SETTLEMENT PATTERNS AND THEIR POTENTIAL IMPLICATIONS FOR LIVELIHOODS AMONG MAASAI PASTORALISTS IN NORTHERN TANZANIA.

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ABSTRACT

In the last century, many mobile pastoralists have transitioned to more sedentary lifestyles. Mobile people can be both pushed into a more settled existence by environmental or political forces, or pulled by new economic opportunities. While researchers have examined the causes and consequences of growing sedentarization, few contemporary studies have examined the patterns of settlement among mobile groups who are shifting to sedentary lifestyles and how these patterns may be related to socio-economic outcomes. This research examines settlement site selection by using GIS and remote sensing techniques to quantify settlement patterns in four Maasai villages in northern Tanzania, exploring the environmental and infrastructure correlates of settlement locations. A subset of these geographic variables is used with social survey data for 111 Maasai households in the study site to test the hypothesis that settlement location impacts livelihood strategies and economic outcomes by creating and constraining access to important resources and infrastructure. Landscape level evaluation of settlement patterns show that certain soil types limit occupation and the potential for agricultural expansion in 30% of the study area. Settlement density and existing agriculture are also clustered in certain parts of the landscape. The spatial models support the hypothesis that proximity to roads and village centers plays an important role in shaping overall settlement patterns. However, models that combine these factors with environmental and geophysical elements show improved explanatory performance, suggesting that competing factors are at play in influencing settlement patterns. Spatial models also indicate that agricultural development may be limiting land available for settlement in some

parts of the study area. Results of the household level outcomes are more ambiguous, with few relationships between geographic variables and household livestock holdings, land under cultivation, annual income. Rather, these factors are influenced largely by demographic variables such as household size, age of the household head, and asset allocation. However, there appears to be less income diversity in households more distant from permanent water sources.

GENERAL AUDIENCE ABSTRACT

Around the world, many people who traditionally have moved from place to place on a seasonal or annual basis have become much more settled, often no longer moving at all. These formally mobile people can be both pushed into a more settled existence by environmental or political forces, or drawn by new opportunities presented by being more settled. While researchers have studied the reasons for these changes and how being more settled affects people, not many studies have examined the patterns of settlement of people who are becoming more settled or how these patterns may be related to how people do economically once they become settled. This study is focused on settlement patterns in four Maasai villages in northern Tanzania. The study used geographic information systems and data collected by satellites to map the location of Maasai households, called bomas, in the four villages, and the environmental characteristic of where people do and do not live on the landscape. This study also looked at measures of income and economic activity for 111 households to see if the location of a household on the landscape effects people's economic choices and outcomes. This study found that certain environmental factors in the area do influence where people live, particularly soils types and climate, but did not find that where people live has strong influence on how they do economically.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

One of the changes apparent in the savannas of East Africa is the increasing sedentarization of previously mobile Maasai pastoralists. Historically, Maasai settlement patterns have exhibited flexibility around the wet and dry seasons, although this pattern was quite variable, with some groups moving yearly and others staying in one location for some years (K. Homewood 2008; R. H. Lamprey and Reid 2004; Jacobs 1965; Western and Dunne 1979). More recently, these patterns of movement are not as common, and most households do not move as extensively, if at all (Fratkin and Roth 2005; Western and Manzolillo Nightingale 2003; Worden 2007).

Nearly all contemporary mobile pastoralists have undergone some level of sedentarization in the last century, and this pattern has deep historical roots (Campbell et al. 1999; Roth and Fratkin 2005; Swidler 1980). The forces driving sedentarization are complex. Mobile people can be both pushed into a more settled existence by environmental or political forces, or pulled by new opportunities (Roth and Fratkin 2005; Western, Groom, and Worden 2009; Western and Manzolillo Nightingale 2003; Worden 2007). There is not necessarily a clear distinction between mobile and settled people, some portion of a population may remain mobile while others become settled (Salzman 1980). While early research argued that people can become mobile again after periods of sedentary lifestyle (Campbell et al. 1999; Salzman 1980), more recent authors have argued this process tends to be unidirectional and more permanent (K. Homewood, Trench, and Kristjanson 2009; McCabe 2003).

Mobile people do not necessarily abandon their former territory but choose a place within that space on which to settle (K. Homewood and Randall 2009). But where do they settle? Is one place just as good as any other? What environmental variables constrain or guide these decisions? Are all locations available for settlement, or do social norms constrain where households can settle? What role has the State played in governing where settlement may take place? People may choose to settle in a particular location in order to maximize a livelihood opportunity (Trench et al. 2009). Conversely, they may have little choice but to occupy a location that constrains their livelihood strategies or limits their outcomes from pursuing certain strategies.

Evolving settlement patterns are of particular interest on the Simanjiro Plains (SP) of northern Tanzania. This region has been of central importance to Kisango Maasai pastoralists for hundreds of years (Igoe and Brockington 1999; Jacobs 1965; Nelson 2012; Peterson 1978). It also represents one of the few remaining strongholds for East Africa's migratory megafauna and is internationally recognized for its biodiversity importance (James Kahurananga and Silkiluwasha 1997; J. N. Kahurananga 1976; H. F. Lamprey 1964, 1963; Morrison and Bolger 2014). Tarangire National Park (TNP) protects 3,000 square kilometers to the west of the SP, but represents only about 10% of the greater Tarangire Ecosystem. Migratory species, such as wildebeest (*Connochaetes taurinus*) and zebra (*Equus burchelli),* move in and out of the park to access seasonally available forage in Maasai villages on the plains (Kiffner et al. 2016; Morrison and Bolger 2014). This makes the region a nexus of competing interests.

How the pattern of settlement unfolds in this region may help us understand positive and negative outcomes for both the Maasai and the local biodiversity. The location and patterns of settlement have the potential to strongly influence livelihood strategies and outcomes (S. B. BurnSilver 2009; Trench et al. 2009). Researchers have found that the economic implications of sedentarization can range from positive increases in economic outcomes to entrenched poverty (K. Homewood 2008). Increasing fragmentation of the area, driven by agricultural development and new settlement patterns, has the potential to undermine wildlife populations by disrupting migratory corridors (Borner 1985; Morrison and Bolger 2014; Voeten et al. 2010). How these patterns change may play a significant role in the long term resilience of social-ecological systems that support both mobile and settled people (Leslie and McCabe 2013).

While some studies have examined the causes and consequences of the growing sedentarization in pastoral communities (Campbell et al. 1999; Fratkin and Roth 2005; J. McPeak and Little 2005; Roth and Fratkin 2005), fewer contemporary studies have examined the broad settlement patterns on the landscape (R. H. Lamprey and Reid 2004; Western, Groom, and Worden 2009; Worden 2007). This study seeks to explore the question of settlement site selection by quantifying settlement patterns in four predominately ethnically Maasai villages situated on the SP of northern Tanzania, examining the environmental and infrastructure correlates of settlement (RQ1). I then examine if these factors are associated with livelihood strategies and outcomes of households within the study area (RQ2).

CONCEPTUAL FRAMEWORK

This research takes the perspective that mobile pastoralism represents an effective livelihood strategy in an environment with resources that are unpredictable both in space and time (Ericksen et al. 2013; M. Thompson and Homewood 2002; Worden 2007). Describing Tanzanian rural communities, Scott said, “they had developed patterns of settlement and, in many cases, patterns of periodic movements that were finely tuned adaptations to an often stingy environment which they knew exceptionally well” (1998, 235). Correspondingly, the current trend in reduced mobility is likely to have profound impacts on livelihood opportunities for the affected communities, as well as the greater ecosystem. I’m primarily motivated by the question of what changes about how mobile people interact with their landscape, both its natural and built elements, given the increasing pressures to lead more sedentary lifestyles.

This research is based, in part on the livelihoods framework, which considers rural livelihoods to be supported by access to five different resources: natural, physical, social, human, and financial (Ellis 2000). For this study, I apply a spatial focus on the natural and physical resources aspects of this framework. My premise is that the physical location of households on the landscape influences their access to these resources. At the landscape scale, settlement patterns reflect the cumulative decision making by people seeking to balance access to resources, while also operating under constraints imposed by both the landscape and external forces. In turn, the locations that people settle in are likely to have consequences for the livelihood strategies people are able to pursue and the outcomes of those decisions (K. Homewood 2008; Leslie and McCabe 2013; Trench et al. 2009; Worden 2007).

LITERATURE REVIEW

In this literature review, I summarize the evolution of scientific thinking on the environmental implications of Maasai pastoralism. I then review some of the broad historic influences on Maasai settlement patterns and examine the literature regarding evolving settlement patterns in East Africa, particularly resource access and environmental constraints, more modern influences including development, conservation, increasing agriculture in the region, and the impact of political forces on settlement patterns. I also review literature relevant to the geographic components of livelihood diversification, a process which is intertwined with settlement.

Changing Scientific Perspective on Land Use

To better understand changing settlement patterns among pastoralists, it is useful to review how scientific perspectives on their interactions with the environment have also changed. Despite the evidence that pastoralists have occupied this part of Africa for millennia (Little 1996; Nelson 2012; M. Thompson and Homewood 2002), much of the early ecological research on African savannas blamed pastoralist overgrazing for a perceived deterioration of rangeland conditions and declining wildlife populations (Borner 1985; H. F. Lamprey 1963; Peterson 1978). These ideas were based on early scientific concepts like carrying capacity and climax systems that were developed to explain ecosystem processes in more temperate regions (K. Homewood 2008; Lambin et al. 2001; Nelson 2012). This perspective lead to conservation policies based on the belief that ecosystems needed to be protected against human mismanagement and over-use (Bilal Butt and Turner 2012; Little 1996).

Starting in the 1990's there was an increasing understanding that stable state ecological models were not appropriate for savanna ecosystems, which are much more stochastic; experiencing cycles of rainfall variability and extended droughts (Little, 1996). From this perspective mobile pastoralism can be seen as adaptive behavior that allows flexible access to resources that are patchy and unpredictable in both space and time (Ericksen et al. 2013; M. Thompson and Homewood 2002). In savanna systems, livestock numbers seldom exceed local carrying capacity because stock die-offs, caused by drought and disease, maintain low densities (Oba 2013). There is also an increasing understanding that pastoral land use may have played a critical role in shaping the current configuration of the landscape through grazing and periodic burning, which prevented brush and trees from encroaching on grasslands. Excluding human use from these systems may in fact trigger dramatic ecological changes (Lambin et al. 2001; Little 1996). This evolving understanding of pastoralist land use helps frame the question of settlement patterns, and raises the question of what the consequences of reduced mobility will be for both human communities and the broader landscape.

Historical Context

The archaeological record indicates that East African rangelands have been the home to pastoralist and agro-pastoralists for millennia (K. Homewood 2008; Little 1996; Nelson 2012). Maasai pastoralists began to control the region in the early 19th century, displacing other Maa-speaking peoples in the region in what is called the *Iloikp* wars (Waller, as cited in Igoe and Brockington 1999, p.5). Not long after this, European colonial administrations began to be active in the East African interior, and Maasai were engaged in a series of military conflicts with both German and then British colonial powers throughout the late 1800s and early 1900s. The cumulative effect of these conflicts, along with an outbreak of rinderpest that decimated livestock populations, severely limited Maasai influence over region (M. Thompson and Homewood 2002). This was followed by a period of increasingly strictly defined territorial boundaries for the Maasai and regular loss of territory to colonial settlers, other African immigrants, and conservation areas. This process continued up until Tanzanian independence in the 1960's, by which time Maasai had been permanently excluded from what had been the most productive regions of their territory (Brockington and Igoe 2006; Rutten 1992). In post-independence Tanzania, and East Africa generally, land use polices continued to be based on the idea that pastoralists overuse rangelands, leading to environmental decline (Lambin et al. 2001). This meant that local inhabitants continued to be evicted from numerous conservation areas, which met with European and American ideals regarding pristine, uninhabited landscapes (Igoe and Brockington 1999; Rutten

1992). This pattern continued throughout the 20th century, and many contemporary national policies in the region are still based on these views.

Drivers of Sedentarization and Arrangement of Settlements

Globally, a nexus of interacting political, social, economic, and environmental factors has led to a general decline in mobile pastoralism. This process has historical roots, but has accelerated recently (Campbell et al. 1999; Western, Groom, and Worden 2009; Worden 2007). Sedentarization can be defined broadly as a change in lifestyle from mobile housing to a more fixed residence. However, there is not a clear line between mobile and sedentary lifestyles, and some groups move between of these two modes of activity, both individually and collectively (K. Homewood 2008; Salzman 1980; Roth and Fratkin 2005; Goldschmidt 1980).

As the pressures to settle have grown, pastoralists have had to balance many competing considerations in selecting a settlement location. While there is a large body of work on the environmental behaviors of pastoralists, most of these studies examine decision-making as it relates to mobility and resource variability (B. Butt 2010a; Miller, Leslie, and McCabe 2014; Nkedianye et al. 2011; Western and Manzolillo Nightingale 2003). Fewer studies have focused on what drives overall settlement locations and patterns (Western and Dunne 1979; Worden 2007). Here, I review the literature on how resource access, geophysical, epidemiological, and political factors may be shaping these patterns. It is worth noting there is significant overlap between the broad factors that increase sedentarization and those that influence where people settle.

Changes in the availability of water between the wet and dry seasons is one of the main drivers of pastoral mobility in semi-arid Africa (K. Homewood 2008). Water availability is so limited that livestock are typically only watered every other day even in the wet season, which conditions them to go three to four days without water in the dry season (Jacobs, 1965). In the modern context, researchers have found that pastoral settlements average distances of between four and eight kilometers from permanent water, although these distances can vary between the wet and dry seasons (Brottem et al. 2014; Bilal Butt 2011; B. Butt 2010a; Coppolillo 2000, 2000). However, in Kenya, Worden (2007) found that increased development of water sources had significantly reduced the distance herds need to travel to reach water, and had increased settlement in previously uninhabited regions.

In East Africa, vegetation productivity is tightly linked to rainfall. This creates a high level of variability in the location and quality of livestock forage (K. Homewood 2008; Western 1982; Western and Manzolillo Nightingale 2003). Despite increasingly diverse income sources, most Maasai still rely primarily on livestock to meet basic nutritional needs, and herding serves as the primary economic asset of most households (K. Homewood, Trench, and Kristjanson 2009). Therefore, access to adequate forage is also a critical constraint for pastoralists settlements (Coppolillo 2000; K. Homewood 2008; Jacobs 1965; Western and Dunne 1979). Research has shown that pastoralists have extensive knowledge regarding annual variations in vegetation productivity and that they preferentially access grazing areas with low levels of year to year variability in quality (Brottem et al. 2014; Moritz et al. 2014). In this region, it has been found that livestock herds must travel extensively from the household location to get adequate forage. In some areas, during the dry season herds will travel over 9 km a day to access forage, although during the wet season they often stay within 2 km (Shauna B. BurnSilver, Boone, and Galvin 2004; B. Butt 2010b; Coppolillo 2000; K. M. Homewood, Rodgers, and Homewood 2004).

The presence of human and livestock pests and pathogens can also drive settlement patterns. Livestock disease has historically been a major limitation on the settlement of pastoral people throughout Africa (K. Homewood 2008). The presence of tsetse fly (*Glossina sp.)*, which transmits trypanosomiasis to both humans and livestock, was a major historic limitation of pastoral land use in Africa in general (Homewood, 2008) and for Maasai in particular (Jacobs 1965; R. H. Lamprey and Reid 2004; Peterson 1978). Tsetse flies need shade for resting sites and successful reproduction, so are associated with denser brush and vegetation (Peterson 1978). In the study area, Sachedina and Trench (2009) speculated that the presence of tsetse fly was suppressing settlement near the Lokisale Game Control Area (LGCA). Tick-borne diseases also play an important role in livestock mortality, and accounted for up to 78% of cattle mortality in a four year period after the Tanzania government stopped providing free cattle dipping services to treat for ticks in 1985 (Sachedina and Trench 2009). However, there is little data available on the geographic extent of tick borne diseases in the study area. Maasai also seek to avoid overlapping livestock with wildebeest calving areas, as wildebeest are the primary vector for malignant catarrhal fever which can be transmitted to cattle (Jacobs 1965; K. Homewood 2008).

Several species of African wildlife can be hazardous to human communities, and high wildlife densities may suppress human settlement. Jacobs reported that Maasai took care to avoid large mammals such as elephant, rhinoceros, hippopotamus, and buffalo (1965). Western and Dunne's (1979) informants indicated that one of the main reasons to avoid dense brush was to minimize the potential for large animals to damage the settlement walls at night or avoid areas where visibility was constrained. In the modern context, these types of encounters are more likely to take place in proximity to conservation areas, where wildlife concentrations are higher (Kaswamila, Russell, and McGibbon 2007). However, even within the broader study area, migrating animals routinely damage crops and predators can prey on livestock and attack people (T. Baird, Leslie, and McCabe 2009; Lewis, Baird, and Sorice 2016). These interactions can have important effects on local livelihoods (Salerno et al. 2015). These adverse interactions with wildlife could be a reason for people to avoid settlement near conservation areas where wildlife densities are higher.

Geophysical features can also play a role in settlement site selection. Western and Dunne (1979) found that overall slope, position on the slope, and local soil conditions were all factors in Maasai settlement selection. However, few studies since that time have examined the influence of these geophysical factors in shaping modern settlement patterns.

Fixed assets such as improved water sources, existing agricultural plots, and village services including schools and clinics have become more prevalent in this region and may increasingly influence settlement patterns (Sachedina and Trench 2009; Leslie and McCabe 2013; Miller, Leslie, and McCabe 2014; T. Baird 2014). Social services, concentrated in villages, can attract educated settlers including government employees and teachers (Sachedina and Trench 2009). Outside food relief after drought or other disasters has also been found to encourage people to sedentarize, often through the creation of service delivery infrastructure in previously underserved areas (K. Homewood 2008; Campbell et al. 1999; Roth and Fratkin 2005). Historically, cattle raiding and other security concerns have motived some pastoralists to abandon more remote rangelands in favor of settled areas in order to avoid conflicts (K. Homewood 2008; McCabe 2004; J. G. McPeak, Little, and Doss 2011; Schilling, Opiyo, and Scheffran 2012). However, these concerns are less common currently within the study area. Expanding road networks have also been found to increase settlement, by improving access to markets for both livestock and farm produce (Kimiti et al. 2016; Serneels and Lambin 2001; Worden 2007).

Sedentarization can also been seen as an economic move out of pastoralism into agriculture or other economic activities (K. Homewood 2008). In the modern context, villages and village centers provide access to goods and labor markets, as well medical facilities and education institutions. These services are often welcomed by mobile people, and have been shown to increase localized settlement (Roth and Fratkin 2005; Western and Manzolillo Nightingale 2003; J. G. McPeak, Little, and Doss 2011). Within the study site, it has been argued that proximity to TNP has boosted outside investment in local infrastructure of some village centers, which may make them more attractive settlement sites (T. Baird 2014).

In the later part of the 20th century, agriculture began to play an increasing role in Maasai livelihoods, which accelerated sedentarization and has complicated settlement strategies. When Jacobs conducted fieldwork among the Maasai in the 1950's, he found that agriculture was uncommon (1965). Working the study area in the late 1970's, Peterson also found cultivation to be rare, totaling only 130 hectares in the Simanjiro plains, and mostly concentrated around settlements (1978). The growth of cultivation in the study area seems to have accelerated in the 1980's (Igoe and Brockington 1999). Conversion of land to agriculture, both by outsiders and pastoralists, can eliminate local grazing areas and so push people towards sedentary development (Coppolillo 2000; J. G. McPeak, Little, and Doss 2011; K. Homewood et al. 2001; K. Homewood 2008). Through conversion of grazing areas, agricultural development may be limiting opportunities for pastoralism throughout East Africa and Tanzania (Leslie and McCabe 2013; Msoffe et al. 2011; Tache 2013), although it has been noted that some pastoralists use agricultural production to support livestock related activities and maintain herd sizes (McCabe, Leslie, and DeLuca 2010).

The political context of the household can also play a large role in settlement patterns (K. Homewood, Trench, and Kristjanson 2009; D. M. Thompson, Serneels, and Lambin 2002; Trench et al. 2009). In the study area, researchers have noted that villages are responding to changing circumstances in significantly different ways, particularly as related to land tenure and management of common pool resources (Leslie and McCabe 2013). Large areas of cultivation are often controlled by local elites who use their financial and social resources to control land, which can, in turn, be leased to outside entrepreneurs for commercial agriculture (Sachedina and Trench 2009; M. Thompson and Homewood 2002). Little research has examined how land is allocated for settlement or agricultural development in the study area. The process of receiving an allocation of land from the village council is largely opaque to outsiders and likely subject to corruption (Sachedina and Trench 2009); Baird personal communication).

As previously discussed**,** conservation has played a significant role in shaping settlement patterns in this region. Historically the creation of large national parks and game control areas has excised large portions of Maasai territory, not only prohibiting settlement but traditional access to water and forage. In this study area, Maasai pastoralists were evicted from TNP when it was designated as a game reserve in 1957 (Igoe and Brockington 1999; Sachedina and Trench 2009). Settlement is also prohibited in the LGCA, although the boundaries of this area are disputed by local villages and it is used for grazing (Sachedina and Trench, 2009, Baird, personal communication). In some parts of East Africa, conservation areas have been shown to attract settlement through creation of economic opportunities related to tourism (K. Homewood, Kristjanson, and Trench 2009; K. M. Homewood, Rodgers, and Homewood 2004; M. Thompson and Homewood 2002; Trench et al. 2009). However, this does not seem to be a significant source of revenue in the study area, where revenue related to wildlife conservation is controlled by the national government (T. Baird, Leslie, and McCabe 2009; Davis 2011; Nelson et al. 2010, 2009). In the project area, there is concern among community members that TNP may expand, resulting in evictions of people settled near the park boundary (T. Baird, Leslie, and McCabe 2009; Igoe and Brockington 1999; Sachedina and Trench 2009). There are also active land tenure disputes between villagers and TNP on the western boundary of the park (Davis 2011). Researchers have also documented some instances of park personnel intimidating herders near, but outside of, the park boundaries in the late 1990s (Igoe and Brockington 1999). These factors are all likely to influence the willingness of people to settle near the protected area.

Historically, many states globally have been one of the main drivers of the sedentarization of mobile people. States sought to sedentarize mobile groups to facilitate administration and attempts to extract resources, especially taxes (P. Burnham 1975; Randall and Giuffrida 2006; J. G. McPeak, Little, and Doss 2011; K. Homewood 2008). States have also promoted sedentarization to control militarily capable nomadic populations and to create more a homogenous national identity (Chatty 1980; Swidler 1980). State mechanisms of sedentarization can include changes in tenure laws, privatization of common pool land, and creation of parks or conservation areas (K. Homewood 2008; Igoe and Brockington 1999; J. G. McPeak, Little, and Doss 2011; Roth and Fratkin 2005). Although pursuing extractive ends, States often used benign justifications for enforcing sedentarization, particularly that it facilitates provision of services like healthcare and education (R. H. Lamprey and Reid 2004; Campbell et al. 1999). While these services are often perceived as beneficial by mobile people and can drive increased sedentarization (J. G. McPeak, Little, and Doss 2011; Western and Manzolillo Nightingale 2003), the process of State enforced settlement can also be highly disruptive (Scott 1998). Improvement in access to social services and improved agricultural development was one of the main justifications for the Tanzania post-independence push to create village centers, called U*jamaa,* championed by the socialist government of Julius Nyerere (Galaty 1980; Ndagala 1982; Scott 1998). This effort coercively, and sometimes forcibly, relocated up to 5 million Tanzanians into state planned villages in the mid-1970s. The program was largely a failure due to the general weakness of the State, poor planning of the village locations, which ignored local environmental conditions, and general resistance on the part of local communities. The program is considered to have been particularly difficult for Maasai and other mobile pastoralists (Sachedina and Trench 2009; Scott 1998).

While political forces are often seen as negative influences towards settlement, there can also be political benefits to being more settled. According to Homewood, "settled peoples have an advantage in claiming tenure over mobile groups, and are better represented in both official administrations and in the process of consultation" (2008,73). Establishing a site of permanent residence can help to ensure a claim to land surrounding the household in an area with uncertain tenure (M. Thompson and Homewood 2002).

Consequences of Settlement for Livelihoods

Settlement and livelihood diversification are closely intertwined processes among East African pastoralists. Concurrent with increased sedentarization, these communities have been diversifying into non-pastoral livelihood strategies for several decades, and this continues to be an ongoing trend throughout the region (K. Homewood, Trench, and Kristjanson 2008; McCabe, Leslie, and DeLuca 2010; Little et al. 2001; Trench et al. 2009). As discussed with settlement patterns, diversification of livelihood strategies has been framed in terms of "push" and "pull" factors, often acting in concert, but affecting different portions of the population in different ways (T. Baird and Leslie 2013; Ellis 2000). Better off and poorer households diversify for different reasons. Wealthy households often diversify to leverage success and expand opportunities, while poorer households diversify out of necessity or pressures on previous income strategies (Little et al. 2001; McCabe, Leslie, and DeLuca 2010; Trench et al. 2009). As noted with settlement, some authors have argued this tends to be a one-way process (K. Homewood, Trench, and Kristjanson 2009; McCabe 2003), while others argue that diversification can be cyclical and pastoralists combine different income strategies at different times as circumstances change (Little et al. 2001).

Livelihood strategies are strongly influenced by the spatial arrangement of resources that individuals or groups can access (S. B. BurnSilver 2009; Serneels et al. 2009; D. M. Thompson, Serneels, and Lambin 2002; Trench et al. 2009). Little et al. (2001) proposed a model of livelihood diversification with three categories of variables; conditional variables, opportunity variables, and local response variables. In this framework, conditional variables are system-wide influences, and include per capita livestock holdings, rangeland access, and population density. Opportunity variables, which influence the range of potential diversification strategies include climactic variables, distance to markets and towns, and levels of education. Local response variables influence how different groups adapt to the other categories and include gender, age, income disparities and other social factors.

The extensive literature on pastoralist livelihoods has evaluated a number of spatial relationships between household locations, livelihood strategies, and economic outcomes. Studies suggest that more densely populated areas tend to be less suitable for livestock raising (Little et al. 2001; Oba 2013; Serneels and Lambin 2001), and that people living closer to villages are more likely to practice agriculture over livestock keeping (Sachedina and Trench 2009). Proximity to towns has been associated with increased livelihood diversification, although different types of urban centers provide different livelihood opportunities (Little et al. 2001; J. McPeak and Little 2005). Smaller rural villages may have opportunities for trade, but likely do not have the wage employment opportunities found in large towns (Little et al. 2001). Some researchers have found that restricted movement patterns may lead to localized resource depletion and smaller livestock herd sizes (Western, Groom, and Worden 2009). It has also been shown that proximity to protected areas is associated with greater livelihood diversification (T. Baird and Leslie 2013; D. M. Thompson, Serneels, and Lambin 2002). The political context of the household can also play a large role in livelihood diversification (K. Homewood, Trench, and Kristjanson 2009; D. M. Thompson, Serneels, and Lambin 2002; Trench et al. 2009). In the study area, researchers have noted that villages respond to changing circumstances in significant ways, particularly as related to land tenure and management of common pool resources which may influence what livelihood strategies people can pursue (Leslie and McCabe 2013).

HYPOTHESIS DEVELOPMENT

Maasai formerly exhibited a significant amount of mobility that was tuned to an environment defined by cycles of rainfall and drought. The increasing pressures of a global economy, land alienation through conservation, agricultural expansion, and growing inequities in resource access are curtailing the flexibility and mobility of pastoralists. Increasingly pastoralists live more sedentary lives, where the location of the household may drive economic opportunities and access to natural resources (Rutten 1992; Western and Manzolillo Nightingale 2003; Worden 2007). These trends suggest a set of competing hypothesis regarding settlement patterns within the study area. The drivers of settlement patterns are not likely to be mutually exclusive, and are also compared with a full model that can be seen a representing the “trade-offs” scenario. I compare these hypotheses to see if any are more predictive of current settlement patterns in the study site.

RQ1-H1 Forage and water access hypotheses

One hypothesis is that settlement site selection is still related primarily to forage and water access. Pastoralists will seek to maximize total available resources and to avoid highly unpredictable resources, both over the space that they can access and over time. Extensive research has also shown that balancing distance to water and access to forage resources is the primary consideration of settlement site selection in traditional East African pastoralist populations (Butt, 2010; Coppolillo, 2000; Jacobs, 1965; Peterson, 1978; Western and Dunne, 1979; Worden, 2007). Accordingly, we should see higher rates of settlement in areas near water sources, and with consistent forage resources that exhibit low temporal variability.

RQ1-H2 Environmental constraints hypothesis

Settlement patterns are primarily constrained by environmental variables. Settlement is denser in better climactic zones and less dense in areas with high likelihoods of livestock and human disease vectors and areas with unfavorable environmental and geophysical features like dense vegetation and extreme temperatures. In 1979, Western and Dunne evaluated settlement site selection criteria for Maasai pastoralists in Amboseli, Kenya. They found strong evidence that Maasai evaluate several different local landscape factors that maximize livestock and human wellbeing, and minimize exposure to hazards, including avoiding certain soil types, positioning boma on favorable slopes, and avoiding areas of dense vegetation. Jacobs (1978) also found that high densities of tsetse fly suppressed settlement in this area. More recently researchers have speculated that tsetse fly could be suppressing settlement near the LGCA (Sachedina and Trench 2009).

RQ1-H3 Modernization hypothesis

Settlement patterns are driven by infrastructure assets like amenities in villages and proximity to roads. Settlement is less dense closer to conservation areas to avoid tenure uncertainties and conflicts with authorities. Maasai are increasingly dependent on alternative livelihood strategies to get by (McCabe et al. 2014). These include agricultural production, as well as work outside the household, such as mining related, small business, and tourism related opportunities. Under this hypothesis we might expect that access to village centers, with their associated amenities like medical clinic and schools, and road networks, which enhance access to markets and travel to other locations, to play an increasing role in settlement patterns.

RQ2-H1 Livelihood impacts.

Settlement locations are likely to influence both household livelihood strategies and economic outcomes. According to Trench et al. (2009), distances to conservation areas, to roads and to towns, as well as agro-ecological factors likely all influence which livelihood strategies households pursue. Little et al. (2001) also proposed a model of livelihood diversification with a variety of geographic variables. Here I test if, when controlling for demographic factors, any geographic variables are associated with livestock holdings, amount of land under cultivation, annual incomes, or annual diversity of income sources for a subset of 111 households with survey data from 2010.

METHODS

Study Area

The study area is four adjacent villages in the Simanjiro District of northern Tanzania: Emboreet, Loiborsoit, Sukuro, and Terrat. The literature regarding current conditions in these villages, particularly as it relates to the intersection of conservation and livelihoods, make this an ideal setting to examine correlates of settlement patterns. These four villages encompass approximately 1,500 square kilometers, roughly 30 kilometers west of TNP (Figure 1). According to the 2012 Tanzania National Census, total population in the villages was 12,055 (Tanzania National Bureau of Statistics 2012). Maasai, primarily of the Il Kisongo (Loitokitok) section, are the predominant ethnic group in the study villages (Sachedina and Trench 2009). There is evidence that these villages are pursuing different strategies related to land use and settlement (Davis 2011; Nelson et al. 2009; Leslie and McCabe 2013) and that they have experienced various levels of infrastructure development (T. Baird 2014).

The study site also broadly overlaps with the Simanjiro Plains which is an important dispersal area for migratory wildlife species that migrate out of TNP during the wet season (Kahurananga and Silkiluwasha, 1997; Kahurananga, 1976; Lamprey, 1964, 1963; Morrison and Bolger, 2014). Although the LGCA lies between these villages and TNP (Figure 1), it's designation is contested by the village authorities (Sachedina and Trench 2009). Although cattle grazing does take place there, Sachadina and Trench (2009) found that there were no permanent structures between the village boundaries and the park.

Overall the region is considered semi-arid, however, seasonal rainfall is highly variable. Generally, it receives on average 600 mm per year of rainfall (Kiffner, Hopper, and Kioko 2016).

Rainfall patterns are bimodal, with a period of shorter rains from October to December and longer rains from March to May (Ericksen et al. 2013). Rainfall patterns are not reliable from year to year and prolonged droughts are common (Igoe and Brockington 1999). The climate of the study area ranges from Lower Mesotropical Subhumid in the Loiborsoit area, to Lower Mesotropical Dry in the south and Upper Thermotropical Dry in the south-east (Sayre et al. 2014).

The general patterns of vegetation in the study site is described in Kindt et al. (2014). The central portion of the study area is identified as an edaphic grassland on volcanic soils, characterized by the presence of *Andropogon greenwayi* and a variety of other grasses. Surrounding this core area are mixed habitats of *Acacia-Commiphora* deciduous wooded grasslands and C*ombretum* wooded grasslands. These habitats are characterized by a single open canopy of a variety of *Acacia* or *Commiphora* thorn trees, typically 3 to 7 meters in height. Canopy cover is less than 40% and the grass species are dominated by *Digitaria macroblephara, Eustachyspaspaloides, Themeda triandra,* and *Pennisetum mezianum,* which are present on poorly drained soils. In the south-eastern portion of the study area, these habitats transition to Somalia-Maasai Acacia-Commiphora deciduous bushland and thicket. This habitat type is more densely vegetated with brush 3 to 5 meters in height. Local areas of brush can be quite dense, precluding travel. Grass cover is sparse in this habitat (Kindt et al. 2014).

Data from the Mlingano Agricultural Research Institute describe the major soils in the project as luvisols, which are moderately acidic dark red sandy clay loams suitable for agriculture. These soils are interspersed with large areas of vertisols; alkaline clays found in poorly drained depressions. Vertisols, known locally as “black cotton soils,” are water logged in the wet season, and have a hard surface which develops deep cracking in the dry season. Tillage of these soils is difficult, but they are productive grassland habitats and are important for grazing (J. N. Kahurananga 1976; Mlingano Agricultural Research Institute 2006).

Data Collection

Geographic Data Collection (RQ1)

To address the question of what geographic variables influence the current settlement pattern in the study area (RQ1), I mapped the location of all identifiably active Maasai bomas within the four study area villages (Figure 2). Bomas are the central unit of Maasai household organization. A traditional boma consists of a round fenced enclosure, with an interior array of huts and a central livestock enclosure. Several household heads and their respective wives may occupy a single boma, with each head having exclusive use of a gate in the outer wall. Huts are built and maintained by the wives of the head of household, and are their exclusive property (Spear and Waller 1993). Jacobs reported that the typical boma was comprised of four to eight households (1965). However, more recent data indicates that large communal households are being replaced by family groups of only 1-2 households (R. H. Lamprey and Reid 2004). Livestock are brought back to the boma nightly and placed in the central enclosure (Jacobs 1965; R. H. Lamprey and Reid 2004; Spear and Waller 1993).

Bomas are visible on high resolution aerial imagery, they are also identifiable in multispectral imagery of sufficient resolution. For this project, I used ESA Sentinel 2 imagery at 15-meter resolution from Feb 4, 2016. Occupied bomas show a characteristic “bulls-eye” pattern of bare ground in the central cattle enclosure, while abandoned bomas show a uniform return of nitrogen enriched vegetation (Figure 3). Bomas are not spectrally distinct enough from the surrounding landscape to reliably delineate through a classification process, so this done visually.

Modern, western style structures typically found in village centers were not counted, as there is no means to determine if they are residential.

To address RQ1, I produced a suite of other geographic variables related to factors identified in the literature as potentially influencing settlement patterns. I used 30-meter resolution digital elevation models from the USGS Shuttle Radar Topography Mission to generate elevation and slope data sets (30m STRM DEM). Data on African soils is available for the project area, although only at 250 meter resolution, and is largely interpolated from widely scattered sample locations (Hengl et al. 2015). Consequently, the extent of the "black cotton" vertisols visible in the study villages were manually digitized from the same ESA Sentinel 2 imagery used to map the boma locations. Climate zones are based on the USGS Isobioclimate dataset for Africa, at 1 kilometer resolution (Sayre et al. 2014). Average annual precipitation and mean annual temperature are based on the World Climate data, at approximately 1 kilometer resolution (Fick and Hijmans 2016). Canopy Cover was derived from a global canopy cover dataset at 30 meter resolution (Hansen et al. 2013). Data on the locations of permanent water sources was based on field data collected in 2010 and further discussed in Baird (2014), these data were also matched with data from Miller (2010). The presence of open water impoundments was confirmed in the February 4, 2016 Sentinel 2 image. In this region, imagery acquired at the beginning of the growing season, between December and January, allows a distinction to be made between bare agricultural fields and green up of local vegetation (Miller 2015). Agricultural fields were digitized from the February 2, 2016 sentinel data at 15-meter resolution. The presence of tsetse fly in the study area was based on UN Food and Agricultural Office GIS models at 1 kilometer resolutions. Although several species of tsetse can be found in the project area, *Glossina swynnertoni* was modeled as having the high probabilities of being present in the in the study area, so this species was used as an indicator species. These data were originally compiled in 2000, so should be viewed with some caution. Vector files of road infrastructure were extracted from the Open-StreetsMap project and confirmed in Sentinel 2 imagery (OpenStreetMap contributors 2016). Locations of village centers are based on data collected by Baird (2012). Boundaries for conservation areas are based on the World Protected Area Database shapefiles (retrieved 12/13/2016). Village boundaries and populations data are based on Tanzania National Census of 2012 (Tanzania National Bureau of Statistics 2012).

To estimate landscape level forage, imagery from the Moderate Resolution Imagining Spectroradiometer (MODIS) was used to derive normalized differential vegetation index (NDVI) measurements for the study site (NASA 2016). There is extensive literature regarding the use of NDVI to characterize vegetation in Africa (Anyamba and Tucker 2005; Budde et al. 2004; Moritz et al. 2014; Pelkey, Stoner, and Caro 2003; Trench et al. 2009). Early studies utilizing NDVI in this region used the Advanced Very High Resolution Radiometer (AVHRR) at 1km resolution (Shauna B. BurnSilver, Boone, and Galvin 2004). However, Butt (2010b) recommends the use of MODIS 250 meter 16 day composites to facilitate creation of cloud free time series. Higher resolution data afforded by Landsat are complicated by the difficulty in creating cloud free images across time series and the failure of the scan line correction on Landsat 7 (B. Butt 2010b). No research utilizing Landsat imagery to characterize NDVI in landscapes comparable to the study site was found. Savanna ecosystems are stochastic in both space and time (K. Homewood 2008), so these two issues need to be addressed when attempting to summarize NDVI values as a proxy for forage resources. Most studies in this region utilizing NDVI have either used a specific time period to calculate summary metrics or made distinctions between the wet and dry seasons (Shauna B. BurnSilver, Boone, and Galvin 2004; Fuda et al. 2016). However, utilizing a single date may not accurately characterize forage availability over longer time periods. For the purposes of this study, summary metrics of NDVI were created based on 15 years of annual MODIS 250 meter images, from 2001 to 2016. To account for potential influence of low quality pixels created by cloud cover in the raw NDVI, the time series data was smoothed using a double logistic smoother in the Timesat program (Jönsson and Eklundh 2004). The results of the smoothing are shown in Figure 4. For the household-level data analysis, which is based on 2010 survey data, NDVI metrics were recalculated for the period from 2000 to 2009.

Two considerations need to be explored when trying to summarize NDVI as metric of forage access. First, since the literature supports the idea that people are living a more settled pattern (Western and Manzolillo Nightingale 2003; Worden 2007), it follows that they are evaluating not just the seasonal productivity of the landscape, but rather need to account for forage quality over a period of time. Second, the literature also suggests that two distinct spatial scales need to be considered; during the wet season when good forage is more abundant cattle typically graze within 2km of the boma. However, during the dry season cattle may need to travel up to 10km from the boma in order to obtain enough daily forage (B. Butt 2010a; Coppolillo 2001, 2000). Conceptually we can think of the mean NDVI as a metric of the overall productivity of a given pixel over time. Correspondingly, we can see the coefficient of variation as an expression of how variable a pixel has been over time (Michaud et al. 2012; Trench et al. 2009).

Household Level Data (RQ2)

To address the question of how settlement locations may influence household livelihoods (RQ2) geographic variables were matched with quantitative household level data collected in the study site in 2010. These data were collected by a structured household survey conducted from

September to December 2010 (T. Baird 2012). Data were collected on livestock holdings, household demographics, and economic activity for the previous 12 months. These surveys were conducted by trained Maasai enumerators. The original data included 216 respondents from six villages, four within the present study area villages and two outside (T. Baird 2012; T. Baird and Leslie 2013). This study uses a subset of 111 households within the four study site villages for which locations were collected by GPS in 2010 and which had no missing data.

Analyses

The first goal of this project was to explore the relationship of various landscape level factors on overall settlement patterns within the study area (RQ1). Examining this relationship consisted of two sets of analyses. The first set included a general evaluation of landscape scale patterns in the distribution of bomas to explore any broad associations with settlement. The second set of analyses consisted of partitioning the study site into occupied and unoccupied areas and constructing a series of models, based on logistical regression, to test a set of competing hypotheses regarding the geographic correlates of settlement patterns. These variables and summary statistics are listed in Table 1. The second goal of this project was to evaluate if geographic variables are associated with household livelihood strategies, diversification, or economic outcomes (RQ2). To examine this relationship, I estimated four linear regression models. The variables for these models are further described in Table 2.

Landscape Scale Factors

Initial analysis of landscape-scale factors consisted of mapping households in the study area and conducting a series of basic geographic analyses to characterize and evaluate broad patterns in settlement density. These analyses evaluated variations in overall settlement density at the village level, as well as within major climactic zones, in relation to soils, and the extent of agricultural development within the study area. Agriculture was not included in the modeling of occupied and unoccupied territory, since this is a human activity that would not be expected to be found far from settlements. While speculatively we could associate proximity of agriculture as a preference for settling near productive soils, it would be better to rely on accurate information on soils data, which is not available at high resolution in the study area. While the literature indicates that many pastoralist households cultivate small plots of several acres near the household (M. Thompson and Homewood 2002), other agricultural holdings may not be directly adjacent to the boma (McCabe, Leslie, and DeLuca 2010), so we cannot directly link individual bomas to specific fields.

Partitioning the Study Site

To develop a model of settlement patterns, I analyzed both occupied and un-occupied areas of the study area. When evaluating the impact of remotely sensed metrics on observational data, it is useful to divide the landscape into equal units of analysis (Michaud et al. 2014). In this instance, nearest neighbor analysis indicated that the mean distance between the mapped bomas was approximately 400 meters. I divided the landscape into continuous non-overlapping hexagons with centers 400 meters apart to approximate a unit of selection for individual households. Visual inspection indicated that most cells hold one boma, although some do hold two, which indicated this is an effective approximation of the household “decision space.” One additional factor that needs to be accounted for is cells that cannot be inhabited for reasons not associated with the variables of interest. As discussed in the Study Area section, “black cotton” vertisols in the study area are inundated by seasonal rains. These areas do not serve as settlement sites, a fact that is clearly identifiable on multispectral imagery. Correspondingly, all cells that contained a majority of this soil type were manually removed from the study grid. This left 6,479 cells for analysis, 772 of which were occupied (12%), as shown in Figure 5. I then calculated mean values at the cell level for each of the geographic variables under consideration, for both occupied and unoccupied cells, except for the NDVI metrics, which were calculated as mean values within the 2 and 10 km buffers around cell center points. These variables and their summary statistics are provided in Table 1. All GIS analysis was conducted in QGIS (QGIS Development Team 2016).

Spatial Modeling

To address RQ1, binomial logistic regression was used to evaluate the impact of individual geographic variables, as discussed in the Data Collection section, on the probability of a given cell being occupied (i.e., containing a boma). To increase inference of the coefficients, NDVI means and Coefficient of Variation measures were standardized. All distances were divided by 1000 to estimate coefficients at 1 kilometer, and elevation in meters was divided by 100. To test if nonlinear relationships were present between settlement probability and distance related variables, linear distances were compared with second degree polynomial transformations. These transformations allow us to test if settlement probability might be higher at intermediate distances from geographic features, rather than immediately adjacent to or far from those features (Msoffe et al. 2011; Serneels and Lambin 2001). In all cases the squared distance terms improved model accuracy and so were included in the final models. In the study area, elevation is highly positively correlated with annual precipitation (0.7995), and negatively correlated with mean annual temperature (-0.9591). Considered individually, elevation had the highest level of discrimination between occupied and un-occupied cells, as compared to precipitation and temperature, so elevation was retained in the combined models. Other researchers have similarly used elevation as a proxy for agro-ecological suitability (Little et al. 2001; Trench et al. 2009). Mean NDVI at 10km and 2km were highly correlated (0.7308), as were the coefficient of variation metrics (0.8229). The metrics for 10km were more discriminatory between occupied and unoccupied cells, so were retained for the final models. The 10km radius for NDVI summary metrics was also used by Trench et al. (2009). These variables were then combined into a suite of models to test the hypothesis in the pastoralist literature regarding settlement patterns. Model comparison was conducted by corrected Akaike Information Criteria (AICc), which compares model fits, but penalizes models with more parameters to avoid overfitting. A lower AICc indicates a more parsimonious model (K. P. Burnham and Anderson 2004). Area under the curve (AUC) is used to give an indication of the accuracy of the model in predicting the occupied classification, with a level of 0.5 being an even chance of predicting the correct category, so larger numbers indicate better predictive capacity (Friedman, Hastie, and Tibshirani 2009). Models were run as generalized linear models with a binomial link function in base R (R Core Team 2017). The final model with the highest predictive capacity was then used to compare predicted settlement patterns with known boma locations.

Household-Level Analysis

To test the hypothesis that a household's location on the landscape is associated with livelihood strategies and outcomes (RQ2), a subset of the variables from the settlement pattern model were tested against a set of measures that represent household-level measures. Similar methods have been used in the study area (T. D. Baird and Gray 2014) and more broadly in the region (Serneels et al. 2009; D. M. Thompson, Serneels, and Lambin 2002; Trench et al. 2009). Four different dependent variables were examined: tropical livestock units (TLU); acres under cultivation; income for the prior 12 months(in Tanzanian Shillings); and a Herfindahl index (T. D. Baird and Gray 2014; Rhoades 1993), which serves as a measure of income concentration (i.e., the inverse of diversification). To create more normal distributions and account for zero values, decimal values of 0.1 were added to the TLU and acres under cultivation metrics and variables were log transformed. Income was also log transformed. Variables and summary statistics are described in Table 2.

Factors from the settlement pattern model that were included are elevation, standardized mean NDVI within 10km[a] of the boma, distance to nearest water, distance to nearest road, distance to village center, and distance to the border of the LGCA. Distance variables were evaluated as quadratic terms, however, did not improve model fits and so were not included in the final models. Also, included as controls were demographic household level factors that have been shown by other researchers to impact household level outcomes: household size; age of the household head; and education status of the household head. TLU (log transformed) and acres cultivated (log transformed), were also included as independent variables for models in which they were not the dependent variable. Similar variables were used by both Trench et al. (2009) and Thompson, et al. (2002). To test for village level effects, villages were included as random effects. Models were run in the R package lme4 (Bates et al. 2015).

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[a] Mean NDVI values were recalculated for the time period of 2001 to 2009.

RESULTS

Landscape Level Settlement Patterns (RQ1)

Utilizing the methods outlined in the data collection section, 953 bomas were identified and mapped within the official boundaries of the 4 study site villages (Figure 2, Table 3). A kernel density map clearly shows clustering of settlement patterns (Figure 6). The spatial pattern of boma locations was also evaluated with Ripley's L test for complete spatial randomness (CSR), where the observed number of neighboring points at a given distance is compared to a simulation of points with a uniform distribution based on the global density of the points. This can be considered the "null model" of spatial distribution, (Baddeley, Rubak, and Turner 2015). This test indicates that these points are non-randomly distributed in a clustered pattern, at least up to the distance of approximately 10km (Figure 7).

As described below, there appear to be three broad landscape scale patterns that may be shaping settlement patterns within the study site; soil conditions suitable for settlement, favorable climactic conditions, and the extent of agriculture.

The most apparent factor affecting distribution of bomas in the study area appears to be the presence of the "black cotton" vertisols (Figure 8). This soil type is clearly visible on aerial imagery of the study area, and only three bomas were mapped on this soil type (which is likely a result accuracy of the digitization of the soil extents). Table 4 summarizes the results of excluding the mapped areas of vertisols from the "habitable" universe of the study area. Overall the density of bomas per kilometer increases from 0.63 to 0.85. Excluding these areas also increases the divergence from the bounds of spatial randomness in the Ripley's L-test, indicating increased clustering of settlements (Figure 9).

Overall climactic patterns also appear to be shaping settlement patterns in the region. As discussed, the region is covered by 3 major climactic zones (Figure 10). Even when excluding areas assumed to be unavailable for habitation, there is evidence of preferential settlement of the wetter, more temperate portions of the study area (Pearson Correlation <.0001). The Lower Mesotrophical zone covers only 26.9 % of the study area, however 41.5% of mapped bomas were found in this zone, which predominates in Loiborsoit. Settlement in the adjacent Lower Mesotropical Dry zone is nearly equivalent with available area; with 42.1 % of the habitable area, and 43.9% of mapped bomas. The Upper Thermotropical Dry zone however constitutes 31% of the total area, but only 14.7% of bomas were mapped in this zone. Consequently, the Subhumid zone has the highest density of households, at 1.30 per square kilometer, while the dryer zone only has a density of 0.40 households per square kilometer. These results are summarized in Table 5. To capture a more continuous range of climatic factors, elevation, mean annual precipitation and mean annual temperature were evaluated in the logistic regression portion of this analysis rather these categorical distinctions.

There are variable amounts of agricultural development across the study site (Figure 11). In total agriculture covers 9% of the total study area. However, this increases to 13% if only considering the habitable zones, which appear to limit agriculture as well. Emboreet has the highest portion of agriculture totaling 13% of the total cover, and 19% of the habitable land. Agriculture is relatively uncommon in Sukuro and totals only 3% of village land (Table 6). In Emboreet the mean distance to an agricultural plot is 180 meters, and 50% of households were within 100 meters of agriculture, and the maximum distance from agricultural plots was 1,500 meters. By contrast, in Sukuro, the mean distance is 652 meters, 50% quantile is 275 meters, and the maximum distance is over 4 kilometers. Distances to agriculture are summarized in Table 6.

Logistic Regressions (RQ1)

The bivariate results of the geographic variables on settlement probability are summarized in Table 7. All the geographic factors were statistically significant predictors of settlement at the $p < .0001$ level, with the exception of slope. However, there is a wide range of predictive capacity. Distance to nearest village was the strongest predictor (both as a quadratic term and untransformed), followed by distance the Lokisale Game Control Area (quadratic), distance to water (quadratic), elevation in meters/100, then distance to roads (quadratic), mean annual temperature, then mean annual precipitation, followed by the NDVI related and other metrics, which all show only modest predictive capacity.

The parameters of the combined geographic models are shown in Tables 8 through 11, models are compared in Table 12. Of the integrated models the resource access model (Table 8) had the lowest predictive ability, and highest AICc. The environmental constraints model (Table 9) showed improved predictive ability, but the AUC was only slightly better than the resource access model. Of the hypothetical models, the modern amenities model had the highest AUC and lowest AICc score (Table 10). However, the combined model (Table 11), which can be considered a balanced of trade-offs between the three other models, had a lower AICc and a 0.06 improvement in the AUC over the modern amenities model. Figure 12 compares the predicted probability of settlement from the combined model with the known locations of bomas. Figure 13 shows a cumulative distribution plot of the number of occupied cells correctly predicted against the modeled occupation probability.

Household Outcomes(RQ2)

Results of the household outcomes models are summarized in Table 13. Of the four models of livelihood strategies and economic outcomes, only the Herfindahl model of income diversity showed any statistically significant association with a geographic variable. According the TLU model, household size had a positive effect on livestock holdings, as did the number of acres under cultivation, there was a positive effect associated with village of Loiborsoit. Age of household head had a negative association with TLU holdings. In the acres planted model, TLU holdings were a positive effect. The income model shows a positive effect of both livestock holdings and household size, while acres planted and age of the household head had negative associations. The model for the Herfindahl index shows a positive relationship (which indicates less diversity, as a lower score reflects more balance between income sources) with household size and distance to water, there was a negative effect with acres planted.

DISCUSSION

Although the consensus among researchers is that formally mobile pastoralists are undergoing a transition to a more sedentary lifestyle, a process closely tied with diversifying livelihoods, few studies have a directly addressed the question of where people settle (Fratkin and Roth, 2005; Western and Manzolillo Nightingale, 2003; Worden, 2007). Leslie and McCabe (2013) specifically point out that the spatial arrangement of settlement and what livelihoods people pursue in different parts of the landscape will influence both the ecology of this region and the resilience of human communities. This thesis has sought to explore where on the landscape people are settling and what consequences that may have for their economic outcomes.

The results of the spatial modeling portion of this research support the hypothesis that both the built and natural environment matter in shaping settlement patterns of Maasai pastoralists within the study site. The most parsimonious spatial model included a combination of factors from each hypothesis, suggesting that a balanced set of tradeoffs exists in shaping settlement patterns. This pattern may also reflect the increasing livelihood diversification of pastoralists, which also involves balancing competing interests and is intertwined with sedentarization (K. Homewood, Trench, and Kristjanson 2008; McCabe, Leslie, and DeLuca 2010; Little et al. 2001; Trench et al. 2009). Household level analysis results were more mixed. While results are generally consistent with the literature on pastoralist livelihoods, I found no evidence that geographic variables influenced livestock herd sizes, land under cultivation, or household income in 2010, controlling for other factors. However, the results do show that households located further from water sources had less diversified income sources.

Spatial analysis of settlement patterns show that that geophysical features of the landscape play an important role in shaping the broad patterns of settlement. The most observable variable impacting settlement patterns in the study area was the presence of “black cotton” vertisols. These soils cover approximately 26% of the study area, are uniformly uninhabited, and apparently do not support agricultural production. This makes logical sense, as these soils are poorly drained and can be seasonally un-traversable (J. Kahurananga 1979). This is also consistent with the findings of Western and Dunne (1979) that Maasai sought to avoid these kinds of areas because of their detrimental impact on cattle and human well-being during the rainy season. However, these soils do have high value for forage for both wildlife and pastoralist livestock (Mlingano Agricultural Research Institute 2006). These areas may represent opportunities to maintain ecological connectivity with strictly protected conservation areas to the west and may also represent reserves of forage, at least seasonally, for pastoralists concerned about loss of grazing lands to agriculture development. At the same time, this also means land availability for both settlement and agricultural expansion is significantly constrained in some parts of the study area, which may lead to increased competition for open land.

This study shows that settlement densities vary significantly across the study area and between villages. Even considering the extent of uninhabited soils, this research found that bomas are more clustered than would be expected by random chance. There is not evidence of strong resource competition that would require individual settlements to maximize their distance from other settlements in order to have exclusive access to local resources. For example, in Kenya, Worden (2007) found that subdivision of land led to a more dispersed settlement pattern compared to areas that were not subdivided. Little et al. (2001) observed that generally the more densely populated an area is, the less land is accessible for communal grazing. However, settlement density of Maasai communities is underexplored in the literature. It is unclear if the higher levels of density evident in parts of the study site would be considered “crowded” by Maasai standards, or if there are upper limits to settlement density that may become evident as population grows in these communities. Few studies have examined how much flexibility Maasai in the study area have in establishing new households, as when young men leave their father’s boma, or moving the household. We know very little about how much density constrains settlement choice in this setting. It may be the case that less densely settled areas allow for more flexibility in settlement location, while in denser areas people need to settle wherever space is available. This would likely be a fruitful line of inquiry for future researchers, particularly comparing more and less densely settled areas.

Of the three a priori spatial models of settlement, the modernization hypothesis performed the best. However, it showed only a small improvement over the other two models. The model combining these various factors should significant improvement in predicting settlement patterns. This supports the idea that multiple forces are at play in determining where people live, and that they may be seeking a balance between environmental constraints on one hand and modern infrastructure and village based amenities on the other. Overall the modeling results support the general theme in the literature that Maasai in the study area may be undergoing a shift in their social ecological-system, transitioning from a mobile lifestyle focused on pastoralism and designed to access seasonally unpredictable resources at broad spatial scales, to a more fixed lifestyle where access to economic opportunities and development assets are also important (T. Baird and Leslie 2013; Leslie and McCabe 2013; Sachedina and Trench 2009; Worden 2007). While there is not particularly strong predicative power at the grid cell level, even in the full model, as reflected in the modest AUC, there is broad agreement between the model and the known occupation pattern at the landscape level (Figure 12). Looking more closely at the cells with a high probability of being occupied in the model, but which are not occupied, shows that many of these cells are covered by agriculture fields, underlining the importance of better modeling approaches to address the interplay between settlement patterns and agricultural development.

The density of agriculture varies broadly across the study site, and the extent of agricultural development likely impacts settlement patterns. It also likely that extensive agricultural development effects the ability of herders to physically negotiate the landscape while moving livestock between the boma and forage or water resources. In other parts of East Africa, pastoralists have expressed concerns that agriculture is crowding out opportunities for livestock keeping

(Kimiti et al. 2016; Western, Groom, and Worden 2009). A local informant from the household surveys conducted in 2010 summed up this tension:

"It will become difficult for the Maasai. Maybe in 10 years' time there will be no land for grazing. It will all be plowed maybe. For the educated this will be okay, but not for those relying on livestock" (Baird unpublished group interview).

Accounting for agricultural impacts on settlement patterns proved difficult to model at the landscape level. Many bomas are located within mix of agricultural plots, so attempting to exclude these areas from the settlement modeling, as was done with the vertisols, would be problematic. Maasai in the study area are very aware of the concerns that conservationists have regarding agricultural development, and are often reluctant to discuss agricultural holdings, particularly their locations, with researchers (Baird, personal communication).

One limitation of this study is the difficulty associated with adequately modeling forage access at scale. While remote sensing helps to evaluate metrics like NDVI at large scales and has proved useful in a number of studies of pastoral land use (B. Butt 2010b; Coppolillo 2001; Moritz et al. 2014; Trench et al. 2009), it remains difficult to identify unique resource areas, embedded in the larger landscape, that may play a critical role in forage access strategies (Shauna B. BurnSilver, Boone, and Galvin 2004; Coppolillo 2000; Miller 2015; Worden 2007). It is also important to understand to what extent differences that are detectable through remote sensing translate to differences in the actual landscape that Maasai might recognize and act on. In other areas, researchers have used GPS tracking to trace and quantify the movements of livestock herds, which may give a better picture of fine scale resource utilization, but is difficult to generalize to other landscapes (Butt, 2010a, 2010b; Coppolillo, 2000; Moritz et al., 2012). Agent-based modeling may be a better approach to modeling forage resource access, but it takes significant technical and computing resources to achieve (Moritz et al., 2010). Also, although dependent on local resources, Maasai have numerous cultural strategies to deal with highly variable resource access, including social networks that emphasize reciprocity (T. D. Baird and Gray 2014) and also sending their livestock to another location where conditions are better (Butt, 2011; McPeak and Little, 2005; Sachedina and Trench, 2009), which obviously complicates modeling resources access from a central location. The generalized forage access model used here could be significantly refined by qualitative work assessing how resources access is affected by local conditions like the prevalence of agriculture and infrastructure development.

This research represents only a single snapshot in time, so inference about how settlement patterns are changing is limited. Our understanding of sedentarization would be greatly enhanced by a longitudinal approach that mapped changes in settlement patterns over time. The wide availability of free, high resolution remote sensing data makes this much more feasible than it has been in the past. Historic information about settlement patterns is also difficult to come by at large spatial scales due to the ephemeral nature of household locations. Working in Kenya, Worden (2007) used field work and local informants to recreate historic settlement patterns that provided some contrast to current patterns. While this approach could be useful in the study area, it would be extremely labor intensive.

The main disadvantage to a spatial, remote sensing approach to evaluating settlement is that we know very little about the identified households beyond where they are. These methods are of limited utility explaining household level decisions, which are highly contingent on individuals' circumstances, history, and social resources, and not easily modeled spatially. There are certainly cultural, social and political pressures that play a role in what portions of the landscape become settled that have not been captured by this study. Ideally, this study would be paired with qualitative field work to further refine and test spatially derived hypothesis and observations.

The results of the household level analysis are mixed, with only the livelihood diversification model showing that diversification is negatively associated with distance from the household to permanent water sources. In the remaining models, household demographic factors were better predictors of economic variables.

The model of TLU showed that herd sizes are positively associated with the amount of land under cultivation. This supports the findings from other researchers that well off pastoralists often utilize agricultural production to maintain or expand livestock holdings and to avoid selling livestock for revenue (McCabe et al. 2014; McCabe, Leslie, and DeLuca 2010; J. McPeak and Little 2005). This model also showed a positive association between household size and livestock holdings, which makes logical sense as more household member allows for the labor necessary to manage large livestock holdings. This relationship has been documented in other Maasai communities (S. B. BurnSilver 2009). This model also shows a positive association between livestock holdings and households in the village of Loiborsoit. While the small sample size cautions much inference from this result, Leslie and McCabe (2013) have documented that Loiborsoit has specifically set aside large areas of common pool grazing lands, which may make livestock keeping a more favorable activity in the village. Formal efforts to protect grazing lands through conservation easements may also be gaining support throughout the study area (Nelson et al. 2010; Sachedina and Nelson 2010), which could influence future livelihood opportunities in proximity to these areas.

In the acres planted model, there was a significant positive correlation with livestock herd size. This supports the hypothesis that households may be using success in agricultural production to maintain livestock herd sizes (McCabe, Leslie, and DeLuca 2010) and that generally wealthier people can afford to diversify into other livelihood opportunities (Little et al. 2001; Trench et al. 2009).

In the income model, acres planted, TLU, and household size are positively correlated with income levels. These results are consistent with other research that has found that income tends to be determined by these factors (S. B. BurnSilver 2009; Nkedianye et al. 2009; Trench et al. 2009). Respondents to the original survey indicated 2010 was good year for rainfall (T. Baird and Leslie 2013), so this result may also reflect the benefits of favorable weather conditions on livestock and agricultural production. Hypothetically, geographic factors might be more likely to impact income levels times of resource stress. For example, people further from permanent water sources may be more impacted by drought conditions. Longitudinal data on how household income strategies vary from year to year would better address this hypothesis.

The Herfindahl income diversity model was the only one to show statistically significant influence of a geographic variable. There was less income diversity associated with greater distance from permanent water sources. In Northern Kenya, McPeak and Little (2005) found that larger livestock herds tend to be located in drier areas, where herders are more reliant on income from livestock. This may also reflect the observation from other studies that opportunities for diversification are limited in areas with poor infrastructure (Trench et al. 2009).

One possible explanation for the lack of correlations between geographic factors and household economic outcomes is that Maasai have effective cultural and social strategies that allow them to overcome limitations associated the household location. Generally, pastoralists have extensive social networks based on reciprocity and exchange which can help them overcome economic setbacks, however these networks may also be under increasing pressure as livelihoods diversify and people pursue more individualized strategies (T. D. Baird and Gray 2014). Qualitative work could be used to more directly understand how the location of the household shapes livelihood diversification and what challenges and opportunities people may face as a result of the location of the household.

One limitation of the household analysis is the small sample size and sampling design. The original surveys were designed to sample from differing sub-villages in proportion to their populations and households with representative of the range of wealth statuses (T. Baird and Leslie 2013). This study utilized a subset of the data with complete data where the location of the household was known, so the sample may not be representative of all the geographic gradients across the study site. Trench et al. (2009) also observed that while spatial variables tend not to be strong predictors of household level incomes, they can often predict where people practice certain strategies. One approach to addresses this issue is to cluster households by livelihood or other income metrics, and to then predict membership in a certain cluster based on geographic and other variables (S. B. BurnSilver 2009; D. M. Thompson, Serneels, and Lambin 2002; Trench et al. 2009). Given the limited sample size of households with known locations, individual clusters would have few members. Correspondingly this was not considered a viable approach for this study, but could be a fruitful avenue for future research. Also while livelihood diversification is generally considered to be unidirectional (K. Homewood, Trench, and Kristjanson 2009; McCabe 2003), other authors have argued that people may exercise considerable annual flexibility in livelihood strategies (Little et al. 2001). An interesting avenue of future research would be to apply a cross sectional approach to the question of how household location influences how flexible livelihood strategies can be.

TABLES

Table 1. Summary statistics for geographic variables in occupied and unoccupied portions of the landscape.

Variable	Occupied Mean	Occupied SD	Unoccupied Mean	Unoccupied SD	Occupied vs. unoccupied[b]
Distance to nearest Village center (km)	6.52	3.11	9.64	5.14	***
Distance to Lokisale GCA (km)	19.76	9.48	22.31	13.62	***
Distance to permanent water (km)	2.95	1.55	4.11	2.47	***
Elevation (meters)	1486.17	4.71	1447.25	78.16	***
Distance to nearest road (km)	1.92	1.74	3.09	2.66	***
Mean annual temp(C)	19.02	0.38	19.23	0.47	***
Mean annual precipitation (mm)	791.44	61.38	758.28	73.16	***
Mean NDVI@2KM	0.396	0.03	0.391	0.03	***
Mean NDVI@10km	0.402	0.02	0.395	0.02	***
Tsetse fly probability (%)	61.81	10.52	65.22	11.34	***
Canopy cover (%)	2.66	2.34	3.48	2.91	***
Coefficient of Variation in NDVI@10km (%)	39.86	2.38	40.20	2.19	***
Coefficient of Variation in NDVI@2km (%)	39.52	1.82	40.04	1.58	***
Slope (%)	2.74	1.19	2.68	1.16	-

[b] Difference in means between occupied and unoccupied grid cells using Students *t* test. *** $p < .001$

Table 2. Variables descriptions and summary statistic for regression models.

Variable	Description	Sample Mean	Sample SD
Dependent Variables			
TLU[c]	Tropical Livestock units	5.11	5.93
Acres Planted	Number of acres planted in the prior year.	7.62	10.98
Income	Household income from all sources in the prior year (Tanzania Shillings)	4,133,062	4,069,820
Herfindahl Index[d] *(%)*	Measure of income concentration, inverse of diversification.	0.71	0.21
Fixed Effects Variables			
Household Size	Total number of people in the household	11.2	7.1
Age of Household Head	Age in years of the head of household	46.93	12.54
Educated (0/1)	Does the household head have any formal education?	32%	-
Elevation	The elevation of boma in meters	1,483.98	61.94
NDVI at 10km	Average Normalized Differential Vegetation Index within 10km of the boma from 2001 to 2009	0.45	0.01
Distance to Water	Distance to the nearest permanent water source from the boma (km)	2.06	1.26
Distance to road	Distance to the nearest road from the boma (km)	1.34	1.42
Distance to Village	Distance to the center point of the nearest village center (km)	4.64	3.38
Distance to Lokisale	Distance to the border of the Lokisale Game Control Area (km)	20.10	9.01
Random Effects Variables			
Village	Which of the four study site villages is the household located.	-	-

[c] Tropical livestock units (TLUs) measure of livestock holdings accounting for different species; one adult zebu cow = 0.71, adult sheep/goat= 0.17 (K. Homewood, Trench, and Kristjanson 2008)

[d] The Herfindahl index is the sum of the squared percentage of income per source of total household income (Rhoades 1993). Sources of income include: livestock, agriculture, wage labor, business activities, and proceeds from leased land.

Table 3. Summary of boma locations by village.

Village	Bomas	Sq. KM	Bomas/sq. km.	2012 Population per Tanzanian Census
Loiborsoit	373	316.93	1.18	4,154
Terrat	152	200.39	0.76	2,944
Emboreet	250	462.54	0.54	2,254
Sukuro	178	552.41	0.32	2,703
Totals	**953**	**15,32.27**	**0.62**	**12,055**

Table 4. Effect of vertisols on settlement density calculations.

Village	bomas	Sq. KM	Settle-ment Density	vertisols extent (sq. km)	vertisols % of Surface Area	habitable area (sq. km)	bomas/hab-itable area
Loiborsoit	373	316.93	1.18	34.33	11%	282.60	1.32
Terrat	152	200.39	0.76	46.68	23%	153.71	0.99
Emboreet	250	462.54	0.54	150.22	32%	312.32	0.80
Sukuro	178	552.41	0.32	172.82	31%	379.59	0.47
Totals	**953**	**1,532.27**	**0.62**	**404.05**	**26%**	**1,128.22**	**0.84**

Table 5. Settlement density by climactic zone.

Climate Zone	***Sq. kilometers (habitable)***	***% of total area***	***# of bomas***	***% of bomas***	***boma/km***	***divergence***
Lower Mesotropical Subhumid	*302.95*	*26.9%*	*395*	*41.5%*	*1.30*	*14.6%*
Lower Mesotropical Dry	*475.23*	*42.1%*	*418*	*43.9%*	*0.88*	*1.7%*
Upper Thermotropical Dry	*350.08*	*31.0%*	*140*	*14.7%*	*0.40*	*-16.3%*

Table 6. Relationship of agriculture to settlements.

Village	**Mean Distance (meters)**	**Min Distance (meters)**	**Max Distance (meters)**	**Quantiles 25%**	**Quantiles 50%**	**Quantiles 75%**	**ANOVA p-value <.0001**
Emboreet	179.93	0	1,494.87	57.45	97.66	170.30	Sukuro, Terrat
Loiborsoit	202.76	0	1,957.13	36.69	75.66	194.99	Sukuro, Terrat
Sukuro	652.90	23.67	4,227.81	125.87	275.81	1,011.36	Emboreet, Loiborsoit
Terrat	580.77	0	3,625.54	73.86	218.80	828.83	Emboreet, Loiborsoit
Study Site	**341.64**	**0**	**4,227.81**	**56.92**	**112.41**	**343.64**	**-**

Table 7. Bivariate logistical regression of geographic variables on settlement patterns.

Parameter	**Estimate**	**SE**	**Odds Ratio**	**Generalized r-squared**	**AUC**
Distance to Village (km) ^2	-0.189 (-0.010)***	0.014 (0.002)	#	0.0976	0.688
Distance to Village (km)	-0.169***	0.083	0.845	0.0916	0.688
Distance to Lokisale GCA ^2	-0.019 (-0.005)***	0.004 0.0003	#	0.0914	0.678
Distance to permanent water (km) ^2	-0.287 (-0.055)***	0.0002 (0.011)	#	0.0462	0.640
Distance to permanent water (km)	-0.260***	0.027	0.771	0.0393	0.638
Elevation (meters)	0.730***	0.057	2.075	0.0388	0.643
Distance to roads(km) ^2	-0.205 (-0.025)***	0.022 (0.009)	#	0.0503	0.626
Distance to roads(km)	-0.226***	0.020	0.798	0.0474	0.626
Mean annual temp(C)	-1.108***	0.094	0.33	0.0452	0.627
Mean annual precipitation(mm)	0.007***	0.0006	1.007	0.0447	0.626
Mean NDVI@2KM (standardized)	0.335***	0.039	1.399	0.0223	0.594
Mean NDVI@10km (standardized)	0.343***	0.041	1.409	0.0221	0.594
Tsetse fly % probability	-2.624***	0.330	0.725	0.0131	0.597
Canopy cover (%)	-0.110***	0.015	0.896	0.0176	0.570
CV NDVI@10(standardized)	-0.247***	0.035	0.306	0.0139	0.539
CV NDVI@2km(standardized)	0.807***	0.036	0.333	0.0100	0.552
Distance to LGCA (meters)	-0.015***	0.003	0.985	0.0076	0.545
Slope (%)	0.035	0.031	1.036	0.0004	0.514

**=p<.05, **=p<.01, ***=p<.001, # odds ratios are not interpretable for compound effects*

Table 8. Resource Access Model parameters.

Variable	**Coefficient**	**SE**	**Odds Ratio**	**Prob>ChiSq**
Standardized Mean NDVI@10km	0.302	0.043	1.35	<0.0001***
Standardized CV NDVI@10km	-0.124	0.092	0.88	0.0004**
Distance to Water/1000	-0.275	0.027	0.76	<0.0001***
Distance to Water/1000^2	-0.052	0.011	#	<0.0001***

Table 9. Environmental Constraints model parameters.

Variable	**Coefficient**	**SE**	**Odds Ratio**	**Prob>ChiSq**
Elevation/100	0.774	0.061	2.167	<0.0001***
Canopy cover %	-0.197	0.018	0.821	<0.0001***
Slope %	0.196	0.035	1.216	<0.0001***
Tsetse probability %	-2.413	0.373	0.090	<0.0001***

Table 10. Modernization model parameters

Variable	**Coefficient**	**SE**	**Odds Ratio**	**Prob>ChiSq**
Distance to Village(km)	-0.110	0.017	0.992	<0.0001***
Distance to Village(km)^2	-0.008	0.003	#	<0.0010**
Distance to Road (km)	-0.158	0.025	0.985	<0.0001***
Distance to Road (km)^2	-0.117	0.009	#	0.0641
Distance to Lokisale GCA(km)	-0.013	0.004	0.998	0.0027**
Distance to Lokisale GCA(km)^2	-0.002	0.0005	#	<0.0001***

*=p<.05, **=p<.01, ***=p<.001, # odds ratios are not interpretable for compound effects

Table 11. Full model parameters.

Variable	**Esti-mate**	**SE**	**Odds Ratio**	**Prob>ChiSq**
Elevation(m)/100	0.597	0.149	1.817	<0.0001***
Mean canopy cover(%)	-0.167	0.021	0.846	<0.0001***
Mean slope(%)	0.117	0.049	1.124	0.0164**
Probability of tsetse(%)	-1.011	0.409	0.364	0.0135**
Standardized mean NDVI @10km	0.706	0.076	2.025	<0.0001***
Standardized CV NDVI @ 10km	-0.054	0.059	0.947	0.3541
Distance to village(km)	-0.034	0.018	0.967	0.0601
Distance to village(km)^2	-0.008	0.003	#	0.0064**
Distance to water(km)	-0.136	0.032	0.933	<0.0001***
Distance to water(km)^2	-0.030	0.013	#	0.021*
Distance to road(km)	-0.129	0.031	0.828	<0.0001***
Distance to road(km)^2	0.006	0.011	#	0.5676
Distance to Lokisale (km)	0.042	0.011	1.021	<0.0001***
Distance to Lokisale (km)^2	-0.002	0.001	#	<0.0001***

**=p<.05, **=p<.01, ***=p<.001, # odds ratios are not interpretable for compound effects*

Table 12. Model Comparisons

Model	**AICc**	**Delta AICc**	**# of Parameters**	**Generalized r-squared**	**AUC**
Resource Access	4441.00	332.23	4	0.0638	0.684
Environmental Constraints	4395.73	286.96	4	0.1006	0.696
Modern amenities	4307.04	198.27	6	0.1266	0.706
Full Model	4108.77	0	14	0.1845	0.768

Table 13. Household outcomes regression parameters.

Variable	TLU (ln)	Acres Planted (ln)	Income (ln)	Herfindahl Index
Geographic Variables				
NDVI (standardized)	-0.187	-0.143	-0.133	-0.016
Elevation(meters)/100	-0.309	-0.343	0.087	0.162
Distance to water(km)	0.032	0.024	-0.009	0.048**
Distance to road (km)	-0.116	0.004	-0.018	-0.005
Distance to Village (km)	0.040	0.009	-0.006	-0.007
Distance to Lokisale GCA (km)	-0.007	-0.020	-0.006	0.005
Household Controls				
Age of Household Head	-0.039***	0.017	-0.010*	-0.002
Household Size	0.093***	0.004	0.028***	0.007*
Educated (0/1)	-0.513	0.374	-0.077	-0.025
Acres Planted (ln)	0.446***	-	-0.011*	-0.041*
TLU (ln)	-	0.259***	0.418***	0.009
Random effects variance	0.356	0.142	0	0.005
Village Loiborsoit	0.657**	-0.344	0	0.043
Village Terrat	-0.103	0.127	0	0.062
Village Sukuro	-0.247	-0.042	0	0.031
Village Emboreet	-0.307	0.260	0	-0.013
Number of households	111	111	111	111
Marginal r-squared[e]	0.339	0.187	0.792	0.288
Conditional r-squared[f]	0.464	0.298	0.792	0.393

**=p<.05, **=p<.01, ***=p<.001*

[e] Marginal r-squared is the impact of the fixed effects (geographic variables and house hold controls) on the model fit (Nakagawa and Schielzeth 2013).

[f] Conditional r-squared is the impact of the fixed and random (village) effects on the model fit (Nakagawa and Schielzeth 2013).

FIGURES

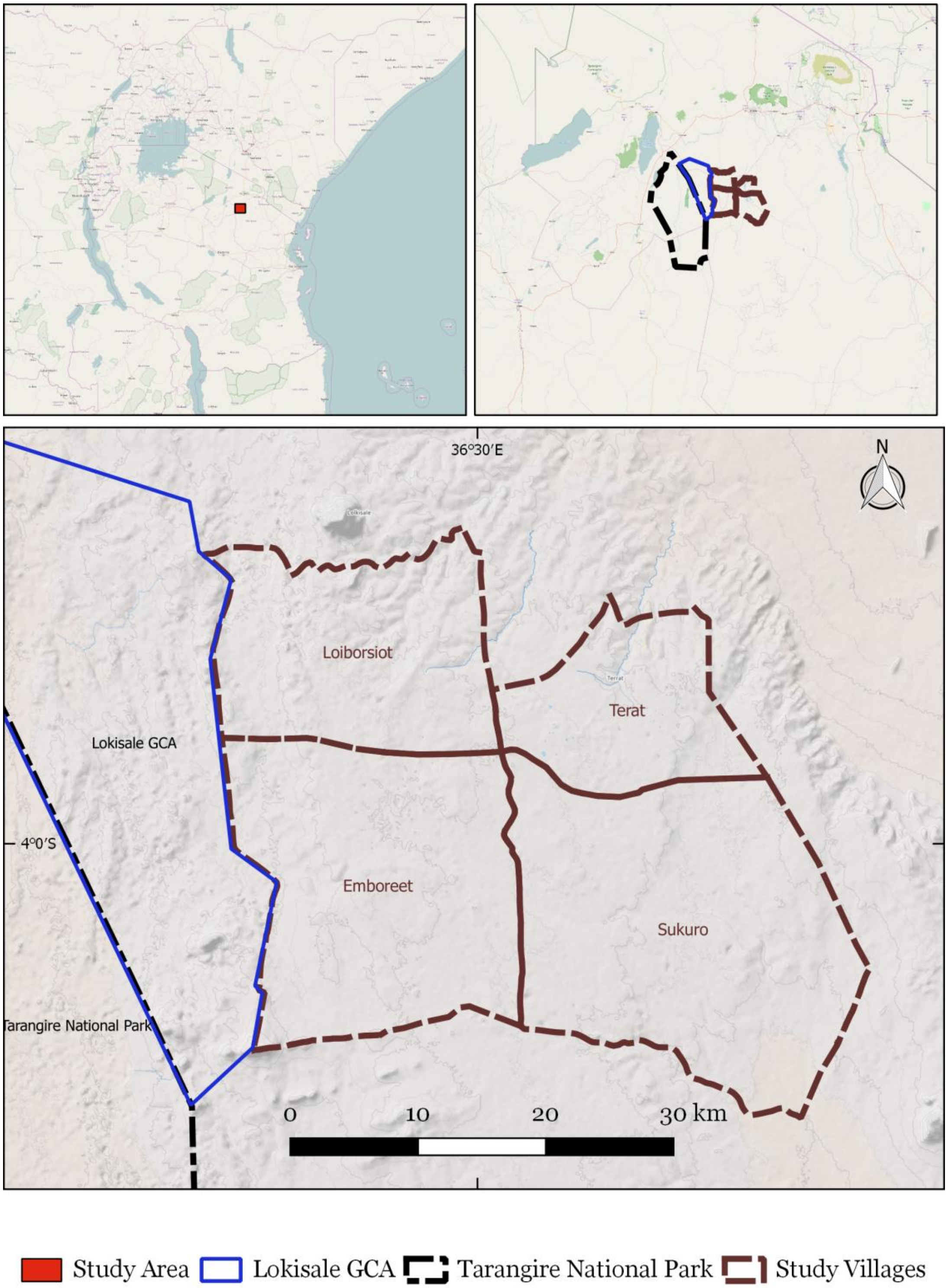

Figure 1. Study site.

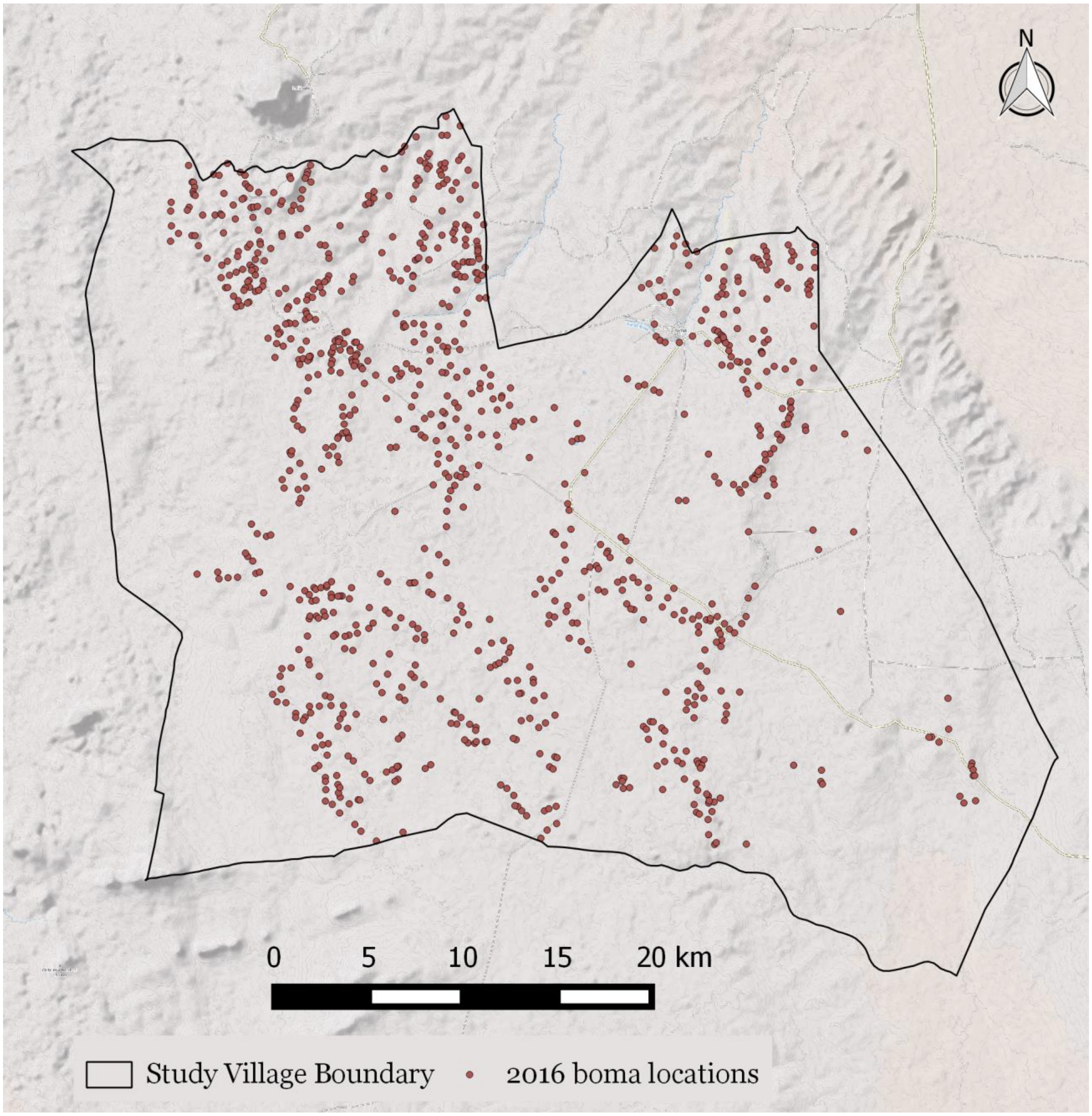

Figure 2. Location of 953 bomas identified in the bounds of the study villages.

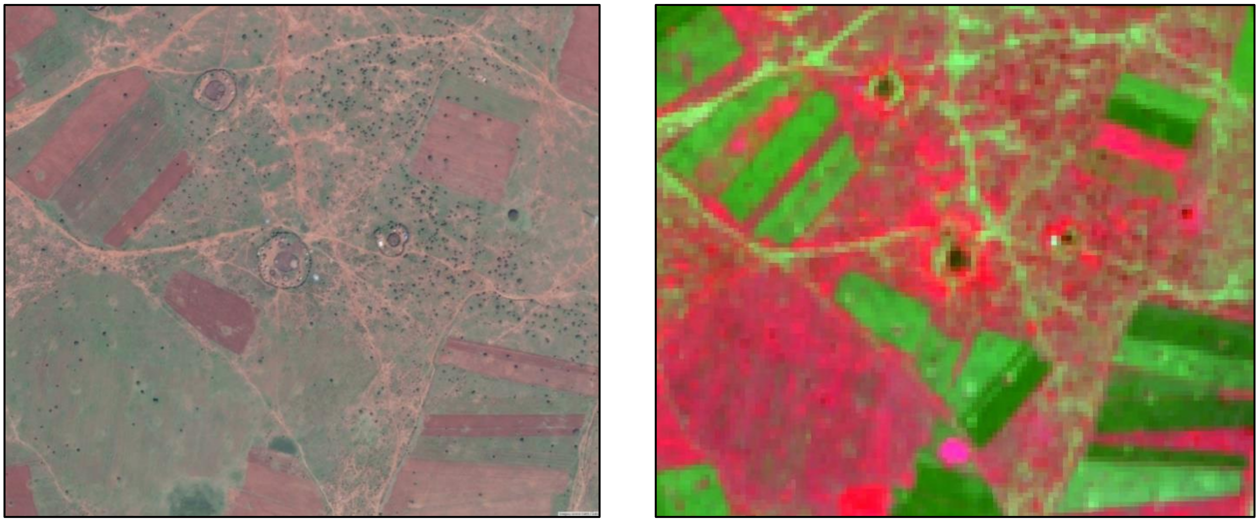

Figure 3: Identification of boma locations. The same area is shown in a Google Earth Image on the left, and a sentinel 2A image on the right.

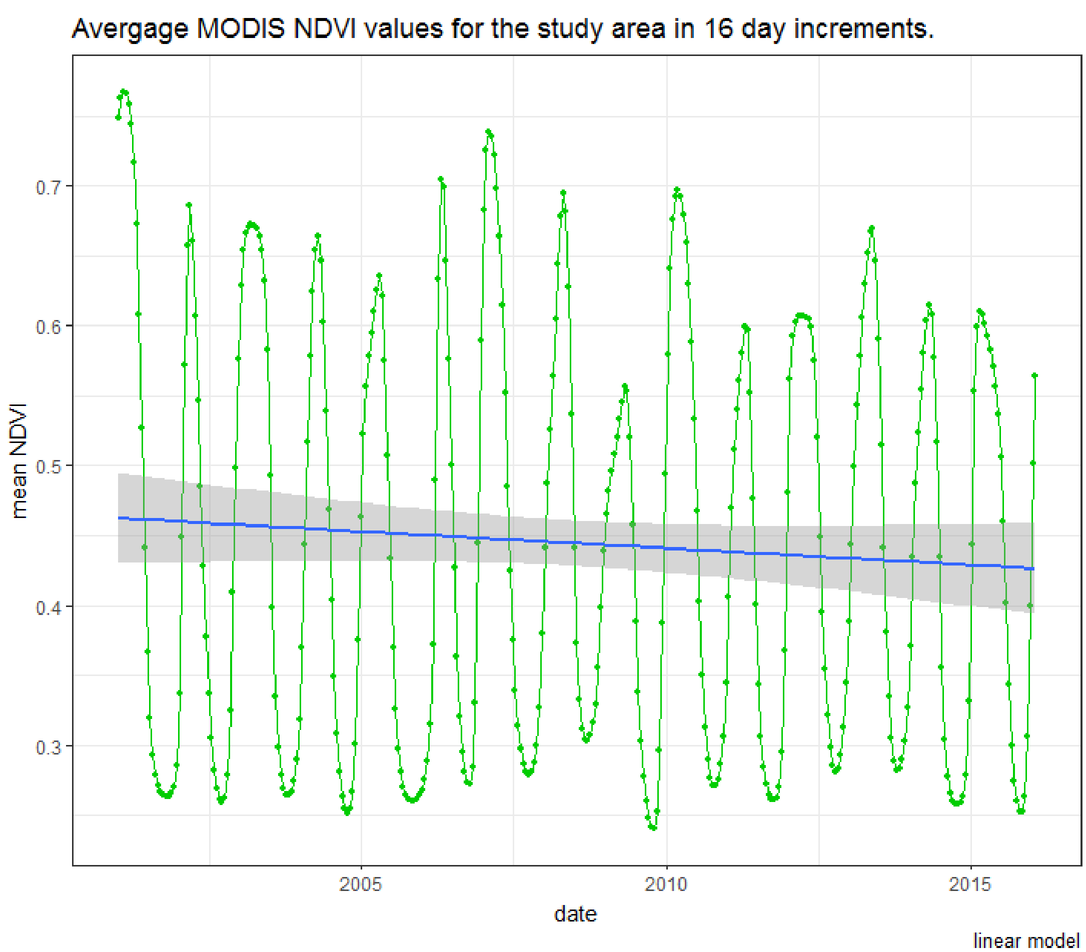

Figure 4. NDVI time series smoothed with linear trend line.

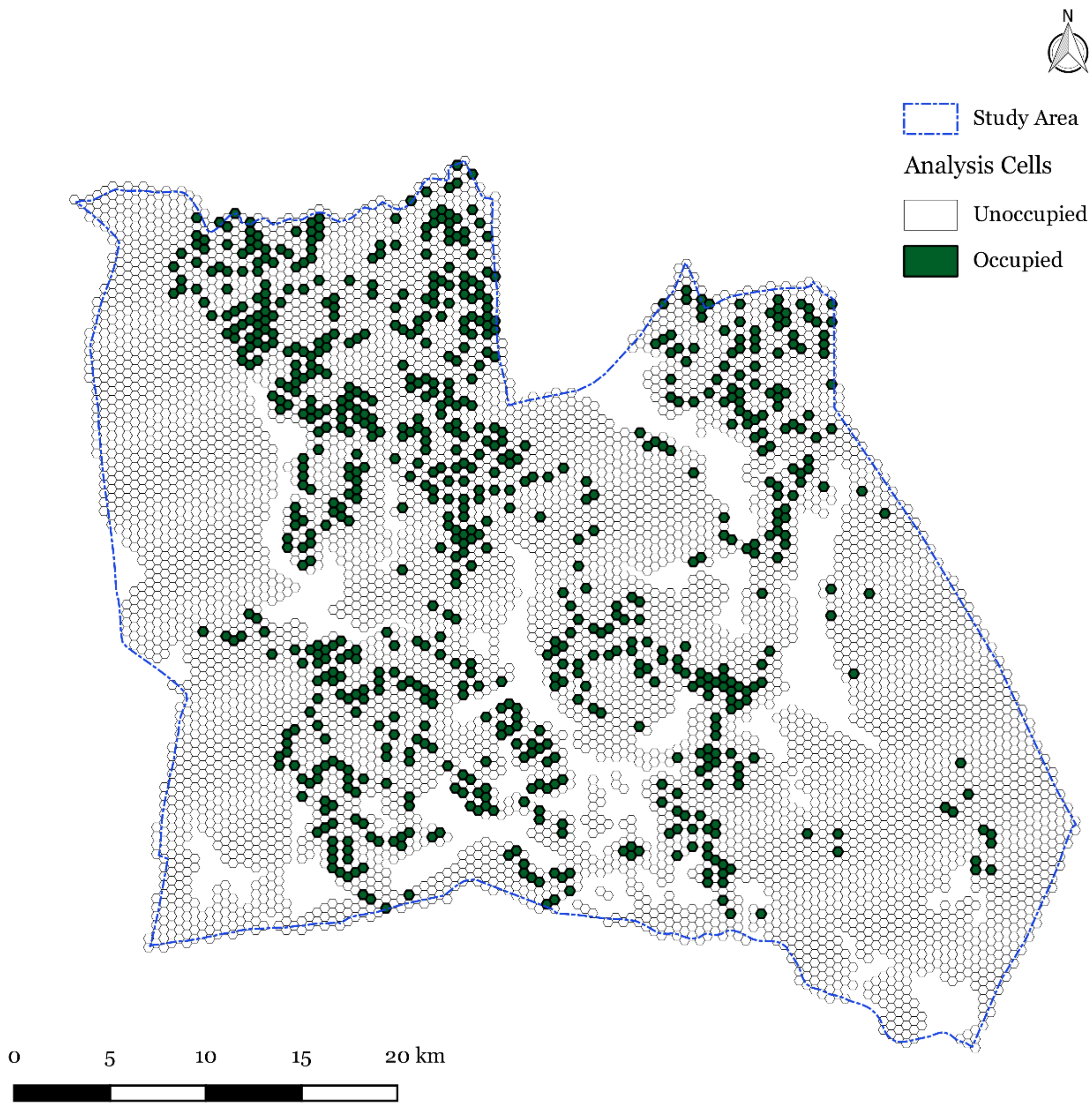

Figure 5. Partitioning of the study site into occupied and unoccupied 400m grid cells.

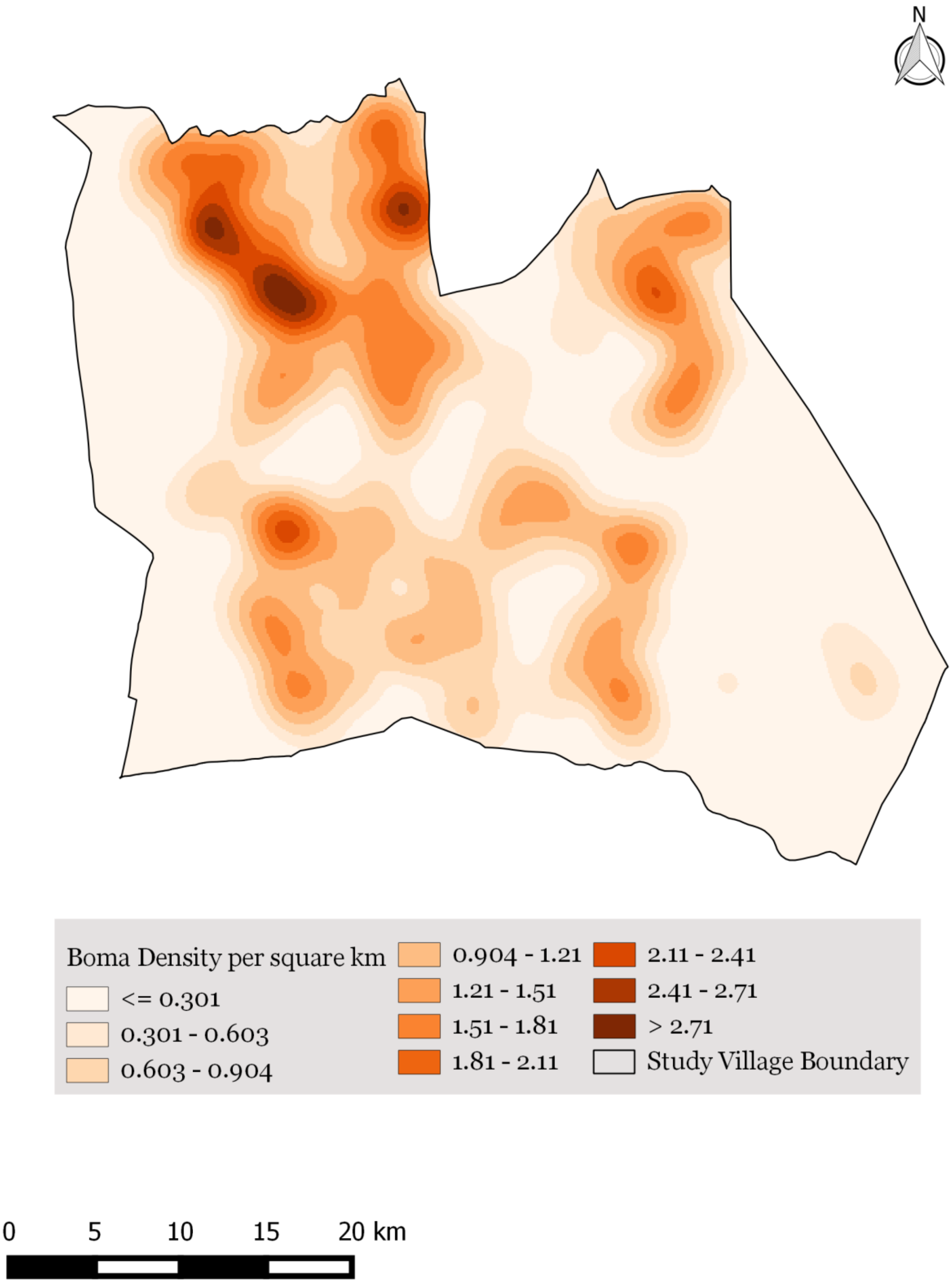

Figure 6. Kernel density map of bomas at 1 km.

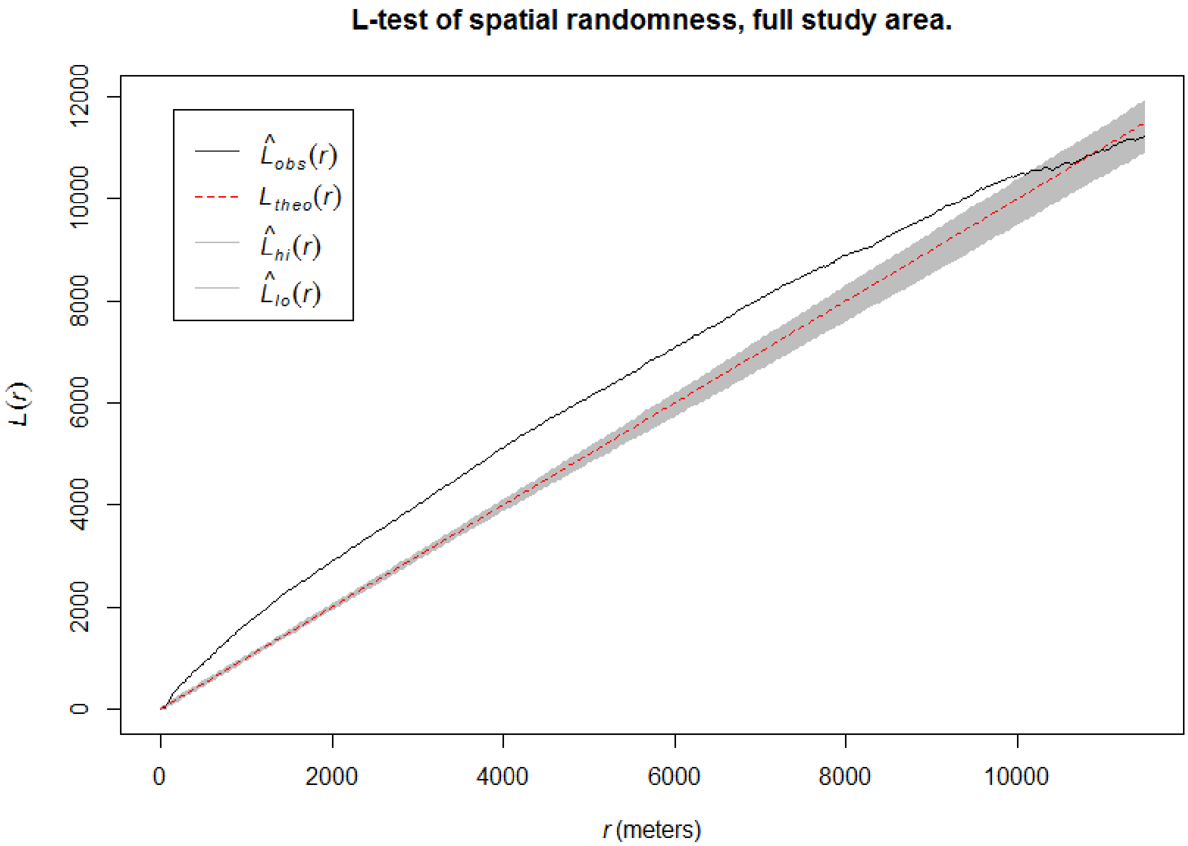

Figure 7. L-test of spatial randomness, full study area.

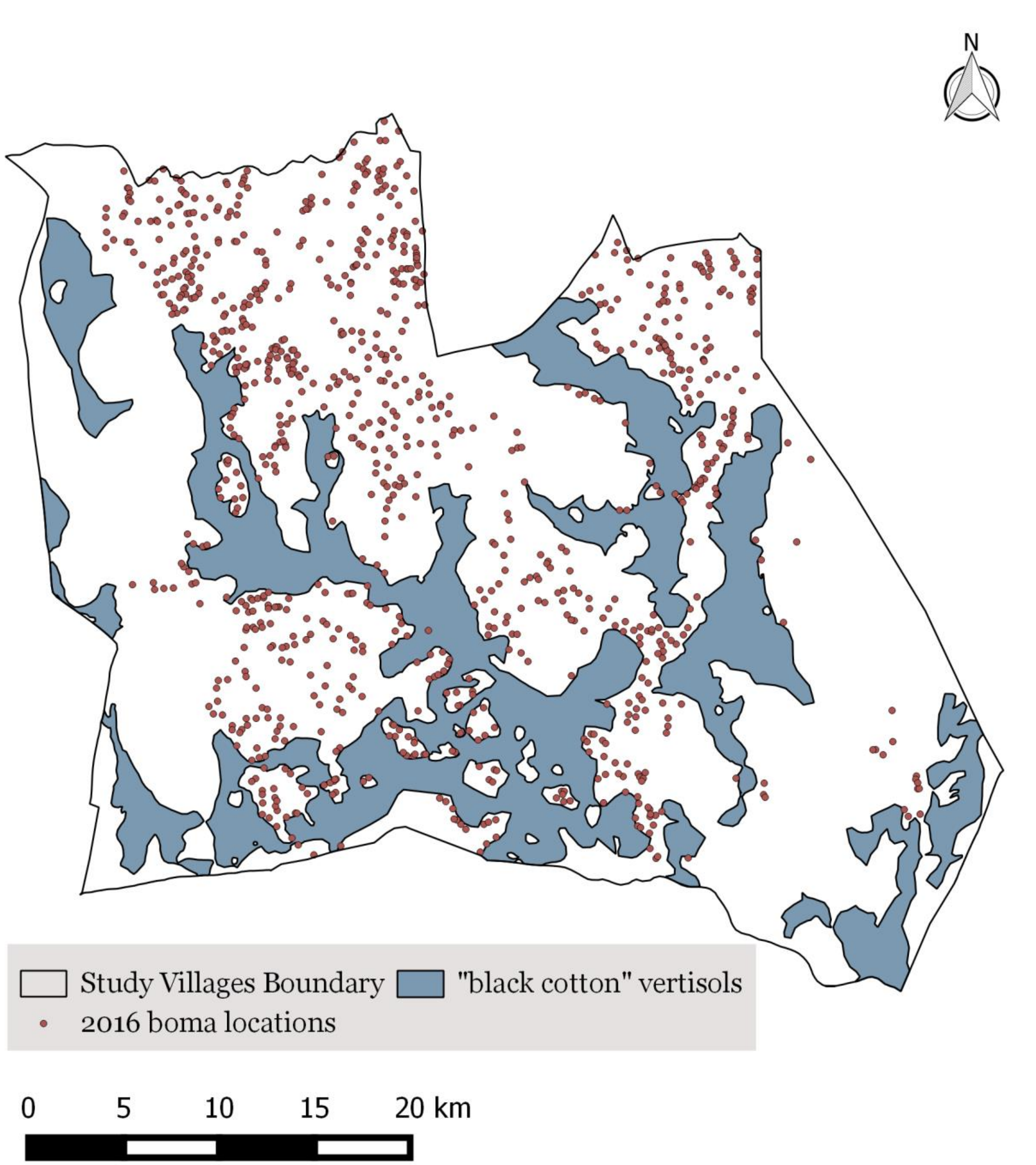

Figure 8. The extent of 'black cotton" vertisols with the study area, superimposed are the known boma locations.

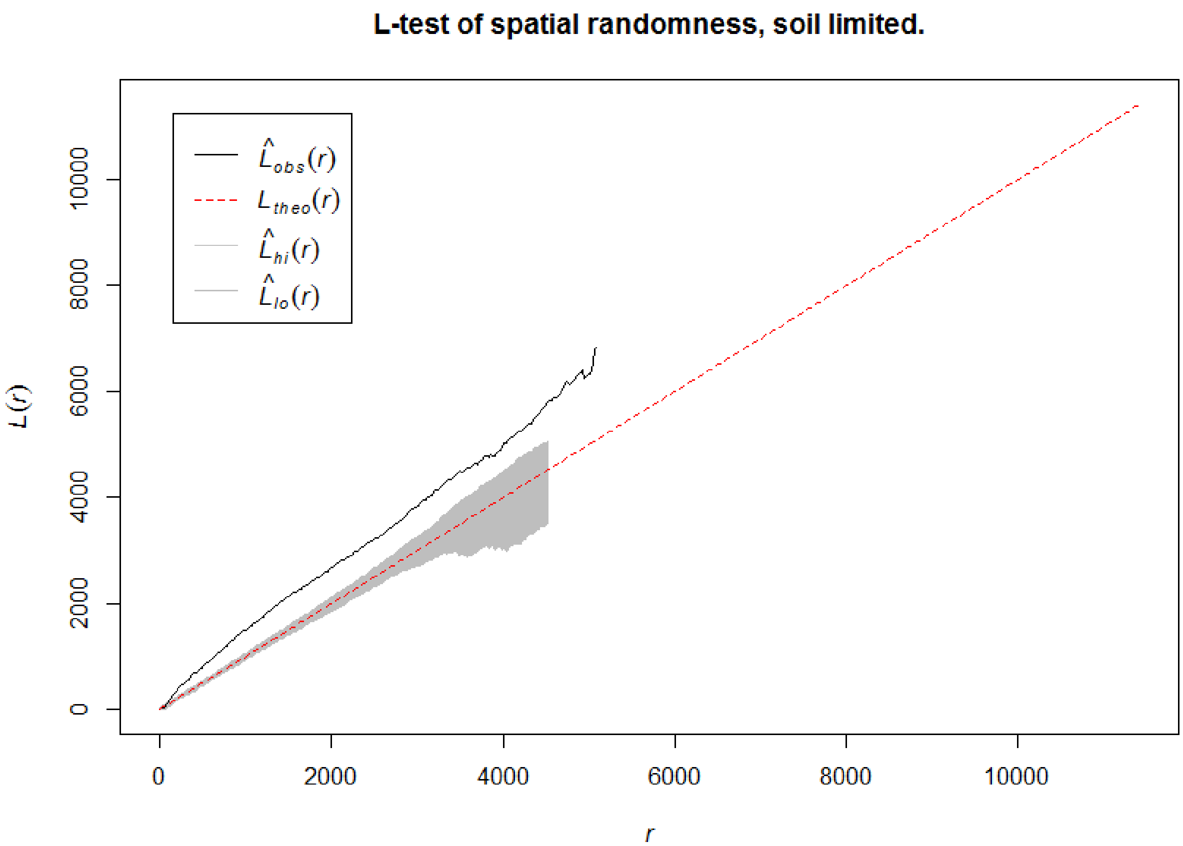

Figure 9. L-test for spatial randomness, accounting for presence of "black cotton" vertisols.

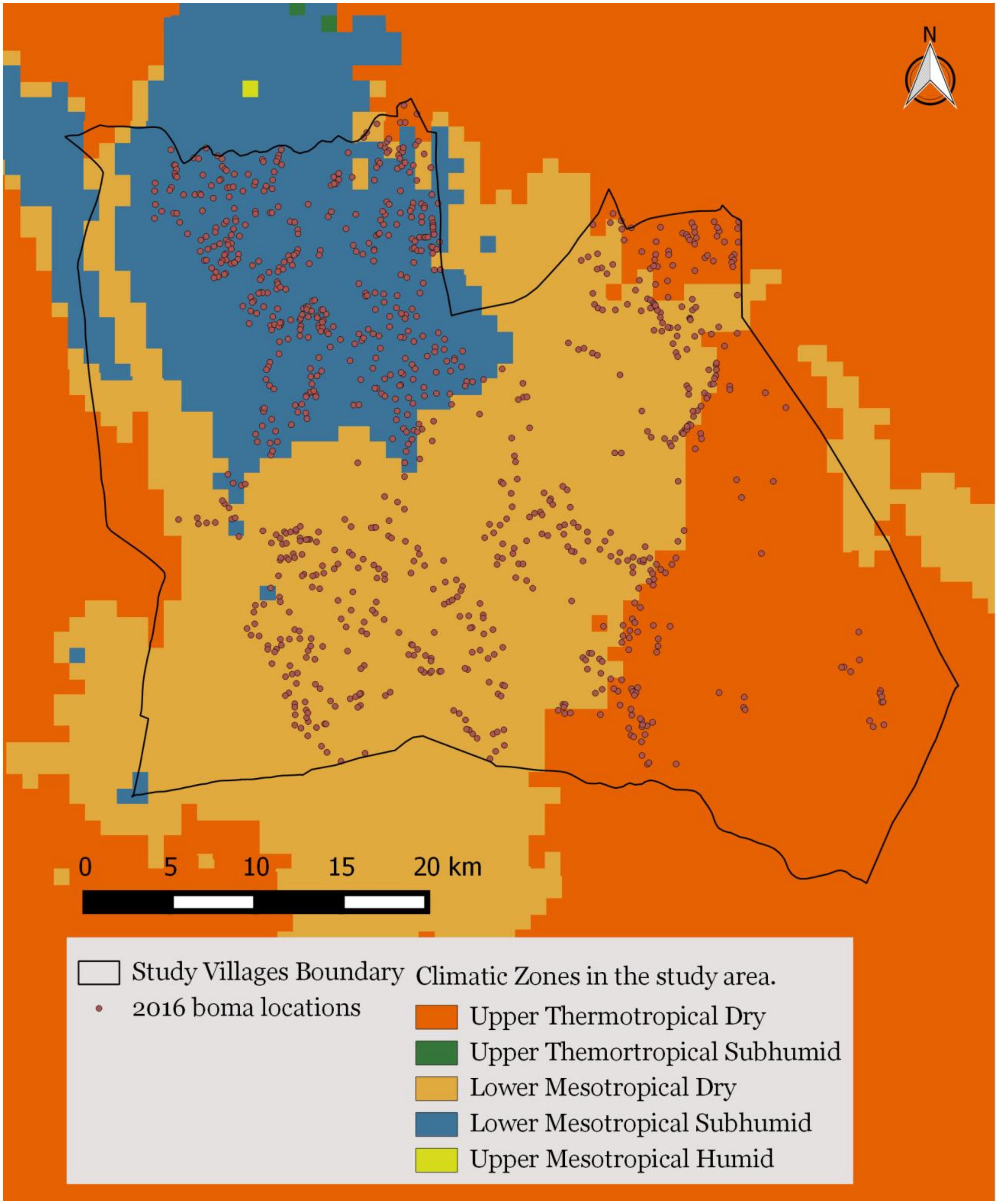

Figure 10. Major Climatic Zones within the study area.

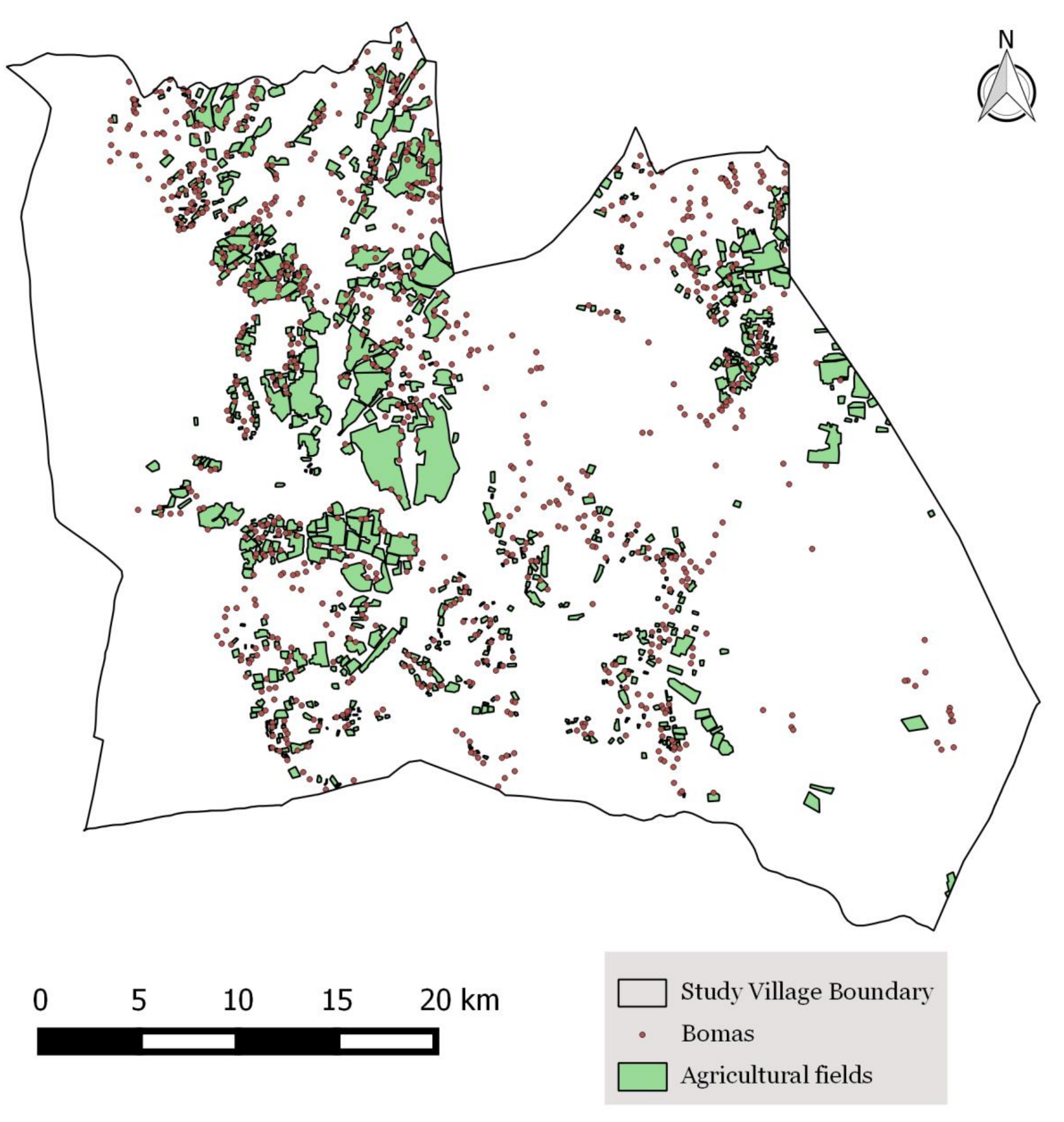

Figure 11. Extent of agriculture within the study site as of February 2016.

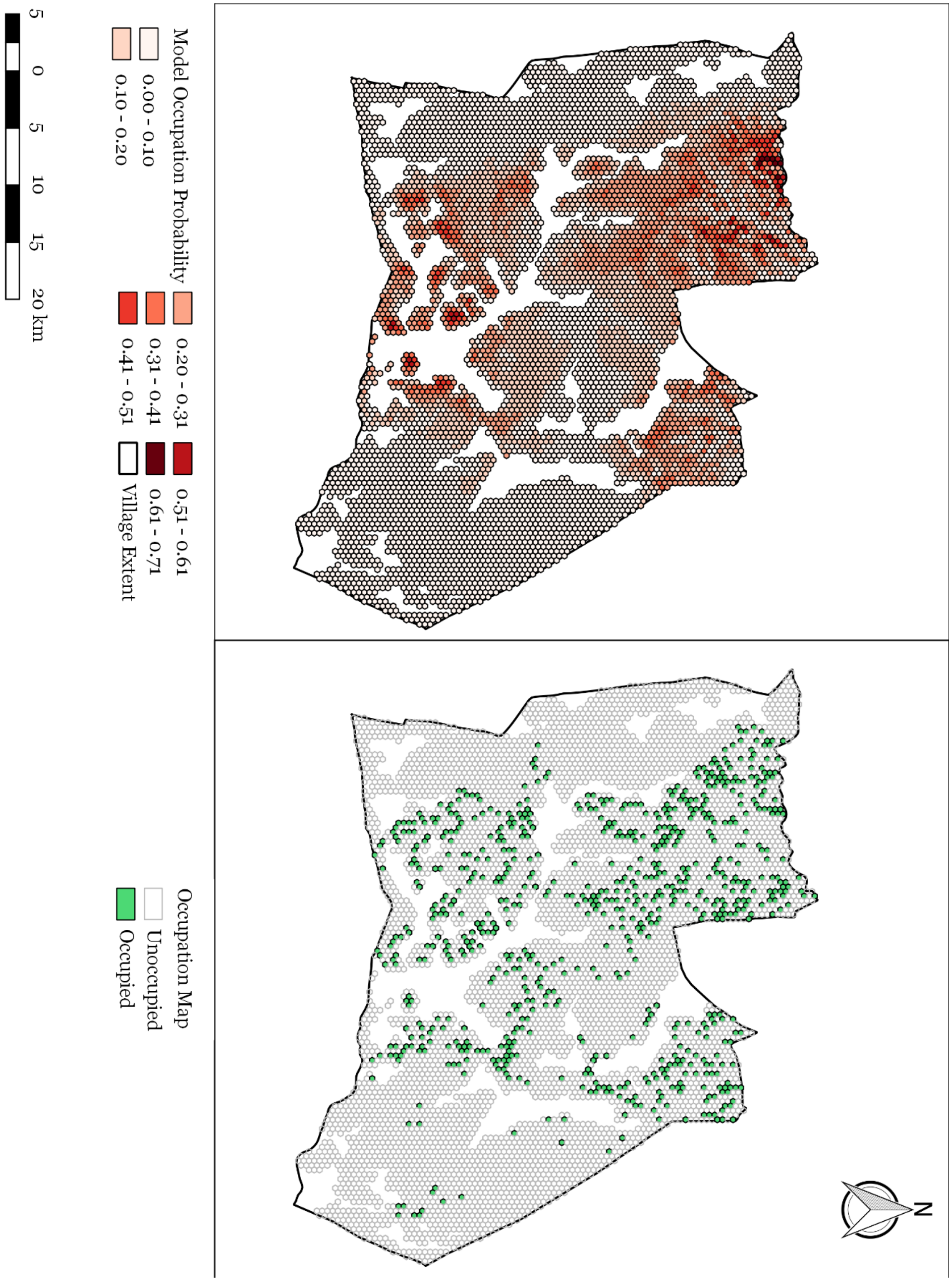

Figure 12. Modeled occupation probabilities and known occupied areas.

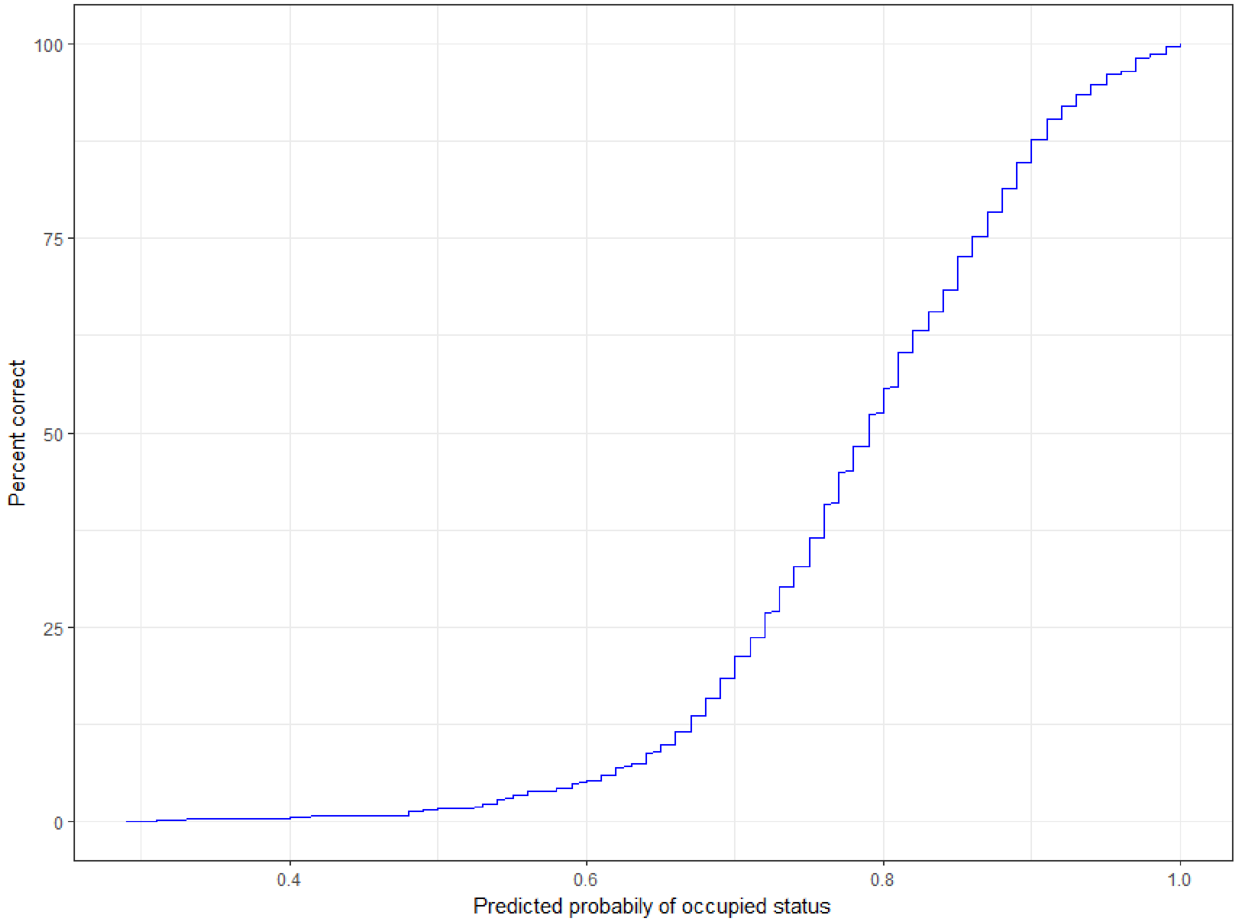

Figure 13. Cumulative distribution of modeled occupation probability and percent of occupied cells correctly identified.

REFERENCES

Anyamba, A., and C. J. Tucker. 2005. "Analysis of Sahelian Vegetation Dynamics Using NOAA-AVHRR NDVI Data from 1981–2003." *Journal of Arid Environments*, Special Issue on The "Greening" of the Sahel, 63 (3): 596–614. doi:10.1016/j.jaridenv.2005.03.007.

Baird, Timothy. 2012. "Conservation as Disturbance: Development, Diversification, and Social Networks near Tarangire National Park, Northern Tanzania." Phd. diss, Chapel Hill: University of North Carolina.

———. 2014. "Conservation and Unscripted Development: Proximity to Park Associated with Development and Financial Diversity." *Ecology and Society* 19 (1). doi:10.5751/ES-06184-190104.

Baird, Timothy D., and Clark L. Gray. 2014. "Livelihood Diversification and Shifting Social Networks of Exchange: A Social Network Transition?" *World Development* 60 (August): 14–30. doi:10.1016/j.worlddev.2014.02.002.

Baird, Timothy, Paul Leslie, and J Terrence McCabe. 2009. "The Effect of Wildlife Conservation on Local Perceptions of Risk and Behavioral Response." *Human Ecology* 37 (4): 463–74.

Baird, Timothy, and Paul W. Leslie. 2013. "Conservation as Disturbance: Upheaval and Livelihood Diversification near Tarangire National Park, Northern Tanzania." *Global Environmental Change* 23 (5): 1131–41. doi:10.1016/j.gloenvcha.2013.05.002.

Bates, Douglas, Martin Maechler, Ben Bolker, and Steve Walker. 2015. "Fitting Linear Mixed-Effects Models Using Lme4." *Journal of Statistical Software* 67 (1).

Borner, Markus. 1985. "The Increasing Isolation of Tarangire National Park." *Oryx* 19 (02): 91–96. doi:10.1017/S0030605300019797.

Brockington, Daniel, and James Igoe. 2006. "Eviction for Conservation: A Global Overview." *Conservation and Society* 4 (3): 424.

Brottem, Leif, Matthew D. Turner, Bilal Butt, and Aditya Singh. 2014. "Biophysical Variability and Pastoral Rights to Resources: West African Transhumance Revisited." *Human Ecology* 42 (3): 351–65. doi:10.1007/s10745-014-9640-1.

Budde, M. E, G Tappan, J Rowland, J Lewis, and L. L Tieszen. 2004. "Assessing Land Cover Performance in Senegal, West Africa Using 1-Km Integrated NDVI and Local Variance Analysis." *Journal of Arid Environments*, Land Cover, Biomass and Soil Carbon Trends in Senegal: Management Options and Climate Sensitivity, 59 (3): 481–98. doi:10.1016/j.jaridenv.2004.03.020.

Burnham, Kenneth P., and David R. Anderson. 2004. "Multimodel Inference: Understanding AIC and BIC in Model Selection." *Sociological Methods & Research* 33 (2): 261–304. doi:10.1177/0049124104268644.

Burnham, Philip. 1975. "'Regroupement' and Mobile Societies: Two Cameroon Cases." *The Journal of African History* 16 (4): 577–94.

BurnSilver, S. B. 2009. "Pathways of Continuity and Change: Maasai Livelihoods in Amboseli, Kajiado District, Kenya." In *Staying Maasai?*, edited by Katherine Homewood, Patti Kristjanson, and Pippa Chenevix Trench, 161–207. Studies in Human Ecology and Adaptation 5. Springer New York. doi:10.1007/978-0-387-87492-0_5.

BurnSilver, Shauna B., Randall B. Boone, and Kathleen A. Galvin. 2004. "Linking Pastoralists to a Heterogeneous Landscape." In *People and the Environment*, edited by Jefferson Fox, Ronald R. Rindfuss, Stephen J. Walsh, and Vinod Mishra, 173–99. Springer US. doi:10.1007/0-306-48130-8_6.

Butt, B. 2010a. "Seasonal Space-Time Dynamics of Cattle Behavior and Mobility among Maasai Pastoralists in Semi-Arid Kenya." *Journal of Arid Environments* 74 (3): 403–13. doi:10.1016/j.jaridenv.2009.09.025.

———. 2010b. "Pastoral Resource Access and Utilization: Quantifying the Spatial and Temporal Relationships between Livestock Mobility, Density and Biomass Availability in Southern Kenya." *Land Degradation & Development* 21 (6): 520–39. doi:10.1002/ldr.989.

Butt, Bilal. 2011. "Coping with Uncertainty and Variability: The Influence of Protected Areas on Pastoral Herding Strategies in East Africa." *Human Ecology* 39 (3): 289. doi:10.1007/s10745-011-9399-6.

Butt, Bilal, and Matthew D. Turner. 2012. "Clarifying Competition: The Case of Wildlife and Pastoral Livestock in East Africa." *Pastoralism: Research, Policy and Practice* 2 (1): 9. doi:10.1186/2041-7136-2-9.

Campbell, B. C., P. W. Leslie, M. A. Little, J. M. Brainard, and M. A. DeLuca. 1999. "Settled Turkana." *Turkana Herders of the Dry Savanna: Ecology and Biobehavioral Response of Nomads to an Uncertain Environment*, 333–52.

Chatty, Dawn. 1980. "The Pastoral Family and the Truck." *When Nomads Settle*, 80–94.

Coppolillo, Peter B. 2000. "The Landscape Ecology of Pastoral Herding: Spatial Analysis of Land Use and Livestock Production in East Africa." *Human Ecology* 28 (4): 527–60. doi:10.1023/A:1026435714109.

———. 2001. "Central-Place Analysis and Modeling of Landscape-Scale Resource Use in an East African Agropastoral System." *Landscape Ecology* 16 (3): 205–19. doi:10.1023/A:1011148503303.

Davis, Alicia. 2011. "'Ha! What Is the Benefit of Living next to the Park?' Factors Limiting in-Migration next to Tarangire National Park, Tanzania" 9. http://www.conservationandsociety.org/article.asp?issn=0972-4923;year=2011;volume=9;issue=1;spage=25;epage=34;aulast=Davis.

Ellis, Frank. 2000. *Rural Livelihoods and Diversity in Developing Countries*. Oxford university press.

Ericksen, Polly, Jan de Leeuw, Philip Thornton, Mohammed Said, Mario Herrero, and An Notenbaert. 2013. "Climate Change in Sub-Saharan Africa." *Pastoralism and Development in Africa: Dynamic Change at the Margins*, 71.

Fick, Steve, and Robert Hijmans. 2016. "WorldClim - Global Climate Data." http://worldclim.org/version2.

Fratkin, Elliot M., and Eric Abella Roth. 2005. *As Pastoralists Settle: Social, Health, and Economic Consequences of the Pastoral Sedentarization in Marsabit District, Kenya*. And & And. Vol. 1. Studies in Human Ecology and Adaptation. New York: Kluwer Academic Publishers.

Friedman, Jerome, Trevor Hastie, and Robert Tibshirani. 2009. "The Elements of Statistical Learning: Data Mining, Inference, and Prediction." *Springer Series in Statistics (*.

Fuda, Rebecca K., Sadie J. Ryan, Jonathan B. Cohen, Joel Hartter, and Jacqueline L. Frair. 2016. "Assessing Impacts to Primary Productivity at the Park Edge in Murchison Falls Conservation Area, Uganda." *Ecosphere* 7 (10): n/a-n/a. doi:10.1002/ecs2.1486.

Galaty, John G. 1980. *The Maasai Group Ranch: Politics and Development in an African Pastoral Society*. Department of Anthropology, McGill University.

Goldschmidt, Walter. 1980. "Career Reorientation and Institutional Adaptation in the Process of Natural Sedentarization." *When Nomads Settle*, 48–61.

Hansen, Matthew C., Peter V. Potapov, Rebecca Moore, Matt Hancher, S. A. Turubanova, Alexandra Tyukavina, David Thau, et al. 2013. "High-Resolution Global Maps of 21st-Century Forest Cover Change." *Science* 342 (6160): 850–853.

Hengl, Tomislav, Gerard B. M. Heuvelink, Bas Kempen, Johan G. B. Leenaars, Markus G. Walsh, Keith D. Shepherd, Andrew Sila, et al. 2015. "Mapping Soil Properties of Africa at 250 m Resolution: Random Forests Significantly Improve Current Predictions." *PLOS ONE* 10 (6): e0125814. doi:10.1371/journal.pone.0125814.

Homewood, Katherine. 2008. *Ecology of African Pastoralist Societies*. James Currey; Ohio University Press; Unisa Press. http://agris.fao.org.ezproxy.lib.vt.edu/agris-search/search.do?recordID=US201300133628.

Homewood, Katherine, Patti Kristjanson, and Pippa Chenevix Trench. 2009. "Changing Land Use, Livelihoods and Wildlife Conservation in Maasailand." In *Staying Maasai?*, edited by Katherine Homewood, Patti Kristjanson, and Pippa Chenevix Trench, 1–42. Studies in Human Ecology and Adaptation 5. Springer New York. doi:10.1007/978-0-387-87492-0_1.

Homewood, Katherine, Eric F. Lambin, Ernestina Coast, A. Kariuki, Idris Kikula, Julius Kivelia, M. Said, S. Serneels, and Mick Thompson. 2001. "Long-Term Changes in Serengeti-Mara Wildebeest and Land Cover: Pastoralism, Population, or Policies?" *Proceedings of the National Academy of Sciences* 98 (22): 12544–12549.

Homewood, Katherine M., W. Alan Rodgers, and Katherine Homewood. 2004. *Maasailand Ecology: Pastoralist Development and Wildlife Conservation in Ngorongoro, Tanzania*. Cambridge University Press.

Homewood, Katherine, and Susan Randall. 2009. "African Pastoralist Demography." *Ecology of African Pastoralist Societies. Athens: Ohio University Press*.

Homewood, Katherine, Pippa Chenevix Trench, and Patti Kristjanson. 2008. "Staying Maasai? Pastoral Livelihoods, Diversification and the Role of Wildlife in Development," 369–408. doi:10.1007/978-0-387-87492-0_10.

———. 2009. "Staying Maasai? Pastoral Livelihoods, Diversification and the Role of Wildlife in Development." In *Staying Maasai?*, edited by Katherine Homewood, Patti Kristjanson, and Pippa Chenevix Trench, 369–408. Studies in Human Ecology and Adaptation 5. Springer New York. doi:10.1007/978-0-387-87492-0_10.

Igoe, Jim, and Dan Brockington. 1999. *Pastoral Land Tenure and Community Conservation: A Case Study from North-East Tanzania*. IIED London, UK. http://pubs.iied.org/7385IIED.html.

Jacobs, Alan H. 1965. "The Traditional Political Organization of the Pastoral Masai." University of Oxford.

Jönsson, Per, and Lars Eklundh. 2004. "TIMESAT—a Program for Analyzing Time-Series of Satellite Sensor Data." *Computers & Geosciences* 30 (8): 833–45. doi:10.1016/j.cageo.2004.05.006.

Kahurananga, J. 1979. “The Vegetation of the Simanjiro Plains, Northern Tanzania.” *African Journal of Ecology* 17 (2): 65–83. doi:10.1111/j.1365-2028.1979.tb00459.x.

Kahurananga, James NM. 1976. “The Ecology of Large Herbivores in Simanjiro Plains, Northern Tanzania.”

Kahurananga, James, and Frank Silkiluwasha. 1997. “The Migration of Zebra and Wildebeest between Tarangire National Park and Simanjiro Plains, Northern Tanzania, in 1972 and Recent Trends.” *African Journal of Ecology* 35 (3): 179–85.

Kaswamila, Abiud, Shaun Russell, and Mike McGibbon. 2007. “Impacts of Wildlife on Household Food Security and Income in Northeastern Tanzania.” *Human Dimensions of Wildlife* 12 (6): 391–404. doi:10.1080/10871200701670003.

Kiffner, Christian, Ryan Hopper, and John Kioko. 2016. “Trends in Seasonal Population Densities of Wildlife Species in Tarangire National Park, Tanzania.” *African Journal of Ecology*, March, n/a-n/a. doi:10.1111/aje.12286.

Kiffner, Christian, S. Nagar, C. Kollmar, and J. Kioko. 2016. “Wildlife Species Richness and Densities in Wildlife Corridors of Northern Tanzania.” *Journal for Nature Conservation*. doi:10.1016/j.jnc.2016.02.006.

Kimiti, Kennedy Sakimba, Oliver Vivian Wasonga, David Western, and Judith Syombua Mbau. 2016. “Community Perceptions on Spatio-Temporal Land Use Changes in the Amboseli Ecosystem, Southern Kenya.” *Pastoralism* 6 (1): 24. doi:10.1186/s13570-016-0070-0.

Kindt, R., Paulo van Breugel, J.-P. B. Lillesø, F. Mbago, H. N. Moshi, H. J. Ndangalasi, L. O. N. Uronu, R. Ramnadass, and L. Graudal. 2014. “Potential Natural Vegetation of Eastern Africa. Volume 10. Atlas and Tree Species Composition for Tanzania.” Copenhagen: Department of Geosciences and Natural Resource Management, University of Copenhagen.

Lambin, Eric F., B. L. Turner, Helmut J. Geist, Samuel B. Agbola, Arild Angelsen, John W. Bruce, Oliver T. Coomes, et al. 2001. “The Causes of Land-Use and Land-Cover Change: Moving beyond the Myths.” *Global Environmental Change* 11 (4): 261–69. doi:10.1016/S0959-3780(01)00007-3.

Lamprey, H. F. 1963. “Ecological Separation of the Large Mammal Species in the Tarangire Game Reserve, Tanganyika1.” *African Journal of Ecology* 1 (1): 63–92. doi:10.1111/j.1365-2028.1963.tb00179.x.

———. 1964. “Estimation of the Large Mammal Densities, Biomass and Energy Exchange in the Tarangire Game Reserve and the Masai Steppe in Tanganyika.” *African Journal of Ecology* 2 (1): 1–46. doi:10.1111/j.1365-2028.1964.tb00194.x.

Lamprey, Richard H., and Robin S. Reid. 2004. “Expansion of Human Settlement in Kenya’s Maasai Mara: What Future for Pastoralism and Wildlife?” *Journal of Biogeography* 31 (6): 997–1032.

Leslie, Paul, and J. Terrence McCabe. 2013. “Response Diversity and Resilience in Social-Ecological Systems.” *Current Anthropology* 54 (2): 114.

Lewis, Ashley L., Timothy D. Baird, and Michael G. Sorice. 2016. “Mobile Phone Use and Human–Wildlife Conflict in Northern Tanzania.” *Environmental Management* 58 (1): 117–29. doi:10.1007/s00267-016-0694-2.

Little, Peter D. 1996. “Pastoralism, Biodiversity, and the Shaping of Savanna Landscapes in East Africa.” *Africa: Journal of the International African Institute* 66 (1): 37–51. doi:10.2307/1161510.

Little, Peter D., Kevin Smith, Barbara A. Cellarius, D. Layne Coppock, and Christopher Barrett. 2001. “Avoiding Disaster: Diversification and Risk Management among East African Herders.” *Development and Change* 32 (3): 401–33. doi:10.1111/1467-7660.00211.

McCabe, J. Terrence. 2003. “Sustainability and Livelihood Diversification among the Maasai of Northern Tanzania.” *Human Organization* 62 (2): 100–111. doi:10.17730/humo.62.2.4rwrt1n3xptg29b8.

———. 2004. “Cattle Bring Us to Our Enemies.” *Ann Arbor: University of Michigan Press*. http://muse.jhu.edu.ezproxy.lib.vt.edu/books/9780472026210/.

McCabe, J. Terrence, Paul W. Leslie, and Laura DeLuca. 2010. “Adopting Cultivation to Remain Pastoralists: The Diversification of Maasai Livelihoods in Northern Tanzania.” *Human Ecology* 38 (3): 321–34.

McCabe, J. Terrence, Nicole Smith, Paul Leslie, and Amy Telligman. 2014. “Livelihood Diversification through Migration among a Pastoral People: Contrasting Case Studies of Maasai in Northern Tanzania.” *Human Organization* 73 (4): 389–400.

McPeak, John G., Peter D. Little, and Cheryl R. Doss. 2011. *Risk and Social Change in an African Rural Economy: Livelihoods in Pastoralist Communities*. Vol. 7. Routledge ISS Studies in Rural Livelihoods. New York: Routledge.

McPeak, John, and Peter D. Little. 2005. “Cursed If You Do, Cursed If You Don’t.” In *As Pastoralists Settle*, 87–104. Springer. http://link.springer.com.ezproxy.lib.vt.edu/content/pdf/10.1007/0-306-48595-8_5.pdf.

Michaud, Jean-Simon, Nicholas C. Coops, Margaret E. Andrew, and Michael A. Wulder. 2012. “Characterising Spatiotemporal Environmental and Natural Variation Using a Dynamic Habitat Index throughout the Province of Ontario.” *ResearchGate* 18 (January): 303–11.

Michaud, Jean-Simon, Nicholas C. Coops, Margaret E. Andrew, Michael A. Wulder, Glen S. Brown, and Gregory J. M. Rickbeil. 2014. “Estimating Moose (Alces Alces) Occurrence and Abundance from Remotely Derived Environmental Indicators.” *Remote Sensing of Environment* 152 (September): 190–201. doi:10.1016/j.rse.2014.06.005.

Miller, Brian W. 2015. “Using Geospatial Analysis to Assess the Influence of Land-Use Change and Conservation on Pastoralist Access to Drought Resources.” *Nomadic Peoples* 19 (1): 120–45. doi:10.3197/np.2015.190108.

Miller, Brian W., Paul W. Leslie, and J. Terrence McCabe. 2014. “Coping with Natural Hazards in a Conservation Context: Resource-Use Decisions of Maasai Households During Recent and Historical Droughts.” *Human Ecology* 42 (5): 753–68. doi:10.1007/s10745-014-9683-3.

Mlingano Agricultural Research Institute. 2006. “Soils of Tanzania and Their Potential for Agriculture Development.” MINISTRY OF AGRICULTURE, FOOD SECURITY AND CO-OPERATIVES. https://www-google-com.ezproxy.lib.vt.edu/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&cad=rja&uact=8&ved=0ahUKEwiCv52S_6PRAhVFQyYKHQxBBQ8QFggtMAI&url=http%3A%2F%2Fwww.kilimo.go.tz%2Fagricultural%2520maps%2Ftanzania%2520soil%2520maps%2FWebbased%2520Districts%2520Agricultural%2520maps%2FDistricts%2520Soil%2FSoils%2520of%2520Tanzania.pdf&usg=AFQjCNFSZ6sSPnfNV_X6CAEapaE41QpOYw.

Moritz, Mark, Ian M. Hamilton, Yu-Jen Chen, and Paul Scholte. 2014. “Mobile Pastoralists in the Logone Floodplain Distribute Themselves in an Ideal Free Distribution.” *Current Anthropology* 55 (1): 115–22. doi:10.1086/674717.

Morrison, Thomas A., and Douglas T. Bolger. 2014. “Connectivity and Bottlenecks in a Migratory Wildebeest Connochaetes Taurinus Population.” *Oryx* 48 (04): 613–621. doi:10.1017/S0030605313000537.
Msoffe, Fortunata U., Mohammed Y. Said, Joseph O. Ogutu, Shem C. Kifugo, Jan de Leeuw, Paul van Gardingen, and Robin S. Reid. 2011. “Spatial Correlates of Land-Use Changes in the Maasai-Steppe of Tanzania: Implications for Conservation and Environmental Planning.” *International Journal of Biodiversity and Conservation* 3 (7): 280–90.
Nakagawa, Shinichi, and Holger Schielzeth. 2013. “A General and Simple Method for Obtaining R2 from Generalized Linear Mixed-Effects Models.” *Methods in Ecology and Evolution* 4 (2): 133–42. doi:10.1111/j.2041-210x.2012.00261.x.
NASA. 2016. *MODIS/Terra Vegetation Indices 6-Day L3 Global 250m SIN Grid*. https://lpdaac.usgs.gov/lpdaac/products/ modis_products_table/vegetation_indices/16_day_l3_global_250m/v5/ terra.
Ndagala, D.K. 1982. "'Operation Imparnati': The Sedentarization of the Pastoral Maasai in Tanzania." *Nomadic Peoples*, no. 10: 28–39.
Nelson, Fred. 2012. “Natural Conservationists? Evaluating the Impact of Pastoralist Land Use Practices on Tanzania’s Wildlife Economy.” *Pastoralism: Research, Policy and Practice* 2 (1): 15. doi:10.1186/2041-7136-2-15.
Nelson, Fred, Charles Foley, Lara S. Foley, Abraham Leposo, Edward Loure, David Peterson, Mike Peterson, Thad Peterson, Hassan Sachedina, and Andrew Williams. 2010. “Payments for Ecosystem Services as a Framework for Community-Based Conservation in Northern Tanzania.” *Conservation Biology* 24 (1): 78–85. doi:10.1111/j.1523-1739.2009.01393.x.
Nelson, Fred, Benjamin Gardner, Jim Igoe, and Andrew Williams. 2009. “Community-Based Conservation and Maasai Livelihoods in Tanzania.” In *Staying Maasai?*, edited by Katherine Homewood, Patti Kristjanson, and Pippa Chenevix Trench, 299–333. Studies in Human Ecology and Adaptation 5. Springer New York. doi:10.1007/978-0-387-87492-0_8.
Nkedianye, David, Jan de Leeuw, Joseph O. Ogutu, Mohammed Y. Said, Terra L. Saidimu, Shem C. Kifugo, Dickson S. Kaelo, and Robin S. Reid. 2011. “Mobility and Livestock Mortality in Communally Used Pastoral Areas: The Impact of the 2005-2006 Drought on Livestock Mortality in Maasailand.” *Pastoralism: Research, Policy and Practice* 1 (1): 17. doi:10.1186/2041-7136-1-17.
Nkedianye, David, Maren Radeny, Patti Kristjanson, and Mario Herrero. 2009. “Assessing Returns to Land and Changing Livelihood Strategies in Kitengela.” In *Staying Maasai?*, edited by Katherine Homewood, Patti Kristjanson, and Pippa Chenevix Trench, 115–49. Studies in Human Ecology and Adaptation 5. Springer New York. doi:10.1007/978-0-387-87492-0_4.
Oba, Gufu. 2013. “The Sustainability of Pastoral Production in Africa.” *Pastoralism and Development in Africa: Dynamic Changes at the Margins. Routledge, London, UK*, 29–36.
OpenStreetMap contributors. 2016. “OpenStreetMap.” http://www.openstreetmap.org.
Pelkey, N. W., C. J. Stoner, and T. M. Caro. 2003. “Assessing Habitat Protection Regimes in Tanzania Using AVHRR NDVI Composites: Comparisons at Different Spatial and Temporal Scales.” *International Journal of Remote Sensing* 24 (12): 2533.
Peterson, David D. 1978. “Seasonal Distributions and Interactions of Cattle and Wild Ungulates in Maasailand, Tanzania.” Virginia Polytechnic Institute and State University.

QGIS Development Team. 2016. *QGIS Geographic Information System* (version 2.18). Open Source Geospatial Foundation. http://qgis.osgeo.org.

R Core Team. 2017. *R: A Language and Environment for Statistical Computing.* (version 3.3.3). Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/.

Randall, Sarah, and Alessandra Giuffrida. 2006. "Forced Migrations, Sedentarisation and Social Change: Malian Kel Tamasheq." *Pastoralists of North Africa and the Middle East Entering The* 21: 431–463.

Rhoades, Stephen A. 1993. "The Herfindahl-Hirschman Index." *Fed. Res. Bull.* 79: 188.

Roth, E. A., and E. M. Fratkin. 2005. "The Social, Health, and Economic Consequences of Pastoral Sedentarization in Marsabit District, Northern Kenya." *As Pastoralists Settle: Social, Health, and Economic Consequences of Pastoral Sedentarization in Marsabit District, Kenya. New York: Kluwer Academic/Plenum Publishers. P1–28.*

Rutten, M. M. E. M. 1992. "Selling Wealth to Buy Poverty : The Process of the Individualization of Landownership among the Maasai Pastoralists of Kajiado District, Kenya, 1890-1990." Book (monograph). *XVI, 510*. https://openaccess.leidenuniv.nl/handle/1887/9046.

Sachedina, Hassan, and Fred Nelson. 2010. "Protected Areas and Community Incentives in Savannah Ecosystems: A Case Study of Tanzania's Maasai Steppe." *Oryx* 44 (03): 390–98. doi:10.1017/S0030605310000499.

Sachedina, Hassan, and Pippa Chenevix Trench. 2009. "Cattle and Crops, Tourism and Tanzanite: Poverty, Land-Use Change and Conservation in Simanjiro District, Tanzania." In *Staying Maasai?*, edited by Katherine Homewood, Patti Kristjanson, and Pippa Chenevix Trench, 263–98. Studies in Human Ecology and Adaptation 5. Springer New York. doi:10.1007/978-0-387-87492-0_7.

Salerno, Jonathan, Monique Borgerhoff Mulder, Mark N. Grote, Margherita Ghiselli, and Craig Packer. 2015. "Household Livelihoods and Conflict with Wildlife in Community-Based Conservation Areas across Northern Tanzania." *Oryx* FirstView (September): 1–11. doi:10.1017/S0030605315000393.

Salzman, C. P. 1980. "Introduction: Processes of Sedentarization as Adaptation and Response." *When Nomads Settle*, . 1-19.

Sayre, Roger, Jack Dangermond, Charlie Frye, Randy Vaughan, Peter Aniello, Sean Breyer, Douglas Cribbs, Dabney Hopkins, Richard Nauman, and William Derrenbacher. 2014. "A New Map of Global Ecological Land Units—an Ecophysiographic Stratification Approach." *Washington, DC: Association of American Geographers*.

Schilling, Janpeter, Francis EO Opiyo, and Jürgen Scheffran. 2012. "Raiding Pastoral Livelihoods: Motives and Effects of Violent Conflict in North-Western Kenya." *Pastoralism: Research, Policy and Practice* 2 (1): 1–16. doi:10.1186/2041-7136-2-25.

Scott, James C. 1998. *Seeing like a State: How Certain Schemes to Improve the Human Condition Have Failed*. Yale University Press.

Serneels, Suzanne, Mario Herrero, Shauna BurnSilver, Pippa Chenevix Trench, Kath Cochrane, Katherine Homewood, Patti Kristjanson, et al. 2009. "Methods in the Analysis of Maasai Livelihoods." In *Staying Maasai?*, edited by Katherine Homewood, Patti Kristjanson, and Pippa Chenevix Trench, 43–67. Studies in Human Ecology and Adaptation 5. Springer New York. doi:10.1007/978-0-387-87492-0_2.

Serneels, Suzanne, and Eric F. Lambin. 2001. "Proximate Causes of Land-Use Change in Narok District, Kenya: A Spatial Statistical Model." *Agriculture, Ecosystems & Environment* 85 (1): 65–81.

Spear, Thomas, and Richard Waller. 1993. "Being Maasai." *London: James Currey*.
Swidler, Nina. 1980. "Sedentarization and Modes of Economic Integration in the Middle East." *When Nomads Settle, Processes of Sedentarization as Adaptation and Response, Edited by PC Salzman. New York: JF Bergin and Praeger*.
Tache, Boku. 2013. "Rangeland Enclosures in Southern Oromia, Ethiopia." *Pastoralism and Development in Africa: Dynamic Change at the Margins*, 37.
Tanzania National Bureau of Statistics. 2012. "2012 Population and Housing Census." http://www.nbs.go.tz/nbstz/index.php/english/statistics-by-subject/population-and-housing-census/258-2012-phc-shapefiles-level-one-and-two.
Thompson, D. Michael, Suzanne Serneels, and Eric F. Lambin. 2002. "Land Use Strategies in the Mara Ecosystem: A Spatial Analysis Linking Socio-Economic Data with Landscape Variables." In *Linking People, Place, and Policy*, edited by Stephen J. Walsh and Kelley A. Crews-Meyer, 39–68. Springer US. doi:10.1007/978-1-4615-0985-1_3.
Thompson, M., and K. Homewood. 2002. "Entrepreneurs, Elites, and Exclusion in Maasailand: Trends in Wildlife Conservation and Pastoralist Development." *Human Ecology* 30 (1): 107–38.
Trench, Pippa Chenevix, Steven Kiruswa, Fred Nelson, and Katherine Homewood. 2009. "Still 'People of Cattle'? Livelihoods, Diversification and Community Conservation in Longido District." In *Staying Maasai?*, edited by Katherine Homewood, Patti Kristjanson, and Pippa Chenevix Trench, 217–56. Studies in Human Ecology and Adaptation 5. Springer New York. doi:10.1007/978-0-387-87492-0_6.
Voeten, Margje M., Claudius A.D.M. Van De Vijver, Han Olff, and Frank Van Langevelde. 2010. "Possible Causes of Decreasing Migratory Ungulate Populations in an East African Savannah after Restrictions in Their Seasonal Movements." *African Journal of Ecology* 48 (1): 169–79. doi:10.1111/j.1365-2028.2009.01098.x.
Western, David. 1982. "The Environment and Ecology of Pastoralists in Arid Savannas." *Development and Change* 13 (2): 183–211. doi:10.1111/j.1467-7660.1982.tb00117.x.
Western, David, and Thomas Dunne. 1979. "Environmental Aspects of Settlement Site Decisions among Pastoral Maasai." *Human Ecology* 7 (1): 75–98.
Western, David, Rosemary Groom, and Jeffrey Worden. 2009. "The Impact of Subdivision and Sedentarization of Pastoral Lands on Wildlife in an African Savanna Ecosystem." *Biological Conservation* 142 (11): 2538–46. doi:10.1016/j.biocon.2009.05.025.
Western, David, and D. L. Manzolillo Nightingale. 2003. "Environmental Change and the Vulnerability of Pastoralists to Drought: A Case Study of the Maasai in Amboseli, Kenya." http://www.oceandocs.org/handle/1834/436.
Worden, Jeffrey S. 2007. "Fragmentation and Settlement Pattern in Maasailand - Implications for Pastoral Mobility, Drought Vulnerability, and Wildlife Conservation in an East African Savanna." Ph.D., United States -- Colorado: Colorado State University. http://search.proquest.com.ezproxy.lib.vt.edu/docview/304859680/abstract/66445602E8E3413CPQ/1.