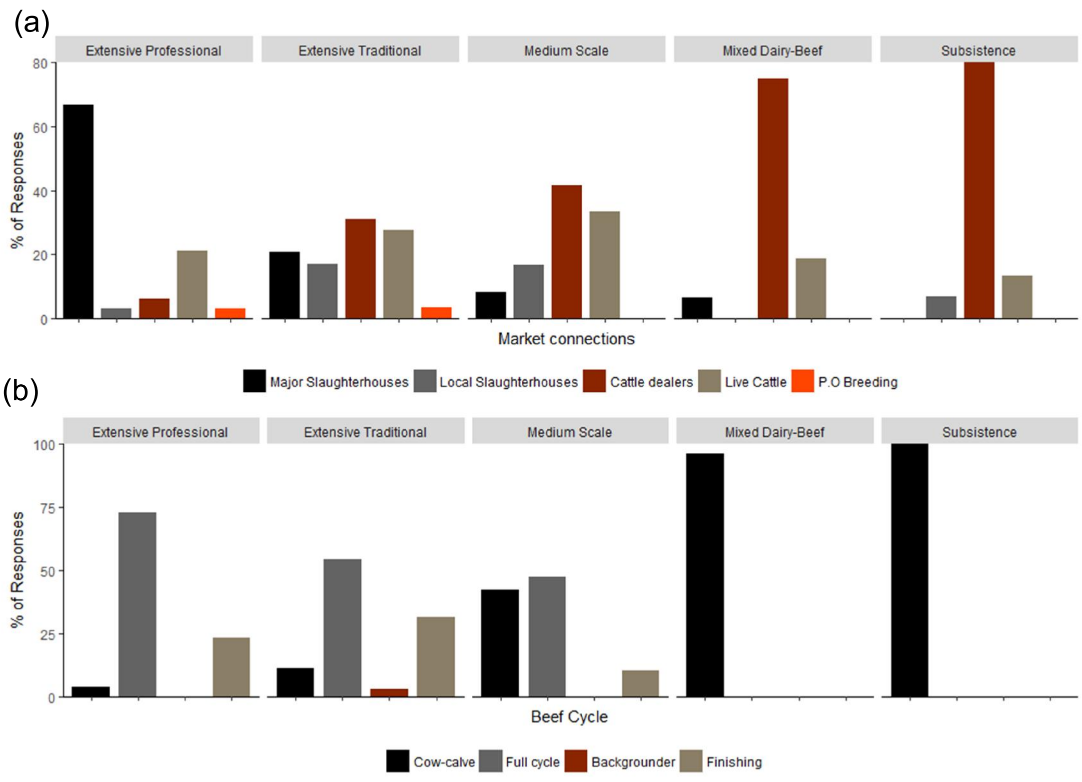
57.89%) and stocking rates from 0.2 to 2 AU/ha (RR = 57.89%), the focus of the beef cycle is the cow-calf stage (100%; RR = 84.2%). Turnover of properties was reported as common. In the Official Settlement Escada Alta in Marabá, from the 100 original occupants only 17 remained, 80% of them dedicated to cattle ranching. In Mãe do Rio, particularly following the last dry season, actors in the Subsistence system are selling herds due to increased production costs.

With respect to public technical assistance, although EMATER-PA (Pará Agency for Technical Assistance and Rural Extension) offices are found in all study sites, since 2010 changes in the legislation regulating public technical assistance to smallholdings have dismantled the institution. In this context, no access to technical assistance was reported in 92.3% of responses, and access to public technical assistance in only 7.7% (RR = 68.4%). As actors´ farming background is limited, and technical assistance is not available, aggravation of pasture degradation and pressure against deforestation are leading to secondary vegetation suppression to expand pastures (62.5%; RR=42.1%). Hence, techniques to preclude degradation are mostly of low impact and include manual weeding (71.4%; RR = 73.7%), fire (66.7%; RR = 47%), and herbicides (55.6%; RR = 47.4%), while techniques of high impact include mechanized weeding (36.4%; RR = 57.9%) only, as chemical fertilization, and pH correction are not applied (RR = 68.42%). Division of pastures when adopted it is for logistical purposes, instead of as pasture management technique (16.7%; RR = 63.2%).

The low level of technification in the Subsistence system is also reflected in the management of herds which includes only supplementation with mineral salt (62.5%; RR = 42.10%), with reproduction being done through natural mating (93.8%) and mating station (6.3%; RR = 84.2%). Market connections regard cattle dealers (80%), live cattle market (13.3%), and local slaughterhouses (6.7%; RR = 78.9%), being the low genetic level of herds pointed out as the primary restriction to the trade of herds produced in this system.

Concerning environmental strategies, operations in the Subsistence system are said to have been constrained by pressure against deforestation although actors in this system are connected to deforestation (40%; RR = 52.6%) and suppression of secondary vegetation (62.5%; RR=42.1%). With respect to compliance with the Forest Code, following changes in 2012, actors holding properties less than 400 ha were amnestied; hence there is no need of compliance.

Figure 3.5 – Market connection and beef cycle of cattle ranching systems: (a) Market connections and (b) Prevailing beef cycles for each system.



3.3.2.2 Mixed dairy-beef system

Associated with small and medium properties, the focus of actors in this system is dairy production, with weaned male calves sold to medium and large ranches. Land-use is diversified and includes permanent fruit crops (cocoa in São Felix do Xingu, and cupuaçu in Tailândia), semi-permanent crops (banana in São Felix do Xingu, açaí in Tailândia, passion fruit and black pepper in Mãe do Rio), and industrial crops (palm oil in Tailândia and Mãe do Rio), with those being an important strategy to generate income and provide financial means for pasture management: "*Expenses with cattle are high, and it is not possible to rely only on cattle. You have to diversify, have a bit of everything, because if you rely only on cattle, you eat a herd per week*". With properties ranging from 21.8 to 645.8 ha (RR = 77.4%), herds from 6 to 550 (RR = 67.74%), and stocking rates from 0.1 to 3.5 AU/ha (RR = 100%), the focus of the beef cycle is the cow-calve stage (96.3%; RR = 87.1%).

Turnover of properties was reported as common: "*Most people who arrived here with me* (in the mid-80s) *are already gone because they cannot see the value of their lands rising*". In São Felix do Xingu, 12 small properties at Vila Nereu have been recently sold to a single rancher. In Tailândia, between 2010 and 2016 at least 1,000 families were reported as having left rural areas. As a constraint to this system, a crisis in the dairy sector was reported in recent years. In Marabá, the local dairy processing facility was said to be operating with 50% of its full capacity as a result of reduced dairy supply. In Mãe do Rio, Novo Repartimento and Itaituba, following sanitary inspections, dairy facilities were closed.

As seen for the Subsistence system, the dismantling of EMATER has also affected access to technical assistance, and 81% of responses reported no access to technical assistance, followed by access to public assistance (14.3%) and inside property assistance (4.8%) (RR = 67.7%). Even in this scenario, the actors with farming background were able to adoption techniques with high impact in precluding pasture degradation including chemical fertilization (45%; RR = 64.51%) and pH correction (29.4%; RR = 54.83%), which are occasionally based on soil analysis (13.3%; RR = 48.38%). Division and rotation of pastures is also adopted (61.1%; RR = 58.1%) and plots range from 4.9 to 15 ha. Notwithstanding, pastures are also managed with low impact techniques such as manual weeding (75%; RR = 38.7%), fire (57.1%; RR = 45.2%), herbicides (50%; RR = 45.2%), and mechanized weeding (47.1%, RR = 54.8%). Suppression of secondary vegetation was reported in 62.2% of responses (RR = 64.3%) either for pasture or cultivation of semi-permanent and permanent crops.

In spite of a higher level of technification, management of herds in the Mixed-dairy beef system are similar to the Subsistence system, with herds receiving supplementation of mineral salt only (42.9%; RR = 45.16%), with no technology being applied in reproduction either; which is done through natural mating (95.5%) and mating station (4.5%) (RR = 71%). Despite low genetic level, market connections include cattle dealers (75%), live cattle (18.8%), and also major slaughterhouses (6.3%) (RR = 51.6%).

In regards to environmental strategies, deforestation was reported in 9.1% of responses (RR = 37.9%), and suppression of secondary vegetation in 64.3% (RR = 48.2%). With respect to compliance with the Forest Code, as properties are mostly smaller than 400 ha, only 15.8% of responses indicated a need of compliance, although so far no strategy was defined.

3.3.2.3 Medium scale system

This systems is very similar to Subsistence and Traditional systems, it is the size of properties the only particular feature identifying this system. With properties ranging from 95.9 to 1,000 ha (RR =65.2%), herds' from 50 to 1,000 animals (RR = 100%), and stock rates from 0.3 to 3.5 AU/ha (RR = 91.3%), the full cycle in different properties (47.4%), cow-calve stage (42.1%), and finishing (10.5%) (RR = 82.6%) are beef stages focused in this system.

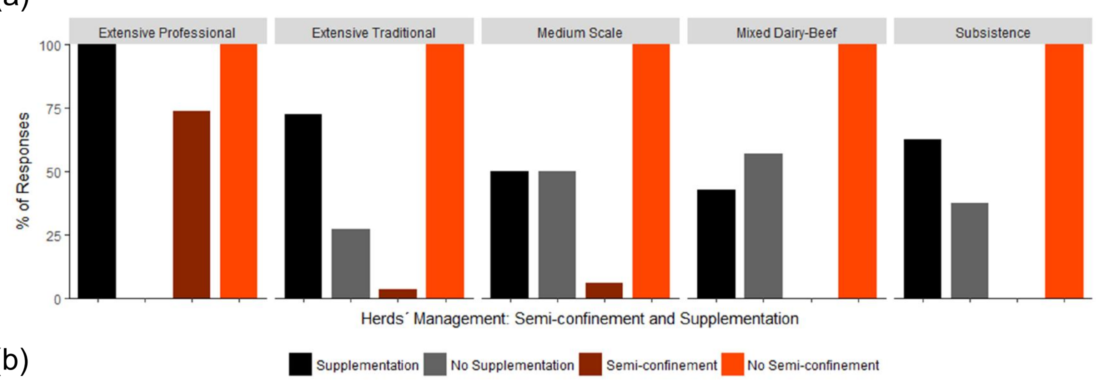
Most actors in this system have no access to technical assistance (60% of responses), while 30% of responses indicated access to private technical assistance, and 10% to technical assistance provided by properties´ own technicians (RR = 43.5%). Techniques and practices to deal with pasture degradation include low to moderate impact techniques such as the use of herbicides (80%; RR = 43.5%), fire (60%, RR = 43.5%), and manual weeding (50%; RR = 26.1%), but techniques of high impact were also reported such as chemical fertilization (37.5%; RR =69.56%), and pH correction (25%; RR = 69.56%) that area occasionally based on soil analysis (20%; RR = 65.21%). Mechanized weeding (71.4%; RR = 60.9%) and division and rotation of pastures

(60%; RR = 65.2%) in which case plots range from 5.7 to 42 ha. Herds management includes nutritional supplementation (50%; RR = 52.17%), and instead of mating station (7.7%) reproduction is done through natural mating or advanced reproductive techniques (46.2%; RR = 56.5%). The use of semi-confinement regarded only 5.9% of responses (RR = 73.9%).

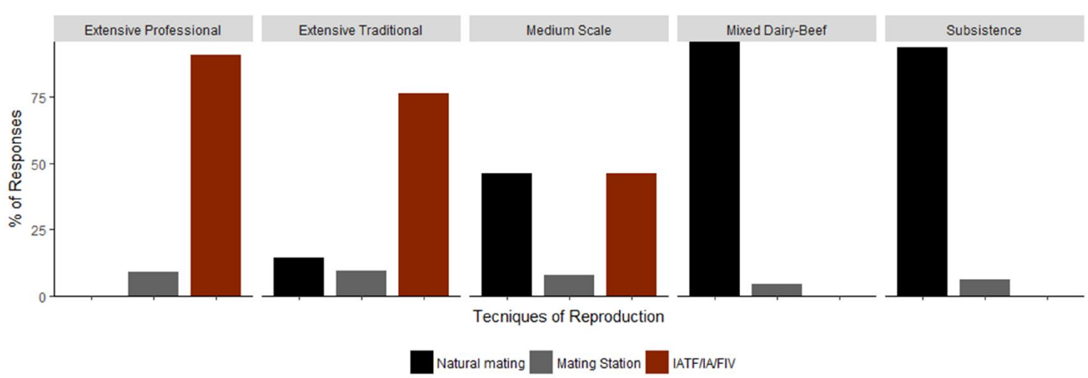
Concerning environmental strategies, deforestation was reported in 44.4% of responses (RR = 39.1%), and suppression of secondary vegetation in 53.8% (RR = 56.5%). With respect to compliance with the Forest Code, 33.3% of responses indicated no strategy was envisioned so far, while both regrowth and compensation regarded 16.7% of responses (RR=26.1%).

Figure 3.6 – Herds management in different cattle ranching systems: (a) Adoption of supplementation and semi-confinement; (b) Reproduction techniques (IATF= Fixed-time artificial insemination; FIV = In-vitro fertilization)

(a)



(b)



3.3.2.4. Traditional system

Exclusively associated with large properties, this large-scale cattle ranching system is distinguished by the diverse background and use of traditional techniques of pasture management. With properties ranging from 200 to 10,000 ha (RR = 45.7%), herds from 250 to 5,000 animals (43%), and stocking rates from 0.6 to 5 AU/ha (RR = 45.71%), beef cycle focuses predominantly the full cycle in different properties (45.7%), and the finishing stage (31.4%) (RR = 100%). Market connections include cattle dealers (31%), live cattle market (27.6%), major slaughterhouses (20.7%), local slaughterhouses (17.2%), and purebred animals market (3.4%) (RR = 82.9%).

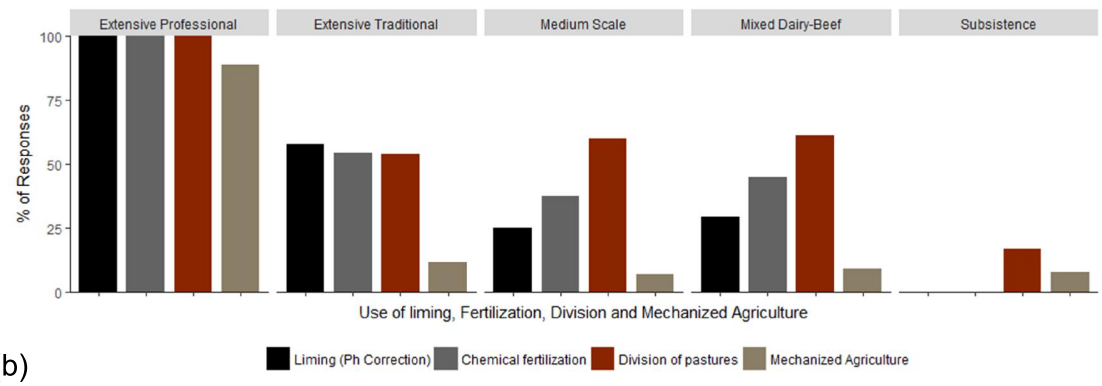
Technical assistance was reported as mostly private (65.2%), followed by inside property assistance (13%), with no access to technical assistance reported in 26.1% of responses (RR = 65.7%). Agricultural inputs suppliers are the primary source of technical assistance: "*Ranchers´ primary ally are agriculture inputs suppliers because you won´t see a fieldwork day organized by any government agency for technical assistance, but only by the labs, and agricultural inputs industry*".

Pastures are managed with low or moderate impact techniques to preclude degradation such as herbicides (87.5%; RR = 47.5%), fire (51.4%; RR = 55.6%), and manual weeding (35.7%; RR = 40%). Techniques of high impact are used, including mechanized weeding (95.2%; RR = 60%), chemical fertilization (54.2%; RR = 68.57%) and pH correction (57.9%; RR = 54.3%) which are occasionally followed by soil analysis (11.1%; RR = 51.4%). Division and rotation of pastures is adopted (53.8%; RR = 74.3%) and plots range from 6 to 33.9 ha. The use of semi-confinement regarded only 3.3% of responses (RR = 85.7%) and mechanized agriculture 11.5% (RR = 74.3%).

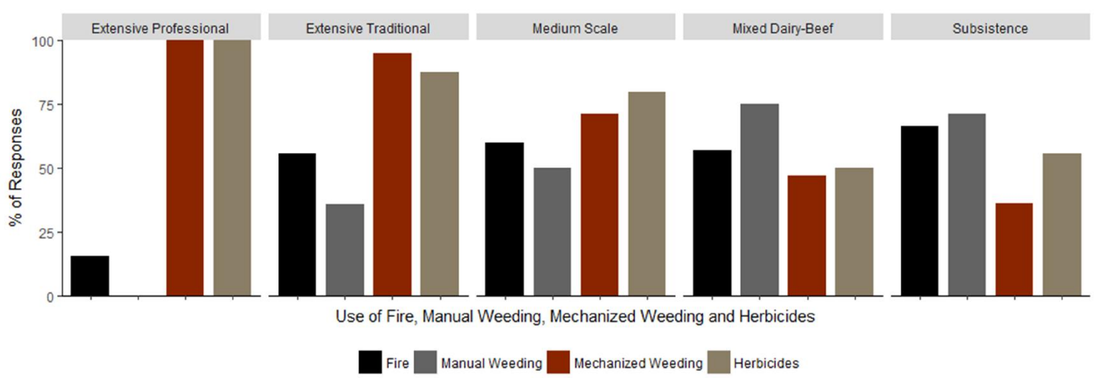
Herds management includes nutritional supplementation (72.7%; RR = 62.8%), with a preference for advanced reproductive techniques (76.2%) and natural mating (14.3%) instead of mating station (9.5%) (RR = 60%). In this respect, the case of Itaituba particularly interesting, despite existence of P.O. cattle raisers who apply advanced reproductive techniques, it was estimated that more than 75% of pastures are degraded as the result of inappropriate management.

Figure 3.7 – Practices and techniques of pasture management: (a) Techniques to increase pasture productivity and competitiveness of grasses; (b) Techniques adopted to control weeds and recover degraded pastures.

(a)



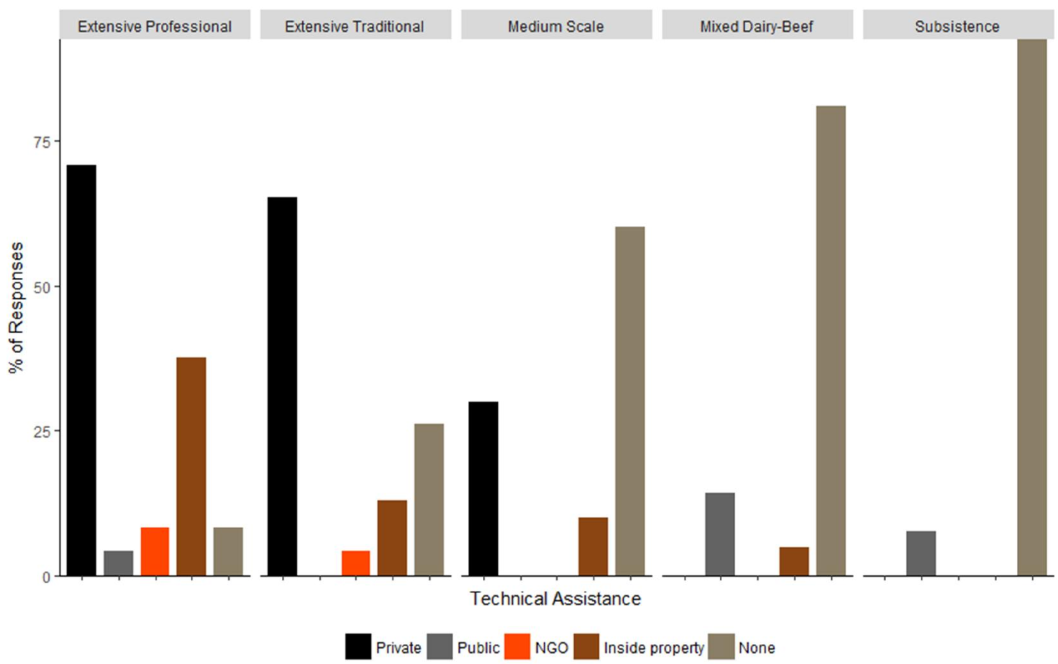
(b)



Despite facilitated access to agricultural inputs, technical support is restricted and, as a result, problems of soil depletion and poisoning by herbicides were reported. Particularly, the inappropriate use of machinery was related to soil depletion in Novo Progresso and Itaituba: "*Mechanization is not a solution for everything* (in a reference to pastures management) *because ranchers have no notion on how to use them properly, respecting local conditions of soil and superficial organic matter. They (*sellers of agricultural inputs*) teach how to* *mount tractor devices but do not make any reference to how they must be used regarding certain features of soil, relief and weather*".

With respect to environmental strategies, deforestation was reported in 60% of responses (RR = 42.8%), and suppression of secondary vegetation in 56.3% (RR = 45.7%). Compliance with the Forest Code, 33.3% of responses indicated compensation as the preferred strategy, followed by regrowth (20%), while 33.3% of responses indicated no strategy has been envisioned so far (RR = 42.9%).

Figure 3.8 – Access technical assistance in different cattle ranching systems.



3.3.2.5 Professional system

Also exclusively associated with large properties, distinguishing features of this system are the prevalence of a traditional rancher profile, improved management of pastures, adoption of semi-confinement, and market connections with industrial slaughterhouses. With properties ranging from 350 to 9,000 ha (RR = 25%), herds from 700 to 3,400 (RR = 21%) and stocking rates from 0.5 to 5.4 AU/ha (RR = 46.42%), actors focus predominantly on the full cycle in different properties (69.2%), and finishing (23.1%) (RR = 92.9%). Technical assistance is mostly private (70.8%), followed by inside property technical assistance (37.5%), and no access to technical assistance was reported as uncommon (8.3%) (RR = 85.7%). Private technical assistance involves occasional visits of technicians, and recommendations for the acquisition of industrial agricultural inputs including fertilizers, herbicides and animal nutritional supplements.

Pastures are predominantly managed with high impact techniques to preclude degradation such as mechanized weeding (71.4%; RR = 100%), chemical fertilization (100%, RR = 71.2%) and pH correction (100%; RR = 67.85%) which are frequently followed by soil analysis (92.3%; RR = 46.42%). Notwithstanding, techniques and practices of low to moderate impact such as the use of herbicides (100%; RR = 64.3%), and fire (15.4%; RR = 46.5%) were reported, and during fieldwork, even in properties where high impact practices and techniques were applied, pastures were being burned. However, after increased law enforcement against fire, herbicides became particularly common, and actors usually state that "*Those who are not using herbicides are done!*"

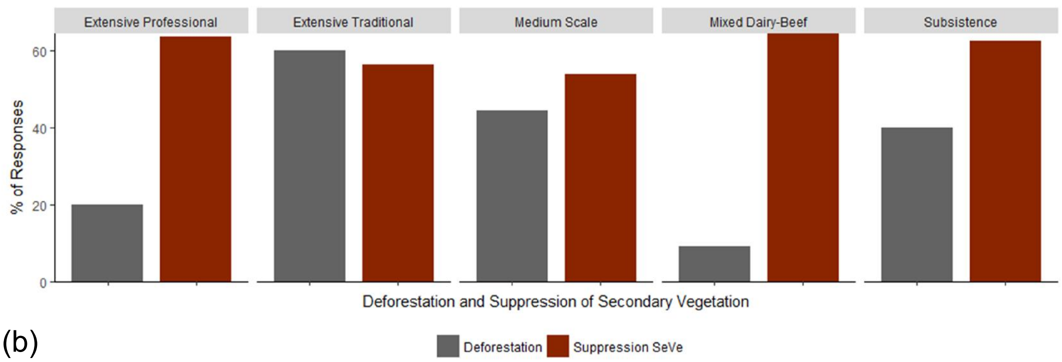
Division and rotation of pastures were reported in 100% (RR = 57.1%), with plots ranging from 7 to 96.8 ha. Herds management includes nutritional supplementation (100%; RR = 82.1%), with advanced reproductive techniques (90.9%) instead of mating station (9.1%) being preferred reproduction technique applied (RR = 78.6%). Semi-confinement regarded 73.9% of responses (RR = 82.14%) as being an important strategy for a higher turn-over ("giro") but also to deal with pasture degradation. As a strategy to promote rapid gains in weight, semi-confinement is attractive, particularly to those actors in the finishing stage because through semi-confinement cattle is finished in half of the time in comparison with pastures, favoring turnover i.e. dynamic trading following best cattle market conditions. In addition, semi-confinement reduces pressure of grazing, being strategically used during dry seasons, hence preventing pasture degradation. Notwithstanding, semi-confinement divides opinions with critics asserting they “mask” the real problem of pasture degradation: “*Ranchers are investing in semi-confinement to compensate low pastures productivity, and indeed semi-confinement allows rapid gains in weight, and ranchers get fascinated. However, the more they invest in this strategy, the faster they sink because profitability is based on grazing but the ranchers don´t do the math”.*

Because of its potential to reduce costs with semi-confinement and renovation of pastures, mechanized agriculture is also being increasingly adopted, and was reported in 88.9% of responses (RR = 64.3%). Mechanized agriculture also worked as a model of profitability and professional management of properties, with ranchers frequently describing how impressed they were by the ability of actors in mechanized agriculture to recover degraded pastures, making them highly productive: “*I have learned a lot with mechanized agriculture, and I was always intrigued by their capacity to produce in areas where cattle ranching could not stand*”.

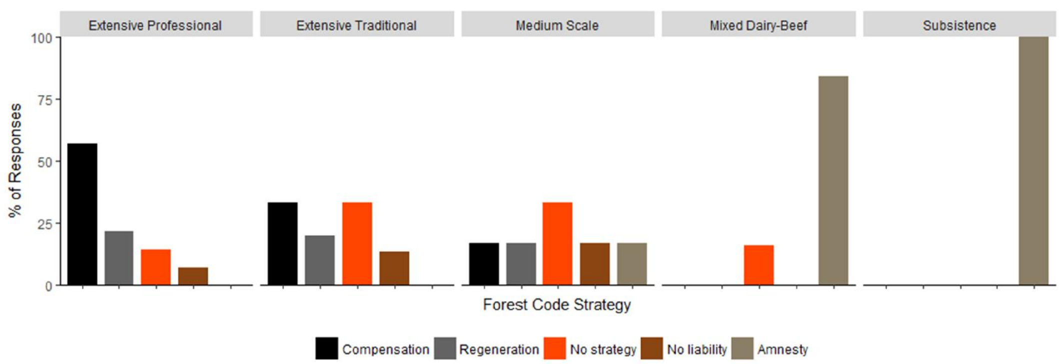
With respect to environmental strategies, deforestation was reported in 20% of responses (RR = 17.8%), and suppression of secondary vegetation in 63.6% (RR = 39.3%). Regarding strategies of compliance with the Forest Code, 57.1% of responses indicated compensation as the preferred strategy, followed by regrowth 21.4%, while 14.3% of responses indicated that no strategy has been envisioned so far (RR = 50%).

Figure 3.9 – Environmental strategies in different cattle ranching systems: (a) Deforestation and suppression of secondary vegetation (SeVe); (b) Compliance with the Forest Code.

(a)



(b)



3.3.3. Potential impacts of practices and techniques over secondary vegetation in different cattle ranching systems

In this section we summarize practices and techniques adopted in pasture management with respect to their potential impacts over secondary vegetation. As listed in Table 3.2, considering the level of adoption and respective impacts of distinct strategies characterizing cattle ranching systems, few practices are expected to have a moderate to high impact in precluding regrowth and secondary vegetation.

Among practices to control invasion by weeds and degradation of pastures, mechanized weeding, for instance, can be highlighted as an effective technique to preclude degradation in three of the four identified systems, although only under the Professional system, it is expected to have a high impact against regrowth. On the other hand, the use of fire which, despite legal regulations, is still largely adopted in pasture management is expected to have a moderate to high impact in most systems.

Among practices to increase pasture competitiveness against invasion by weeds, chemical fertilization and liming, are also expected to have a high impact against regrowth, although, as previously described only occasionally chemical fertilization and liming are done following soil analysis, in which case effectiveness of this technique can be reduced. On the other hand, division of pastures was reported in different systems but only in the Professional and Mixed dairy-beef systems this technique is expected to have a high impact in precluding degradation. By the same token, semi-confinement is restricted to the Professional system.

Table 3.2 - Summary of practices and techniques adopted in different cattle ranching systems and their potential impacts in regrowth and secondary vegetation cover. (1) Impact (RR<50%): Low < 60%; Moderate = 60-90%; High >90%) / Impact (RR >50%): Low < 40%; Moderate = 40-60%; High >60%).

Practice Technique	Evidence from literature and Implications for regrowth	Impact(1)			
		Professional	**Traditional**	**Mixed dairy-beef**	**Subsistence**
Stocking rates	**Evidence:** Without appropriate management of grazing periods, high stocking rates imply overgrazing which leads to losses in the superficial organic matter, facilitating soil depletion and invasion by weeds, factors favoring degradation and eventual abandonment of pasture (Días-Filho, 2011). On the other hand, depletion of soil properties can negatively impact the unfolding dynamics of regrowth in which case, pastures are invaded by weeds but soil compaction and lack of organic matter can preclude regrowth to advance.	0.5 – 5.4 AU/ha (RR=46.42%)	0.6 – 5.4 AU/ha (RR=45.71%)	0.1 – 3.5 (RR=100%)	0.2 – 2.0 (RR=57.89%)
	Implications: For all systems stocking rates < 5 AU/hectare are expected to have a low impact with respect to degradation and regrowth, but if grazing has not been properly managed, even under this threshold, although pasture may be invaded by weeds and abandoned, forest regrowth can be precluded. This can be especially critical in small-scale operations in which division and rotation are limited, and stocking rates tend to be higher	Low	Low	Low	Low
Manual weeding	**Evidence:** If used respecting the phenology of the different species of weeds (i.e. before flowering and fruit-set seasons) manual weeding can preclude annual weeds growth (Dias-Filho, 2011).	Not used (RR=53.6%)	35.7% (RR=40%)	75% (RR=38.7%)	71.4% (RR=73.7%)
	Implications: Only in the Subsistence system manual weeding may have a negative impact over regrowth, but considering the small-scale of these operations, implications are negligible.	No impact	No impact	No impact	No impact

continue

Table 3.2 - Continuation

Mechanized weeding	**Evidence:** The use of bulldozers in mechanized weeding reduces seed availability, survivorship and growth of seedlings of tree species, in particular when frequently applied and after long-term use (> 10 years). It removes sprouting roots and underground stems which could work as colonizers in the initial stages of regrowth (Dias-Filho, 2011; Nepstad et al 1996; Uhl et al 1988; Moran et al 1994).	100% (RR=71.4%)	95.2% (RR=60%)	47.1% (RR=58.6%)	36.4% (RR=57.9%)
	Implications: Overall impact of mechanized weeding is expected to be negative on regrowth especially under large-scale systems and when combined with chemical fertilization and pH correction.	High	Moderate	Moderate	Low
Fire	**Evidence:** The use of fire reduces seeds availability but not sprouting of species able to maintain underground stems (Dias-Filho, 2011). It reduces seeds availability, sprouting roots, survivorship and growth of seedlings of tree species after long-term use (> 10 years) (Nepstad et al 1996; Uhl and Jordan, 1984; Uhl et al. 1988; Moran et al 1994). It has also the potential to reduce biomass accumulation (Wandelli and Fearnside 2015). The use of fire eliminates seed banks and stump sprouts of primary forest species from pastures, leaving only *Vismia* spp which have the ability to sprout (Williamson and Mesquita, 2001).	15.4% (RR=46.4%)	55.6% (RR=51.4%)	57.1% (RR=48.2%)	66.7% (RR=47%)
	Implications: Based on percentage of use, the expected impact is low to moderate, although more intensive use in the past (previous to law enforcement), have the potential to affect current dynamics as soil and seed banks depletion are long-term processes.	Low	Moderate	Low	Low
Herbicides	**Evidence:** Herbicides have a limited impact to control invasion by weeds in non-degraded pastures and when adequately planned and executed (combination of different agrochemicals), however in pastures already under degradation herbicides have very limited or no impact (Dias-Filho, 2011)	100% (RR=64.3%)	87.5% (RR=45.7%)	50% (RR=48.2%)	55.6% (RR=47.4%)

continue

Table 3.2 - Continuation

Herbicides	**Implications:** Herbicides have been largely used to deal with degradation and avoid losses of herds by poisoning as some weeds are toxic, a problem particularly critical in small-scale systems. Effectiveness of these agrochemicals however is highly questionable as herbicides are very specific with respect to plant physiology and phenology, and their use although widespread is done without almost any technical concerns (e.g. field evaluations, recommendations and application). In this sense, their negative impacts may very limited.	Low	Low	Low	Low
Chemical fertilization **Ph Correction (Liming)**	**Evidence:** Increases forage yield and strengths the root system of grass species, especially after the second year of use (Boaretto et al. 2003)	100% (RR=71.42%)	54.2% (RR=68.57%)	29.4% (RR=58.6%)	0% (RR=68.42%)
		100% (RR=67.85%)	57.9% (RR=54.82%)	45% (RR=68.9%)	0% (RR=68.42%)
	Implications: In the Professional, Traditional and Mixed dairy-beef systems chemical fertilization and liming have the potential to effectively preclude regrowth but for the Subsistence system, no impact over regrowth are expected.	High	Moderate	Low to Moderate	No impact
Division of pastures	**Evidence:** Division and rotation of pasture are described as highly effective in reducing pressure of grazing (overgrazing) on pastures thus increasing grasses competitiveness against weeds invasion (Días-Filho, 2011)	100% (RR=57.1%)	53.8% (RR=74.3%)	61.1% (RR=62%)	16.7% (RR=63.2%)
	Implications: Under more technified systems i.e. Professional and Mixed dairy-beef, it is expected that division and rotation of pasture will have a negative impact over regrowth not only as a result of higher percentages of use of these practices but also because this is effectively part of a management routine in properties.	High	Moderate	High	Low
Semi-confinement	**Evidence:** Although there are no evidence on the impacts of semi-confinement in precluding pasture degradation, we consider that increased use of this strategy will be so or more effective than division and rotation concerning a reduced pressure over pastures	73.9% (RR=82.14%)	3.3% (RR=85.71%)	0% (RR=77.41%)	0% (RR=84.21%)

continue

Table 3.2 - Conclusion

Semi-confinement	and increased competiveness of grasses (Días-Filho, 2011)				
	Implications: Semi-confinement will have a negative impact over regrowth by reducing pressure over pastures, especially in drier regions where carrying capacity of grasslands is reduced.	High	No impact	No impact	No impact
Deforestation (Reduced forest stocks)	**Evidence:** Reduced primary forest stocks limit dispersal of wind-dispersed seeds (i.e. areas > 100m far from forest edges) and animal-dispersed seeds (i.e. areas >500m from forest edges) (Nepstad et al 1996; Mesquita et al. 2001). It also favors seed trees predation (Nepstad et al. 1996) and reduces the population of long-distance seed dispersers, in particular in severely or chronically disturbed sites where seed dispersal can be the only mechanism for regeneration (Uhl et al. 1988). It also reduces seed rain from primary forest species as distances from the forest edge increase (Thomas et al. 1988; Willson & Crome 1989; Gorchov et al. 1993; Aide & Cavelier 1994).	20% (RR=17.8%)	60% (RR=42.8%)	9.1% (RR=37.9%)	40% (RR=52.6%)
	Implications: Although deforestation was reported as low for all systems, in regions such as the southeast where large-scale operations have already largely reduced primary forests, highly negative impacts over regrowth are expected.	Low	Low	Low	Low

3.4 Discussion

Historically developed as large-scale and low agriculture inputs systems, cattle ranching has been pointed out as the primary driver of changes in forest cover in the Brazilian Amazon (ALMEIDA et al, 2016; LAPOLA et al 2014; BOWMAN et al., 2012; WALKER et al., 2009a).More recently, investigations suggest that more effective practices and techniques to manage pastures and herds can improve productivity, and therefore reduce expansion over primary forests (ARIMA et al. 2014; PACHECO; POCCARD-CHAPUIS, 2012). In this respect, evidence shows that increased law enforcement over the beef production chain has played an important role in the process (BORNER et al. 2014; 2015; GIBBS et al., 2015; ARIMA et al., 2014). Considering large-scale operations, our results show that changes were restricted to sites where farming background of actors and predominance of market connections with industrial slaughterhouses favored the emergence of the Professional system, characterized by practices and techniques of high impact to deal with pasture degradation. For the other regions, although some high impact techniques were reported, pastures are still predominantly managed through techniques and practices with low impact. Hence, the role of cattle ranching in reducing regrowth and secondary vegetation is restricted to the Professional. With respect to small and medium scale operations, by judging from practices and techniques adopted, only the Mixed dairy-beef system has the potential to preclude regrowth and reduce secondary vegetation.

Pressure over the beef production chain against deforestation stimulated rapid changes in meatpackers and ranchers behavior, and major slaughterhouses have favored purchasing from properties without deforestation. These measures were pointed out as relevant in the reduction of deforestation (ARIMA et al., 2014, GIBBS et al., 2015, BORNER et al., 2014; 2015).Our results show that actors have a strong negative perception of environmental norms, suggesting that law enforcement may indeed had an effect in decisions whether or not to adopt high impact practices and techniques to cope with pasture degradation, this applies especially for actors in large-scale systems. As Borner et al (2014) shows income loss is relatively high for actors located near roads where the opportunity costs of complying with legal measures are also high, a situation these authors particularly relate to the southeastern Pará where high fine revenues were also observed. This helps to explain why the Professional system emerged in this region, while in more remote regions, such as Itaituba, high impact techniques and practices are not often adopted.

Such differences in responsiveness of actors with respect to the adoption of more intensive practices and techniques to preclude pasture degradation is also largely the result of their farming background and formal education. In the Professional system, for instance, more actors have formal education and farming background when compared with the Traditional system. Moreover, the Professional system was primarily identified in Southeast Pará, a region where cattle ranching is a traditional activity (LAU, 2006; POCCARD-CHAPUIS, 2004; PACHECO; POCCARD-CHAPUIS, 2009).

The same applies to small-scale systems in which, although actors ordinarily lack enough financial means, their farming background, as seen in the Mixed dairy-beef system, implied land-use diversification, making it possible for them to apply high impact practices and techniques to deal with pasture degradation. Instead, actors in the Subsistence system, lacking farming background, rely exclusively on cattle, which implied severe pasture degradation. In agreement with Souza-Filho et al. (2011), reduced financial resources, the lack of technical assistance and limited or no experience with farming activities are particularly limiting factors concerning the adoption of new technologies especially by small farmers.

In this regard, for actors in large-scale systems, lack of financial control and productive indexes are characteristics that put in check the progressive adoption of high impact practices and techniques to deal with pasture degradation, particularly where pressure for land reform is historically high

(LAPOLA et al; 2014; PEREIRA, 2013; SCHMINK, 1982). Hence, despite the emergence of a Professional system, large areas are expected to be converted to mechanized agriculture, or become vulnerable to land occupation as degradation of pastures progresses. Actors in large-scale systems who lack financial means to recover pastures may find in properties fragmentation a solution to better cope with pastures degradation and hence remain on business (PACHECO; POCCARD-CHAPUIS, 2009). Additionally, expansion of mechanized agriculture and palm oil crops is taking place in sites where cattle ranching emerged as a secondary activity(e.g. Tailândia and Mãe do Rio), or where hilly areas accommodated cattle operations while mechanized agriculture occupied plain areas (e.g. Paragominas). Fragmentation of properties and substitution of pastures by more profitable land-uses were already detected in the Brazilian Amazon (GOLNOW; LAKES, 2014; ARIMA et al., 2011; PACHECO; POCCARD-CHAPUIS, 2009). Arima et al. (2011), modeling the indirect changes in land-use related to soybeans expansion after the Soy Moratorium in Mato Grosso, found that expansion of soybeans in settled agricultural areas led to a beyond one-to-one replacement of new for old pastures indicating a progressive substitution of pastures for soybeans. Gollnow and Lake (2014) identified the same process along BR-163 in Mato Grosso although emphasizing that this was a temporal displacement, which was detected previously and not after law enforcement was put in place.

Defined as a “pioneer” land-use, large-scale cattle ranching has been historically the driver of land occupation in forest frontiers where substantial natural resources, low land prices, newly implemented pastures and no infrastructure favor its implementation and expansion. Over time, changes in regional contexts however displaces cattle to newer frontiers, being this land-use progressively substituted by more profitable and technified ones for which required financial investments and technology are higher (ESCADA et al 2005; HECTH, 1985; 1993; VALVERDE, 1967). In study sites where cattle emerged as a secondary activity, and actors with no farming background predominated, increased law enforcement is pushing cattle out, and lands previously occupied by degraded pastures were partially or completely leased or sold to industrial agriculture. On the other hand, in sites where cattle ranching was the main activity and actors had a farming background, impossibility of further deforestation and the more valuable lands implied in persistence of cattle ranching, with actors adopting high impact practices and techniques to preclude degradation.

3.5 Concluding remarks

Based on that, we conclude that law enforcement had an impact regarding increased adoption of high impact practices and techniques to deal with pasture degradation. This impact however was not uniform, being particularly connected to the Professional and Mixed dairy-beef systems which, considering large and small-scale operations respectively, can be characterized as more technified. This, as a consequence, precluded regrowth and reduction of secondary vegetation are expected to take place where these systems can be identified i.e. southeast of Pará, and along the Northeast and Southeast regions, including portions of BR-230.

With respect to large-scale systems, the Professional system is not only embedded in a network of major slaughterhouses, but the fact that actors have a farming background, facilitated "technification". In the Traditional system, which corresponds to the historical pattern of land-use by cattle ranching(i.e. progressive pasture degradation and expansion of herds over newly deforested lands), although pressure of law enforcement was perceptible, adoption of high impact practices and techniques is restricted, either as a result of lacking of a farming background, or lacking of stimulus, because as market connections are diversified, these actors don´t rely solely on major slaughterhouses to trade. Therefore, regrowth and secondary vegetation are not expected to have changed in lands under these systems. Moreover, especially if law enforcement is relaxed and new rises in deforestation occur, regrowth and secondary vegetation will maintain the historic pattern of accumulation.

For small-scale systems, while the Mixed dairy-beef system can be related to less regrowth and secondary vegetation, under the Subsistence system no changes are expected to have taken place, and secondary vegetation cover has been maintained as a result of aggravated pasture degradation. In this respect, as stated by different interviewees, this system is expected to disappear and be substituted by industrial agriculture or large-scale cattle operations. As industrial agriculture expands, displacing cattle, the progressive substitution of degraded pastures and under regrowth vegetation can work as a driver leading to less secondary vegetation.

4 CHANGES IN SECONDARY VEGETATION IN DIFFERENT CATTLE RANCHING SYSTEMS IN PARÁ

4.1 Introduction

Although the importance of investigating the dynamics of secondary vegetation under different land-use systems has been pointed out in previous works (CHAZDON, 2003; 2012; POORTER et al., 2016; MESQUITA et al., 2015), in this regard, studies have so far being mostly focused in slash-and-burn agriculture (MORAN et al., 1994; 1996; PERZ; SKOLE, 2003; SILVA et al. 2015) and on the ecological pathways of forest regrowth in abandoned pastures (MESQUITA et al., 2001; 2015; PRATES-CLARK et al., 2009). However considering the role secondary vegetation may play as carbon sinks (NEEF et al., 2005; ORIHUELA-BELMONTE et al., 2013; AGUIAR et al., 2016), potential areas for agriculture and livestock expansion (PEREIRA; VIEIRA, 2001; STRASSBURG et al., 2014) and in biodiversity conservation (BENAYAS et al., 2009), improving our comprehension on the dynamics of this cover under different land-use systems and regional contexts is especially important in a world of rapid social and environmental changes.

Being the outcome of use and periods of abandonment, changes in secondary vegetation are related to three primary land-use decisions: integration into a land-use system (e.g. swidden), land abandonment (e.g. degraded pastures), and intensification through conversion into perennial or semi-perennial land-uses (e.g. industrial agriculture) (COSTA, 2004; 2009). Hence, this dynamics relate to social factors (labor, family age structure, market, technology) and environmental factors (soil fertility, declivity, and forest stocks) which define different land-uses (PRATES-CLARK et al., 2009; MESQUITA et al. 2001; 2015). In cattle ranching systems, for instance, secondary vegetation is historically a by-product of forest clearing and establishment of pastures which, following rapid degradation, are eventually abandoned (COSTA, 2004; 2009; NEPSTAD et al., 1996; MESQUITA et al., 2001; 2015; UHL et al., 1988). In abandoned pastures, determinants of secondary vegetation recovery include grazing intensity, use of fire, continued cutting, and remaining primary forest stocks were highlighted as relevant (UHL et al., 1988; NEPSTAD et al., 1996; MESQUITA et al., 2001). Longer grazing by cattle increases the likelihood of soil compaction, and destruction of emerging tree shoots, factors that negatively impact seed banks and establishing seedlings (GUARIGUATA; OSTERTAG, 2001; NEPSTAD et al., 1996; PRATES-CLARK et al., 2009). Frequent use of fire to clean pastures was also detected as a primary factor precluding regrowth because of its impacts on the seed banks (MESQUITA et al., 2001; UHL et al., 1981), and depletion of soil properties (Dias-Filho, 2011). Intensive management of pastures using bulldozing delayed or even entirely precluded recovery of secondary vegetation after abandonment (NEPSTAD et al., 1996; UHL et al. 1981). Reduced stocks of primary forests, resulting from the large-scale deforestation for pastures establishment, was also shown to negatively impact the availability and dispersal of seeds, affecting regrowth after abandonment (CHAZDON, 2003; MESQUITA et al. 2001).

Notwithstanding, considering the diversity of strategies and regional contexts in which cattle ranching is developed (CEZAR et al., 2005; ESCADA et al., 2005; WALKER et al, 2009a; 2009b; POCCARD-CHAPUIS, 2005), responses of secondary vegetation with respect to this land-use are also expected to be diverse, particularly as a result of differences in practices and techniques adopted by actors to cope with pasture degradation, which represents the primary connection between cattle ranching and secondary vegetation cover (COSTA, 2004; DIAS-FILHO, 2009; 2015). In this context, we build on the results of Chapter 3, in which a field investigation of cattle operations in Pará identified five distinct cattle ranching systems which, depending on the background of actors and their market connections, present different characteristics with respect to practices and techniques adopted to deal with pasture degradation. As a consequence, considering different strategies with respect to pasture degradation and recovery, distinct systems will potentially determine differences in the unfolding dynamics of secondary vegetation in which case more technified systems would lead to accumulation of low values of secondary vegetation, and less technified systems to accumulation of high values of this cover in relation to total deforested area.

Based on that, in this chapter, we focus on how the spatial diversity of cattle ranching systems relates to the dynamics of secondary vegetation in Pará. We advance in exploring our hypothesis that after increased law enforcement over the beef production chain to halt deforestation, strategies adopted by actors to deal with pasture degradation differed among systems thus implying distinct clustering patterns of secondary vegetation. However, as seen in Chapter 3, these changes were restricted to more accessible regions, where market connections with major slaughterhouses and law enforcement are stronger. On the other hand, where less restrictive market connections prevailed and law enforcement was weaker, less intensive practices and techniques to cope with pasture degradation still led to the historical pattern of secondary vegetation accumulation. This same rationale i.e. more technification leading to less secondary vegetation, can be applied to the Mixed dairy-beef system, which besides presenting a higher technification level, is located in more accessible areas, being in this way stronger affected by law enforcement.

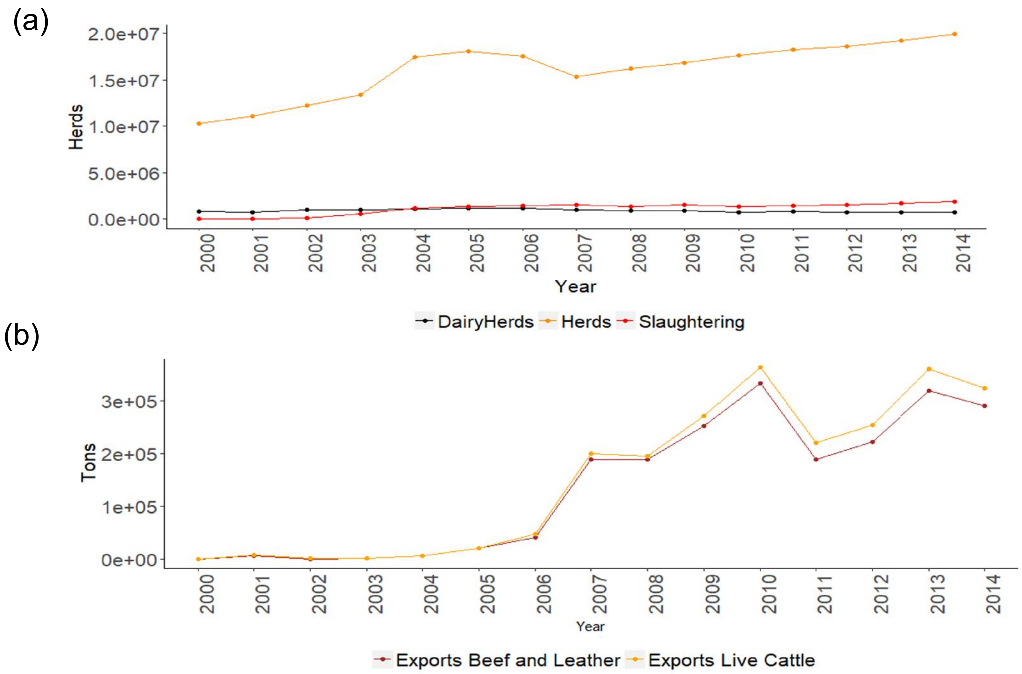
To achieve our purposes we (i) spatialized cattle ranching systems identified in Pará, (ii) analyzed the spatial- temporal patterns of secondary vegetation and clean pasture in each system, and (iii) performed a spatial-temporal analysis of clustering patterns of low (cold spots) and high values (hotspots) of secondary vegetation for each system in pre (i.e. 2000-2004) and post-law enforcement (i.e. 2010-2014) periods, followed by an exploratory analysis of drivers associated with these clusters in different systems. In this sense, this work was structured as follows: in the second section we present our study area, the process of database construction, and methods used to spatialize cattle ranching systems. Following that, we perform an exploratory analysis of the representativeness of clusters of high and low values of secondary vegetation and pastures, followed explore association between drivers and clusters in each system. In this section, we also detail the categories of drivers and variables representing them. In the fourth section, we present our results, and close with a final section in which we discuss our findings considering differences in the adoption of practices and techniques which describe each system and how these changes may be reflected in different associations between drivers and clusters in pre and post-law enforcement.

4.2 Methods

4.2.1 Study area

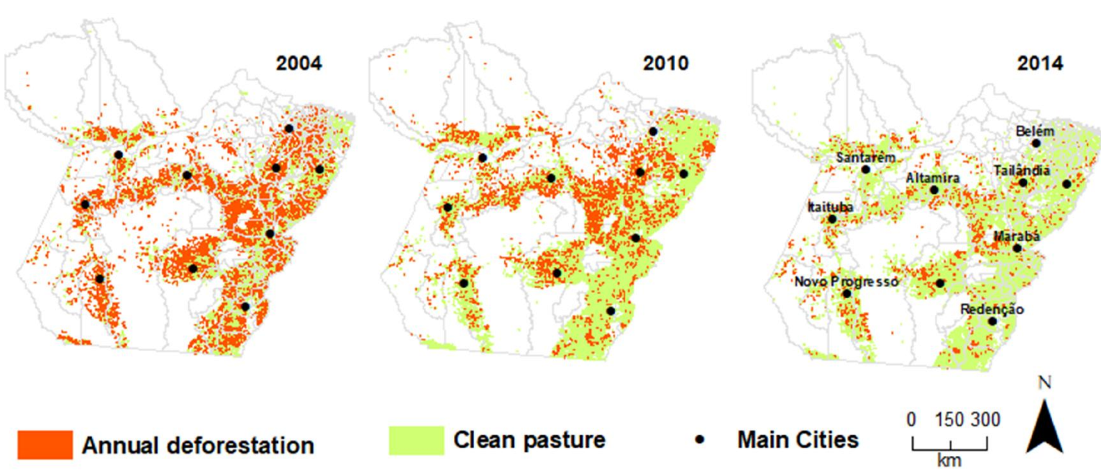
With 1.24 million km^2, Pará is a heterogeneous state regarding land-use dynamics, as a result of differences in government policies of occupation, infrastructure and settlement which have also implied in differences with respect to prevailing land-uses. In this respect, cattle ranching has proved to be particularly relevant, largely as a result of increased demand in national and international markets, and consolidation of a network of industrial slaughterhouses, with pastures currently covering 14.6 million ha or 11.7% of the state (ALMEIDA et al., 2016). Until 2005, only two industrial slaughterhouses were registered in SIF (literally Federal Inspection Sanitary Service), while in the following decade, a total of 12 new facilities requested their registration in this system. In addition, 11 minor slaughterhouses are also registered in the SIE (State Inspection Sanitary System). As Figures 4.1.a and 4.1.b show, herds doubled from 10.2 to 20.2 million in Pará, followed by increases in exports of live cattle, beef and leather. In the same period, as shown in Figure 4.2, despite a decrease in deforestation rates, clean pastures expanded 16.5% (85.5 to 99.7 km^2).

Figure 4.1 – Dynamics of herds and exports in Pará: (a) Dairy herds, herds and slaughtering; (b) Exports of beef-leather and live cattle



Source: COMEX-STAT/MDIC (2016); IBGE (2014).

Figure 4.2 – Expansion of pastures and reduction of annual deforestation in Pará between 2004 and 2014.

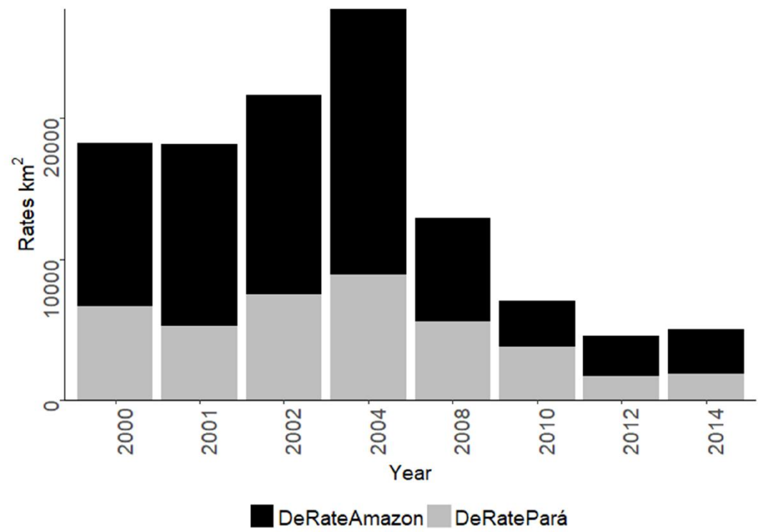


Source: TerraClass (2014).

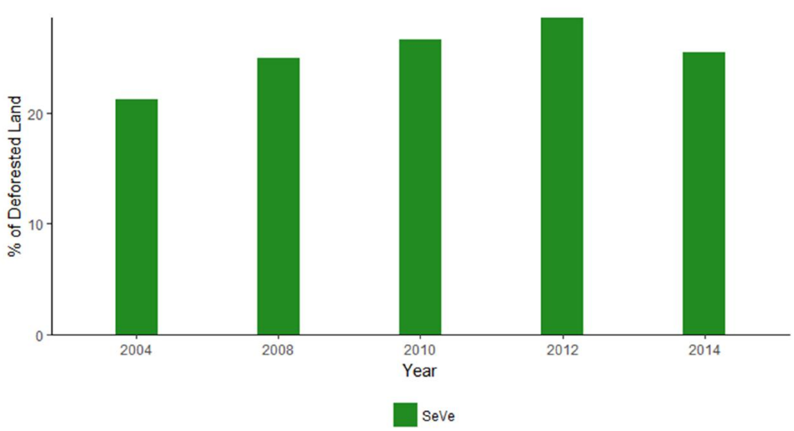
During past 15 years, as seen in Figure 4.3.a, deforestation rates in Pará decreased from 8.9 km^2 in 2004 to 1.8 km^2 in 2012, following the general pattern for the Brazilian Amazon, as a result of measures to halt deforestation which, as seen in Figure 4.3.b, strongly targeted Pará.

Figure 4.3 – Deforestation, secondary vegetation and law enforcement: (a) Deforestation rates; (b) Percentage of secondary vegetation in relation to total deforested land; (c) Time-line of law enforcement.

(a)

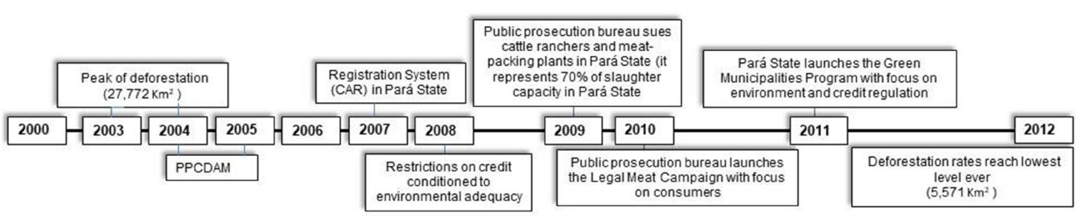


(b)



(c)

Source: PRODES (2017); TerraClass (2014).



Considering all that, in this chapter we jointly analyze these factors, and their potential role as drivers of change of secondary vegetation through the process of degradation and recover of pastures in different cattle ranching systems. For this purpose, we prepared a spatial database covering the period between 2000 and 2014, with all data being organized as attributes of 10 km x 10 km cells. Data were included using the FillCell Plugin (TerraME),an add-on plugin to calculate attribute values for the cellular space using attribute tables of layers. Fill Cell Plugin allows information coming from different geometries (vector, raster, or cellular) to be homogenized and aggregated in a single spatial-temporal layer, providing a database for modeling and statistical analysis.

In this database, we also included as attributes, data clusters of low values (cold spots) and high values (hotspots) of secondary vegetation in relation to total deforested areas detected in 2004 and 2014. For more details on methods and results of these analyses see Chapter 2.

4.2.2 Spatialization of cattle ranching systems

To explore how different practices and techniques were associated to distinct dynamics of secondary vegetation, we spatialized cattle ranching systems identified in Pará. Criteria used in this spatialization were defined based on data provided by the classification of cattle ranching systems (see Chapter 3) in which five different systems were identified: two large-scale (Professional and Traditional), and three small to medium-scale systems (Medium scale, Mixed dairy-beef and Subsistence). This classification of cattle ranching systems was based on several characteristics including the profile of actors (background and education), size of properties, and percentages of use of different practices and techniques. However, in the spatialization presented here this classification was simplified to include four attributes (i) stocking rates, (ii) area under different classes of property size, and percentage of area under clean and dirty pastures. All cells under protected areas were excluded, except Environmental Protected Areas (APAs) where, in agreement with the Brazilian legal framework (SNUC) which defines uses and objectives of conservation of protected lands, productive activities are allowed. In addition, three regions (i.e. Belém metropolitan, Marajó Island and Lower Amazon river regions) were excluded from our analysis because, considering their past histories of occupation and current dynamics, cattle ranching operations found there differ from those in lowland regions of Pará. Table 4.1 presents the threshold criteria used to spatialize each system.

In the spatialization of the Professional and Mixed dairy-beef systems additional attributes were used. In the spatialization of the Professional system, found to be more strongly connected with industrial slaughterhouses we used the weighted distance to the nearest slaughtering facility measured by a Generalized Proximity Matrix (GPM), and exports of beef and leather. In the spatialization of the Mixed dairy-beef system, particularly related to dairy production, we used the total number of dairy herds. For both systems, threshold criteria considered that values for these systems were above the mean in both years (Table 4.1). Only the two small and the two large-scale systems were spatialized, and this choice is justified by the fact that the Medium scale system, except for the size of properties, presents features of management of pasture and herds very similar to the Traditional system.

Having in mind that our focus was to explore changes in the dynamics of secondary vegetation in distinct cattle ranching systems in pre and post-law enforcement, the same thresholds applied to spatialize systems in 2014 were used to spatialize these systems in 2004 to have representation of each system in the period corresponding to pre-law enforcement. In this case, we used the same thresholds applied to data in the period between 2010 and 2014, to the period between 2000 and 2004. For 2004, data on stocking rates was based on the literature (PACHECO; POCCARD-CHAPUIS, 2012). Table 4.1 presents threshold attributes used to spatialize systems in pre and post-law enforcement periods.

Table 4.1 – Threshold criteria applied in the spatialization of cattle ranching systems found in Pará. Reference data – Information provided by the systems; Attribute data –Dataset values used to define limits of different systems.

Stocking rates (AU/hectares of clean pasture in 10,000x10,000 cells)				
	Professional	Traditional	Mixed dairy-beef	Subsistence
Reference data	1.0 - 2.8	1.39-2.0	0.55 – 1.10	0.66 - 1
Thresholdin 2014	1.0 - 2.8	1.39-2.0	0.55 – 1.10	0.66 - 1
Threshold in 2004	0.5 – 0.8	0.5 – 0.8	0.9 – 1.8	0.9 – 1.8
Properties< 100 (hectares in 10,000x10,000 cells)				
	Professional	Traditional	Mixed dairy-beef	Subsistence
Reference data	Not used	Not used	Above the mean	Above the mean
Threshold in 2014	Not used	Not used	(>73,898.79)	(>73,898.79)
Threshold in 2004	Not used	Not used	(>47,324.23)	(>47,324.23)
Properties>101 AND <200 (hectares in 10,000x10,000 cells)				
	Professional	Traditional	Mixed dairy-beef	Subsistence
Reference data	Not used	Not used	Above the mean	Above the mean
Threshold in 2014	Not used	Not used	(>51,028.29)	(>51,028.29)
Threshold in 2004	Not used	Not used	(>44,580.83)	(>44,580.83)
Properties>201 AND <500 (hectares in 10,000x10,000 cells)				
	Professional	Traditional	Mixed dairy-beef	Subsistence
Reference data	Not used	Not used	Above the mean	Above the mean
Threshold in 2014	Not used	Not used	(>86,974.35)	(>86,974.35)
Threshold in 2004	Not used	Not used	(>31,804.17)	(>31,804.17)
Properties>501 AND <1000 (hectares in 10,000x10,000 cells)				
	Professional	Traditional	Mixed dairy-beef	Subsistence
Reference data	Not used	Not used	Not used	Not used
Threshold in 2014	Not used	Not used	> 86974.35	86974.35
Threshold in 2004	Not used	Not used	> 31804.17	> 31804.17
Properties>1001(hectares in 10,000x10,000 cells)				
	Professional	Traditional	Mixed dairy-beef	Subsistence
Reference data	Above the mean	Above the mean	Not used	Not used
Threshold in 2014	(>460,716.4)	(>460,716.4)	Not used	Not used
Threshold in 2004	(>234,922.37)	(>234,922.37)	Not used	Not used
Area of clean pasture (hectares in 10,000x10,000 cells)				
	Professional	Traditional	Mixed dairy-beef	Subsistence
Reference data	Very high (2SD> mean)	Low (< mean)	High(> the mean)	Low (< mean)
Threshold in 2014	(>0.4593)	(<0.0975)	(>0.0975)	(<0.0975)
Threshold in 2004	(>0.3615)	(<0.0664)	(>0.0664)	(<0.0664)
Area of dirty pasture (hectares in 10,000x10,000 cells)				
Reference data	Low (< mean)	Very high (2SD>mean)	Low (<mean)	High (>mean)
Threshold in 2014	(<0.0218)	(>0.1150)	(<0.0218)	(>0.0218)
Threshold in 2004	(<0.0173)	(>0.1095)	(<0.0173)	(>0.0173)

continue

Table 4.1 - Conclusion

Weighted distance to the nearest slaughterhouse (in 10,000x10,000 cells)				
	Professional	Traditional	Mixed dairy-beef	Subsistence
Reference data		Not used	Not used	Not used
Threshold in 2014	(< 1,042,271.4)	Not used	Not used	Not used
Threshold in 2004	(< 1,042,271.4)	Not used	Not used	Not used
Dairy herds (Number of Dairy Herds in 10,000x10,000 cells)				
	Professional	Traditional	Mixed dairy-beef	Subsistence
Reference data	Not used	Not used	Not used	Not used
Threshold in 2014	Not used	Not used	(>8,803.14)	Not used
Threshold in 2004	Not used	Not used	(>14,959.72)	Not used
Exports ofbeef and leather (Tons of Beef and Leather in 10,000x10,000 cells)				
	Professional	Traditional	Mixed dairy-beef	Subsistence
Reference data	Above the mean	Not used	Not used	Not used
Threshold in 2014	>=7400.8699	Not used	Not used	Not used
Threshold in 2004	(>=71.7923)	Not used	Not used	Not used
Exports of live cattle (Tons of Live cattle in 10,000x10,000 cells)				
	Professional	Traditional	Mixed dairy-beef	Subsistence
Reference data	Above the mean	Not used	Not used	Not used
Threshold in 2014	>=13716.6785	Not used	Not used	Not used
Threshold in 2004	>= 37.3492	Not used	Not used	Not used

4.2.3 Analysis of spatial-temporal patterns of secondary vegetation in cattle ranching systems

Based on the spatialization of cattle ranching systems, we investigated the spatial-temporal representativeness of secondary vegetation and pastures in each system, using clusters of low (cold spots) and high (hotspots) values of secondary vegetation in relation to the total deforested area (see Chapter 2). As we assume in our hypothesis that distinct levels of adoption of practices and techniques to cope with pasture degradation were possibly an outcome of increased law enforcement, these analyses were performed for the pre-law (2000-2004) and post-law (2010-2014) enforcement periods separately. In this way, analyses of spatial-temporal patterns for pre-law enforcement were performed using clusters detected for 2004 and systems spatialized based on values of 2004 as defined by threshold criteria, and for post-law enforcement using clusters detected for 2014 and systems spatialized based on values of 2014 also as defined by threshold criteria.

4.2.4 Analysis of drivers of secondary vegetation in cattle ranching systems

To uncover the potential associations between drivers and clusters of secondary vegetation in each cattle ranching system we used the spatialization of systems to perform an exploratory analysis of the potential relations between clusters and variables in six categories of drivers identified during our previous investigation of cattle operations in Pará as relevant with respect to our hypothesis. Table 4.2 describes the variables in each category of driver represented in our analysis which represent the following categories of drivers:

Dynamics of herds - These drivers reflect the role of expansion of herds and pastures in the dynamics of secondary vegetation, either leading to pasture degradation (i.e. total herds, dairy herds and stocking rates), or reflecting this process (i.e. clean and dirty pasture and stocking rates) in different systems.

Technification - Drivers in this category indicate how access to technical assistance and to agricultural inputs (e.g. use of bulldozers, chemical fertilization and liming, and herbicides) differed among systems thus reflecting the adoption of more intensive practices and techniques potentially impacting secondary vegetation dynamics. In addition, considering the widespread use of fire in pasture management we included it among technification drivers.

Market - The adoption of more intensive practices and techniques, as previously explained, was not generalized but instead restricted to systems in more accessible regions which are, in general, more strongly connected to market. Thus drivers in this category reflect the role of beef and dairy production over secondary vegetation dynamics.

Law enforcement - This category reflects the application of particularly relevant legal norms against deforestation and illegal logging (areas under embargo by environmental offense), and slavery working conditions (workers released).

Following law enforcement, in particular for large-scale systems, these drivers were reported as important adoption of practices and techniques in pasture management.

Biophysical characteristics - Based on accumulated knowledge on the dynamics of secondary vegetation, several biophysical factors were identified as relevant to secondary vegetation dynamics, either by reflecting limiting conditions to regrowth (e.g. forest stocks), or by favoring abandonment and eventual regrowth (i.e. agricultural adequacy).

Land holding context - As previous investigations have shown concentration of small properties and small-scale agriculture positively affected accumulation of secondary vegetation, while protected areas, on the other hand, were found to negatively affect this cover. Expanding that, we included in this category other drivers i.e. price of bare land (VTN), small-scale and mechanized agriculture.

Table 4.2 – Categories of drivers and respective variables potentially related to clustering patterns of low (cold spots) and high values (hotspots) of secondary vegetation in cattle ranching systems identified in Pará. For a more detailed description see Appendix C.

Drivers	Variable	Description
Dynamics of Herds	Stocking rates	Animal units per area of clean pasture.
	Herds	Herds per municipality
	Dairy herds	Dairy herds per municipality
	Clean pasture per deforested area	Productive pasture with 90% to 100% of herbaceous vegetation cover (grass species)
	Dirty pasture per deforested land	Productive pasture with 50% and 80% of herbaceous vegetation cover (grass species) in association with 20% to 50% of sparse shrub cover.
Market	Slaughtering	Herds slaughtered per municipality
	Exports of live cattle	Live animals exported per municipality
	Exports of non-live cattle	Frozen beef, fresh beef and leather exported per municipality
	Distance to slaughtering facilities	Distance from each cell to the nearest facility considering paved and non-paved roads.
	Dairy production	Production of fresh milk per municipality

Continue

Table 4.2 - Conclusion

Biophysical	Stock of primary forests	Area (in hectares) covered by primary forests
	Areas under regrowth	Non-productive pasture with 30% to 60% of herbaceous vegetation cover (grass species) in association with 40% to 70% of shrub cover and eventually occurrence of trees (0% to 15%).
	Precipitation in the rainy season	Average precipitation in the 3 rainiest months
	Precipitation in the dry season	Average precipitation in the 3 driest months
	Agriculture adequacy	Classification of potential for agriculture based on fertility, physical and morphological features, and also limitation of topography
	Slope	Inclination with respect to the horizontal surface in degrees with values ranging from 0 to 90°
Technification	Technical assistance	Number of properties accessing technical assistance per municipality
	Bulldozers	Number per municipality
	Chemical fertilization and liming	Number of properties adopting chemical fertilization and liming per municipality
	Herbicides	Number of properties using herbicides per municipality
	Use of Fire	Number of foci of fire
Law enforcement	Enforcement of environmental norms	Area under embargo per municipality
	Enforcement of labor norms	Workers released from slavery or similar conditions per municipality
Land holding context	Hectares of land in different classes of property size	<100 hectares
		> 101 and < 500 hectares
		> 501 and < 1,000 hectares
		> 1,001 hectares
	Small-scale agriculture	Land-use characterized by small-scale agriculture developed in association with cattle ranching.
	Mechanized agriculture	Land-use characterized by mechanization.
	Price of bare land (VTN)	Price of bare land per municipality. VTN is defined and divulged annually for purposes of amendment in case of land expropriation.

Using geovisuzalition (DYKES et al., 2005) and spatial analysis tools (ANSELIN, 1995), we explore the spatial distribution of variables in space considering each system as a separate unit, and covering pre and post-law enforcement periods separately. To improve geovisualization of drivers we mapped clusters of high and low values for all drivers in 2004 and 2014, based on a calculation of the local Moran's I using a fixed distance band of 20,000 meters and a statistical significance of p-value < 0.05. Finally, we performed a Pearson analysis of correlation to check the strength and direction of potential associations between drivers and clusters in different cattle ranchingsystems.

4.3 Results

4.3.1 Spatialization of cattle ranching systems

Figure 4.4 presents the spatial distribution of cattle ranching systems for 2004 and 2014. Described as the most technified, the Professional system, as seen in Figure 4.4.a, was predominantly identified in the southeast where better infrastructure and a concentration of major slaughterhouses is found. In 2004, this system covered less than 7% of the state area, having expanded +5.28% between 2004 and 2014 (Table 4.3). On the other hand, the Traditional system, identified as the usual system through which large-scale cattle ranching operations are developed in lowlands was, as seen in Figure 4.4.b, found predominantly in the southwest, and northeast, being also identified in the Northeastern region. Before law enforcement, this system occupied 21.32% of the State, being reduced in more than 30% after that (Table 4.3).

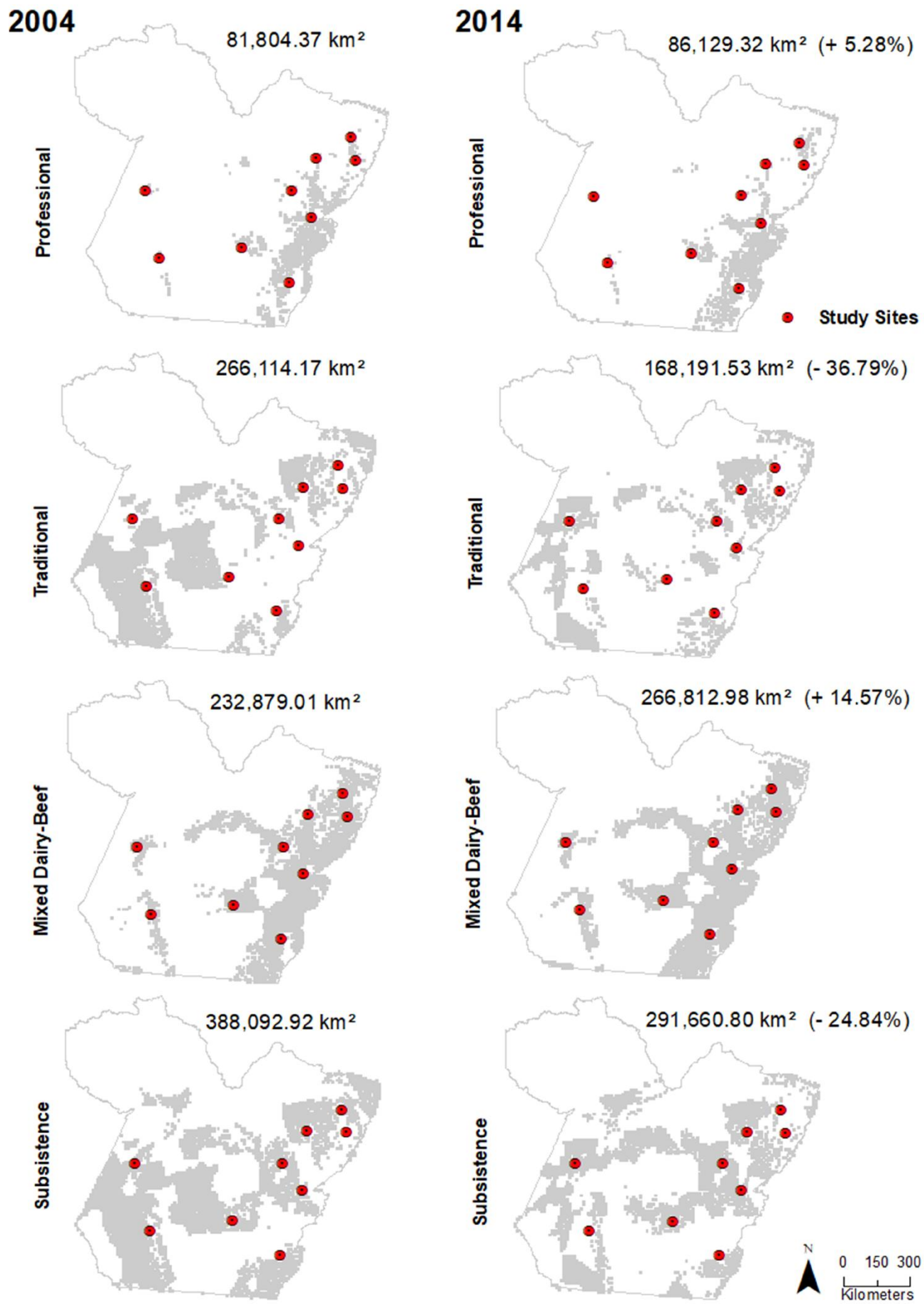
As shown in Figure 4.3.c, the technified small-scale system, the Mixed dairy-beef, was identified nearby major slaughterhouses and dairy processing facilities from northeast to southeast, along BR-230 (Transmazônica), and to a lesser extent along BR-163. In 2004, it covered 18.66% of Pará, having expanded its limits after that to 21.38% (+14.57%). The Subsistence system, the least technified, had spatial boundaries similar to the Traditional system i.e. Southwestern and Northeastern regions, although especially before law enforcement it occupied a considerable portion of the southeast. This system covered 31.10% of the State, being the largest system, identified in our spatialization. Even so it experienced a reduction of -24.84% between pre and post-law enforcement periods.

Table 4.3 – Area occupied by different cattle ranching systems identified in Pará.

System	Area in 2004 (km^2)	%(1)	Area in 2014 (km^2)	%(1)	Change (%) (2)
Professional	81,804.37	6.56	86,129.32	6.90	5.28
Traditional	266,114.17	21.32	168,191.53	13.48	-36.79
Mixed dairy-beef	232,879.01	18.66	266,812.98	21.38	14.57
Subsistence	388,092.92	31.10	291,660.80	23.37	-24.84

(1) Percentage relative to total area of Pará.
(2) Percentage of change in area with respect to the previous period.

Figure 4.4 – Cattle ranching systems identified in Pará. Spatialization using attributes for 2004 (left) and using attributes for 2014 (right). Values on top of each figure indicate the area occupied by each system, followed by percentage of change between years.



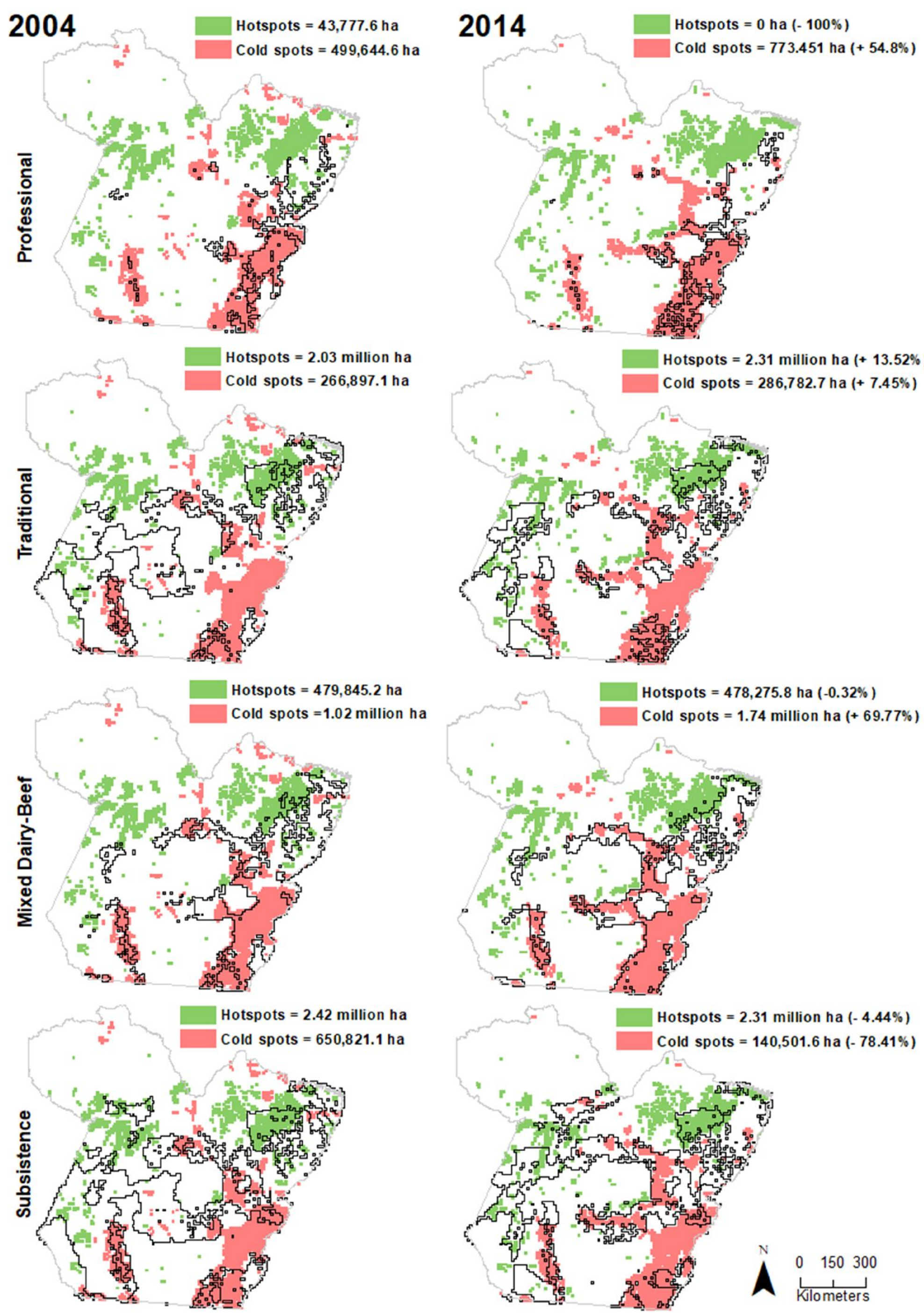
4.3.2 Spatial-temporal patterns of pastures and secondary vegetation in cattle ranching systems

Figure 4.5 shows clusters of low (cold spots) and high (hotspots) values of secondary vegetation in 2004 and 2014, superimposed over different cattle ranching systems. Figure 4.6 illustrates the quantitative changes of secondary vegetation (Figure 4.6.a) and pasture (4.6.b) in relation to the area of the system.

In agreement with our initial hypothesis, these results show how diverse spatial-temporal patterns of secondary vegetation are across cattle ranching systems. With respect to more technified systems (i.e. Professional and Mixed dairy-beef), although percentage of secondary vegetation in relation to deforested area remained basically the same between periods, the analysis of clusters unveils changes in their respective spatial patterns. As seen in Figure 4.5.a and 4.5.c, cold spots were particularly associated to these systems which, considering the area of the system, presented the highest percentages of these clusters (see also Figure 4.6.a). The area occupied by cold spots in these systems also increased over time (+54.8 and 69.77%), while the area under hotspots decreased in the same period, especially in the Professional system (Figure 4.5.b).

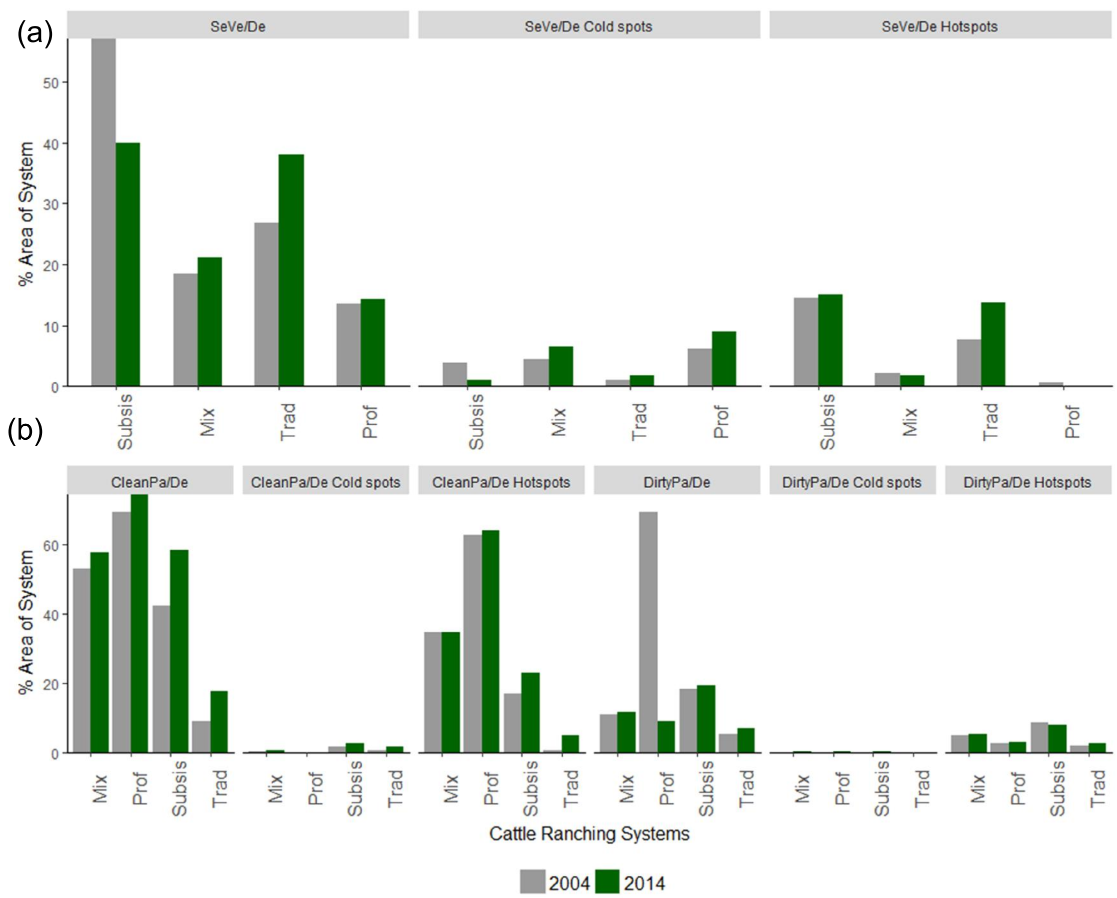
In less technified systems (i.e. Traditional and Subsistence), on the other hand, changes in area under cold spots reflected either small increases (+7.45% in the Traditional system) or decreases (-78.41% in the Subsistence system). In the Subsistence system, the observed drastic reduction seems however to be more related with the whole reduction of its area in the period (Table 4.3). With respect to hotspots, in the Traditional system the percentage of area under these clusters was slightly higher in 2014 in comparison to 2004 (+7.45%), while for the Subsistence system, it was detected a slight decrease in the total area under these clusters (-4.44%).

Figure 4.5 – Cattle ranching systems (black lines) superimposed over clusters of low (cold spots) and high values of secondary vegetation in 2004 (left) and 2014 *(*right*)*. Values on legends indicate area occupied by each type of clusters, followed by percentage of change between years.



Only the Subsistence system showed a considerable reduction in the area of secondary vegetation per deforested land over time. Notwithstanding, both less technified systems had more area under hotspots than under cold spots, showing an inverse pattern with respect to more technified ones.

Figure 4.6 – Representativeness of clusters of low (cold spots) and high (hotspots) values of secondary vegetation, clean and dirty pastures in pre (2004) and post (2014) law enforcement periods with respect to the area of the different systems: (a) Percentages of secondary vegetation per deforested area (SeVe/De) and of clusters of SeVe/De. (b) Percentages of clean and dirty pasture per deforested area (CleanPa/De and DirtyPa/De) and of respective clusters.



Another important result illustrated in Figure 4.6.b is that, between 2004 and 2014, the percentage of clean pasture per deforested land increased in all systems, reflecting the general expansion in-between. While more technified systems had higher percentages of their areas under hotspots of clean pastures, in less technified systems representativeness was lower although they increased between periods. Noteworthy is that the Professional system presented a dramatic reduction in the area under dirty pasture per deforested land, reinforcing the idea that investments in pasture recover were larger in this system.

4.3.3 Drivers of secondary vegetation dynamics in cattle ranching systems

In this section, we present our exploratory analysis of drivers correlated with clusters of low (cold spots) and high (hotspots) values of secondary vegetation in different cattle ranching systems in both pre (2004-2004) and post-law (2010-2014) enforcement periods. For a complete list of correlation values reported in this section see Appendix D.

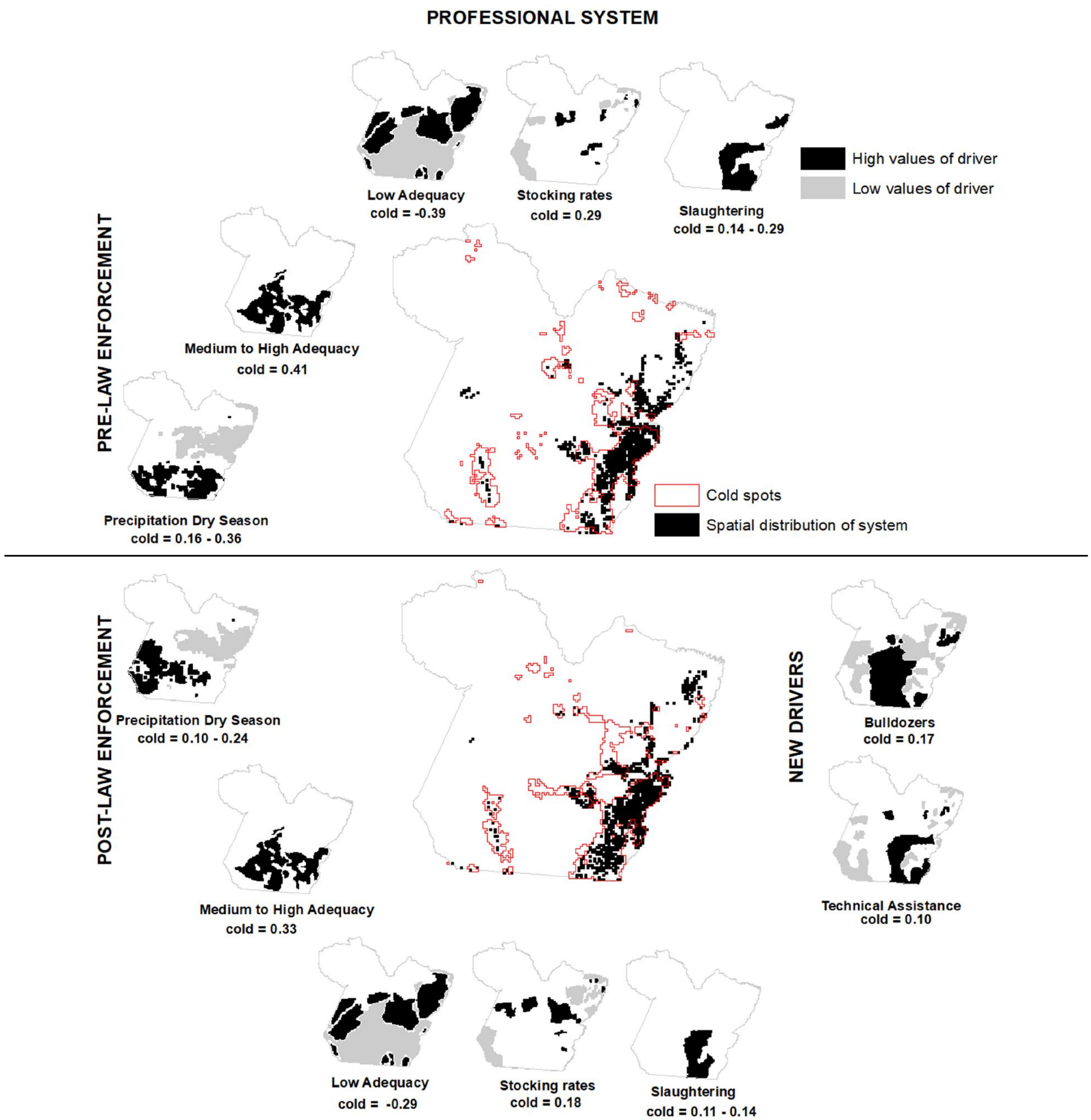
4.3.3.1 Professional system

In Figure 4.7 we present the spatial distribution of selected drivers (clusters of high and low values) related to cold spots of secondary vegetation in the Professional system in pre and post-law enforcement. Biophysical (agricultural adequacy and precipitation in the dry season), market (slaughtering), dynamics of herds (stocking rates) and technification (chemical fertilization) were the drivers correlated with cold spots in both periods. Technification drivers (use of bulldozers and access to technical assistance), on the other hand, were correlated with cold spots only after law enforcement. Concerning forest stocks, a positive correlation (0.12) was detected with hotspots but only in pre-law enforcement.

Precipitation in dry season and agricultural adequacy were detected in both periods as positively correlated with cold spots (Figure 4.7), what can be explained by the spatial distribution of this system which is concentrated on medium to high agricultural adequacy lands. Low adequacy, on the contrary, showed an inverse association with these clusters, being negatively correlated with them in both periods (Figure 4. 7), what may suggest that less regrowth has taken place in better agricultable lands. Other drivers detected as relevant in both periods were stocking rates and slaughtering, both positively correlated with cold spots in pre and post-law enforcement (Figure 4.7). Curiously, chemical fertilization was negatively correlated with cold spots in both periods (-0.15 and -0.19), an unexpected result because increased use of this input was supposed to positively contribute to pastures competitiveness thus favoring accumulation of areas of low values of secondary vegetation.

With respect to drivers associated with clusters in different periods, the use of bulldozers and access to technical assistance were correlated with cold spots after law enforcement but not associated with any clusters before that (Figure4.7). These results suggest a slightly increase agricultural inputs use. The VTN was positively correlated with cold spots only in pre-law enforcement (0.42), and negatively correlated with them after that (-0.16). INCRA settlements, on the contrary, which were not correlated with any clusters in pre-law, had negative correlations (-0.12) with them in the second period.

Figure 4.7 – Drivers of secondary vegetation dynamics in the Professional system. Spatialization of system andcold spots of secondary vegetation (center). Smaller maps show the spatial distribution of areas of high and low values of drivers in pre and post-law enforcement. For each driver, correlation values with clusters are presented.



4.3.3.2 Mixed-dairy beef system

In Figure 4.8 we present the spatial distribution of some of the drivers (clusters of high and low values) correlated to cold spots and hotspots in the Mixed dairy-beef system (center) in pre and post-law enforcement. Drivers correlated with clusters in both periods were biophysical (agricultural adequacy and precipitation in dry season), market (slaughtering), dynamics of herds (clean pasture, pasture dirty, stocking rates and herds), technification (chemical fertilization) and land tenure (VTN). On the contrary, dairy herds and dairy production were correlated with clusters only in post-law enforcement. In addition, forest stocks were negatively correlated with cold spots only in pre-law (-0.12).

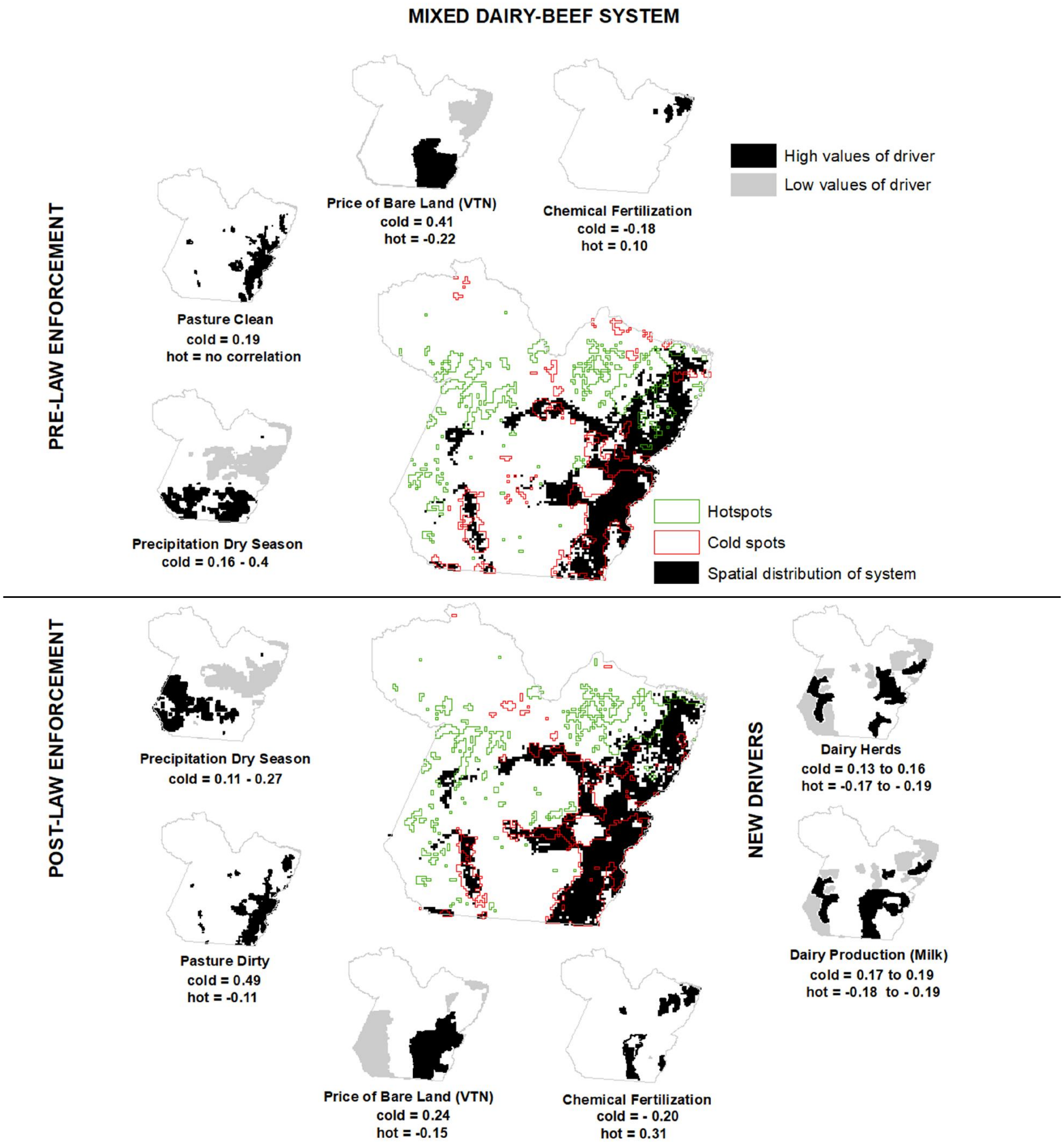
As seen before in the Professional system, cold spots also had in both periods positive correlations with precipitation in the dry season (Figure 4.8) and medium to high agricultural adequacy (0.41 and 0.34, respectively). Besides that, medium to high agricultural adequacy was negatively correlated (-0.14 and -0.12, respectively) with hotspots, while low agricultural adequacy was negatively correlated with these clusters (-0.35 and -0.30, respectively). Noticeable also is that the price of bare land (VTN) too had positive correlations with cold spots, and negative correlations with hotspots in both periods (Figure4.8). These results reinforce a pattern in which better and, as a consequence more valuable lands, potentially had less regrowth.

Chemical fertilization was in both periods negatively correlated with cold spots and positively correlated with hotspots (Figure4.8), what as previously stated was an unexpected result considering accumulated knowledge on the potential impacts of this practice against regrowth. Small-scale agriculture was also correlated with clusters in both periods, being positively associated with hotspots (0.26 to 0.47, respectively), and negatively associated with cold spots (-0.14 to -0.17, respectively).

With respect to the dynamics of herds, in both periods, clean pastures (Figure 4.8) and stocking rates were positively correlated with cold spots (0.15 and

0.13), and negatively correlated with hotspots (-0.12). While for dairy herds and dairy production, important variables describing this system, in post-law enforcement these drivers were positively associated to cold spots and negatively associated with hotspots (Figure 4.8). In this respect, these results suggest that expansion of ranching activities were relevant for the concentration of low values of secondary vegetation in this system.

Figure 4.8 – Drivers of secondary vegetation dynamics in the Mixed dairy-beef system. Spatialization of system, cold spots and hotspots of secondary vegetation (center). Smaller maps show spatial distribution of areas of high and low values of drivers in pre and post-law enforcement. For each driver, correlation values with clusters are presented.



4.3.3.3 Traditional system

Figure 4.9 brings the spatial distribution of some of the drivers (clusters of high and low values) correlated to cold spots and hotspots in the Traditional system (*center*) in pre and post-law enforcement. Drivers correlated with clusters in both periods were biophysical (medium to high adequacy, precipitation in rainy season, and forest stocks), market (slaughtering), dynamics of herds (herds, pasture clean and pasture dirty), land tenure (VTN and properties>1,001), law enforcement (embargo) and technification (chemical fertilization). Some of these drivers however had also different associations with clusters considering pre and post-law enforcement among these were law enforcement (embargo), technification (fire, herbicides, technical assistance and use of bulldozers), market (exports), and dynamics of herds (stocking rates).

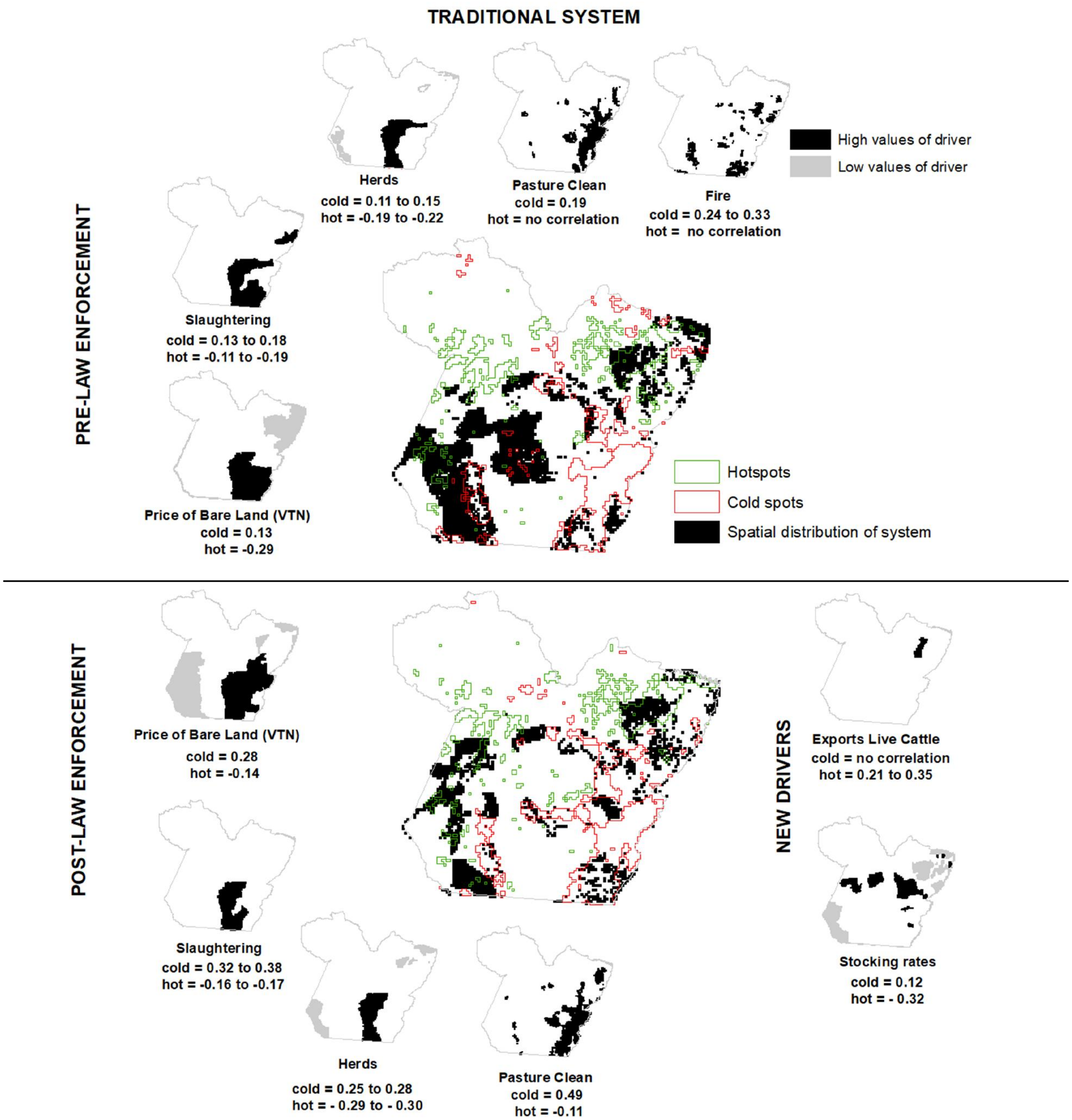
As previously shown for the Professional and Mixed dairy-beef systems, medium to high adequacy had a positive association with cold spots (0.33) and negative association with hotspots in pre and post-law (-0.23 and -0.15 respectively). In addition to that, as also seen for the other systems, the price of bare land (VTN) was also positively correlated with cold spots, and negatively correlated with hotspots in both periods (Figure 4.9), being these results an additional evidence that less regrowth could have taken place in more valuable lands. Similarly to what was previously seen in the Mixed dairy-beef system, herds and slaughtering were all positively correlated with cold spots, being negatively correlated with hotspots in both years (Figure 4.9), reinforcing that increases in herds were a potential driver of accumulation of areas of low values of secondary vegetation. Forest stocks were negatively correlated with cold spots in pre-law (-0.28), being unexpectedly negatively correlated with high values of secondary vegetation in both periods (-0.25 and -0.22, respectively).

Differently from other systems, drivers of law enforcement appeared as related to clusters in the Traditional system with embargoed areas being in both periods negatively correlated with hotspots (-0.10 to -0.20, and -0.12 to -0.18, respectively), and positively correlated with cold spots in pre-law enforcement (0.10 to 0.18).

Drivers having different patterns in-between included those describing the dynamics of herds (stocking rates) and technification (technical assistance and use of bulldozers). Stocking rates had negative correlations with hotspots and positive correlations with cold spots (Figure 4.9). The use of bulldozers (0.23) and technical assistance (0.28) were both positively correlated with cold spots in post law-enforcement. However, the use of bulldozers was identified also as negatively correlated with hotspots in both periods (-0.16 and -0.21). Differently from the other systems, exports of live cattle (Figure 4.9) and beef-leather (0.18 to 0.35) were positively correlated with hotspots in post-law enforcement. Considering that the northeast concentrates operations of two major feedlot facilities, this association should be carefully examined especially for exports of live animals, as it may be more an "artifact" of the spatial distribution of drivers and clusters than an indication of an association.

As also seen for the Mixed dairy-beef system, chemical fertilization was positively correlated with hotspots, with no correlation with cold spots being detected. By the same token, as previously detected in the Professional system, technical assistance (0.28) and bulldozers (0.23) were positively correlated with *cold spots*, being this last driver also negatively correlated with hotspots (-0.21) in post-law enforcement. Still with respect to technification, in pre-law enforcement the use of fire was found to be correlated with cold spots.

Figure 4.9 – Drivers of secondary vegetation dynamics in the Traditional system. Spatialization of system, cold spots and hotspots of secondary vegetation (center). Smaller maps show spatial distribution of areas of high and low values of drivers in pre and post-law enforcement. For each driver, correlation values with clusters are presented.



4.3.3.4 Subsistence system

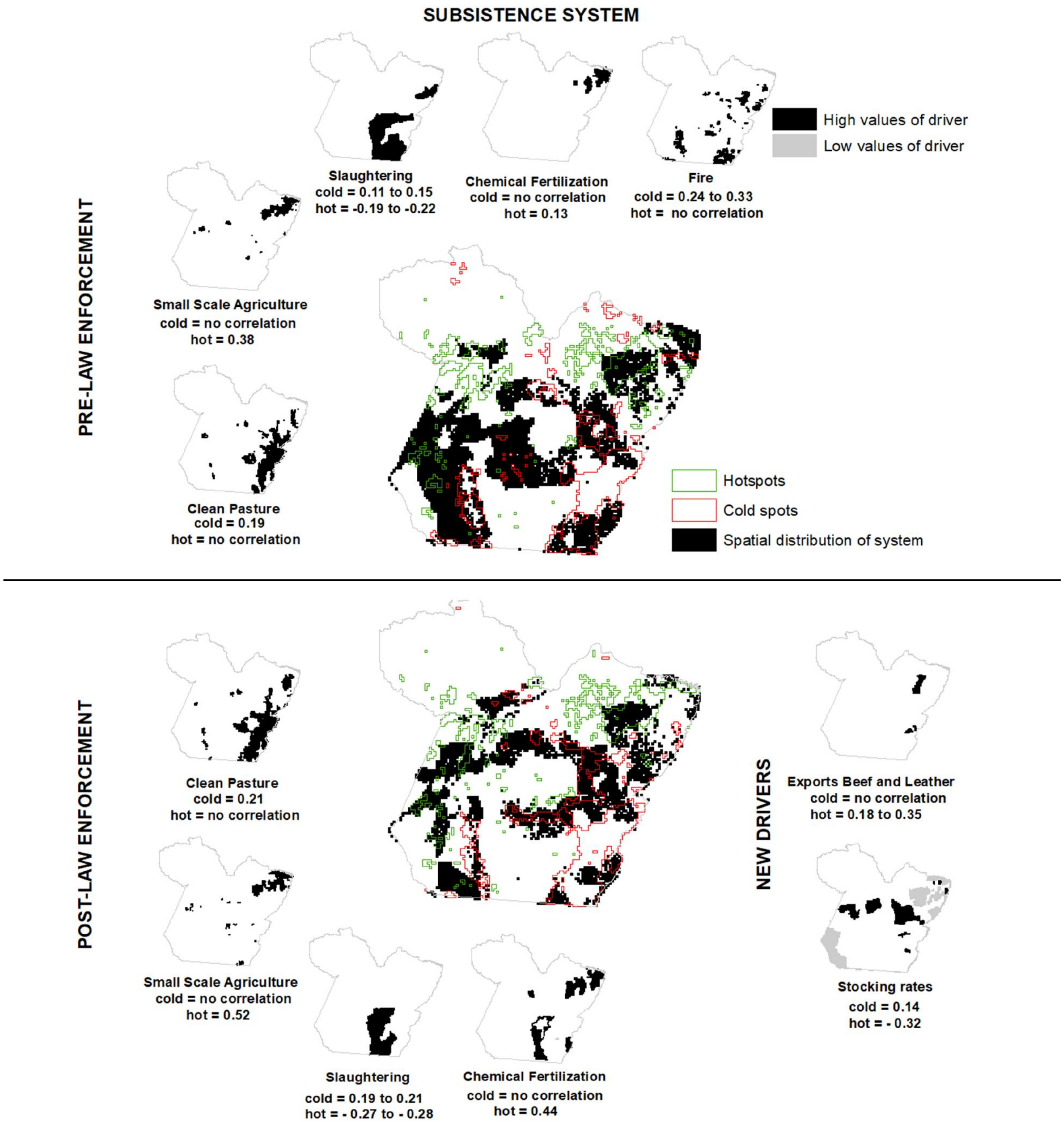
In Figure 4.10, we present the spatial distribution of some of the drivers (clusters of high and low values) found to be correlated with cold spots and hotspots in the Subsistence system (center) in pre and post-law enforcement. Drivers correlated with clusters in both periods were market (slaughtering), dynamics of herds (herds), land tenure (VTN and properties under 500-100 ha and >1,001 ha), and technification (chemical fertilization). Similar to the Traditional system, drivers of technification (fire and herbicides), market (exports), and dynamics of herds (stocking rates) had different associations with clusters between periods, showing a pattern similar to the one described. Forest stocks as well were negatively correlated with high values of secondary vegetation in post-law enforcement.

As seen in other systems, in both periods, not only the price of bare land (VTN) was positively correlated with cold spots (0.13 and 0.15) and negatively associated to hotspots (-0.29 and -0.10 respectively), but we also detected that high adequacy was negatively correlated with hotspots (-0.23 and -0.12). Similarly, as seen in the Mixed dairy-beef system, small-scale agriculture was positively correlated with hotspots and negative correlated with cold spots (Figure 4.10). This is an interesting finding which corroborates previous studies highlighting the importance of small-scale agriculture to the concentration of high values of secondary vegetation. With respect to law enforcement, as seen in the Traditional system, embargoed areas was in both periods negatively correlated with hotspots (-0.10 to -0.19 respectively) and positively correlated with cold spots in pre-law enforcement (0.10 to 0.18).

Herds, clean pasture and dirty pastures were all positively correlated with cold spots, and negatively correlated to hotspots in both periods. Also, as seen in the Traditional system, stocking rates were found to be positively correlated with cold spots in post-law enforcement, having a negative association with hotspots (Figure4.10). These results reinforce that the expansion of ranching was related with secondary vegetation dynamics. Also seen in the Traditional system, exports had a positive correlation with hotspots in both periods (Figure4.10).

With respect to technification, chemical fertilization was, as seen for other systems, positively correlated with hotspots although no correlation with cold spots was detected (Figure4.10). Still with respect to technification, as detected for the Traditional system, in pre-law enforcement use of fire was correlated with cold spots, while herbicides were, on the other hand, positively correlated with hotspots (Figure 4.10).

Figure 4.10 – Drivers of secondary vegetation dynamics in the Traditional system. Spatialization of system, cold spots and hotspots of secondary vegetation (center). Smaller maps show spatial distribution of areas of high and low values of drivers in pre and post-law enforcement. For each driver, correlation values with clusters are presented.



4.4 Discussion

Assuming the dynamics of secondary vegetation as an outcome of the decisions of actors with respect to the techniques and purposes applied to a land-cover which define different land-use systems (LMABIN, GEIST; LEPERS, 2003; LAMBIN et al., 2001; LAMBIN; GEIST, 2006), we used a spatial distribution of cattle ranching systems to investigate the spatial-temporal dynamics of clusters of low and high values of secondary vegetation in relation to total deforested area, and to analyze whether law enforcement implied differences in drivers associated to these dynamics.

Although, so far no investigations have approached the dynamics of secondary vegetation under different land-use systems in this level of detail, our results corroborate some previous findings. Our results show that more technified systems were not only associated with low values of secondary vegetation, but also with high values of clean pasture, an inverse pattern as observed in less technified systems. In addition, the area concentrating low values of secondary vegetation also increased over time in more technified systems, suggesting that indeed increased adoption of high impact techniques to preclude degradation took place in-between periods. Also noticeable was that the area of high values of dirty pasture dramatically decreased in the Professional system under which high impact techniques to preclude regrowth were expected to have a high impact. Land-use intensification as a potential factor precluding regrowth and accumulation of secondary vegetation was already identified in other Amazon regions, especially when connections with market are stronger (MELLO and ALVES, 2011; ALVES et al., 2007; FAMINOW, 1998), which is precisely the case of more technified systems identified in Pará which, as seen by their spatial distribution, coincide with better infrastructure, facilitated access to consumer markets and network of major slaughtering and dairy facilities.

Despite considering systems as separate units, as showed by their spatial distribution, they overlapped in both space and time and, regardless their particularities, common drivers were associated with clustering of low and high values of secondary vegetation in different systems. Among these, noteworthy to be mentioned are forest stocks, agricultural adequacy, price of bare land and slaughtering which had the same persistent patterns of association with clusters in both pre and post-law enforcement periods.

Among biophysical factors influencing regrowth, reduced forest stocks negatively affect several ecological processes related to regeneration (AIDE; CAVALIER, 1994; NEPSTAD et al., 1996; HOOPER et al., 2005).Although in agreement with the results of our field-work (Chapter 3) deforestation was reported as currently low to moderate in all systems, more technified systems were concentrated to the Southeast and Northeastern regions, where as a result of a longer history of occupation, primary forests are already reduced. Less technified systems, on the other hand, had a more widespread distribution that included regions with large forest stocks. Notwithstanding, the general pattern was of negative correlations between forest stocks and low and high values of secondary vegetation what, considering the accumulated knowledge on the importance of forests stocks to regrowth, this was an unexpected result for whattwo possible intepretations can be outlined.As previously mentioned secondary vegetation represents mostly a by-product of deforestation therefore more primary forests means that less deforestation may be taking place explaining the negative correlations foundwith clusters of high values. On the other hand, negative correlations between low values of secondary vegetation suggests that reduced forest stocks, being associated with more expensive lands and more intensive systems,would thus imply in precludedregrowth.

Some authors have emphasized the role light heavy rains and steeper slopes play with respect to increased land-abandonment thus working as positive factors favoring regrowth (ASNER et al., 2009; LAUE; ARIMA, 2014; PERZ; SKOLE, 2003). Heavy rain regimes, for instance, by accelerating soil degradation and propagation of plants and animals´ diseases stimulate early land abandonment, favoring regrowth (LAUE; ARIMA, 2014; PERZ; SKOLE, 2003). Steeper sloped lands were found to negatively affect recruitment of seedlings (BENTOS et al., 2014) being also related to land abandonment, especially concerning increased demand for the use of technification (BENAYAS et al., 2007; LAUE; ARIMA, 2014;SPERA et al., 2014). Considering agricultural adequacy as a measure of how biophysical factors affect the success of productive activities, our results go in hand with these evidences as they suggest not only that lands with medium to high agricultural adequacy had less regrowth, but also that lands with lower adequacy, on the other hand, had more regrowth. Still, it is also relevant that the price of bare land (the VTN) had also positive associations with cold spots, and negative associations with hotspots in all systems. In this vein, considering that better lands are expected to have higher prices in the land market, these associations also reinforce that less regrowth may have taken place in best, and as consequence, more valuable lands, either as a result of improved management or higher agriculture adequacy (i.e. better rain regimes, slope and fertility).

As discussed in Chapter 3, although predominantly a large-scale land-use, cattle ranching operations also respond to diverse local and regional contexts either with respect to background of actors or access to market and pressure of law enforcement which are factors that, as previously discussed were identified as important forces behind decisions shaping different land-use strategies over time. Although some drivers proved to be relevant for all systems, we have also detected specificities in associations of drivers and clusters of secondary vegetation in different systems. In large-scale systems, for instance, drivers of technification such as the use of bulldozers and access to technical assistance were positively correlated with cold spots in post-law enforcement, what goes in hand with our results presented in Chapter 3 showing that increased pressure against deforestation was a stimulus for actors to improve pasture management. Although few studies about the responsiveness of actors at local scales to law enforcement are available, evidences show that the deterrence effect of field-based operations tended to be stronger where opportunity costs of compliance were higher, either due to confiscation of equipment or higher costs of fines (BORNER et al., 2014; 2015). This applies to large-scale systems, especially when located in regions with better access where opportunity costs of compliance are indeed higher. In a scenario of pressure to coerce deforestation, the progressive adoption of more intensive practices and techniques to deal with pasture degradation, instead of expansion of pastures over newly deforested lands may be a worthy strategy.

In small-scale systems, on the other hand, the area under small-scale agriculture proved to be a relevant driver of accumulation of secondary vegetation, having a positive association with hotspots, corroborating previous studies showing that small properties and prevalence of small-scale agriculture favor the accumulation of secondary vegetation (AGUIAR et al., 2007; PACHECO, 2009, ALMEIDA et al., 2010). Although this pattern was also detected for the Traditional system, considering that there is an overlapping between systems, we assume this is more an artifact of its spatial distribution than an intrinsic feature of this system.

As different authors have emphasized, the use of fire has been historically connected with the implementation and management of pastures in the Amazon region, being also an important factor precluding regrowth in abandoned lands as, among other negative impacts, it reduces seeds availability, survivorship and growth of seedlings of tree species after long-term use (> 10 years), also eventually reducing sprouting (NEPSTAD et al., 1996; UHL, 1987; UHL,BUSCHBACHER; SERRÃO, 1988; UHL et al., 1988; MORAN et al., 1994). In less technified systems, in pre-law enforcement, the use of fire was associated with cold spots of secondary vegetation, reinforcing that this practice is indeed effective against regrowth. With respect to changes in practices and techniques however, it should be carefully examined because, although it may suggest that law enforcement could have worked as an incentive to reduce the use of fire, this practice, as discussed in Chapter 3, was not abandoned at all. Still, with respect to law enforcement, only in less technified systems we could detect an association between clusters and embargo, while for other systems drivers of law enforcement (i.e. embargo and slavery) were only occasionally associated with clusters, with no pattern being detected. In this regard, as different authors have discussed (ARIMA et al., 2014; BORNER et al. 2014; 2015) base-field operations tend to be concentrated in active deforestation frontiers which, considering our systems spatialization applies better to less technified systems than to more technified ones which are concentrated in areas where deforestation is currently less intense.

4.5 Concluding remarks

The primary focus in this chapter was, based on the spatialization of cattle ranching systems, to understand changes in secondary vegetation considering the heterogeneity of cattle operations over time. In this context, our results uncovered relevant associations between cattle ranching systems and the dynamics of secondary vegetation, especially regarding the representatives of clusters of low and high values of secondary vegetation and pastures in more and less technified systems, and distinct associations of drivers regarding different systems. Although the observed associations of agricultural adequacy, price of bare land and the expansion of herds with low and highvalues of secondary vegetation can be connected to law enforcement in the sense that higher agricultural adequacy, more valuable lands and large herds are also assets at stake in face of non-compliance, we conclude that, regardless the scale, cattle operations respond to a much more complex process of decision making which goes beyond law enforcement.

5 CONCLUSION

In this thesis I investigated the heterogeneity of processes underlying secondary vegetation dynamics in cattle ranching systems in Pará, with a particular focus on the potential impacts of the strategies of actors to cope with pasture degradation. Having in mind that more than 60% of all cleared lands in the Brazilian Amazon were already deforested for pastures and that, mostly, secondary vegetation is a by-product of this process, cattle represents a major force behind regrowth. As evidences of the effectiveness of legal and alternative coercive measures against deforestation accumulated, together with different analysis suggesting intensification in cattle ranching, it seemed logic that an investigation of the connections among these three components i.e. law enforcement, secondary vegetation and cattle should focus on the process of pasture degradation. Approaching such a complex phenomenon however required not only choosing the appropriate tools of investigation but also that these tools could be combined in an interdisciplinary approach which also respected the spatial and temporal scales in which this phenomenon took place. In this vein, this final chapter was organized as follows: in the first section I summarize my major findings and discuss how they relate to the initial hypothesis underlying this research. In this section, I also highlight the main contributions this work adds to knowledge so far accumulated concerning the three components investigated. In the second section, I discuss some of the limitations and implications with respect to the methods adopted in this investigation. In the final section, based on my findings and methods adopted I identify opportunities for future research in this field.

5.1 Hypothesis and major findings

This thesis was structured to investigate the hypothesis that following increased law enforcement, the historical pattern of secondary vegetation accumulation, observed until the beginning of the 2000s changed. In a scenario of increased pressure against deforestation, unable to continually expand pastures over newly deforested lands, as customarily done in the past (BOWMAN et al., 2012;

COSTA, 2004; ESCADA et al. 2007; HECTH, 1983; 1995; WALKER et al. 2009), actors were forced to adopt more intensive practices and techniques to cope with pasture degradation what, as a consequence, negatively impacted regrowth and secondary vegetation. However, considering the local and regional diverse contexts in which cattle ranching is developed, results indicate that these changes were not widespread but instead restricted to regions where connections with major slaughterhouses and law enforcement were stronger. On the contrary, in regions where law enforcement was weaker or prevailing market connections were less restrictive, traditional and less intensive practices and techniques still imply concentration of secondary vegetation.

As a first step to explore this hypothesis (Chapter 2) I analyzed the spatial-temporal patterns of secondary vegetation in Pará during the last decade, identifying how regional prevailing land-uses such as small-scale agriculture, and industrial agriculture (mechanized agriculture and palm oil), and cattle ranching were related to clustering patterns of secondary vegetation. In this respect, using tools to investigate the spatial clustering patterns of these different land-uses, I found that clusters of high values of secondary vegetation in relation to the deforested area (hotspots of SeVe/De) prevailed in the north of Pará, while clusters of low values (cold spots of SeVe/De) prevailed in the south, a pattern explained by distinct stories of occupation and deforestation dynamics, but also by regional differences in prevailing land-uses. I showed that after 2010, the progressive expansion of pastures, mechanized and industrial agriculture was somehow accommodated in already previous cleared lands and, that under this new dynamics, more secondary vegetation was re-converted into pastures and industrial agriculture.

Conversions of small-scale agriculture, dirty and under regeneration pastures were also relevant to allow the expansion of these covers. Pastures proved to be an important driver of changes in secondary vegetation, not only due to the expansion of clean pastures over secondary vegetation in the south, but also as a result of the conversion of pastures under regeneration into secondary vegetation in the north. In this respect, these results support our hypothesis in the sense that evidences are that not only large-scale agriculture advanced over secondary vegetation, but also that cattle ranching, instead of progressively adding more area to it, on the contrary, also expanded over these areas. In addition, our results showed that dirty and under regrowth pastures were important in these dynamics, suggesting that more effective practices in precluding pasture degradation were, to some extent, indeed adopted.

It is important to mention that so far, this is the only investigation focusing the dynamics of secondary vegetation under a scenario of law enforcement against deforestation. As a first main contribution of my thesis, these results are important not only to improve our comprehension on the dynamics of secondary vegetation in a different scenario (i.e. reduced deforestation) but also regarding potential effects of environmental policies implemented in the Amazon region.

Following that, I started then to focus on the specific dynamics of cattle operations. Here, I used dynamics of herds and insertion in the network of major slaughterhouses to define the best sites to investigate how differences in cattle operations could be related to the clustering patterns identified in Chapter 2. I reconstructed the unfolding dynamics of cattle operations in nine different sites and three different regions of Pará, being also able to characterize actors involved in small, medium and large cattle operations. Besides describing the motivations, beliefs and strategies of actors, I classified the systems these actors operate and quantified the use of practices and techniques applied in pasture management. The systems identified were: Subsistence, Mixed dairy-beef, Traditional and Professional. Finally, based on accumulated knowledge on regrowth, I analyzed the potential impacts of strategies adopted in the different systems. I concluded that impacts were restricted to regions where farming background of actors and predominance of market connections with industrial slaughterhouses favored the emergence of the Professional system, and also under areas where the Mixed dairy-beef system is found. In other regions, although some highly effective practices and techniques were reported, pastures are still predominantly managed with low impact practices to preclude degradation. Therefore, all systems considered, the role of cattle in reducing regrowth and secondary vegetation is in general limited, as different levels of technification still co-exist in space and time. In this respect, results also support my hypothesis, especially when considering that the spatial distribution of more technified systems largely overlapped clusters of low values of secondary vegetation.

These results are an important contribution to understanding how cattle operations have taken place in the Brazilian Amazon during the last decades, as I have not only focused on the technical aspects of this land-use, but also reconstructed the historical contexts in which ranching emerged, and accessed valuable data about actors, putting some light on the decision making process in which they are crucial. I emphasize that until now, discussions around cattle ranching have mostly being focused on its role as a major driver of deforestation, with very few studies (ADAMS, 2010; 2015; HOELLE, 2011; 2015) having investigated actors and how their respective backgrounds, trajectories and perceptions relate to the decision making process behind cattle ranching.

As a final stage in building this thesis (Chapter 4) I combined the spatialization of systems identified in Pará with an analysis of the spatial-temporal responses of secondary vegetation in each system. I was able to uncover relevant associations between cattle ranching and the dynamics of secondary vegetation and pastures, especially with respect to the representativeness of clusters of low and high values of secondary vegetation and clean pasture. In this sense, while low values of secondary vegetation and high values of clean pasture were better represented in more technified systems, an inverse pattern was found for less technified systems in which clusters of high values of secondary vegetation and clusters of low values of clean pasture were better represented. Following that I performed an exploratory analysis of a comprehensive dataset to access positive and negative associations of variables in six categories of drivers with the clusters of low and high values of secondary vegetation. Despite some of the observed associations suggest that law enforcement worked as a turning point of changes in actors´ strategies, results of exploratory analysis are not conclusive to confirm the hypothesis that law enforcement was the major force behind decisions of actors in adopting high impact practices and techniques to deal with pasture degradation, with decision making proving to be more complex, going beyond responsiveness to law enforcement

5.2 About methods: limitations and implications

A major limitation faced in this work was the impossibility of performing a classification of land-cover data time-series to support the performed analyses. Classification of land-cover data is time costly and, if not appropriately performed implies serious wrong inferences which can jeopardize any investigation (CONGALTON and GREEN, 2008). Therefore, as described in Chapter 1, land-cover data used in all analyses was obtained from the TerraClass Initiative (TC), a long-term project of land-cover/land-use classification of deforested areas which provides data for 15 different land-cover classes (ALMEIDA et al., 2016). Data on palm-oil used in Chapter 2 was obtained from Benami et al (2018) which provides land-cover data of palm oil crops covering the period between 1998 and 2012.

In this respect, I rigorously observed the description of classes provided by supporting material (BENAMI et al., 2018; TERRACLASS, 2008) and, in addition, for a better understanding of the implications and possible limitations in using previously classified data, I performed a thematic accuracy analysis for 2012. Based on the representativeness of each class, I generated a list of random points, which were validated using RapidEye images. Based on this validation, I calculated the Cohen´s Kappa coefficient to estimate accuracy. The sample of 381 random points validated, returned a 64.6% overall accuracy, with annual agriculture (89.7%), secondary vegetation (70.7%) and clean pasture (56.4%) presenting the best levels of agreement. Although after joining the four original classes of pasture, a second error matrix returned a 77.7% overall accuracy, with increases in levels of agreements for two of the three main classes of interest i.e. secondary vegetation (70.7%) and pasture (69.5%), I maintained the original classification scheme as it is presented in Chapter 1. For more details of this analysis of accuracy see Appendix E.

A second important choice I have done in building this thesis was to adopt semi-structured interviews based on guiding questions instead of closed-questionnaires (HOELLE, 2011; 2015; BERNARD, 2006; PIKETTY et al., 2005; KELLEY et al., 2003; BARRIBALL; WHILE, 1994). When using closed-questionnaires, the investigator has control of the sample, as incomplete or non-valid responses are, following the standard procedure, eliminated. Hence, the final sample is represented only by valid and complete questionnaires. On the other hand, closed-questionnaires are based on pre-defined categories which should be carefully structured otherwise there is a considerable risk of losing valuable information, in the sense that data not fitting in any pre-defined category cannot be integrated to the sample.

As explained in Chapter 3, a primary disadvantage of semi-structured interviews resides precisely in having limited control over sampling because although I was able to interview 94 informants in the nine study sites, computing a total of 133 valid responses, I used response rates (RR) (BARRIBALL; WHILE, 1994; BARUCH, 1999; KELLEY et al., 2003) to standardize data quantification by giving, in terms of percentage, an idea of the universe of responses (samples) from which data was extracted. In this respect, with some exceptions, response rates were coherent inside each category, although diverse among different ones, what to a large extent can be explained by the sensitiveness of some of the aspects investigated especially size of herds (sensitive with respect to taxes and vaccination), and use of fire, deforestation, and suppression of secondary vegetation (sensitive for being environmental offences).

Spatializing cattle ranching systems and defining drivers and respective variables was the third important step in building this thesis (Chapter 4). To my knowledge, few works had so far used spatialization to represent systems and investigate processes related to them. Almeida et al (2016), for instance, adopted a decision-tree approach using land-use maps from remote sensing data of the TerraClass initiative, combined with economic data, to reconstruct the regionalization of agricultural production in Rondônia. ARAÚJO (2018) also using a decision-tree procedure built a typology of cattle ranching systems as part of an investigation on how the hydrological cycles in the Pantanal biome related to different strategies of actors in these systems. In this thesis, I adopted an interdisciplinary approach in which, using a classification of systems developed based on field-work I defined thresholds for variables specifically related to cattle ranching.

The major implication of this procedure resides in, although I adopted a fragmented approach of analysis assuming each system as a separate unity and analyzed associations of variables considering each data set as unique, systems, to various extents, overlap and interact, also sharing common data-sets. In this context, the impacts of drivers analyzed using this spatialization also overlaps but not necessarily operate simultaneously in both space and time, being possible that some of them can take place through path dependency i.e. the outcomes of a processes in the future being determined by past trajectories. In this context, ideally dataset preparation should consider using regional sets of data what is unfeasible as most data collection is done in the scale of municipalities.

5.3 Opportunities for future research in this field

In this section I point out the main possibilities for future investigations regarding the three components approached in this investigation i.e. law enforcement, secondary vegetation and cattle ranching systems.

(i) Updating the data-set to include the recently publicized Rural Census 2018 would add a considerable amount of information not only with respect to technification but also to land tenure after law enforcement. As previously mentioned, data used to analyze changes in the adoption of technification were based on Census 2006 which, although have captured the effects of law enforcement in place since 2004, does not reflect law enforcement targeting the beef production chain after 2009. With respect to land tenure (i.e. size of properties), in spite of having used data provided by CAR in 2016, data on land tenure in Census 2017 could be useful to validate this information which, as result of several technical and political issues, has been questioned.

(ii) Improving the quality of stocking rates data could be also very useful for the quality of the data-set. On this respect, the gap of information about productive indexes in cattle operations compromises many initiatives related to this activity including research.

(iii) Regarding the use of modeling tools to test the hypothesis explored in this thesis, an Agent Based Model (ABM) would be the most appropriate to represent and test processes investigated in this thesis because these models allow an explicit representation of simple and complexes processes related to human decision making. Allying real premises and data simulations, the ABM aggregate cells represent the land-use and a component representing the decision making processes by an agent.

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APPENDIX A – CLUSTERS OF HIGH AND LOW VALUES OF SECONDARY VEGETATION IN RELATION TO TOTAL DEFORESTED AREA (2008 – 2012)

Figure A.1 - Clusters of secondary vegetation secondary vegetation (SeVe) in (a) 2008, (b) 2010 and (c) 2012; Clusters of secondary vegetation per deforested area (SeVe/De) in (d) 2008, (e) 2010 and (f) 2012.

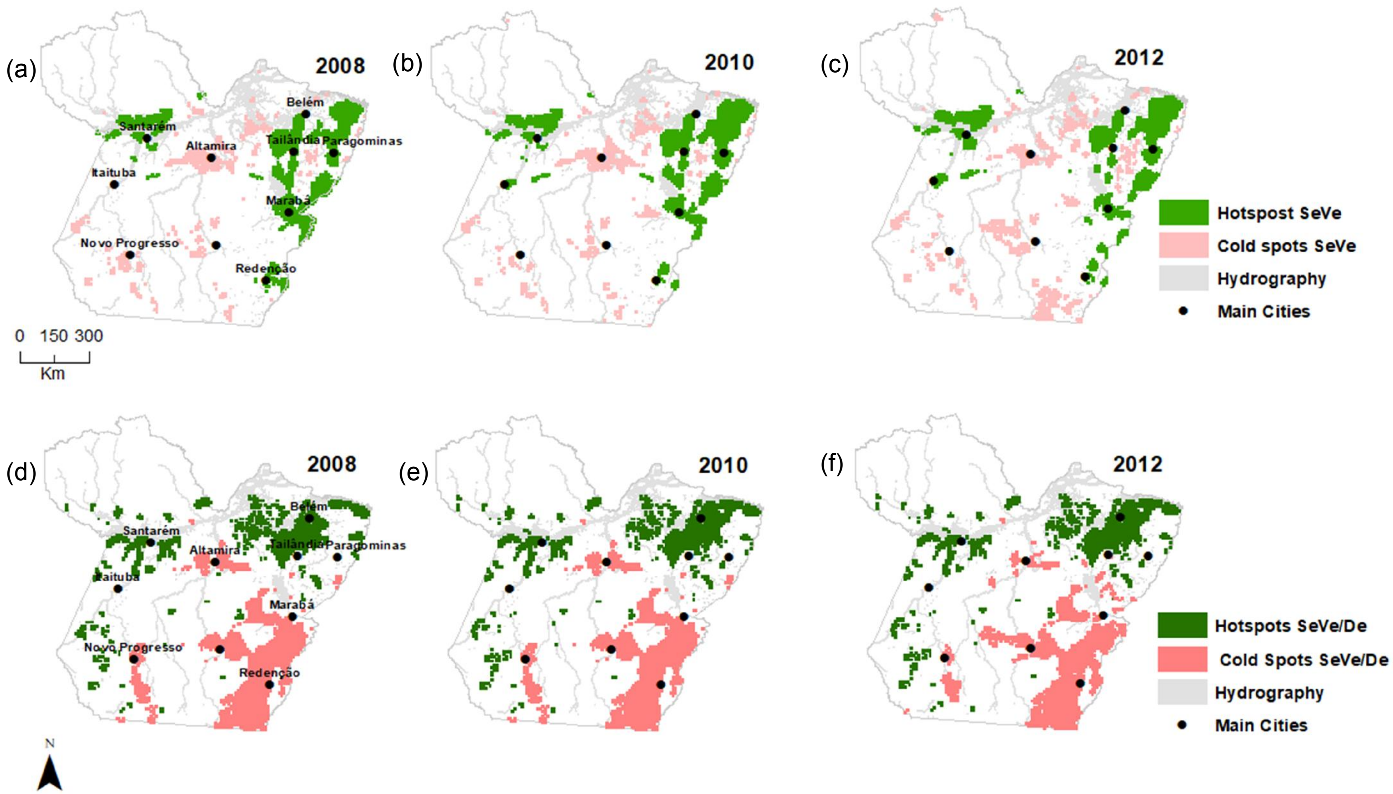


Figure A.2 - Clusters of pasture superimposed over clusters of secondary vegetation in 2008, 2010 and 2012. Clean pasture (PaClean) (a, b and c); Dirty pasture (PaDirty) in (d, e and f); and Regeneration with pasture (PaRe) (g, h and i).

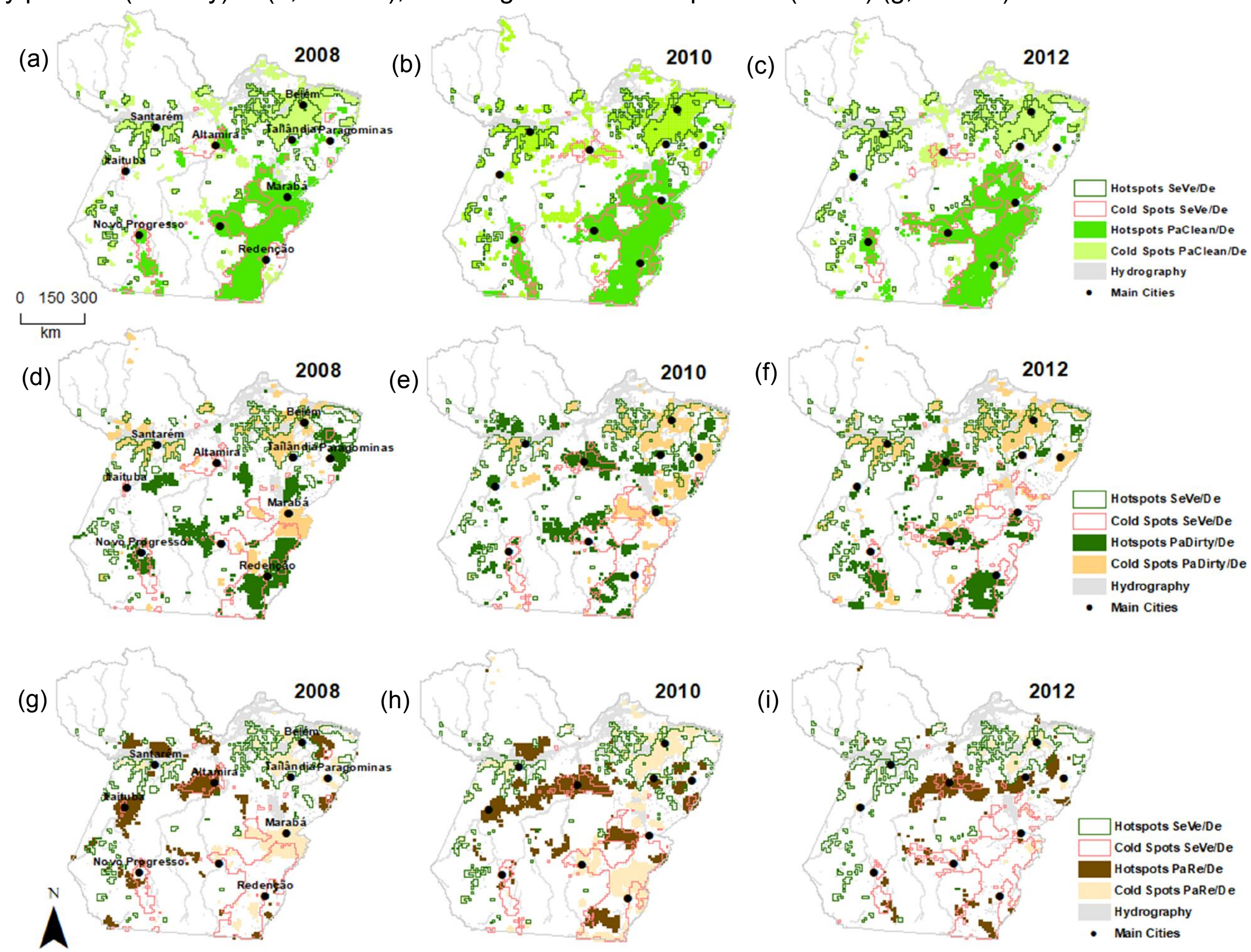
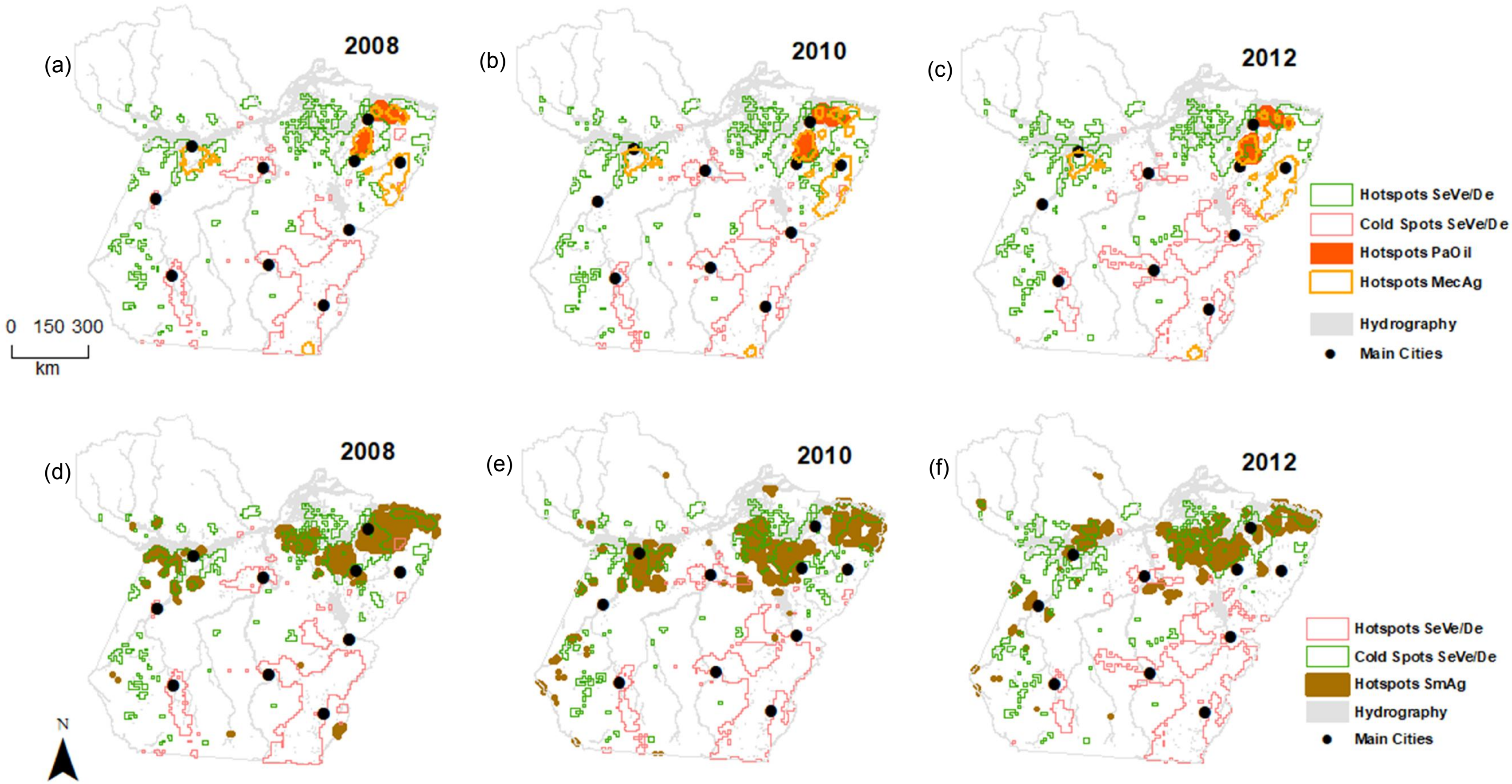


Figure A.3 - Clusters of secondary vegetation and agriculture in 2008, 2010 and 2012. Hotspots of industrial agriculture (MecAg) and palm oil (PaOil) (a, b and c); Hotspots of small-scale agriculture (SmAg) (d, e and f).



APPENDIX B – ACTORS´ PROFILE, CHARACTERISTICS OF CATTLE RANCHING SYSTEMS, AND ENVIRONMENTAL STRATEGIES. NR = NUMBER OF AFFIRMATIVE RESPONSES; RR = RESPONSE RATE.

	NR Professional	RR (%)	NR Traditional	RR (%)	NR Medium	RR (%)	NR Mixed dairy-beef	RR (%)	NR Subsistence	RR (%)
Actors										
Education	16	57.1	22	62.9	10	43.5	12	41.3	8	50.0
Formal Education	11	68.8	6	27.3	0	0.0	0	0.0	0	0.0
No Formal Education	5	31.3	16	72.7	10	100.0	12	100.0	8	88.9
Background	21	75.0	27	77.1	12	52.2	16	55.1	16	100.0
Farming	19	90.5	12	44.4	6	54.5	13	81.3	6	37.5
No Farming	2	9.5	15	55.6	6	54.5	3	18.8	10	62.5
Profile	26	92.9	29	82.9	11	47.8	17	58.6	17	89.5
Traditional rancher	19	73.1	13	44.8	2	18.2	0	0.0	0	0.0
Small farmer	0	0.0	0	0.0	3	27.3	15	88.2	6	35.3
Diverse background	0	0.0	14	48.3	6	54.5	2	11.8	11	64.7
Private company	7	26.9	2	6.9	0	0.0	0	0.0	0	0.0
Properties and herds										
Property size	7	25	16	45.7	15	65.2	24	82.7	19	100
Minimum (ha)	350		200		95.9		21.8		5.0	
Maximum (ha)	9,000		10,000		1,000		645.8		336	
Herds size	6	21	15	43	23	100	21	72.4	11	57.89
Minimum	700		250		50		6		100	
Maximum	3,400		5,000		500 - 1,000		550		200	
Stocking rate (AU/hectare)	13	46.42	16	45.71	21	91.3	29	100	11	57.89
Minimum	0.5	1.0	0.6	0.6	0.3	0.5	0.1	0.2	0.2	0.3
Maximum	5.4	5.4	5.0	5.0	3.5	3.5	3.5	3.5	2.0	2.0
	NR Professional	RR (%)	NR Traditional	RR (%)	NR Medium	RR (%)	NR Mixed dairy-beef	RR (%)	NR Subsistence	RR (%)
Beef cycle and market connections										
Beef cycle	26	92.9	35	100.0	19	82.6	27	93.10	16	84.2
Cow-calve	1	3.8	4	11.4	8	42.1	26	96.3	16	100.0
Full cycle	18	69.2	16	45.7	9	47.4	0	0.0	0	0.0

continue

continuation

Backgrounders	0	0.0	1	2.9	0	0.0	0	0.0	0	0.0
Finishing	6	23.1	11	31.4	2	10.5	0	0.0	0	0.0
Purebred animals (full cycle)	1	3.8	3	8.6	0	0.0	0	0.0	0	0.0
Market connections	33	117.9	29	82.9	12	52.2	16	55.1	15	78.9
Slaughts Major	22	66.7	6	20.7	1	8.3	1	6.3	0	0.0
Slaughts Local	1	3.0	5	17.2	2	16.7	0	0.0	1	6.7
Cattle dealers	2	6.1	9	31.0	5	41.7	12	75.0	12	80.0
Live Cattle	7	21.2	8	27.6	4	33.3	3	18.8	2	13.3
Purebred animals	1	3.0	1	3.4	0	0.0	0	0.0	0	0.0
Pastures and herds management										
	NR Professional	RR (%)	NR Traditional	RR (%)	NR Medium	RR (%)	NR Mixed dairy-beef	RR (%)	NR Subsistence	RR (%)
Reproduction technique	22	78.6	21	60	13	56.5	22	75.8	16	84.2
Natural Mating	0	0.0	3	14.3	6	46.2	21	95.5	15	93.8
Mating Station	2	9.1	2	9.5	1	7.7	1	4.5	1	6.3
IATF/IA and FIV	20	90.9	16	76.2	6	46.2	0	0.0	0	0.0
Nutrittional Supplem	23	82.14	22	62.85	12	52.17	14	45.16	8	42.10
% of Use	23	100.0	16	72.7	6	50.0	6	42.9	5	62.5
Semi-confinement	23	82.14	30	85.71	17	73.91	24	77.41%	16	84.21
% of Use	17	73.9	1	3.3	1	5.9	0	0	0	0
Pastures management techniques										
	NR Professional	RR (%)	NR Traditional	RR (%)	NR Medium	RR (%)	NR Mixed dairy-beef	RR (%)	NR Subsistence	RR (%)
Soil analysis	13	46.42	18	51.42	15	65.21	15	51.72	14	73.68
% of Use	12	92.3	2.00	11.1	3	20.0	2	13.3	0	0
Ph Correction	19	67.85	19	54.28	16	69.56%	17	58.6	13	68.42
% of Use	19	100.0	11	57.9	4	25.0	5	29.4	0	0
Chem. fertilization	20	71.42	24	68.57	16	69.56	20	68.9	13	68.42
% of Use	20	100.0	13	54.2	6	37.5	9	45.0	0	0
Fire	13	46.4	18	51.4	10	43.5	14	48.2	9	47
% of Use	2	15.4	10	55.6	6	60.0	8	57.1	6	66.7
Manual weeding	15	53.6	14	40.0	6	26.1	12	38.7	14	73.7

continue

continuation

% of Use	0	0.0	5	35.7	3	50.0	9	75.0	10	71.4
Mech.weeding	20	71.4	21	60.0	14	60.9	17	58.6	11	57.9
% of Use	20	100.0	20	95.2	10	71.4	8	47.1	4	36.4
Pastures management techniques										
	NR Professional	RR (%)	NR Traditional	RR (%)	NR Medium	RR (%)	NR Mixed dairy-beef	RR (%)	NR Subsistence	RR (%)
Herbicides	18	64.3	16	45.7	10	43.5	14	48.2	9	47.4
% of Use	18	100.0	14	87.5	8	80.0	7	50.0	5	55.6
Mech.agriculture	18	64.3	26	74.3	15	65.2	22	75.8	13	68.4
% of Use	16	88.9	3	11.5	1	6.7	2	9.1	1	7.7
Division of pastures	16	57.1	26	74.3	15	65.2	18	62.0	12	63.2
% of Use	16	100.0	14.00	53.8	9	60.0	11	61.1	2	16.7
Minimum Plot (ha)	7	7.0	6.00	6.0	6	5.7	5	4.9	_	_
Maximum Plot (ha)	97	96.8	33.88	33.9	42	42.0	15	15.0	_	_
Technical assistance*	24	85.7	23	65.7	10	43.5	21	72.4	13	68.4
Private	17	70.8	15	65.2	3	30.0	0	0.0	0	0.0
NGO	2	8.3	1	4.3	0	0.0	0	0.0	0	0.0
Property	9	37.5	3	13.0	1	10.0	1	4.8	0	0.0
Public	1	4.2	0	0.0	0	0.0	3	14.3	1	7.7
No technical assistance	2	8.3	6	26.1	6	60.0	17	81.0	12	92.3
Environmental Strategies										
	NR Professional	RR (%)	NR Traditional	RR (%)	NR Medium	RR (%)	NR Mixed dairy-beef	RR (%)	NR Subsistence	RR (%)
Deforestation	5	17.8	15	42.8	9	39.1	11	37.9	10	52.6
% of adoption	1	20.0	9	60.0	4	44.4	1	9.1	4	40.0
Supression of secondary vegetation	11	39.3	16	45.7	13	56.5	14	48.2	8	42.1
% of adoption	7	63.6	9	56.3	7	53.8	9	64.3	5	62.5
Forest Code	14	50.0	15	42.9	6	26.1	19	65.5	19	100.0
Compensation	8	57.1	5	33.3	1	16.7	0	0.0	0	0.0

continue

continuation

Regrowth	3	21.4	3	20.0	1	16.7	0	0.0	0	0.0
No strategy	2	14.3	5	33.3	2	33.3	3	15.8	0	0.0
No liability	1	7.1	2	13.3	1	16.7	0	0.0	0	0.0
Does not apply (< 400 ha)	0	0.0	0	0.0	1	16.7	16	84.2	0	0.0

Percentages higher than 100% indicate multiple market connections or the adoption of more than one practice or technique.

APPENDIX C – DRIVERS ASSOCIATED TO CLUSTERS OF SECONDARY VEGETATION IN PRE AND POST-LAW ENFORCEMENT PERIODS.

Process	Variable	Data source	Period [5]	Attribute(10km x 10km cell)
Dynamics of Herds	Stocking rates	Terraclass[1] PPM [2] (IBGE)[3]	2004 / 2008 / 2010 / 2012 / 2014	AU/hectare
	Herds	PPM (IBGE)	2000 - 2014	AU
	Dairy herds	PPM (IBGE)	2000 - 2014	AU of Dairy herds
	Clean pasture per deforested area	Terraclass	2004 / 2008 / 2010 / 2012 / 2014	area of clean pasture per deforested area
	Dirty pasture per deforested land	Terraclass		area of dirty pasture per deforested area
Market	Slaughtering	PPM (IBGE)	2000-2014	number of herds slaughtered
	Exports oflive cattle	Alice web [4]	2000-2014	live cattle (tons)
	Exports of non-live cattle	Alice web	2000-2014	beef (frozen and fresh) and leather (tons)
	Weighted distance to the nearest slaughtering facility calculated using the GPM (Generalized Proximity Matrix)	Lucc-Me Lab[5] (INPE)[6]	All facilities (federal and state inspection) registered until 2012	GPM is an extension of the spatial weights matrix in which spatial relationships take into consideration not onlyabsolute spatial relations (e.g. Euclidian distance) but also spatial relationships in real world. It is a concept used to establish relations between origins and destinations, using different strategies to define how two objects are connected. In our database. GPM was included as a basicgeographical relation i.e. intersection with a network of paved and unpaved roads. In our dataset, lowest values of the GPM imply proximity to a given slaughterhouse considering a displacement through paved and unpaved roads, while highest values represent the largest distances considering the same concept.
	Dairy production	PPM (IBGE)	2000 - 2014	dairy production (liters)

continue

continuation

Market				
Biophysical	Slope	Ambdata[8] (INPE)	No data	values from 10 to 89 (degrees)
Biophysical	Stock of primary forests	Terraclass	2004/2008/2010/ 2012/2014	hectares/cell
	Areas under regrowth			
	Precipitation in the rainy season	Lapig[9]	2000 - 2014	mm/cell
	Precipitation in the dry season	Lapig	2000 - 2014	mm/cell
	Agricultural Adequacy	IBGE (Atlas)	2002	class 1= low; and Class 4 = medium to high)
Technification	Technical assistance	IBGE Rural Census	1996/2006	number of properties
	Bulldozers	IBGE Rural Census	1996/2006	number of properties
	Chemical fertilization and liming	IBGE Rural Census	1996/2006	number of properties
	Herbicides	IBGE Rural Census	1996/2006	number of properties
	Use of Fire	INPE	2000 - 2014	total count/cell
Law enforcement	Embargoed areas	IBAMA[10]	2000 - 2014	hectares/cell
	Slavery	Reporter Brasil[11]	2000 - 2014	Number workers released/municipality/cell

continue

continuation

Land tenure	Concentration of properties in 5 classes of size	IBGE CAR(12)	1995-2006 (IBGE) 2017 (CAR)	hectares/cell
	Occurrence of small-scale agriculture	Terraclass	2004 / 2008 / 2010 / 2012 / 2014	hectares/cell
	Price of bare land (VTN) (13)	CEPAF(13)	2008 / 2010 / 2011 / 2015	value of the hectare in R$/cell
	Protected Areas	LAPIG	2004 - 2014	hectares/cell
	INCRA settlements	LAPIG		hectares/cell

(1) Terraclass ; (2) PPM ; (3) IBGE; (4) Alice web (Ministry for Commerce) ; (5) Lucc-Me Lab; (6) INPE; (7) GpmWIehgt; (8) Ambdata; (9) Lapig; (10) IBAMA; (11) Reporter Brasil; (12) CEPAF - Pará State Council for Agriculture, and Land Tenure; (13) VTN = VmrxFaxFbxFcxFdxFexFfxFg x FhVmr where Vmr = Valor médio da terra para a região de inserção da área requerida; Fa = Índice do fator topografia; Fb = Índice do fator fertilidade dos solos; Fc = Índice do fator distancia à sede municipal; Fd = Índice do fator acesso ao imóvel; Fe = Índice do fator hidrografia do imóvel; Ff = Índice do fator áreas de preservação permanente; Fg = Índice do fator reserva legal; Fh = Índice do fator dimensão da área

APPENDIX D – CORRELATION BETWEEN DRIVERS AND CLUSTERS OF SECONDARY VEGETATION IN DIFFERENT CATTLE RANCHING SYSTEMS.

BIOPHYSICAL

	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot
	PreLaw	PostLaw	PreLaw	PostLaw	PreLaw	PostLaw	PréLaw	PostLaw	PreLaw	PreLaw	PostLaw	PostLaw	PreLaw	PostLaw	PreLaw	PostLaw
	Prof	Prof	Prof	Prof	Mixed	Mixed	Mixed	Mixed	Trad	Trad	Trad	Trad	Subsis	Subsis	Subsis	Subsis
Forest Stocks (2004/2014)	no	no	0.12	no	-0.12	no	no	no	no	-0.28	-0.25	-0.22	no	no	-0.25	-0.35
Prec Rainy Season (2000/2010)	no	no	no	no	no	0.11	no	no	no	no	0.15	0.15	no	no	0.15	0.25
Prec Rainy Season (2001/2011)	-0.48	no	0.14	no	-0.39	no	0.17	no	no	-0.1	0.28	no	no	no	0.28	no
Prec Rainy Season (2002/2012)	no	no	no	no	0.15	no	no	no	no	no	0.12	0.13	no	no	0.12	0.11
Prec Rainy Season (2003/2013)	-0.27	0.12	no	no	-0.16	0.19	0.19	no	no	0.12	0.12	0.11	no	no	0.12	0.14
Prec Rainy Season (2004/2014)	no	-0.10	no	no	0.17	no	no	no	0.17	no	no	0.22	0.17	no	no	0.22
Prec Dry Season (2000/2010)	0.16	0.10	-0.10	no	0.15	0.11	no	0.14	no	-0.13	no	0.25	no	-0.1	0.16	0.25
Prec Dry Season (2001/ 2011)	0.36	0.24	-0.10	no	0.4	0.11	no	no	0.19	no	no	no	no	no	-0.1	no
Prec Dry Season (2002 / 2012)	0.25	0.12	-0.12	no	0.22	no	no	no	no	no	no	no	no	no	no	no
Prec Dry Season (2003 / 2013)	0.28	0.19	-0.12	no	0.26	0.16	no	no	no	no	-0.12	no	no	no	no	no
Prec Dry Season (2004 / 2014)	0.23	no	no	no	0.16	0.27	0.12	-0.1	no	0.11	no	no	no	no	-0.15	no
Slope	no	0.19	0.13	no	no	0.12	-0.14	-0.25	no	no	-0.24	-0.31	no	no	-0.24	-0.31
Low Adequacy	-0.39	-0.29	0.13	no	-0.35	-0.3	0.16	0.12	no	-0.14	0.16	no	no	no	0.16	no
HighAdequacy	0.41	0.33	-0.10	no	0.41	0.34	-0.14	-0.12	no	0.33	-0.23	-0.15	no	0.13	-0.23	-0.12

MARKET

	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot
	PreLaw	PostLaw	PreLaw	PostLaw	PréLaw	PostLaw	PréLaw	PostLaw	PreLaw	PreLaw	PostLaw	PostLaw	PreLaw	PostLaw	PreLaw	PostLaw
	Prof	Prof	Prof	Prof	Mixed	Mixed	Mixed	Mixed	Trad	Trad	Trad	Trad	Subsis	Subsis	Subsis	Subsis
Weighted Distance (GPM)	no	no	no	no	no	0.11	no	-0.1	no	no	-0.2	-0.17	no	no	-0.2	-0.21
Slaughtering (2000 /2010)	no	0.11	no	no	0.11	0.16	no	-0.1	no	0.34	no	-0.16	no	0.16	no	-0.13
Slaughtering (2001/2011)	no	0.13	no	no	no	0.18	no	-0.11	no	0.35	no	-0.17	no	0.16	no	-0.13

continue

continuation

Slaughtering (2002/2012)	0.29	0.14	no	no	0.26	0.18	-0.11	-0.11	0.18	0.38	-0.11	-0.17	0.18	0.17	-0.11	-0.13
MARKET																
	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot
	PreLaw	PostLaw	PreLaw	PostLaw	PréLaw	PostLaw	PréLaw	PostLaw	PreLaw	PreLaw	PostLaw	PostLaw	PreLaw	PostLaw	PreLaw	PostLaw
	Prof	Prof	Prof	Prof	Mixed	Mixed	Mixed	Mixed	Trad	Trad	Trad	Trad	Subsis	Subsis	Subsis	Subsis
Slaughtering (2003/2013)	0.14	0.12	no	no	0.15	0.17	no	-0.1	0.13	0.32	-0.19	-0.16	0.13	0.15	-0.19	-0.13
Slaughtering (2004 /2014)	0.21	0.11	no	no	0.18	0.16	-0.13	-0.1	0.14	0.33	-0.17	-0.17	0.14	0.15	-0.17	-0.13
Export live cattle (2000/2010)	no	no	no	no	no	no	no	no	no	no	no	0.21	no	no	no	0.21
Export live cattle (2001/2011)	no	-0.10	no	no	no	no	no	0.19	no	no	no	0.33	no	no	no	0.33
Export live cattle (2002 /2012)	no	-0.10	no	no	no	no	no	0.19	no	no	no	0.35	no	no	no	0.35
Export live cattle (2003/2013)	no	no	no	no	no	no	no	0.19	no	no	no	0.35	no	no	no	0.34
Export live cattle (2004 /2014)	no	-0.10	no	no	no	no	no	0.19	no	no	no	0.35	no	no	no	0.35
Exportbeef-leather (2000/2010)	no	no	no	no	no	no	no	no	no	no	no	0.18	no	no	no	0.19
Exportbeef-leather (2001/2011)	0.13	no	no	no	0.17	no	no	no	0.17	no	no	0.24	0.17	no	no	0.27
Exportbeef-leather (2002/2012)	0.1	no	no	no	0.14	no	no	0.16	no	no	no	0.33	no	no	no	0.33
Exportbeef-leather (2003/2013)	no	no	no	no	no	no	no	0.16	no	no	no	0.33	no	no	no	0.33
Exportbeef-leather (2004 /2014	no	no	no	no	no	no	no	0.17	no	no	no	0.35	no	no	no	0.35
Dairy production (2000/2010)	no	0.11	no	no	no	0.17	no	-0.19	no	0.2	-0.14	-0.26	no	0.16	-0.14	-0.25
Dairy production – 2001 / 2011	no	0.12	no	no	no	0.17	no	-0.19	no	0.2	-0.1	-0.27	no	0.16	-0.1	-0.26
Dairy production – 2002 / 2012	no	0.12	no	no	no	0.17	no	-0.19	no	0.13	-0.1	-0.25	no	0.1	-0.1	-0.24
Dairy production – 2003 / 2013	no	0.15	no	no	no	0.19	no	-0.18	no	0.12	-0.12	-0.25	no	no	-0.12	-0.23
Dairy production – 2004 / 2014	no	0.16	no	no	no	0.18	no	-0.18	no	0.1	-0.12	-0.24	no	no	-0.12	-0.23
LAW ENFORCEMENT																
	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot
	PreLaw	PostLaw	PreLaw	PostLaw	PreLaw	PostLaw	PreLaw	PostLaw	PreLaw	PreLaw	PostLaw	PostLaw	PreLaw	PostLaw	PreLaw	PostLaw
	Prof	Prof	Prof	Prof	Mixed	Mixed	Mixed	Mixed	Trad	Trad	Trad	Trad	Subsis	Subsis	Subsis	Subsis
Embargoed area (2000/2010)	0.21	no	no	no	0.24	no	no	no	0.1	no	-0.1	-0.16	0.1	0.12	-0.1	-0.17

continue

continuation

Embargoed area(2001/2011)	no	no	no	no	no	no	no	no	0.12	no	-0.18	-0.12	0.12	0.12	-0.18	-0.13

LAW ENFORCEMENT

	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot
	PreLaw	PostLaw	PreLaw	PostLaw	PreLaw	PostLaw	PreLaw	PostLaw	PreLaw	PreLaw	PostLaw	PostLaw	PreLaw	PostLaw	PreLaw	PostLaw
	Prof	Prof	Prof	Prof	Mixed	Mixed	Mixed	Mixed	Trad	Trad	Trad	Trad	Subsis	Subsis	Subsis	Subsis
Embargoed area (2002/2012)	no	no	no	no	no	no	no	no	0.15	no	-0.15	-0.17	0.15	no	-0.15	-0.19
Embargoed area (2003/2013)	no	no	no	no	no	no	no	no	0.18	no	-0.2	-0.16	0.18	no	-0.2	-0.19
Embargoed area (2004/2014)	no	no	no	no	0.11	no	no	no	no	no	-0.19	-0.18	no	no	-0.19	-0.2
Slaverylabour(2000/2010)	0.1	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no
Slavery labour(2001/2011)	no	no	no	no	no	no	no	no	no	no	no	no	no	0.16	no	no
Slavery labour(2002/2012)	0.16	no	no	no	0.17	no	-0.1	-0.11	0.19	0.14	-0.11	-0.21	0.19	0.21	-0.11	-0.21
Slavery labour(2003 / 2013)	no	no	no	no	no	no	no	-0.11	no	no	-0.12	-0.16	no	0.11	-0.12	-0.16
Slavery labour(2004/2014)	-0.24	no	0.30	no	-0.15	no	no	-0.1	no	no	-0.16	-0.15	no	no	-0.16	-0.16

DYNAMICS OF HERDS

	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot
	PreLaw	PostLaw	PreLaw	PostLaw	PréLaw	PostLaw	PréLaw	PostLaw	PreLaw	PreLaw	PostLaw	PostLaw	PreLaw	PostLaw	PreLaw	PostLaw
	Prof	Prof	Prof	Prof	Mixed	Mixed	Mixed	Mixed	Trad	Trad	Trad	Trad	Subsis	Subsis	Subsis	Subsis
Herds (2000/2010)	0.2	no	no	no	0.14	0.14	-0.11	-0.13	0.11	0.25	-0.22	-0.29	0.11	0.19	-0.22	-0.27
Herds (2001/2011)	no	no	no	no	no	0.15	no	-0.14	0.11	0.25	-0.19	-0.29	0.11	0.19	-0.19	-0.28
Herds (2002/2012)	no	no	no	no	no	0.15	-0.1	-0.14	0.1	0.26	-0.19	-0.29	0.1	0.2	-0.19	-0.28
Herds (2003/2013)	no	no	no	no	no	0.15	-0.1	-0.14	0.11	0.26	-0.2	-0.29	0.11	0.2	-0.2	-0.28
Herds (2004/2014)	no	no	no	no	0.1	0.15	-0.13	-0.14	0.15	0.28	-0.21	-0.3	0.15	0.21	-0.21	-0.28
Dairy Herds (2000/2010)	0.11	0.13	no	no	no	0.15	no	-0.19	no	0.22	-0.13	-0.25	no	0.17	-0.13	-0.24
Dairy Herds (2001/2011)	no	0.12	no	no	no	0.13	no	-0.17	no	0.21	-0.11	-0.25	no	0.17	-0.11	-0.24
Dairy Herds (2002/2012)	no	0.13	no	no	no	0.14	no	-0.18	no	0.21	-0.1	-0.26	no	0.15	-0.1	-0.25
Dairy Herds (2003/2013)	no	0.17	no	no	no	0.16	no	-0.18	no	0.19	-0.12	-0.26	no	0.11	-0.12	-0.24
Dairy Herds (2004/2014)	no	0.17	no	no	no	0.15	no	-0.17	no	0.18	-0.12	-0.25	no	0.1	-0.12	-0.23

continue

continuation

Clean pasture (2004/2014)	no	no	no	no	0.21	0.2	-0.14	-0.17	0.19	0.49	no	-0.11	0.19	0.21	no	no
DYNAMICS OF HERDS																
	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot
	PreLaw	PostLaw	PreLaw	PostLaw	PréLaw	PostLaw	PréLaw	PostLaw	PreLaw	PreLaw	PostLaw	PostLaw	PreLaw	PostLaw	PreLaw	PostLaw
	Prof	Prof	Prof	Prof	Mixed	Mixed	Mixed	Mixed	Trad	Trad	Trad	Trad	Subsis	Subsis	Subsis	Subsis
Dirty pasture (2004/2014)	0.14	0.10	no	no	0.19	0.12	no	no	0.21	0.46	no	-0.1	0.21	0.16	no	no
Clean pasture per deforestedland(2004/2014)	no	no	no	no	0.2	0.22	-0.2	-0.27	0.15	0.37	no	-0.2	0.15	0.21	no	-0.17
Dirty pasture per deforested land (2004/2014)	0.14	0.10	no	no	0.16	0.12	no	no	0.27	0.34	no	-0.14	0.27	0.21	no	no
Stocking rates (2004/2014)	0.29	0.18	-0.12	no	0.15	0.13	no	-0.12	no	0.12	no	-0.32	no	0.14	no	-0.32
LAND-HOLDING CONTEXT																
	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot
	PreLaw	PostLaw	PreLaw	PostLaw	PréLaw	PostLaw	PréLaw	PostLaw	PreLaw	PreLaw	PostLaw	PostLaw	PreLaw	PostLaw	PreLaw	PostLaw
	Prof	Prof	Prof	Prof	Mixed	Mixed	Mixed	Mixed	Trad	Trad	Trad	Trad	Subsis	Subsis	Subsis	Subsis
Indigenous Lands	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no
Sustainable Use	no	no	no	no	no	no	no	no	no	no	no	-0.11	no	no	no	-0.13
Strict Protection	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no
INCRA Settlements	no	-0.12	no	no	no	no	no	no	no	no	no	no	no	no	no	no
Properties < 100	no	no	no	no	no	no	no	-0.1	no	0.14	no	-0.17	no	0.2	no	-0.17
Properties 101 – 200	-0.1	no	no	no	no	no	-0.1	-0.13	no	no	-0.22	-0.24	no	0.15	-0.22	-0.25
Properties 201 – 500	-0.1	no	no	no	no	no	-0.12	-0.13	no	no	-0.29	-0.27	no	0.16	-0.29	-0.28
Properties 1000	no	no	no	no	0.11	no	-0.1	-0.11	0.14	no	-0.28	-0.24	0.14	0.12	-0.28	-0.25
Properties 1001	no	no	no	no	0.17	no	no	-0.13	0.17	0.2	-0.25	-0.3	0.17	0.13	-0.25	-0.28
Mechanized agriculture (2004/2014)	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no
Small-scale agriculture(2004/2014)	no	no	no	no	-0.14	-0.17	0.26	0.47	no	no	0.38	0.51	no	no	0.38	0.52
Mechanized Agriculture per deforested land (2004/2014)	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no

continuation

LAND-HOLDING CONTEXT																
	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot
	PreLaw	PostLaw	PreLaw	PostLaw	PréLaw	PostLaw	PréLaw	PostLaw	PreLaw	PreLaw	PostLaw	PostLaw	PreLaw	PostLaw	PreLaw	PostLaw
	Prof	Prof	Prof	Prof	Mixed	Mixed	Mixed	Mixed	Trad	Trad	Trad	Trad	Subsis	Subsis	Subsis	Subsis
Small-scale agriculture per deforested land (2004/2014)	no	no	-0.16	no	-0.17	-0.18	0.27	0.45	no	no	0.29	0.33	no	no	0.29	0.33
Price of bare land (VTN) (2008/2015)	0.42	-0.16	0.21	no	0.41	0.24	-0.22	-0.15	0.13	0.28	-0.29	-0.14	0.13	0.15	-0.29	-0.1

TECHNIFICATION																
	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot	Cold	Cold	Hot	Hot
	PreLaw	PostLaw	PreLaw	PostLaw	PréLaw	PostLaw	PréLaw	PostLaw	PreLaw	PreLaw	PostLaw	PostLaw	PreLaw	PostLaw	PreLaw	PostLaw
	Prof	Prof	Prof	Prof	Mixed	Mixed	Mixed	Mixed	Trad	Trad	Trad	Trad	Subsis	Subsis	Subsis	Subsis
Technical assistance	no	0.10	no	no	no	0.11	no	no	no	0.28	no	no	no	0.14	no	no
Chemical fertilization and Liming	-0.15	-0.19	no	no	-0.18	-0.2	0.1	0.31	no	no	0.13	0.44	no	no	0.13	0.44
Herbicides	no	no	no	no	no	no	0.11	no	no	no	0.15	no	no	no	0.15	no
Slope correction	no	-0.12	no	no	no	-0.1	no	0.12	no	no	-0.14	0.44	no	no	-0.14	0.44
Bulldozers	no	0.17	no	no	no	no	no	no	no	0.23	-0.16	-0.21	no	0.1	-0.16	-0.19
Sowers	-0.15	no	no	no	-0.12	no	0.12	no	no	no	no	-0.19	no	no	no	-0.18
Harvesters	-0.18	no	no	no	no	no	no	no	no	no	0.13	-0.1	no	no	0.13	no
Trucks	-0.1	no	no	no	no	no	0.1	-0.11	no	0.15	-0.14	-0.23	no	0.13	-0.14	-0.22
Small trucks	no	no	no	no	0.12	no	no	-0.1	no	0.11	-0.25	no	no	no	-0.25	no
Fire – 2000/2010	no	no	no	no	no	0.16	no	no	no	no	no	no	no	0.22	no	no
Fire – 2001/2011	no	no	no	no	no	no	no	no	no	no	no	no	no	no	no	0.12
Fire – 2002/2012	no	no	no	no	0.13	no	no	no	0.24	no	no	no	0.24	no	no	no
Fire – 2003/2013	no	no	no	no	no	no	no	no	0.25	no	no	0.24	0.25	no	no	0.29
Fire – 2004/2014	no	no	no	no	no	no	no	no	0.33	no	no	no	0.33	no	no	0.11

APPENDIX E– SAMPLE DATA AND CONFUSION MATRIX OF THE THEMATIC ACCURACY ANALYSIS

The 381 random points validation returned 64.6% overall accuracy; with annual agriculture (89.7%), secondary vegetation (70.7%) and clean pasture (56.4%) presenting the best levels of agreement. After joining the four original pasture classes,a second error matrix returned a 77.7% overall accuracy, with increases in levels of agreements for two of the other three main classes of interest i.e. secondary vegetation (70.7%) and pasture (69.5%). Based on these results wejoined the classes of pasture.

Land cover	Area (hectares)	(%)[a]	Number of random points	Agreement[b]	Omission[b]	Commission[b]	Agreement[c]	Omission[c]	Commission[c]
Agriculture	236,555.2	2.83	11	87.27	12.7	0.03	87.49	12.48	0.03
Pasture clean	8,803,354.1	51.3	141	66.54	7.97	25.5	80.79	7.85	11.35
Pasture dirty	1,722,282.4	8.9	60	19.69	57.99	22.32			
Pasture degraded	893,901.6	4.62	26	22.9	49.62	27.48			
Pasture bare soil	699.1	0.0004	4	44.4	-	55.56			
Secondary vegetation	4,835,646.0	28.9	95	65.19	16.32	18.49	63.12	18.98	17.90
Reforestation	140,913.7	0.65	2	20	-	80	20	-	80
Others	515,829.6	2.64	49	28.17	45.95	25.88	21.49	58.47	19.89
Total	17,149,182	100	388	70.3	29.7	29.7	84.06	15.94	15.94

a. Representativeness of each cover class with respect to area in 2012.
b. Values considering pasture cover classes taken apart
c. Values for pasture cover classes taken together