From Treeless Pastures to Silvo-pastoral Systems: The Extent and Drivers of Tree Management Styles

by

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A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Ecology and Evolutionary Biology)
in the University of Michigan
2017

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DEDICATION

To Amelie and Sebi for making me smile.

ACKNOWLEDGEMENTS

I wouldn't be here if it weren't for my parents who have always given me unconditional support. My siblings Gabriela and Oscar are my inspiration. I also want to thank my best friends Stephanie Rodríguez and Francia Herrera that have been in my life since I was born. There are many people that have been there along this long journey and I will try to not forget anyone. Over 54 farmers in Panama spend days helping me understand their farm, their trees, and their aspirations. Not one of them closed their doors. I will always be indebted to them and I hope one day I can return the favor.

I want to thank my adviser John Vandermeer. When I first arrived to Ann Arbor and was placed to teach a course called Food, Energy and the Environment I knew I was in the right place. John's unique approach to teaching these topics quickly transformed my worldview and made me feel as if I had finally found the "truth." John's support gave me confidence to pursue a dissertation I was truly passionate about and for that I will always be extremely grateful. I have been puzzled, but I have learned so much. I am ready and eager to share everything I've learned.

I am very grateful to my research committee that have inspired me and supported me since my first year in Ann Arbor. Fortunately I got to see Ivette Perfecto and Catherine Badgley during our weekly new world agricultural and ecology group meetings (NEWAEG). I learned so much from them, particularly about the power of science, knowledge, commitment and solidarity. I thank Lesli Hoey for guiding and supporting me through the journey of qualitative research. Maria Carmen Lemos positivity and energy during my time in at Michigan has given me confidence to pursue socio-ecological work.

I am so thankful I had the opportunity to work with two great mentors before coming to Michigan, Henry Hank Howe and Sunshine Van Bael. Sunshine Van Bael was my first academic mentor and she was the first to teach me about John Vandermeer and Ivette Perfecto's work. Before coming to Michigan I worked with her in the cattle pastures of Panama. Her support during my first field seasons in Panama was very important. It was during my time working in Mexico with Hank that I learned about Ivette and John's agricultural matrix work. I was hooked and Hank's support gave me confidence to pursue these topics and to move forward with graduate school.

My collaborators in Panama and the USA are amazing: Trevor Caughlin, Tiaris Olmos, and Erin Figley. There are no Post-Docs in the Vandy Lab so working with Trevor for me has been a great opportunity. I also want to Bruce Ferguson for teaching me about cattle ranching and disturbance. I want to thank the institutions in Panama that helped with this work: Smithsonian Tropical Research Institute, National Authority of the Environment, the University of Panama and the Ministry of Agricultural Development. While I was doing field work I met Elizabeth Valdes. She took care of me, fed me and treated me like I was family. I never thought I would be so fortunate when I decided to do fieldwork in Panama. I also want to thank the family Saavedra for letting me stay at their house during my fieldwork seasons.

I never thought I would come to Michigan to learn about fishes, but thanks to Douglas Nelson now I really do believe that fishes are the most interesting living organisms. I want to thank Doug because he has been my supervisor but also my friend. I will definitely miss my days working at the museum. I want to thank the Ecology and Evolutionary Biology Program for giving me the opportunity to do a Ph. D. in the U.S.A and for supporting me throughout my stay. I want to thank my dissertation writing group: Shannon Dowd, Catalina Esguerra and Elise Hernandez who have read all my Chapters and given me significant feedback. There help has been immense and I also enjoyed reading their manuscripts. Finally I want to thank the University of Michigan for providing funding and research permits (including IRB) for this research.

My lab mates and other colleagues at University of Michigan always made me feel like I was not alone. We were all going through this process together and seeing them deal with their own challenges always gave me strength and inspired me to move on. I thank my former and current lab mates: Aaron Iverson, Dave Allen, Beatriz Otero, Naim Edwards, Senay Yitaberk, Paul Glaum, Gordon Finch, Theresa Ong and the entire Perfectomeer lab. I am very grateful that I am part of this academic family and I looking forward to continue working with all of you.

My home for the past five years has been the Escher house at the ICC COOP. I have learned so much from this experience and there are so many people that I have met that have enriched my life and also helped me re-discover my passion for cooking. This is my Ann Arbor family: Chef Lynn, Nagesh Beludi, Raghav Reddy, Jason Sequeira, Molly Keenan, Anish Lahiri, and Aritra Chakrabarty. In 2012, I met Steven Morris at the ICC COOP and we have been inseparable since. Thank you Steven for loving me, supporting me and helping my throughout this Ph. D. journey.

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ABSTRACT

Cattle ranching is generally depicted in the conservation literature as a driver of forest destruction. A closer look at the cattle pastures in Central America indicates that some ranchers incorporate trees into pasture management but at different tree densities. We ask: why are there different tree densities across the cattle pastures? We develop a socio-ecological framework to answer this question and apply this framework to understand the case of tree cover across 54 farms that raise cattle in the Republic of Panama.

Our framework proposes that the relationships between tree cover and cattle density (or another driver) may be linear, non-linear or multivalued with a hysteretic condition. Hysteresis occurs when a change in the cattle density (or other driver) does not lead to an immediate change in the tree cover because the system is resilient, that is, any perturbation results in a quick recovery. When tipping points are reached, transitions are catastrophic and unpredictable. In the zone of hysteresis two tree cover states are possible under the same cattle density (or condition of the driver) and transitions from the high to low tree cover states (or vice versa) are slow, but when they occur they are catastrophic. Bimodality in the frequency distributions of tree cover across farms would indicate that the underlying dynamics are hysteresis.

We found that average total tree cover across the 54 farms in the Republic of Panama, ranged from 10 to 70%. When the total tree cover is broken down, we found that farmers are managing seven landscape patterns including: riparian vegetation, dispersed trees on pasture, live fence, forest, fallow, horticulture, and forestry plantation. Dispersed trees on pastures is bimodal but with only two farms for the high tree density mode. Live fence frequency distributions show

clear bimodality. The 54 farms are actively managed with reported cattle densities that range from 0.14 to 3.52 reported cattle ha^{-1} and does not predict tree cover in our model. Overall we did not find alternative tree cover states but farmers are managing trees at different densities.

We employ the balances framework proposed by Chayanov in the early 1900s to analyze the drivers of tree cover. The drivers can be envisioned as a spectrum of farms that range from those that operate under the utility-drudgery balance and those that operate under the capitalist mode of profit maximization.

In depth interviews with the 54 farmers indicate that farmers make decisions about tree management by balancing the utility of trees for cattle production with the drudgery (or hardship) involved in maintaining desired tree species through planting and weeding. Farmers also balance other factors like the need to take care of trees today so that they can protect cattle from heat stress in the future as the dry seasons get longer. Farmers' perceptions over government corruption affects their decisions on tree management in the farm. They perceive that farmers and companies with more monetary and political influence get more government assistance and often impunity if they cut large tracts of forest. Meanwhile, as small farmers with little political influence, they get penalized. Farmers' overall avoid dependency by avoiding commercial tree planting and agricultural practices that require heavy use of inputs and technical assistance. Farmers see trees as a valuable resource within the farm but avoid depending on trees for profit maximization.

CHAPTER I

INTRODUCTION

In the conservation literature of the Neotropics, the cattle ranchers have been exclusively portrayed as the drivers of deforestation (Steinfield et al. 2006), reinforcing the notion that cattle ranchers are antagonists to forest conservation goals. In addition, this notion implies that the relationship between trees and cattle ranching is negative linear (Steinfield et al. 2006, Heckadon-Moreno 2009, Hoelle 2011). That is, with a small change in cattle density (or other driver), you expect to see a small change in tree cover. Conservationists argue that population growth and increasing urbanization leads to more cattle ranching expansion and therefore deforestation (Steinfield et al. 2006). This rhetoric, however, ignores the fact that colonization and land reform programs of the 1970's across Latin America gave benefits to farmers that expanded into the forest and cut the forest as a means to claim land (Hecht 1985, Rudel 2005). The process of colonization required cutting the forest as an indicator of territorial claim (Hecht 1985). In addition, state led programs and other structural forces that promote intensive agriculture and ranching practices outweigh those that incentivize ranchers to conserve the forest (Coomes et al. 2008). In view of these structural forces that promote deforestation, the simple linear notion that cattle ranching has a negative linear relationship with the forest due to economic and demographic factors, including population, is outdated. Instead, we argue that the relationship between cattle ranching and the forest is complicated by farmers' subjective decisions as they navigate structural forces at the farm scale.

In other parts of the world, cattle and other livestock that graze pasture have been an important component of sustainable agricultural systems. In Spain, for example, exists the Dehesa system, which is a silvo-pastoral system in which farmers manage Oak trees in combination with pasture grasses, and livestock. These systems have existed for many centuries as a living example of sustainable human modified system. In the Dehesa system, trees are necessary for the long-term socio-ecological sustainability of the grass-livestock system since trees maintain soil humidity and nutrients, conserve wildlife, provide feed for the livestock, and provide resources that are sold in the market (Joffre et al. 1999, Papnastasis et al. 2009). In the Neotropics, there is evidence suggesting that farmers are also incorporating trees into their cattle ranching management (Harvey et al. 2011, Lerner et al. 2014). Such examples imply that the relationship between cattle ranchers and tree conservation is not necessarily antagonistic. Throughout this dissertation we challenge the notion that cattle ranching in the Neotropics is exclusively antagonist to forest conservation. We examine different styles of cattle ranching primarily based on their tree management practices, and challenge the notion that cattle ranching has a negative linear relationship with the forest.

Challenging the linear notion requires a deep examination of the voluntary silvo-pastoral systems that exist across the Neotropics. Studies in Central and South America indicate that trees are incorporated into the pasture management at different tree densities. For example, Harvey et al. (2011) found that from Nicaragua to Costa Rica ranchers managed an average density of dispersed trees in cattle pastures that ranges from 7.97 trees ha^{-1} to 33.4 tree per ha^{-1}. In Ecuador, Lerner et al. (2014) found that farmers can manage tree densities at a range of 30 to 200 trees ha^{-1}. Sanfiorenzo-Barnhard et al. (2009) found that pasturelands in Mexico can have tree covers that vary from <10% to >80% tree cover. Recently, a global estimate of tree cover area on agricultural land revealed that Central America is one of the regions in the world with largest tree cover, with >45% of tree cover area (Zomer et al. 2016). In view of this recent research, we ask, why do we see variation in tree densities across the Neotropical cattle pastures? We develop and employ a socio-ecological framework for studying the "styles" of tree density management across the cattle pastures of the Neotropics, and apply this framework to a case study of 54 farmers in the Republic of Panama. We work in the Republic of Panama because pasture for cattle covers 79% of the agricultural land and because previous studies in the region suggest that farmers incorporate trees into their cattle pasture management (Wright and Samaniego 2008, Garen et al. 2011). However, the extent to which trees are incorporated into pasture management in the Republic of Panama remains unknown.

In Chapter 2, we propose a socio-ecological framework that relaxes the linear assumptions and dynamics are evaluated. Recent examples in natural systems indicate that savanna and forest across the world can be alternative states under some range of precipitation. These alternative states are possible because trees in the forest state maintain humid conditions that keep fires from occurring. However, when tree densities become too low trees can no longer maintain humidity making fires possible. At the low tree densities, the forest system critically transitions into a savanna system. Fires then maintain the savanna state stable (Hirota et al. 2011, Staver et al. 2011). These two alternative states indicate that the dynamics underlying the tree to savanna transitions are non-linear and in fact, are hysteretic. In the case of the forest-savanna system, hysteresis is the result of a lag in response in tree density with change in precipitation, which results in two possible states (savanna and forest) under a certain range of precipitation. In Chapter 2, we propose that the anthropogenic savannas of the Neotropics may behave similarly to the forest-savanna systems with two tree cover states, the high tree cover state and the low tree cover state. If hysteresis is the underlying dynamic that characterizes transitions from the high tree cover state to the low tree cover state than a small or large change in cattle density (or other driver) may not lead to a large change in tree cover, and the tree cover state can recover easily with any perturbation to the system (Scheffer 2009). Hysteresis has important implications that managers would have to consider. If hysteresis is the underlying dynamics that characterizes transition from high to low tree cover, then managers have to consider that transitions between high and low tree covers will be unpredictable and abrupt, that simply manipulating the tree densities directly won't lead to a desired outcome, and that the pathway to a low tree cover state is different than the pathway to a high tree cover state (Scheffere 2009). Understanding which are the underlying dynamics is important, because if hysteresis is the underlying dynamic then the implications for management will be distinct than if the underlying dynamics are linear.

In Chapter 2, we argue that testing the kinds of dynamics (linear, non-linear and hysteretic) is necessary before implementing management techniques, and that there is evidence that suggest the hysteresis may be at play in these systems. However, before testing the dynamics, it's necessary to define the response variable and the drivers. We propose that the response variable is tree density. While most studies that have examined tree densities across the cattle pasture focus on the dispersed trees in pastures (Harvey et al. 2011, Lerner et al. 2014), we take a closer look at the other tree landscape patterns that are formed in the farm. Landscape patterns are the spatial groupings of trees present in the cattle ranch that are a consequence of the farmers' management decision. Landscape patterns aside from dispersed trees on pastures, include live fences, forest fragments and riparian vegetation.

Tree covers found in the cattle pastures depend on the interaction between the natural tree regeneration processes and the disturbance caused by cattle ranching through cattle trampling on seeds, and weeding. In chapter 2, we propose that the tree cover on pastures is driven by social-processes that interact with disturbance. We draw from Chayanov's Theory of Peasant Economy, to define the on-farm processes that are at play and that result in the tree density outcome (Chayanov 1966, van der Ploeg 2013, Steckley and Weis 2016). Chayanov argued that the family (or peasant) farm was governed by a balance between the "utility" of producing one more item and the "drudgery"(or hardship) of producing that one more item. Chayanov made a distinction between the family farm and capitalist farm in that the capitalist farm was governed by profit and therefore labor was just an additional input necessary for the production of the commodity. In the family farm, labor comes primarily from the family members, reason for which families have to balance the labor with the consumption of the household. The family members that provide the labor will only produce as much as the utility of producing one more item outweighs the drudgery of producing that one more item. Chayanov concludes that while the family farm is governed by the utility-drudgery balance, the capitalist farm is governed by profit maximization. Accordingly, the family farm and the capitalist farm will react differently to changes in market price and other factors. We employ Chayanov's framework to analyze how farmers make decisions about incorporating trees into their cattle pasture management. We argue that farmers decisions about how much cattle to manage, how frequently they weed, and how many trees they conserve is related to the Chayanovian balances and to the capitalist mode of profit maximization. We propose that while some farmers make decisions more along the likes of the Chayanovian balances, others make decisions more like the capitalist mode and that these two distinct economies relate to the observed tree covers.

The concept of Chayanovian balances is not limited to the labor-consumption and utility-drudgery balance. Rather, Chayanov generalizes the idea of balances to all aspects of the family farm. The idea of Chayanovian balances has recently been employed by van der Ploeg (2013) in which he categorizes several kinds of balances that govern the family farm operation. For example, farmers must balance farm production with farm reproduction, through which they make decisions today to guarantee the long term sustainability of the farm. Farmers also balance their use of internal farm resources which makes them more self-sufficient vs. having to rely on external farm resources that they buy from the market. Farmers also balance farming as a resource extraction operation vs. farming as an operation that can improve nature. Finally, farmers balance autonomy with dependency. Structural forces and class relations tend to exploit farmers and make them more dependent on external farm inputs, as well as restrict their ability to self-determine how to manage their farm. Van der ploeg (2014) argues that farmers' ability to balance is absolutely necessary to improve their livelihoods. While structural forces and class relations may pull farmers in a direction of capitalist farming, the family farmer pushes back as it seeks autonomy. In Chapter 2, we argue that the incorporation of trees into the cattle pasture is part of farmers' decision making to improve their livelihood. Therefore, farmers balance tree management with other aspects of their cattle ranching operation. Nonetheless, some farmers may be more "capitalist" and operate under the mode of profit maximization which is a mode of high dependency. We propose that the drivers of tree cover across the farms of the anthropogenic savanna are a spectrum of farms that go from those situated as Chayanovian balances to those situated as capitalist driven by profit maximization.

We hypothesize that the family farms that operate under the Chayanovian balances are going to integrate trees into their farm operation as trees are integral to guaranteeing the long term ecological sustainability of the farm by maintaining water, and are an important economic resource that is used within the farm. The capitalist farm, which relies more on external inputs (van der ploeg 2009), may be less concerned with trees. That is, a capitalist farm can buy the wood necessary for construction and repairs, whereas a family farm may not be able to. In this case, the family farm is more likely to conserve trees that he/she finds useful.

In Chapter 3 and 4, we employ a case study of 54 farms across the Republic of Panama to characterize the cattle ranch based on tree cover and to identify farmers motivations to incorporate trees into the cattle pastures by employing the Chayanovian balance framework. In Chapter 3, we define the response variable based on total tree covers and the presence of the landscape patterns. In Panama, we obtain farm boundaries and employ Google Earth © imagery to calculate the total tree cover area of each of the 54 farms. The total tree cover area is also classified into different landscape patterns based on how farmers report the use of the trees. To determine if there are different tree management styles we examine the total tree cover frequency distributions. Bimodality in the frequency distributions would indicate that there are different tree management styles. We also examine the frequency distribution of each of the landscape patterns separately because differences in the management of the landscape patterns would indicate that total tree cover alone does not capture the complete picture of how farmers are managing trees. Difference in the management of landscape patterns may indicate that farmers are integrating trees into pasture management in different ways and for different reasons.

Finally, in Chapter 4, we employ Chayanov's peasant balances framework to identify what motivates farmers to incorporate trees into their cattle pasture management, what obstacles they encounter when trying to incorporate trees and what forces may influence the way in which they balance the motivations with obstacles. To fulfill these objectives we carry out in depth interviews with the 54 farmers employing semi-structured open ended questionnaire that focus on the utility of trees, obstacles, history of farm use, future aspirations and policies that regulate the trees on the farm. We employ the Chayanovian balances framework to examine if farmers are making decisions about tree management more like the family farm described by Chayanov or the capitalist farm that seeks to maximize profit. Finally, we classify farmers responses based on the different Chayanovian balances.

In this dissertation we develop a new conceptual framework to understand the drivers of tree cover across the cattle pastures of the Neotropics. We also put our framework to the test by employing a case study of 54 farmers in the Republic of Panama which is a country dominated by cattle ranching but in which farmers are known to integrate trees into pasture management although at different degrees. In the Republic of Panama there are also multiple efforts both from the state and non-profits to encourage farmers to incorporate trees into their cattle pastures. We expect our framework will inform these efforts and we argue that before enforcing conservation practices, it is necessary to understand how farmers may be distinctly managing trees and what forces actually lead to the low and high tree cover ranching styles.

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CHAPTER II

Sudden change in silvo-pastoral systems: relaxing the linear and monotonic assumptions

ABSTRACT

In this paper, we conduct a review of the literature on tree management across pastures of the Neotropics to uncover the dynamics behind tree cover transformations in the cattle pastures. Recent research demonstrates that the cattle ranchers incorporate trees into their pasture management. We present a framework for analyzing tree management styles across the Neotropics. Tree cover variability across cattle pastures can be envisioned as a series of "syndromes of production," among which the transformation may be linear, non-linear or multivalued. The dynamics framework indicates that moving from a treeless cattle pasture to a silvo-pastoral system entails complex interactions among socio-ecological variables that ultimately lead to non-linearities and multivalued dynamics.

We divided the literature into three sections. First, we define the components that make up tree cover including density, diversity, and spatial aggregation. Second, we define the ecological drivers of tree cover across cattle pastures and argue that structural diversity across the farming landscape stands as the most significant ecological driver. Third, in defining the social drivers of tree cover, we draw from the "peasant balances" framework proposed by Chayanov in the early 1900's. We propose that the disturbance caused to trees during pasture management is influenced by the "balances" that farmers are making in their everyday lives.

2.1 INTRODUCTION

Conversion of forest into pastures in the Neotropics has been a topic of great concern for conservation since the large cattle ranching expansion of the 1960's (Hecht 1985, Howard-Borjas 1995, Grandia 2009, Zahawi et al. 2015). Less concern has materialized with respect to the nature of those pastures, especially regarding the incorporation of trees into the production system. It is evident from casual observation that Neotropical farms with cattle vary dramatically in tree densities (Harvey and others 2011).Yet efforts to document and understand why we see this variation have not been common. It wasn't until 2009 that the World Agroforestry Center published the first global scale report on agroforestry land (Zomer et al. 2016). Meanwhile, silvo-pastoral techniques with an agro-ecological vision have been proposed and promoted as a sustainable alternative to the treeless cattle pastures so evident across the Neotropics (Payne 1985, Pagiola et al. 2007, Murgueitio et al. 2011, Broom et al. 2013, Ruiz et al. 2007). Although such tree friendly techniques are commonly encountered among small-scale producers throughout the Neotropics as a technique that has been promoted, there is scant evidence of large scale adoption (Dagang and Nair 2003, Pattanayak 2003, Mercer 2004, Calle et al. 2009). We argue that observed variability in silvo-pastoral systems can be envisioned as a series of "syndromes of production" (Andow and Hidaka 1989, Vandermeer 1997) (see figure 2.1), among which the dynamics of transformation may be envisioned through application of a dynamics framework (see figure 2.2a, 2.2b, and 2.2c), as commonly applied in other ecosystems (e.g., (Scheffer et al. 2001, Scheffer 2009, Staver et al. 2011). Employing a dynamics framework, we argue that moving from a treeless cattle pasture to a silvo-pastoral system entails complex interactions among socio-ecological variables, ultimately leading to non-linearities and multivalued dynamics (Vandermeer and Perfecto 2012; Vandermeer et al., 2015). Multivalued dynamics are characterized for having multiple values on the Y axis for one value on the X axis (see figure 2.2c). We argue that the dynamics framework may provide unique insights into how silvo-pastoral systems emerge in the first place.

Combing through history, it is not difficult to imagine that many (perhaps most?) agricultural transformations are hysteretic, that is, not readily reversible by simply inverting the sequence of events (Lockwood and Lockwood 1993). For example, in San Andres Lagunas, in Oaxaca Mexico, emigration led to transforming sustainable irrigation systems into degrading slash-and-burn agriculture (Garcia-Barrio and García-Barrios 1990). The process of emigration resulted in the breakdown of centralized institutions that were the core of these terrace/irrigation system. Since the governing institutions of those communities won't naturally be reorganized with the return of the population, simply reversing the population decline will not automatically lead to the recovery of the traditional terrace/irrigation systems. Many other examples could be cited, for example, the dust bowl in the American southwest (Schubert et al. 2004), the eroded hillsides in Greece (Hughes and Thirgood 1982), salinization of Hokocam soils (Ackerly 1988), and transformation of oak savannahs (Peterson and Reich 2001).

The present review seeks to place the issue of silvopastoralism in the Neotropics within this particular framing. It seems obvious that the quantitative and qualitative features of the trees that ranchers and farmers conserve in pastures result from complex socio-ecological forces that govern the farm. Frequently there is a tacit assumption that those socio-ecological forces, while themselves complicated, can effectively be put into a one-to-one relationship with trees, which is to say that a graph of tree quantity (or some other measure of "tree") represented as a function of socio-economic force, will appear as a simple monotonic function. Monotonic functions are presented in figure 2.1 and 2.2a where there is one value on the Y axis for every value on the X axis. This assumption, seemingly evident, may be fundamentally in error. We propose that the dynamics that more likely to characterize this relationship may be multivalued (figure 2.2c). The multivalued dynamics include the important condition of hysteresis. The implications for management will be very different depending on the underlying dynamics. An analysis of the dynamics that connect trees and socio-ecological forces can not only provide some understanding of the political ecology of silvopastoral systems, but also help uncover the type of socio-ecological changes necessary to move towards more sustainable agricultural management.

We formulate the problem, initially, as a general cause-and-effect problem with the response variable on the Y axis presented as “tree density” and the driving variable on the X axis as some measure of socioecological “disturbance” (figure 2.1 and 2.2). Disturbance in our usage refers to any socioecological process that results in the reduction of trees directly or serves as a barrier for the future establishment of trees. Although it may seem initially that the relationship between disturbance and tree density is approximately one-to-one negative (figure 2.1 and 2.2a), there are variants on that relationship that have important consequences. It is perhaps natural to assume that the relationship between tree density and disturbance is quasi-linear, which is to say, a small change in disturbance frequency will generally lead to a small change in tree density, while a large change in disturbance frequency will generally lead to a large change in tree density (fig 2.2a). Yet experience has made it clear that such a quasilinear assumption does not necessarily accord well with actual practice, and frequently small changes in management (disturbance) can lead to much larger changes in tree density (fig 2.2b). Yet there is another potential pattern, the multivalued pattern mentioned above that involves the condition of hysteresis (fig 2.2c), that seems to pass with little notice. We point out and analyze this specific pattern.

We conceive of the relationship between disturbance frequency and tree density as falling into one of three qualitatively distinct patterns: quasi-linear (figure 2.2a), strongly nonlinear (figure 2.2b) or multivalued (figure 2.2c). In the latter case, there is inevitably a hysteretic zone which is the result of a retardation in the Y axis when the X axis changes (figure 2.3a). The consequence of hysteresis is that there are two values for tree density (large or small) under any disturbance value within the hysteretic zone. This hysteretic potential carries with it important lessons for ecosystem management in that if hysteresis actually characterizes a particular system, we expect that system to be resistant to change in the driving force but result in dramatic and sudden change when the driving force reaches a threshold, or tipping point (figure 2.3b).

The agroforestry systems literature emphasizes adoption of silvo-pastoral systems that involve intentional tree planting as part of the initial agronomic designs (Calle et al. 2009, Garen et al. 2009, Broom et al. 2013). However, with the exception of live fences in some areas, most trees in Neotropical pastures exist either because they survived initial pasture establishment or have been a result of natural regeneration that ranchers and small farmers foster or tolerate (Sanfiorenzo-Barnhard et al. 2009, Harvey et al. 2011, Ramírez-Marcial et al. 2012, Somarriba et al. 2012). We begin by conceptualizing “frequency of disturbance” as farmer’s management strategies. We suggest this because trees respond to disturbance and because many, if not most, of the individual complex socio-economic, political and ecological forces imposed by the farmer within the embedded society influences their farming strategies. The objectives of this review are: 1) use the dynamic framework summarized in figure 2.2 to explore how linear, non-linear and multivalued dynamics (figure 2.2a, 2.2b and 2.2c, respectively) can be applied to understand the extant and potential for change of tree cover densities across the silvo-pastoral landscape; 2) focus especially on the possibility that multivalued dynamics may be operative, to think beyond obvious or intuitive cause and effect relationships, thus uncovering new insights that may better explain the patterns we see across socio-ecological systems; and 3) Discuss possible socio-economic drivers that interact with disturbance at the farm level.

2.2 A GENERALIZED CONCEPTUAL FRAMEWORK

The framework we employ is motivated in part by natural processes. The gradient from a high-density treescape silvopastoral system to a treeless pasture can be conveniently conceptualized by comparison to the similar natural systems of tropical vegetation (Hirota et al. 2011, Staver, et al. 2011). Along an X axis of annual precipitation one can identify a low level of precipitation that will inevitably produce a savannah, and a high level of precipitation that will inevitably produce a forest. It is at some intermediate state of precipitation in which historical evidence suggests that there are two tree density values (savanna state and forest state) for any precipitation value. At that level of annual precipitation, some critical density of trees will have a snowballing effect because the trees themselves create locally more humid conditions, thus resisting fire and eventually resulting in a forest. Yet, at that same setting of annual precipitation, if the tree density is below the critical density, the humidifying effect of the trees cannot be realized, and the system will move to the periodic fire and savannah state. The zone in which such critical tree densities mark the dividing line between ultimate forest and ultimate savannah is a hysteretic zone. Model frameworks that attempt to project the consequences of global climate change on forest and that don't consider hysteretic zone present an unacceptable prejudice into projections for these kinds of systems.

The conceptual framework we present is parallel to this natural example. Furthermore, it replicates precisely the social prejudice inherent in the climate change projections of tropical forests and savannah, in that practitioners presume that, no matter how the explicit drivers are conceptualized, there is an implicit assumption that no hysteretic zone exists. In this review we explore how linear, non-linear and multivalued dynamics can be applied to explain shifts in agro-ecosystem management, particularly silvo-pastoral systems, similarly to the framework now common in explaining shifts in natural vegetation (Rietkerk, et al. 2004, Kéfi et al. 2007, Hirota et al. 2011). Our region of interest is the Neotropics, where much natural forest has been converted into cattle pastures, yet casual observations leave little doubt that there is great variability in the density of trees in these cattle systems. We specifically ask the question as to whether the implicit assumption of a lack of hysteresis is a reasonable one, and emphasize the possibility that multivalued dynamics with thresholds and critical transitions may more closely approximate what happens in nature, thus potentially providing better understanding of both predictable and unpredictable states (in the sense that alternative states are extant), providing a sense of understanding of less predictable turnovers (Hobbs and Suding, 2009, Chapter 1).

The first challenge in constructing this frame of reference is objectively defining the variables involved, which is to say, identifying the relevant drivers of the system and the measure of arborization of the system. At the most abstract level we can begin with the simple variables "density of trees" as the response variable plotted on the Y axis and stocking rate (as a depiction of disturbance) as the driving variables, presuming that the various social forces involved in connecting the two result in a meaningful relationship (figure 2.3a). As cattle density is increased, it is more likely that trees will become less desirable in the system and we can expect a relationship as pictured in figure 2.3a. If such a relationship exists, the expectation from a random sample of cattle farms will reveal a bimodal distribution of tree density, some farms with very high tree densities and others with close to zero trees. Essentially, there will be "styles" or "syndromes" of silvo-pastoral systems that vary according to tree cover density. Our hypothesis is that these two syndromes maintain their resiliency through positive feedbacks among the components that make the syndrome. In figure 2.3b, a catastrophic transitions occurs when positive feedbacks weaken and resilience of the syndrome is lost. It is clear that both the syndromes (many trees versus few trees) and the drivers (various levels of stocking rate) are oversimplifications, presented here for heuristic purposes. In the rest of this review we examine what we regard as some of the most important complications, remaining within the basic hypothesis of syndromes which are possibly resilient, nevertheless sometimes change dramatically and suddenly due to underlying catastrophic transition, a pattern that may be the norm for actual practice in nature.

We begin with discussions of both sides of this framework, first the syndromes that seem to emerge in the examples of cattle ranching across Central America and Brazil where most of the literature is currently situated. Second, we discuss the socioecological drivers that represent a sort of independent variable that gives rise to those syndromes.

2.3 A BRIEF HISTORICAL CONTEXT OF THE NEOTROPICCAL RANCHER AND THEIR RELATIONSHIP TO THE FOREST

Across many areas of the world, silvo-pastoral systems have persisted for substantial periods of time. The classic examples are those from the Mediterranean regions in Europe among which are the Dehesa system in Portugal and Spain (Joffre et al. 1999) with tree densities that can range from less than 10 trees ha^{-1} to 50 trees ha^{-1}. Other examples include the Kermes Oak forest and the Valonia Oak systems in Greece which grow on sub-Mediterranean climate and under which goats and sheep roam. Some of these systems, like the dehesa system, have persisted for centuries (Papanastasis et al. 2009). Similar to the Neotropical silvo-pastoral systems, these Mediterrenaen systems are human modified and exploited for livestock management in combination with other uses and are a means of subsistence for a remarkable rural sector. The Neotropical silvo-pastoral system, however, has existed for less time than the European system, so how they will persist across the landscape is a matter of debate.

The Neotropical silvo-pastoral system as we know it today arises from a set of policies across the Neotropical region which promoted a very specific form of cattle ranching management. Although cattle ranching was already a component of rural livelihood across Latin America, it wasn't until the 1960's that under pressure by the USA, Latin American countries began to implement land reform that led to the well-known colonization programs. The colonization programs incentivized landless farmers to cut the forest as a means to claim land, but were also driven by land-speculation (Rudel 2007). State-led cattle ranching resulted in a cattle ranching culture that perceives agriculture as incompatible with trees based on the notion that trees on the farm imply that the land was being underutilized (Muchagata and Brown 2003). As a result, farmers' perceptions over tenure security possibly influences motivations to conserve forest or fallow within their properties (Hecht 1985, Muchagata and Brown 2003, Heckadon-Moreno 2009, Rudel 2007, Zahawi et al. 2015). In the mid 1980's the governments across Latin America became fiscally strapped having to sign structural adjustment agreements with the International Monetary Fund (Hetch et al. 2006, Rudel 2007). These agreements meant that the governments would have to stop supporting farmers, leaving them to the mercy of the market, a policy that persists until today. In the 1990's land titling programs that spread across many regions of Latin America (less so in Brazil) have converted the farm into private property, making it marketable (Borras et al. 2012) and allowing ranchers and small farmers to make use of bank loans to manage their cattle ranch. Titling has allowed certain groups to make more permanent claims to land, possibly modifying their perceptions over the role that deforestation plays for claiming land.

Another important context across Latin America are the environmental policy efforts introduced during the 1990's. After the state-led rampant deforestation of the colonization period, international environmental agencies mostly from Europe and the USA pressured Latin American governments to "save the rainforest." Since then, many "environmental" forces, which have been mostly state led (but often with international support), have existed in the realm of pasture management. Literature argues that environmental legislation which is often regulated through the use of a penalty system has been difficult to enforce since state agencies are understaffed (Kaimowitz 1996). Therefore, only in places where the state has a presence, these policies may actually have a direct effect on how farmers manage the farm. However, when it is enforced, these policies have led to a lot of conflict between ranchers and conservationists, often leading to more deforestation. For this reason, governments like Brazil have invested in efforts like the agro-extractivist settlements in Brazil, where the state aimed to integrate farming with forest conservation. These programs, however, have often been poorly developed for lack of infrastructure and limited access to the markets (Muchagata and Brown 2003).

Recently, there has also been state support for pilot programs for market mechanisms including PES (payment for environmental services) and payment for Carbon, which are efforts that also require substantial technical assistance which remains weak across most regions. One example is the implementation of silvo-pastoral systems through a PES system. Although farmers have expressed appreciation for these programs, these have not been adopted at a large scale (Calle et al. 2013). Thus, although there is no direct effect of these policies on farmers, the idea that it might be possible to gain profit from tree conservation or that there are penalties if certain rules aren't followed may shape the behavior of farmers to some extent (Kaimowitz 1996, Pagiola et al. 2007).

In many areas, cattle ranching continues to boom as better access roads to markets continue to grow (Walker 2009, Hoelle 2011). For many farmers rearing cattle is no longer just a means to acquiring land, but as a means to obtain government benefits or necessarily economically inefficient. Instead, cattle ranching is perceived as a means of subsistence, a source of profit, and a very important component of culture (Hoelle 2015). The value that trees have in the cattle pastures and to the cattle rancher has been understudied but there is some literature that suggests that farmers across Central America and Brazil are doing different things when it comes to tree management (Lerner et al. 2014, Harvey et al. 2011). This literature contrasts the most general idea that cattle ranchers are a homogeneous group of people in regards to their relationship with the forest and trees. In the following sections, we explore the idea that there are syndromes of cattle ranching production in regards to their management of trees.

2.4 THE SYDROME

In elaborating the nature of the syndrome, tree density is the most obvious variable associated with our ability to identify one or another syndrome (figure 2.1). But it is not the only one. Another important characteristic variable is spatial aggregations of trees. In our experience, the common landscape arrangements can be categorized into four distinct patterns: dispersed trees in pasture or agricultural plots, live fences, riparian vegetation, and forest fragments. At times the trees are highly clumped at particular sites on the farm, other times they are interspersed with the pasture or agricultural plots (Santillán et al. 2007, Caughlin et al. 2016). Live fences are commonly found in cattle pastures across the Neotropics (Caughlin et al. 2016). Trees may also be clumped as small forest fragments or riparian vegetation that have either regenerated after past land-use or may be remnants of what once was continuous forest. The density of dispersed trees is clearly related, although in complex ways, with management practices. Trade-offs between shade provided by dispersed trees and grass production are often acknowledged by farmers, but shade for cattle has been cited as one of the main reasons for retaining trees in pastures (Harvey and Haber 1998, Love and Spaner 2005, Sanfiorenzo-Barnhard et al. 2009, Lerner et al. 2014). Dispersed trees also have multiple uses such as timber, fruit crops (Harvey et al. 2011, Lerner et al. 2014) and fodder (Love and Spaner 2005) reflecting some diversification of utility. Ecological, aesthetic (Lerner et al. 2014) and other values may also be attached to these trees and selectivity by the farmer for particular tree species may be reflected in the diversity of dispersed trees. Thus the density of dispersed trees is clearly related to particular style of management practice.

A third and final variable that we take to be an important indicator of the silvo-pastoral syndrome is tree biodiversity. Trees in agro-silvo-pastoral systems are managed by the farmer who consequently directly determines the biodiversity by: 1) allowing certain species to remain standing after forest clearing (Harvey and Haber 1998), 2) managing regeneration of certain species (Love and Spaner 2005, Ramírez-Marcial et al. 2012, Somarriba et al. 2012, Lerner et al. 2014)) or, 3) directly planting trees (Simmons et al. 2002, Love and Spaner 2005). Forest clearing and managing regeneration seem to be more important methods for maintaining dispersed trees in pastures than direct planting (Lerner et al. 2014, Sanfiorenzo-Barnhard, García-Barrios et al. 2009). In the process of "allowing" trees to regenerate in pastures, farmers select those tree species that regenerate (Harvey and others 2011, Ramírez-Marcial et al. 2012, Lerner et al. 2014). Planting trees species is more common in the process of constructing living fences, although farmers tend to underestimate the number of species used as living fences relative to what botanical surveys indicate (Love and Spaner 2005). Sometimes ranchers and farmers will have clusters of trees in the form of tree plantations for timber (for example, Teak, Mahogany), or for commercial fruits (for example, Brazil nut) (Simmons et al. 2002). These operations have very high tree densities but low biodiversity compared to riparian vegetation and forest fragments where rancher and farmers “allow” natural regeneration.

Woody cover within agrosilvopastoral systems may also be quite dynamic because ranchers and farmers may allow plots to turn into fallow areas or even young forests either permanently or temporarily (Uhl et al. 1988, Perz and Walker 2002, Muchagata and Brown 2003). In the latter case, ranchers and farmers may clear most of the forest but keep some trees interspersed within the renewed pastureland. This process may repeat itself across time and space creating interesting, sometimes enigmatic, tree patterns. The significance of these emerging tree patterns across agricultural systems has not been analyzed thoroughly and is often ignored by conservation planners (Hecht et al. 2006).

Ecologically, trees have multiple functions. Many studies indicate that increase in tree community complexity, including the density, diversity, and canopy structure, correlates with a high density of insects, mammals, and birds in coffee systems (Perfecto and Vandermeer 2002, Philpott and Dietsch 2003), cacao systems (Van Bael et al. 2007) and pastures (Harvey and Haber 1998, Harvey et al. 2006). Scattered trees and live fences are important for the movement of organism within agricultural landscapes (Estrada and Coates-Estrada 2001, Stoner 2001, Perfecto and Vandermeer 2008). Trees also provide multiple ecosystem services, and the degree to which these prevail depend on the complexity of the community, but some that are clear across the literature include provision of habitat for insects that provide biological pest control (Vandermeer et al. 2010) and pollination in coffee systems (Tscharntke et al. 2005). Trees also reduce vulnerability to extreme climate change events including extreme precipitation (Lin et al. 2008). Their deep and extended roots reduce the runoff of superficial water and allow better absorption of humidity and nutrients into the soil and they reduce the effect of compaction that comes with raising cattle (Joffre et al. 1999, Ogden et al. 2013). Trees also protect the soil diminishing the effect of direct sunlight (Santillán et al. 2007).

2.5 THE DRIVERS

The processes behind the dynamics presented in figure 2.2 derive from the interaction of many "factors", some of which may be direct and others indirect drivers of the observed emergent tree community in the farm. The factors that we include are those that we consider relevant to the cattle rearing community, including farmers that rear cattle and cattle ranchers across the Neotropical forests; they include both positive and negative forces. We conceive of them along a single axis that is constructed in a quasi-quantitative fashion, as a system that couples both social and ecological forces.

2.5.2 Ecological drivers

As defined earlier, disturbance refers to any process that eliminates trees directly or serves as a barrier for the future establishment of trees. Certain characteristics of disturbance may have different outcomes for tree establishment. Some characteristics include the frequency of the disturbance, the scale at which it occurs, the magnitude, duration, and the type of disturbance. Disturbance can be caused by natural events (e.g. a hurricane, flooding, fires) or, in our conceptualization, by management action (e.g. deforestation) (Chazdon 2003, Walker and Meyers 2004). In grazing systems, the main goal of management is to maintain low-lying vegetation, mainly grasses (but of necessity legume forage also), which often requires a combination of fires, grazing, change in stocking rate, and use of industrial herbicides and fertilizers, all of which necessarily modifies the plant community (Westoby et al. 1989). Of course, there are feedbacks between management action and natural events (e.g. reduction of stocking density during a drought year) (Chazdon 2003). Whether extensive or intensive, grazing systems are characterized by rotating livestock in pastures that are subdivided such that each receives both rest and grazing periods (Westoby et al. 1989). The probability of a tree establishing in these pastures will depend on the interaction between disturbance caused by management action and ecological processes of natural regeneration. Structural diversity that can facilitate regeneration processes is a positive driver whereas disturbance processes that come along with management are negative drivers.

2.5.2.a Regeneration processes and structural diversity

It is clear that the structural diversity of trees along a "disturbance" gradient is one of the most significant variables in facilitating tree recruitment and regeneration across landscape (Ferguson et al. 2003). As mentioned previously, regeneration along these open habitats plays a more important role than direct tree planting by farmers (Harvey and others 2011, Ramírez-Marcial et al. 2012, Lerner et al. 2014) often because tree planting efforts are too difficult to pursue (Holl 1999). Remnant vegetation among pastures plays a critical role in forest recovery, promoting rapid increase in species richness, tree density and aboveground biomass (Guariguata and Ostertag 2001). As mentioned before, this remnant vegetation may be found in the form of forest fragments, living fences, isolated trees, fallow and riparian vegetation across the agricultural landscape.

Plants can regenerate through seed germination or resprouting (Chazdon 2003). Resprouting can be a more common process of regeneration than seed germination after disturbance both in forested and pasture habitats. For example, resprout species dominated seed bank species in a forest regeneration plot following a hurricane in the Atlantic coast of Nicaragua (Yih et al. 1991, Vandermeer et al. 1995). In abandoned pastures of dry forest regions, re-sprouts have been demonstrated to be the primary mechanism of regeneration (Vieira and Scariot 2006, Griscom et al. 2009). The process of resprouting in itself can be diverse since both below ground and above ground tissue can be important for regeneration depending on the habitat and level of disturbance (Kammesheidt 1999).

While structural diversity is positively correlated with tree densities across open habitats, seed banks appear to not contribute much since they are nearly absent from the pasture soils that have been so heavily eroded. In open habitats, there are no pioneer seed banks. A restoration experiment on a 30-year cattle pasture at Los Tuxtla, Mexico, reported that recent seed dispersal events played a much larger role in recruitment than seed banks after five years of cattle exclosure. In fact, seed banks were mostly limited to two species that were part of the structural diversity of the farm five years before the census (Howe et al. 2010, De la Peña-Domene et al. 2013). The same study found that the majority of woody recruits were animal opposed to wind dispersed species, highlighting the importance of animals as dispersal agents in the pastures. Thus, we see that increasing diversity in open habitats depends on recent dispersal processes by wind and animals, the latter playing a much more important role for increasing diversity.

The problem lies in that few dispersing animals move from the forest into treeless habitats (Ferguson, et al. 2003). Structural diversity in pastures might be important as an attractive focus for birds and other dispersers thus acting as a colonization nuclei (Guevara et al. 1986, Vieira et al. 1994, Galindo-González et al. 2000, Slocum and Horvitz 2000, Chazdon 2003, Ferguson et al. 2003). The long-lasting effect that these remnant trees have on succession was demonstrated in a 20 year post-agricultural succession plot, where remnant trees had the largest effect on the species composition of the surrounding forest (Sandor and Chazdon 2014). Trees in silvo-pastoral systems are the structural diversity. This structural diversity appears through natural regeneration processes “allowed” by the farmers. The structural diversity is then affected negatively by disturbance. However, if a silvo-pastoral system has high tree density and diversity it will more easily recover from disturbance both through resprouting, and recent dispersal (Boucher et al. 2001, Ferguson et al. 2003).

But structural diversity is not the only factor important for forest recovery. Forest recovery is accelerated if prior land-use intensity was low, if recovering areas are relatively small, and if soils are fertile (Guariguata and Ostertag 2001, Chazdon 2003). Natural regeneration can be a relatively quick process in the humid tropics but it’s not guaranteed due to pastures long exposure to disturbance (Santillán, et al. 2007). Long exposure of the land to cattle pastures leads to soil degradation by elimination of top soil layers with the majority of nutrients accessible to plants and by reducing the ability of the land to conserve water. These degraded microclimatic conditions limit the ability of seeds to thrive once they’ve been dispersed to a particular pasture site.

Similar to the forest – savanna example presented previously, the structural diversity is a component of the silvo-pastoral system that leads to positive feedbacks that maintain the tree community stable by attracting seed dispersers and maintaining soil conditions among others. The more structural diversity, the easier it will be for the tree community to recover after disturbance. However, with more and more disturbance, a critical tree density may be reached and the silvo-pastoral system will no longer be stable. At this critical tree density the system may go through a catastrophic transition (figure 2.3b).

2.5.3 Disturbance processes

Disturbance is regarded as a negative driver of tree density (Muchagata 2003). Disturbance in the context of pasture management is thought of as the processes designed to maintain the pastures through management of weeding, paddock rotation and cattle densities. Arguably we can summarize disturbance into four factors: cattle disturbance, competition between introduced grasses and tree seedlings, and the various forms of weeding.

Forests are transformed into pastures through the introduction of exotic grasses and cattle, with obvious management of trees from the beginning by removing at least some of them. Both agents can have direct negative and indirect negative effects on regeneration. Cattle directly negatively affect seedling growth rate and survival of any plants dispersed into the area by trampling and browsing on seedlings (Guevara et al. 1986, Harvey and Haber 1998). High density of cattle and their continuous roaming of the land also compacts the soil, increasing runoff during the rainy periods creating poor soil conditions for seedling growth. In the Republic of Panama dry forest region, plots with cattle decreased tree density and basal area compared to plots without cattle but had no effect on diversity (Griscom et al. 2009). Cattle density or stocking rate then is a negative driver of tree density. However, cattle can also play a role in dispersing seeds to different areas of the farm perhaps facilitating regeneration in certain areas where it is not possible otherwise (Miceli-Méndez et al. 2008). Cattle can also fertilize the soil and create humid soil conditions that may be favorable to tree establishment (Broom et al. 2013). Cattle's positive effect on regeneration can retard the negative effect it has at high densities creating the lags observed in figure 2.2c.

Cattle trampling is not the only factor affecting tree densities. Trees often don't establish in the pastures because of competition with grasses and forbs. The dense root system of grasses competes for moisture and nutrients with the trees and the thick grass canopy limits light availability (Nepstad et al. 1996). Grasses are so aggressive, that some suggest it is necessary for shrub species to colonize pastures before trees. Shrubs then can shade out grasses, and create microhabitats that facilitate the establishment of tree species (Aide et al. 1995). Although grasses are mostly negative for tree establishment, they can have some positive effect by offering humidity that protects the seedlings from desiccation during the dry season (Knoop and Walker 1985, Gerhardt 1993, Holl 1999). The meaning of this grass positive effect on seedlings is that although grasses have an overall negative effect on tree seedling establishment, there negative effect can be retarded. This retardation can possibly result in a hysteretic zone as the one presented in figure 2.3a.

Farmers use herbicide, manual or mechanical weeding, and fire to manage the grasses and control "weeds", many of which are trees in the early stages of growth. The goal is to maintain the pasture, or the anthropogenic grassland and push away the woody vegetation and other weeds. Continuous application of herbicide also has dire consequences on tree growth. Griscom et al. (2005) reported that herbicide application along with cattle exclusion had a positive effect on growth rates, although herbicide treatment also caused soil moisture loss and considerably eliminated shrub sprouts which was the major source of regrowth in the study area. Mechanical or manual weeding also has a direct negative effect on tree density since it directly eliminates the source of regeneration. Fire is a tool used to create and maintain pastures and savannas in areas where native vegetation has no tolerance to fires (Murphy and Lugo 1986). Fire in combination with deforestation and intensive use of soil can transform tropical forests into savannas of which there are many examples in Central and South America (Cavelier et al. 1998). Plant species from savannas frequently have characteristic structures such as thick cork bark and the capacity to sprout from underground organs (Cavelier et al. 1998). Furthermore, many grass species are fire dependent (Cavelier et al. 1998). Exotic grasses such as *Hyparrhenia rufa* (Nees) Stapf may also perpetuate a fire disturbance regime (Janzen 1988). Weeding presents itself as a negative force that eliminates tree densities not just immediately, but also creates conditions for the future that will make it hard for trees to establish in the future.

Continued burning, overgrazing and weeding tend to eliminate the seedlings, sprouts and the seed bank from the original standing forest, leaving seed dispersal as the only source of trees (Aide et al. 1995). However, stressful microclimatic conditions, competition with grasses and agricultural weeds, low soil fertility, and high soil compaction create barriers to the regeneration of these seeds (Vieira et al. 2009). The review on the effects of disturbance on tree densities indicates that these negative drivers generate a long-lasting disturbance effect. If a farmer wants to embark on the task of increasing the tree density in a land that has been heavily disturbed through weeding, cattle trampling and the introduction of exotic grasses, he may find it to be an impossible task since the natural conditions of the land no longer have the components that are suited for tree establishment. Positive feedbacks between soil degradation and lack of seed dispersal events make it so that the treeless pasture stay treeless. Ultimately, his efforts may show no immediate results. A lot of effort may be necessary to reach the critical tree density described in figure 2.3b that would lead to a catastrophic transition towards the high tree density state.

In view of the negative effect of disturbance on trees a simple conceptual monotonic model may be seductive (Westoby et al. 1989). However, a focus on succession of Neotropical woody vegetation is less likely to suggest such a simple monotonic model. Rather, as we argue above, a hysteretic model may be most likely. The application of the hysteretic model into rangeland literature is not new. Similar to our review, Westoby et al. (1989) challenged the idea of monotonicity in the rangeland successional model. The assumption of monotonicity is a problem since farmers would assume that there is a specific disturbance condition that creates a specific desired or climax-type silvo-pastoral system and would apply management prescriptions accordingly (figure 2.2a). Ignoring that there may be retardations in the systems response to management can lead to unexpected and frustrating failures. In different fields of study, monotonicity has long been an unquestioned assumption (Sudding et al. 2004) sometimes leading to unwarranted conclusions about the world.

2.5.4 Social drivers

Many social variables that drive and prevent the incorporation of trees into agricultural management have been documented primarily through three fields of study, with some overlap among them: 1) conservation policy analysis that attempts to incorporate traditional knowledge into biodiversity conservation employing qualitative methods (Charnley et al. 2007); 2) agroforestry literature with the evaluation of farmer's success or failure to adopt agroforestry projects employing mixed qualitative and quantitative methods (Pattanayak et al. 2003, Mercer 2004, Calle et al. 2013); and 3) land-use change science that aims at understanding the socio-economic drivers of forest transitions at a regional and national scale employing quantitative methods (Perz and Walker 2002, Perz 2007, Lerner et al. 2014). Most of this literature focuses on the social drivers and less on the ecological (Mercer 2004). Most of these fields of study tend to focus on the farmers as the object of forest destruction, and less on them as agents of their livelihoods (Perz et al. 2006). There is no baseline study that we know of that rigorously evaluates silvo-pastoral systems already being managed across these landscapes.

We borrow from the food sovereignty literature to explore the social drivers of tree management across the farms. We employ Chayanov's *Theory of peasant economy* which places farmers and their farm at the center and argues that these farmers are generally governed by a balance between the utility of producing an item and the drudgery of producing that item, among other more complicated trade-offs. Its modern take by Van der ploeg (2013) argues that farmers need to have the capacity to evaluate these balances. Outside forces may attempt to keep farmers from making these evaluations, but farmers often resist. In the end, their capacity to balance is what allows them to improve their livelihood freely. In this view, we argue that tree management is one component of the farm management that most farmers that rear cattle must include in their calculations. Hence, how farmers balance tree management with other components of farm management results in a more holistic understanding of what drives the silvo-pastoral system.

2.5.4.a <u>Chayanovian economics</u>

Chayanov's *Theory of peasant economy* emerged during the early 1900's in Russia, where in the wake of industrialization there was a lot of discussion regarding the role and future of the peasantry as society transitioned into socialism and capitalism. On the one hand, Lenin was focused on class differentiation and argued that the countryside would be split into agrarian capital and labor. On the other, Chayanov developed a Theory of Peasant Economy that was concerned with the actual process of decision-making within the peasant families (Bernstein 2009, Van der Ploeg 2013). The Chayanovian framework makes an important and useful distinction between the capitalist farm and the family farm. While the capitalist farm prioritizes maximizing profits, the family farm (which is composed of the family) prioritizes household needs, which Chayanov formalized as a "balance" that exists between household labor and family consumption (Chayanov 1986, Steckly and Weis 2016). Therefore, there are three main distinctions between the capitalist farm and the family farm made by Chayanov: 1) the capitalist farm is governed by maximizing profits and the family farm is governed by the “balance” between household consumption and labor. 2) The source of labor in the capitalist farm is different than in the family farm. In the family farm labor is produced by the family. In the capitalist farm the source of labor is determined by the amount of advanced capital and what Chayanov called “the objective national category of wages and workers required for a particular task” (Chayanov 1986, page 196). 3) The final distinction made by Chayanov is that capital circulates differently in the capitalist compared to the family farm. In a capitalist farm the earnings are divided into renewing advanced capital to maintain the companies’ operation and profit. Labor is a commodity and because it is determined by advanced capital, it is indistinguishable from other means of production needed to continue production in the capitalist mode of production. In the family farm, contrarily, earnings are used to reproduce the labor force which is provided by the family. The amount of labor that goes into production is determined by the size of the family and driven by an equilibrium between the consumption patterns of the family and the labor necessary to supply that consumption. Beyond direct consumption and the labor required, other tasks on the farm need doing (they have a utility) yet imply a certain degree of unpleasantness involved in carrying them out, what Chayanov refers to as drudgery, giving rise to the famous balance of utility and drudgery. Chayanov proposes and concludes that the forces that govern the family farm are complicated and contingent, much different from the simple maximization of monetary returns of the capitalist farm (Chayanov 1986, page 195-198).

The Chayanovian system is framed within the context of complex “balances.” The idea of balancing a varied set of planned activities is probably characteristic of many human systems, where we continuously, if sometimes only tacitly, weigh alternatives of positive and negative.

Chayanov viewed family planning from this perspective, asking precisely which considerations the family was concerned with. Chayanov focus was on two balances: 1) the "labor/consumption" balance and 2) "utility/drudgery" balance. He argued that the amount of labor that went into production was subjective to the peasant family's situation but generally determined by farmer's perceptions over the utility of producing one more item in relation to the drudgery of producing that item. This particular balance is certainly recognizable in modern terms within both the small family farms that rear cattle and the ranchers of the Neotropics.

The utility/drudgery balance is probably implicit in the thoughts of almost all farmers, not just Russian peasants. This inevitability results in the necessary condition that there must be a point at which the farmer decides that the next unit of utility is not worth the next unit of drudgery, conditions that automatically imply a local equilibrium. It is evident that such thought processes are at least sometimes in the minds of farmers as they make decisions about how to manage their cattle. We believe this framework can be effective in forming an approximate scale that could be plotted on the X axis of figure 2.2. Chayanov was writing at the advent of industrialization in Russia when there was an ongoing debate as to what would happen to the peasantry with the rise of capitalism, socialism, and industrialization. Today farmers in our context of the Neotropics are embedded in the capitalist economies but the extent and form in which they are embedded varies as some attempt to fully incorporate and others resist capitalist contracts (Van der Ploeg 2009, Vennet et al. 2016, Steckley and Weis 2016). We present the idea that on one extreme of the X axis (in figure 2.2c) family farms are governed by Chayanovian balances. On the other extreme you have the farms governed by maximizing profit. The axis then becomes the degree to which Chayanovian decision-making dominates the farm. The natural follow up question and our contribution is: how do we position particular farmers on that axis?

2.5.4.b Farming styles

In this section, we envision the positioning of farmers on the X axis based on Van der ploeg (2013) scale and intensity balance proposal. Van der ploeg (2013) introduces a modern interpretation of the Chayanov balances and argues that because farmers are now connected to the capitalist economy they have to handle a broader set of balances than the ones proposed by Chayanov (Steckey and Weis 2016) including the balance between people and living nature, production with re-production, external with internal resources, autonomy and dependency, and balance between scale and intensity.

Although all the balances are connected, for our purposes it is useful to focus on the balance between scale and intensity. Scale and intensity are the two ways in which a farmer can increase production. Van der ploeg et al. (2013, page 64) explains that scale and intensity can be organized in a two dimensional space leading to the 4 different styles of farming: 1) style of farming intensively (small scale intensive farming), 2) large-scale intensive farming style, 3) style of farming economically (small scale low intensity farming), and 4) labor saving style (low intensity large scale farming) (see figure 2.4a). Scale refers to the number of labor objects including the size of the land, number of workers etc. Intensity refers to the "production per object of labor." Land, labor, cattle, machines, networks, knowledge, expectations and activities are organized differently across the four farming styles (Van der ploeg 2010, Vennet et al. 2016). For example, intensification of the farm or cattle ranching system can be determined by the stocking rate, the use of specialized cattle breeds, health care applied, the quantity and quality of fences (Muchagata 2003). The organization of these components is done in a carefully planned way and depends on the "needs, interests and prospects of the farming family" which occurs through tuning the different "balances" (van der Ploeg 2013, page 63).

Farmer’s embeddedness in the market is an important factor determining styles since it says something about their place in the food regime (Friedmann 1982, McMichael 2005, McMichael 2009, Vennet et al. 2016). Based on our discussion of disturbance, we can argue that both intensity and scale are related to disturbance on the farm. Presumably, the more intensive the farming operation is, the higher the stocking rate will be and the employment of exotic grass varieties over other native species will be prioritized as will the frequency of pesticide use.

In the literature, there does not seem to be much attempt to classify cattle ranches into “farming styles” based on tree management. Specifically regarding Brazilian cattle ranching, there has been substantial attention focused on how the processes of land colonization affects forest transition, with cattle farming playing a central role. This literature highlights the possibility of styles. For example, in Marabá, Brazil, Muchagata (2003) describes three stages of ranching that can lead to three models that vary in intensity and specialization. Perz et al. (2006) also describes three kinds of farmers and their relation to deforestation in the region of Uruará Brazil including: the small land holder, the large cattle rancher and the farmer that emerges from a process of land consolidation. Finally, Hoelle (2015) describes two kinds of farmers in Acre Brazil, those that are small farmers that use to be rubber tappers and large cattle ranchers that had colonized the area once occupied by the rubber tappers. Based on this literature we can argue that today there are roughly four styles of farmers based on their connection to the food regime and the intensity and scale of operation: the large corporate operation (Borras and Franco 2012, Bowman et al. 2012, Taravella 2012, Walker et al. 2009, Grandia 2009, Hecht and Cockburn 1990); the entrepreneurial farmer (Taravella 2012, Muchagata 2003); the permanent small land holder (Perz and Walker 2002); and the frontier farmer (Walker et al. 2009, Perz and Walker 2002, Muchagata and Brown 2003). Of course, this is a generalization and the context of each place will shape different styles of farmers. In addition, transitions from one style of ranching to another is common (Muchagata 2003).

As some have suggested, there is not an inevitable relationship between scale and sustainable management (Brown and Purcell 2005). That might very well be the case in cattle ranching since traditionally cattle ranching has been practiced as a form of extensive management in which farmers try to decrease the capital-labor ratio. Many large ranchers may have many trees on their farm if they do a form of extensive ranching management in which low cattle densities roam across large tracks of pastures. In the extensive ranching mode, weeding events may be sparse as labor is low. Some of these ranchers may be well connected to the market, but often these large ranchers are far away from markets and managing mostly as a means to maintain claims on their property (Hetch 1985). In a heuristic sense, we can place this category of farmer in the large scale but low intensity farming styles proposed by van der Ploeg 2013 in which the farmer focuses mainly on minimizing labor. On the other end of the spectrum, is the frontier rancher or farmer which generally speaking is the "poor" farmer who is not well connected to the market and may rear cattle but mostly as a means of subsistence (Walker et al. 2000, Muchagata 2003, Coomes et al. 2008). Van der ploeg (2013) argues that while some call these farmers inefficient (Santillán et al. 2007), these farmers are in fact balancing scale with intensity, resulting in a small scale low intensity farming style or in other words, economical farming. The small scale low intensity farmer may have forms of weeding that allow fallow formation or secondary forest succession at least temporarily (Muchagata 2003, Perz and Walker 2002). Finally, there is the high intensity farming which is characteristic of the entrepreneurial farmer, not necessarily tied to large land holdings. Presumably, the high intensity farmer or rancher operates a form of management that has a negative relationship with tree densities. The extreme version of ranching intensively would be the Concentrated Farming Operations or (CAFOS) (Borras et al. 2009) but these would only really take place in large ranches where economies of scale are at play. Such farmers have very tight connections with the market and are essentially the embodiment of today's dominant food regime since they are the style of farming that is a "co-construction of agrarian policies and technological development (Van der ploeg 2013 page 64)."

Finally, the scale-intensity balance occurs simultaneously with other balances including nature and society and that between production and reproduction. A general notion exists in the cattle ranching culture that trees are incompatible with pasture management (Calle et al. 2013). However, ranchers and farmers also use trees for their various economic purposes (Garen et al. 2011), and some literature has revealed that they also value trees for the long-term sustainability of the farm (Lerner et al. 2014). In this view, there may be a range of perceptions regarding the balances between nature and society. The balance between nature and society is connected to the balance between production and reproduction, in that if farmers entertain the notion that trees are incompatible with pasture management, then they may not find it valuable for the reproduction of the farm. Those that do find compatibility between trees and the pasture may agree that trees are a necessary component to farm management. The perceptions over production, reproduction, nature and society can vary across the different styles that we have outlined and as such the various perceptions about these balances can be plotted on the X axis. In figure 2.4b we depict how disturbance, the Chayanovian balances and farming styles are related to each other.

2.5.4.c Placing the balances on the X axis

The Chayanovian framework states that although family farms may be connected to the commodities market, they are not fully governed by capitalist goals such as generating surplus.

Rather, these farmers are governed at least partially by Chayanovian balances. As a small-scale family farm moves toward the capitalist framework, the importance of complex Chayanovian balances recedes and simple calculations of what is imagined as "profit" emerge as dominant. A family worker will try to minimize self-exploitation while a hired hand is viewed differently, more like a classical proletarian. Therefore, the hypothesis we draw is that farmers that are drawn to capitalization of the farm will more intensely manage weeding, manage higher cattle densities, and make more use of modern technology and toxic herbicides that degrades the land when compared to the family farm, because the family farm will only intensify production to the extent that the drudgery can be justified by a sometimes vaguely defined utility. As Chayanov states in reference to the capitalist farm vs. the family farm:

> "*… when stalling cattle the number of cows and, consequently the amount of capital spent on them and on the means of production serving them will be established on the capitalist farm by the objective disadvantage of further expanding the herd. On the family farm, the amount will be set by the number of cows, where looking after the last one involves no more drudgery than not satisfying those demands that the income from this '"marginal'" cow might meet*." Page 215 (Chayanov 1986).

This difference between the family farm and capitalist farm occur in part because capital in the family farm circulates differently than in the capitalist farm. In the family farm, the amount of economic activity and labor is determined by family size and Chayanovian balances. In the capitalist farm, the amount of economic activity is determined by the size of capital advanced (money for land, equipment, and labor). In the capitalist farm, the gross income is meant to renew advanced capital, including fixed capital (machinery and land) and variable capital (labor), while what remains is profit. In the family farm, there is advanced capital to be sure, but labor effectively remains outside of the basic structure, remaining unalienated because of its position as part of the family.

Our perspective of placing farm decisions along an axis is that of an X axis ranging from purely Chayanovian to purely "Capitalist." At one end of the axis we conceive of standard capitalist modes of production with attendant categories of analysis (alienated labor, land rent, surplus value, etc . . .). At the other end we conceive of a non-capitalist framing, where dominant forces are mainly as conceived by Chayanov (utility/drudgery balance, labor/consumption balance, etc. . .). Thus the framing is clear from abundant previous literature at the extremes, but becomes complicated at intermediate scales. So, for example, if weeding activities are dependent on some degree of family labor, but also on some degree of hired hands, or if stocking rates are mainly to supply milk for the family, but encroaching markets create opportunities to sell surplus milk on the local market, the details of how the family thinks about and carries out the management plan for the farm is more complicated than it is at either end of the scale. Nevertheless, it is, we argue, possible, and useful, to recognize positions on that axis as some fraction of Chayanovian versus Capitalist intentions. If we take our four styles of farmers based on scale and intensity we can argue that some of these styles are more integrated to the capitalist mode of production than others. Essentially, the large and medium scale entrepreneurial are well integrated with the capitalization of beef and milk, whereas the permanent family farm and colonizer are only loosely integrated. In figure 2.4b we depict the relationship between integration into the food regime, style of farming, balances, and disturbance. The food regime refers to a food system world order that involves "specialization of agriculture and competition among producers" (Friedman 1982, McMichael 2005). In this view, farmers that are well integrated into the global food regime will apply technology that is suited to producing food for capitalization as would be the case of the intensive farmers (small scale and large).

2.6 CONCLUSIONS: THE MULTIVALUED MODEL -- A NEW CONCEPTUAL FRAMEWORK

We employ Chayanov's framework to analyze the drivers of tree densities across cattle pastures, and to argue that the possible low and high tree density styles of farming are driven by these two distinct economies: the family farm and the capitalist farm (figure 2.4b). We argue this is an important step in the research because the literature focused on cattle ranchers and their management of trees has developed a narrow view of the cattle rancher at various scales of research. On the one hand, literature that focuses on tree management in the cattle farm has focused on the drivers of deforestation and regeneration (Perz and Walker 2002, Perz 2007, Sloan 2015) and the ethnobotany of traditional tree uses (Harvey et al. 2011, Garen et al. 2011). On the other hand, conservation organizations (Kaimowitz 1996) often don't distinguish different styles of cattle ranching, boxing all the cattle ranchers within the title of forest destroyer which leads them to funnel funds and develop policies according to that idea. Finally, industry continues to promote a specific style of cattle ranching generally known as "conventional cattle ranching" which is characterized by the employment of improved grass varieties, herbicides and so forth (Calle et al. 2013) disregarding the potential for sustainable cattle ranching systems, farmers experiences, knowledge, and ways of management.

In this literature review we find that while there is literature on the differentiation of coffee, cacao, and even soy cropping systems (Moguel and Toledo 1999, Greenbert 2000, Vennet et al. 2016), very little research has been done on the differentiation of different styles of cattle ranching based on tree densities. We argue that exploring the dynamics that lead to low or high tree densities in the farm is important because it can help find ways to promote the conditions necessary for farmers remain at high tree densities or begin to incorporate tree into their farms. In this view, we have proposed three general steps: 1) described on the y axis on figure 2.1a; 2) described on the X axis based on degree of disturbance, Chayanov's balances, farming styles and farm's embeddedness in the food regime (figure 2.4b), and 3) exploration of the dynamics between the X axis and tree cover.

In previous sections, we were able to describe the Y axis which can become operational through the use of remote sensing data that captures the tree cover of farms and to a certain extent the species (Caughlin et al. 2016) in combination with field observations (Sanfiorenzo-Barnhard et al. 2009, Lerner et al. 2014). These tree covers can further be classified into landscape patterns (Harvey et al. 2011, Caughlin et al. 2016) to have a finer understanding of how trees are being used on the farm. Ideally this would be done across the entirety of the Neotropics in areas were rainforest once stood but that are currently dominated by cattle ranching. An analysis of the distribution of the tree cover across all these farms is bound to show multimodal distributions suggesting that there are possibly different styles of tree management across the landscape (Staver et al. 2011, Hirota et al. 2011) (figure 2.1). The X axis is more complicated since we have introduced the concept of disturbance, balances, and farming styles which are based on how the farmer organizes the components of the farm based on the Chayanovian balances. What all these drivers have in common, however, is that they are organized through the balances and have a dialectic relationship with our notion of "disturbance" that occurs at the farm scale. Ultimately the disturbance is what directly leads to a particular tree cover outcome. A way to make these socio-ecological drivers operational is to aggregate them and generate an axis of socio-economic “farming styles” based on the balances. Presumably, farms that are balancing nature with society, production with reproduction, and scale with intensity will be at the lower end of the X axis (figure 2.4a). The farms and ranches that are not balancing and instead operate as a capitalist enterprise will necessarily fall at the higher end of X axis. At this stage, we can test our hypothesis of the dynamics between the tree cover and the socio-economic farming styles using quantitative analytic methods that test for non-linearity in the data (Staver et al. 2011, Hirota et al. 2011).

Non-linearities are conceivable with both theoretical and empirical examples, at least in natural ecological systems. One classic example is that of predator-prey, or herbivore-plant interactions ((Noy-Meir 1975). Noy-Meir (1975) anticipated critical transitions as a dynamic force that arises naturally from a general model of grass (or plant) and cattle (herbivore) interactions. In his model, alternative herbivore productivity states arise under a particular condition of herbivore density. Multiple equilibrium points have also been demonstrated empirically for natural systems. Staver and colleagues (Staver, Archibald et al. 2011) demonstrated that at some condition of precipitation alternative states of forest and savanna are possible, indicating that there is a hysteretic zone at which it is possible to be either forest or savanna, depending on the starting conditions. Across socio-ecological systems at least two alternative states have been proposed for agricultural systems: the highly-degraded state and the non-degraded state (Vandermeer and Perfecto 2012). Further, the multivalued relationship between farming styles and peasant balances can be easily visualized theoretically.

Understanding these kinds of dynamics in socio-ecological systems like agricultural systems is not just an intellectual exercise. Systems can reach tipping points from which there is no return and this idea has been observed in range systems across the world (Abel and Blaikie

1989). Restoration efforts in such systems have failed with tremendous loss in resources. One lesson from these failures is that once systems are degraded they stay as such because there are positive feedbacks among the components of the system that keep the system from changing (Suding et al. 2004, Cale & Allen-Diaz 2009). Identifying the positive feedbacks that maintain a system resilient to any form of management has now become an important aspect of research in many fields of study (Suding et al. 2004). In the case of the silvo-pastoral systems we are dealing with ecological components and social components. Identifying these positive feedbacks requires that we understand both components and how they interact.

In the farms and cattle ranching system of the Neotropics we can discuss some possible positive feedbacks that could keep the different syndromes of tree cover stable, even as the drivers of tree cover change. Cattle grazing unarguably decreases grass density and woody density through grazing, trampling and soil erosion. As depicted in figure 2.2c, at a given stocking rate, the high tree density state may persist, but once a critical tree density is reached the system will catastrophically transition towards the low tree density state. Here we present a series of positive feedbacks that could keep either the high or low tree density state stable:

1) *Positive feedback between structural diversity and seedling recruitment in the high tree density state*. As mentioned previously, recruitment of woody species depends on the surrounding structural diversity, dispersal event, and soil conditions. If cattle density is moderately increased in a non-degraded high tree density farm, it will be possible for the system to recover as long as trees have enough time to form viable seedlings or juveniles before they die. However, if cattle density is greatly increased, then a critical tree density may be reached. At this point viable seedlings will not have time to form and the system will go through a catastrophic transition.

2) *Positive feedback between poor soil conditions and high disturbance*. Starting with a degraded low tree density system, decreasing cattle density may not result in increased tree cover because the soil conditions and dispersal events are so poor that the few viable seedlings are quickly trampled or grazed by cattle. The cattle density would have to decrease greatly in order for enough seedlings to establish, but soil recovery may be unreachable.

3) *Positive feedback between perceptions over tree value for farm reproduction*. A farmer maintains the tree density that he sees is necessary for the farm reproduction. If the farmer's perceptions over tree density and cattle density is that of compatibility, a farmer would maintain a high tree density. This farmer may have found a balance between the scale and intensity of his operation as well as between the production and reproduction of his farm resources. That farmer may start cutting trees if he wants more space for the cattle or if he becomes more capitalized, but if the market conditions deteriorate he may quickly return to his original state which is possible because the structural diversity and soil conditions will allow for trees to easily recover. If the farmer, however, cuts too many trees as he becomes more capitalized then he may reach a critical tree density and catastrophically transition, making it impossible for him to return to his original condition when markets deteriorate.

4) *Positive feedback between perceptions over trees as obstacles to farm reproduction*. A farmer in a treeless pasture may perceive that trees are not necessary for the reproduction of the farm operation since he is concerned with immediate profit and not the long-term sustainability of the farm. In this scenario, the farmer views nature as separate from cattle ranching. If this farmer were to change his perception over the value of trees, it would be

very difficult from him to transition from a treeless pasture into a silvo-pastoral system due to the positive feedback between poor soil conditions and high disturbance. This process could reinforce his perception over the incompatibility between trees and cattle density.

During the early 1900's, Chayanov was concerned with the agrarian question. The expansion of capitalism has resulted in different farming styles because farmers can shift their production which is a necessary capacity to survive (Van der Ploeg 2013, Steckley and Weis 2016,). Today we see that in spite of all the forces that have affected the rural landscape since Chayanov, the peasantry persists vibrant. In fact, in many areas there is a cultural evolution towards a new kind of peasantry that derives from a push back to the neoliberal imposition. Farmers resist contracts with the state or corporations that will restrain their ability to self-determine how to manage their farm. Farmer's ability to "balance" is the essential tool for upholding self-determination (Van der Ploeg 2013, Steckley and Weis 2016). If the balance is lost, autonomy over the farm management is lost. In view of farmer exposure to Neoliberal forces, food sovereignty has risen as a practice and farming philosphy. Farmers that abide to the food sovereignty principles strive for autonomy (McMichael 2009, Van der Ploeg 2010, Van der Ploeg 2013). It remains to be seen how much of the employment of food sovereignty principles has transferred to the cattle ranching culture and in turn how much that will affect the social-nature balance.

In the Neotropics, at least, this has not been documented widely, perhaps for lack of research and not because it doesn't exist. To understand exactly the "regimes" of cattle ranching and its accompanying tree densities it will be important to qualitatively evaluate farmer's goals and to understand what shapes the consumption – labor balance that helps achieve these goals.

Later it will be necessary to quantify what this qualitative expression leads to in terms of tree densities, land use, and household economy. Finally, we have to address the socio-political and ecological context of the farmers and how this context makes farmers vulnerable to shifts.

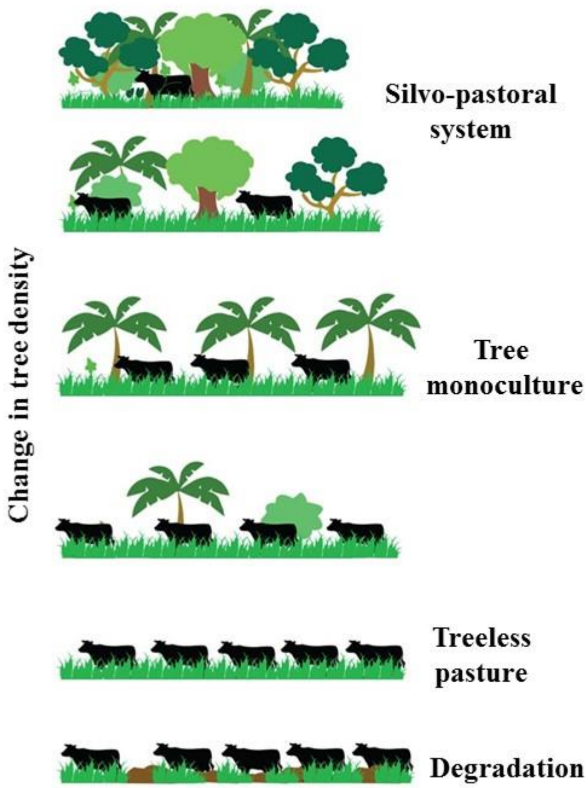

Figure 2.1. Illustrates the syndromes of production, formulated as a linear relationship between cattle density (or other disturbance) as the driving variable and tree density as the response variable.

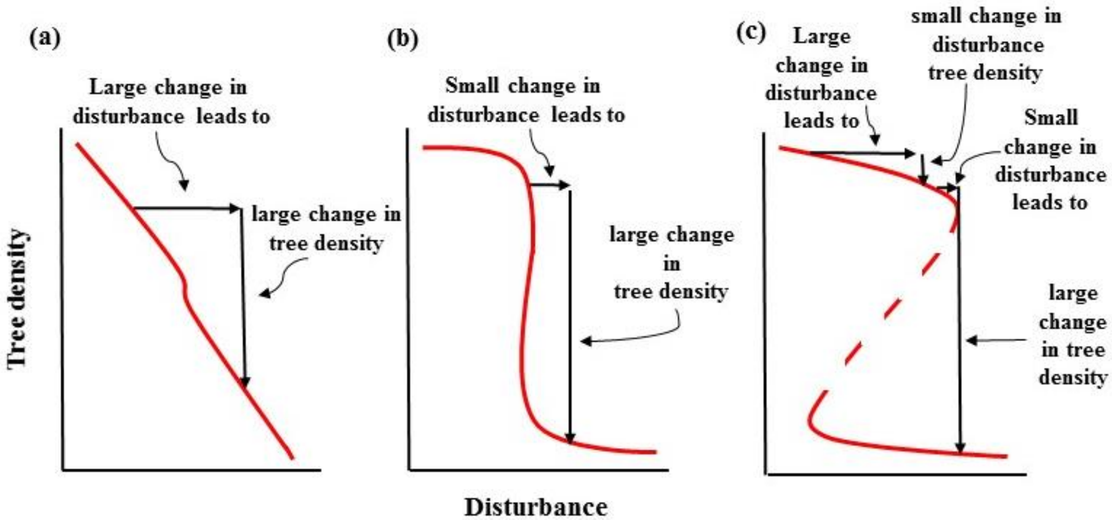

Figure 2.2. Dynamics between disturbance and tree density (a) Quasi- linear dynamics in which a large change in the disturbance results in a large change in tree density. (b) A strong but monotonic non-linear dynamics in which a small change in the disturbance leads to a large change in the tree density. (c) A multivalued pattern in which different equilibria may result from the same disturbance value.

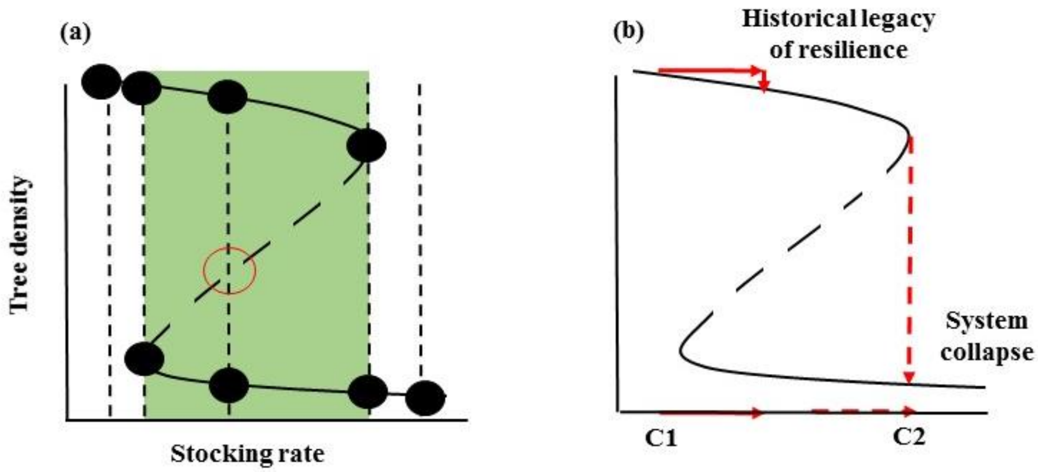

Figure 2.3 Depicts hysteresis (a) proposed relationship between stocking rate (a particular "disturbance") and tree density. The vertical lines represent various conditions of disturbance. The stable equilibrium points are designated by the black bold circles. The unstable equilibrium point is designated by the open red circle. The rectangle indicates the zone of hysteresis. (b) Proposed relationship between stocking rate (a particular "disturbance") and tree density. When cattle density increases in this example tipping points are reached.

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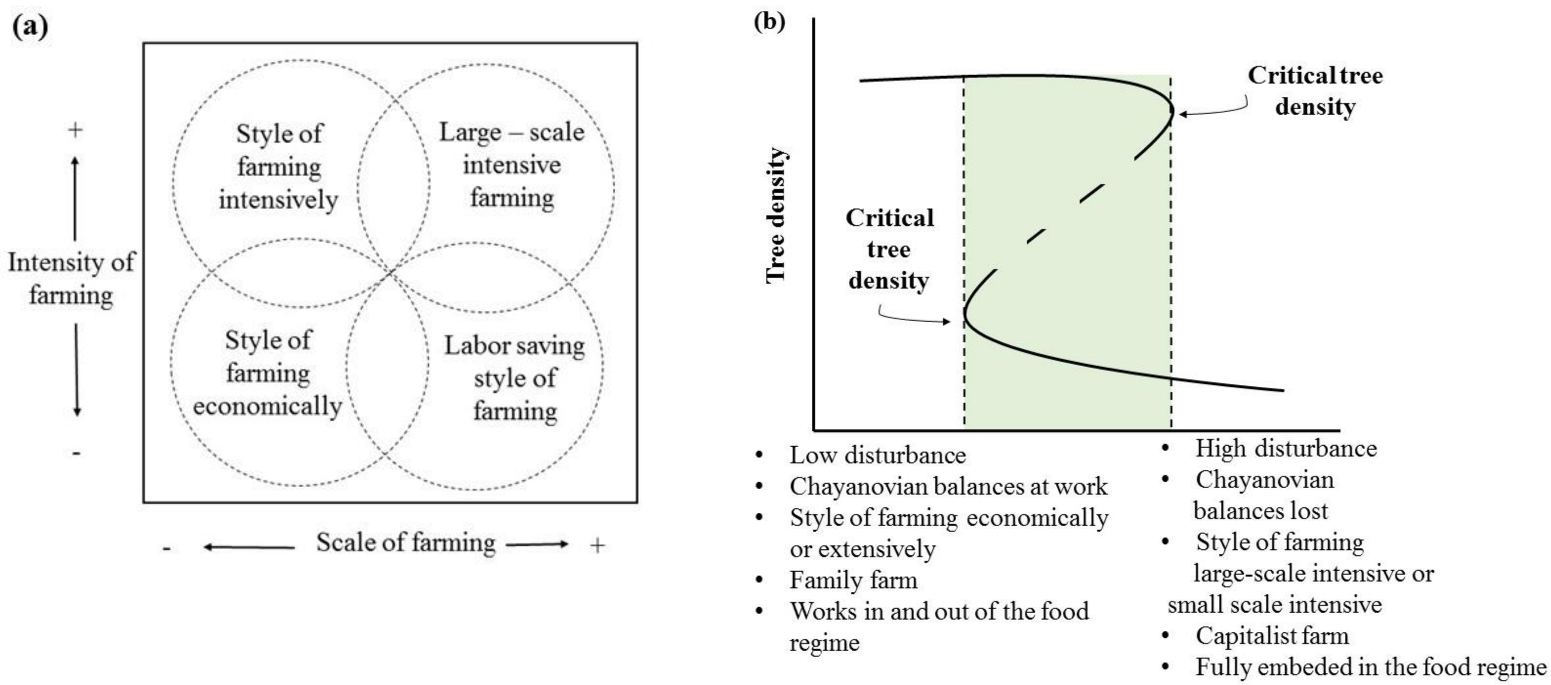

Figure 2.4. Depicts the general relationship between the Chayanovian balances and tree density. (a) Van der ploeg (2013, page 64) farming styles based on scale and intensity balance. (b) Multivalued dynamic with tree density on the Y axis. On the X axis we show the relationship between disturbance, Chayanovian balances, and farming styles. The green rectangle represents the zone of hysteresis under which two values of tree density are possible under one value for disturbance. Disturbance is influenced by the Chayanovian balances which leads to a specific kind of farming styles. The Chayanovian balances are lost in the capitalist farm which tends to be large-scale intensive and well embedded in the food regime.

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CHAPTER III

Variation of tree densities across cattle pastures in the Republic of Panama

ABSTRACT

Recent research indicates that the extent to which trees are incorporated into pasture management varies across cattle ranches. Yet efforts to document and understand this variation are scant. The main question arises: 1) how does tree management vary across cattle pastures? If there are different tree management styles, then we expect the frequency distributions of tree densities to show multiple modes each representing a different style. Fifty-four ranches and farmers across the Republic of Panama were visited in 2014 to document different tree management styles. Farm boundaries were obtained for each farm and Google Earth ® imagery was employed to digitize the tree canopy which was classified into landscape patterns. Bimodality amplitude function, histograms and kernel density estimates were employed to determine if the total tree cover and each landscape pattern cover area a is bimodal. We employed multiple and linear regressions to test if the tree cover distributions could be explained by physical, socio-economic, and management covariates. The mean percent tree cover per farm area across 54 farms was 33.39% (SD = 15.21) and ranged from 10.44 to 76.52%. We found 7 landscape patterns: dispersed trees on pastures, live fence, riparian vegetation, horticulture, forest fragment, fallow, and forestry plantation. Physical, socio-economic, and management variables including cattle density do not have an effect on total tree cover area. Frequency distributions, kernel density estimates and bimodal amplitude functions showed moderate evidence for

bimodality of the live fence and dispersed trees on pasture. These results suggest that with a larger sample size bimodalities and alternative states are possible. Given the importance of tree diversity for wildlife conservation in the tropics, we argue that tree management studies across cattle pastures are necessary for the management of sustainable agricultural systems

3.1 INTRODUCTION

Cattle production across the Neotropics has commonly been associated with the deforestation of tropical rain forest and other ecosystems resulting in the degradation of soil, water, and biodiversity (Muchagata 2003) and overall contributing to climate change. Trees in cattle pastures are important for conserving, retaining soil nutrients, providing shade for cattle, capturing carbon and conserving water sources among many other benefits to both the environment and the sustainability of the ranch (Murgueitio et al. 2011, Ogden et al. 2013, Karp et al. 2015). Efforts to document how farm management affects tree cover has not been well documented (Zomer et al. 2016), yet there have been multiple efforts to encourage farmers to plant more trees (Calle et al. 2013). In Costa Rica and Nicaragua, trees dispersed in pastures are managed within 8 tree ha^{-1} to 33.4 trees ha^{-1} (Harvey et al. 2011) and in Ecuador, farmers have been found to manage dispersed trees at densities between 30 tree ha^{-1} and 400 tree ha^{-1}. In addition, traditional cultural values have been associated with trees. Since cattle pastures play such an important role in the Neotropics, here I ask if the different styles of tree management commonly observed in the Neotropics are different tree management states. We characterize 54 farms in the Republic of Panama to determine if there are different tree management syndromes based on the tree-covers of the farms.

Trees on cattle pastures are comparable to the alternative states forest and savanna that exist under a certain range of precipitation (Hirota et al. 2011, Staver et al. 2011). Trees in cattle pastures may also occur as alternative states, with treeless pastures and high tree density silvo-pastoral systems as two possible, extreme styles. The Dehesa silvo-pastoral systems of Portugal, for example, has persisted for centuries as a stable silvo-pastoral system. It has been hypothesized that the stability of this system is related to water resources playing an important role in regulating the balance between woody plants and herbaceous vegetation (Joffre and Rambal 1993). The deep root systems of the trees pump water and nutrients to the surface from deep soil layers making these resources available for the grasses. They also maintain humidity (Joffre and Rambal 1993). In this view, the "stability" or "persistence" of silvo-pastoral systems is plausible since there are multiple examples of silvo-pastoral systems that have persisted for centuries in Europe (Papanastasis,et al. 2009, Joffre et al. 1999). On the other end of the tree spectrum, anthropogenic savannas in the Neotropics have been documented, with savannas containing fire tolerant tree species intermixed with pastures in areas that once used to be forest (Cavelier et al. 1998). Low tree density savanna-like systems are possible as well in the Neotropical pastures, and their long term persistence could have significant implications for stakeholders. Farmers may decide to plant trees or allow trees to grow to improve the ecology of the farm, but this may not be possible since in the treeless pasture state (or anthropogenic savannas) the eroded conditions of the top soil layers perpetuates the treeless pasture state.

A first step to examine if there are tree density "styles" in cattle pastures is to examine tree density frequency distributions. Drivers of tree density can create different distributions. For example, either forest or savanna states can persist under the same range of precipitation, forests being maintained when a critical tree density maintains humidity to the point that fires are not possible (Hirota et al. 2011). However, when tree density is too low, even though the precipitation is the same, fires are possible and savanna systems are maintained. In the cattle pasture, socio-ecological drivers may operate in a similar fashion to produce such alternative states. Thus, under one set of socio-ecological drivers, pastures with higher tree density will maintain that density, while pastures with lower tree density will maintain that low tree density. Small deviations in tree densities will tend to revert to the stable conditions of either high density or low density, a situation of bimodality. If this is the case, we expect to see bimodality (or multimodality) across a random sample of farms.

Empirically we see two “styles” of tree management, the high and low tree density (although more are possible). These styles can be both active and directed, and casual and undirected through the management of landscape patterns including: 1) trees dispersed widely, 2) forest fragments, 3) riparian corridors, and 4) live fences (Harvey et al. 2001, Safiorenzo-Barnhard et al. 2009, personal observations). These landscape patterns are the result of pre-existenting knowledge and values of the farmers. Understanding that knowledge and those values is an integral part of strategies to alleviate the perceived and real negative effects of cattle ranching. In this context, a first step to exploring farmer’s pre-existent knowledge and values is to quantify and classify trees into landscape patterns and to evaluate how this management varies across farms. Variations in tree incorporation would indicate that there are different “styles” of tree management, and further inquiry could reveal what leads farmers to manage which particular style.

Geographical, socio-economic, and management variables can illuminate the specific context of the region of study. On the other hand, the relationships of geographical, management, and socio-economic context variables with tree cover, often show contradictory results across regions of the world, indicating that they are context specific (Perz 2007). For example, working in Ecuadorian pastures, Lerner et al. (2014) found that distance to the nearest town had a positive relationship with stem density whereas elevation had a negative relationship with stem density. In the same study, variables associated with management including the pasture area and time since the farm had been owned had a negative relationship with stem density. In Brazil, Perz et al. (2006) found contradictory results, with a positive correlation between secondary tree growth and years of ownership, and no relationship between secondary growth and pasture area. In essence, two different landscape patterns, dispersed trees in pasture and secondary forest growth, respond differently to the same variables. In this view, geographical, socio-economic, and management variables could predict total tree and landscape pattern area. For this reason, we describe the relationship between tree cover and possible covariates across the 54 farms.

We report on a case study of 54 farms across the Republic of Panama, located across two regions that differ primarily in the lengths of dry and wet seasons. We ask: can cattle farms be classified into discrete categories based on the total tree cover and management of each of the landscape patterns? The hypothesis is that if there are different farm pastoral "styles" we would see multimodality (and more specifically bimodality) across the total tree cover and the cover area of the landscape patterns. In addition, we characterize the geographical, socio-economic, and management context of the farms. Finally, we discuss the importance of understanding the possibility of "styles" in tree management for the multiple efforts that exist in the region to restore the agricultural landscapes.

3.2 METHODS

3.2.1 Population sampling

Initially, 15 farmers were identified in three provinces in the Republic of Panama with the help of the Ministry of Agricultural and Livestock Development (MIDA). A total of fifty-four farms ranging from 5-2,000 ha were identified by contacting farmer associations and through chain referral sampling (Lerner et al. 2014).

3.2.2 Background of the study area

Farms included are located in the provinces of Chiriqui, Cocle and Los Santos in several villages within these three provinces in the Republic of Panama (see table 3.1). The Chiriqui province is located in a wet region in which the dry season last 4 months. Cocle and Los Santos are located in the dry region where dry seasons are more severe and last 5 and 6 months respectively (ANAM 2011, Garen et al. 2011). The various regions were chosen with an eye to capture a range of tree management styles.

Farms were situated in what is commonly called the "interior" of Panama. These areas have already gone through agro-expansion and farmers here have formal land tenure (Sloan 2015). All the farms had at least one plot of land near paved roads that lead to markets and towns. Most farmers had more than one plot of land. Some of these plots were far from pave roads making them difficult to access. Census data from 2011 (obtained from the National Center for Statistics and Census from the General Treasury of the Republic of Panama) indicate that the Chiriqui region overall manages cattle more intensively than the other two provinces. The Chiriqui region has larger cattle herds and higher percentage area of improved grass varieties (or modern varieties) compared to Los Santos and Cocle (see table 3.1).

Cocle and Los Santos are in the dry regions or area called the "Arco Seco" of Panama (Garen et al. 2011). Coclé is a much drier site with 6 months of dry season compare to Los

Santos with .5 months of dry season (Garen et al. 2011, see table 3.1). The dry forest of Los Santos and Cocle is an endangered ecosystem that has almost completely disappeared in the dry regions (Pacific coast) of Panama and Central America primarily due to cattle and other agricultural production. Many of the remaining dry forest fragments are located within cattle ranches similar to the ones sampled in this study (Caughlin et al. 2016). Chiriquí province is a much wetter region then Cocle and Los Santos (see table 3.1). The Chiriquí region has diverse ecosystems and the lowlands where most farms are located is a mosaic of semi-deciduous humid forest fragments and mangrove (ANAM 2011).

3.2.3 Farm land-use and tree landscape pattern classification

We attempted to capture the entire farm area and to break down the total tree cover into different landscape patterns based on how farmer managed the trees. The classification of the farm landscape patterns was conducted with the help of the farmer and employing a GPS coordinate system (Garmin GPS 60^{TM}). Each farm boundary was marked by walking, driving or riding a horse around farms. In the larger farms, boundaries were approximated by asking farmers to point out the boundary of their farms using aerial born images from Google Earth ® maps. Farm visits ranged in duration 1 to 4 days depending on the size of the farm and the available time provided by the farmer. During the farm visit, a land use was assigned to each area of the farm visited. Land use was assigned based on farmer’s description of the land-use taking place in a giving plot at the moment and this later informed the tree landscape pattern classification. For example, there were areas that had natural regeneration. We classified those areas as fallow since farmers said explicitly that the land was in fallow (or temporary and soon to be cut). We classified as forest the areas in which the farmers said that they had allowed that area to regenerate for many years and were not planning to cut it down.

The sampling effort was estimated by recording the amount of land owned by the farmer in comparison to the amount of land documented during the sampling of the farm. On average we sampled 80% (n = 54, min = 14% and max = 100%) of the land area owned (in hectares) by the farmers. Some farmers had multiple properties of land that were separated by other owner's properties. The 54 farmers together owned 95 separate properties (based on reported data) and tree cover area was recorded for 75 of those properties.

All the GPS coordinates were entered into Google Earth ©. Employing free available Google Earth ® data (through their user interface). Google Earth © is a high-resolution internet based tool that allows clear observation of the landscape patterns. Google Earth © makes available images from different dates across a region. The data in the Google Earth © interface employed was provided by CNES/Airbus and corresponded to different years and locations depending on where the farm was located. The Google Earth © data available for the 54 remaining farms was from 2013 or 2014, which were the same years in which fieldwork was carried out. Images available on Google Earth ® were taken between December and April which corresponds to the dry season in both study areas. We classified tree cover and other types of covers within the farms by drawing polugons in the Google Earth © interface. The Google Earth © data has been employed previously for the same purposes, including verifying classifications derived from lower resolution data (Clark et al. 2010, Zahawi et al. 2015).

The main author and a research assistant drew polygons around the trees employing the Google Earth © interface. Within each farm the tree covers were classified into different landscape patterns based on the land use assigned in the field and observed imagery (see table 3.2 for more details on the landscape patterns). In addition we drew polygons around pasture area, other agricultural plots and buildings (or other human infrastructure). The Google Earth ©

polygons were transferred and projected into ArcMap (ESRI) to measure the polygon area. An error in classification was estimated employing ground-truthed points. The ground truthed points were selected by random sampling and identified on Google Earth © by three people who did not know what points were on the ground. We found a mean percent accuracy of 86% with a range of 83.7 – 88.4 %. Accuracy is comparable to other studies that have used participatory mapping and machine learning algorithms in Panama (Vergara-Asenjo et al. 2015).

3.2.4 Physical, socio-economic and management context

3.2.4.a Farm Survey

Farmers can manage different cattle densities, weed at different intensities, rent land and practice different kinds of agricultural practices. To understand the management context of the farm we developed a survey to document the socio-economic and management context of the farms. Questions from the survey are presented in table 3.2. We present the summary statistics of answers, including number of respondents, averages, and standard deviations in the case of continuous quantitative data.

3.2.4.b Spatial and physical variables

On table 3.3 we outline the important spatial and physical variables and their significance in this study. Spatial and physical data available through open sources were used to inform on the physical and socio-economic context of the 54 farms. Precipitation data was obtained from "Climate Hazards Group InfraRed Precipitation with Stations data" (CHIRPS) which is a spatial resolution data set from 1979 to 2010 (for further description see López-Carr et al. 2014). We averaged annual precipitation for each farm from the year 2000 to 2013 from the CHIRPS data set. We obtained the elevation and slope data (degree of slope) from digital elevation models (DEM) derived from the shuttle radar topography mission dataset available through USGS (for more details see Hall et al. 2005). The DEMs for the different regions of the study were projected into the UTM coordinate system (WGS 1984, North Hemisphere Zone 17). Hydrological features, roads, and towns were obtained through the Smithsonian Tropical Research Institute Map Portal (http://strimaps.si.edu).

For each farm, we recorded one value for each of the physical and socio-economic variables (see table 3.3 for more details). To calculate the value all the Google Earth ® polygons representing tree cover area were transformed into point data. We downloaded the .kml files from Google Earth ® and transferred into ArcMap. In ArcMap the data we projected into UTM WGS 1984, North Hemisphere Zone 17 projected coordinate system. The tree polygons were later transformed into raster data cell size 20 pixels. We chose size 20 pixels because it represented the size of one large tree crown when visually compare the 20 size pixels with the Google Earth ® images. Each raster was later turned into point data. For each point we calculated the elevation, slope, and distance to water source, town, house, coast and road. For the distance data, we obtained each of these by employing the "Distance to" function in ArcMap. We then averaged these values for each farm to obtain one value per farm. These averaged values were used in the analysis.

3.2.5 Data analysis

In order to determine if there are "styles" of tree cover management, histograms for the total tree cover area and for each of the landscape patterns were generated. We also employ the kernel density estimation function which is a smooth version of the histogram. Kernel density estimates a non-parametric density function of a random variable (Baxter et al. 1997). A bimodal (or multimodal) pattern can be interpreted as two (or more) forms of tree management that the farmers are employing (Sokal and Rohlf 1994). We also present a quantitative estimate of bimodality employing the bimodality amplitude function. This function calculates the amplitude of bimodality indicating the proportion of bimodality and the existence of bimodality. Values lie between 1 and 0 where the value 0 indicates that there is no bimodality and the value 1 indicates that there are two normal components (Deevi 2016). We also present descriptive statistics and a description of each of the landscape patterns based on farmers' experiences.

Summaries of the socioeconomic, physical, and management context variables are presented with their descriptive statistics. In addition, we present the management categorical variables identified from the survey. Multiple linear regressions were used to test the effect of physical and socio-economic variables on the total tree cover across 54 farms. The total tree covers were arcsine transformed so that it approximates normality. Exploring possible relations helps understand the context of the farms. In addition, we test the effect of cattle density on tree cover across the 36 farms that reported a complete breakdown of the different kinds of cattle that they manage. I employ linear regressions. Q-q plots of standardized residuals with theoretical quantiles for multiple linear regression and linear regression models were generated to understand of residuals fit the normality assumption.

3.3 RESULTS

The average tree cover across the 54 farms was 33.39% (SD = 15.21). Total tree cover ranged from 10.44 to 76.52 percent. The skew is 1, indicating that the distribution of total tree cover is moderately to highly skewed to the left. Kurtosis of 0.81 indicates that there is a long tail which is visible on figure 3.1a and b starting at approximately 40% tree cover. The histogram of, the kernel density estimation plots and the bimodality amplitude (0.22) of total tree cover area (figure 3.1a and b) suggest that there is no bimodality. The large standard deviation for total tree cover indicates that there is substantial variation across the farms. Figure 3.4 shows farms that fall under different groups of tree covers: a) < 20% tree cover (n = 10; figure 3.4a), 2) farms between 20 – 40% (n = 31; figure 3.4b), and 3) farms with >40% (n=13; figure 3.4c). The majority of the farms fall between 20-40% total tree cover.

Seven landscape patterns were identified (see table 3.3): live fence, dispersed trees, riparian, horticulture, fallow, forest fragment and forestry plantation. The description of each landscape pattern is presented in table 3.3 and representative images are in figure 3.5. Live fence, dispersed trees, and riparian vegetation were found across the majority of the farms, whereas fallow, forest, and forestry plantation were rare (figure 3.6a). Horticulture plots were mostly surrounding the farmer's home, but the farmers didn't always live in the plots we sampled. Therefore, some farmers may manage horticulture plots but we did not capture that fact.

Average tree cover across all farms was highest for riparian area (10.84%) followed by live fence (7.79%) and dispersed trees (7.48%). The maximum tree cover area across all farms was highest for fallow (59.76%), forest (59%), and dispersed trees (42.93%). Outliers are particularly prominent on fallow (figure 3.2e , 3.3e), forest fragments (figure 3.2f , 3.3f), and dispersed tree landscape patterns (figure 3.2b, 3.3b) indicating that with a larger sample size bimodality may be possible. All landscape patterns are highly left skewed and have high kurtosis. Live fence histogram, kernel density estimation and bimodal amplitude (0.90) (figure 3.2a, 3.3a) suggest bimodality with two classes: 1) between 9-13% cover area (n=18) and 2) class with tree cover <9%. Dispersed trees on pastures histogram, kernel density estimation and bimodal amplitude (1) (figure 3.2b, 3.3b) also suggest bimodality with two classes: 1) below

20% (n = 52) and 2) above 40% (n=2). Fallow (bimodal amplitud = 0.95) and forestry plantations (bimodal amplitud = 0.99) have high bimodal amplitude but the main modes is at "0" tree cover.

Most farms had 4 landscape patterns (figure 3.6b). Farms with 3, 4, and 5 landscape patterns had tree covers that range from the 10th percentile to the 60th percentile suggesting that more landscape patterns don't necessarily lead to higher total tree covers area. In addition, the composition of landscape patterns across different tree cover areas (figure 3.7) indicate that fallow and forest when present can lead to very high total tree cover areas. Riparian vegetation and dispersed trees on pastures can also occupy very large areas in some farms contributing to very large total tree cover areas (see figure 3.7).

Results of multiple linear regression models show that the variables in table 3.3 have no linear effect on the total tree cover (n=54, $F_{8, 45}$ – statistics = 1.40, multiple R^2 = 0.20, and p<value = 0.22.). The q-q plots of the residuals do not comply with the normality assumption. Regardless, a simple plot of the data indicates that linear relationships among variables are unlikely.

In table 3.4, we summarize the management variables based on surveys. All farms are managed for cattle rearing but there are variations. The majority of the farmers grew up in the farm. Few farmers rented (n = 12) land and on 19 farms, the farmers owned just one plot. The average reported cattle density was 1.32 cattle/ha (n =36). Twenty-six farmers managed more than one kind of ranching and the majority were dairy producers. Chemical control of weeds varied across the farms but only 10 said they did not use chemical herbicides. Ten farmers said they employed burning to eliminate weeds.

Linear regression models show that there is no relationship between cattle density and tree cover across 36 farms (n = 36, $F_{1,35}$= 0.007, R^2 = 0.0002, p-value = 0.93). The residuals don't perfectly align with the q-q plots because there are a few outliers. However, a look at the scatter plots, demonstrate that the linear relationship is unlikely (see figure 3.8). The farms with highest cattle density indicates that all are farms with <50 ha of land and are located in the Chiriqui region.

3.4 DISCUSSION

Live fence and dispersed trees on pastures are bimodal indicating that tree management states are possible in these systems. The landscape patterns reveal that simply studying dispersed trees on pasture or the total tree cover area of the farm is not enough to comprehend how these systems are managed. We found that different landscape patterns show different kinds of distributions indicating that underlying processes in farm management are complex since some landscape patterns may be managed similarly across farms, but others not. A study with a much larger sample size is sure to reveal interesting patterns in regard to bimodalities and perhaps multimodalities in tree cover. Bimodalities and multimodalities indicate that farmers are not all managing trees in the same way and interesting lessons may arise from understanding what keeps some from having high tree densities.

The extent of and determinants (drivers) of agroforestry systems across the world have been understudied (Zomer et al. 2016, Papanastasis et al. 2009). Compared to other areas of the world, Central America has been found to rank second in terms of total tree cover (>45%) and carbon biomass (53 tC ha^{-1}) in agricultural land, suggesting that trees play an important role in agricultural management (Zomer et al. 2016). In our case study of 54 farms, we found that actively managed pastures can range from 10% to 70% tree cover area across the entire farm. These levels of tree cover have been described in other places as well. For example, Sanfiorenzo-Barnhard et al. (2009) depicts cattle pasture in Mexico that range from <10% to >60%. Our study is comparable to other regions.

This study is unique in that we were able to capture the entirety of the farm and describe the different landscape patterns that compose the farm. The landscape pattern classification expands the concept of how trees are being managed in the farm. This has practical importance because when coarse scale resolution satellite imagery is employed, actively managed farms with very high tree covers can be discretely classified as forest and/or categorized as abandoned farms (Caughlin et al. 2016, Perz 2007). Combining field observations, farm interviews and high resolution satellite imagery freely available on Google Earth © , it was possible to generate a detailed classification of the landscape patterns that included the total tree cover areas of 54 farms. Previous studies had mostly reported tree cover measurement for only a portion of the farm since it is difficult to obtain cadastral data that covers the entire farm. At the same time, they tend to focus on one landscape pattern, often dispersed trees in pastures or live fences (Lerner et al. 2014, Sanfiorenzo-Barnhard et al. 2009, Harvey et al. 2011). Forest and fallow management in the cattle pasture has more commonly been reported in the context of forest transition (Perz et al. 2006). Here we closely depict the actively managed farms and their landscape pattern composition.

As depicted in other studies we find substantial variation in dispersed trees on pasture (Lerner et al. 204, Harvey et al. 2011). The two farms with the highest dispersed tree cover area were in the Chiriqui province. One farm had 1000 ha and the other was 100 ha. Both of these farmers had inherited their farm and explicitly said they managed “silvo-pastoral systems.” We also found substantial variation in riparian vegetation and live fence cover area, although riparian was not bimodal. Farms with over 20% riparian vegetation area included two of the smallest farms sampled (4 and 5 ha) and one of the largest farms sampled (850 ha). The farmer with the largest riparian vegetation cover area owned 850 ha of land and was located close to the coast. In fact, this was one of the two farms in our sample that had mangrove. Environmental policy in Panama prohibits cutting mangrove vegetation and the farmer was very clear about this policy. National level studies of forest transition remove mangrove forest from their estimations under the assumption that mangrove areas are not suitable for pastures (Sloan 2015). Whether they are suitable or not, mangroves are part of private property and farmers have to make decisions about their management. Live fence cover area depends on the length of the live fences and also the size of the tree crown. Some lives fences had very large tree crowns while other didn't. Farmers generally prune the live fences. The bimodality of the live fence area may be a reflection of the dynamism of live fence management.

The 4 farms with higher tree densities also happen to be the farms with highest fallow or forest. The farmer with the highest tree cover was a small farm with 2 cows and large forest cover. The farmer explained that he sells and buys cattle and keeps them at low densities. It was noticeable that some farmers with forest were actively managing the forest for long term conservation. At the time of study, one farmer with high forest cover had cut a small portion of the forest to plant crops. This indicates that when forests are present it's because farmers are allowing it and that these patterns are dynamic.

While farmers had forest fragment across all the provinces, fallow vegetation was more common in Los Santos Province. Fallow vegetation is managed very different then forest because it is considered temporary (Muchagata and Brown 2003). Farmer from Los Santos explained that fallow is useful during the dry season for livestock feed. A species of *Heliconia* sp. was often coined as essential for livestock feed which led farmers to allow fallow growth in some parts of their farm.

All of these farms were actively managed. The majority of the farm area was pasture. Cattle roamed across all of the tree landscape patterns although at different degrees. For example, farmers sometimes have the calves in the horticulture plots but not the cows, heifers or steers. We also observed cattle roaming under the teak plantations. In the dry season, cattle also eat the post-harvest corn, rice and sugar cane "fallow." In the dry regions, some farmers reported that fallow vegetation was important as an alternative source of cattle feed. In addition, cattle densities were not correlated with tree cover, suggesting that tree cover is not directly influenced by the cattle density and that instead tree cover may be more closely related to farmer's perceptions over the value of trees. Yet farmer decisions are not the only processes that determines tree cover, since ecological processes can play a role in keeping farms at a given tree density.

The ecological importance of some of these landscape patterns have been documented. Cattle pasture can be heavily degraded systems in which natural regeneration after abandonment is slow (Griscom et al. 2011). Where fires occur, these systems can remain as savannas (Cavelier et al. 1998, Garen et al. 2009). Studies suggest that at least a moderate number of dispersed trees in combination with forest fragments are necessary for natural regeneration to be possible in cattle pastures (Ferguson et al.2003, Sandor and Chazdon 2014). Dispersed trees on pastures will attract animals that will disperse seeds from the remnant forest into the pastures (Guevara et al. 1986, Estrada and Coates 2001). Some of the farms in this study that have a lot of trees may maintain natural regeneration in the pasture viable. Other farms may not, and the low tree cover may be a combination of both farm management and arrested succession (Griscom et al. 2011). If this is the case, then farmers with low tree densities would find it difficult to increase tree densities if needed. The farmers only option would be tree planting (Griscom et al. 2011) and tree planting can be difficult to manage (Pattanaya, Dangan and Nair).

3.5 CONCLUSION

Across the Neotropics we see attempts to scale up agro-ecological practices, including silvo-pastoral systems (Murgueitio et al. 2011). To a lesser extent has there been focus on understanding what the farmers are doing in terms of tree management. Across the 54 farms we find moderate tree cover bimodalities. Bimodalities indicate that these are different styles of management. For example, we found that two farmers had very large dispersed tree cover area indicating that they are employing some strategies that allow the observed tree cover outcome. Understanding what motivates and keeps these farms at high tree densities can help uncover the variables that can help farmers adopt agro-ecological techniques. Understanding what farmers with few trees are doing is necessary as well. This can help identify the factors that keep farmers from adopting tree management. The proposed approach should be a step previous to implementing silvo-pastoral techniques.

Table 3.1. Description of study sites. The ecological region, average annual precipitation across farms located in the study region, and province level agricultural census data. Precipitation data obtained from Climate Hazards Group InfraRed Precipitation with Stations data (CHIRP). Cattle head, pasture land, and electric fence data obtained from the National Center for Statistics and Census from the General Treasury of the Republic of Panama.

Province	Region*	# of Villages where farms are located	# of farms sampled	Precipitation across farms	Average cattle head per hectare at the province level	% area in pasture across the agricultural land of the province	% of agricultural area with improved grass varieties at the province level
Chiriquí	Subequatorial climates with a dry season; humid lowland forest	13	28	$\bar{x}$ = 3672.00 max = 4281.83 min = 3029.36	1.5	64%	45%
Los Santos	Tropical climate with prolonged dry season; dry forest	3	22	$\bar{x}$ = 1372.53 max = 1439.63 min = 1269.85	1.0	82%	20%
Coclé		1	4	$\bar{x}$ = 1767.60 max = 1780.82 min = 1740.21	0.9	44%	9%

*****Two farms had mangrove forest which is separate ecoregion from the humid lowland forest and the dry forest (ANAM 2011)

Table 3.2 Socio-economic and management survey questions. N represents the number of farmers to whom questions were asked.

Category	Question	N
Management	How much land do you manage?	54
	Do you rent land?	54
	How many properties do you own?	54
	For how long have you managed your land?	52
	How many cattle do you manage? How many cattle are you lactating, how many are heifer, steers for fattening, bulls and calves?	54
	What kind of ranching do you practice?	54
	What weeding techniques do you employ?	50

Table 3.3 Description, descriptive statistics and bimodality amplitude (BA) for the total tree cover and seven tree landscape patterns found across 54 farms.

Landscape pattern	Measured area	Percent of farms with landscape pattern	Statistics	Description of land-uses associated to landscape pattern
Total tree cover	Tree cover area / farm area.	100	$\bar{x}$ = 33.39 SD = 15.21 min = 10.44 max = 76.52 skew = 1 kurtosis = 0.81 BA = 0.22	Includes all the trees from all the landscape patterns.
Live fence	Live fence area / farm area.	100	$\bar{x}$ = 7.48 SD = 4.78 min = 0.62 max = 27.49 skew = 1.41 kurtosis = 4.43 BA = 0.90	Live fences delineate farm and paddock boundaries. They are planted and regularly managed. Trees species on live fence are multipurpose either for soil fertilization, cattle feed, timber or fruit.
Dispersed trees	Dispersed tree area / pasture area	98.14	$\bar{x}$ = 7.79 SD = 4.42 min = 0 max = 42.93 skew = 2.89 kurtosis = 9.68 BA = 1	Trees that are interspersed with the pasture in the paddocks. They are used for shade, timber, medicinal, livestock feed and fruits for household consumption. Result of natural regeneration or planting.
Riparian vegetation	Riparian vegetation area / farm area.	92.59	$\bar{x}$ = 10.84 SD = 8.23 min = 0 max = 36.20 skew = 1.08 kurtosis = 1.14 BA = 4.07 E^{-4}	Vegetation found along rivers and streams. Primarily result of natural regeneration. Farmer associate this landscape pattern with water and wildlife conservation calling it “sacred”. They also associate this landscape pattern with the environmental regulation authority.

Table 3.3 Continued

Landscape pattern	Measured area	Percent of farms with landscape pattern	Statistics	Description of land-uses associated to landscape pattern
Horticulture	Horticulture area / farm area.	42.59	$\bar{x}$ = 0.97 SD = 2.05 min = 0 max = 10.46 skew = 2.86 kurtosis = 8.95 BA = 0.006	Primarily fruit, timber, and medicinal trees mixed with crops for household consumption. Most horticulture plot where behind the farmers house but two farmers had horticulture plots in the midst of the pasture. Generally these are planted trees.
Fallow	Fallow area / farm area.	20.37	$\bar{x}$ = 2.57 SD = 9.71 min = 0 max = 59.76 skew = 4.95 kurtosis = 25.85 BA = 0.95	Area temporarily not weeded, but cattle still roam in those plots. Fallow is important for livestock feed during the dry season. Fallow is the result of natural regeneration.
Forest fragment	Forest fragment / farm area	20.37	$\bar{x}$ = 3.16 SD = 9.44 min = 0 max = 59.00 skew = 4.51 kurtosis = 23.85 BA = 0.026	Areas of secondary successional forest that is typically a remnant of a larger forest. Forest fragments are the result of natural regeneration.
Forestry plantation	Forestry plantation area /farm area	7.41	$\bar{x}$ = 0.55 SD = 2.11 min = 0 max = 9.16 skew = 3.81 kurtosis = 13.32 BA = 0.99	Plots of land where farmers had actively planted trees in a systematic way with a plan to harvest in the future. No pasture for livestock feed is found under those plots but cattle roam on those plots. Includes oil palm (n=1), mahogany (n=1) and teak plantation (n=2). The result of tree planting.

Table 3.4. Physical and socio-economic variables with their description and associated hypothesis. Descriptive statistics and p – value for multiple regression (n=54, $F_{8, 45}$ – statistics = 1.40, multiple R^2 = 0.20, and p<value = 0.22.). The q-q plots show that residuals do not comply with the normality assumptions, but, a simple plot of the data indicates that linear relationships among variables are unlikely.

Category	**Variable**	**Definition / justification / metrics**	**Descriptive statistics**
Physical variables	Precipitation	Areas with more precipitation have been found to have more forest and trees in agricultural plots (Zomer et al. 2006, Hirota et al. 2011)	$\bar{x}$ = 2594.11 SD = 1157.35 min = 1269.85 max = 4281.83 Skewness = 0.02 Kurtosis = -1.89 P value = 0.11
	Distance to hidrography	Riparian buffer zones are common and sometimes the only source of trees in agricultural land.	$\bar{x}$ = 231.12 SD = 176.85 min = 5.87 max = 717.12 Skewness = 1.05 Kurtosis = 0.58 P value = 0.04
	Elevation	Farmers often leave trees or forest fragments on the top of the hills.	$\bar{x}$ = 162.72 SD = 118.25 min = 6.53 max = 628.57 Skewness = 1.03 Kurtosis = 2.97 P value = 0.19
	Slope	Steep slopes may be more prone to erosion in agricultural land. However, trees on slopes may be harder for farmers to access and cut.	$\bar{x}$ = 5.42 SD = 2.93 min = 1.63 max = 12.00 Skewness = 0.48 Kurtosis = -1.09 P value = 0.25

Table 3.4. Continued

Category	Variable	Definition / justification / metrics	Descriptive statistics
Physical variables	Distance to the coast	In the region of study, farms closer to the coast are flat and also adjacent to mangrove ecosystems. While the mangrove vegetation may contribute to total tree cover, the flatness of the farm may make it easier for the farmers to eliminate trees.	$\bar{x}$ = 15537.82 SD = 7634.59 min = 1407.61 max = 32485.09 Skewness = -0.43 Kurtosis = -0.64 P value = 0.17
Socio-economic variables	Distance to roads	Farmers that have plots of land closer to towns and roads may manage those plots more intensely, with higher cattle densities possibly resulting in less tree densities. At the same time, plots closer to roads and towns may be more prone to state regulation which would increase the possibility of penalty for logging. As such, distance to roads and towns indirectly may influence tree cover on farm.	$\bar{x}$ = 290.61 SD = 222.72 min = 17.98 max = 1526.08 Skewness = 3.34 Kurtosis = 17.27 P value = 0.51
	Distance to town		$\bar{x}$ = 1178.44 SD = 615.33 min = 386.60 max = 3322.05 Skewness = 1.34 Kurtosis = 1.78 P value = 0.87
	Farm size	Indicator of wealth. Larger farmers may manage more extensively, indicating that they would be less weary of dispersed tree regeneration.	$\bar{x}$ = 162.44 SD = 345.19 min = 4 max = 2000 Skewness = 3.77 Kurtosis = 16.03 P value = 0.12

Table 3.5. Summary of management variables based on farm survey.

Farm attribute	Category	Description	Number of farms
Tenure time	Family farm	Most farmers managed the ranch previously owned by a family member.	44
	Bought land < 30 years ago	Few farmers manage land not previously owned by the family.	8
Rent land	When farmers pay to use someone else land.		12
Properties of land owned	Number of properties owned by the farmer that are separated by other people's land.	1 property	19
		2 properties	15
		3 properties	13
		4 properties	5
		6 properties	2
Cattle head (total number of cattle)	Average of heifer cattle, lactating cattle, steer for fattening and calves across 36 farms.	$\bar{x}$ = 114.42 SD = 207.40 Min = 2 Max = 1000 Skew = 3.68 Kurtosis = 11.74	36
Cattle density (total number of cattle reported divided by the farm area reported)	Average of the density of heifer, lactating, steer and calves across the 36 farms.	$\bar{x}$ = 1.32 SD = 0.88 Min = 0.14 Max = 3.52 Skew = 1.22 Kurtosis = 0.92	36

Table 3.5. Continued.

Farm attribute	Category	Description	Number of farms
Kind of ranching	Raising calves.		9
	Fattening for beef.		10
	Fattening for beef dual purpose.		6
	Genetics		2
	Dairy		13
	Dairy dual purpose		20
Chemical weeding frequency	None.		2
	Every 2 years or more.		5
	1 a year.		20
	More than 1 a year.		7
Burning	Employ fire to eliminate weeds.		10
	Do not employ fire for weeding.		28

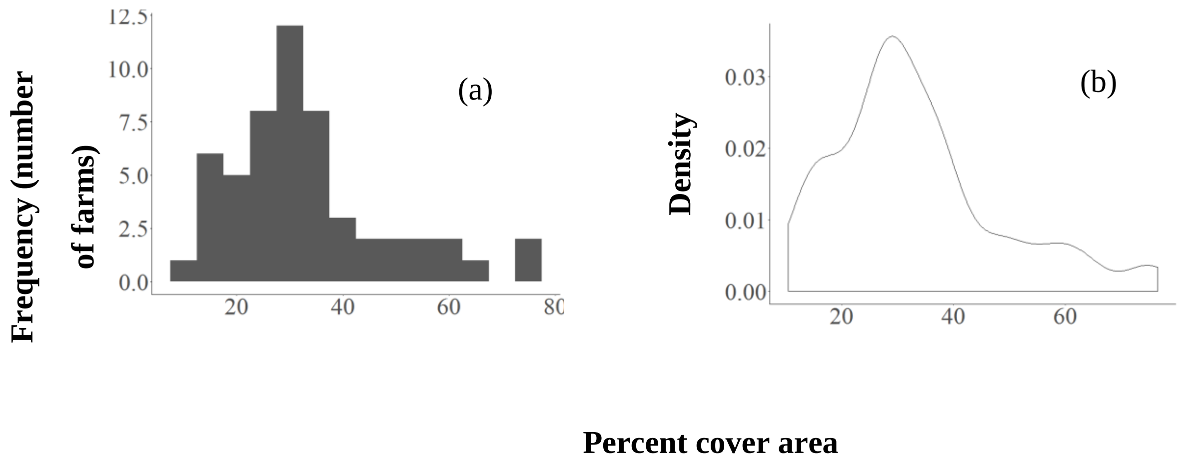


Figure 3.1 Frequency distribution for the total tree cover area across the 54 farms (a) histogram of total tree cover area (bin width = 5), and (b) Kernel density plot estimation for total tree cover area (bandwidth = 3.87).

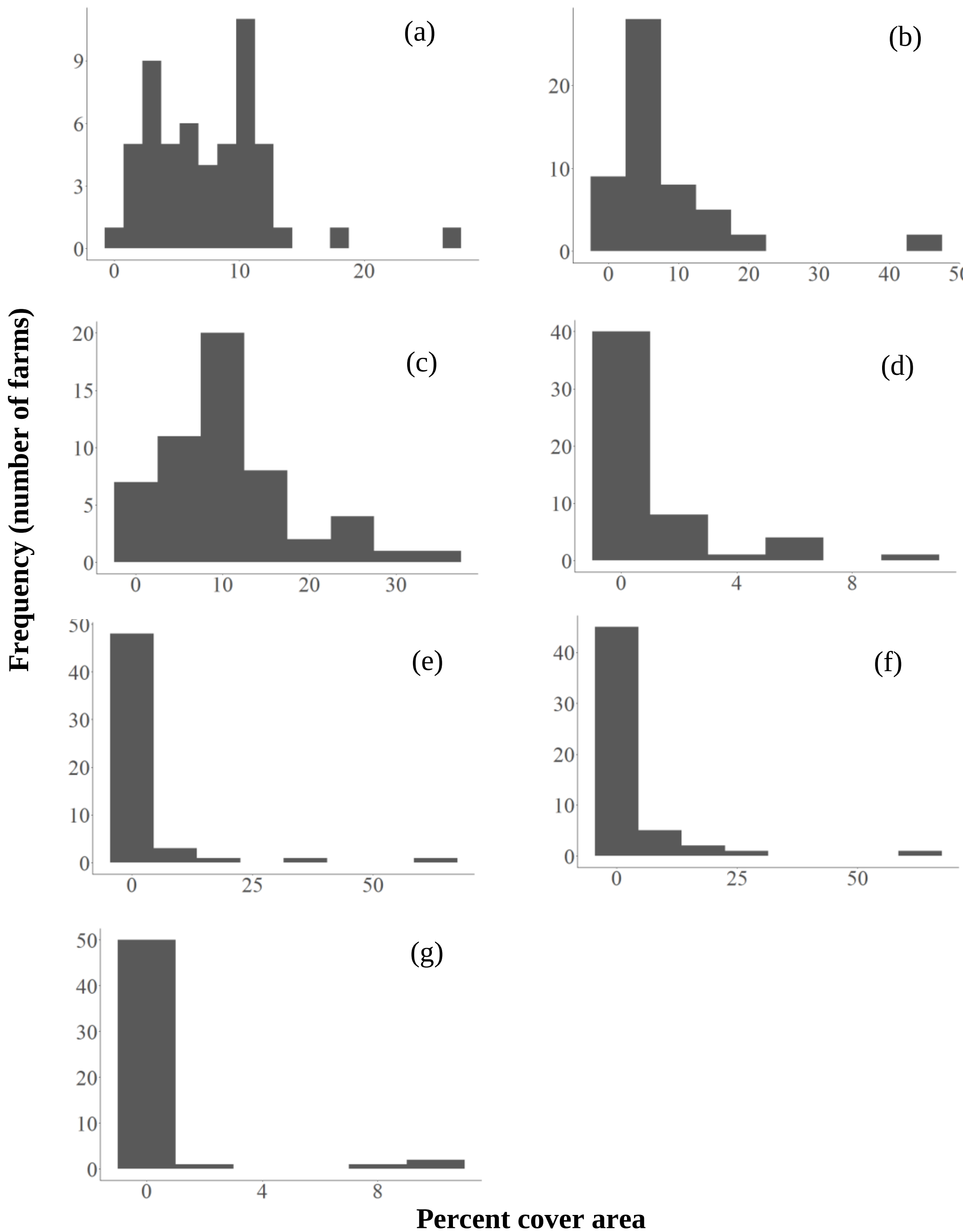


Figure 3.2. Frequency distribution for each landscape pattern across the 54 farms (a) live fence (bin width = 1.5), (b) dispersed tree (bin width = 5), (c) riparian (bin width = 5), (d) horticulture (bin width = 2), (e) fallow (bin width = 9), (f) forest (bin width = 9), (g) forestry plantation (bin width = 2).

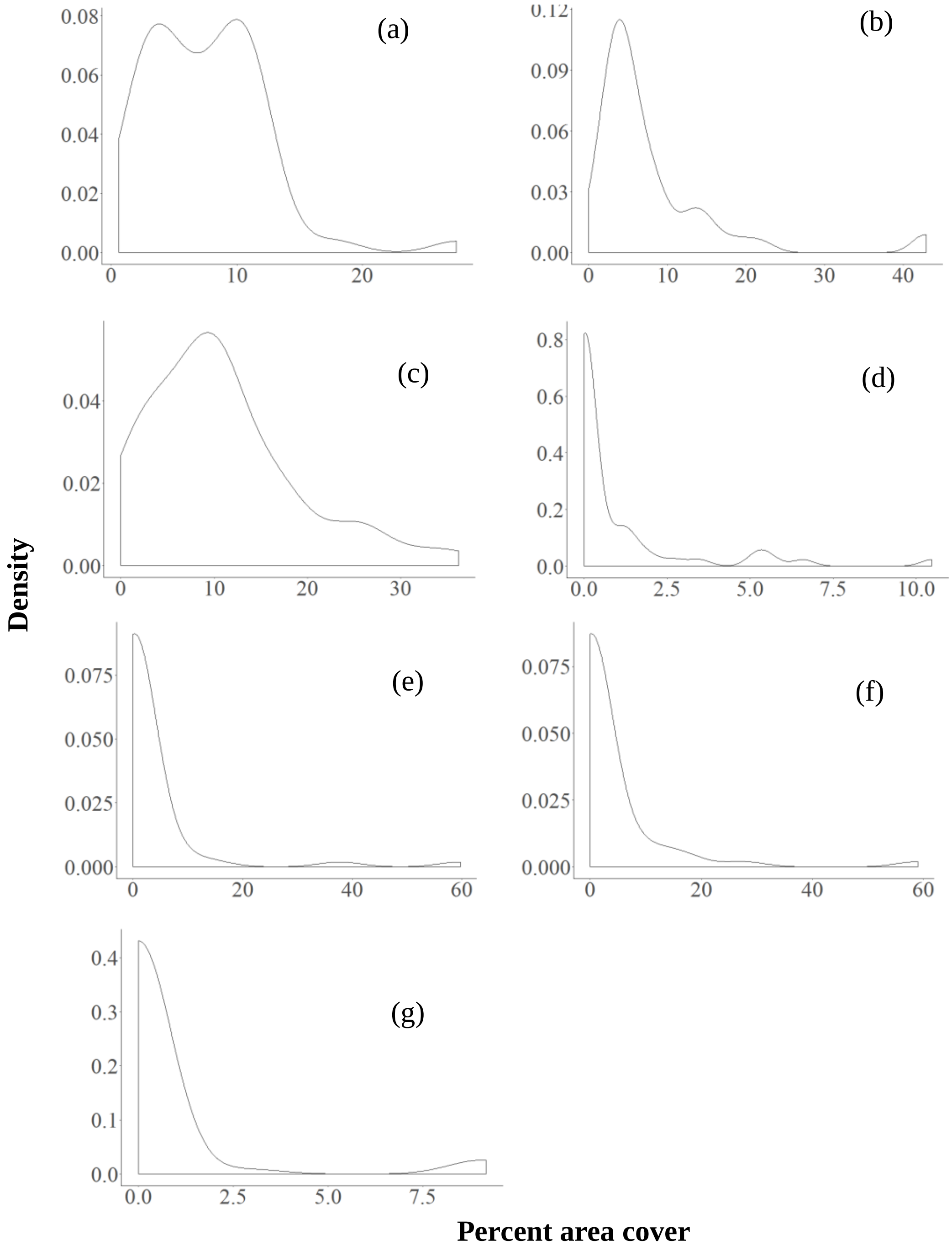


Figure 3.3. Kernel density plot estimation for each landscape pattern cover area across the 54 farms (a) live fence (bandwidth = 1.94), (b) dispersed tree (bandwidth = 1.67), (c) riparian (bandwidth = 2.95), (d) horticulture (bandwidth = 0.33), (e) fallow (bandwidth = 3.94), (f) forest (bandwidth = 3.82), and (g) forestry plantation (bandwidth = 0.86).

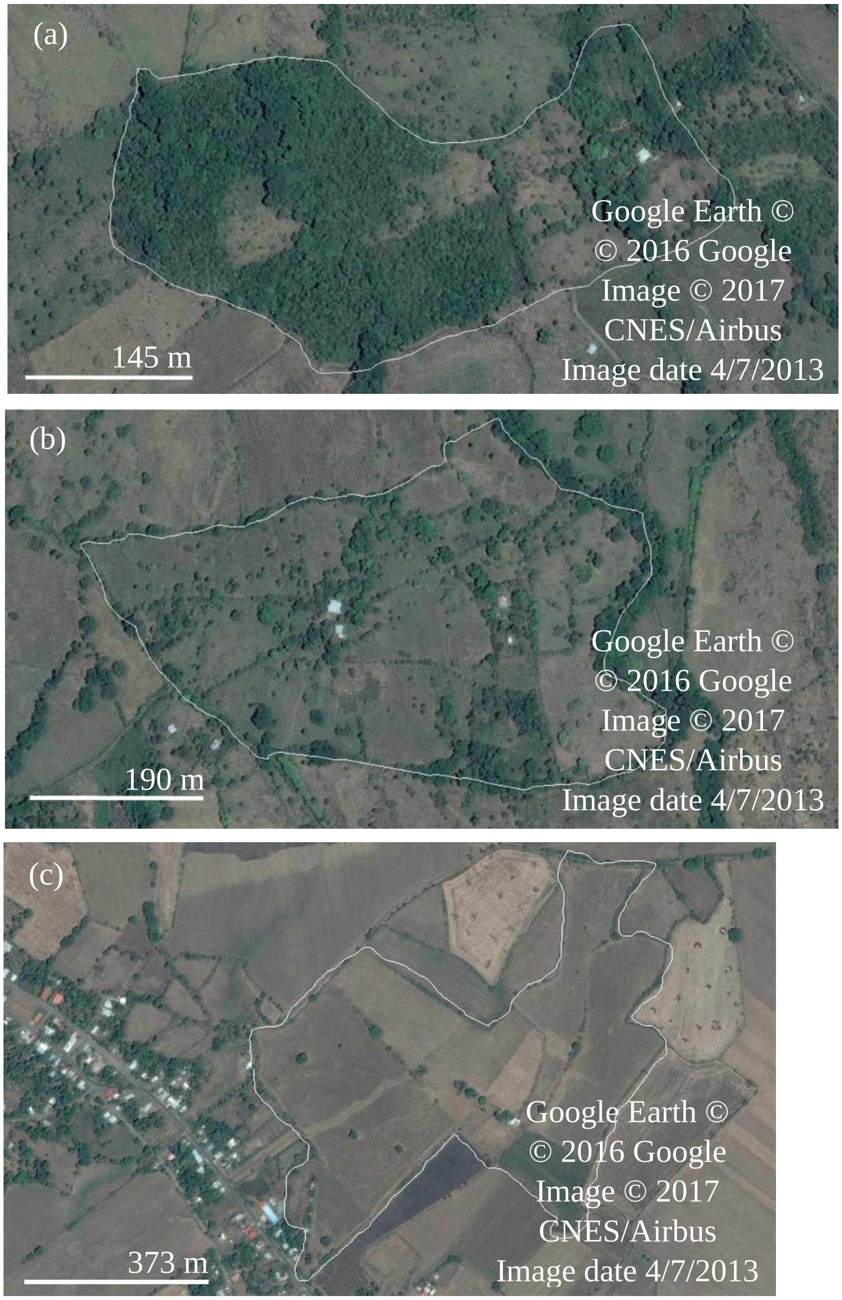


Figure 3.4 Google Earth © images of farms with different tree covers: a) farm with 15.04% tree cover; b) farm with 33.53% tree cover and; c) with 76.52 % tree cover.

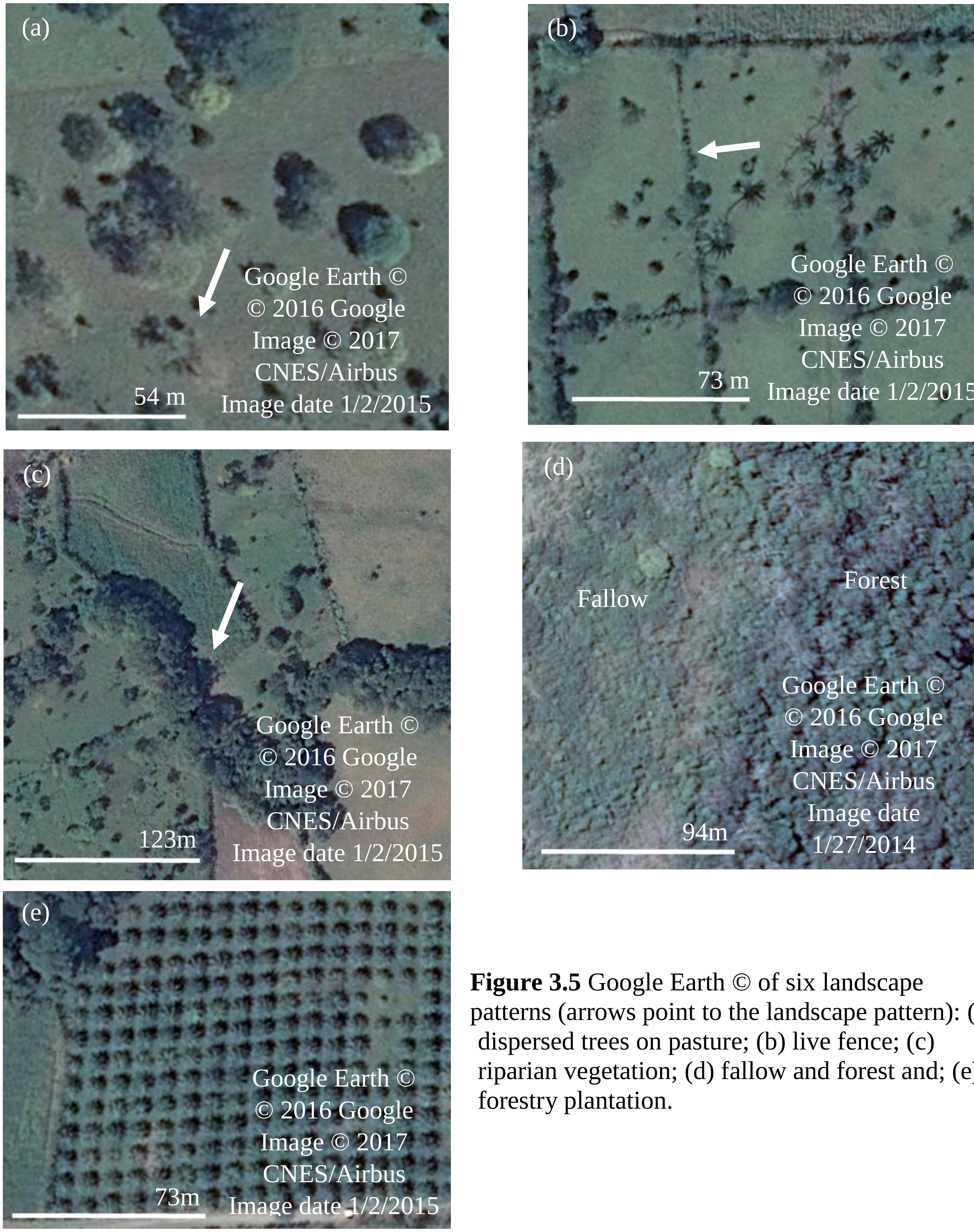
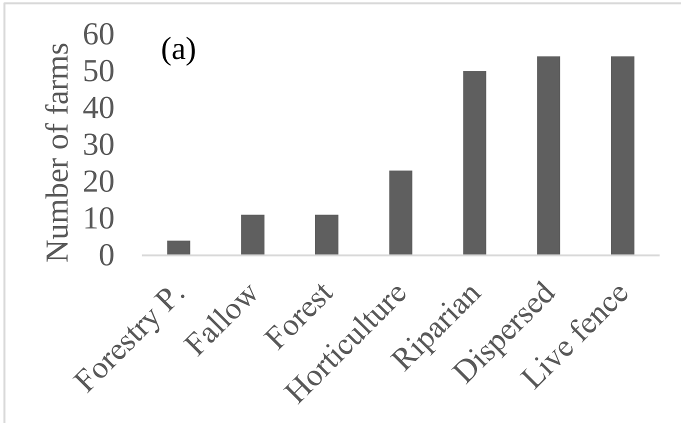


Figure 3.5 Google Earth © of six landscape patterns (arrows point to the landscape pattern): (a) dispersed trees on pasture; (b) live fence; (c) riparian vegetation; (d) fallow and forest and; (e) forestry plantation.



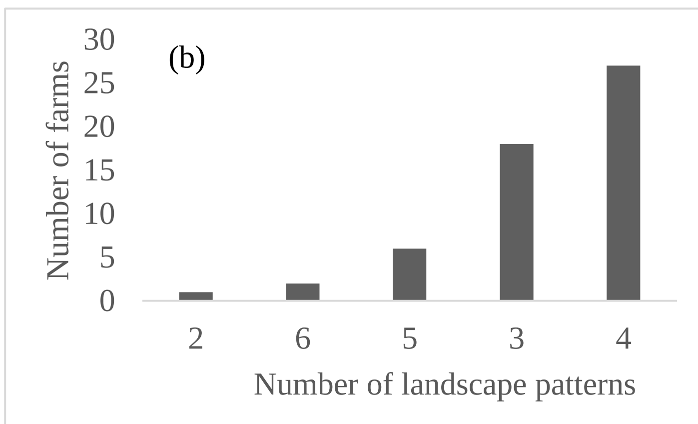


Figure 3.6. Frequency of the distribution of the landscape patterns: (a) frequency of the landscape patterns across farms; and (b) distribution of landscape patterns per farms.

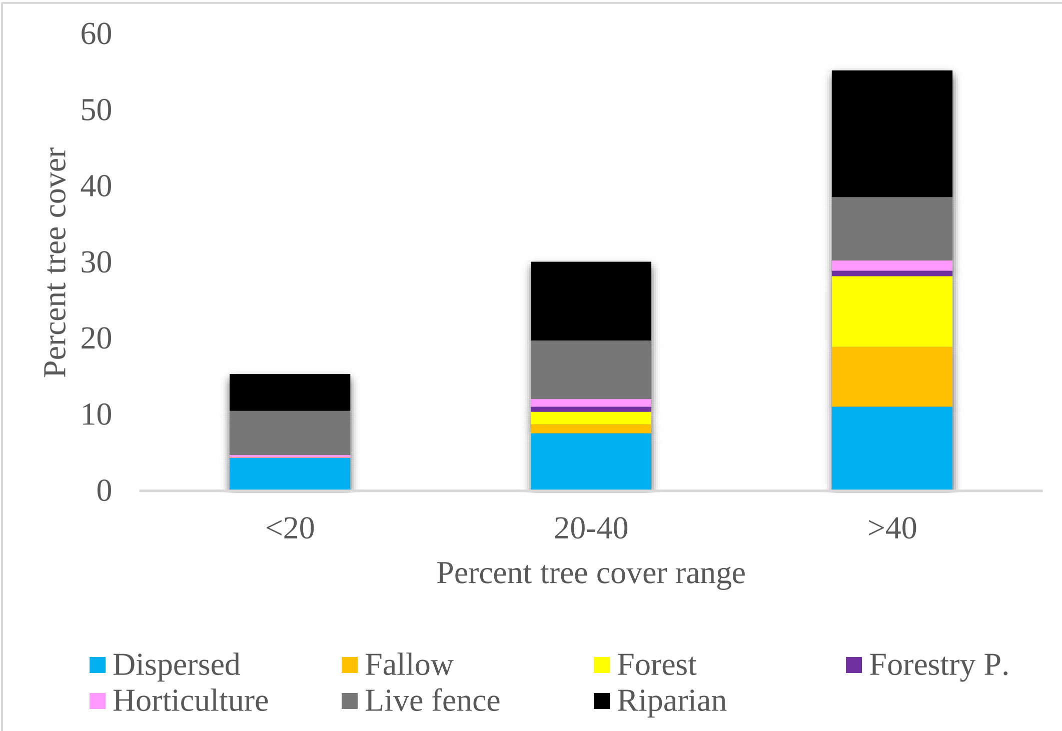


Figure 3.7. The landscape pattern average and composition across three tree cover ranges (<20, 20-40, and >40).

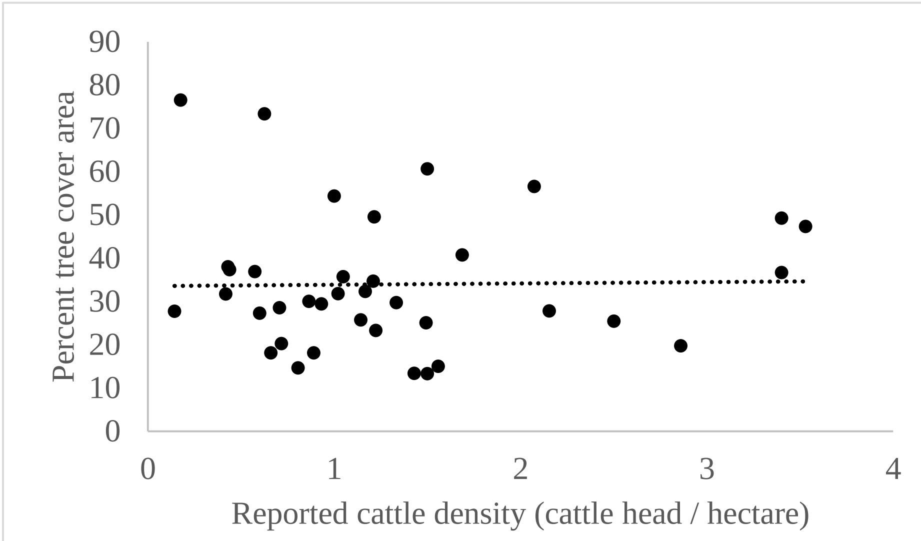


Figure 3.8. Scatter plot of reported cattle density (cattle head / hectare) against percent tree cover with linear fit (n = 36, $F_{1,35}$-statistic = 0.007, R^2 = 0.0002, p-value = 0.93).

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CHAPTER IV

Farmer perception and drivers of tree densities across cattle pastures in the Republic of Panama

ABSTRACT

Trees play a critical role for maintaining sustainable cattle ranching operations in the Neotropics. A push toward sustainable agricultural systems requires a deep examination of farmers' aspirations. I employ the peasant balances framework proposed by Chayanov to understand what roles trees play in fulfilling farmers' aspirations, particularly those related to cattle pasture production. I ask: what are the drivers of tree cover in farmers' cattle pastures? I conducted 54 in depth interviews with farmers in the Republic of Panama to examine their motivations for managing trees, perceived obstacles, and forces out of their control. Findings suggest that farmers believe that the utility of trees is important for the farm management, but they balance this utility with their aspirations to increase production. Reproduction emerges as a balance when farmers want trees for their shade so that they can make the farm resilient to extended droughts. Drudgery emerges through the difficulty involved in managing trees, and the notion that trees may decrease the grass area. Forces out of farmer control, including environmental regulation policy and perceived government corruption, limits their ability to self-determine how to manage their trees on the farm.

4.1 INTRODUCTION

The conversion of tropical rainforest into pastureland has been one of the most discussed topics in conservation biology since the great cattle ranching expansion which began in the mid 1900s across Latin America, intensifying during the 1970s and onward. The socio-ecological problems with this conversion include loss of biodiversity, increase CO_2 emission, overall degradation of fertile soil and water sources, increase land concentration and displacement of people (Hecht 1985, Kaimowitz 1996 (a), Muchagata and Brown 2003, Steinfield et al. 2006, Heckadon-Moreno 2009, Walker et al. 2009, Borras et al. 2012, Zahawi et al. 2015). Today, approximately 27% of the Latin American and Caribbean rural region is covered with pasture land for animal grazing (Murgueitio et al. 2011). In the Republic of Panama alone, 56% of the land area is agro-pastoral, dedicated to grazing (Sloan 2015). In this landscape, the cattle rancher has been painted as a homogenous object of tropical rain forest destruction (Walker et al. 2000, Steinfield et al. 2006, Heckadon-Moreno 2009). Recent research, however, demonstrates that the cattle ranchers are more complex and occupy a whole range of diverse ethnicities, topographies, and socio-economic classes with some indication that there are varying perceptions over the incorporation of trees into pasture management (Hoelle 2011, Lerner et al. 2014). These examples complicate the general rhetoric that ranchers are culpable of forest destruction and that they perceive that trees are therefore incompatible with cattle pasture management.

Ranchers have often been painted as the basic object of forest destruction and that they perceive an incompatibility between trees and cattle ranching management. Some argue that the ideology of “incompatibility” from the farmer’s perspective emerges from the management practices promoted by the conventional model for cattle production (which requires the grass monoculture) and that spread quickly in Latin America (Steinfield et al. 2006, Calle et al. 2013).

Others have found that cutting trees was the basis for territorial claims during the periods of the 19060's and 19070's when cattle ranching increasingly expanded across Latin America (Hecht 1985, Muchagata and Brown 2003, Rudel 2007, Heckadon-Moreno 2009). State led policies sparked a massive migration into areas that were presumably unoccupied and forested. Of course, many of these lands were occupied by indigenous communities or other farmers. The result was massive forest destruction and the consolidation of land by larger farming operations (Rudel et al. 2007, Broom et al. 2013). Land claims were cemented by cutting the forest and introducing agriculture or pasture. Farmers had to prove that they were "working the land" and the first step to working the land was "land-clearing or cutting the forest" (Hetch 1985, Rudel 2007, Grandia 2009).

Without disregarding the merit of these two explanations, I argue that the focus on this idea of "dualism" or "incompatibility" makes researchers ignore the on-farm processes that are at play in the cattle ranch and that have been analyzed for other kinds of farming systems (Van der ploeg 2009, 2013, 2014, Vennet et al. 2016). Instead, research has focused on understanding how regional and national economic factors lead to forest re-growth (Perz and Walker 2002, Perz 2007). The majority of the focus has been on labor scarcity as the main driver, all the while ignoring the nature of that labor, including the difference between wage labor and kinship relationships. In addition, multiple efforts have gone into agro-forestry projects that aim towards having farmers incorporate tree management practices on their farms to improve farmers' livelihoods. Such projects focus on encouraging farmers to allow natural regeneration or to plant trees (Mercer 2004, Browder et al. 2005, Haglund et al. 2011, Calle et al. 2013). Some of the lessons from these kinds of projects is that planting is too risky for most farmers to do it without any added benefit beyond generating "profit." These efforts tend to ignore how certain structural drivers interact with farmers' desires to improve their livelihood by incorporating trees into their management. Instead, we are stuck in the "peasant question" that assumes that the peasantry will disappear because farming itself is economically and ecologically inefficient (Santillán et al. 2007).

Recent literature acknowledges that cattle ranching is an important component of regional economies in Latin America whether practiced in small scale family farms or large scale agribusinesses farms (Santillán 2007, Coomes et al. 2008, Walker et al. 2009, Taravella and Sartre 2012, Acosta and Díaz 2014). Research also shows that cattle ranchers will incorporate trees into their pasture management through the management of live fences, dispersed trees in pastures, and forest fragments (Harvey and Haber 1999, Harvey et al. 2005, FAO, Santillán et al. 2007, Garen et al. 2010, Lerner et al. 2014). However, the extent to which they incorporate trees into pasture management varies. For example, from Costa Rica to Nicaragua farmers can manage dispersed trees in pastures at densities that vary from 8 tree ha^{-1} to 33.4 trees ha^{-1} (Harvey et al. 2011). In Panama, I found that mean percent tree cover across 54 cattle ranches was 33.39% (SD = 15.21), with a minimum of 10.44% and a maximum of 76.52% (unpublished results). In view of these results, I pose the general question: What are the factors that motivate farmers to incorporate trees into cattle pastures? A natural step to answer this question is to ask farmers directly what their motivations are for incorporating trees into their pasture management. Asking farmers directly creates a place specific description of the drivers to incorporating tree into pasture management. Here I present a case study of 54 farmers across the Republic of Panama which manage different tree densities.

4.1.2 Forest and cattle ranching in Panama

In Panama, there are general concerns over the effect of deforestation on land degradation (Heckadon-Moreno 2009), particularly in the Panama Canal Watershed which is surrounded by pasture land and recent urbanization. Research has emerged on the effect of different land-uses on water runoff, showing that the forest retains more rainfall water in Panama's forested landscapes when compared to pastures and agroforestry land (Ogden et al. 2013, Heckadon-Moreno 2005). In view of the effects of pasture land on degradation, there have been many efforts to conserve Panamanian forest through state-led regulations of deforestation in private land and through the designation of national parks and reserves. The state authority in charge of regulation is the "Mi Ambiente" (although at time of research it was called ANAM or the National Authority of the Environment) which regulates tree management in private land through "The Forestry Legislation that occurs through Law Nº1 of the Legislative Assembly of February 3, 1994." The article 94 from the Law Nº 1 states that farmers will be penalized if they: 1) burn without permits, 2) cut forest or isolated trees without proper permits, and 3) sell trees without proper permits. The penalty is unclear but the law says it depends on the impact and socio-economic status of the farmer. Under an additional law, called "Forestry Law or Law Nº 24 of the Legislative Assembly of November 23 of 1992" farmers can cut trees from lands that have been restored by them if they can prove those trees were managed by them and that the land indeed transitioned from agricultural plot to forest. To date I have not found any studies that look at the impact of these laws on tree cover, although some suggest these strict laws may discourage farmers from wanting to conserve or plant trees in their farms (Buttuod 2013).

Academic efforts in Panama have been concentrated on the reforestation of what used to be pasture land, focused on the effect and value of planting native vs. exotic tree species (Griscom et al. 2005, Garen et al 2009, Griscom et al. 2009, Hall et al. 2011, Griscom et al.

2011). Most of the research on reforestation in the cattle ranch has been in response to forest conversion into pasture and the perverse effect of state-led programs that promote the plantation of teak and other exotic timber tree species (Simmonns et al. 2002). Recently, farmers with the support of United Nations (UN), local and international NGOs (for example the Peace Corps and the Center for research on the investigation of sustainable agricultural and livestock systems), and research institutions like the Smithsonian Tropical Research Institute and the Ministry of Agricultural Development (or MIDA) have begun to incorporate intensive silvo-pastoral systems through pilot projects (personal observation). In spite of all this technical work, there haven't been many efforts to understand farmers' motivations to manage trees beyond documenting traditional tree uses in cattle ranches (Fischer and Vasseur 2000, Aguilar and Condit 2001, Love and Spaner 2005, Garen et al. 2010). These studies suggest that cattle ranchers in Panama do manage a great variety of tree species for their uses. Less attention has been paid to what motivates farmers beyond the value use of trees, although some have found that planting is limited by lack of land-tenure and government support (Simmons et al. 2002).

While trees on pasture benefit the long term ecological sustainability of the farm (Estrada and Coates-Estrada 2001, Stoner 2001, Santillán 2007, Perfecto and Vandermeer 2008, Broom et al. 2013, Van Bael et al. 2013) few have evaluated what densities are necessary to maintain that sustainability (Ainsworth et al. 2012, Martinez et al. 2014). Most research that examines the role of trees in pastures is based on experimental tree plantations and the idea of encouraging farmers to plant trees in the form of mixed plantations (Rhoades et al. 1998, Piotto et al. 2010). Meanwhile, trees play an important role in the cattle pastures contributing to the ecology and socio-economic sustainability of the agricultural landscape (Martínez et al. 2014). For example, in the long lived dehesa systems in Spain, areas under tree shade have been found to be ecologically different than the pasture areas with no shade. This difference is the result of the trees ability to pump nutrients and water from deep horizons (Joffre et al.1999). Trees also attract animals that defecate dropping organic matter into the soil (Guevara et al. 1986, Joffre et al.1999, Slocum and Horvitz 2000, Martínez-Garza and González-Montagut 2002, Van Bael et al. 2013). In addition, trees - by conserving moisture and nutrients - can increase the growing season of grass species; this depends, however, on the grass species (Scholes and Archer 1997, Broom et al. 2013) and the threshold at which shade stops being negative and begins to be positive for grass productivity (Ainsworth et al.2012). The extent to which farmers perceive trees to offer such benefits and how they balance these benefits with desires to increase production and improve their livelihood is an open question that I address.

4.2 FRAMEWORK

I employ a framework recently employed by rural economist to understand how trees fit into farmers' aspirations to improve their livelihoods, using the theory of peasant- balances proposed by Chayanov in the early 1900's and its recent resurrection by J. Van der Ploeg (2013, 2014). The argument is that all farmers seek to improve their livelihoods by increasing production, but they do so by balancing certain aspects of their household and farm operation. The peasant-balance framework focuses on the on-farm process and the specific situation of the farmer. I employ this framework to understand how trees fit into the specific farm operation and livelihood improvement. The peasant balances are a "tuning device" that results in farmer's particular response; trees on the farm is the outcome of a particular kind of response. (Van der ploeg 2013).

Viewing trees as a particular kind of response unsettles the paradigm of "dualism" between trees and production which is common across the conservation literature. Van der Ploeg (2013, 2014) argues that the process of production is linked to "farmers constant search for emancipations so that they can improve their livelihoods" and that Chayanov "provides a theory to examine the translation of emancipation (Van der ploeg 2014, page 1004)." Chayanov proposed that farmers are governed by a balance between "utility" and "drudgery." Utility "refers to the ability of satisfying aspirations and drudgery refers to the hardship of the labor that goes into satisfying those aspirations" (Van der ploeg 2014, page 1007). An equilibrium point is reached between these two under which there is a certain amount of production. What is interesting is that farmers' perceptions of utility and drudgery may change, causing them to take actions that result in increased or decreased production. If trees are perceived as an important component to increasing production, then the process of maintaining and managing trees in the farm would be part of the "calculation" that farmers make when balancing utility and drudgery.

The peasant balances framework also allows us to incorporate subjective farm situations and structural factors that influence farmers into our analysis. Farmers' experiences and structural factors like conservation policies can influence how farmers balance utility with drudgery. In some instances, structural factors can repress farmers' ability to increase production in a way that is suitable to their subjective farm situation. In these scenarios, farmers may resist such structural forces. Recently, the Chayanovian framework was employed to analyze why Haitian farmers do not respond positively to state-lead programs that encourage mango production for agro-export (Steckley and Weis 2016). In this qualitative study, Steckly and Weis (2016) find that farmers are resistant to planting mangoes because it requires giving up their traditional land-uses, making it risky for their livelihoods. Farmers perceived that mangos as a crop do not guarantee household security and therefore rejected projects. Farmers' decisions were based on an evaluation of their own farm situation after noting that some neighbors had not done well with the mango projects.

The ability for farmers to self-determine the use of their land is also recognized as an important factor to consider in conservation policy (Fischer and Bliss 2008). If farmers lose their ability to self-determine how to manage their farm, then they reject government driven conservation efforts. In this scenario, farmers are resisting or rejecting the forces that affect their ability to balance different needs (for examples see Van der ploeg 2008, Van der ploeg 2010, McMichael 2009). Alternatively, farmers can lose the ability to control when these programs are introduced, which may lead them to losing their livelihood (for example, Sainath 1996). Van der ploeg (2013, 2014) names this ability to self-determine the "space for emancipation", that is the space to improve their livelihoods. Understanding how this space is configured in the cattle ranch can help explain some of the farmers' responses to certain forms of tree management.

I analyze farmers' motivations to manage trees through the lens of Chayanov's and Van der Ploeg's theory of balances focusing on the variables farmers balance when they incorporate trees into their farm management. In this view, I can describe the dynamics that are at play in the farm without a value judgement and without assuming a "dualism." In this Chapter I employ qualitative methods to build an initial understanding of farmers' perceptions on tree management within their farms and in the context of their farm operation. In doing so, I look at 1) what variables motivate farmers to manage trees, 2) what obstacles they face to incorporating trees into pasture management, and 3) how forces out of their control affect their motivations or ability to implement their desired management practice. I analyze their perceptions employing the balances framework. Although I present here a small case study of 54 farmers, I argue that our findings reveal variables and insights that have been ignored previously.

4.3 METHOD

4.3.1. Population sampling

Initially, 15 farmers were identified for interviews with the help of the Ministry of Agricultural and Livestock Development (MIDA). Unstructured interviews with these 15 farmers led to the design of a semi-structured questionnaire. Fifty-four farms that have land ranging from 5-2,000 ha were later identified by contacting farmer associations and through chain referral sampling (Lerner et al. 2014). In Panama, cattle ranching is a male dominated activity (Love and Spaner 2005), for this reason participants were mostly male. The background of the study area is described in the methods section of Chapter 3 of this dissertation.

4.3.2. Semi structured interview

I was primarily interested in understanding farmers' motivations to incorporate trees into the cattle farm; the obstacles associated to incorporating trees and; the effect that political economy factors would have on their perceptions on tree management in the cattle pasture. The questions are presented on table 4.1. Questions were classified based on the kind of questions including farmers' motivations, obstacles, and forces outside of farmers control (see table 4.1 for details).

4.3.3. Analysis

Interviews were coded and analyzed using Dedoose software following descriptive, theme and analytical coding methods from Miles and Huberman (1994). On the first round of coding I created descriptive codes which were based on the interview questions and additional themes that emerged from the interviews. On a second round of coding I created themes that were often nested within a particular description. The themes were based on what farmers described as drivers of tree management as well as management actions including planting, cutting, and pruning. The analysis of the codes consisted of summarizing what farmers said in regard to each theme, classifying themes based on frequency, and later interpreting the themes employing Chayanov's framework of "balances."

4.4 RESULTS

Similar to other studies, I found that the primary goal of the cattle rancher in my study site is to improve his livelihood by maintaining a healthy pasture that can stock a profitable cattle density. I also found that the cattle rancher values trees (see table 4.2), primarily for its various uses, but that the process of tree management is challenged by a general trade-off between the utility of trees and the pasture area. Farmers can decide to have a large tree cover area but this has to be balanced with the cost it will have on production. The tree utility- pasture area trade-off seems to be a simple "give- or – take" scenario in which farmers can simply give up pasture area. However, I found that farmers will decide to employ different management techniques depending on the factors that are influencing their decisions including: 1) tree preservation; 2) cutting down a tree; 3) planting trees; 4) pruning trees; and 5) allowing the natural regeneration of trees. Implementing these techniques can be challenging and complicate the simple trade-off. The management techniques emerged across all interviews. I highlight them here because they are essentially the result of the farmers' evaluations of Chayanov's balances.

In the following sections, I describe various management strategies that emerged and explain how they are associated to the farmers' balance of the utility of trees with the pasture area. In addition, I found that farmers often find themselves in a scenario that is outside of their control (for better or for worse), complicating the simple trade-off even further and ultimate management action taken. In the following section I will present: 1) the reasons why farmers want to have trees; 2) the challenges associated to managing trees in the midst of the cattle pasture; and 3) the factors that are outside farmers' control and that appear to complicate the general trade-off.

4.4.1. The reasons why farmers want to have trees

Uses associated with tree management on the farm and the main reasons why farmers keep the trees are presented on table 4.2. I personally observed that all famer's employed trees in live fences although not all famers talked about them. In the interviews, shade and wood emerged as the main reasons for keeping trees. Fruit and livestock feed followed. Although, unlike shade and wood which emerged without prompting, I asked farmers directly about fruit and livestock feed. Less than half of the farmers said they sold trees for their wood. Ornamental uses and environmental uses like soil conservation also emerged but were not common responses. Reasons outside the use of trees include to create resilience for lengthening dry seasons and the desire to create multifunctional landscapes that provide food security and that are esthetically pleasing. In addition, a sense of stewardship, or motivations to conserve trees for the welfare of others, emerged as an important behavior among some farmers.

4.4.1.a Tree use and value

4.4.1.a.1 Shade is essential to cattle ranching

It is common to walk into a cattle pasture and find all the cattle ruminating under the shade of a tree. For the cattle, the shade helps avoid caloric stress (Ainsworth et al. 2012). The shade is also valuable to the farmer. While he is doing his daily chores, the shade under the tree is the ideal place to rest (personal observation). In fact, when I was walking the pastures with the farmers, I found myself sitting under a tree every time we took a break. Farmers often noted how trees were useful "*for the freshness of the farm*", for example: "*I leave the trees, because regardless, it is useful for the humidity, the shade for the cattle, for the freshness of the farm. I always leave the big trees*…" The term "*freshness*" encompasses more meanings than shade. The term "*freshness"* alludes to the function that "shade" has to maintain the humidity of the soil, water sources, and the general coolness of the farm.

4.4.1.a.2 Resilience to the dry season

One reason farmers explained that they allow natural regeneration or plant trees for shade is that it will help with the lengthening of the dry season. How they manage trees is very specific to their farm. In this regard, they adopt different tree spatial arrangements. For example, one farmer explains how he plants and allows natural regeneration *"speaking with the workers, sometimes I tell them to leave the trees. Sometimes I go and we plant trees… Those same trees are the ones that remain…"* The same farmer explains how his management of tree spatial arrangement is different to his neighbors and specific to his farm: *"In the end you have a pasture that is different to other pastures that have a lot of trees. Here you are going to find little clumps that have a lot of trees..."* The farmer then makes an explicit remark on what he is evaluating when he decides how to manage the specific tree spatial arrangement: "*From the point of view of the grass, it is not going to allow you to have so much cattle, but from the point of view of the wood, it is going to allow me to also have some wood for next year."* Finally, the farmer puts his evaluation in the context of the dry season: *"Also, there is going to be shade for the cattle. The cattle are not going to stress so much due to the heat… The summer here gets too hot"*

As explained by the farmer, the benefit that tree shade provides to the farm is enhanced in the presence of a severe dry season. Cattle struggle as the dry season heat strikes, but the farmer perceives that trees will generate some resilience. In light of uncertain weather, the farmer is balancing the benefit of the tree shade with the cost he perceives it will have to grass production. Thirty percent of the respondents explicitly talked about the importance of trees during the dry season either for their provision of shade or additional feed for the cattle. As another farmer noted:

> *"What I am trying to do is to put the trees in the center of the property and not put them on the corner …* [I planted] *about 600, 700 meters of fruit trees. That is what we are doing right now, because the cow looks for the shade more every time, because every time the summers get hotter and the winters with less water*."

In both of the previous quotes, farmers recognize that they want trees that provide additional "utility" than just shade. One farmer wanted trees that produced fruit, and the other wanted trees that he could use for its timber. The multi-functionality of trees is an important component to what species of trees they will choose to conserve, plant or allow to regenerate. The botanical characteristics of the trees also appear to be an important factor that farmers consider when choosing the tree species they will allow in the pasture. For example, some farmers explicitly said they preferred trees that did not provide an overwhelming amount of shade so that the grass could still grow under the tree. Two examples of trees that farmers perceived did not provide an overwhelming amount of shade were Macano (*Dyphisa americana*) and Guacimo (*Guazuma ulmifolia*) which have small leaves. In addition, both quoted farmers spoke of a specific and desired tree arrangement that reflect the Chayanovian balances. Both farmers want to grow trees in small clusters in the middle of the pastures area so that trees do not take too much pasture area but at the same time offer cattle access to shade.

The summer (or dry season) heat has been a topic of concern for cattle ranchers at the national level as well. I interviewed farmers towards the end of the dry season of 2014 (late April and early May) all through what should have been the beginning of the wet season (late May to late August). Farmers were warned by the local news outlets that 2014 was an El Niño year which would extend the dry season even further then previous years (Esquivel 2016, La Estrella de Panam). It was clear to me that farmers' perceptions over the value of trees was to a certain extend influenced by the ongoing concern over the extended 2014 dry season and the overall warning from the news outlets. There are expectations that the dry season will only become longer with the effects of climate change (La Estrella de Panamá 2015).

In conclusion, farmers clearly rely on trees to maintain cattle free of caloric stress, and to maintain the water sources. These are perceived as important to help them confront longer drought seasons. It appears that climate change awareness and their own experience with longer dry seasons is driving their desire to have more trees in the pasture areas of the farm. Farmers approach tree management by carefully evaluating which tree species they allow in the pasture and in which arrangements they will allow them to flourish. The evaluation is then weighed by the different challenges that they confront in the process of managing shade in the farm.

4.4.1.a.3 <u>Farmers want their shade trees to be timber and fruit producing trees</u>

When farmers spoke about wanting more shade trees, they also talked about wanting to have more economically important shade trees that were either timber or fruit producing trees. Fruit and timber trees are not just found on the pasture, however. On many farms they are concentrated close to the farmer's home. Eighty eight percent of participants spoke of timber species and eighty seven percent spoke of fruit trees. Farmers spoke of 36 tree species that they use for their wood compared to 39 fruit tree species. Timber tree species mentioned by more than ten farmers are: Cedro Amargo (*Cedrela odorata* L.), Cedro Espino (*Pachira quinata* (Jacq.) W.S. Alverson), and Macano (*Diphysa americana* (Mill.) M. Sousa). Among the three most commonly mentioned fruit tree species are: Mango (*Mangifera indica* L.), Naranja (*Citrus* sp.), and Nance (*Byrsonima crassifolia* (L.) Kunth). Farmers said that timber tree species are important in the farm because they can be sold providing additional cash to the household. The majority of farmers, however, said that the wood of trees are mostly used within the farm for stakes, fuel, carpentry for furniture and tools, and donations to schools or friends. Fruit trees species are also important on the farm and were associated with multiple functions including household consumption, cattle forage, food for wildlife, medicinal, gifts for friends, and to improve the soil. Only 4 farmers said they sold the fruit, and the only fruit that was sold by farmers was orange. Based on the interviews, famers perceive timber tree species to be more prone to generating cash for the household than fruit tree species since 39 percent of the farmers said they had sold timber at some point. Ultimately, farmers associate shade trees with multiple functions among which timber and fruit trees are the most common (see table 3 for more details on trees species and uses in the farm).

4.4.1.b Multifunctional landscapes

The majority of farmers cut, plant and allow natural regeneration to occur in their farm. While most wood and fruit tree species are likely to be the result of natural regeneration, insights on drivers of tree management emerged when I asked them about planting and cutting trees. Planting across farms resulted in a series of landscape patterns including live fences, monoculture tree plantations, agro-silvo-pastoral plots, and horticulture plots. Dispersed trees in pastures were often associated with natural regeneration, although some farmers admitted to also planting trees in pastures for the purpose of creating an agro-silvo-pastoral plot. Farmers also reported planting trees along streams to strengthen the riparian areas.

4.4.1.b.1 Farmers are not interested in commercial tree planting:

Farmers in my study site are largely uninterested in planting and selling trees for commercial purposes. Instead, they prefer to plant trees that add to cattle production and their livelihood by way of selling them when necessary or to use within the farm. In other words, the majority of farmers are not interested in planting trees following the intensification model that is so common among forestry plantations practices. In the following, I present evidence that suggests that although farmers are interested in having trees that generate cash, they are not interested in commercial tree planting.

- Few farms had monoculture tree plantations. Across the 54 farms, monoculture tree plantations were rare. I found three kinds of monoculture tree plantation: 1) oil palm, although often categorized as a crop (Kröger 2014); 2) caoba; and 3) teak. Oil palms, caoba and teak plantations were often planted as monoculture across several hectares.

- When given the opportunity, farmers create agro-silvo-pastoral systems and not monoculture tree plantations. The task of planting trees came easy to a group of 7 farmers from the Vallerriquito region that had engaged in a collaborative project with a civil engineering company called Constructora MEDCO S.A. The 7 farmers engaged in a reforestation project that involved planting a mix of desired fruit and timber tree species within pasture plots to compensate for the deforestation involved in the creation of a new access road by the MEDCO company into the Vallerriquito village. Farmers made an arrangement with MEDCO. In the arrangement with

MEDCO, farmers agreed to lend their land for reforestation as long as the company promised to aid in the management of the seedlings planted. The goal of the farmers was to plant tree species that they could use in their farm for consumption including fruit trees and timber species. The plantation was only one year old in 2014. The process required farmers to give up pasture land and to envision that as one's trees grew, the cattle would roam under the trees resulting in a lush silvo-pastoral system. In general, the Vallerriquito farmers were uninterested in engaging in commercial tree planting and envisioned a mixed agroforestry system that could also be a silvo-pastoral system.

- Farmers don't plant many timber tree species. Farmers planted trees close to their home in horticulture plots and dispersed across the pasture, but, farmers did not report planting a diverse number of species. Eighty seven percent of farmers said they planted trees. Out of the 36 timber trees reported, farmers only said they planted 4 tree species: Teak, Caoba, Macano, and Cedro Amargo. Based on the interviews, these are the same species that have a materialized market. In the quote below, the farmer explains that he is always trying to plant Caoba: "*I always have timber. And I am always trying to plant Caoba, like the one I showed you.*" The farmer is making reference to a set of Caoba trees he had planted near his house.

- When talking about planting timber tree species farmers explain that within farm use is more important than cash. Twenty four percent of farmers said they sold trees for their wood, compared to thirty seven percent that said they used wood trees within the farm. In the quote below, a different farmer explains that he likes to plant Macano, and Cedro.

> "*I like to plant Macano, because it is very fine wood. Macano is for stake, for the fence. I like to have Cedro, although it lost its value because now there is Teak and they say it*

sells better. But before, Cedro was the tree that everyone used for timber, for the house, to make furniture, for everything."

In the quote, the farmer emphasizes on the importance of Macano, and also hints at a possible decline of the Cedro market. I interpret the decline in the Cedro market as an important factor that may influence farrmer's interests in planting Cedro or other trees for commercial purpose. However, the farmer emphasizes on the importance of Cedro for the household as it is used to build houses, furniture and "everything." The farmer weighs the value of Cedro for cash vs. it's value within the household.

- Timber species are rarely sold, and if they are sold it's generally because the trees are close to dying. In the following quote the farmer answers with some resistance,

"Yes I have sold in some occasions. For example, Cedro Amargo, it has a life that it reaches a moment in which if you do not cut it, it is going to get damaged and you are going to lose it… But it's not something that I am in a hurry to do, no. I am not excited about selling."

When I asked 20 farmers if they "extracted/or sold timber from their farm," only 13 farmers said they did and they responded in a defensive manner which uncovered another reason for why they are uninterested in commercial tree planting. Farmers associated the question of extraction and selling to a business model of tree production. Many of the farmers that said no, said they were "not in the tree business."

Selling trees did not emerge from the interviews. Based on their answers, it is clear that the majority of the cattle ranchers are not interested in the business of selling trees, although they do like having trees that can be sold if necessary. Evidence is presented in the following paragraphs.

-Farmers generally wait and make sure that they or some family member doesn't need those trees first. Farmers often conserve trees for their family members. The following quote is an example: "*Well the other day I cut some tree that I used commercially, but they were meant to make boxes. But trees that are fine wood, I rarely sell them or touch them. Those are relic for the children and grandchildren further on*." The farmers' resistance to cutting trees may be a reflection of them prioritizing trees for household use, or alternatively, perceiving them as a bank savings to be used only when in extreme need. Other responses to the tree extraction question are that most of the time when trees are extracted they are often used in the farm, and if timber species are sold, generally it will be to people that come to the farm and request them, or to friends. In other words, farmers are not actively seeking to sell their trees, instead they prioritize their use in the farm.

- Farmers won't sell the trees because they don't think they will get a good exchange in the process:

> *"I am not with the aim of selling the trees. None. The ones I have used has been for the management of the farm. To make a house, or a ranch or something…The trees have more then 30, 40 years and people look for me so that I can sell it to them. But they want to pay me little and I say its better that I leave them here protecting the watersheds."*

This particular farmer acknowledges that there is a trade-off between income from selling trees and the benefits that trees have on the environment and his farm's ecology. Having said this, it does seem that having a market for some timber species like Cedro amargo makes these trees appear more “useful” and likely to be preserved, planted, and taken care of.

- Farmers have timber tree species as a source of “subsistence” and every day chores: “*One doesn’t have to think that I have to buy wood to fix the fence, none of that. Having a good quantity I can take advantage of them [the trees]. The fact that I have the material in my own farm means that I don’t have to go buy it, and I can use them immediately, making the job faster.*”

4.4.1.b.1 Farmers are interested in integrating trees into cattle pasture management

While farmers were not interested in commercial tree planting or selling, most were very interested in integrating trees into their cattle ranching management, especially fruit trees. I argue that there are two main reasons for their interest in fruit trees. First, they perceive a fruit tree scarcity in their farms. Second, farmers perceive fruit trees as multifunctional trees when compared to timber tree species, making them more attractive for incorporating into pasture management. I present the evidence below.

- Farmers want to plant fruit and timber species they can integrate with pasture management:

When I asked farmers “What are your future plans?” they said they wanted to plant either fruit or timber tree species and integrate them into their cattle ranching practices. For example: “*I want to plant more. I could sort more and populate more but it would be with timber trees and with fruit trees. Something that produces. So that I can add to animals.*” My interpretation is that the farmer wants to integrate cattle with tree management. In the quote below, another farmer explicitly talks about creating a silvo-pastoral system by planting fruit and timber tree species.

"*Now you saw that I deforested in that part, but my project is that when I can't harvest anymore I am going to plant trees and grass under. Trees either fruit trees or timber trees.*" This farmer had cut down some forest to plant rice and other crops. He was planting crops at a very small scale but was planning to plant pasture and trees after the harvest season. In both examples the farmers have a vision of planting trees in the pasture and integrating these useful timber and fruit tree species into the cattle management practice.

- Farmers frequently said they wanted more fruit trees when thinking about the future:

In the following two quotes, both farmers also talk about wanting to integrated tree management into cattle ranching, but they more specifically talk about wanting more fruit trees. For example,

> *"…I have the idea of making some small forests with fruit trees but just to have something. It's not for business. Right? It's to have some parts to make a forest in the paddocks that will provide shade for the animals…Maybe one can put a mango, avocado. That is more or less the idea that I have for the future."*

The farmer is very clear in that he does not have a vision of planting trees for commercial purposes, and he wants the fruit trees for the dual purpose of shade and fruits. In the quote below, the farmer also wants more fruit trees and not so much timber species*: "Fruit trees, above all fruit trees. Some timber, but above all fruit trees. I mean, if the project remains or not, I still want to put trees in that farm of the Guaca and the one here."* The farmer is referring to the project with MEDCO.

- Farmers want more fruit trees because they perceive a fruit tree scarcity. When asking farmers about their future plans they often said they wanted more fruit trees because they thought they didn't have enough fruit trees. For example: *"Well, we practically don't have fruit trees because since we have the cattle, and we occupy a certain amount of land for the Palm [oil palm] and the plantain then we don't have fruit trees. We do want to make a small plot close to home."* The farmer is not planning to plant more trees in the pasture. Instead, he prefers to plant fruit trees near his home. Clearly the farmer is balancing the pasture area with the utility of trees on pasture based on other land-uses that he has in the farm. The following quote is from a farmer that also perceives his farm needs more fruit trees: "*And I also think we are lacking fruit trees. Oranges, pear, mandarin, grapefruit, mango, avocado. I feel that that we are lacking [fruit trees and timber trees] to complement with the shade and so that there is a variety*." The farmer expresses that he wants more fruit and timber trees, so that he can have a variety of trees. So although he is interested in timber tree species, what he is really looking for is a variety of trees that can help complement cattle ranching in various ways including the provision of shade.

I argue that farmers want trees so that they can add multifunctionality to the farm operation. The argument is based on farmers' perception of fruit tree scarcity. In addition, most farmers reject commercial tree planting and the tree business model. The longing of having a variety of trees materialized for the farmers in the Vallerriquito region, were 7 farmers were able to plant multiple fruit and timber producing tree species through their alliance with the MEDCO Company.

4.4.1.c Stewardship as a value to conserving fruit and timber tree species

Another important theme that emerged from the interviews was a sense of stewardship which here I define as a sense of responsibility that farmers perceive they have to preserve trees, not just for themselves and their cattle production, but for social and ecological reasons. It is clear that this sense of stewardship is related to their perceptions of the overall loss of wildlife and tree cover in their communities and beyond. In addition, farmers acknowledge the temporality component to tree growth, explaining that they plant for future generations and not for themselves. Unlike timber trees, fruit trees were often associated with wildlife conservation adding another function to having fruit trees in the pasture. Timber tree species were more often associated with the temporality of tree growth, in the sense that they were planting a living bank for future savings. Forty four percent of the farmers expressed their sense of stewardship by saying at least one of the following:

- Farmers want to help with wildlife and cooperate with nature: Multiple farmers said that their farms, with all their fruit trees in the pasture and horticulture plots, were some of the few sources of food that squirrels and birds had. In the quote below the farmer lays out this scenario: "*We have dedicated ourselves to fruit trees like mango that has good vegetation, produces shade, and fruits. It can be eaten, you can give it to a family, to a friend and like that. But the squirrel now eats it. What happens is that those that have a lot of land cut [the trees] and then have no fruits left so they [the squirrels] come looking for what one plants*."

The farmer's perception appears to be anachronistic since on the one hand animals are pests that eat her fruits, but on the other, perceives an endearment over those animals that have nowhere else to go. In addition, the farmer speaks of the other use fruit trees have including household consumption, shade and as gifts for her family and friends. Again, the importance of the multi-functionality of fruit trees becomes apparent, alongside the stewardship component.

- They want to conserve rare tree species that young people can't enjoy anymore: For some farmers, their perception over rare or old-growth tree scarcity was a reason for having more trees. In the quote below the farmer explains that his farm had been deforested previous to his tenure:

"*We did notice when we bought the farm that they were cutting a lot of trees and specially everything close to the forest. There [in that forest] we conserve 4 hectares that are in forest and we have tried to conserve the forest as it is. Practically, we are conserving all the timber trees*"

In addition to conserving the forest, this farmer managed and conserved timber tree species on the pasture. He also conserved fruit trees including various species of palm trees. Overall, the farmer seems to embrace a sense of responsibility over taking care of the forest fragment that is within his territory.

Some farmers explicitly said they conserved timber tree species because they were rare and wanted future generations to be able to benefit from these species: "*And timber trees there is Quirá. Let's leave it for those that come behind because that is something that you don't see anymore, so they can learn, it is not going to exist"* Quirá is a highly valued and precious timber tree species. I did not see farmers planting Quirá, instead they are mostly the result of natural regeneration.

- For future generations: Finally, trees take a long time to grow before they can be used. For this reason, farmers perceive that planting trees might not benefit them directly, but might benefit their children or grandchildren, as previous quotes also alluded. In the following quote, the farmer explains he is not interested in trees as a source of cash. Instead, he plants trees for his kids, ornamental and shade.

"So we do plant. Not with the goal of selling, but because they flower and they look pretty and provide shade. That is what we do here in the farm. When we can plant some

type of tree in some place we plant they remain there for the future in case the sons want to sell it. To plant it with the goal of business right now, no."

The farmer talks specifically about planting trees for esthetics and future timber value. Other farmers talk about preserving trees for their children: *"Cedro amargo, Cedro espino, Laurel, they are wood for construction…so we have wood for construction. I have several over there. The people here want me to sell it to them but because we have children and grandchildren we have to wait to see if they are going to make a house."* As he suggests, the farmer is prioritizing his children's welfare over an immediate income he may receive from selling the trees.

Based on the interviews, farmers are motivated by a sense of responsibility towards future generations. In this view, farmers demonstrate that they are weighing the value of trees based on the scarcity of trees, the value it has to household self-sustenance, the value it has in the market in case they need additional cash, the value it has to wildlife and future generations. Some farmers appear to conclude that forgoing selling a tree today will be worthwhile in the future when they will still be able to enjoy the benefits of those trees. Farmers, however, don't weigh their options in a vacuum and in the following sections we will see how incorporating trees into the cattle pastures is complicated by the hardship associated to tree management and the nature of cattle pasture management.

4.4.2. There are obstacles to incorporating fruit and timber tree species into the farm

Obstacles to tree management that emerged across the 54 interviews are presented on table 4.2. The most significant management oriented obstacles to tree establishment were those related to the tree's interaction with production.

4.4.2.a *Shade-grass trade-off*

Paradoxically, when farmers talked about shade as a value to maintain the "freshness of the farm", 46 percent of farmers also talked about shade as an obstacle to pasture growth alluding to the general trade-off between tree cover area and pasture area. The general trade-off emerged when farmers spoke about grasses losing productivity when they were under the shade. In the excerpt that follows, the producer explains that he had failed at an attempt to plant an improved grass variety, and attributed the failure to having too much shade: *"Coincidentally, this year I made grass and I was observing that where I threw the seed there was not much germination because there is too much shade. I have to open."* In the quote, the term "open" refers to the direct management action of cutting trees so that the sunlight can reach the seeds. This farmer had been struggling with keeping his dairy farm operation up and running. He had lost a lot of his cattle because he had invested in a bull that did not provide off-spring, and diseases had also taken a toll on some of the calves. His herd had been decreasing steadily throughout the years. It was clear that he was looking for ways to improve his farm operation by planting new grass varieties. His farm was also small but had an above average tree cover area when compared to the other farms I visited. Low cattle densities, small farm area, failure to successfully plant the grass, and a large tree area cover possibly led him to perceive an imbalance between the tree cover area and the grass area. For the farmer, shade became a reason to cut trees.

Some farmers said shade was not an obstacle. This statement was generally followed by a strategy to manage shade, for example: *"Trees don't bother me because I prune them…and also the cattle eats peacefully under the shade."* The farmer perceives that shade is not a problem since he already has a strategy for managing shade through pruning. The farmer appears to have found a balance between the tree area and pasture area through the action of pruning. A different strategy is to plant trees in rows instead of randomly dispersed on the pasture, for example: "*The farm is small, and with a lot of trees we are not going to have enough food for the cattle because of the problem with the shade. For that reason we have planted in lines. It does not bother the farm and you have shade*." The farmer appears to be contradicting himself. The farmer planted trees in a corridor in order to control the amount of shade in the pasture area. Therefore, he does perceive shade as an obstacle, but seems to have found a balance between tree cover area and grass area by planting trees in a row. Based on these interviews, farmers express the constant need to balance shade with grass areas and those that do not see shade explicitly as an obstacle probably have found a balance suited to their specific situation.

4.4.2.b Weeding is a barrier to natural regeneration

4.4.2.b.1 Kind of weeding:

When trees grow in the pasture, farmers may determine that they are undesirable and weed them as part of their regular pasture management processes. Weeding refers to the elimination of plant species that will outcompete the grasses that are intended for cattle forage. Farmers call the process of weeding "limpieza" (or cleaning). Weeding or "limpieza" is an important and constant process in cattle ranching management and it is essentially the most important production related process that determines what trees grow and what trees don't grow in the pasture area of the farm. In the interviews I found three main forms of weeding that occur across the study regions: 1) mechanical weeding which refers to the elimination of weeds employing tools like machete and "coa" (long handled narrow spade), 2) chemical weeding, which refers to the elimination of weeds employing agro-chemicals (for example glyphosate, and 2,4 D), and 3) fire burning. Fifty one farmers described the weeding process in their farm. While all 51 said they employed mechanical weeding, 86% said they employed chemical weeding, and 25% said they have employed burning. The type of weeding likely depends on the kinds of weeds farmers have on their farm. In total, farmers mentioned 68 common names of weeds, of which 10 were trees (see table 4 for more details on species). These weeding methods are described below.

- <u>Mechanical weeding to eliminate the "monte"</u>: Mechanical weeding is a continuous process in farming. When I was walking the pastures with the farmers I could see that they were constantly weeding out herbs and woody shrubs with their machetes. A farmer makes reference to an instance in which I saw him stop to cut weeds: *"You saw where we were that I stayed there cutting with the machete?... that's bush."* "Bush" or "Monte" refers to the plant species that are naturally regenerating in the pasture area. When farmers talk about "monte" they are generally referring to fallow vegetation which is temporary. Sometimes farmers call standing forest "monte" with a tone of disgust, suggesting that the standing forest is a sign of land that is being underutilized. A pasture with fallow is considered a "dirty pasture" or "potrero sucio." During the walks on the farm, if farmers perceived that the pastures had too many weeds, they would say that the farm needed to be "cleaned" or "limpiado." In the following quote, the farmer talks about controlling the weeds through mechanical weeding and makes reference to a specific area of his farm that is "limpio" because it has no "monte": *"Last year I was with the coa and some workers pulling them out [the weeds]. For that reason you see that over there, there is little bush and it's clean. Those sprouts I pulled them out."* Farmers employ mechanical weeding to eliminate woody species including woody lianas, trees saplings, and shrubs.

- <u>Chemical weeding to eliminate the herbaceous weeds</u>: Farmers employ chemical weeding methods mostly to eliminate herbaceous weeds. Famers tend to weed intensively on a seasonal basis. Across participants the frequency of weeding varied: 1) 26 of the farmers weed intensively once or twice a year; 2) 20 said they chemically weeded once a year and; 3) 6 farmers said they chemically weeded twice a year. In general, chemical weeding is done once or twice a year in specific plots that have too much "monte." Farmers explained that they weed primarily in May during the beginning of the rainy season and those that weed twice a year also weed in December towards the end of the wet season, in both cases avoiding the rainy season. In the following quote the farmer explains why using chemical weeding during the rainy season is risky: *"…rain falls on top of you [in reference to the weed] and it cleans everything and it falls on the soil. On the soil it doesn't work. The herbicide is foliar and has to be in contact with the leaf so that it can work."* Six farmers said that the frequency of chemical weeding "depends" and that they did it every 2, 3 or 5 years. Overall, farmers also explained that chemical weeding was not done over the entire farm area. The farmer below explains that he employs chemical weeding but not on a regular basis. When he employs chemical weeding he will only work on one plot of the farm per year and he will not return to weed that plot until many years after:

> "*…I had not thrown any [herbicide] up there. The first time up there. We use to use the machete and this year we threw some. Maybe from here to three years we will throw again to the little bush. If you see little bush you go with the machete and cut it, instead of poisoning yourself. That is poison."*

In this view, the frequency of weeding is also influenced by the farmer's perception over the toxicity of the herbicides.

- Burning: Burning refers to the use of fire to eliminate the weeds. It is more commonly used in areas that have a lot of fallow with woody saplings and shrubs that are not easily removed with machetes or chemicals. The traditional grass Faragua (*Hyparrhenia rufa* (Nees) Stapf) has historically been managed with fire, whereas the newly improved grass varieties that were introduced just 10-20 years ago are rarely managed with fire. In the quote below the farmer explains how he employs fire to remove weeds in the farm areas that have Faragua: *"I only burn over there in Orea that has Faragua. Where the improved grass is I don't burn."* The farmer explains that he employs fire but that he does it specifically where the grass Faragua grows and that he doesn't burn where there are improved grasses. My interpretation from the interviews is that Faragua is more susceptible to being outcompeted by weeds, and therefore requires burning to outcompete the weeds. The interviews and personal observation seems to suggest that burning is more common in the Azuero region. Among the 13 farmers that said they had employed burning, 11 were from the Azuero region. Farmers in the Azuero region employed the traditional grasses more than the improved grasses. Those that had employed the improved grasses did so only in small portions of their land.

In the end, not many farmers acknowledged that they currently burn. Instead, 5 farmers talked about accidental burning occurring in their farms, for example: "*no, here we haven't burned, only in the summer that people burn our pastures. You know, people with a cigarrete or to be mean they do it, but we don't burn here.*" Farmers select which species of plants they let regenerate and which they don't. This process that they described during the interviews became more obvious as I was walking through the pastures with the farmers, described below.

4.4.2.b.2 Farmers select what species to weed:

Selective weeding of plant species is possible when the methods employed are mechanical or chemical. Burning does not really lend itself to selecting weeds, since it is an extensive process that covers entire plots with fire flames. Evidence of how farmers discriminate which weeds to weed are presented as follows.

- Farmers discriminate which trees are weeds, and which are not weeds depending on how common that tree is. How common a tree is depends on how easily dispersed it is throughout the pasture and on how quickly it regenerates. For example, in the quote below, the famer talks about eliminating Jagua, which is a plant species that cattle and horses eat and disperse throughout the pasture.

> *"You know which one I've been elimination? The Jagua. Jagua is a tree that the cattle and horses eat. So there is a problem which is that seedling carpets are formed. The horse doesn't destroy the seed of the Jagua. It disperses. It eats Jagua here, and takes it to another place in the paddock and then everything stays over there. We are eliminating that. The Jagua for that reason."*

At the end of the quote, the farmer makes reference to the Jagua seedling carpet as "monte." Here the farmer is making a balance that is very specific to his farm. In his farm Jagua seems to regenerate very easily becoming a problem since it takes up the space for the grass area. Although Jagua is a useful plant within the farm (the timber can be used to make tools), in great quantities it is perceived as a weed.

- Farmers will discriminate depending on whether a plant is a nuisance or not. A nuisance plant species is that which is bothersome or that somehow makes the process of pasture management harder. One example is the corozo trees (*Acrocomia aculeate*), which is a palm that has a lot of thorns. In the following quote the farmer explains that the corozo tree has "pencas" or palm leaves that can hurt the animals, especially the calves: *"…in regards to the palm when there is a lot of quantity, because sometimes it does affect the animals because of the palm leaves that can hurt the calves; when there is a large quantity it can affect in that sense."* Corozo is also a palm that farmers value since the fruit of corozo is eaten by cattle. However, similar to the Jagua, it is also dispersed across the pasture, therefore regenerates easily, but also presents itself as a nuisance because of the dangerous thorns. In this view, farmers have to balance the nuisance of keeping the palm with the utility for cattle forage.

The three forms of weeding I have outlined in this section are important in that they will have distinct effects on the natural regeneration process. For example, the use of chemical herbicides have been shown to negatively affect the soil quality (Griscom et al. 2009) which positively feeds back into the stagnating natural regeneration. However, the employment of herbicides can be done sparsely throughout the fields allowing farmers to select which species they allow to regenerate. Burning on the other hand, when done extensively can potentially cover a much larger area than chemical weeding. In this view, it is important to note that the mode of weeding and the intensity at which it is employed will have different effects on natural regeneration across the farm.

Finally, weeding was often associated to labor. All forms of weeding require labor, although some forms may require less labor than others. For example, mechanical weeding may require a lot more labor than chemical weeding.

What is important to consider at the end of this section is that farmers have to balance the utility of the tree with the grass area, and they do this by assessing how easily a plant will regenerate, and how effective or eroding to the process of regeneration of a particular form of weeding will be. Farmers must come up with a way of balancing this in addition to assessing the labor force necessary to manage the process of natural!

4.4.2.c Cattle trampling

Farmers spoke of cattle trampling as an obstacle to tree planting and emphasized on how building fences around planted seedlings is monetarily costly, as well as labor intensive because it requires too much care. One farmer explains,

> "*I told you that I planted thirty five trees and I bought them from MIDA and they all grew. And when they were growing the cattle started eating it and started breaking the branches. If they are delicate they dry out and die. The only tree that you can plant on the live fence and let grow is the orange*."

The reason why he considers orange is the only tree cattle let grow is because orange has thorns. Multiple farmers that share similar experiences argue that taking care of naturally regenerating seedlings is a better strategy then planting. Farmers have some control over cattle trampling if they decide to fence the trees. However, cattle will try to go over the fence which makes it tedious for the farmer to manage. Farmers were not generally open to the idea of allocating land for natural regeneration. They often claimed that it was easier to let plants naturally regenerate instead of planting because of cattle trampling.

4.4.3 Forces out of farmers control

For better or for worse, there are forces that farmers cannot control. Here I classify these forces as: 1) stochastic, 2) historical farm management, 3) experiential knowledge, 4) structural drivers. These forces amount into a series of psychological barriers which make tree management seem like an overall drudgerous task.

4.4.3.a. <u>Stochastic barriers to planting, managing and facilitating the natural regeneration of trees</u>

Almost all farmers allow natural regeneration and have had experiences planting trees. Tree extraction is also very common but mostly for within farm use. Across the interviews farmers explained the various aspects of tree management. In this section I argue that tree management is difficult because farmers are confronted by forces out of their control including unpredictable weather events, pests and uncooperative neighbors.

4.4.3.a.1 Ecological forces out of their control: After shade, unpredictable weather conditions were the most common obstacle to tree management. Farmers spoke about how cyclones cause the loss of standing trees and drought in the dry season makes tree planting difficult. For example, *"I planted 5 guayabos and 5 marañón. Marañón curazao. Only one is left. They all dried in the summer and only one marañón curazao is left."* Other farmers (17%) had trouble with pests and pathogens on fruit trees and timber tree species. As one farmer explained, *"I had a lot of oranges over here. I would take into Panama large trucks of oranges, but a plague has fallen on them. They have died, hundreds of orange trees."* This farmer was one of the few farmers that sold fruits in the market, but after a fungal pathogen attacked his fruit trees, he stopped relying on trees for income.

4.4.3.a.2 Uncooperative neighbors: A few farmers (9%) said that people either robbed trees, burned their farm, or wanted to cut down their standing forest. For example, "*same as in the fallow the obstacle that has happened to me, since I have conserved [a forest] there then last time they burned. And it's not an accident. It's a hairy hand, I mean, a harm, something personal*." At least one farmer also said that his neighbors wanted to destroy his standing forest. Although there was a low percent of respondents on the theme of uncooperative neighbors, it does appear that farmers often would prefer to plant economically valuable tree species closer to their homes where they could take better care of them.

At the time it was all over the news that people were stealing one particularly precious timber tree species called Cocobolo (*Dalbergia retusa* Hemsl). Farmers spoke about this situation and claimed that other people around their neighborhood would still their trees.

4.4.3.b <u>The history of farm management matters</u>

Is there anything about the history of the farm management that influences farmers' decisions about the future? Trees take many years to grow and the constant weeding across the farm can have a long lasting effect on tree densities that we see today. At the same time, farmers' experiences growing up in the farm can influence the way in which they make decisions about the future of the farm. Since the majority of the famers were born and raised on their farms (90% of farmers), I asked them to talk about tree cover change, previous land-uses on their farm and their experiences in managing the farm. Ten percent of the farmers where not born in the farm and had owned their farm for less than 20 years, therefore I asked them to compare since the time they had acquired the land. Forty three farmers talked about perceived changes in *tree density* over time. Farmers spoke about having "more" or "less" trees in specific areas of the farm and not across the overall land they own. Therefore, they possibly only spoke about areas of the farm where they had perceived a change. In this view, the insights of this section are not about their overall perception of tree change across the entirety of the farm. Instead, the insight is about specific forms of management that lead to more or less trees in the farm and how those forms of management have changed over time and influenced their decisions about tree management today. Some farmers said they had more trees than their parents; others said they had less trees then their parents. Among the 43 farmers that talked directly about their perception on change in tree cover within their farm, 39% said they had less trees than their father, 37% said they had more trees than their father, and 18% said they had the same amount of trees than their father. The reasons for tree change vary and are introduced in the following paragraphs.

- Farmers perceive that they have less trees because they cut down the fallow to give room to improved grass varieties

Those that perceived having less trees then their parents also said they had less forest and fallow then their parents (28%). For example: "*in that one in Orea there is also a change because when I got it had a lot of bush*." The concept of "la he trabajado" or "working the land" is also connected to the idea of improving the land by making it more productive. A necessary method involved in working the land is weeding out the fallow or cutting the forest employing both mechanical weeding (coli) and the chemical weeding (motobomba). Farmers talked about working the land when they talked about introducing the improved grass varieties. For example, "*…before there were more trees but what happens is that I had to cut because it was very clumped on the pasture…and so that did not give much product. The grass did not want to work, and for example the improved grass was not working very well."* Four farmers explicitly explained that this was a necessary process for the successful introduction of improved grasses and that introducing improved grasses meant that they had worked the land.

- Farmers perceive they have more trees because they allow natural regeneration in areas where it use to not be allowed

Those that said that they had more trees than their parents also said they allowed more natural regeneration and planting than their father (14%), for example: *"I think there is more now. There is more because before we tried to clean everything. But now one goes and leaves a lot of kinds of trees."* Nine farmers said that they had more trees dispersed in pasture or in horticulture plots because they either plant more trees or allow more natural regeneration than previous owners. Seven out of nine of these farmers also said that they thought they had more trees than the previous owner. Five out of the nine farmers that said they had more trees, also said they had less fallow and forest area than the previous land owner. What this means is that they perceive they have more dispersed trees but less forest.

<u>-Farmers perceive that areas of the farm that use to be in agriculture have less trees today because cattle ranching allows natural regeneration whereas agriculture doesn't</u>

Throughout the interviews it became clear that the historical legacy of agriculture was an important variable to consider as a driver of tree densities in the farm. When I asked farmers how their farm had changed over time, 6 farmers said that the prior owner practiced agriculture, primarily rice and sugar cane, which requires complete clearing of the land. "*Yes it has incremented because before the farm was used for rice, and rice would reach the shore of the fence, exteriors, and the shore of the stream was trees. The rest was all crop. Now it has incremented uff! A lot the quantity of trees, since we started having cattle*." Farmers perceive that more dispersed trees arise in the farm as the farmers switched from agriculture to cattle ranching. Although not in reference to the farm's previous land use, six additional farmers spoke about trees not being managed within agricultural plots because agriculture requires complete land clearing.

<u>-Farm's previous land-use affects decisions about future use</u>: Farmers' perceptions over previous land-uses may motivate their actions over the future management and this is apparent across the interviews. For example, some farmers perceived that the tree across the pasture area were clumped, as this one did:

> "*I consider that I should have more trees. What happens is that there are trees that are close together, too close together. They should be more spaced out, I think, because there*

are parts where there are none [trees]…I cut a tree because they were too close…What I am saying is that this was a farm of plow to produce rice, and corn, so all the trees were cut down and the ones that remain are clumped in several parts."

In the quote the farmer shows dissatisfaction with the spatial arrangement of trees that is a result of past land-use history. In some areas of the farm he finds that there are few trees and in other areas he finds that trees are too clumped loosing areas for the grass. Overall, the spatial arrangement of the trees creates problems in the design of the paddock rotation scheme. This farmer has tried to solve this problem by planting trees dispersed in some areas of the farm that have no trees while cutting trees from the clumped areas. However, he has problems with cattle trampling complicating his ability to balance tree cover with the grass area.

4.4.3.c. Experiential knowledge

The majority of farmers that answered the questions about knowledge admitted that it came from their experience growing up in the farm. Experiential knowledge comes from what they had learned from their fathers and grandfathers, trial and error, as well as interactions with neighbors. The practice of integrating trees into the agricultural management often comes from traditional knowledge. The following two quotes are examples in which farmers explained how they learned to integrate trees with agricultural and pasture management.

"Since I was little I learned from my grandfather. He had a small farm over there, he had to work a lot because there was no water for the pasture. So he would plant a little plant, he would plant yuco, rice and the trees…He would leave them there and let them grow. When he would cut them three times the trees would grow and soon the bush was there again. When leaves the trees so that they grow and then you cut them again. See? That's the way it is. And cattle ranching, since I was little I have been cattle ranching."

The following quote is another example in which the farmer explains how he learned to integrate trees with the cattle pasture:

> *"I've never seen something against it but you have to know how to work it. If you exceed in the forest, no cow goes in there, but if you cut everything you don't give any protection to the grass, nor the trees, or the birds or the cattle. That is, everything goes hand in hand. The truth is that, the teachings is that everything goes hand in hand. That Roble tree can give you money, 700 dollar but 700 dollars are gone. But that tree there gives you flowers, nests, the cow there goes under to rest. That's good! It's what I am dedicated to. So we try to make a balance. To not hurt and it does not affect us. But that I think is instilled from childbirth."*

The two farmers are born into cattle ranching and their perceptions on how to integrate trees into the cattle pasture is essentially inherited. But for some farmers, the integration of trees into the cattle pasture may very well not be inherited. Integrating trees into cattle pasture management may be easier for farmers that grew up learning how to manage the silvo-pastoral system.

Farmers that did not inherit knowledge to integrate trees with pasture management may have difficulties when trying to manage silvo-pastoral systems. Balancing tree cover area with pasture area requires some knowledge about the ecology of the trees, grasses, and cattle. Based on these factors the farmer has to "calculate" how much area of grass they are willing to give up in order to obtain the benefits of having trees in pasture (conserve shade, good soil and grass quality) while maintaining a profitable cattle density. In the following quote another farmer explains the difficulty in balancing the benefit of silvo-pastoral systems with yields:

"So you have a lot of factors that you have to deal with, so in the same way you have to see what you are going to do. Cattle density vs. amount of shade vs. amount of grass, the humidity, hours of daily sunlight. You have to find the way that everything works. For that reason the silvo-pastoral systems to a certain point work well but at the same time a lot of people don't like it because instead of having 6 steer per hectares sometimes you have 4. When you have 20 hectares its 40 steer that you want to have. And the value of the steer in the market, it's a lot of money. So that is what you have to see."

The farmer, explains that although necessary, a silvo-pastoral system is not very easy to operate and requires experience.

Farmers' spoke of other ways that experiential knowledge is implemented in the farm as well. For example, some spoke of choosing trees that provide "appropriate shade". Farmers consider that some trees are very bad for the soil and therefore the grass is not going to grow under that tree. These trees were often called "mala sombra." One tree that was commonly called "mala sombra" was teak. Other trees might provide too much shade to the extent that nothing grows underneath, such as mango trees. Farmers don't like trees with a lot of shade because cattle will aggregate under that shade and erode the soil. In addition, farmers learned over time which trees are appropriate for the live fences. Some trees are not appropriate for the live fence because they deteriorate the wire, whereas other trees hold the wire for a very long time. Choosing the appropriate trees for creating the life fence is important since there is large amounts of labor involved in fixing the deteriorating life fences. Farmers talked about which plants are weeds, which trees provide bonus forage for cattle, which trees grow fast and which grow slow. They talked about the amount of time a plot can handle a particular stock of cattle, the best place to plant the new improved grass variety and crop. Knowledge about all these factors can only be the consequence of having managed the same farm for their entire lives. After some time, farmers find a way to balance their livelihood needs according to what their farm can and cannot provide.

4.4.3.d <u>Structural forces</u>

Farmers are constantly seeking ways to improve their farm operation to improve their livelihood. The structural forces that come from outside the farm affect how farmers balance the trade-off between tree cover area and pasture area. This became very clear early on. When I asked about farm management and perceptions about changes in the immediate landscape, farmers unexpectedly talked about the state. State forces which farmers could not disengage from tree and cattle management included: 1) ANAM (Environmental regulation authority); 2) the Neoliberal government project in rural Panama and bank credits for cattle; and 3) the role of the Ministry of Agricultural Development and other forms of assistance.

4.3.3.d.1 <u>Environmental regulation policies</u>

The Environmental Authority in Panama is the one institution that directly regulates farmers' management of trees. Buttuod (2013), had regarded environmental policy in Panama and other countries in Central America as a disincentive for maintaining trees in farms because the regulations are too strict to the point that farmers don't see the value of conserving trees in their farm. The policy of ANAM actually states that farmers must obtain permits to be able to cut their trees. Various themes were common among farmers when I asked them about their perceptions on the process of ANAM regulation.

The majority perceived the ANAM regulations as being inefficient in various ways: 1) To obtain permits, the institution technician must come and do an inspection of the farm but technicians are scant and therefore it's hard to get permission. 2) Since technicians are scant, law enforcement is also scant and people can do illegal logging. 3) Farmers perceive that technicians favor farmers with more monetary or political influence by giving them more assistance. 4) Having to pay a fee for cutting trees is inefficient for environmental protection since the only obstacle to cutting trees is payment (regardless of stated environmental preservation objectives). 5) Perhaps one of the most common criticisms to the ANAM authority is that farmers perceive that their efforts to conserve trees are not validated since they are often not allowed to cut the trees in their farm even if they have taken care of them. This is especially true in the riparian corridors. Take this extended quote for example:

> *"…it's already this big, it's about 3 meters away from the edge of the stream that goes over there. That is not life water, it's dry. In the summer it dries up. I brought an official from the ANAM to cut it and she didn't give me the permit. So it has to be far from the stream for them to let you cut it. But those are the things that I reproach to the ANAM and when we have the opportunity I tell them that the trees, I take care of them, they grow, so when I have to use them I have to pay them. Since I was little I could have cut them, but I take care of them, they grow… Other people from the government that have influence, they cut. Actually, up there where the stream is born, there is a forest that I don't know who owns, it's of someone in Panama, someone with money. They have cut so much forest they probably did not pay. Instead I cut one tree here and the give you a fine…"*

The farmer's perception was common in the Chiriquí region as they often alluded to state-led projects that they perceived were more destructive than their tree management practices. In the past decade, the government has given hundreds of land concessions to different companies. The concessions are for hydroelectric and mining projects. Many farmers that I interviewed live close to rivers that have hydroelectric upstream. Farmers say that they have seen vast deforestation when these projects are implemented. In this view, farmers perceive the contrast between the changes in tree densities across the landscape driven by the hydroelectric projects. At the same time, they perceive that they conserve trees but get penalized if they want to use them. Overall, they perceive themselves as being the stewards of conservation as opposed to the government, who are the destroyer of trees. Meanwhile, they perceive that while they receive punishment for cutting trees that are necessary for their livelihood, the government receives impunity for massive deforestation. For some farmers, this scenario may create psychological barriers to implementing tree management on their farm. Attitudes in regard to ANAM policy appear to be subjective, however, because some farmers argued that although they don't fully agree with ANAM policies, they won't stops growing and managing trees. They argued that although policies are inefficient, they are necessary to conserve trees.

Eleven out of the 25 farmers that responded said they did not see the laws as an obstacle and argued that they had no difficulty obtaining permits from the ANAM. Most of these farmers were concentrated in Vallerriquito, suggesting that in this particular town farmers had more access to the ANAM assistance. For example,

> *"In this area we don´t have problems because you go, solicit [the permits] and they come to do the inspection. They ask if it's a timber tree and if you are going to use it. If it's for selling they increase the cost a little bit. If it's to make a door, furniture for the house they give you a modest price. As long as the trees are not close to a stream - I don't know at how many meters they don't give you permits – they deny them."*

The commercial use of timber tree species is not easy via the environmental policies. The idea that permits for species that are to be sold are higher price may restrict farmers from wanting to engage in commercial tree planting. Perhaps this is the objective of the fee, but the end result is that farmers sell their trees when they need quick cash or when the trees are old and ready to fall. For example,

> *"The wood we sell is because I am under a treatment for Osteoporosis. That is expensive. Every month. So only with the dairy it is not enough so I use that other money. The other [money] is for the house and the animals. It's not because we want to cut just to cut. We cut, and like my son says, we plant so that the fauna is not lost."*

The farmer's statement reinforces the idea that farmers want trees to add to their livelihoods.

4.3.3.d.2 The Neoliberal project in rural Panama (the role of influence)

Neoliberal changes in Panama began with the presidency of Perez Balladares in the late 1990s that resulted in the privatization of public services. In 1998, Panama's Institute of Hydrologic Resources and Electrification (IRHE) was privatized leading to more than seventy new hydro concessions. The claims of "sustainable renewable energy projects" have allowed the pursue of Neoliberal agendas at the cost of the environment and indigenous livelihoods by providing hundreds of land concessions for hydroelectric and mining (Finley-Brook and Thomas 2011). Free trade has affected primarily the agricultural sector, most noticeably the rice producers.

The effect of the Neoliberal Project at the farm scale emerged across the interviews. The Neoliberal project emerged when I asked farmers about their perception on landscape level land-use change perceptions. Generally, farmers criticized the state and state officials for supporting the larger farmers as opposed to the smaller farmer. This perception emerged as farmers talked about certain projects including oil palm plantations, hydroelectric projects and rice imports. In addition, farmers perceive that there has been a change from a subsistence based livelihood in which farmers grow their own food into one in which most farmers do not grow food. These two perceptions align with what some have proposed as farmers being "pushed out of the rural."

Only two farmers had an oil palm plantation, although a third one had rented out part of his land for oil palm plantations. One of the farmers acknowledged the obstacles when managing the oil palm:

> *"Experience tell us that the business of the palm [oil palm] it's going to stay with the big ones. With the big companies. At least here they just bought the farm and everything from over there is being bought by a company from Guatemala. We cannot compete with them. We pay the workers 12 dollars a day, they pay 15 dollars. We cannot compete. And every day there is less people to work in the fields so I rather go to a business I can manage, that my sons can manage and not work with the Palm right now…So I prefer dairy."*

Across the three provinces, farmers perceive that finding labor is hard because there is less wage labor available and also because they have to compete with the larger companies for labor. In Los Santos, farmers often spoke of how construction projects for tourism development close to their towns had drawn labor away from the farms because construction pays more.

In the Chiriqui region farmers could not talk about change in landscape without talking about the hydroelectric projects both of which lead to deforestation. In the quote below the farmer criticizes the state for given away so many land concessions for hydroelectric which he perceives has generated a water scarcity phenomenon in the region:

> *"In Alanje they spend 80,000 on the irrigation project [for rice]. They put 12 electric concessions up there, now there is no water for anyone. So the government invested 80,000 but signed the concessions for the hydroelectric so they threw away the money. Now the producers cannot produce because there is no water…They dried it. Who owns it? All the rich people from Panama."*

In addition to constructing a hydroelectric upstream, rice producers have been confronting change in market prices as the government increments the rice imports. In the quote below another farmer talks about a case in which the government began to import rice, lifting all the support for rice producers and leading to rice producers abandoning rice: *"…thousands of hectares that produced rice stopped producing this year, due to bad politics…the issues is that they thought it was better to bring rice from outside. They stopped incentivizing the rice producer from here."* Overall farmers across the regions appear to sense that there is a phenomenon of land-concentration. The default form of production is cattle ranching. Any other form of agriculture is too risky, possibly because the market is volatile and the cost of inputs is very expensive.

Many farmers argued that farming is easier now because there is more technology, however, the cost of inputs and the unpredictable market makes it hard for them to really build a livelihood around agriculture. At least this was the case in 2014. In the following quote the farmer describes how he had a bad experience planting corn: *"So when production is good, the abundance, there is no market. We are always struggling from one side. I made that little bit of corn…What happened?...no one came to buy corn…No. So now I have a lot of corn there. The* *investment is there."* During the 2014 presidential elections in Panama, the president elect's entire campaign was aimed at rural areas and improving the apparent "food security" problem in Panama by giving no-interest loans to incentivize young people to go back into agriculture. That is to say, the lack of agriculture has been used as a political tool to gain votes, meanwhile the president elect owns one of the largest sugar cane plantations in Panama.

Overall, farmers perceive that subsistence agriculture is disappearing. Instead, most of the farms are dominated by the cattle ranching enterprise. This seems to be common across the board from Chiriqui to Cocle and Los Santos. In fact, when I asked farmers what sort of benefits they receive from the government, across the board the answer was bank credits for cattle production. They never mentioned any other form of economic support from the government. Overall it appears that farmers perceive that thesState is putting all the burden of both food production and forest conservation in their hands without really supporting them economically. Instead, the government appears to be supporting forms of land concentration through hundreds hydroelectric concessions, and allowing foreign imports.

4.3.3.d.3 <u>Government assistance</u>

Farmers overall don't view the MIDA as significant source of help neither historically nor in 2014. In the following quote, an 80 year old farmer explains this view point,

> "*Well with cattle ranching honestly the governments have not supported us almost…the cattle rancher has gone through a lot of work. The inputs are very expensive, the medicines to vaccine the cattle and everything is very expensive. The wage for the worker has gone up a lot. So with cattle ranching the government has always held us back. This*

year the cattle price went up but now it is down again. The ones that are suffering are the cattle ranchers here because the bankers, the ones that buy they don't suffer this…"

The farmer argues that he has received no help from the government for cattle ranching. The same farmer then talks about the trees:

"The tree –f sometimes I see the government has helped a little bit but not much either. Because, look, I made that farm, I tell you 2 hectares of trees and the government has not helped me in anything. Not with workers to plant, or on medicine, or to buy trees, nothing. All of that I have had to buy from my pocket. In what does it help? In nothing. So the government, what happens is that the day that we want to cut a tree, we have to get a permit, a thousand things, the government does not help, and we have to get permit and pay for a permit. Why do we have to pay for a permit for a tree that we have planted ourselves?

Lack of state support along with the pressures from the Neoliberal project makes the farmers feel as if they were in a state of "servitude" as they are trapped between producing food and conservation.

The only materialized form of support that I saw in the field was that through MIDA technicians and PNUD (Program de las Naciones Unidas para el desarrollo), which is a United Nations Program aimed at assisting small farmers through development projects. Twenty three of the farmers I interviewed belonged to a project with PNUD that funded farmers so that they could implement silvo-pastoral techniques. The silvo-pastoral techniques were aimed at improving the ecology of the farm by planting forage shrubs and trees, as well as improving paddock rotation using electric fences. The project aimed at improving the ecology of the farm while improving production. The funds helped hire a Colombian NGO called CIPAV. The NGO provided technical assistantship. In the Chiriquí region the farmers aligned with the MIDA to obtain funds from PNUD. In the Los Santos region farmers aligned with the Peace Corps to obtain these funds from PNUD.

Overall the farmers that participated in these projects had positive insights and experiences. Farmers expressed that they do not have this kind of assistance regularly and for this reason the farmers were very appreciative of the “schooling” from CIPAV and the economic support from PNUD. However, once the funding was gone, the farmers struggled to keep the projects going, primarily because it required technical knowledge on how to operate the electric fences and implement the forage shrub species that were essential to the silvo-pastoral system. Overall my impression is that farmers welcome this kind of state-led support because it lifts the burden and they feel supported by the state to carry out the immense task of protecting the ecology as well as producing food. As described by Van der Ploeg (2013), farmers are constantly seeking for ways to improve their livelihoods by balancing. The balance is what allows them to break out and cope with the perceived and objective obstacles.

4.4.4 The constant search to improve their livelihood: a vision for the future, and the role of knowledge

Farmers seek to improve the farm condition by engaging with projects with the state through the MIDA and PNUD. In addition, farmers regularly attend meetings organized by the Banks, agro-companies, NGO and research institutions like the Smithsonian Tropical Research Institute. Farmers also organize in the form of farmer associations and cooperatives. They do so to find support when they experience shocks like structural adjustment policies, or to negotiate with a company that wants to collaborate with them in a forestry plantation project or a silvo-pastoral project. When this happens, farmers have to re-evaluate and re-calculate what will work for their livelihoods given their farm's conditions. What farmers learned from their parents and their own experience may lead them to engage or not with these outsiders. For example, since farmers found that both they and their parents failed at agriculture, they are unlikely to engage in a project that requires planting crops. I addition, since farmers have seen their neighbors experience failures at implementing the forestry plantation model, they will be unlikely to engage in a project that pushes them in that direction. If their experience thus far has been that cattle ranching is what works within their context and farm conditions, then moving towards a different direction is unlikely. Any project that requires them to give up land or increase shade area will be very hard to implement unless they have very supportive outsiders. In fact, this is what happened briefly with the farmers that had engaged with the PNUD and MIDA project. It seemed like for a couple of years the organizations were well engaged with the farmers, but once the agencies were gone, farmers returned to their previous practices.

Based on the interviews, farmers that had engaged with these agencies still implemented some of the learned lessons within their management, particularly those related to the diversity of cattle forage grass and herb species, and those related to conserving water. It appeared that these were the easiest to implement since all it required was managing natural regeneration. It's possible that these experiences have helped farmers develop new goals to improve their farm operation. When I asked farmers about their future plans, farmers wanted more fruit and timber trees species, they wanted to reduce the size of their paddock to improve rotation (learned from PNUD and MIDA project), and they wanted to install water pumps across the farms. Some farmers also wanted to diversify their farm operation. All these goals may to some extent be influenced by their own experience, their neighbor's experience, and from the lessons learned from these collaborations. Farmers want to improve their livelihood and they see these changes as essential to the improvement of their cattle ranching operations.

4.5. DISCUSSION

4.5.1 The space for emancipation

Van der ploeg (2014) argues that farmers need the "politico-economic space" to improve their production. The evidence I present indicates that farmers incorporate trees into their pasture management to improve their livelihoods and production, challenging the rhetoric that cattle ranchers see cattle ranching as incompatible with tree management. Two reasons emerge from the literature that discuss the perceived incompatibility: 1) because cutting trees is a means to territorial claims (Hecht 1985, Muchagata and Brown 2003, Heckadon-Moreno 2009, Rudel 2007) and, 2) because the conventional mode of cattle ranching that has been intensely promoted across the region excludes trees (Calle et al. 2013). In this section I argue that instead of farmers perceiving incompatibility, farmers don't have the "politico-economic space" to incorporate trees into their pastures management to improve their livelihoods.

The idea that farmers perceive that trees are incompatible with cattle ranching is too simple. Land tenure has been documented as an important factor for allowing trees to grow on the farm (Simmons et al. 2002, Muchagata and Brown 2003). Most of the Panamanian farmers I interviewed had already titled their land. The process of land titling generally happened after buying the land off from their fathers or other relatives. This is different from some other areas of Panama where there are still many lands in "Derecho posesorio" and that haven't been accurately titled yet (Runk 2011). Territorial claims, ultimately, did not emerge as a driver related to tree management in this study.

Farmers did, however, share the notion that forested or fallow land was under-utilized. Farmers were incessantly critical when other farmers allowed fallow to grow in areas where they use to manage grasses since it they perceived it as a sign of paddock mismanagement and negligence. Converting the land back into pasture is very costly and also requires decreasing the number of cattle in the farm or renting land (Muchagata and Brown 2003). For this reason, farmers are intolerant to the tree seedlings that outcompete the grass. I argue that instead of their being a perceived incompatibility between conventional ranching and trees, there is instead a threshold. The threshold is the instant in which farmers do not tolerate trees because they perceive it has a negative effect on the pasture management and improving production. In essence, farmers want trees to improve their livelihood but there is a threshold at which they perceive trees no longer help achieve their farming goals.

Farmers' sentiments over trees role in territoriality and perceived land mismanagement interacts with the perceived corruption from the government and conservation agency. Farmers' perceptions over the value of trees is in conflict with the ANAM, because they have historically observed the ANAM giving impunity to other ranchers with more influence or to multinational companies that create mines and hydroelectric projects. Part of the Neoliberal program in Panama has been expressed in the form of land concessions given by the state (with approval of ANAM) to private multinational corporations. In the western part of the country, where Chiriqui province is located, hundreds of land concessions have been given to these companies to build hydroelectric under 2 justifications: 1) under the claim that it's a form of clean energy; and 2) under the claim that the country with all its population growth needs energy. The ANAM has been at the center of granting land to the private companies (Finley-Brook and Thomas 2011). Although the indigenous communities appear to be the most affected as they have lost their lands, the cattle ranchers also feel the effect, but primarily through perceived water shortages and observations of vast deforestation. Afterwards, these companies promote tree planting to local stakeholders as a form of "social responsibility" (Finley-Brook and Thomas 2011), burdening even further the stakeholders both from the indigenous communities and from the cattle ranching communities.

These conflicts, along with the practical incentives (through bank credits) to practice conventional cattle ranching may create psychological barriers that keep some farmers from managing silvo-pastoral systems. The space for emancipation is further reduce when the government restricts farmers from "freely" using the trees in their farm, all the while lacking incentives and technical support that promote silvo-pastoral systems.

What do farmers balance?

On table 4.4 I present a definition and description of the Chayanovian balances found across the interviews. Farmers manage cattle to improve their livelihoods and trees play a role in this process. Farmer balance drudgery with utility, production with reproduction, internal with external farm resources, autonomy with dependency, and people with living nature.

Van der ploeg (2014) explained that the small farmer aim towards agricultural growth, but generally external reasons don't allow this. In the previous section I discussed what those external reasons were. Van der ploeg (2014) discusses how the aspirations for emancipation lead to the increase in production by adjusting the balance between utility and drudgery. Van der ploeg (2014) also talks about the balance between production and co-production. Co-production "*is the ongoing encounter and mutual interaction of man and living nature, or, more generally, of the social and the material*" (Van der ploeg 2014, page 101). Based on interviews in this study, I argue that trees are part of the balance between production and co-production. They are part of the material or the living nature and are transformed by society. At the same time, trees can shape society as farmers' values shift. This dialectic comes across in the interviews in very explicit ways, for example in their sense of stewardship, which seems to increase as they have children and grandchildren.

Van der ploeg 2014 also talks about the balance between production and re-production. Farmers can view the role of trees in the pastures as one to increase production. Particularly dairy farmers that were concerned with caloric stress under the lengthened dry seasons saw trees as a way to increase milk production. In light of climate change and expected droughts, farmers perceive trees as essential to continue their cattle ranching operation in the future.

When it comes to incorporating trees into the cattle pasture I found that there is a tree utility – drudgery balance. The tree utility comes in form of: 1) shade, 2) fruits, 3) timber and, 4) general perceived benefits that trees have to the ecology of the farm. Drudgery comes in the form of the: 1) cost trees have to pasture area, and 2) the hardship of planting and facilitating natural regeneration with all its obstacles. The balance is influenced by the context in which farmers are making these decisions which can shift both the notion of how drudgerous a particular task is and the utility of the producing trees. The historical context in particular, appears to play an important role. For example, farmers that inherited farms with a lot of trees may find it easier to manage trees than farmers that inherited farms with few trees. Hence the balance is subjective to the farmer's specific situation. Therefore, the task of increasing trees to increase yields may be desirable for all farmers but easier for some farmers to achieve then others based on their experience and farm's past land-use history.

Farmers perceive tree scarcity which is the result of their own management practices. This perception along with ideas about the role that trees plays in conserving resources (spread by news outlets, NGOs, ANAM) may lead them to want to have more trees in their farm. However, this step is generally weighed against the practical function of those trees for the cattle production, the household, and generating social capital (as they give fruits and wood as gifts). Farmers don't want to "produce trees", since it is not their primary source of income. This idea is reflected on farmers' rejection of Teak and Oil palm plantation projects. Farmers' rejection was based upon the idea that a monoculture of either of these species would destroy their land for agriculture and cattle ranching, that inputs were costly and that neighbors had limited success. Thus, co-production is primarily reflected on farmers' desire to generate what could be called a "multifunctional" landscape. This idea is not new, since farmers have traditionally been doing this for many decades, but what I want to emphasize is that farmers are constantly balancing the pasture area and tree cover with this idea of multifunctional landscapes and the threshold of necessary tree cover. The role that trees play in co-production is influenced by this idea of multi-functional landscapes, but also by the "space" that farmers have to create these landscapes.

Conclusion

Aspirations to emancipate came across farmer interviews as they found allies in some institutions and they desire a farm with a lot of trees with a lot of functions etc. My findings also suggest that farmers think carefully about the kinds of trees they will cut and about the arrangements in which they want to plant them or let them regenerate. Some farmers also think carefully about the kinds of trees that would help with production as they can be used as an additional source of livestock feed or to improve the soil conditions by fertilizing nitrogen. Farmers know what they want their farm to look like, and trees play a role in those aspirations.

Employing Chayanov’s utility-drudgery curve, I found that farmers in this case are trying to change they utility curve. As Van der ploeg (2014) argues, changing that curve can be risky for farmers if they don’t find the necessary support to do so. However, some are willing to take the risk if they believe that that shifting that curve will make them more self-sufficient and independent from the outside forces including the market and ANAM policies. This is what in the food sovereignty literature would be described as the alternative farmers that are building movements around healthy, equitable, and fair food systems.

Table 4.1. Semi-structured interview questions and number of participants asked each question. The number of questioned is the number of respondents because all farmers to whom I asked a question responded. Answers that emerged are cases where I did not ask a question directly, yet the theme emerged during the interview.

Category	Question	Description	Questioned	Emerged	Total answered
Farmer's motivations	What are the reasons for having trees in the farm?	Farmers describe uses and other motivations for having trees.	54	0	54
	follow up What fruit trees do you have in your farm?	Often farmers did not talk about fruit trees so I created a follow up question.	27	20	47
	follow up Do you plant tree?	To understand details about tree management and reasons that may lead to actively or passively managing trees.	27	22	49
	follow up Do you extract tree species from your farm?		24	20	44
	follow up Do you allow trees to naturally regenerated in your farm, if so, how?		25	22	47
	follow up Do cattle eat fruit trees?	Often farmers did not talk about trees as livestock feed so I created this follow up question.	35	10	45
	What are your future plans in terms of management?	To understand farmers' aspirations.	18	18	36
	follow up Do you have plans to increase or decrease trees in your farm? If so in which way?	To understand farmers' aspirations in terms of tree management.	13	20	33
Obstacles	Can you explain the process of weeding in your farm?	Based on observations and conversations, weeding quickly emerged as a particularly important aspect of tree management.	51	0	51

Table 4.1 Continued

Category	Question	Description	Questioned	Emerged	Total answered
Obstacles	Do you perceive that tree cover area has changed in your farm?	Management history of the farm can influence how farmers make decisions about tree management today.	37	4	41
	follow up What land-use was practiced in your farm previous to cattle?		42	6	48
	What obstacles do you perceive when managing trees in the farm?	To understand what aspects of tree management are drudgerous	30	20	50
	follow up Can you talk about obstacles in planting trees?		6	15	21
	follow up Can you talk about obstacles when trying to extract or sell trees?		5	8	13
Forces out of their control	How do you perceive that land-use has changed in your surrounding landscape?	Trees are long lived, so I wanted to know if there was anything about the land-use history across the vicinity of their farm that influences the management of trees in their farm.	22	11	33
	Where and how did you learn to manage trees and cattle production?	Aspects of experiential knowledge that may influence farmers tree management decisions.	22	13	35
	In which ways have you received state assistance to manage your farm?	Aspects of government assistance that may influence farmers tree management decisions.	22	25	47

Table 4.1 Continued

Category	Question	Description	Questioned	Emerged	Total answered
Forces out of their control	What are your perceptions on the regulations of tree management enforced by the Panamanian Environmental Authority (ANAM)?	Buttoud (2013) argued that policies that regulate tree harvest and transportation in Panama are very strict suggesting that it discourages farmers from wanting to even plant trees or possibly conserve trees. I wanted to know if the Environmental Policies that regulate tree management across the farm was perceived as an obstacle to tree management.	21	13	34

Table 4.2 Drivers for incorporating trees into the cattle farm including motivations, obstacles, and forces out of their control. The percent of respondents is out of 54.

Category	Driver	Specific themes	Description	Percent respondents
Reasons why farmers want trees	Utility of trees	Live fence	Fence rows of living trees.	100
		Shade and/or Water	When farmers said either shade in pasture area and/or to conserve streams.	88
		Wood	Farmers that said they planted or conserved trees for their timber (not including live fences)	88
		Fruit trees	Farmers that said they planted, or conserved trees for their fruits	87
		Feed for livestock	Farmers said cattle ate trees either their leave or fruits.	83
		Conserve soil, controls erosion, benefits grasses, and benefits wildlife	When they said that it benefited the soil, the grasses	16
		Ornamental	To beautify the farm.	9
		Money	Trees that are marketable.	39
	Climate change	Resilience to the dry season	Trees help in the dry season by conserving humidity in the soil and providing feed for livestock.	30
	Multifunctional landscapes	Trees with multiple uses	Cutting and planting trees are actions taken to add to the cattle ranching operation reason for which they want trees that have multiple functions.	44
	Stewardship		Responsibilities that farmers feel about conserving trees.	44
Obstacles	Production	Shade-grass area trade-off	Shade produced by trees reduces the grass area available for cattle to eat.	46
		Weeding	Some trees are considered weeds when in high abundances.	94
		Nuisance trees	Trees that make cattle ranching and farm management more troublesome.	11
		Cattle trampling	Cattle trample on seedlings.	17

Table 4.2 Continued

Category	Driver	Theme	Description	% of respondents
Forces out of their control	Stochastic	Ecological	Pests and unpredictable weather conditions make it difficult to manage trees in the farm.	46
		Uncooperative neighbors	Neighbor's actions create insecurity making farmers lose motivation to manage trees in the ranch.	9
	Subjective	Farm land-use history	Farm's land-use history influences how farmers decide to manage in the future.	78
		Experiential knowledge	Farmer's experiences in farming influences their decisions about management.	65
	Structural	Environmental legislation	Objective and psychological barriers created by the way in which environmental legislation is implemented.	44
		Neoliberal project	Objective and psychological barriers created by the way in which the state promotes and allows the abuse of resources.	41
		Government assistance	Objective and psychological barriers created by the way in which the state doesn't provide incentives that support the rancher.	41

Table 4.3 List of trees mentioned by farmers including common names, species name, family, uses associated, and frequency mentioned. The uses are summarized as follow: W = wood; FR = Food / Fruit; T = other traditional uses; FW = firewood; SH = shade; LF = live fence; M = medicinal; W = water conservation; E = environmental including soil and wildlife conservation; FL = food for livestock; WE = weed; M = cash tree; OR = ornamental; NU = nuisance. Farmer talked about 112 species, but 6 could not be identified reason for which this list includes 106 species.

Common	**Species**	**Family**	**Use / Values**	**Frequency**
Mango	*Mangifera indica*	Anacardiaceae	FR, SH, WA, FL, NU	36
Cedro amargo	*Cedrela odorata*	Meliaceae	W, SH, WA	32
Guacimo negrito	*Guazuma ulmifolia*	Sterculiaceae	FW, SH, WA, FL, WE	27
Macano	*Diphysa americana*	Fabaceae / Papilionoidae	W, SH, LF, WA, FL	27
Naranja	*Citrus sinensis*	Rutaceae	FR, SH, FL	27
Laurel	*Cordia alliodora*	Boraginaceae	W, SH, WA	26
Almacigo	*Bursera simaruba*	Burseraceae	LF, FL	23
Balo	*Gliricidia sepium*	Fabaceae / Papilionoidae	SH, LF, E, WA, FL	21
Espave	*Anacardium excelsum*	Anacardiaceae	W, WA, E	21
Guayaba	*Psidium* sp.	Myrtaceae	W, FL, WE	21
Corotu	*Enterolobium cyclocarpum*	Fabaceae / Mimosoide	W, SH, WA, FL	20
Nance	*Byrsonima crassifolia*	Malpighiaceae	W, FR, FW, SH, FL, WE	19
Aguacate	*Persea americana*	Lauraceae	FR, SH, WA, FL	18
Jobo	*Spondias mombin*	Anacardiaceae	LF, SH, WA, FL, NU	17
Roble	*Tabebuia rosea*	Bignoniaceae	W, LF, WA, WE	16
Higueron	*Ficus* sp.	Moraceae	SH, WA, LF, E, FL, WE	15
Guabo	*Inga* sp.	Fabaceae / Mimosoide	FR, WA, E, FL	12
Marañon	*Anacardium occidentale*	Anacardiaceae	FR, SH	12
Palma vino / Palma corozo / Palma Pacora	*Acrocomia aculeata*	Arecaceae	FR, T, FL, NU	12
Caoba	*Swietenia macrophylla*	Meliaceae	W	11
Cedro espino	*Pachira quinata*	Bombacaceae	W	11

Table 4.3 Continued

Common	Species	Family	Use / Values	Frequency
Guachapali	*Samanea saman*	Fabaceae / Mimosoide	W, LF, FL	11
Palo Santo	*Erythrina* sp.	Fabaceae / Papilionoidae	LF, FL	11
Teca	*Tectona grandis*	Verbenaceae	W, WA, M, NU	11
Ciruelo	*Spondias purpurea*	Anacardiaceae	FR, LF	10
Limones	*Citrus limon*	Rutaceae	FR	10
Guanabana	*Annona muricata*	Annonaceae	FR, SH	9
Guayacan	*Tabebuia guayacan*	Bignoniaceae	W, SH, OR	9
Jagua	*Genipa americana*	Rubiaceae	W, FL	9
Sigua	*Ocotea* sp. / *Nectandra* sp. / *Licaria* sp. / *Cinnamomum* sp.	Lauraceae	W, FW, SH, E	8
Cana Fistula	*Cassia fistula*	Fabaceae / Caesalpinoidae	W, FL	7
Chumico	*Curatella americana*	Dilleniaceae	SH, WA, E, WE	7
Cocobolo	*Dalbergia retusa*	Fabaceae / Papilionoidae	W, E	7
Quira	*Platymiscium pinnatum*	Fabaceae / Papilionoidae	W, WA	6
Bongo	*Ceiba pentandra*	Bombacaceae	WA	5
Leucaena	*Leucaena leucocephala*	Fabaceae / Mimosoide	SH, E, FL	5
Madroño	*Calycophyllum candidissimum*	Rubiaceae	W, LF	5
Algarrobo	*Hymenaea courbaril*	Fabaceae / Caesalpinoidae	W, OR	4
Barrigon	*Pseudobombax septenatum*	Bombacaceae	SH	4
Cabimo	*Copaifera aromatica*	Fabaceae / Caesalpinoidae	T	4
Caimito	*Chrysophyllum cainito*	Sapotaceae	FR, FL	4
Caratillo	*Bursera tomentosa*	Burseraceae	LF	4
Guarumo	*Cecropia* sp.	Cecropiaceae	W, FL	4
Papaya	*Carica papaya*	Caricaceae	FR	4
Arino	*Cojoba* sp.	Fabaceae / Mimosoideae	SH	3

Table 4.3 Continued

Common	Species	Family	Use / Value	Frequency
Guabita	*Inga* sp.	Fabaceae / Mimosoide	FR, WA	3
Maria	*Calophyllum brasiliense*	Clusiaceae	W	3
Pixba	*Bactris gasipaes*	Arecaceae	FR, E	3
Zapatero	*Hieronyma alchorneoides*	Euphorbiaceae	W	3
Arraijan	*Miconia sp.*	Melastomataceae	SH	2
Café	*Coffea arabica*	Rubiaceae	FR, E	2
Chuchupate	*Guarea* sp.	Meliaceae	W	2
Conejo	*Trichilia hirta*	Meliaceae	E	2
Cortezo	*Apeiba tibourbou*	Tiliaceae		2
Jobito	*Spondias radlkoferi*	Anacardiaceae	LF	2
Mandarina	*Citrus reticulata*	Rutaceae	FR	2
Marañon Curazao	*Syzygium malaccense*	Myrtaceae	FR	2
Nispero	*Manilkara zapota*	Sapotaceae	W	2
Palma corocito	*Elaeis oleifera*	Arecaceae	FR	2
Palma Real	*Attalea rostrata*	Arecaceae	T, M	2
Palomo	*Dendropanax arboreus*	Araliaceae	WA	2
Pava	*Schefflera morototoni*	Araliaceae		2
Periquito	*Muntingia calabura*	Muntingiaceae		2
Toreta	*Annona purpurea*	Annonaceae	FR, WE	2
Toronja	*Citrus maxima*	Rutaceae	FR, FL	2
Zapote, Mamey	*Pouteria sapota*	Sapotaceae	FR, FL	2
Achiote	*Bixa orellana*	Bixaceae	FR	1
Alcornoque	*Ormosia panamensis*	Fabaceae / Papilionoidae		1
Amarillo	*Terminalia oblonga*	Combretacceae	W	1
Arcabu	*Zanthoxylum setulosum*	Rutaceae		1
Balso	*Ochroma pyramidale*	Bombacaceae	W, T	1
Berbá	*Brosimum alicastrum*	Moraceae	FL	1

Table 4.3 Continued

Common	***Species***	**Family**	**Use / Value**	**Frequency**
Calabazo	*Crescentia cujete*	Bignoniaceae	T	1
Cana fistula de montana	*Cassia* sp.	Fabaceae / Caesalpinoidae	W	1
Canela	*Ocotea* sp.	Lauraceae	T	1
Canillo	*Miconia argentea*	Melastomataceae	WA	1
Caraño	*Trattinnickia aspera*	Burseraceae	LF	1
Carne asao	*Roupala montana*	Proteaceae	W	1
Cedron	*Simaba cedron*	Simaroubaceae	M	1
Coloradito	*Casearia guianensis*	Flacourtiaceae	WA	1
Coquillo	*Jatropha curcas*	Euphorbiaceae	LF	1
Flor the mayo	*Vochysia ferruginea*	Vochysiaceae	SH	1
Fruta de pan	*Artocarpus altilis*	Moraceae	FR	1
Guabo de mono	*Inga* sp.	Fabaceae / Mimosoide	WA	1
Guacimo colorado	*Luehea seemannii*	Tiliaceae		1
Laureña	*Senna reticulata*	Fabaceae / Caesalpinoidae	FL	1
Majagua	*Heliocarpus americanus*	Tiliaceae		1
Malagueto	*Xylopia frutescens*	Annonaceae		1
Mamon	*Melicoccus bijugatus*	Sapindaceae	FR	1
Mangosteen	*Garcinia mangostana*	Clusiaceae	FR	1
Mangostin	*Spondias dulcis*	Anacardiaceae	FR	1
Melina	*Gmelina arborea*	Verbenaceae	W	1
Neem	*Azadirachta indica*	Meliaceae	WA	1
Palo Lagarto	*Sciadodendron excelsum*	Araliaceae		1
Panama	*Sterculia apetala*	Sterculiaceae		1
Pavito	*Ardisia revoluta*	Myrsinaceae		1
Pipa	*Cocos nucifera*	Arecaceae	FR	1

Table 4.3 Continued

Common	***Species***	**Family**	**Use / Value**	**Frequency**
Poma Rosa	*Syzygium jambos*	Myrtaceae	FR	1
Poro poro	*Cochlospermum vitifolium*	Cochlospermaceae	LF, OR	1
Rasca	*Licania arborea*	Chrysobalanaceae		1
Satra	*Garcinia intermedia*	Clusiaceae	FR	1
Siguatón	*Ocotea insularis*	Lauraceae	SH, WA	1
Tamarindo	*Tamarindus indica*	Fabaceae / Caesalpinoidae	FR	1
Zorrillo	*Astronium graveolens*	Anacardiaceae	LF	1
Cierito	*Mouriri myrtilloides*	Melastomataceae		1
Platano	*Musa x paradisiaca*	Musaceae	FR	1

Table 4.4 The most common Chayanovian balances across interviews with the 54 cattle ranchers.

Kind of Balance	Balance description	Discussion
Utility - dudgery	The utility of producing one more item with the drudgery of production that one more item (Van der ploeg 2013).	Farmers balance the utility of trees for cattle production (for example shade), with the drudgery of maintain specific tree species through planting, weeding, and protecting seedlings from cattle trampling.
Production - reproduction	The perception that farm management today is to maintain the sustainability of the farm for the future (Van der ploeg 2013).	Farmers conserve and want to plant trees today so that they can guarantee their will be shade and water to maintain the continuity of cattle ranching in the future.
Internal - external	The balance between resources obtained in the farm with resources they obtain outside the farm, for example from the market (Van der ploeg 2013).	Farmers conserve trees because they find them more useful in the farm then selling them in the market. If they conserve a tree today they don't have to buy it in the market tomorrow.
Autonomy - dependency	Forces out of farmers control may push farmers in a direction that does not allow them to self-determine how to manage. These forces are balanced through strategies that farmers employ to be more autonomous and guarantee self-determination (Van der ploeg 2013).	Farmers avoid commercial tree planting and large scale agriculture because it creates more dependency in external farm inputs, complying with the market demands, and wage labor. Farmers choose cattle ranching and trees that help cattle ranching because it allows more flexibility to choose what and how they want to manage..
People – living nature	Farming is not necessarily a destructive and extractive practice. Farming can also improve nature. Farming as extractive and as improving are balanced in the farm (Van der ploeg 2013).	Farmers plant and conserve trees for their multi-purposes and not for extractive purposes driven by profit maximization.

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CHAPTER V

CONCLUSION

Agroforestry managers and planners have long tried to persuade farmers across the world to incorporate certain "styles" of tree management (Dangang and Nair 2003, Mercer 2004, Calle et al. 2013). There has been less interest to understand how and why farmers incorporate trees into their cattle ranching operation. In light of previous literature that had documented variation in tree cover across farms of Central and South America (Harvey et al. 2011, Lerner et al. 2014), we seek out to determine why we see variation in tree densities across farms.

In Chapter 2, we develop a socio-ecological framework for understanding variations in tree densities on cattle farms. While socio-ecological systems are complex, incorporating a dynamics framework can allow us to understand if the dynamics between tree cover and drivers are linear, non-linear or multivalued. Understanding the dynamics is an important step previous to implementing management practices since each of these dynamics will have different implications for tree management. For example, if the relationship between tree cover and cattle density is linear, then simply eliminating cattle from the system will result in forest recovery. However, if the dynamics are multivalued, with the condition of hysteresis, then eliminating cattle will not lead to the desired forest recovery (Suding et al. 2004). Bimodality in the tree cover frequency distributions would suggest that hysteresis is probably the underlying dynamic that characterizes the tree covers (Hirota et al. 2011). We review the literature to develop our socio-ecological framework and find that there are examples in the rangeland literature (Westoby et al. 1989) and restoration ecology literature (Suding et al. 2014) that suggest that hysteresis is possible in the anthropogenic savannas. In addition, recent literature suggest that the natural forest and savanna systems are alternative states under some range of precipitation (Hirota et al. 2011, Staver et al. 2011). We propose that similar to the forest-savanna example, the high and low tree covers found across cattle pastures are alternative states.

Before determining if the tree covers found across cattle pastures are alternative states, it's necessary to define the response variable. While most studies that describe trees on cattle pastures focus on the dispersed trees on pastures (Harvey et al. 2011, Lerner et al. 2014), we argue that a deep understanding of the total tree cover (or response variable) also necessitates the calculation of tree richness and diversity. In addition, farmers use trees in various ways that result in tree spatial groupings or landscape patterns. These landscape patterns include dispersed trees on pasture, live fence, riparian vegetation, forest fragments, fallow, and horticulture plots. We argue that quantifying the area occupied by the different landscape patterns can help grasp a more complete picture of the role that trees play in the cattle ranch. Bimodality in the frequency distributions of total tree cover, richness, diversity, or any of the landscape patterns would suggest that there are different tree management styles or states, and that underlying dynamics carry the condition of hysteresis (Hirota et al. 2011).

Beyond characterizing the response variable, we define the socio-ecological drivers. First, there are ecological processes involving natural regeneration. The structural diversity prior to disturbance is crucial for natural regeneration and in many degraded landscapes the lack of seed sources can limit natural regeneration (Chazdon 2003, Ferguson et al. 2003, Sandor and Chazdon 2014). Second, the disturbance caused by pasture management is crucial in driving tree covers as weeding techniques, including mechanical, chemical, and fire, can reduce tree cover to the extent that the system may reach a state where succession is no longer possible (Esquivel et al. 2008). Cattle and their stocking rates can also affect tree cover by damaging seedlings and saplings.

We define the social drivers by employing the peasant balances framework (Chayanov 1966, van der Ploeg 2013) to focus on the on-farm processes that may lead to one or another tree cover area. Chayanov (1966) proposes that the family (or peasant farm) produces as much as the utility of what it produces outweighs the drudgery (or hardship) of producing it. In the capitalist farm, the amount produced is driven by profit maximization. The distinction between the family and capitalist farm emerges because labor in the family farm comes primarily from the family, whereas in the capitalist farm it's mostly wage labor. The utility-drudgery balance governs the family farm, but if the family farmer decides to change his farm operation into one that is capitalist and dependent on external inputs, the balances are lost and profits govern the farm instead. In this view, we can plot a spectrum that goes from utility-drudgery balance to capitalist farm as the driver of tree cover. The family farmer is characterized by being autonomous whereas the capitalist farmer is dependent on the market, new technologies and technical assistance necessary to abide to the market. Van der ploeg (2013) highlights that Chayanov also referred to other balances aside from utility-drudgery. These other balances include the one between autonomy and dependency. Van der ploeg (2013) argues that the balances are absolutely necessary for the family farm to improve its livelihood, and it does so by seeking autonomy and avoiding dependency.

Our hypothesis is that trees may provide resources to the farmers that make them less dependent on having to buy inputs for the farm operation. Resources provided by trees include timber for construction or cash, wood for fuel, fruits for livestock and household consumption, water and soil conservation (Garen et al. 2010). If farmers perceive that trees provide resources that will be necessary in the long term, and that will make them less dependent on having to buy certain items, then farmers will balance the utility of trees with drudgery. Since the capitalist farm is heavily dependent on outside inputs, it is not concerned with the resources that trees may provide to the farm operation. In this view, the family farm will manage trees whereas the capitalist farm will not concern itself with the management of trees.

In Chapter 3, we characterize the different tree management styles. We describe one primary component of the response variable, which is the total tree cover across 54 farms in the Republic of Panama. Previous studies only had quantified dispersed trees in pastures (Harvey et al. 2011, Lerner et al. 2014). Here, we quantify the total tree cover area of the farm and also seven landscape patterns aside from the dispersed trees in pastures. These include: riparian vegetation, dispersed trees in pastures, live fence, forest fragment, fallow, horticulture, and forestry plantation. We found that styles of tree managements based on bimodalities are possible. The dispersed trees on pastures frequency distribution has two modes, although one mode is composed of only two farms that have disproportionately more trees than the rest. Live fence tree cover area shows clear bimodality. These results are modest, but indicate that with a larger sample size bimodality may be possible.

Our findings also suggest that calculating the tree cover area of just one landscape pattern does not depict farmers' management of trees on pastures. Instead, various combinations of different landscape patterns can lead to similar total tree cover areas indicating that they are all important. While the majority of farmers have dispersed trees on pastures, riparian vegetation and live fences, other farmers employ different strategies when they have additional landscape patterns. For example, the four farms with the highest tree cover were also farms with large tracks of fallow or forest area. Only 4 farmers had forestry plantations, indicating that this is not a common strategy but can be employed. There are important outliers to consider in the case of dispersed tree cover. Two farms with disproportionate dispersed tree areas indicate that some farmers may be employing different strategies when it comes to dispersed tree area management. The significance of our finding is that while some farmers may not have too many dispersed trees on pastures, they may be managing a forest fragment or large tracks of riparian vegetation or live fence that may be compensating for the lack of dispersed trees.

Most studies that characterize the silvo-pastoral systems focus on the dispersed tree in pasture, but based on our findings, this may be a limited view. Farmers may opt to allocate tree cover area and manage natural regeneration of trees outside of the pasture area, but at densities that could be enough to maintain important ecological processes including seed dispersal events. Landscape patterns outside of dispersed trees are also important for cattle management indicating that the silvo-pastoral system extends beyond the pasture area. In addition, we found that cattle can roam across all of these landscape patterns and that farmers actively and purposely manage each of these landscape patterns. None of these landscape patterns are an accident. In addition, cattle density does not explain tree cover across farms. Some farms with tree densities above average also manage reported cattle densities that are above average for the study regions.

In Chapter 4, we examine the drivers of tree cover. We draw from Chayanov's peasant balances framework which allows us to focus on the on farm process, particularly the balances between utility (utility of producing one more item) and drudgery (the hardship of producing one more item) and how these lead to the tree cover outcome. We hypothesize that if farmers perceive that trees are an important component to the improvement of their livelihood, then they will balance tree management with other aspects of their livelihood. In addition, Van der Ploeg

(2014) introduces the concept of “space for emancipation”, or the ability famers have to self-determine how to manage their farm. If farmers can’t balance utility with drudgery then they can’t improve their livelihoods. We explore the space for emancipation in the cattle ranch. We interviewed 54 farmers across the Republic of Panama employing open ended semi-structured questionnaires. We find that the farmers are constantly evaluating the utility of having trees against cattle production. We also find that the space for making those evaluations within the farm is reduced in the presence of state regulators that operate with impunity.

By far, the most important utility aside from live fences, is the use of trees for their shade to protect cattle from the heat and to conserve water sources. These responses were related to the lengthening of the dry season which is perceived across the regions. However, shade as a value was quickly followed by shade as an obstacle since farmers perceive that the tree shade competes with the grass reducing the livestock feed. All other tree utilities in the cattle ranch are evaluated based on the shade as a value vs. shade as an obstacle. Farmers also oppose management strategies that require they allocate pasture land for tree planting. Such practices are perceived as risky because they reduce the amount of pasture area available for livestock feed and because planting is drudgerous and often fails.

Cattle ranchers avoid dependency from the national environmental authority. Perceptions on tree planting and cutting trees was often associated to their ability or inability to use those trees in the future, which is not guaranteed since the national environmental authority regulates these practices. Farmers perceive that there is a dissonance between the way in which the environmental regulatory agency penalizes farmers in the farm, and the way it regulates deforestation at a national level. They find that the environmental authority gives impunity and more assistance to farmers with more political influence and to corporations when they cut large tracks of land. This notion appears to make farmers less eager to make plans that involve high investment in tree planting as there is no guarantee that they will be able to use those trees in the future, and risk being penalized if they don't get the proper government assistance to acquire permits to cut. All the while, in some regions it's difficult to obtain the permits because the agency is understaffed. They also perceive certain forms of monoculture tree planting can damage the soil for future use. In this view, they choose agricultural practices that are more flexible and that they know they can successfully produce and use. Cattle ranching guarantees more flexibility than tree planting. Farmers then prefer cattle ranching and reject practices that require allocating cattle ranching land for tree planting. Instead, they prefer trees that have multiple uses and want them for multiple purposes in various part of the properties as long as they contribute to the cattle ranching operation. Exactly how they decide where to allow trees to grow and on which landscape patterns is subjective to the farm situation and as we observed in Chapter 3, can vary from farm to farm.

Overall, my dissertation suggests that the farmers are not all managing trees in the same way, but instead have different tree management strategies which are reflected in their choice to manage certain landscape patterns over others on the farm. Riparian vegetation is very important since it occupies the largest area across the 54 farms. Farmers also perceive that riparian vegetation is vital because it protects water sources and it is necessary for the reproduction of the farm operation. In addition, riparian vegetation has been heavily regulated by government institutions which appears to have an effect on their perceptions. On the other end, forestry plantations are not a strategy. Farmers reject these practices because they are drudgerous and because they are in conflict with their sense of autonomy. Forestry plantations require more labor and out of farm inputs. Overall, forestry plantations are a more "capitalist" mode of incorporating trees into the farm since farmers will have to see the monetary returns to their very high investment in inputs. Farmers have observed that these kinds of practices damage the land for other crops (including cattle ranching) and that neighbors that have attempted commercial tree planting fail because they are unable to sale at a good price or because trees don't grow adequately. In this view, commercial tree planting overall limits their ability to determine how they can manage their farm in the future, reason for which they decide not to manage. Live fences, on the other hand, also require a lot of labor and inputs, but they directly benefit cattle ranching by providing shade for cattle, livestock feed, and delimiting property. They are also re-usable in the farm, and farmers can choose to use those trees for timber in the future without much concern for the environment regulatory agencies.

Future inquiry into these agro-pastoral systems will examine the relationship between farmer perceptions and tree cover on farms. This approach can uncover the underlying dynamics between tree covers and drivers in this case study of 54 farmers. For more practical purposes, future studies also must examine the necessary tree densities to maintain the long-term sustainability of the Neotropical cattle ranch.

The findings of this study are timely, as million dollar projects that aim to promote reforestation across the Neotropics are being proposed in Latin America. For this reason, Panama created a new law called "law for forestry incentives" currently under debate at the National Assembly and meant to promote reforestation through monetary incentives including small funds for projects and by enhancing markets. This law specifically targets the landscape patterns identified on this dissertation, with a strong emphasis on riparian vegetation and forestry plantations which, at least in this case study, farmers already manage. The extent to which this new law considers on-farm processes including those related to the contribution of trees to cattle management and farmer's livelihood is unclear. However, much of the leaning appears to be towards promoting more commercial tree plantations or intensive silvo-pastoral systems which are both very labor intensive and require a lot of technical assistance to implement. Based on our findings, both wage labor and technical assistance are not accessible to the small farmer, indicating that commercial tree planting and intensive silvo-pastoral systems are unlikely to be adopted widely, at least by the small farmers that have less access to political influence. Structural changes are necessary, otherwise, there is a risk that this new law and others like it will continue to benefit the political class and disregard the aspirations of the family farm.

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