# LINKING CONSERVATION GOALS AND OUTCOMES: THE SOCIAL-ECOLOGICAL DYNAMICS OF DROUGHT RESOURCE MANAGEMENT IN EAST AFRICA

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**ABSTRACT**

BRIAN WILLIAM MILLER: Linking Conservation Goals and Outcomes: The Social-Ecological Dynamics of Drought Resource Management in East Africa
(Under the direction of Paul W. Leslie)

The establishment of conservation areas is a widespread strategy for protecting the environment from human activities, and it is clear that conservation areas also have a variety of consequences for human communities. However, the ways in which the social effects of conservation then translate into environmental outcomes are not well studied. This dissertation illustrates one approach to studying these interactions by drawing on theory and methods from landscape, human, and political ecology.

I focused on locations within rangeland systems that maintain resource availability during periods of low-rainfall (e.g., swamps and rivers), which support unique vegetation communities, and wildlife and livestock populations. I analyzed the distribution of these drought resource areas (DRAs) in relation to conservation areas and land use changes in East Africa, the effects of changes in DRA access on the livelihood decisions of Maasai pastoralists, and the relationships between livelihoods, land use, and rivers. These analyses required a combination of remote sensing data and information that I collected in six villages that are varying distances from Tarangire National Park (TNP), including semi-structured group and individual interviews, household surveys, geographic locations of water sources and land cover types, and channel cross-sections and sediment samples from four rivers.

Conservation areas and land use changes have affected pastoralist access to DRAs, but their relative influence varies by spatial scale. The herding practices of Maasai households during recent and historical droughts suggest that the establishment of TNP had a less dramatic effect on drought resource use than was previously thought. This unexpected finding is likely due to changing perceptions of resource availability and the complexity of resource-use decisions, which are affected by household and contextual factors. For many households, small rivers and ephemeral streams continue to serve as critical DRAs. These waterways have been resistant to recent land use changes (e.g., roads, cultivation), possibly because they have adjusted to the historical effects of wild and domestic ungulates on water and sediment supply. Reduction in the availability or productivity of these DRAs would have far-reaching effects on local land users, and, consequently, on the use of natural resources within this iconic conservation landscape.

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INTRODUCTION

### *1.1. Overview & Justification*

*"It's like when you are moving livestock. When you want to do that, you first need to go there and see how much grass and water there is."*
– Maasai community leader, regarding the purpose of research

During the drought that afflicted East Africa in 2009, Maasai herders in search of water and grazing for their livestock had to contend with a variety of obstacles that affect natural resource availability in the Kenya/Tanzania border region, including local resource use rules and national park boundaries. On the other hand, these world-renowned conservation areas (e.g., Serengeti National Park) are coping with considerable challenges of their own; specifically, maintaining wildlife populations and tourism industries in the face of human activities that threaten to block wildlife migrations and increase their ecological isolation (Newmark 2008).

This situation illustrates that finding durable solutions for reconciling the concurrent, and sometimes conflicting, imperatives of environmental conservation and socio-economic development remains a substantial challenge (Adams et al. 2004). It is clear that humans affect their environment (e.g., deforestation), and that conservation initiatives can have substantial effects on local people (e.g., relocation). Less well understood are the feedbacks between conservation and social-ecological systems; that is, how conservation initiatives affect social changes that in turn impact the environments targeted by conservation efforts (Miller et al. 2012). My objective is to advance methods for studying these reciprocal impacts by examining the links between natural resource access, livelihood decisions, and resource use.

In particular, I focus on habitats that are critical for sustaining herding livelihoods and rangeland ecosystems: dry-season/drought resource areas. Rangelands cover more of the Earth's terrestrial surface than any other land use (Asner et al. 2004), and are characterized by spatial and temporal variability in rainfall and primary production. Rangelands also sustain areas of predictably higher productivity and water availability (e.g., riparian areas, highland forests). These dry-season/drought resource areas (DRAs) are important seasonal habitats for wildlife as well as herders and their livestock; however, the joint access of wildlife and pastoralists to these forage and water sources can be inhibited by agricultural development, privatization, and conservation area establishment. Exclusion from resource use has potentially far-reaching implications for the viability of herding livelihoods, which are considered more compatible with migratory wildlife conservation than alternative land uses such as cultivation – an increasingly prominent feature of pastoralist production strategies.

Despite the well-documented importance of dry-season/drought resource areas (DRAs) to the viability of livestock and wildlife populations, there is little research on the interactions of DRA management and pastoralist livelihood change. As a result, this research asks: <u>how do DRA management and Maasai livelihoods interact</u>? I address this overarching question through three more specific subquestions:

1) What is the spatial distribution of DRAs in relation to conservation areas and agriculture development in the Kenya/Tanzania border region and more locally?

2) How have changes in access to DRAs influenced pastoralist livelihood decisions?

3) In the face of these livelihood decisions, how do Maasai communities manage available water resources, and what are the consequences for river systems?

I evaluate these questions with a mixed-methods approach, using quantitative and qualitative data that I collected in six study villages in the Simanjiro Plains, Tanzania (an area that serves as a seasonal wildlife dispersal zone for Tarangire National Park, TNP) that have varying levels of water development, natural resource availability, and distance from TNP. Addressing these research questions is meant to clarify the feedbacks between conservation initiatives and local land users by describing the influence of conservation on natural resource availability (question 1 above), the role of resource dislocation in livelihood change (question 2), and the relationship between these livelihood changes and the local institutions that are managing natural resources (question 3). At the same time, this study will also help fill several gaps in our understanding of social-ecological interactions, including the relative influence of access to natural capital in pastoralist livelihood decision making; and the social-ecological resilience of rangeland systems to conservation measures that alter drought resource access.

In this chapter, I lay the foundation for exploring my study questions by first reviewing and synthesizing the literatures of landscape, human, and political ecology. I then describe my conceptual framework and guiding research approach. Finally, I provide an overview of the study site and population. The following three chapters (chapters 2, 3, and 4) correspond to each of the three subquestions listed above; these are structured as standalone manuscripts, and therefore contain some redundancies. I synthesize my findings in terms of their theoretical and practical relevance in the final chapter (chapter 5).

### *1.2. Background*

Our understanding of ecological processes has advanced considerably since the introduction of the term 'ecosystem' by Tansley in 1935. Early studies, such as Clements' (1916) depiction of linear vegetation succession toward climax communities, Lotka's (1925) and Volterra's (1926) mathematical models of population interactions, and Lindeman's (1942) descriptions of trophic dynamics informed later studies of energy and nutrient transfer within closed systems (i.e., ecosystem ecology - Odum 1969). These intellectual advancements laid the groundwork for current ecological inquiry and contributed substantially to research in related fields.

Yet despite decades of research that has built upon and challenged these findings, the notions of ecological stability and predictability conveyed by these early works persist. Within some scientific, public, and policy circles ecosystems are still thought of as closed systems that can be predictably controlled through the regulation of human activities that threaten their natural balance (Scoones 1999). This is particularly troubling since these misconceptions can lead to ineffective, and even socially and environmentally damaging resource management initiatives.

Here I examine three 'ecologies' that have played important roles in challenging these misconceptions: landscape ecology, human ecology, and political ecology. Landscape ecology offers a perspective for understanding the processes and patterns of environmental heterogeneity. These patterns are in part shaped by the activities of people who have developed sophisticated strategies for persisting within variable landscapes; production strategies and their interactions with biophysical and socio-cultural factors are central to human ecology. Political ecology emphasizes the influence of political and economic factors on livelihoods and resource use.

Although each of these fields is ostensibly interdisciplinary, their areas of specialization are sometimes criticized as being too narrow, requiring greater engagement with either social or ecological theories and methods. Scholars have independently called for greater integration of the social sciences with landscape ecology (Wu 2006) and ecology more broadly (Lowe et al. 2009), further study of the political and economic factors affecting human-environment interactions (Scoones 2009), and additional attention to ecology within political ecology research (Walker 2005). These disciplinary challenges and shortcomings can instead be viewed as complementarities, particularly if one adopts the notion that social and ecological systems are inextricably linked (Berkes et al. 2000).

Recognition of the linkages between social and ecological systems led to the development of resilience thinking, a way of conceptualizing systems in terms of their capacity to endure shocks or disturbances (Walker and Salt 2006). I argue that it also offers a framework for integrating landscape, human, and political ecology, whose individual challenges can be addressed, not by expanding the scope of each field independently, but by employing their unique insights in combination. In line with resilience thinking, the three ecologies exhibit strong interdisciplinarity and emphasize the importance of including the perspectives of local land users in cross-scale research. Their literatures overlap substantially, and the following categorization is intended more as an organizational structure than an attempt to classify the literature cited. This literature review focuses on rangeland ecosystems and pastoralist societies, particularly those in sub-Saharan Africa. Through this review I highlight the studies and research gaps that inform and motivate my study of the feedbacks between conservation areas and social-ecological systems.

### *1.2.1. Landscape Ecology – Pattern & Process*

Stated simply, physical environmental characteristics structure the potential ranges of species, and biotic processes such as competition, dispersal, and predation influence their actual ranges (Hutchinson 1957, Pulliam 2002). The influence of biotic factors varies across different physical conditions (Connell 1961), and the interactions and feedbacks among biotic and abiotic factors yield uneven and dynamic spatio-temporal species distributions (Wiens 1976). Identifying and describing environmental heterogeneity, and understanding its interactions with ecological processes is the crux of landscape ecology (Risser et al. 1984). Although research within this field emphasizes relatively large spatial extents, the primary focus is on detecting patterns and processes at multiple scales (Turner 2005). Landscapes are conceptualized as mosaics of habitat patches (Watt 1947), and their patterns result from the interactions of physical variables (e.g., nutrient availability), biotic processes (e.g., competition, dispersal) and disturbance regimes (e.g., fire) (Urban et al. 1987).

Environmental heterogeneity is an especially prominent theme in the literature on rangeland ecosystems, which are characterized by substantial spatial and temporal variability in primary production. Rangelands are areas that provide suitable habitat for herds of wild or domestic ungulates, and are typically characterized by an herbaceous understory dominated by grasses with varying levels of canopy cover[1] (Pratt et al. 1966). The dynamic mosaic of rangeland vegetation communities is shaped by the interaction of climatic variability, geomorphology, herbivory, and fire. Climate, soils, and topography influence water availability, thereby affecting vegetation communities, primary production, and forage quality (i.e., nutrient content and palatability). These characteristics in turn affect the distribution of consumer populations and fuel loads, which further influence vegetation patterns through herbivory and fire (a more detailed treatment of the interaction of these variables is provided in the study site description below).

Accounts of ecosystem variability have been central to debates about whether rangelands are more accurately viewed as equilibrium or non-equilibrium systems (or a recent review, see Vetter 2005). Equilibrium theory adheres to Clements' (1916) view that vegetation communities exhibit linear successional stages progressing towards a climax community. Each stage of plant succession, or species association, can support a certain number of consumers (i.e., the carrying capacity); in other words, the size of the

[1]For East African rangelands, 20% canopy cover marks the division between woodland and wooded grassland, but vegetation types exceeding 20% canopy cover (e.g., bushland and woodland) may still be classified as rangeland depending upon understory composition and moisture availability (Pratt et al. 1996).

consumer population is linked to the resource base and is therefore density dependent. Exceeding the carrying capacity can shift the system to an earlier successional stage, and can even cause irreversible damage and population collapse. This model of herbivore-vegetation feedbacks implies that because vegetation responds to grazing pressure, habitat condition can be altered through stocking rates.

Scholars have challenged the Clementsian view of plant community succession and community organization (Gleason 1926, Whittaker 1956), and the associated density-dependence of consumer populations (Davidson and Andrewartha 1948). This shift in thinking is especially evident in the literature on arid and semi-arid rangelands (Ellis and Swift 1988, Westoby et al. 1989, Behnke et al. 1993). Non-equilibrium theory posits that successional stages can be non-linear (i.e., non-sequential), and that stochastic abiotic factors (e.g., precipitation) have effects on vegetation and consumer populations that are independent of population density. High variability in rainfall drives frequent changes in primary production that cannot be tracked closely by herbivore populations; in other words, herbivore populations are not tightly coupled to their resource base and are therefore density-independent. Due to periodic droughts, for example, livestock populations rarely reach densities that are high enough to cause long-term vegetation degradation. By this logic, livestock can affect the vegetation but are not the primary drivers of vegetation change, and therefore, destocking or placing limits on stocking rates are ineffective tools for managing vegetation communities (Vetter 2005).

Although the non-equilibrium view has gained momentum among rangeland scientists, most systems exhibit both equilibrium and non-equilibrium characteristics depending on metric, spatial scale, timeframe, and habitat (Connell and Sousa 1983, Oba et al. 2003, Vetter 2005). Structural features such as biomass, and compositional features such as species abundance may exhibit temporal stability at different scales (Busing and White 1993). System characteristics also vary with timeframe; livestock populations may be dictated by density-independent factors (e.g., drought) during some periods, but regulated by density-dependent factors (i.e., stocking rates) in others (Scoones 1993, Desta and Coppock 2002). The mobility of consumer populations must also be considered, as livestock population dynamics are influenced by the opportunistic exploitation of spatially distributed resource patches (Scoones 1993).

Illius and O'Connor (1999) have suggested that even in highly variable systems, livestock populations are regulated by density-dependence due to limited dry season resources. In this view, key resource areas[2] maintain livestock populations through periods of plant dormancy, and therefore regulate regional livestock population dynamics. In arid and semi-arid ecosystems, these are typically dry-season/drought resource areas (as opposed to winter pastures in more temperate areas). Soil infiltration and topographic features such as elevation gradients and drainage lines dictate the location of these habitats, which include swamps, highland forests, and riparian areas.

The physical and vegetation characteristics of riparian areas are a product of nutrient availability, water table characteristics, biotic processes, and disturbances such as floods and wildlife activity (Naiman et al. 1993, Naiman and Rogers 1997). These areas maintain vegetation communities and wildlife assemblages that are distinct from the surrounding landscape mosaics. For instance, East African riparian zones support remnants of tropical rainforest that became isolated and fragmentary due to climatic

[2] Vetter (2005: 332) defines key resource areas as, "small, highly productive areas which make a disproportionately large contribution to the area's total forage production." Similarly, Ngugi and Conant (2008) characterize them as dry-season forage zones that maintain higher mean primary production.

drying around 4000 YBP, and which intergrade with surrounding savanna communities (Medley and Hughes 1996). Dry-season water and forage availability makes them important habitats for consumers, and their spatial distribution structures wild ungulate migrations (Western 1975) as well as livestock movements (Coppolillo 2000).

Given these unique biophysical characteristics, it is not surprising that human populations use these areas extensively. East African riparian ecosystems face threats from resource extraction, damming, settlement, and agriculture development (Stave et al. 2001, Stave et al. 2003, Stave et al. 2007). There are conflicting findings about the impact of livestock on these systems, with some studies indicating negative grazing and browsing impacts (Mathooko and Kariuki 2000), others suggesting positive influences on tree regeneration and browse production (Reid and Ellis 1995, Oba 1998), and others reporting inconclusive findings (Stave et al. 2001). These mixed findings may be artifacts of inconsistent and poorly designed livestock exclosure research, which have yielded uncertainty in studies of western U.S. riparian systems (Sarr 2002).

Although researchers have documented these changes and described the vegetation communities of East African riparian systems (e.g., Hughes 1988, Medley and Hughes 1996, Mathooko and Kariuki 2000, Stave et al. 2003, Maingi and Marsh 2006), there have been few studies that analyze the relationships between riparian resource use and changes in rural livelihoods. This is a substantial shortcoming, as it limits our understanding of the proximate and distal drivers of environmental change. In the words of McCabe (2004: 73-74): "ecological studies that ignore the social and cultural rules by which access to resources is gained provide little insight into how these resources are actually used." This criticism applies to many landscape ecology studies, which often pay little attention to these ‘upstream’ influences on human use of the environment. The social and cultural factors influencing resource use are central to human ecology.

### *1.2.2. Human Ecology – Pastoralist Livelihoods*

Human ecology is a broad body of research that ties together elements of ecology, anthropology, sociology, and geography to investigate human-environment interactions. It encompasses the approaches of cultural ecology, ecological anthropology, and human behavioral ecology. These subfields overlap considerably and are sometimes referred to interchangeably. I distinguish between them in order to briefly illustrate the development of human-environment research, which I collectively refer to as ‘human ecology’.

Julian Steward’s (1955) study of the influence of the environment on cultural traits pushed beyond descriptive studies of particular geographic areas and social groups to explore more general comparisons across cultures, and eventually lead to models of the sources of cultural similarities (Robbins 2004b). Despite this advancement toward a more unified science of human-environment interactions, early cultural ecology was criticized for its emphasis on cultures (rather than populations) as the unit of analysis, material traits, and the effect of the environment on humans rather than their interactions (Orlove 1980). Identification of these shortcomings informed the development of ecological anthropology, and research (e.g., Rappaport 1968) that drew on Odum’s systems approach to study human populations and their cultural adaptations to the environment (Kottak 1999). Increasing recognition of non-equilibrium dynamics, the reductionist shortcomings of a focus on energy transfers, and the difficulty of defining a unit of analysis motivated studies of individual responses to hazards (Vayda and McCay 1975), and the contextualization of these responses into wider and denser "complexes of causes and effects." (Vayda 1983: 270) The investigation of individual behaviors is also central to human behavioral ecology, which employs an evolutionary perspective to study the flexibility and adaptive tradeoffs of cultural traits, biological characteristics, and behavioral patterns (Laland and Brown 2002). These ecological and evolutionary perspectives on human societies continue to inform a wide array of studies of the demographic, behavioral, health, land use, and cultural aspects of human-environment interactions.

Livelihoods, or the ways in which people make a living[3], are a critical interface of people and their environment. The livelihoods approach maintains that households draw on assets (i.e., natural, social, human, physical, and financial capital) in order to engage in activities (e.g., farming, herding, wage labor). A household's impact on the environment is influenced by its access to these five types of assets, the accumulation and use of which are mediated by cultural, institutional, economic, and environmental factors (de Sherbinin et al. 2008).

Studying livelihoods is an approach that is employed across a variety of disciplines (e.g., sociology, anthropology, and economics), and is especially useful for examining resource use due to their interface with social factors and ecological dynamics. Livelihoods influence the functioning of social-ecological systems by altering population distributions (de Haan 1999), resource use (Chambers and Conway 1992), land cover (Birch-Thomsen et al. 2001), food security (McCabe 2003, Pedersen and Benjaminsen 2008), disease transmission (Masanjala 2007), and social structures (Bryceson 2002).

[3] I adopt the definition of livelihood proposed by Chambers and Conway (1992: 5-6), that it is "a means of gaining a living." Or more formally, "a livelihood comprises the capabilities, assets (stores, resources, claims, and access) and activities required for a means of living."

They offer a useful analytical perspective because they capture multiple aspects of living and working conditions beyond income, such as activities, resources, and social relations (Ellis 1998, Barrett et al. 2001); furthermore, the livelihoods approach accounts for salient differences in the origin and means of attaining household resources, which are characteristics that can be overlooked by metrics such as socioeconomic class (Birch-Thomsen et al. 2001). Research on production strategies has proven fruitful for exploring the dynamic interactions of social organization, economics, local knowledge, and environmental constraints and opportunities (e.g., Netting 1993).

Livestock-based production strategies (i.e., pastoralism[4]) have allowed people to persist in arid and semi-arid environments around the world. Evans-Pritchard's (1940) influential ethnography of the Nuer was at the forefront of the proliferation of literature on pastoralist societies. These studies reflect the great diversity, both within and across pastoralist groups, of social organizations, livestock species, diets, and involvement in alternative livelihoods (Dyson-Hudson and Dyson-Hudson 1980, for a recent review of African pastoralism, see Homewood 2008). Yet several elements of pastoralism are found across a variety of settings: mixed-species herding, mobility, and social institutions for resource management and exchange (e.g., Scoones 1995 - Zimbabwe, Little and Leslie 1999 - Kenya, Fratkin and Mearns 2003 - Mongolia and Tanzania, Baker and Hoffman 2006 - South Africa, McAllister et al. 2006 - Australia). These attributes allow herders to capitalize on the spatial and temporal variability in rainfall and primary

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[4]This is an intentionally broad definition of pastoralism that encompasses transhumant and nomadic pastoralism as well as ranching in order to include a diversity of literature on rangeland systems. Ingold (1980) summarizes the differences between ranching and pastoralism in terms of their ecological and social opposition. Pastoralism is characterized by a protective relationship between humans and livestock and the fulfillment of domestic needs, while ranching is an essentially predatory, market oriented strategy of livestock production. In other words, "pastoralists derive their security from a combination of herd size maximization and mobility, rancher from a combination of herd size limitation and territoriality." (247-8)

production that characterize arid and semi-arid rangelands (Coughenour et al. 1985, Ellis and Swift 1988).

Early studies emphasized the role of cattle as symbols of prestige and wealth (Herskovits 1926), and although cultural valuation of cattle may be an important aspect of livestock accumulation, there are ecologically rational reasons for this behavior as well. Not only do livestock allow for the exploitation of patchy resources, but cattle also exhibit metabolic responses to drought - such as the timing of milk supply, changes in metabolic rate during droughts, and post-drought recovery - that make combined milk and meat production an energetically efficient strategy compared to beef production alone (Western and Finch 1986). Large herds are also "capital on the hoof," providing a buffer against periodic drought and disease epidemics that substantially reduce livestock populations (Western 1982). Furthermore, surplus stock can be invested in family formation (through the payment of bridewealth[5] and supporting children), and creating alliances with other herders through gifts or exchanges (Western and Finch 1986, de Vries et al. 2006). Building families and stock associations allow herders to recoup livestock losses, and provide access to labor for splitting herds based on age, sex, lactation, and species; smaller herds can then be grazed in different locations in order to spatially partition rangeland use, and to accommodate species-specific grazing/browsing preferences (Coppock et al. 1986). The dispersal of livestock across a range of individual herders and locations also reduces the risk of losing all livestock to drought, disease, or raiding (McCabe 2004), and can provide considerable contributions to herd growth during non-crisis periods as well (de Vries et al. 2006).

[5]Bridewealth is the transfer of payment, in this case livestock, from the family of the groom to that of the bride.

Herders redistribute their livestock over different habitats to balance trade-offs in water, nutrients, biomass, disease, and predation. This redistribution may involve anything from the exploitation of different local habitats, to movements of several kilometers to exploit altitudinal gradients, to latitudinal movements over hundreds or thousands of kilometers (Homewood 2008). Herders often undertake these movements in order to capitalize on seasonal flushes of high-nutrient vegetation in areas that do not maintain sufficient biomass or water availability during other times of year. As water and fodder become scarce during periods of low rainfall, herders move livestock to locations that maintain higher water availability and herbaceous biomass per unit area, such as rivers or swamps, even though these sites may have lower nutritive value and higher risk of disease or predation (Western 1982, Homewood and Lewis 1987, Scoones 1995). The distribution of dry-season water can affect grazing patterns during both the wet- and the dry-seasons (Coppolillo 2000), and entire households may relocate nearer to these sites during droughts (Butt et al. 2009).

Higher elevation moors or forests can serve as drought resource areas (DRAs), but sites such as rivers, streams, and swamps are often preferred because they can be easier to access (i.e., proximity and gentler terrain - Ngugi and Conant 2008). Riparian areas and wetlands are important resource areas for agriculturalists and pastoralists throughout Africa (Scoones 1991, Homewood 2008). Some sites provide permanent surface water, and ephemeral streams can be used as locations for digging wells to access sub-surface water. They also supply a variety of products, such as fuelwood, building materials, livestock fodder, food, medicines, and meeting places (Barrow 1990, Mathooko and Kariuki 2000, Stave et al. 2007). Environmental income from forests is a substantial component of household income across rural populations in developing countries (Vedeld et al. 2007), and it appears that riparian forests are no exception.

Sustained access to DRAs is essential for maintaining livestock populations and system resilience (Scoones 1995, Desta and Coppock 2002), but pastoralist access to dry-season forage and water sources can be inhibited by land subdivision and fragmentation (Sheridan 2001), agriculture development (Campbell 1999), and conservation areas (Homewood and Rodgers 1991, Igoe 2002, Western and Manzolillo-Nightingale 2004). Because water or mineral sources are often limiting factors on livestock production, the loss of access to DRAs has far-reaching implications for the viability of herding livelihoods. In the words of Homewood (2008: 61): “dry-season and drought access to wetland, swamp, and riverine resources on the one hand, or alternatively highland refuges on the other, is of central importance to pastoralist systems. Loss of access to these areas can mean collapse of the pastoralist system.” Specifically, Desta and Coppock (2002) suggest that the loss or degradation of DRAs may decrease the intervals between crashes in livestock numbers. Cases of DRA appropriation are relatively well documented in the literature, and based on pastoralist ecology, it follows that this resource loss would induce changes in herd variability. It seems plausible that such changes in livestock populations could be one factor driving the livelihood diversification that is occurring among pastoralists, but this relationship has yet to be conclusively demonstrated[6].

The livelihood diversity of rural populations has been increasing in recent decades (Reardon 1997, Ellis 1998, Barrett et al. 2001), and this pattern is reflected among African pastoralists, who are increasing their reliance on activities such as agriculture and

[6] Demonstrating this relationship may be difficult due in part to the fact that the loss of resources is sometimes an insidious process of attrition, rather than a punctuated and dramatic event (Turner 2004).

wage labor (Homewood 2008). There has been an associated increase in the number of studies of pastoralist livelihood diversification (Fratkin 2001, Homewood et al. 2001, Little et al. 2001, Thompson and Homewood 2002, McCabe 2003, Desta and Coppock 2004, Adriansen 2006, Berhanu et al. 2007, Thornton et al. 2007, Homewood et al. 2009, McCabe et al. 2010). Explanations for this phenomenon often include declining livestock:human ratios, but impoverishment induced by population pressure does not fully explain the livelihood shifts, as even wealthy families have begun cultivation (Little et al. 2001, McCabe et al. 2010).

Pastoralist livelihoods are shaped as much by social factors as they are by biophysical features. For instance, livelihood shifts interact with changing cultural norms, such as the acceptability of taking part in cultivation (McCabe et al. 2010). The availability of household assets are also relevant, as inter-personal livestock exchanges, household labor availability, market access, and land tenure exert substantial influence on livestock management decisions and participation in other livelihoods (Homewood 2008). Resource availability and livestock movements can also be affected by territoriality and conflict between groups (McCabe 2004). During periods of drought, areas of greater water availability become increasingly important, and as a result, DRAs can be focal points of competition (Campbell et al. 2000). This competition can be manifested as conflicts between herders and farmers (Turner 2004), or as intragroup disagreement about territorial boundaries (Western 1994).

Political and economic factors influence livelihood constraints and opportunities, including access to the resources needed to sustain livestock-based production strategies. State actions can structure the availability of household assets; for example, the establishment of conservation areas can block access to natural capital, and thereby impose opportunity costs on local land users and alter the source and quantity of a household's environmental income (Sjaastad et al. 2005). The loss of access to key grazing and watering sites due to governmental intervention has led to increased tension between conservation authorities and communities (Campbell 1999), and some pastoralists have resisted these losses through protest killings of high-value wildlife (Western 2002). These cases demonstrate that natural resource use, including the aforementioned variation in pastoralist livelihood strategies, should be examined in light of political, ideological, and economic motivations (Scoones 2009).

### *1.2.3. Political Ecology – Degradation & Conservation*

Studies of human-environment interactions and their response to political-economic forces have come to be known as political ecology, a term coined by Eric Wolf in 1972. Bernard Nietschmann's (1973) ethnography of the Miskito was an early advancement in describing the interactions of local production strategies and ecosystems, and how these relationships change with increasing integration into national and global politics and economic markets. Political ecology does not necessarily give primacy to larger-scale forces; rather, it seeks to recognize the historical and locational contingencies that yield unique struggles over resources, and that require consideration of multiscalar and translocal factors (Moore 2005). In other words, it emphasizes the perspective of local land users in cross-scale research. A "scale-skeptical approach" (as opposed to a hierarchical one) allows the investigator to uncover localized processes that are influential to higher order scales (Robbins 2004a), and to avoid the pitfall, identified by Vayda and Walters (1999), of assuming that political influences are always important.

There are four major theses within political ecology: degradation and marginalization; environmental conflict; conservation and control; and environmental identity and social movement (Robbins 2004b). I focus on the nexus of the degradation and conservation theses, as these are directly relevant to my research question, and have been influential in the rangeland literature. Moreover, critical assessment of degradation narratives was a flashpoint for political ecology. Blaikie and Brookfield (1987) highlighted the varied and contingent definitions of degradation, its interactions with economics and the state, and the importance of scale in evaluating degradation and its causes. Their analysis yielded some important general conclusions about land use: degradation for some can mean accumulation for others; local land users, although central to land management, may not be solely responsible for degradation; and population pressure is not a sufficient or necessary condition for degradation, due to innovation and intensification (also seeBoserup 1965, Netting 1993).

Pastoralism is often considered detrimental to rangeland ecosystems, but this perspective has been challenged through the identification of theoretical and methodological flaws in degradation claims. In particular, the rangeland degradation narrative has largely been based on inconsistent definitions and flawed metrics of degradation; inappropriate models of rangeland ecology; and/or misrepresentations of local resource management institutions. Nonetheless, claims of rapidly declining rangeland condition have proven influential, and motivated some hasty, ineffective, and at worst, inhumane rangeland conservation and development initiatives (Sandford 1983).

First, the identification of degradation is complicated by its varied definitions and metrics. For rangelands, it has been measured in terms of changes in soil (fertility, infiltration, erosion), vegetation (ground cover, species composition, bush encroachment), and livestock production (condition, yields, fertility, mortality) (Behnke and Scoones 1992). Attempts to differentiate anthropogenic changes in these metrics from those driven by "natural" biotic or abiotic processes are generally confounded by climatic variability, historical legacies, and human/livestock mobility. Using experimental manipulation to alter one variable (i.e., livestock grazing) and failing to account for the interactions of fire, climate, and grazing has, in many cases, yielded inaccurate accounts of livestock impacts (Curtin 2002b, Curtin et al. 2002). Incorporating local perspectives is a promising approach for understanding the drivers of observed environmental changes (West and Vásquez-León 2008).

In addition to the methodological difficulties of identifying and interpreting degradation, theoretical models of ecosystem function and resource management have also been problematic. First, equilibrium models of rangeland ecosystems played an important role in framing the impacts of humans and their livestock, and justifying carrying capacities and stocking rates. As previously discussed, this front of the rangeland degradation paradigm has been challenged by ecological and anthropological studies of pastoral energy use (Coughenour et al. 1985), livestock physiology (Western and Finch 1986), and the biotic and abiotic factors that influence livestock demography (Ellis and Swift 1988). In addition to the identification of non-equilibrium dynamics and the conceptual flaws of setting stocking rates in these settings, the notion of carrying capacity has been criticized for being ideal, static, and numerical - characteristics that are inconsistent with complex, dynamic systems whose management approaches are rarely as objective and quantifiable as carrying capacities suggest (Sayre 2008).

Second, the "tragedy of the commons" thesis initially described by Gordon (1954) and later popularized by Hardin (1968) has been a particularly influential narrative within rangeland discourse. In this view, pastoralists seek personal gain through increasing herd sizes, and in the absence of resource management systems, this individual gain comes at the collective cost of rangeland degradation. The fundamental flaw in applying the tragedy of the commons model to most pastoralist systems is its misrepresentation of resource management institutions. There is an important distinction between Hardin's vision of unregulated or open access, and common property resource management institutions, wherein a defined group of people shares a set of rules that regulate the use of a resource (Bromley and Cernea 1989, Ostrom 1990). Case studies have demonstrated that pastoralist societies frequently employ common property resource management institutions (e.g., McCabe 1990, Homann et al. 2008, Mwangi and Ostrom 2009)[7]. More broadly, the misunderstandings of rangeland management reflect a failure to recognize that livestock distributions and impacts are as much determined by social factors as they are by biophysical variables, including livestock markets, individual herding decisions, and interactions with other groups (Turner 1993).

The rational choice approach of common property theory interprets resource conflict as a product of institutional failure; the breakdown or absence of structures that govern access to resources results in degradation and "socially-produced resource

[7]Turner (1999) called attention to the fact that some institutions that resemble common property regimes may actually exhibit dynamic user groups and rules of access (i.e., the rules of access are negotiated and contested, not static and definable), or govern resources that do not have defined spatial locations (e.g., rainfall, manure) - characteristics that violate definitions of common property resource management institutions.

scarcity" (Turner 2004: 865). This view goes beyond neo-Malthusian explanations of competition over scarce resources and directs attention to the non-material aspects of conflict, such as longer-term struggles for control and political influence (Toulmin 1992, Turner 2004). For instance, claims to a particular parcel may not only be motivated by the resources themselves, but by strategic interest in user membership, cultural standards of what constitutes proper resource use, and control over access routes and the associated tax revenues. In other words, struggles over property rights are not purely the result of economic factors, but also ideological and political motivations (Ensminger and Rutten 1991).

In situations of resource scarcity, the identification of degradation, conflict, and institutional failure requires careful attention. Supposed resource conflicts may be manifestations of ideological or political struggles rather than competition for resources themselves; conversely, resource competition can stimulate, exacerbate, or be manifested as political or ideological conflict. To complicate things further, apparent degradation may only be short-lived environmental change. This is not to say that rangeland degradation does not occur; rather, it is important to critically evaluate the evidence for, and the proximate and distal drivers of environmental change. For example, overgrazing of southwestern U.S. rangelands at the end of the 19$^{th}$ Century resulted from the combined effects of federal land policy and an unregulated influx of livestock from the Great Plains. This livestock transfer was stimulated by large foreign and domestic investment in the Plains stock industry that was followed by cattle die offs from overstocking, drought, and blizzards. As a response, livestock were shipped to locations such as Arizona, where federal land policy granted homesteaders parcels that were of inadequate size to support dryland ranching. This lead to overgrazing and further livestock die offs, and encouraged people to claim exclusive use rights to well-watered sites (Sheridan 2001).

Perceived degradation, whether real or imagined, has influenced rangeland development policy and been used to marshal support for conservation initiatives. The misunderstandings stemming from "Hardin's thesis had a large impact on public understanding and scientific research concerned with famine and environmental degradation in arid lands… [and] also provided rationalization for World Bank programs calling for sweeping privatization of land and commercialization of livestock production." (Fratkin 1997: 240-241) For instance, vivid yet unsubstantiated accounts of desertification and environmental destruction underpinned the World Bank's National Environmental Action Plans, whose "cookie-cutter" land use policies were required as part of financial assistance for developing countries (Bassett and Zuéli 2000).

Top-down policies have marginalized traditional land tenure arrangements and land use patterns, often to the detriment of rangeland condition and local land users. U.S. ranchers are increasingly choosing or being forced to sell or subdivide their land due to the lack of governmental support for communal land tenure, the difficulty of securing pastures of sufficient size and water availability, and new economic pressures (e.g., rising land prices and property taxes from expanding exurban areas) (Sheridan 2001). Subdivision and the spread of exurban areas have further consequences for land cover change, and are also interfering with critical ecological processes such as fire (Sayre 2005). In Africa, land appropriation and development efforts (e.g., land privatization, water development, and sedentarization) have increased pressure on available resources and marginalized the traditional institutions for managing them; in particular, interventions have eroded systems of exchange, access, and mobility that had previously governed livestock distributions and range condition (e.g., Sandford 1983, Fratkin 1997, Homann et al. 2008, Mwangi and Ostrom 2009). Systems for regulating riparian resource use are also threatened by national forestry policies that ignore indigenous knowledge and tenure arrangements (Stave et al. 2001, Stave et al. 2007).

There have been recent efforts to recognize group property rights and to decentralize land administration in Africa, but this too has been met with substantial challenges. In many places there are overlapping claims of tenure and conflicting resource demands across groups, and within groups there are problems related to power sharing, accountability, and equitability (Mwangi 2009). Moreover, societies that exhibit mobility, exchange, and negotiation may require nested management structures that operate at multiple scales. It may also be necessary for management institutions to accommodate mobility and resource variability by allowing for flexibility in user membership; attempting to specify and set user groups or resources can be less effective than strengthening the rules for negotiating resource access (Turner 1999).

Top-down rangeland management policies have also been implemented through the establishment of conservation areas, such as national parks. Conservation areas are often established based on claims of degradation, which can be especially powerful when paired with notions of 'pristine wilderness' that ignore the historical role humans have played in shaping contemporary landscapes (Cronon 1995, Neumann 1998). Passionate but unsupported claims of exceptional biodiversity, ecosystem fragility, and livestock-induced degradation have justified the relocation of pastoralists and the establishment of conservation areas such as Mkomazi Game Reserve (Homewood and Brockington 1999). Upon exclusion of pastoralists from Mkomazi, the 'degraded' vegetation recovered quickly, indicating that livestock impacts were ephemeral and the ecosystem was resilient, even though it had purportedly been pushed to the verge of collapse (Brockington and Homewood 2001). Human exclusion from conservation areas has even been associated with declines in habitat diversity because the loss of interactions between elephants and grazers affected tree recruitment (Western and Maitumo 2004). In other locations, accounts of environmental damage and livestock population growth have been refuted by environmental assessments (e.g., Ngorongoro Conservation Area - Homewood and Rodgers 1984). Long-standing beliefs in pastoralist degradation are also contradicted by the persistence of wildlife populations in areas long inhabited by pastoralists, as well as pastoralists' contributions to current conservation efforts outside of national parks and preserves (Little 1996).

Although the establishment of conservation areas can, and sometimes does, provide positive benefits for local communities in the form of economic opportunities and ecosystem services, it can also yield displacement in the form of physical relocation and/or resource access restriction (Cernea 2005). Scholars have described the consequences of such displacement across a variety of settings (for a review, see West et al. 2006). In particular, Cernea (1997) identified eight types of risk associated with displacement: landlessness, joblessness, homelessness, marginalization, food insecurity, loss of access to common property resources, increased morbidity, and community disarticulation. A central premise of my research is that these risks also hold less obvious, indirect implications for environmental conservation efforts; that is, conservation initiatives affect human communities in ways that hold important consequences for the attainment of conservation goals (Miller et al. 2012). I discuss these feedbacks in greater detail in the *Conceptual Framework* section.

*1.2.4. Literature Synthesis*

These three ecologies have different research foci, and engage livelihoods, a central component of my research, in different ways (Figure 1.1). Human ecology typically views livelihoods as the interface of social and ecological systems; in the process, these studies sometimes neglect larger-scale social or ecological phenomena. This focus on the social-ecological interface is not as prevalent in the landscape or political ecology traditions – landscape ecology generally treats livelihoods as factors affecting environmental characteristics[8], and political ecology largely treats them as an indication of household opportunities and constraints that are influenced by broader political and economic forces. These research foci are reflected in the critiques of each field: political ecology often lacks ecological analysis (Walker 2005), studies of human-environment interactions should give more attention to political and economic forces (Scoones 2009), and landscape ecology could benefit from greater integration with the social sciences (Wu 2006). I suggest that combining the three ecological research areas through resilience thinking will be more effective than independently expanding the scope of each field.

[8]This is evidenced by the statement from Wu (2006: 1) that "…landscape ecologists around the world have long been cognizant of the importance of humans in *influencing* landscapes." (emphasis added)

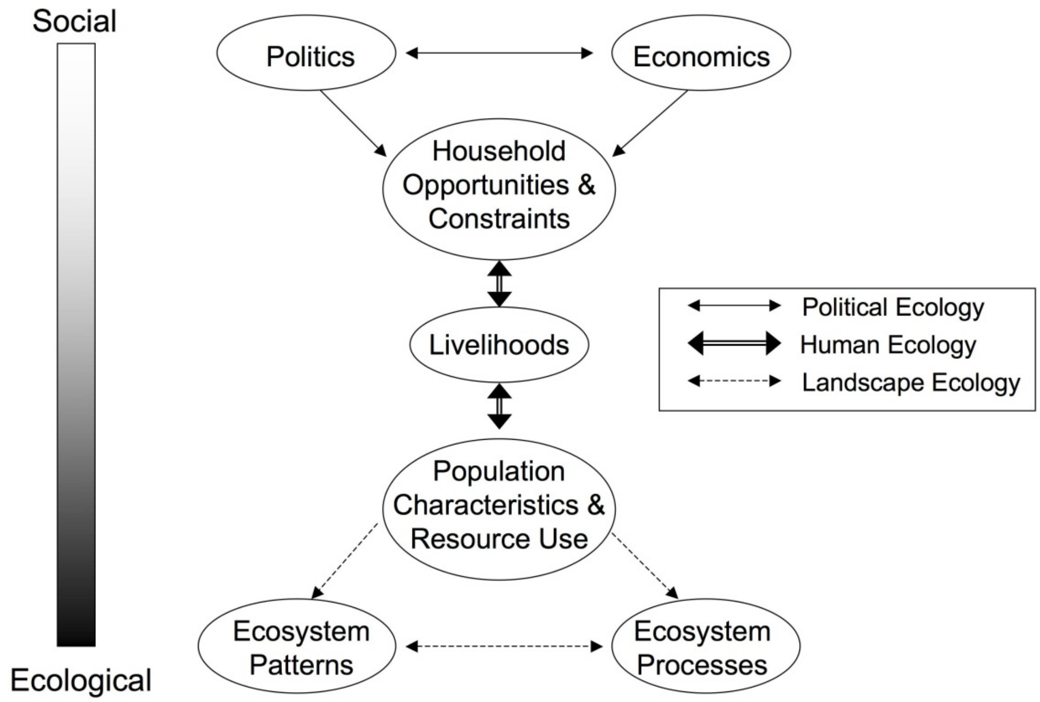


**Figure 1.1.** Research foci of political, human, and landscape ecology with respect to livelihoods. The grayscale indicates the associated attention to social and ecological factors

These disciplinary critiques, and my suggestion for addressing them, are consistent with the notion that social and ecological systems are linked and cannot be understood in isolation because of feedbacks[9] between system components (Berkes et al. 2000). Social-ecological systems are complex and adaptive[10], having alternate states or regimes that are separated by thresholds. The persistence of a social-ecological system in a particular state is dependent upon its resilience, or its capacity "…to absorb disturbance; to undergo change and still retain essentially the same function, structure, and feedbacks. In other words, it's the capacity to undergo some change without crossing

[9]Feedbacks are "the secondary effects of a direct effect of one variable on another, they cause a change in the magnitude of that effect. A positive feedback enhances the effect; a negative feedback dampens it." (Walker and Salt 2006: 164)

[10]Complex-adaptive systems exhibit large-scale dynamics that emerge from interactions and feedbacks across scales. They are characterized by diverse and independent components, interaction between components, and a selection process that produces variation and novelty in the system (Levin 1998).

a threshold to a different system regime – a system with a different identity." (Walker and Salt 2006: 32) Resilience and stability are distinct features of social-ecological systems. Stability denotes a return to equilibrium after a disturbance, whereas resilience is the persistence of a system and the relationships within it. Systems can have low stability (i.e., high fluctuation) and high resilience (i.e., persistence), and in fact, instability can foster resilience (Holling 1973).

Social-ecological systems exhibit phases of rapid growth, conservation, release, and reorganization (Walker and Salt 2006). This series of phases is an adaptive cycle, which describes how a system and its resilience behave over time. For example, a forest initially establishes itself through fast-growing pioneer species (rapid growth phase), which give way to specialists that are efficient at energy capture and growth (conservation phase). This increase in efficiency entails a loss of redundancy, increasing the likelihood that a disturbance will cause the accumulated energy and biomass to be released (release phase). Once this occurs the system can be organized in a different way depending on the conditions and system components that remain after the release phase (reorganization phase).

Adaptive cycles exist at multiple levels and are linked across scales. The phases occurring at one social or ecological scale (e.g., household or leaf) are linked to the phases at other scales (e.g., national economy or ecosystem). This dynamic, linked hierarchy is known as "panarchy" (Gunderson and Holling 2001), and indicates that what happens at one scale can influence what happens at another. For example, different patches of a forest may be in different phases of the adaptive cycle. This habitat heterogeneity, or patchiness, increases resilience of the forest as a whole because the diversity of habitat types maintain different species assemblages and age structures that respond differently to disturbances such as fire or parasite infestations. This differential response increases the likelihood that the system components and relationships will persist (Walker and Salt 2006).

Resilience thinking can be applied to both social and ecological subsystems; for example resilience can be evaluated in terms of the diversity of system components, regardless of whether these components are species or institutions. Redundancy in institutions or species can enhance resilience in two ways: institutions/species can serve different roles or functions within a system (functional diversity) and institutions/species with the same function can respond to change or disturbance in different ways (response diversity). In the event of a shock or disturbance, these two forms of diversity increase the capacity of the system to retain its essential relationships and function (Walker et al. 1999, Elmqvist et al. 2003, Walker and Salt 2006).

The applicability of resilience thinking to both social and ecological dynamics speaks to the strengths of resilience theory as an overarching framework for combining the three ecologies, which emphasize different aspects of social-ecological systems. I use this integrative perspective to advance research of the human dimensions of environmental conservation.

### *1.3. Conceptual Framework*

In summarizing the literature on the conflicts between environmental conservation initiatives and local land users, Robbins (Robbins 2004b: 148) maintains that "apolitical ecology would direct attention to two factors, population growth at the park boundaries and the inherent tragedy that emerges from producers seeking individual good at collective costs." On the other hand, political ecology would view the problem "as one of control over access, aesthetics, and landscape production." This dichotomy is reflected in the two dominant types of research on the social dimensions of conservation; most peer-reivewed research focuses either on the effects of people on the environment (e.g., poaching, deforestation, invasive species, indigenous management), or the effects of conservation initiatives on people (e.g., relocation, resource access restriction, employment, tourism revenues) (Miller et al. 2012). Books that compile and review research on the interactions of conservation initiatives and human communities (e.g., Borgerhoff Mulder and Coppolillo 2004) present both views but do not necessarily tackle the mutual effects of conservation initiatives and human activities.

The social effects of conservation initiatives and the environmental impacts of human communities are more productively viewed as interdependencies, wherein conservation initiatives affects social changes that in turn impact human behavior, and hence the environment and the attainment of conservation goals (Figure 1.2) (Miller et al. 2012). These 'physical' feedbacks between conservation and social-ecological systems are distinct from the 'informational' feedbacks of adaptive management wherein ecological monitoring/assessment informs policy development and implementation. Ideally, adaptive management recognizes, examines, and responds to the physical feedbacks, but doing so is not a necessary condition of adaptive management, which is defined by its cycle of project planning, implementation, evaluation, and modification (Stem et al. 2005). Adaptive management is focused on project application and outcomes, not necessarily the dynamics that produce those outcomes. Identifying these dynamics requires close examination of conservation-induced social changes and their ecological implications. In other words, there is a need for research on the social changes that mediate conservation initiatives and environmental outcomes (Miller et al. 2012).

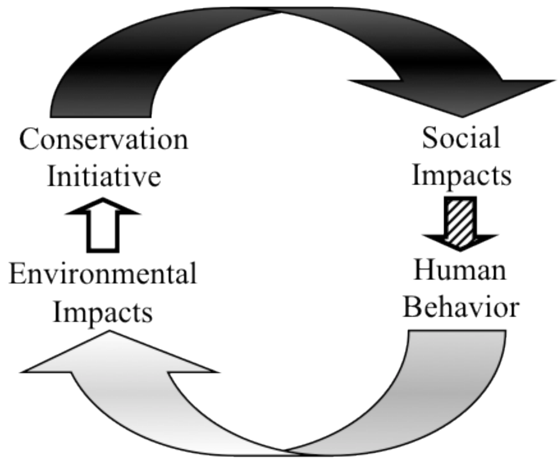


**Figure 1.2.** Feedbacks between environmental conservation initiatives, social dynamics, and the environment (black arrow, effect of conservation on the economic, cultural, and political characteristics of proximate human communities; hatched arrow, behavioral responses of local land users to conservation-induced social changes; gray arrow, effect of local resource users on the environment; unshaded arrow, environmental effects may lead to changes in conservation policy or practice) (from Miller et al. 2012)

This notion is consistent with other assessments of the literature on conservation evictions; although eviction due to conservation efforts has been well-documented, "few studies of the impacts of eviction offer good quality information on the social impacts of removal. Fewer still examine what has happened with their ecology." (Brockington and Igoe 2006: 454) Moreover, this observation is symptomatic of the critiques leveled by Vayda and Walters (1999) and by Walker (2005) that political ecology is, in many cases, lacking the ecology. A notable exception is Schmidt-Soltau's (2003, 2005) work examining the social and ecological risks of conservation displacement using Cernea's (1997) risk framework. This research is an important contribution, but its generalized description of the varied and complex processes associated with displacement would benefit from a more detailed treatment of displacement risks.

### *1.4. Research Approach*

My literature review demonstrates that landscape, human, and political ecology are complementary, and resilience thinking takes this idea one step further, indicating that their research foci cannot be fully understood in isolation. This is the theoretical foundation for my conceptual framework of the feedbacks between conservation initiatives and social-ecological systems. The goal of my dissertation is to empirically describe these feedbacks by studying how resource management is affecting the social-ecological resilience of the study system to drought. However, implementing resilience thinking in empirical research requires a more specific analytic approach.

Analyzing resource management requires an understanding of resource structure and flow, user attributes, and rules governing resource use (Ostrom 1990). This assertion is echoed in the more actor-oriented sustainable livelihoods framework (Scoones 1998): in a particular *context*, what livelihood *resources* allow for what combination of livelihood *strategies*, with what *outcomes*, and how are these outcomes mediated by *institutions*? This approach addresses the interactions of social and ecological components of the study system, and provides an indication of the individual and institutional capacity to address problems (i.e., adaptability) and respond to disturbances (i.e., resilience). This contrasts to the more common definitions of sustainability that focus on efficiency and optimization, which can reduce system resilience (Walker and Salt 2006).

The stustainable livelihoods framework serves as a guide for splitting my overarching study question into more specific subquestions (above) and tasks. I use geospatial analysis to identify patterns of resource availability (question 1, chapter 2), and provide *context* for evaluating the effect of dry-season/drought *resource* access on Maasai livelihood *strategies* (question 2, chapter 3). I also describe the resource management *institutions* of four major rivers in Simanjiro in order to compare environmental *outcomes* (question 3, chapter 4).

In the process, this research will clarify the feedbacks between conservation initiatives and local land users by describing the influence of conservation and development on resource access at multiple scales (question 1 and black arrow in Figure 1.3), the effects of changes in resource access on household livelihood decisions (question 2, hatched arrow), and the relationships between livelihoods and the environment (question 3, gray arrow).

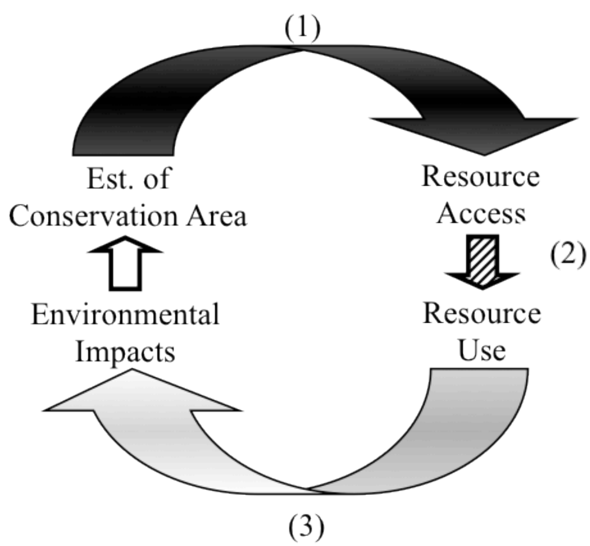


**Figure 1.3.** Conceptual framework. This dissertation addresses the feedbacks between conservation and human communities by examining (1) the effects of TNP on natural resource access, (2) the role of resource access in livelihood decisions, and (3) the influence of resource-use choices on the environment. The connection between environmental impacts and conservation policy is beyond the scope of this research, but indicates an opportunity for future research (adapted from Miller et al. 2012)

Collectively, this work will identify system components, relationships, elements of continuity, and sources of innovation, which together provide an indication of system resilience (Robinson and Berkes 2010). These insights may also reveal strategies for enhancing the resilience of rangelands and pastoralist societies more broadly. Although pastoralist societies have been the subject of much research, "the resilience literature has not yet given much attention to pastoralism and particularly to the social elements of pastoralist *social*-ecological systems." (Robinson and Berkes 2010: 337)

### *1.5. Study Site & Population*

#### *1.5.1. East African Rangelands*

About 79% of the East African land surface is rangeland (Kenya 87%, Tanzania 74%, Uganda 79%) (Pratt and Gwynne 1977). These iconic landscapes maintain remarkable populations of large mammals (e.g., wildebeest, elephant, rhino, lion), as well as archaeological evidence that humans and our ancestors have also occupied this landscape for millions of years (Burney 1996). Although East Africa is often depicted as a timeless wilderness landscape, it has a long history of social dynamics (including the relatively recent immigration of Maasai pastoralists discussed below), and is currently undergoing land use alterations that are associated with shifting livelihoods, demographics, and political-economic priorities.

The rangelands of northern Tanzania and southern Kenya receive a mean annual rainfall of about 300mm to 1200mm (Gichohi et al. 1996). According to the updated Köppen-Geiger climate classification (Peel et al. 2007) these rangelands are a conglomeration of tropical savanna (Aw), hot arid steppe (BSh), and temperate warm summer, dry winter (Cwb). This area also contains pockets of hot arid desert (BWh) and temperate dry/warm summer (Csb). Tropical monsoon (Am) and tropical rainforest (Af) zones are found at higher elevations. Annually, the climate regime is characterized by one long dry-season from June to October, and one rainy-season from November to May (Figure 1.4), which is subdivided into the short rains (November to January) and the long rains (February to May) (Prins and Loth 1988).

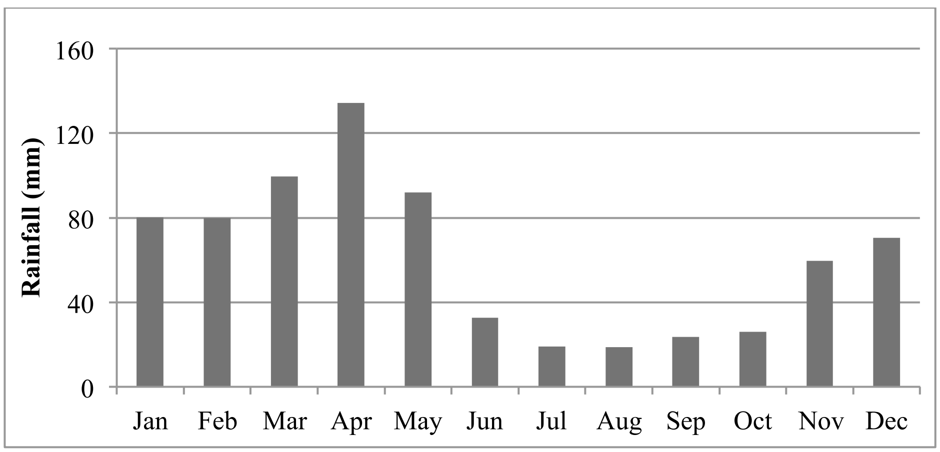


**Figure 1.4.** Monthly Mean Rainfall (mm) for Narok, Kenya (1913-2003); data from the Royal Netherlands Meteorological Institute

Seasonal rainfall is a result of north-south movments of the Intertropical Convergence Zone (ITCZ). The ITCZ is an area of low pressure that forms as heated air rises and draws air masses from the north and south. These moisture-laden air masses rise as they hit the warm ITCZ, causing the air to cool, and water vapor to condense and precipitate. The ITCZ follows the overhead sun (i.e., the sun’s zenith) with lag of 2 weeks (Homewood 2008). It shifts southward during the long rains, a season which account for about 42% of annual rainfall in East Africa (Indeje et al. 2000). During the long rains there is weak correlation between rainfall at different stations, indicating large spatial variability. The short rains account for about 25% of annual precipitation. During this season there are strong station-to-station and seasonal-to-annual rainfall correlations (Nicholson 1996, Indeje et al. 2000), indicating that the short rains are a better predictor of annual rainfall, and that there are more uniform spatial patterns of precipitation during this season. Intra-annual variability is inversely related to mean annual rainfall (Prins and Loth 1988). Mean annual rainfall is positively correlated with elevation, especially during the long rains. The region exhibits very high inter-annual rainfall variability, and low-rainfall years are a common feature of the climate in East Africa (Figure 1.5) (Prins and Loth 1988).

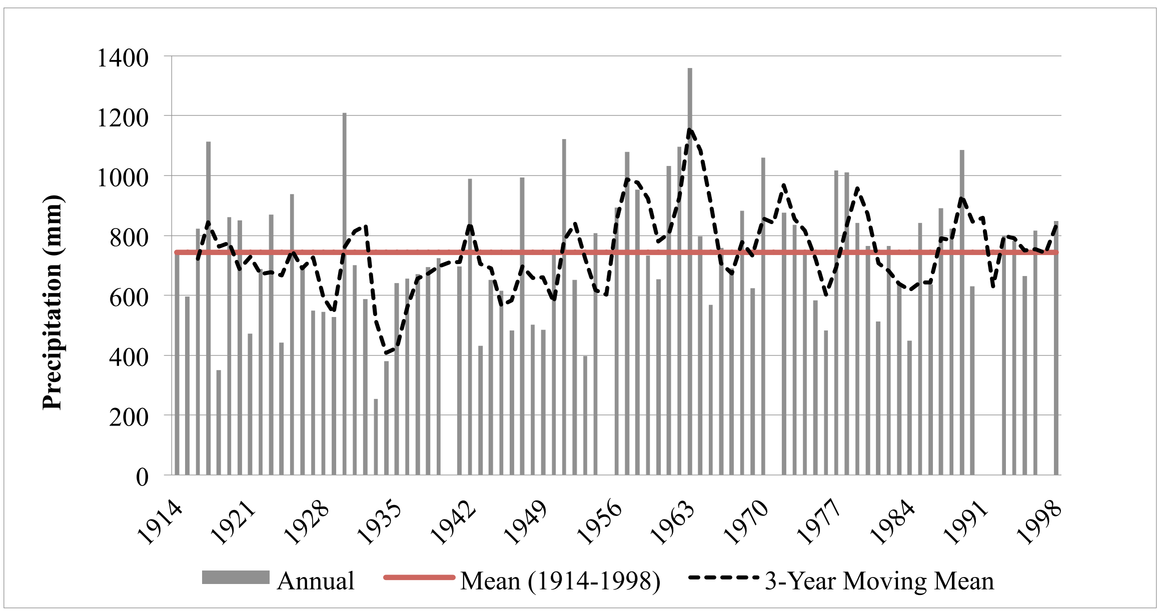


**Figure 1.5.** Annual, long-term mean, and 3-year moving mean precipitation for Narok, Kenya (1914-1998); empty cells indicate missing data; data obtained from the Royal Netherlands Meteorological Institute

There are four major types of drought: meteorological, hydrological, agricultural, and socioeconomic. These are defined, respectively, in terms of: the magnitude and duration of departure from normal precipitation; the effect of precipitation shortfalls on surface and subsurface water supply; the effect of soil moisture on crop yields; and the effect of drought on other human activities (American Meteorological Society 1997). These types of drought are distinct, but often related. In sum,

> *"many definitions have been offered for the term 'drought', but no single parameter (whether it be precipitation, runoff ,evapotranspiration, temperature, soil moisture or crop yields) can serve as an adequate or comprehensive drought index. Drought implies an extended and significant negative departure in rainfall, relative to the regime around with the society is stabilized. Thus, drought conditions in one region may be considered normal conditions in a more arid region, or during a more arid epoch." (Rasmusson 1987: 8)*

The context specific nature of droughts has resulted in different standards for identifying drought years according to annual precipitation. Meze-Hausken (2004) classifies years with 50 to 75% of a 30-year average as 'below-normal' and 0 to 50% as 'much-below-normal.' McCabe (2004) follows Stoddart et al.(1975) in using 85% of long term average as the cut-off for drought years.

Despite the ambiguity in defining droughts, they have substantial social and ecological effects that make them more clearly identifiable within a given region. Campbell (1999) identifies 20$^{th}$ Century drought years in the Kenya/Tanzania border region as: 1933-35, 1943-46, 1948-49, 1952-53, 1960-61, 1972-76, 1983-84, and 1994-95. This is consistent with Rasmusson's (1987) characterization of East African drought durations of one to three years (as opposed to longer term "dry regimes" of ten years or more that characterize the Sahel). Rainfall data from the Serengeti ecosystem of southern Kenya and northern Tanzania reveal no clear rainfall periodicity at scales larger than the annual cycle, except for a variable 5- or 10-year cycle (Pennycuick and Norton-Griffiths 1976).

More recent regional climate analyses demonstrate a correlation between the El Niño Southern Oscillation (ENSO) and annual rainfall. Warm ENSO (El Niño) years are associated with above normal rainfall, especially during the short rains, and post-ENSO (+1) years are associated with below normal rainfall (Nicholson 1996, Indeje et al. 2000, Camberlin et al. 2001). Cold ENSO (La Niña) cycles are also linked to decreased annual rainfall (Nicholson and Selato 2000, Paeth and Friederichs 2004). Over millennial timescales, climate reconstruction from sediments in Lake Naivasha, Kenya indicate the occurance of a dry, 'Medieval Warm Period,' (AD 1000-1270) and a wet, 'Little Ice Age' (AD 1270-1850) that was punctuated by 3 dry episodes (AD 1380-1420, 1560-1620, and 1760-1840) that were more severe than any recorded in the 20$^{th}$ Century (Verschuren et al. 2000).

Spatio-temporal patterns in rainfall interact with soil characteristics, herbivory, and fire to produce a mosaic of habitat types. Rainfall is positively correlated with primary production and animal biomass (Coe et al. 1976); however, geomorphology can substantially alter this relationship and the extent of different vegetation communities through differences in topography, soil nutrients, and infiltration (Bell 1982, Western 1982). For example, wetlands can be found in the poorly drained valley bottoms of otherwise low-rainfall areas. In other locations, hardpans (produced by calcium carbonate leaching and accumulation) restrict root penetration and sustain short-grass communities (Sinclair 1979). The eight basic physiognomic vegetation types are classified based on the height and density of trees and shrubs, and range from arid dwarf shrub grassland to humid forest[11]. These can be subdivided into vegetation communities based on the dominant genera or species present (Pratt and Gwynne 1977).

Invertebrates and fire consume most primary production, but larger herbivores structure vegetation biomass and community composition as well (Gichohi et al. 1996). The timing of fire is related to rainfall, with most fire occurring late in the dry season. Fire incidence and intensity interacts with vegetation biomass and herbivory. Grazing can reduce fire intensity through decreased fuel loads, thereby allowing for an increase in woody vegetation. On the other hand, browsing can decrease woody vegetation and enhance grass growth, thereby increasing fuel loads, and causing more intense fires that lead to greater declines in biomass (Van Langevelde et al. 2003). Pastoralists sometimes use fire to produce flushes of nutrient rich vegetation, clear dense bush, reduce parasite loads, and prevent large, catastrophic fires (Western 1982, Homewood and Rodgers 1991, Butz 2009).

The impacts of herbivores on vegetation condition and composition are varied and depend on the type of herbivore and habitat (Olff and Ritchie 1998). In the Serengeti ecosystem of northern Tanzania, grazing has been shown to increase grass quality and growth rate (McNaughton 1985). Moderate grazing has been associated with a doubling in grass production under certain levels soil moisture availability, and productivity can be maintained even under very heavy grazing (McNaughton 1979). Large herbivores also influence nutrient distributions (e.g., maintaining nitrogen levels in productive areas - Augustine et al. 2003), and seed dispersal (Miller 1996). On a larger scale, the combined

[11] The eight main physiognomic vegetation types identified by Pratt and Gwynne (1977) are forest, bushland, woodland, shrubland, bush grassland, wooded grassland, shrub grassland, and permanent swamp. Interestingly, Pratt et al. (1966) describe forest and swamp as “vegetation types of little value as rangeland.” I expect that the present paper will counter this view.

effects of elephants and pastoralists increase habitat diversity by creating and maintaining large-scale mosaics of woodland and grassland (Western and Maitumo 2004).

Forage abundance and quality (i.e., protein and mineral concentrations) as well as predator avoidance structure seasonal wildlife migrations (Fryxell and Sinclair 1988, McNaughton 1990). The availability and quality of forage declines during the dry-season (Sinclair 1975), which prompts a migration to foraging sites that maintain higher primary production. Water availability also exerts a strong influence on wildlife concentrations, especially during dry periods and in more arid areas, and swamps and rivers attract large numberes of wildlife (Amboseli Swamps - Western 1975, e.g., Tarangire River - Gereta 2004).

Riparian forests exhibit vegetation links to savanna woodland and tropical rainforest (Hughes 1988). Thus, riparian zones sustain distinct vegetation communities as well as an array of local and migratory fauna (e.g., large mammals, birds, and non-human primates - Hughes 1988, Mathooko and Kariuki 2000). Not only do these systems support wildlife, but animals such as elephants and hippopotami structure riparian zones through their influence on vegetation structure, channel morphology, and microtopography (Naiman and Rogers 1997). Annual or biannual flooding are also important agents of change (Hughes 1988, Stave et al. 2003, Maingi and Marsh 2006). Thes unique biophysical characteristics of riparian zones are of value to both conservationists and local land users. As a result, riparian zones, and DRAs in general, can be focal points for competition and conflict; however, this shared interest can also be viewed as an opportunity to develop partnerships in maintaining ecosystem function and resource availability.

*1.5.2. Maasai*

A variety of pastoralist, agriculturalist, and hunter-gatherer groups have shaped the rangelands of East Africa. The area of northern Tanzania and southern Kenya that is predominantly inhabited by Maa speakers who identify themselves as Maasai is informally known as Maasailand (Figure 1.6) (Homewood et al. 2009). Maa speakers are linguistic descendents of the eastern branch of the Nilotic languages, a group that originates in the southern Sudan; this origin indicates a north-south movement of Maa-speakers beginning early in the 1$^{st}$ millennium AD (Sommer and Vossenpp 1993). They were present in Tanzania by around the mid-16$^{th}$ century to early 17$^{th}$ century, but did not develop their specialized livestock-based economy and culture until around the 18$^{th}$ century, when Maasai consolidated and expanded their territory (Galaty 1993). Flexibility in herd composition, movement, social institutions, and household structure, including interaction with other ethnic groups in the region, have allowed Maasai to cope with the environmental variability of this region (Homewood and Rodgers 1991).

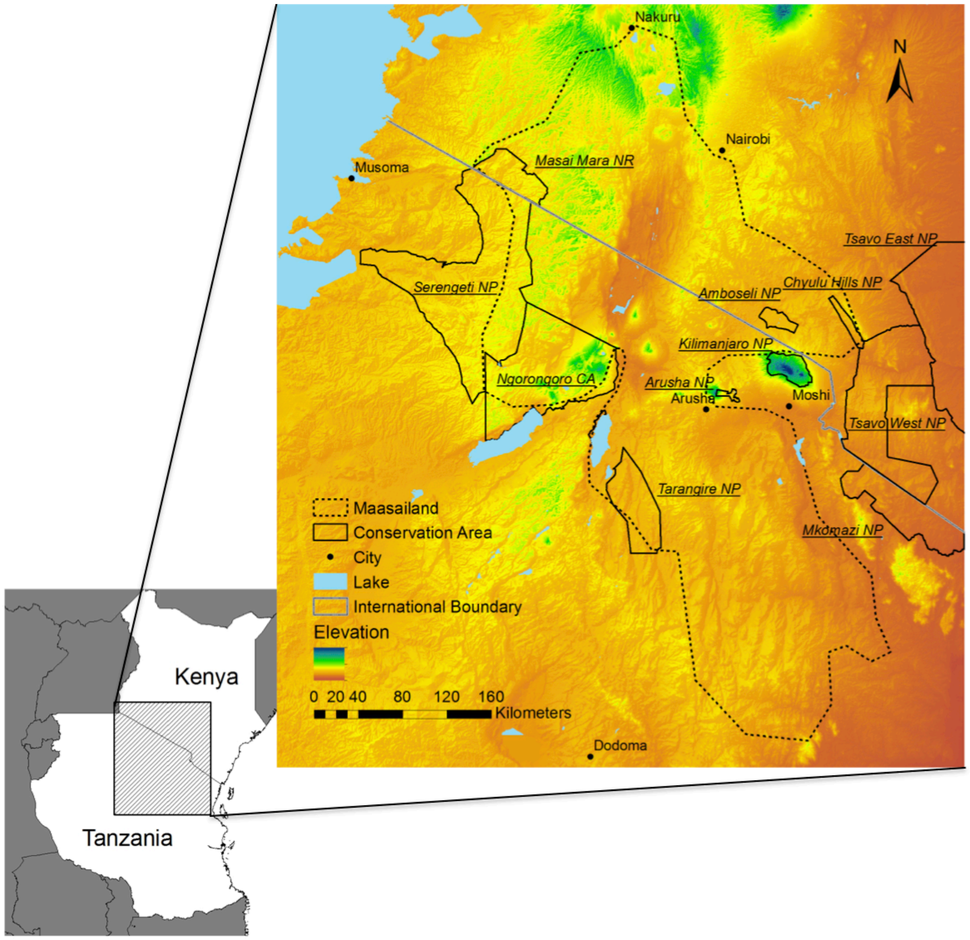


**Figure 1.6.** Approximate extent of contemporary Maasailand (based on Homewood et al. 2009); NP=National Park; NR=National Reserve; CA=Conservation Area

Maasai society is primarily structured by section, clan, and age set. Sections act as political units as well as territorial groupings that share grazing and water resources. Clans are patrilineal groups which constrain marriage opportunities, and provide geographically dispersed social support networks. Age sets cross-cut sections and are male cohorts that pass through life stages or age grades (boy, warrior, junior elder, senior elder, retired elder) together, each stage having its own set of norms and responsibilities. During the warrior age grade members acquire a name that identifies them as an age set and remains with them throughout their life. Different age sets may share different values (e.g., livelihood preferences) and thus endorse different cultural norms as they pass through life stages (Homewood and Rodgers 1991, Spencer 1993).

Maasai traditionally herd cattle, goats, sheep, and donkeys, and exhibit regular seasonal movement of their livestock (i.e., transhumance). Given their pastoral livelihood base, it is a common misconception that Maasai rely solely on blood, milk, and meat; rather, among Maasai households "a purely pastoral diet is the exception rather than the rule, and this has probably always been the case." (Homewood and Rodgers 1991: 228) This diverse diet is in part due to interactions with other groups. Maasailand is not a homogenous territory, but is an "interdependent regional economy and culture", wherein pastoralists, farmers, and hunter-gatherers exchange goods and cultural traits to varying degrees (Spear and Waller 1993).

A historical period (1883-1902) that had substantial bearing on current Maasai consumption patterns is collectively referred to as *Emutai*, meaning "to finish off (completely)" in reference to the complete destruction of their herds (Waller 1988: 74). First, an outbreak of bovine pleuropneumonia reduced livestock numbers, then a disease that afflicts livestock and wild ungulates known as rinderpest swept through sub-Saharan Africa during the 1890's, killing about 90% of the cattle and large numbers of domestic sheep and goats (Normile 2008). As a result, an estimated two-thirds of Maasai in Tanzania died of starvation, and the famine stimulated livestock raiding between different Maasai sections. Concurrently, smallpox killed many people because they had no prior exposure to the disease. This decline in livestock, wild ungulate, and human populations led to a reduction in grazing and burning activities. As a result, areas of bushland expanded, facilitating the spread of tsetse flies and trypanosomiasis, which discouraged people from returning to some areas (Homewood and Rodgers 1991). This series of disasters led to increased interaction with cultivators in the region (e.g., Kikuyu, Arusha, and Meru), including intermarriage and the exchange of goods (Spear and Waller 1993).

Although Maasai are thought to have exchanged goods with neighboring agricultural communities for quite some time, they are increasingly participating in cultivation and wage-labor (Thompson and Homewood 2002). The adoption of agriculture by Maasai herders has accelerated over the past 30-40 years, and is now quite widespread. This has typically consisted of the establishment of modest sized "kitchen gardens" and expansion of cultivation to larger farm plots (McCabe et al. 2010). Some Maasai households appear to have diversified their livelihoods in response to shortfalls in household resource production, but as previously mentioned in reference to other pastoral groups, insufficient livestock production induced by population pressure does not fully explain the livelihood shifts, as even wealthy families have begun cultivation. Some households adopted cultivation to reduce risk or to avoid selling livestock for needed food or money, while for others it was an opportunity for further economic gain and security (Little et al. 2001, Homewood et al. 2009, McCabe et al. 2010). This phenomenon reflects changing cultural and social norms, including what is appropriate behavior for Maasai. Government policies have also influenced Maasai livelihood diversification. Under the Tanzanian Villagization Program ("Ujamaa") following independence in 1961, people were required to leave rural areas and live in permanent structures in proximity to village centers. Pastoralists were also encouraged to cultivate (McCabe et al. 2010). Overall, the adoption of agriculture has been influenced by a variety of factors, including household and regional demographics, cultural norms, and political-economic context.

These changes in land use are interacting with considerable changes in land tenure and availability. Colonial rule reduced Maasai territory, and influxes of cultivators from other areas increased pressure on rangeland resources – particularly the better-watered hills and riparian areas – stimulating Maasai to claim individual or group title to land (Campbell 1993). The shift from communal land tenure to private ownership was also influenced by pressure from World Bank structural adjustment programs during the 1980's, and commercial agriculture activities (e.g., wheat, barley, and flowers) that reduced land and water availability (Fratkin 2001). The establishment of conservation areas by the colonial and post-colonial governments of Kenya and Tanzania exacerbated competition for resources (Campbell et al. 2000).

A number of studies have described the effects of particular conservation areas on Maasai communities (e.g., Igoe 2002, Western and Manzolillo-Nightingale 2004). These descriptions of land/resource loss and of the marginalization of traditional management institutions are valuable contributions that call attention to injustices and policy failures, but it is yet unclear how these case studies fit into a broader picture of resource access in the region. Moreover, they do not address the specific ways in which Maasai have actually responded to drought resource appropriation (e.g., changes in livestock movements, participation in other livelihoods).

It would be productive to move beyond descriptions of resource loss, and to explore the strategies that herders are using to cope with this phenomenon. For instance, the establishment of group ranches in Kenya has given way to unequal subdivision of land among group members (Mwangi 2007). In the face of these changes, some land-holders are reaggregating their parcels, or redistributing livestock among kin and friends. Subdivision was initially a defensive strategy against loss of land, and they are now attempting to maintain livestock-based production strategy through internal negotiation of access rights and resource management (Mwangi 2007). In Tanzania, some Maasai appear to be using cultivation as a tactic for resisting the expansion of nearby conservation areas, or at least qualifying for compensation if their land is appropriated (Baird et al. 2009, Sachedina and Trench 2009).

Increased participation in agriculture suggests a concomitant shift in resource availability. Maasai in Kajiado District, Kenya fenced off areas in anticipation of land subdivision and privatization, and increased cultivation around the margins of swamps and rivers (Campbell 1999). This begs the questions of whether or not this is occurring in other areas of Maasailand, and how Maasai resource management institutions and households are mitigating and coping with these changing resource demands.

### *1.6. Conclusion*

Landscape, human, and political ecology emphasize different aspects of social-ecological interactions, and each approach has its limitations. I suggest that these deficiencies can be most effectively addressed, not by expanding the scope of each field independently (as others have suggested), but by employing their unique approaches in combination. This suggestion stems from the notion that social and ecological systems are inextricably linked and can be understood in terms of their resilience, or ability to endure disturbances and still retain their fundamental structure and function. Resilience thinking is highly generalizable in that it can be applied to social and ecological dynamics at various scales, but applying this thinking to more specific research questions requires the use of more specific analytical approaches. Livelihoods interface with social and ecological subsystems, and the sustainable livelihoods framework is a useful guide for developing a research strategy while accounting for relevant system components and relationships. In sum, resilience thinking provides a justification for combining the three ecologies, and the sustainable livelihoods framework offers a more specific research strategy.

My objective is to use this approach in order to advance research on the social dimensions of environmental conservation initiatives. Most studies of the interactions between conservation areas and human communities have focused either on the effects of people on the environment, or the effects of conservation on people (Miller et al. 2012). Examining their mutual causality (i.e., feedbacks) is necessary in order to understand the processes that mediate conservation initiatives and outcomes. This knowledge would enhance our capacity to predict the social and environmental outcomes of conservation policies, and may help to resolve some of the challenges plaguing conservation and development initiatives.

I pursue this research objective by studying the connections between pastoralist livelihoods and rangeland conservation efforts. Pastoralists worldwide are undergoing livelihood changes that have the potential to substantially alter rangeland ecosystems (e.g., Little et al. 2001, Sheridan 2001, Fratkin and Mearns 2003). Despite the proliferation of studies examining this phenomenon, the role of natural resource exclusion in livelihood decision-making, the response of resource management institutions to livelihood changes, and the consequences of livelihood diversification for resource use are largely unexplored. In other words, the literature on livelihood change would benefit from further examination of the institutional and behavioral responses to resource dislocation.

The causes and consequences of this livelihood change are of interest to conservation and development initiatives alike. This knowledge is critical to maintaining pastoralism as a viable livelihood option, which is gaining recognition as a land use that is more compatible with conservation efforts than alternatives such as cultivation or exurban development (Brunson and Huntsinger 2008). Drought resource areas are especially germane because they present an opportunity for local land users and conservationists to partner in establishing access rights and management strategies that maintain both ecosystem function and resource availability. Developing such management plans for drought resource areas is a promising means of enhancing the resilience of pastoralist systems (Robinson and Berkes 2010).

Unfortunately, the importance of dry-season/drought resources to sustaining pastoralism is often underappreciated (Little 1996). This is especially troubling given that herders, cultivators, and conservationists are all vying for these relatively small, yet productive areas. It would be constructive to learn from the individual strategies and the collective resource management institutions that have allowed some households to remain in the pastoral sector in spite of changes in resource availability. In the process, I hope to elucidate specific opportunities for improving the social and environmental well-being of the study area.

# CHAPTER 2

## THE DISTRIBUTION OF DROUGHT RESOURCE AREAS IN EAST AFRICA AND IMPLICATIONS FOR PASTORALIST LIVELIHOODS

### *2.1. Introduction*

*"We have only two good days a year: the day it rains, and the day after."*
– Resident of Loiborsoit

Rangelands cover more of the Earth's terrestrial surface than any other land use (Asner et al. 2004). These areas are characterized by an herbaceous understory dominated by grasses with varying levels of canopy cover, and provide habitat for wild and domestic ungulates (Pratt et al. 1966). Rangelands exhibit substantial spatial and temporal variability in primary production, but relatively small areas of the landscape known as key resource areas maintain forage during periods of plant dormancy (Vetter 2005).

Key resource areas can be winter pastures in temperate zones, or dry-season/drought resource areas (DRAs) in arid and semi-arid ecosystems. Soil infiltration and topographic features such as elevation gradients and drainage lines dictate the location of DRAs, which include swamps, highland forests, and rivers. DRAs oftentimes maintain vegetation communities that are distinct from the surrounding rangeland mosaics. For instance, East African riparian zones support remnants of tropical rainforest that became isolated and fragmentary due to climatic drying around 4000 YBP and which intergrade with surrounding savanna communities (Medley and Hughes 1996), producing distinct species assemblages (e.g., Hughes 1988, Medley and Hughes 1996, Mathooko and Kariuki 2000, Stave et al. 2003, Maingi and Marsh 2006). The maintenance of water and forage availability through periods of low rainfall makes DRAs important habitats for consumers. The spatial distribution of DRAs structures wild ungulate migrations (Western 1975) as well as livestock movements (Coppolillo 2000), and may even regulate regional livestock population dynamics (Illius and O'Connor 1999).

DRAs are important resource areas for agriculturalists and pastoralists throughout Africa (Scoones 1991, Homewood 2008). These sites provide surface water or sites for digging wells to access sub-surface water, as well as a variety of other natural resources such as fuelwood, building materials, livestock fodder, food, medicines, and meeting places (Barrow 1990, Mathooko and Kariuki 2000, Stave et al. 2007). Yet East African wetlands and riparian ecosystems face threats from resource extraction, damming, settlement, and agriculture (Stave et al. 2001, Stave et al. 2003, Stave et al. 2007).

These activities also threaten resource access for livestock herders. For instance, cultivation has limited the access of Maasai pastoralists to dry-season forage and water resources in Kajiado District, Kenya (Campbell 1999). In other parts of East Africa, the establishment of conservation areas has inhibited Maasai rersource access (Homewood and Rodgers 1991, Igoe 2002, Western and Manzolillo-Nightingale 2004). The loss of access to DRAs has far-reaching implications for the viability of herding livelihoods and rangeland ecosystems since water and mineral sources are often limiting factors on livestock production (Western 1975, 1982, Scoones 1995, Western and Manzolillo-Nightingale 2004, Ngugi and Conant 2008).

Although previous studies have identified instances of resource displacement and anthropogenic environmental threats to DRAs, none have empirically evaluated the changing distribution of DRAs in relation to conservation areas and land use/land cover (LULC) change in East Africa. Moreover, patterns in DRA availability have not been examined across multiple spatial scales in order to identify relationships that are scale dependent, or commonalities across scales.

The detection of patterns and processes at multiple scales is an overarching theme of ecological research (Levin 1992), and a focus of landscape ecology in particular (Turner 2005). I engage with this fundamental feature of ecological research by analyzing natural resource distributions and patterns of access at regional, watershed, and local scales. The Kenya/Tanzania border region provides context and a broad picture of resource availability, the greater Tarangire watershed is a central conservation landscape within the region, and the Simanjiro Plains are an important wildlife dispersal area for Tarangire National Park and include the villages which are the focus of my fieldwork. I analyze remote-sensing data at these three scales in order to address the question: <u>what is the spatial distribution of DRAs in relation to conservation areas and agriculture development in the Kenya/Tanzania border region, the greater Tarangire River watershed, and the Simanjiro Plains, and how has this changed over time?</u>

I expect that conservation and agricultural areas play important roles in structuring the accessibility of DRAs. In terms of the distribution of DRAs across land use zones, I hypothesize that at all three scales, conservation and agricultural areas contain disproportionately high percentages of DRAs compared to land that is neither conserved nor cultivated. Terrain (e.g. steep hillsides) may also be an additional factor limiting access for livestock and humans, and I anticipate that at all three scales, non-conserved, non-cultivated DRAs are primarily found in areas with high slope angles compared to conserved and cultivated DRAs.

### *2.2. Study Area*

The arid and semi-arid rangelands of East Africa are a dynamic mosaic of vegetation communities that are shaped by the interactions of soil, topography, herbivory, fire, and rainfall (Gichohi et al. 1996). These interactions have produced iconic savanna landscapes that support extraordinary populations of migratory mammals and a network of world-renowned conservation areas. Tarangire National Park (TNP) is centrally located between multiple conservation areas in northern Tanzania, and is home to remarkably high concentrations of African elephants (*Loxodonta africana*), as well as substantial populations of resident and migratory ungulates (i.e., wildebeest - *Connochaetus taurinus,* Burchell's zebra - *Equus burchelli,* Thomson's gazelle - *Gazella thomsoni*, and Grant's gazelle - *G. granti*), yielding wildlife densities estimated at up to 250 animals per square mile during the dry season (Lamprey 1964). Wildlife distributions are structured by water quality (particularly salinity; Gereta et al. 2004), and habitat and food preferences (Lamprey 1963), but they are also attracted to TNP by water in the Tarangire River and the Silalo Swamp.

During the wet season, wildlife – especially zebra and wildebeest – migrate to the adjacent Simanjiro Plains (Kahurananga 1981, Kahurananga and Silkiluwasha 1997). The Simanjiro Plains are semi-arid with an average annual rainfall of around 600 mm. The vegetation consists of short grassland dominated by *Digitaria macroblephara* and

*Panicum coloratum*, and smaller areas of *Acacia tortilis* and *Commiphora schimperi* woodland, *Acacia stuhlmannii* bushland, and *Pennisetum mezianum* and *Acacia stuhlmannii* bushed grassland that is seasonally water-logged (Kahurananga 1979). Simanjiro is also home to agriculturalists and pastoralists, but they are not allowed within TNP.

For the purposes of this study, the Simanjiro study area (or 'local scale') is defined by the western border and northernmost edge of TNP, the Nyumba ya Mungu reservoir to the east, and the southern border of Mkungunero Game Reserve (Figure 2.1). The next larger scale of analysis, referred to as the 'watershed scale,' matches the extent of the Landsat image that encompasses both the local scale of the Simanjiro Plains as well as the watershed of the Tarangire River to the west. Lastly, the regional study area is definied by the boundaries of Tanzanian and Kenyan districts that are primarily rangeland and encompass the approximate extent of contemporary Maasailand (Homewood et al. 2009). In order to reduce bias that might be introduced by district boundaries that were created based on resource distributions or geographic features, I expanded the regional study area using a 10km buffer.

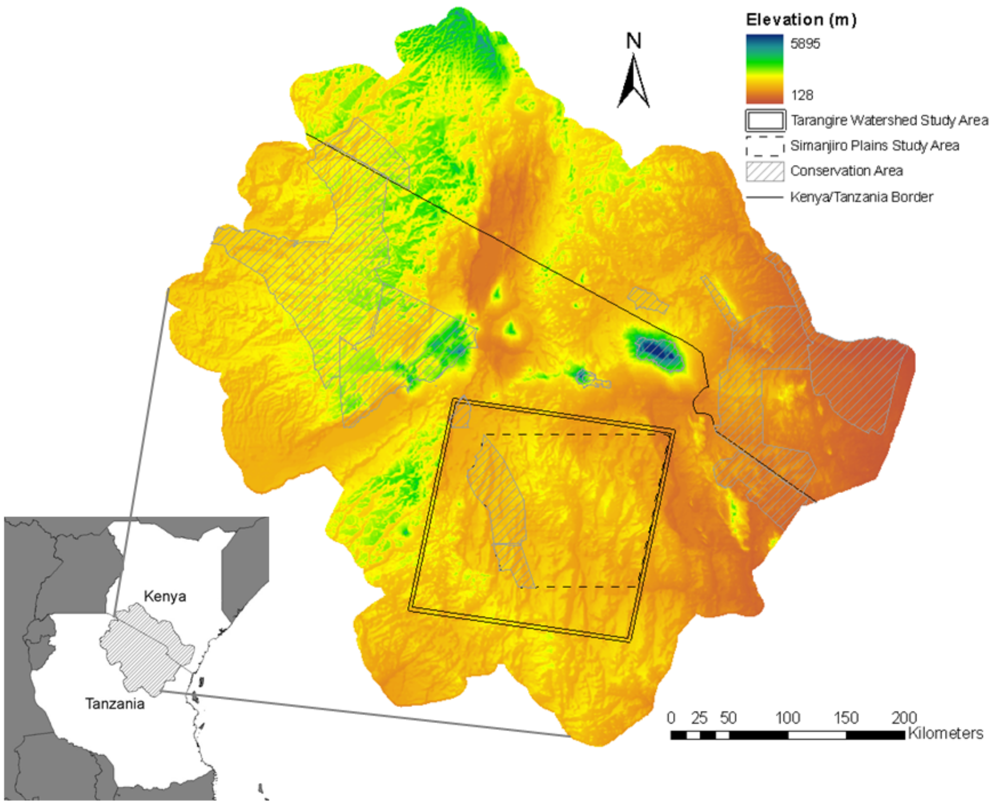


**Figure 2.1.** Regional study area highlighting the watershed and local scales of analysis and major conservation areas; see Table 2.1 for information on data sources (regional elevation, water bodies, administrative boundaries, and conservation areas)

## *2.3. Methods*

In order to investigate patterns of resource availability, I mapped the distribution of DRAs relative to land use changes, conservation areas, and terrain. This required data on primary production, land cover, elevation, and administrative boundaries, which I derived from a variety of satellite imagery and shapefiles (Table 2.1). I also collected ground truth data in June and July of 2009 and 2010, and from March to November 2011; these data were used to calibrate and validate the analysis.

Remote sensing data products were selected based on historical coverage and trade-offs between spatial extent, resolution, and cost. Sensor revisit time and cloud cover limited the choice of particular images, and the availability of Landsat images after 2003 was further limited by the Landsat ETM 7 scan-line error. Within these constraints, I selected images that spanned the longest possible period including the 2009 drought, and also had comparable dates and mean primary production (which was measured using the Normalized Difference Vegetation Index, described below).

I used images from the late dry-season for detecting DRAs, and images from the middle of the wet-season for LULC classifications. Dry-season images provided contrast in primary production across different parts of the landscape, which is useful for detecting DRAs. Images from December and January provided spectral contrast between cultivated areas, rangeland, and forest that was necessary for LULC classifications; at that time of year, much of the cultivated land is plowed, while uncultivated land has generally started greening. Images from later in the wet-season, when fields have higher primary production, could have led to the misclassification of natural areas of higher primary production as crops, and produced inflated estimates of the overlap of DRAs and agriculture. Images from the dry-season would not have been as effective for differentiating cultivated and uncultivated land because of low primary production in both land use classes.

I used *ENVI 4.8* to derive LULC classifications and calculate NDVI from satellite imagery, mask clouds and cloud shadows, and standardize image formats. Thematic LULC designations for the watershed and local scales were created using supervised maximum likelihood classification. I chose training data based on visual interpretation of images and knowledge of the study area in an iterative process of adding training data in order to refine the classified output image. I created ground truth regions based on GPS locations from ground truth survey data. Unsupervised classification using the ISODATA algorithm produced a similar number of classes, but with larger errors; the results of post-classification error analysis are available in Appendix I.

At the regional scale, I used the 500m gridded MODIS land cover type product. These data were originally classified into 17 classes defined by the International Geosphere Biosphere Program by using a supervised decision-tree classification method (USGS 2009). Training data for the classification were developed primarily from higher resolution data such as Landsat TM images (Hodges 2002). I did not use the same LULC classification method as the watershed and local scales because I did not have access to the same training and ground truth data for images with such large spatial resolution and extent, and attempting classification without these data would have yielded a LULC classification with unknown accuracy. I did, however, consolidate land cover types from the 17 thematic classes into 5 classes in order to match LULC categories of the other scales of analysis.

Dry season foraging zones and areas with aseasonal water availability in Kenya are associated with higher mean Normalized Difference Vegetation Index (NDVI) values, indicating that NDVI is a relevant indicator of rangeland soil moisture and primary production (Ngugi and Conant 2008). NDVI is a metric of vegetative productivity and is calculated from the visible red (VIR) and near infrared (NIR) regions of the electromagnetic spectrum as

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{VIR})}{(\mathrm{NIR} + \mathrm{VIR})}$$

After calculating NDVI values and generating thematic LULC classifications, I imported the processed images into *ArcGIS 10.1* for analysis. I first reconciled the data projections and extracted major water bodies from satellite images (in order to reduce classification errors and to restrict analysis to accessible land). I then classified NDVI data into deciles, and defined DRAs as cells in the highest NDVI decile. I calculated LULC change and DRA change across two time points at each spatial scale, and then examined the overlap of these changes.

I also created composite DRAs by identifying cells that remained in the highest NDVI decile across 2 or more dry-season images. This definition of DRAs is consistent with an analysis of key resource areas in Kenyan rangelands, which found that the majority of key resource areas are considered permanent, or "a reliable forage source in all droughts." (Ngugi and Conant 2008: 826) Moreover, the proportion of the total land area that I classified as composite DRAs was comparable to the area of key-resource areas in semi-arid Kajiado District in southern Kenya calculated by Ngugi and Conant (2008). Creating composite DRAs was also necessary in order to control for background spatial and temporal variation in primary production in my analysis of the relationship between DRAs and land use zones

Land use zones were divided into three basic categories: 'cultivated' zones were those areas categorized as 'agriculture' in the LULC classification; 'conservation' zones were those areas within nationally designated conservation areas that substantially limit resource access such as national parks, reserves, forest reserves, game reserves, and conservation areas (conservation areas did not include wildlife management areas, game controlled areas, UNESCO Man and the Biosphere Reserves, or Wetlands of International Importance); and 'available' zones were defined as non-conservation, non-cultivated land.

Lastly, in order to describe the terrain characteristics of DRAs within each land use zone I derived slope angle from the 30-meter resolution ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) and 90-meter SRTM (Shuttle Radar Topography Mission) digital elevation models. I measured slope angle using the surface analysis slope tool in *ArcGIS 10.1*, which calculates the maximum rate of change in elevation between each cell and its eight neighbors. I assessed the significance of differences in the mean slope angle of composite DRAs in each land use zone over time using matched-pairs t-tests (two-tailed distribution).

**Table 2.1.** Geospatial data types, descriptions, and sources

| *Data Type* | *Description* | *Spatial Resolution* | *Date of data production* | *Source* |
|---|---|---|---|---|
| Primary Production | Region: 16-day composite NDVI from NASA's Terra Earth Observing System Moderate resolution Imaging Spectroradiometer (MODIS) sensor | 250m | 09/29/2000, 09/01/2009 | NASA/USGS Land Processes Distributed Active Archive Center (LP DAAC), https://lpdaac.usgs.gov/ |
| | Watershed and Local: NDVI derived from Landsat Thematic Mapper 4 & 5 images (Bands 4 & 3) | 30m | 10/01/1988, 09/04/2009 | USGS Global Visualization Viewer (GloVis), http://glovis.usgs.gov |
| Land Cover | Region: MODIS Terra + Aqua Land Cover Type Yearly L3 Global SIN Grid | 500m | 2001, 2009 | NASA/USGS LP DAAC, https://lpdaac.usgs.gov/ |
| | Watershed and Local: derived from Global Land Survey and Landsat TM5 images (Bands 1-7) | 30m | 02/25/1987, 01/31/2010 | USGS GloVis, http://glovis.usgs.gov |
| Elevation | Region: Digital elevation model (DEM) from the NASA Shuttle Radar Topography Mission v4 (SRTM v4) | 90m | Feb. 2000 | NASA/USGS, Consortium for Spatial Information (CGIAR-CSI), http://srtm.csi.cgiar.org/ |
| | Watershed and Local: DEM from NASA's Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER-Terra) sensor | 30m | 01/01/2000-02/28/2011 | NASA/USGS LP DAAC, https://lpdaac.usgs.gov/ |
| Water Bodies | Shape files produced by SRTM v2 | N/A | Feb. 2000 | NASA SRTMv2, http://www2.jpl.nasa.gov/srtm/ |
| Administrative Boundaries | Shapefiles of national and district administrative boundaries | N/A | Kenya: 1998 Tanzania: 2002 | Kenya: International Livestock Research Institute Tanzania: Tanzanian Census |
| Conservation Areas | Shape files of nationally designated and internationally recognized conservation areas | N/A | Ongoing updates | World Database on Protected Areas & International Livestock Research Institute |

## *2.4. Results*

### *2.4.1. Land Use/Land Cover Change*

Rangeland was the predominant LULC class at all scales (Figure 2.2). Both the watershed and regional scales exhibited a decline in forest cover (3.3% to 2.7%, and 31.6% to 28.6%, respectively). The proportion of bare ground and agriculture declined at the regional scale, but increased at the other scales. The amount of agricultural land increased from 10.2% to 15.5% at the watershed scale, and 1.8% to 3.3% at the local scale. The proportion of bare ground increased from 1.2% to 9.9% for the watershed, and 6.2% to 7.5% for the local scale.

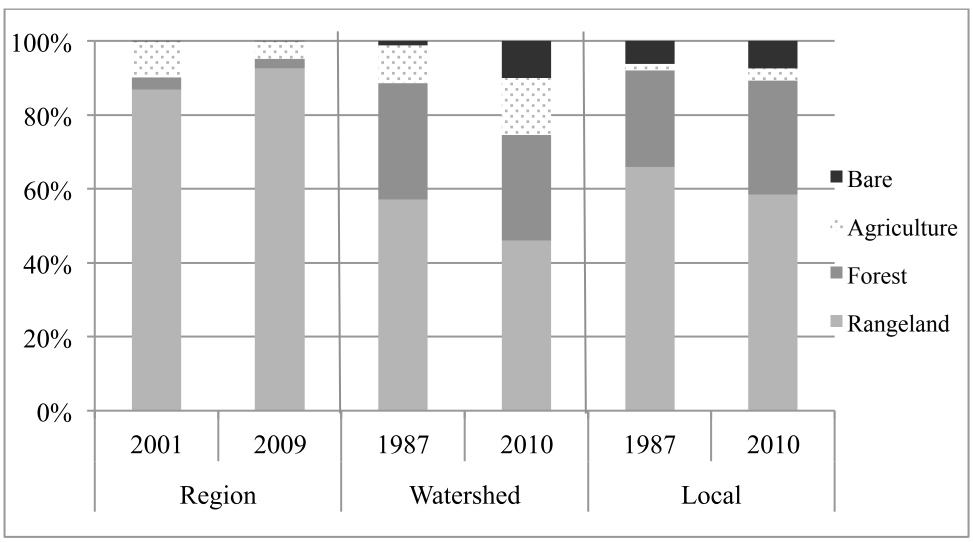


**Figure 2.2.** Proportion of land area in each LULC class at three spatial scales; the water class was omitted from the figure because it accounted less than 0.5% of area

The majority of the increase in agricultural land at the watershed and local scales was driven by land that transitioned from rangeland to agriculture (Tables 2.2 and 2.3). For these scales, there were also notable proportions of land area that transitioned from forest to rangeland and from agriculture to rangeland. Similarly, at the regional scale, the majority of land that was classified as agriculture in 2001 was rangeland in 2009 (Table 2.4).

**Table 2.2.** Land use/land cover change matrix for the local scale (1987-2010) ($km^2$ in parentheses)

| | | 1987 | | | | |
|---|---|---|---|---|---|---|
| | | *Rangeland* | *Forest* | *Agriculture* | *Bare* | *Water* |
| **2010** | *Rangeland* | **68.0% (7,882.1)** | 36.8% (1,692.5) | 74.7% (233.7) | 44.7% (487.6) | 0.3% (0.0) |
| | *Forest* | 21.0% (2,431.9) | **60.6% (2,786.6)** | 3.8% (11.8) | 10.2% (111.0) | 0.4% (0.0) |
| | *Agriculture* | 4.4% (508.5) | 0.5% (25.1) | **15.5% (48.5)** | 1.2% (12.8) | 0.1% (0.0) |
| | *Bare* | 6.6% (765.8) | 2.0% (93.1) | 6.1% (19.0) | **43.3% (472.2)** | 38.2% (0.8) |
| | *Water* | 0.0% (3.3) | 0.1% (4.0) | 0.0% (0.0) | 0.6% (6.4) | **61.0% (1.2)** |
| | *Total* | 100.0% (11,591.6) | 100.0% (4,601.3) | 100.0% (313.0) | 100.0% (1,089.9) | 100.0% (2.0) |

**Table 2.3.** Land use/land cover change matrix for the watershed scale (1987-2010) ($km^2$ in parentheses)

| | | 1987 | | | | |
|---|---|---|---|---|---|---|
| | | *Rangeland* | *Forest* | *Agriculture* | *Bare* | *Water* |
| **2010** | *Rangeland* | **58.8% (10,136.9)** | 31.0% (2,957.7) | 26.8% (826.9) | 14.6% (51.3) | 16.1% (1.7) |
| | *Forest* | 18.4% (3,164.8) | **54.5% (5,193.7)** | 5.9% (183.3) | 5.1% (17.8) | 5.9% (0.6) |
| | *Agriculture* | 12.8% (2,198.5) | 10.0% (955.0) | **48.8% (1,506.7)** | 14.9% (52.1) | 37.6% (3.9) |
| | *Bare* | 9.9% (1,707.9) | 4.3% (411.8) | 18.4% (569.5) | **65.3% (228.9)** | 25.0% (2.6) |
| | *Water* | 0.1% (23.0) | 0.1% (10.2) | 0.1% (3.3) | 0.2% (0.7) | **15.3% (1.6)** |
| | *Total* | 100.0% (17,231.1) | 100.0% (9,528.3) | 100.0% (3,089.6) | 100.0% (350.8) | 100.0% (10.3) |

**Table 2.4.** Land use/land cover change matrix for the regional scale (2001-2009) (km$^2$ in parentheses)

| | | *2001* | | | | |
|---|---|---|---|---|---|---|
| | | *Rangeland* | *Forest* | *Agriculture* | *Bare* | *Water* |
| ***2009*** | *Rangeland* | **96.6%** **(221,354.3)** | 28.1% (2,431.0) | 79.4% (20,556.0) | 38.3% (125.0) | 3.5% (25.0) |
| | *Forest* | 0.5% (1,227.8) | **62.7%** **(5,429.5)** | 1.5% (382.8) | 5.0% (16.3) | 4.6% (32.5) |
| | *Agriculture* | 2.8% (6,523.8) | 9.0% (779.0) | **19.0%** **(4,929.3)** | 2.1% (7.0) | 0.4% (2.5) |
| | *Bare* | 0.0% (109.3) | 0.1% (6.0) | 0.0% (7.0) | **46.5%** **(151.8)** | 4.0% (28.5) |
| | *Water* | 0.0% (17.3) | 0.1% (10.0) | 0.0% (7.3) | 8.1% (26.5) | **87.6%** **(625.0)** |
| | *Total* | 100.0% (229,232.3) | 100.0% (8,655.5) | 100.0% (25,882.3) | 100.0% (326.5) | 100.0% (713.5) |

### *2.4.2. Drought Resource Areas*

The proportions of land area in the highest NDVI decile during only the first year ('Lost DRAs') or only the most recent year ('Gained DRAs') were highest for the local scale and lowest for the regional scale (Table 2.5). The inverse was true for the proportion of land that remained in the highest NDVI decile between the two time points ('Composite DRAs'), which was highest for the regional scale and lowest for the local scale.

**Table 2.5.** Total land area and mean NDVI change of cells in each DRA category [a] [b]

| | ***Region*** | | ***Watershed*** | | ***Local*** | |
|---|---|---|---|---|---|---|
| | *Area* | *Mean NDVI Change (S.D.)*[c] | *Area* | *Mean NDVI Change (S.D.)* | *Area* | *Mean NDVI Change (S.D.)* |
| Composite DRAs | 6.6% | 0.061 (0.051) | 2.9% | 0.070 (0.064) | 1.9% | 0.054 (0.050) |
| Lost DRAs | 2.0% | 0.150 (0.098) | 2.5% | 0.094 (0.082) | 3.6% | 0.040 (0.034) |
| Gained DRAs | 1.7% | 0.179 (0.092) | 4.5% | 0.118 (0.053) | 6.4% | 0.098 (0.051) |
| Non-DRAs | 89.7% | 0.030 (0.033) | 90.0% | 0.028 (0.023) | 88.1 % | 0.023 (0.019) |

(a) DRA categories and NDVI changes refer to the following time points: Region=2000-2009; Watershed=1988-2009; Local=1988-2009

(b) DRA categories refer to grid cells that were classified in the highest NDVI decile during both years ('Composite DRAs'), the first year only ('Lost DRAs'), last most recent year only ('Gained DRAs'), or neither year ('non-DRAs')

(c) Mean NDVI change and standard deviations were calculated for each category based on the absolute value of the difference in each cell's NDVI value at the two time points

The relationship between DRA and LULC change varied by scale, but the majority of DRA change occurred in areas where LULC remained the same. At the regional scale, the majority (65%) of change from DRA to non-DRA (i.e., 'lost DRAs') occurred in locations that were classified as rangeland at both time points, while 13% occurred in areas that changed from agriculture to rangeland, and 10% from rangeland to agriculture. At the watershed scale, the largest proportion of DRA loss occurred in areas that changed from forest to rangeland (15%) or remained forest (15%) (Figure 2.3). At the local scale, most (36%) DRA loss occurred in locations that remained rangeland, followed by those that remained forest (22%) and those that changed from rangeland to forest (19%).

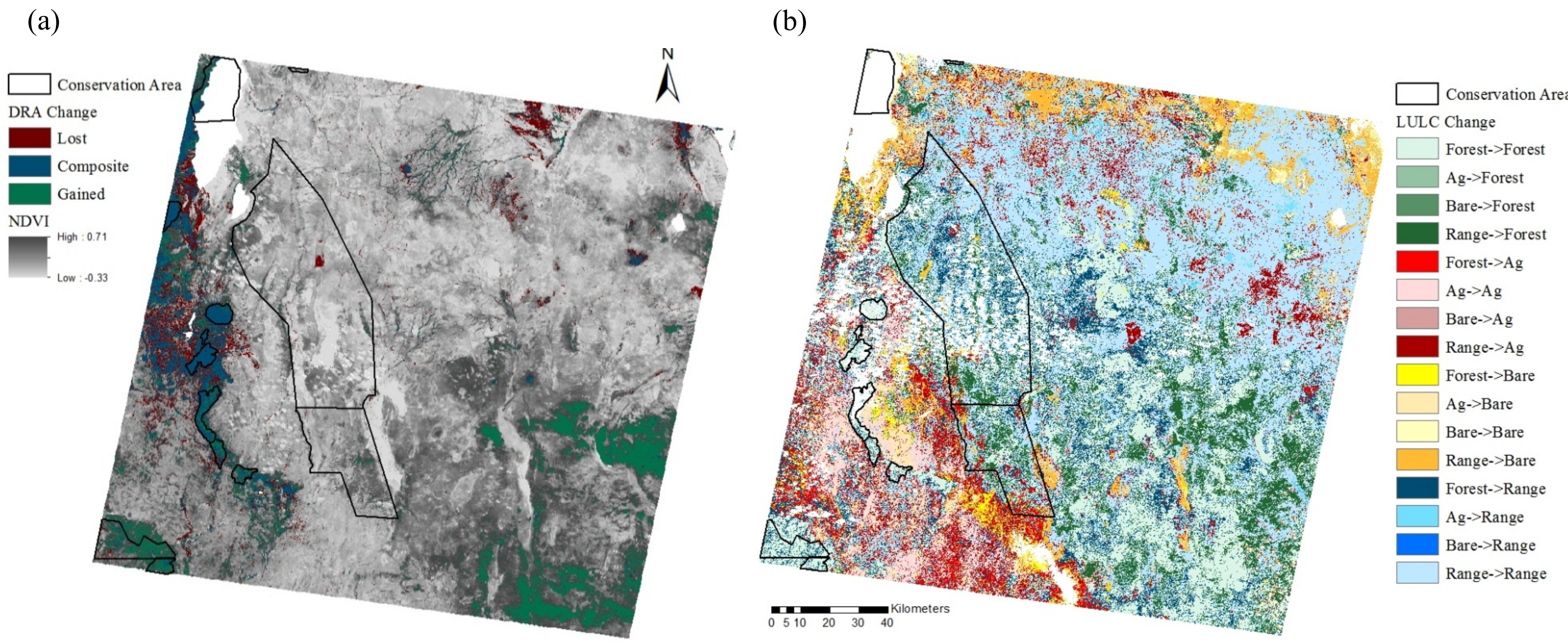


**Figure 2.3.** (a) DRA change (1988-2009) and (b) LULC change (1987-2010) at the watershed scale

In order to control for background variation in primary production I also compared the distribution of LULC change and composite DRAs (Figure 2.4). The proportion of agricultural DRAs was highest for the regional scale. This proportion increased over time at the regional scale, declined at the watershed scale, and remained the same at the local scale. The watershed and regional scales exhibited a decline in the proportion of forest DRAs and increase in rangeland DRAs, but this pattern was reversed at the local scale.

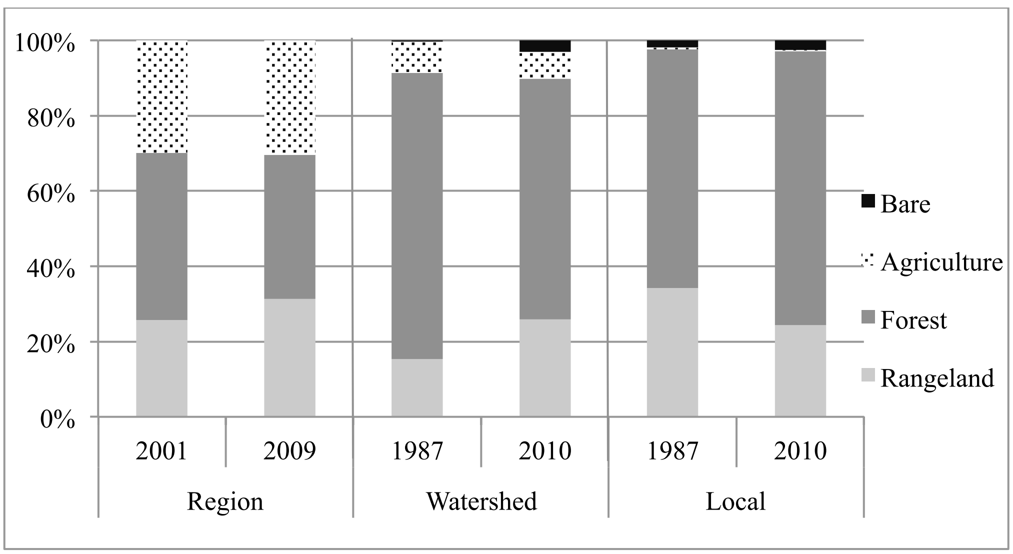


**Figure 2.4.** Composite DRA distribution by LULC category; the water class was omitted from the figure because it accounted for less than 0.5% of area

Conservation areas were also important features of the landscape that affected resource availability, covering about 23% of the total regional land area. Conservation areas contained a disproportionate amount of composite DRAs compared to available zones at both the regional and watershed scales (Table 2.6). At the regional scale, however, the proportion of the conservation zone classified as composite DRA was far exceeded by the proportion of DRA land area in the cultivated zone. This was not the case for the local scale, where available zones had the highest proportion of DRA land area. Moreover, the establishment of Mkungunero Game Reserve in 1996 (Nelson et al. 2007), which largely encloses swamp and rangeland, did not substantially change the proportion of DRAs within the conservation zone.

**Table 2.6.** Composite DRA land area as a proportion of the total area in each land use zone ($km^2$ in parentheses)

| | ***Region*** | | ***Watershed*** | | ***Local*** | |
|---|---|---|---|---|---|---|
| | *2001* | *2009* | *1987* | *2009* | *1987* | *2009* |
| Available | 3.3% (6,144) | 3.2% (6,187) | 1.7% (420) | 2.2% (505) | 2.0% (305) | 2.1% (306) |
| Cultivated | 21.2% (4,466) | 42.4% (4,427) | 1.5% (44) | 1.1% (51) | 0.4% (1) | 0.2% (1) |
| Conservation | 9.1% (5,092) | 8.4% (4,951) | 5.4% (117) | 5.3% (189) | 1.0% (20) | 1.0% (33) |
| Study Area [(a)] | 6.0% (16,010) | 6.0% (16,006) | 1.9% (586) | 2.3%[(b)] (746) | 1.9% (327) | 1.9% (341) |

(a) The study area includes all zones, and is provided as a reference category for comparison across zones at each scale
(b) Differences in the proportion of cells classified as composite DRAs at the watershed scale is due to differences in cloud cover

Composite DRAs were located on terrain with higher mean slope angles compared to non-DRAs across all land use zones and at all three scales (Figure 2.5). At the regional and watershed scales, conserved DRAs had the highest mean slope angle, while cultivated DRAs had lower slope angles than available and conserved DRAs. There were significant changes in the slope angle of DRAs in all categories, including a significant increase in the slope angle of available DRAs at watershed and local scales, and decrease at the regional scale ($p<0.05$).

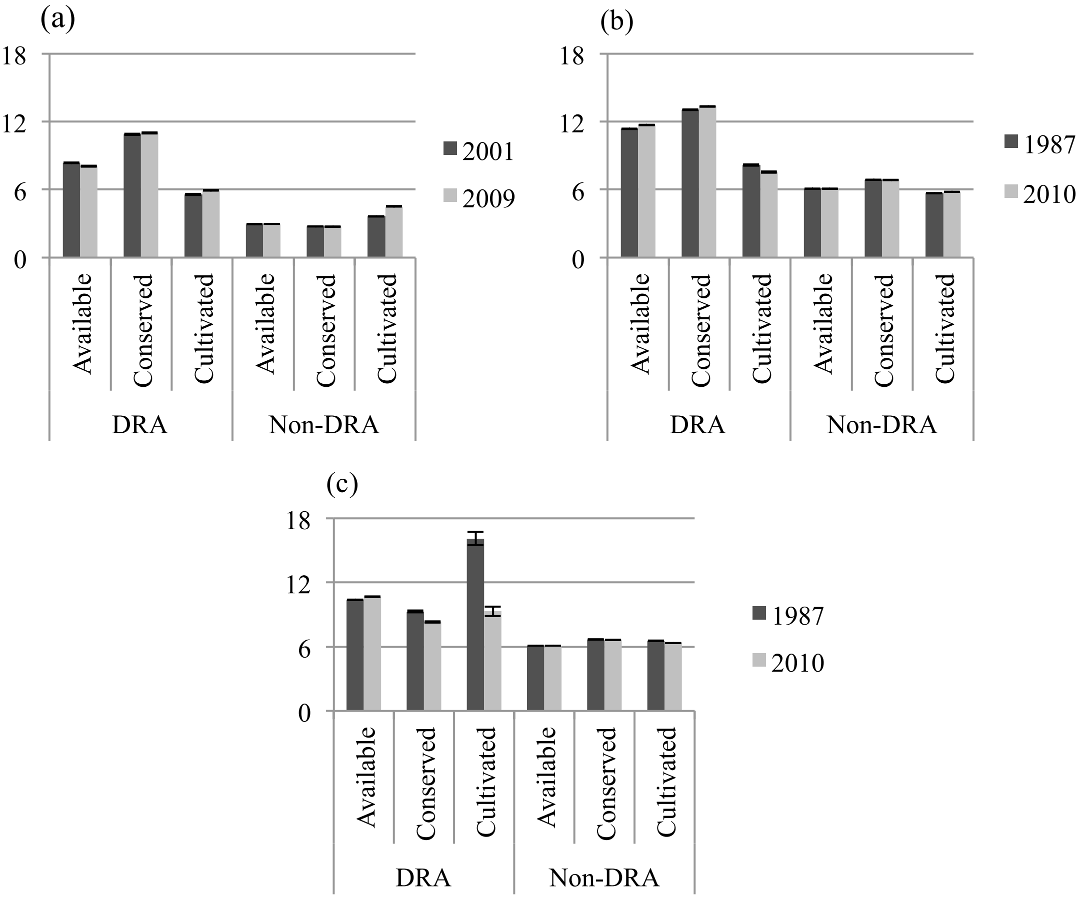


**Figure 2.5.** Mean slope angle of (a) regional, (b) watershed, and (c) local composite DRAs by zone. Error bars represent the 95% confidence interval

### *2.5. Discussion*

This study has yielded several substantive findings regarding the relationship between DRA availability, LULC change, and conservation at three spatial scales in East Africa. First, DRAs are variable over space and time, above and beyond changes in land use. At the watershed scale, the proportion of lost DRAs was highest for areas that did not change LULC class between 1987 and 2010. Furthermore, of all locations that were in the highest NDVI decile at the earliest time point and remained non-cultivated, 27%, 43%, and 65% at the regional, watershed, and local scales (respectively) were no longer classified as DRAs at the most recent time point. These findings suggest that land use is not the primary driver of DRA change in my analysis, but rather, the spatial and temporal variability of primary production. The amount of inter-annual variation of areas in the top 10% of the NDVI distribution is surprising, and underscores the variability of semi-arid rangelands.

Another relevant finding is the increase in the proportion of cultivated land area at the watershed and local scales. The data show that agriculture is impacting rangeland and forests at the watershed scale, which is consistent with recent concerns over cultivation in the Tarangire River catchment (Charnley and Overton 2006). At the local scale, agricultural change largely occurred in rangelands, and is of particular concern in the northern portion of the Simanjiro Plains (Figure 2.6). These findings are consistent with the increased use of agriculture among Maasai households in recent years (Thompson and Homewood 2002, McCabe et al. 2010).

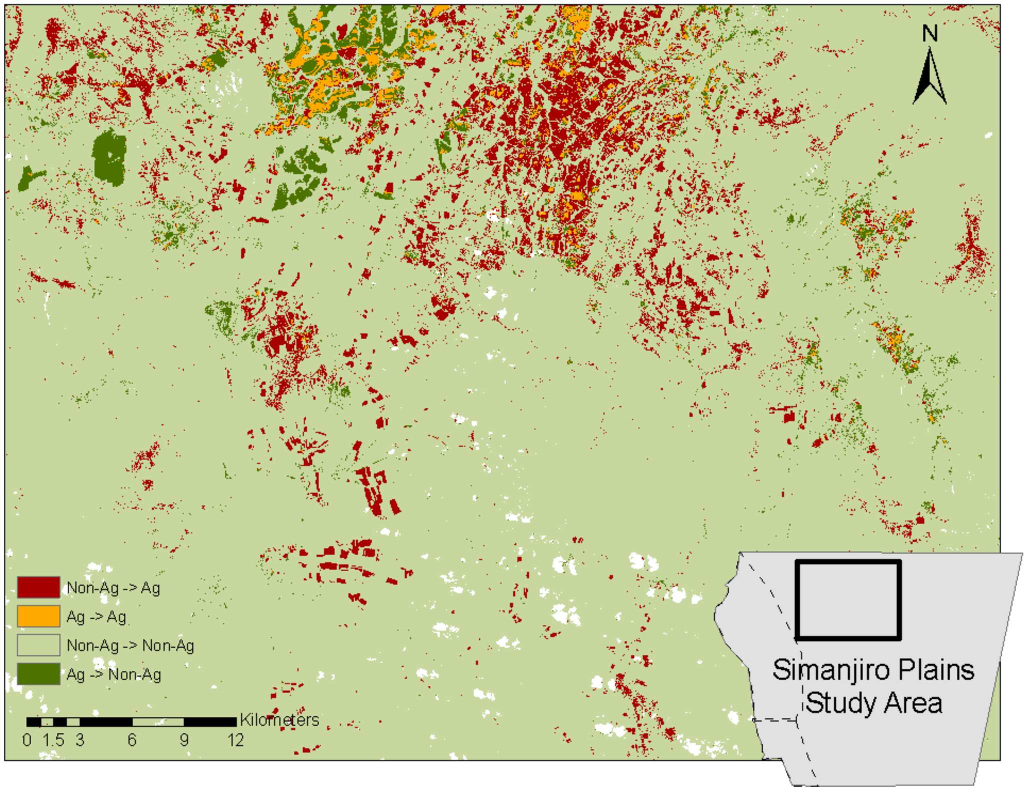


**Figure 2.6.** Change in cultivated land area between 1987 and 2010 in the northern portion of the Simanjiro Plains study area. Dashed lines within the inset map indicate the boundaries of Tarangire National Park and Mkungunero Game Reserve

Temporal patterns in the overlap of agriculture and DRAs call attention to an alternative methodological approach that could be useful for future studies. The proportion of DRAs that were classified as agricultural land increased over time for the regional scale, but, surprisingly, this number decreased for the watershed scale, even over a much longer time period. At the regional scale, 10% of all past DRAs changed from uncultivated to cultivated, and of those, 77% were still classified as DRAs after the LULC change. This compares to 13% and 20%, respectively, at the watershed scale, and 2% and 7% at the local scale. These numbers suggest that finer resolution images may be less likely to capture the effect of agriculture on DRAs in post hoc analyses.

A likely explanation for this is that smaller cells that are entirely (or mostly) composed of cultivated land have very low NDVI values in the late dry-season even if the field is located in a historically highly-productive area, because crops have been harvested and fields are more likely to be barren by that time of year. Coarser resolution data, on the other hand, may be better able to identify cultivated DRAs because these larger cells can capture the matrix of cultivated/bare and non-cultivated/vegetated land around a field, and thus yield a higher total NDVI value for that cell. So although the combination of wet-season LULC data and dry-season NDVI data was intended to provide a conservative estimate of the overlap of DRAs and agriculture, the higher spatial resolution of the data used for identifying DRAs at the watershed and local scales may have yielded especially low estimates of this overlap.

One method for detecting cultivated DRAs without sacrificing the spatial resolution of LULC classifications is to combine coarse resolution NDVI data with higher resolution LULC data. To explore this idea, I combined 250m composite DRAs (from 2000 & 2009) with 30m LULC classifications (from 1987 and 2010) for the watershed scale. These data are not perfectly compatible due to their differing temporal coverages, but the resulting increase in the proportion of DRAs classified as agriculture over the 23-year period (Table 2.7) seems more realistic than the decline in agricultural DRAs described above. Ideally, data products with longer time spans could improve the reliability of estimates of LULC drivers of DRA change, but in the absence of these data, finer resolution LULC classifications combined with relatively coarse resolution NDVI data may be useful for estimating changes in DRA availability over time.

**Table 2.7.** 250m resolution composite DRA distribution by 30m LULC category at the watershed scale

| | ***1987*** | ***2010*** |
|---|---:|---:|
| *Rangeland* | 16.6% | 23.1% |
| *Forest* | 74.0% | 62.8% |
| *Agriculture* | 9.0% | 10.2% |
| *Bare* | 0.4% | 3.8% |
| *Water* | 0.1% | 0.1% |
| *Total* | 100.0% | 100.0% |

The distribution of composite DRAs by land use zone (i.e., available, cultivated, and conservation) varies by the scale of analysis. At the local level, DRAs are relatively evenly distributed between available, conserved, and cultivated zones, but at the regional and watershed scales, DRAs are less evenly distributed (Table 2.6, above). For the region, cultivation overlaps with a disproportionate number of DRAs, and available areas have the lowest proportion of DRAs. This is not surprising given that cultivation would be more successful in wetter areas within this semi-arid region. Conservation areas contain a disproportionate area of DRAs at both the regional and watershed scales. The comparatively low proportion of DRAs within conservation areas in Simanjiro is likely due to the fact that this scale of analysis does not encompass highland forest reserves (the mean NDVI of highland forest reserves is greater than for other conservation area types). It is also possible that the high concentrations of wildlife within TNP (the predominant conservation area at the local scale) during the dry-season may also be impacting estimates of primary production within conservation areas at the local scale.

Terrain analysis indicates that cultivation has predominantly occurred in DRAs with lower slope angles. Conserved DRAs at the regional and watershed scales exhibited higher slope angles compared to the local scale, where the main conservation areas (e.g., TNP) encompass swamps and rivers, rather than highland forests. The seemingly drastic reduction in the slope angle of cultivated DRAs at the local scale should be interpreted with caution because a very small proportion of all local DRAs were in the agricultural zone. Moreover, the local scale had the lowest mean NDVI, so DRAs may have included a different set of vegetation communities (e.g., woodlands and grasslands) than the other scales. Nonetheless, the decreasing mean slope angle of cultivated DRAs suggests that cultivation in Simanjiro may be expanding beyond the fringes of mountains to productive areas of the plains, which is consistent with the above findings regarding LULC change.

The result that available DRAs are generally of intermediate or high slope angle (8-12 degrees or 14%-20% grades) could have been biased by data resolutions that were not high enough to capture smaller streams that have low slope angles. Nonetheless, this finding indicates that the terrain of most remaining DRAs renders access for livestock relatively difficult, and that available bottomland sites such as swamps and rivers are relatively scarce.

These findings should be interpreted in light of limitations related to cross-scale comparisons, LULC classification errors, and the definition of DRAs using remote sensing data. First, the regional data had different temporal coverage and classification methods than the other two scales; this may account for some differences in LULC change, particularly the much larger proportion of landscape classified as forest at the regional scale as compared to the watershed and local scales. Areas that were classified as forest at the more local scales included woodlands and small riparian forests, which were not included in the regional scale forest class due to coarser data resolution.

Second, despite reasonably encouraging error analysis results (Appendix I), the supervised LULC classifications were a potential source of error. Accuracy assessments of remote sensing LULC classifications, including the widespread reliance on confusion matrices, face considerable challenges, such as bias due to non-random ground truth sampling designs (Foody 2002). The ground truth data for this study were not gathered using a random sampling design – rather, most data points were restricted to areas along roadways within the Simanjiro Plains, instead of randomly throughout the broader Tarangire watershed, due to time constraints and challenging terrain. Moreover, points were mostly obtained from clearly representative land cover types (e.g., grassland, forest, agriculture) rather than areas of transition (e.g., ecotones or agricultural gradients).

It appears that my LULC classification suffered from classification errors related to rainfall variability. For instance, the large proportion of forested area that changed to rangeland is likely related to the variable spectral signatures of savanna woodlands, which may have been included in the forest LULC class at the first time point but not at the next time point due to natural variation in primary production. In some years, woodlands may have a more distinct spectral signature from adjacent wooded grasslands, but in other years, this distinction may be less pronounced. This limitation is also not surprising considering that rangelands, and particularly savannas, are often characterized by gradients and ecotones, rather than distinct boundaries between LULC types. In Simanjiro, these gradients are widespread and also apply to small-scale agriculture, which intergrades with the surrounding savanna (Binford 2011).

The classification of agricultural areas at the regional scale may have been especially influenced by rainfall variability. 79.4% of area that was classified as agricultural land at the regional scale in 2001 were classified as rangeland in 2009 (Table 2.4, above); the drastic decrease in agricultural land cover at the regional scale was likely related to the severity of the 2009 drought and the resultant misclassification of agricultural cells due to failed harvests or abandoned fields, whose spectral signatures were more similar to rangeland than productive cultivated land. As a result, it is probable that the dramatic increase in the proportion of cultivated DRAs from 2000 to 2009 resulted from a spurious reduction in the total cultivated land area, rather than a dramatic increase in the cultivation of DRAs. These potential sources of error indicate that this and other regional analyses of agricultural land cover change are especially sensitive to rainfall variability. A more nuanced LULC classification that addresses these sources of error requires data products with higher spatial resolution; however, such fine-grained classifications over large spatial extents could be inhibited by cost, as well as the need for substantial training and ground truth data.

Third, my analysis does not account for relevant DRA characteristics other than size and terrain. Combining my analysis with data on other variables such as water availability, forage quality (e.g., plant nutrients), and disease risk (e.g., exposure to vectors of livestock disease such as ticks and tsetse flies) is a promising avenue for future research of DRA availability, especially as more remote sensing data products become available. I explore how some of these factors relate to resource-use decision making in the following chapter.

### *2.6. Conclusion*

DRAs are of considerable conservation value due to their unique biophysical characteristics and role in sustaining wildlife populations, as well as anthropogenic threats to their existence. Yet DRAs are also essential for maintaining livestock populations and pastoralist livelihoods (Scoones 1995, Desta and Coppock 2002). This study has shown that both environmental conservation efforts and land use changes are affecting the availability of DRAs in East Africa, but their relative influence varies by spatial scale.

Cultivation is exerting an especially strong influence on DRA availability across the region, but conservation areas also contain a disproportionate area of DRAs at regional and watershed scales. The higher proportion of conserved DRAs at the regional and watershed scales is mostly related to forest reserves, which sustain water production for downstream human communities and conservation areas such as TNP. At the most local scale of analysis (the Simanjiro Plains and TNP), the distribution of DRAs is more even across land use zones. However, it is likely that the small area of available, stable DRAs – which account for about 2% of the available landscape – is critically important for many households in the study area. The number of "available" DRAs is even fewer considering that there are restrictions associated with terrain, disease, forage type, and resource management institutions (I address these aspects of resource availability and access in the following chapters).

My findings have both methodological and practical implications. For one, this study provides a cautionary lesson for interpreting remote sensing analyses of rangelands: rangeland LULC classifications can be subject to substantial errors from temporal variability in primary production, and the predominance of ecotones and gradients. Additionally, in the absence of remote sensing data that cover longer time scales, it can be useful to combine coarse resolution NDVI imagery with fine resolution LULC classifications in order to evaluate changes in key resource areas. This runs contrary to the increasingly common use of higher resolution data in geospatial analyses of LULC change.

There are also several practical implications of this study's findings. First, the productivity of key resource areas within rangelands may be less predictable than previously thought. The variability of DRA locations from year-to-year is especially high for Simanjiro compared to DRAs at the watershed and regional scales. This variability underscores the need for large areas of connected land for ensuring that livestock and wildlife have continued access to DRAs, whose variability may be further influenced by climate change.

The spatial arrangement of cultivation in Simanjiro is a growing concern for the maintenance of seasonal wildlife migration routes (Msoffe et al. 2011a, Msoffe et al. 2011b) and for livestock mobility. Discussions with residents of the study area indicate that rangeland fragmentation due to cultivation is restricting access to seasonal pastures in some areas of the Simanjiro Plains. When asked about the compatibility of livestock keeping and cultivation, one man went so far as to say, "these two projects can't go together. They are like enemies. Some grazing areas we can't use anymore. It's like our sub-village is an island. We went to the village and asked them to stop cultivation because we couldn't even get out." These words were echoed in other villages in Simanjiro as well.

It is yet unclear if the LULC changes observed in this and other studies are being driven primarily by smallholder plots or large-scale commercial farms. Household plots are generally smaller and provide an important source of income and food for many Maasai households (Little et al. 2001, McCabe 2003, Homewood et al. 2009, McCabe et al. 2010). Commercial farms, on the other hand, have alienated residents from large tracts of land, and in some cases been transferred to private interests illegally (Igoe and Brockington 1999, Igoe 2004). Land alienation and development are a concern in Maasailand, especially because these processes are marginalizing traditional institutions for managing resources (Mwangi and Ostrom 2009). There is a need for information on the relative influence of household and commercial land use change on landscape connectivity and resource availability.

Overall, this study yielded a more comprehensive picture of DRA access than previous research, which has focused on the social effects of specific conservation initiatives in East Africa (Ngorongoro Conservation Area - Homewood and Rodgers 1991, e.g., Mkomazi Game Reserve - Brockington and Homewood 2001, Tarangire NP - Igoe 2002, Amboseli NP - Western and Manzolillo-Nightingale 2004). The results of my analysis do not dispute this body of research; rather, my findings complement previous studies by providing a broader view of the influence of both conservation and LULC change on resource availability in East Africa. Remote sensing analyses illustrate larger-scale patterns and dynamics, whereas ethnographic methods yield detailed information on human perceptions and human-environment relationships (Jiang 2003).

In the following chapters, I provide a more detailed account of the social and environmental effects of changing DRA access by addressing the following questions: how have changes in resource access affected the livelihood decisions of Maasai households? How are these decisions affecting DRAs, and how are resource management institutions mitigating these impacts? Answering these questions is fundamental to sustaining rangeland productivity.

# CHAPTER 3

## COPING WITH NATURAL HAZARDS IN A CONSERVATION CONTEXT: RESOURCE-USE DECISIONS OF MAASAI HOUSEHOLDS DURING RECENT AND HISTORICAL DROUGHTS

### *3.1. Introduction*

*"Our area is quite dry and the biggest problem we have is water."*
– Member of Parliament, Simanjiro District

*"Every time you think of anything, you think of water."*
– Resident of Landanai

Decision making is the link between people's context and actions. Through decisions, people integrate information about their situation and translate those perceptions into behaviors that have impacts on themselves and their surroundings. This process is relevant to a wide range of academic and applied fields because people frequently "...want to predict group behavior in situations in which it is *individuals* who are making the decisions, they want a social scientist to tell them *why* most of the individuals in the group make the choices they do." (Gladwin 1989: 8)

Decision modeling is meant to address these questions, and it has been applied to a variety of topics, including the study of health behaviors (Johnson and Williams 1993, Ryan and Martínez 1996), agricultural economics and practices (Gladwin 1976, 1992), and psychology (Beck 2005). Decision modeling has also been used to evaluate different stakeholder perspectives on environmental management options (Redpath et al. 2004), but this is distinct from most applications of decision modeling, which predict actual behaviors (Ryan and Bernard 2006). Decision-making analysis is also different from agent-based modeling, which requires the formalization of 'choices' within a simulated environment but does not identify the factors influencing real behaviors. In fact, understanding decision-making processes could reveal key variables affecting resource use and be instructive for developing agent-based models (Miller et al. 2010).

Because of its demonstrated utility in a variety of applications, there have been calls for more decision-making analysis in political ecology research (Robbins 2004b). It could be especially informative for studying the ways in which the social impacts of environmental conservation initiatives translate into human behaviors that have environmental consequences (Miller et al. 2012). Livelihood decisions are particularly relevant to these feedbacks due to their interface with social factors and ecological dynamics. Livelihoods influence social-ecological systems by altering population distributions (de Haan 1999), resource use (Chambers and Conway 1992), land cover (Birch-Thomsen et al. 2001), food security (McCabe 2003, Pedersen and Benjaminsen 2008), disease transmission (Masanjala 2007), and social structures (Bryceson 2002). Livelihoods also capture multiple aspects of living and working conditions beyond income, such as activities, resources, and social relations (Ellis 1998, Barrett et al. 2001). Furthermore, the livelihoods approach accounts for salient differences in the origin and means of attaining household resources, which are characteristics that can be overlooked by metrics such as socioeconomic class (Birch-Thomsen et al. 2001).

Livestock-based livelihoods (broadly referred to here as pastoralism) have allowed people to persist in arid and semi-arid environments around the world. Several elements of pastoralism are found across a variety of settings: mixed-species herding, mobility, and social institutions for resource management and exchange. These attributes allow herders to capitalize on the spatial and temporal variability in rainfall and primary production that characterize arid and semi-arid rangelands (Coughenour et al. 1985, Ellis and Swift 1988).

During droughts, herders typically move their livestock to areas that maintain water and grazing such as rivers, swamps, and forests, but pastoralist access to these drought resource areas (DRAs) can be inhibited by cultivation and conservation. This resource access restriction may be influencing the livelihood decisions of pastoralists living adjacent to world-renowned protected areas, which are coping with considerable anthropogenic environmental changes. The objective of this study is to better understand how these challenges are interrelated by examining resource-use decisions of Maasai pastoralists. In particular, how have changes in access to DRAs influenced pastoralist livelihood decisions, particularly decisions about where to water livestock during droughts?

I address this research question by focusing on Maasai households living in communities that vary in proximity to Tarangire National Park (TNP). I hypothesize that resource access restriction due to the establishment of TNP has influenced Maasai livelihood decisions, such as where to take livestock during dry periods. In particular, I expect that households living near TNP responded to the loss of access to the Tarangire River and Silalo Swamp following the establishment of TNP in 1970 by shifting resource use to a small number of remaining bottomland sites; however, the factors affecting decisions about where to water livestock during droughts also vary with levels of village water development. Despite water development projects in some villages, I anticipate that riparian water sources continue to be widely used.

### *3.2. Study Area & Population*

As described in the previous chapter, the Simanjiro Plains are a critical wet-season dispersal zone for wildlife from TNP, and are home to Maasai pastoralists as well as smaller numbers of people from a variety of other ethnic groups. This study focuses on four villages in Simanjiro that vary in proximity to TNP and have different levels of water development: Emboreet, Loiborsoit, Sukuro, and Terrat. This work is also informed by a limited amount of quantitative and qualitative data from the villages of Loiborsiret and Landanai (Figure 3.1).

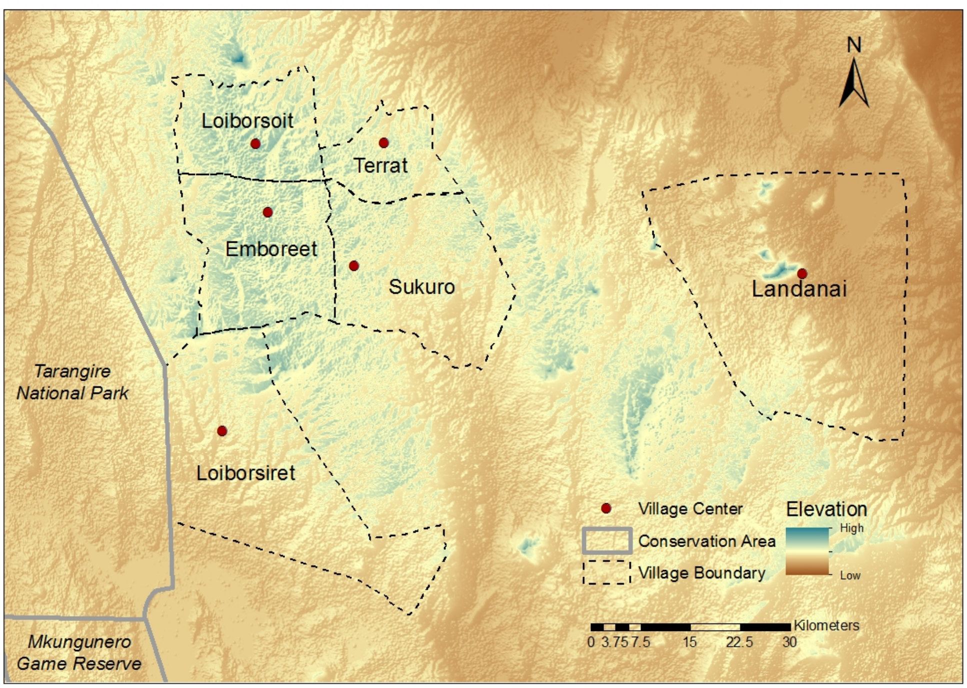


**Figure 3.1.** Map of study villages

Maasailand has undergone considerable changes in land tenure and availability. Colonial rule reduced Maasai territory, and influxes of cultivators from other areas increased pressure on rangeland resources, stimulating Maasai to claim individual or group title to land (Campbell 1993). The shift from communal land tenure to private ownership was also influenced by pressure from World Bank structural adjustment programs during the 1980's, and commercial agriculture activities (e.g., wheat, barley, and flowers) that reduced land and water availability (Fratkin 2001). Moreover, Maasai are increasingly participating in cultivation and wage-labor (Thompson and Homewood 2002). The adoption of agriculture by Maasai has accelerated over the past 30-40 years, and is now quite widespread. The adoption of agriculture has been influenced by a variety of factors, including household and regional demographics, cultural norms, and political-economic context (Little et al. 2001, Homewood et al. 2009, McCabe et al. 2010).

The establishment of conservation areas by the Kenyan and Tanzanian national governments exacerbated competition for remaining resources (Campbell et al. 2000). Western and Manzolillo-Nightingale (2004) claim that the loss of access to DRAs due to conservation and cultivation in Kajiado District (Kenya) has diminished the capacity of Maasai to cope with drought using traditional strategies of transhumance. Similarly, the establishment of TNP in Tanzania separated Maasai from the Tarangire River and Silalo Swamp, arguably two of the most reliable dry-season water and grazing sites in the ecosystem. In the words of Sachedina (2006: 12-13):

> *"The gazettement of Tarangire NP in 1970 evokes particularly painful memories for Simanjiro Maasai. The main reason is that exclusion from Silalo Swamp in the east of Tarangire NP. Silalo is a permanently watered*

*swamp with extensive grasslands and an important drought refuge for pastoralists."*

According to Igoe (2002) this dramatic resource dislocation altered Maasai herding systems and reduced livestock productivity. Although these descriptions of land loss and the marginalization of Maasai pastoralists are valuable contributions that call attention to injustices and policy failures, they do not empirically address the ways in which households have responded to drought resource appropriation and water development projects. This information is necessary for informing socially and environmentally responsible conservation and development initiatives.

### *3.3. Methods*

I carried out preliminary fieldwork in June and July of 2009 and 2010, and 8 months of research in Simanjiro from March to November 2011. During this time I conducted 43 semi-structured group interviews and collected a total of 199 household surveys. Interviews and surveys were collected with the assistance of two Tanzanian field assistants who have worked with advisor Leslie and colleagues for more than 10 years, and who are fluent in English, Kiswahili, and Maasai.

The following analyses are based on surveys with 120 male household heads in the 4 focal villages. The survey sample was based on an ongoing longitudinal study of household demographics and economics being conducted by advisor Leslie and colleagues, and was structured to capture variation in household wealth, sub-village location (i.e., near and far from the village center), and ageset of heads of household. An additional 14 surveys were collected with male heads of households in Landanai (n=9) and Loiborsiret (n=5), but these data were only included in the following analyses of historical droughts if the respondent was living in one of 4 focal study villages at the time of the past drought. Otherwise, these surveys were not included in the following analyses due to small sample sizes. Another 65 surveys addressed women's water gathering decisions, and will be analyzed in future work (see below for details).

I used ethnographic decision modeling to analyze decision-making processes. This multi-step process was based on the approach described by Bernard (2002) with an added step of using logistic regression to analyze aggregated data and to guide the selection of relevant variables for village-level analyses. I also constructed a hydrologic event calendar by gathering information on historical droughts and water development projects through interviews with village leaders. I used this calendar in combination with a chronology of social landmarks (e.g., age set initiation) constructed by advisor Leslie and colleagues in order to improve recall of past resource use patterns during interviews and surveys.

For the first step of ethnographic decision modeling, I conducted semi-structured group interviews in order to evaluate household responses to changing DRA availability induced by TNP, cultivation, and water development projects. These interviews concentrated on where people have taken livestock and acquired household resources during recent and historical droughts (see Appendix II for interview guide). I focused on water sources in order to streamline analysis and because it was frequently cited as the resource of greatest concern; however, the interview format allowed for the possibility that the availability or location of other resources (e.g., fodder) influenced water-use decisions.

In addition to gaining a general understanding of drought resource use, the objective of these interviews was to identify decision criteria (e.g., distance to resource, labor requirements, rules/restrictions) that influenced where people obtained water during droughts. Responses from group interviews were compiled into decision-making criteria. For example, if an interviewee stated that he used a borehole during the last drought because it was the closest source of water to his household and he did not have to wait to use it, this response would have yielded proximity to household and waiting time as the criteria for resource use. Group interviews thereby elicited an aggregated set of criteria that influenced people's decisions about resource acquisition.

Building decision models requires data relating criteria to actual resource use choices, so the next step entailed gathering these data through surveys with male household heads. I asked the same open-ended questions from the group interviews about where they watered livestock during the 2009 drought and during the first drought they could remember, and why they used those sites. I then asked Yes/No questions pertaining to watering cattle that were derived from the list of decision-making criteria elicited from the group interviews (see Appendix III for survey instrument). Yes/No Responses were coded as 1 or 0 respectively, and the result was a table of individual resource use choices (or outcomes) and the conditions (or factors) associated with those choices. Factors reflect respondents' perceptions of household and resource conditions. This is a fundamental principle of ethnographic decision modeling, which "…starts from the assumption that the decision makers themselves are the experts on how they make the decisions they make." (Gladwin 1989: 9)

I then used logistic regression to analyze aggregate data and to identify significant predictors of water source use across all study villages. Those respondents who were not living in one of the four study villages during the earliest drought they remembered were dropped from the analyses of historical droughts. Variables were added to each model based on pairwise correlations with the outcome variables, and regression models were tested for specification error, goodness of fit (Hosmer-Lemeshow statistic), and multicollinearity.

I used crisp-set Qualitative Comparative Analysis (QCA) to evaluate resource-use decisions within each study village. QCA allows for "…systematic cross-case comparisons, while at the same time giving justice to within-case complexity, particularly in small- and intermediate-N research designs." (Rihoux and Ragin 2009: xviii) Cases are chosen to maximize diversity on factors of interest; hence my sample of villages that vary in terms of distance from TNP, level of water development, and availability of natural water sources, and households that vary in wealth, age, and distance to village center. I then used Boolean algebra to sort the conditions (e.g., closest available water source, well ownership) into those that were necessary and those that were sufficient to produce a given outcome (i.e., the use of a specific water source). In particular, I used the *TOSMANA* and *fsQCA* software packages to generate decision-models through an iterative process of improving model fit, similar to the analytic induction approach used by Ryan and Bernard (2006), and recommended by Gladwin (1989).

Model building and refinement involved minimizing contradictions and remainders while at the same time maximizing coverage and consistency. Contradictions are those configurations of factors that have mixed outcomes, and remainders are configurations that are not represented in the sample. Coverage is the "…number of cases following a specific path to the outcome divided by the total number of instances of the outcome," and provides an indication of the importance of a particular causal combination (Ragin 2006: 299). Consistency is "…the proportion of cases with a given cause or combination of causes that also display the outcome." (Ragin 2006: 293) For instance, if 10 out of 15 cases displaying a causal combination also display the outcome, then the consistency is 0.67.

QCA identifies the different causal models (not one causal model) existing among comparable cases, which allows for different combinations of factors to yield the same result. Causality is specific to the combination of factors and context; in other words, this is not an averaging of cases, but an explicit consideration of their diversity (Rihoux and Ragin 2009). In sum, I used QCA to analyze interview data and identify the combinations of factors that influenced where people in each study village watered livestock during recent and historical droughts.

### ***3.4. Results***

#### *3.4.1. Household Demographics & Economics*

Basic household demographic and economic data provide context for the subsequent results of livelihood decision-making analysis. A man, his wives, and their dependents form a unit referred to as an *enkishomi* or *olmarei*, and these household units are traditionally affiliated with other *olmarei* that are organized within a compound called an *enkang* (O'Malley 2000, McCabe et al. 2010). Each *olmarei* typically owns a combination of cattle, goats, and sheep. Due to the different sizes and productivity of these livestock species, I standardized the number of livestock owned by each household by converting the number of animals to tropical livestock units (TLU's). Small-stock were valued at 0.1 TLU and cattle at 1.0 TLU (based on Fratkin and Roth 1990, McCabe 2004).

The study sample included households with a wide age and size range (Table 3.1). The median TLU per capita within the 4 core villages was 3.5. There was substantial variation within each village, but variation across villages was non-significant (non-parametric K-sample test of medians: p>0.05) (Figure 3.2).

**Table 3.1.** Descriptive household demographic statistics (n=120)

| | *Mean* | *Std. Dev.* | *Min.* | *Max.* |
|---|---|---|---|---|
| Approximate Age of Household Head | 50.4 | 13.2 | 24 | 101 |
| Wives | 2.3 | 1.7 | 0 | 8 |
| Children | 8.4 | 6.7 | 0 | 31 |
| Others in the household (*olmarei*) | 0.4 | 1.2 | 0 | 7 |
| Total in the household (*olmarei*) | 12.1 | 8.1 | 1 | 39 |
| Dependency Ratio | 2.2 | 1.1 | 0 | 5 |

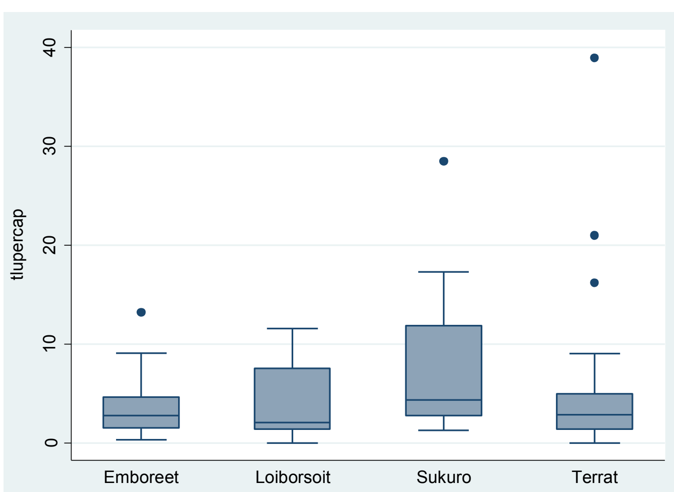


**Figure 3.2.** Box plot of Tropical Livestock Units per capita for each of the four study communities

There was a significant difference between historical droughts and the 2009 drought in the proportion of respondents that reported having a large herd size (two-tailed Fisher's exact test: $p<0.01$). The difference in perceived household labor availability was not significant. The majority of respondents reported a general decline in their herd size (Table 3.2), and enough labor available during both recent and historical droughts (Table 3.3).

**Table 3.2.** Changes in perceived herd size

| | | ***Large Herd in 2009?*** | | |
|---|---|---|---|---|
| | | *No* | *Yes* | *Total* |
| ***Large Herd in Past?*** | *No* | 20.2% (21) | 3.9% (4) | 24.0% (25) |
| | *Yes* | 44.2% (46) | 31.7% (33) | 76.0% (79) |
| | *Total* | 64.4% (67) | 35.6% (37) | 100.0% (104) |

**Table 3.3.** Changes in perceived labor availability

| | | ***Enough Labor in 2009?*** | | |
|---|---|---|---|---|
| | | *No* | *Yes* | *Total* |
| ***Enough Labor in Past?*** | *No* | 4.8% (5) | 4.8% (5) | 9.6% (10) |
| | *Yes* | 10.6% (11) | 79.8% (83) | 90.4% (94) |
| | *Total* | 15.4% (16) | 84.6% (88) | 100.0% (104) |

### *3.4.2. Drought Resource Use*

During the wet-season and non-drought periods, respondents generally preferred watering cattle from rainwater/standing water, or at small dams that had been built by a household or a collection of households (referred to as "charcoal dams"). More respondents preferred using rivers[12] than boreholes or large dams, but preferences varied

[12]I use the term "rivers" loosely to refer to rivers, streams, and korongos. The vast majority of drainages in the study area were intermittent or ephemeral.

by village: charcoal dams were the first choice of most respondents in Emboreet and Sukuro, compared to rivers in Loiborsoit, and standing water in Terrat. Rainy-season preferences for livestock watering sites were mostly influenced by proximity to the source, and to a lesser extent, perceptions of water quality.

The earliest drought that was referenced by a respondent had been passed down through oral history and reportedly took place in 1886 (see Appendix IV for drought timeline). Similarly, respondents in Terrat described a collective memory of the period in the late $19^{th}$ century called *Emutai*, meaning “to finish off (completely)” (Waller 1988: 74) in reference to the complete destruction of herds from a series of livestock diseases (i.e., bovine pleuropneumonia, rinderpest, and trypanosomiasis), and a devastating smallpox epidemic and raiding between Maasai sections (Homewood and Rodgers 1991, Normile 2008). The earliest drought remembered by an individual respondent occurred in the mid-1940s (approximately 1944-47).

Some prominent drought years include 1952-54, ‘61, ’74-77, ‘83-84, ‘93-94, ‘97, and 2009. One respondent cited 2008 and another 2006 as drought years, but these outliers were dropped from my analysis of past droughts in order to more clearly distinguish between ‘recent’ and ‘historical’ droughts. During group discussions, 2009 was often agreed upon as the most severe drought in memory, but some people believed that it only became a problem in Simanjiro because of the influx of people and livestock from other, more severely impacted areas. During that year, Maasai moved into the Simanjiro from as far away as southern Kenya in search of water and livestock fodder, and crop failures had dire consequences for many households. The mid-1940's was also a particularly bad drought, and was referred to as a year of "Red Bone Marrow Disease."[13]

Respondents were generally the ones responsible for making the herding decisions during the 2009 drought. During historical droughts, 50% of respondents stated that their father made the herding decisions, with smaller proportions being represented by the respondent's brother (24%), the respondent themselves (24%), and other friends and family.

The mean estimated traveling time (with livestock) from the *enkang* or temporary *enkang*[14] to the water sources used during droughts was about one and a half hours, or roughly 3 km. However, some respondents walked up to 5 hours or as far as 15km. The mean estimated traveling time was significantly lower for 2009 compared to historical droughts (1.3 hours in 2009 compared to 1.6 hours during previous droughts). During droughts, herders waited anywhere from several hours to several days to water their livestock, depending on the source, but some reported no wait at all. At some river wells, people could only water a few livestock at a time and would have to wait several hours for the well to recharge before watering the next group of animals.

Roughly half of respondents used natural sources (i.e., rivers, korongos, and swamps), and half used built sources (i.e., dams or boreholes) (Table 3.4 and Table 3.5). Many of the sites used during historical droughts were also used in 2009. A variety of small drainages have remained in use, and the Terrat River has continued to serve as an important DRA. On the other hand, there was a decline in the proportion of households in

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[13]"Red bone marrow disease" refers to the unusual look of the bone marrow of an animal that has died from lack of food and water, rather than an infectious disease, which occurs during particularly severe droughts.

[14]Temporary *enkang* are sometimes established during dry-seasons and droughts when livestock are moved to areas that are far from the household.

the sample that were using the Sinya River and an increase in those using the Kikoti River. Another notable difference is that no respondents used dams during the worst part of the 2009 drought, whereas this was a relatively common practice during historical droughts. There was also an increase in the use of boreholes.

**Table 3.4.** Primary watering site for cattle during historical droughts (n=105)

| *Type* | *Name* | *N* | *Percent* |
|---|---|---|---|
| Boreholes | Emboreet | 21 | 20.0% |
| | Lektejo | 4 | 3.8% |
| | Mererani | 1 | 1.0% |
| | Nabarera | 1 | 1.0% |
| | Total | 27 | 25.7% |
| Dams | Narakauwo | 3 | 2.9% |
| | Red | 4 | 3.8% |
| | Sapuro | 1 | 1.0% |
| | Sukuro | 18 | 17.1% |
| | Total | 26 | 24.8% |
| Rivers & Korongos | Emugur ee Ndara | 1 | 1.0% |
| | Kiti Engare | 7 | 6.7% |
| | Komolo | 2 | 1.9% |
| | Loiborsiret | 2 | 1.9% |
| | Lorosorutia | 1 | 1.0% |
| | Nyorit | 3 | 2.9% |
| | Sinya | 19 | 18.1% |
| | Terrat | 17 | 16.2% |
| | Total | 52 | 49.5% |

**Table 3.5.** Primary watering site for cattle during 2009 drought (n=119)

| *Type* | *Name* | *N* | *Percent* |
|---|---|---|---|
| Boreholes | Emboreet | 11 | 9.2% |
| | Lektejo | 5 | 4.2% |
| | Lenaitunyo | 15 | 12.6% |
| | Loiborsoit | 4 | 3.4% |
| | Mowarak | 17 | 14.3% |
| | Nomokon | 3 | 2.5% |
| | Terrat | 8 | 6.7% |
| | Total | 63 | 52.9% |
| Rivers & Korongos | Emugur ee Ndara | 1 | 0.8% |
| | Kikoti | 19 | 16.0% |
| | Kiti Engare | 4 | 3.4% |
| | Loiborsiret | 2 | 1.7% |
| | Nyorit | 2 | 1.7% |
| | Sinya | 3 | 2.5% |
| | Terrat | 21 | 17.6% |
| | Total | 52 | 43.7% |
| Other | Kimotorok Swamp | 3 | 2.5% |
| | Nabarera Wells | 1 | 0.8% |
| | Total | 4 | 3.4% |

19 respondents, representing all four villages, recalled herding practices during a drought prior to the establishment of TNP in 1970. None of these respondents cited the use of Tarangire River or Silalo Swamp (now located inside TNP). Instead, these respondents cited the use of 5 rivers, 2 dams, and 2 boreholes located outside of the park. All of these individuals stated there was sufficient grazing near the watering sites they used.

Group interviews suggested that the selection of livestock watering sites depends on two choices: water source location and type. I operationalized these outcomes as choosing between free and pay sources, and between local and distant sources. Pay sources were almost exclusively boreholes[15], but not all boreholes required payment, especially during past droughts. I coded sources as local if they were within or very near the respondent's home village boundary, and distant if they were well outside of their village or if they required multiple days of travel to reach the water source. Although this categorization was somewhat subjective, the distinction between local and distant sources was generally clear given the limited number of resource options available to households during droughts. This dichotomization was also meaningful in terms of demands on household labor, finances, and time.

There was a significant increase in the proportion of respondents who watered livestock at distant sources (Fisher's exact test: $p<0.01$); the proportion increased from 11% during historical droughts to 25% during the 2009 drought. There was also a significant decline in the proportion of respondents using the nearest *available* source ($p<0.05$); 72% of respondents used the nearest available source during historical droughts, while only 58% of respondents used the nearest available source during the 2009 drought. The proportion of people that used distant sources varied significantly by village, both during historical droughts and during the 2009 drought ($p<0.01$). There was a significant increase in the proportion of respondents that used distant sources in Loiborsoit, and a significant but less pronounced decrease in Terrat (Figure 3.3).

[15] Water from boreholes cost approximately 20 to 50 Tanzanian Shillings (TSH) per cow (or about \$0.01-0.03 USD/cow), but some boreholes charged users diesel fuel by the herd, with prices ranging from 0.5 liter for 200 cows up to 0.75 liter for 10 cows. This relatively large price range may reflect variable or negotiated pricing.

There was a significant increase in the use of pay sources from 14% during historical droughts to 53% during the 2009 drought (Fisher's exact test: p<0.01). The proportion of people that used pay sources also varied significantly by village, both during historical droughts and during the 2009 drought (p<0.01) (Figure 3.4). In Sukuro, most respondents used dams in the past and boreholes in 2009. In Emboreet, nearly 90% of respondents used boreholes during historical droughts, and people used boreholes exclusively during the 2009 drought. In Loiborsoit and Terrat the majority of respondents used rivers during both periods.

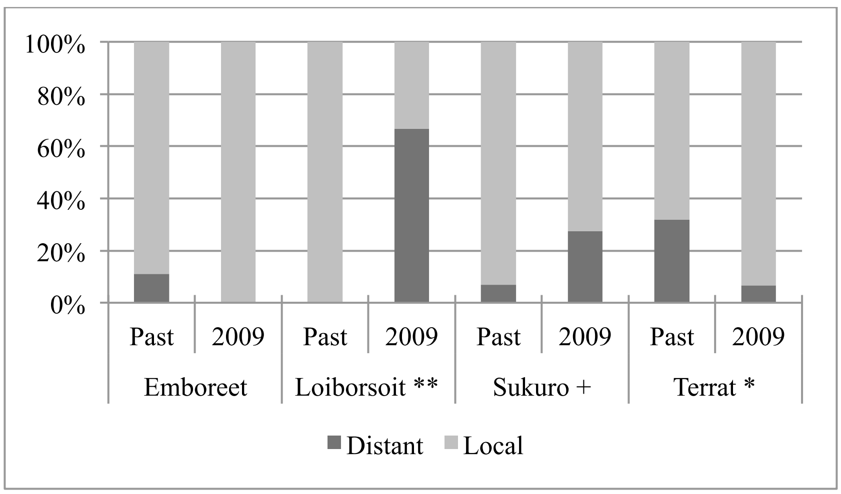


**Figure 3.3.** The proportion of respondents in each village that used local or distant water sources during the 2009 drought and historical ("past") droughts
+ *p*<0.1; * *p*<0.05; ** *p*<0.01 for Fisher's exact test of change between the two time points
Villages refer to the respondent's village at the time of drought

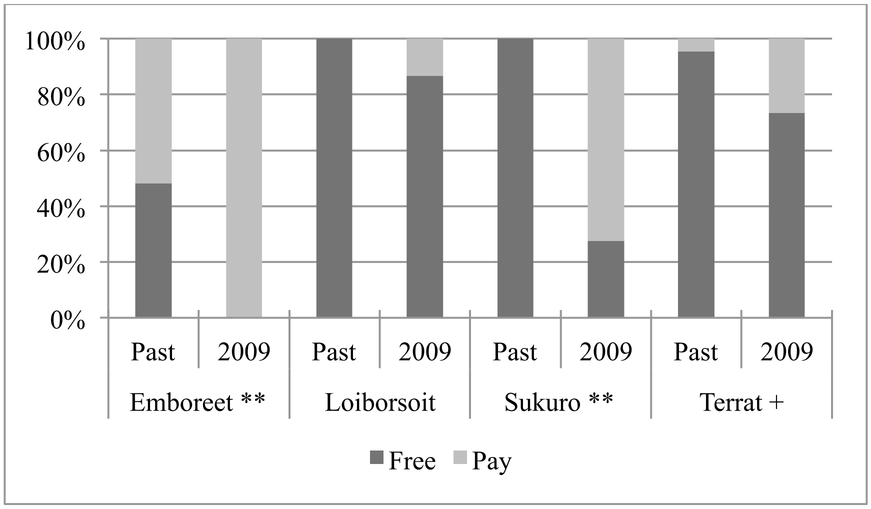


**Figure 3.4.** The proportion of respondents in each village that used free or pay water sources during the 2009 drought and historical ("past") droughts
+ $p<0.1$; * $p<0.05$; ** $p<0.01$ for Fisher's exact test of change between the two time points
Villages refer to the respondent's village at the time of drought

In terms of changes in individual resource use, the majority of respondents continued using the same type of source (i.e., distant or local, free or pay). Of those that changed, a greater proportion changed from using local to distant sources than vice versa, and a greater proportion changed from using free to pay sources.

### *3.4.3. Regression Analysis*

Social capital and perceptions of livestock disease risk were significant predictors of the choice of free versus pay sources (Table 3.6). Free sources were more likely to be associated with the availability of social capital (i.e., having a friend or relative who owned a well in a river) and livestock disease compared to sources such as boreholes, but there was also a significantly greater likelihood of using free sources if there was perceived risk of livestock disease at pay sources. The effect of proximity and herd size became non-significant once village membership was controlled for. Although village membership appears to have affected odds ratios, models two and three are difficult to compare; Emboreet respondents were dropped from the full model because all respondents from that village used pay sources.

Diagnostic statistics for model one showed no specification error and good model fit ($p>0.05$), but these were contradicted by low pseudo R-square (0.30). The link test for model two indicated specification errors, and both models two and three had poor fit ($p<0.05$). These problematic diagnostics may be the result of an omitted variable or interaction term, but adding predictors to the full model was unrealistic given the small sample size and large number of independent variables.

**Table 3.6.** Logistic regression models of the choice of water sources that cost money or diesel with odds ratios and robust standard errors in parentheses

| | *Model 1* | *Model 2* | *Model 3* |
|---|---|---|---|
| Large Herd | 3.804<br>(1.889)** | 8.111<br>(6.137)** | 0.332<br>(0.357) |
| Enough Labor | 0.964<br>(0.603) | 0.512<br>(0.738) | 0.210<br>(0.297) |
| Social Capital at Source | 0.016<br>(0.016)** | 0.000<br>(0.002)* | 0.000<br>(0.001)** |
| Grazing Available at Source | | 0.126<br>(0.167) | 0.011<br>(0.034) |
| Nearest Available Source | | 18.998<br>(14.091)** | 3.257<br>(3.554) |
| Disease at Source | | 0.011<br>(0.022)* | 0.025<br>(0.029)** |
| Disease at Alternate Source | | 0.015<br>(0.021)** | 0.059<br>(0.073)* |
| Conflict at Source | | 7.242<br>(9.639) | 3.835<br>(5.369) |
| Conflict at Alternate Source | | 1.093<br>(1.324) | 2.410<br>(4.513) |
| Cultivation Affected Access to Source | | 1.621<br>(1.954) | 3.752<br>(3.319) |
| Cultivation Affected Access to Alternate Source | | 0.202<br>(0.256) | 2.022<br>(2.315) |
| Community [(a)] | | | |
| Emboreet (omitted) | | | 1.000<br>(0.000) |
| Loiborsoit | | | 0.010<br>(0.016)** |
| Terrat | | | 0.020<br>(0.051) |
| *N* | 113 | 111 | 83 |

Outcome: Use a source that costs money or diesel (0=free; 1=pay)
[(a)] Sukuro is the reference category
+ $p$<0.1; * $p$<0.05; ** $p$<0.01

Grazing and perceived herd size were significant predictors of the choice of water source location (Table 3.7). Local sources were less likely to have grazing in the immediate vicinity, and households with large perceived herds were less likely to use local sources. Perceived risk of livestock disease was marginally less likely to affect access to local sites than distant ones. Controlling for village membership eliminated the significance of the coefficients for resource cost and perceived risk of livestock disease at other sources, but a large number of observations were dropped from the full model because all respondents from Emboreet used sources within or near the village. Tests for errors associated with model fit and specification were significant for models one and two. Model three was properly specified and had a reasonably good fit, but the sample was small for the number of parameters.

**Table 3.7.** Logistic regression models of the choice of water sources that are near the village center with odds ratios and robust standard errors in parentheses

| | *Model 1* | *Model 2* | *Model 3* |
|---|---|---|---|
| Large Herd | 1.061 | 0.328 | 0.039 |
| | (0.496) | (0.228) | (0.051)* |
| Enough Labor | 0.112 | 5.261 | 9.685 |
| | (0.120)* | (6.131) | (15.079) |
| Social Capital at Source | 0.301 | 8.503 | 0.558 |
| | (0.181)* | (14.147) | (0.799) |
| Grazing Available at Source | | 0.003 | 0.002 |
| | | (0.006)** | (0.003)** |
| Paid for Water | | 118.401 | 0.544 |
| | | (173.213)** | (0.757) |
| Disease at Source | | 0.580 | 0.117 |
| | | (0.525) | (0.131)+ |
| Disease at Alternate Source | | 36.857 | 2.612 |
| | | (50.572)** | (2.963) |
| Conflict at Source | | 0.517 | 1.248 |
| | | (0.668) | (1.189) |
| Conflict at Alternate Source | | 0.336 | 0.270 |
| | | (0.602) | (0.323) |
| Cultivation Affected Access to Source | | 0.078 | 0.093 |
| | | (0.152) | (0.166) |
| Cultivation Affected Access to Alternate Source | | 2.936 | 3.194 |
| | | (2.723) | (3.028) |
| Community [(a)] | | | |
| Emboreet (ommitted) | | | 1.000 |
| | | | (0.000) |
| Loiborsoit | | | 0.163 |
| | | | (0.176)+ |
| Terrat | | | 12.128 |
| | | | (25.485) |
| *N* | 115 | 113 | 85 |

Outcome: Water source location (0=distant/outside of village; 1=near)
[(a)] Sukuro is the reference category
+ $p$<0.1; * $p$<0.05; ** $p$<0.01

Overall, regression model results were suspect due to small sample sizes and issues with model specification and fit. Using maximum likelihood with samples smaller than 100 is unreliable, especially with many independent variables (Long 1997). Moreover, the variable for waiting time could not be included in any of the above regression models because it had too little variation.

Regression models could also not be used to predict resource use during historical droughts because so few respondents paid for water or used distant sources during those periods. Moreover, several predictor variables would have been omitted (e.g., grazing and disease) from historical models due to lack of variation. It was also difficult to assess the relative influence of social capital because of the absence of formal water committees associated with boreholes at the time. Nonetheless, ANOVA indicated that village membership had a significant effect on the choice of local versus distant sources and free versus pay sources during historical droughts.

*3.4.4. Qualitative Comparative Analysis*

I used QCA to assess decision-making within each village (where sample size was small/intermediate), and to analyze decision-making during historical droughts (when reduced variation in the outcome variables and a greater number of missing values for some independent variables prevented aggregate analysis). QCA results are presented as a series of "implicants" or sets of conditions whose relationships are displayed using notation from Boolean Algebra: "*" means "and;" "+" means "or." Variable codes in capital letters represent presence (value=1), lower case letters represent absence (value=0). Below, I present complex solutions, which exclude remainders. I do not include parsimonious solutions, which include remainders for reduction, because these results often require simplifying assumptions and may exclude necessary conditions. I also exclude contradictions in an effort to avoid simplifying assumptions; as a result, the consistency for all implicants presented below is 1. For brevity, I present a subset of the outcomes and implicants that were tested. I also omit villages and years with no variation in the outcome (i.e., Emboreet, 2009 source type and location; Loiborsoit, historical source type and location; and Sukuro, historical source type).

The majority of respondents from Loiborsoit used free sources to water livestock during the 2009 drought. Taking livestock to the nearest available source was a necessary condition for the use of pay sources in Loiborsoit, and people used the nearest available borehole even if they did not know someone on the borehole committee, or if they knew someone who owned a well in the nearest river (Table 3.8). The majority of Sukuro respondents used pay sources, and those who used free sources reported the availability of both social capital and grazing at the site used. In Terrat, short waiting times were a sufficient but not necessary condition for the use of pay sources. There was only one respondent who used a pay source despite waiting for a long time to water his animals; he owned a large herd and reported that there was not enough water in the Terrat River and there were many people and animals using the river. This was reflected in the implicants for the use of free sources in Terrat, where long waiting times were a necessary condition, even for people living near the village center or using the nearest available source.

**Table 3.8.** Results of QCA analysis of the choice of free versus pay sources during the 2009 drought

| *Village* | *Outcome* | *Prime Implicants* | *Coverage* | *Remainders* |
|---|---|---|---|---|
| Loiborsoit | Pay (n=4) | **NEAREST** * ALTCAPITAL + | 0.75 | |
| | | **NEAREST** * capital | 0.50 | |
| | | Combined Solution | 1.0 | 1 |
| | Free (n=26) | nearest * ALTCAPITAL + | 0.615 | |
| | | CAPITAL*altcapital | 0.385 | |
| | | Combined Solution | 1.0 | 1 |
| Sukuro | Pay (n=21) | grazing + capital | 1.0 | 0 |
| | Free (n=8) | GRAZING * CAPITAL | 1.0 | 0 |
| Terrat | Pay (n=8) | wait + | 0.875 | |
| | | enkdist * nearest | 0.250 | |
| | | Combined Solution | 1.0 | 0 |
| | Free (n=22) | NEAREST * **WAIT** + | 0.909 | |
| | | ENKDIST * **WAIT** | 0.727 | |
| | | Combined Solution | 1.0 | 0 |

ALTCAPITAL=social capital at an alternate source; CAPITAL=social capital at the source used; ENKDIST=*enkang* located near the village center; GRAZING=grazing at or near the source used; NEAREST=used the nearest available source; WAIT=long waiting times at the source used
Note: necessary conditions are highlighted in bold; "*" = "and"; "+" = "or"; lowercase letters represent absence (value=0)

For those using distant sources during the 2009 drought, the availability of social capital was a necessary condition for Loiborsoit residents, whereas the availability of grazing was a necessary condition for Sukuro respondents (Table 3.9). People from Sukuro used distant sources that required payment if those sources were perceived to not have problems with livestock disease. Sukuro residents used distant sources seen as riskier for disease if the source was free and they also had a large herd. Grazing availability and large herd size were also related to long distance livestock movements for people from Terrat, but having enough labor was also a necessary condition.

**Table 3.9.** Factors affecting the choice of local versus distant water sources during the 2009 drought

| *Village* | *Outcome* | *Prime Implicants* | *Coverage* | *Remainders* |
|---|---|---|---|---|
| Loiborsoit | Distant | **CAPITAL***HERD*GRAZING + | 0.350 | |
| | (n=20) | **CAPITAL***herd*grazing*enkdist+ | .700 | |
| | | **CAPITAL***GRAZING*ENKDIST | .050 | |
| | | Combined Solution | .850 | 7 |
| Sukuro | Distant | **GRAZING** * disease * COST + | 0.5 | |
| | (n=8) | **GRAZING** * HERD * DISEASE * cost | .125 | |
| | | Combined Solution | 0.625 | 9 |
| Terrat | Distant | GRAZING * HERD * LABOR | 0.50 | |
| | (n=2) | Combined Solution | 0.50 | 1 |

CAPITAL=social capital at the source used; COST=payment for water; DISEASE=disease at the source used; ENKDIST=*enkang* located near the village center; GRAZING=grazing at or near the source used; HERD=large herd size; LABOR=enough labor availability
Note: necessary conditions are highlighted in bold

During historical droughts, labor availability affected the choice of source type for residents of Emboreet (Table 3.10). Households that did not have enough labor used a free source if it was also the nearest available source and there were concerns about disease at alternative sources[16]. In Terrat, proximity was a sufficient, but not a necessary condition for the use of free water sources during historical droughts. Having a small herd was also associated with the use of a free source, even if it was not the nearest available source. The one household with a large herd who used a free source that was not the nearest available option expressed concern about conflict at an alternate source.

[16]There were several contradictory cases (i.e., cases that had different outcomes – some people used free sources and some used pay sources – for the same combination of factors), but only because some boreholes were free and some were not during historical droughts. All of these respondents were using boreholes.

**Table 3.10.** Factors affecting the choice of free versus pay water sources during historical droughts

| *Village* | *Outcome* | *Prime Implicants* | *Coverage* | *Remainders* |
|---|---|---|---|---|
| Emboreet | Free (n=14) | labor *NEAREST *DISOTHER *WAIT + | 0.643 | |
| | | LABOR * nearest * WAIT + | 0.143 | |
| | | LABOR * nearest * DISOTHER + | 0.143 | |
| | | LABOR * NEAREST *disother * wait | 0.071 | |
| | | Combined Solution | 0.930 | 7 |
| Terrat | Free (n=22) | NEAREST + | 0.762 | |
| | | herd * cftother + | 0.333 | |
| | | HERD* CFTOTHER | 0.095 | |
| | | Combined Solution | .953 | 1 |

CFTOTHER=conflict at alternate source; DISOTHER=disease at alternate source; HERD=large herd size; LABOR=enough labor availability; NEAREST=used the nearest available source; WAIT=long waiting times at the source used

Households in Emboreet used distant sources during historical droughts if they had a large herd and concerns about disease at other locations, even if they had to wait for a long time to water their animals (Table 3.11). When I added variables for drought years, large herd size was the only necessary condition for using distant water sources (although this approach eliminated contradictions and increased the coverage to 1, I did not include the result in Table 3.11 because it increased the number of remainders dramatically). In Terrat, perceptions of conflict, cultivation, disease, and waiting times affected the choice of watering location during historical droughts. Most respondents that used distant sources did not report issues with conflict and did not wait long to water their animals, but some indicated that cultivation was affecting their access to alternative water sources[17]. The respondent who reported conflict and long waiting times at a distant source that they used stated that there was disease at alternative water sources. Only 2 respondents from Sukuro used distant sources during historical droughts. One referred to a drought during the 1940s, and reported that the Terrat River was the nearest available

[17]The two respondents that reported issues with cultivation were referring to the relatively recent 1993/94 drought

source. The other respondent referred to the 1993/94 drought and stated that the dams were dry and the Kiti Engare River (the nearest river) was crowded with many people and livestock.

**Table 3.11.** Factors affecting the choice of local versus distant water sources during historical droughts

| *Village* | *Outcome* | *Prime Implicants* | *Coverage* | *Remainders* |
|---|---|---|---|---|
| Emboreet | Distant | HERD * DISOTHER * WAIT | 0.500 | |
| | (n=4) | Combined Solution | 0.500 | 2 |
| | | | | |
| Terrat | Distant | cft * CULOTHER * disother + | 0.286 | |
| | (n=8) | cft * culother * wait + | 0.429 | |
| | | CFT * culother * DISOTHER * WAIT | 0.143 | |
| | | Combined Solution | 0.857 | 8 |

CFT=conflict at source used; CULOTHER=cultivation affected access to alternate source; DISOTHER=disease at alternate source; HERD=large herd size; WAIT=long waiting times at the source used

The choices of water source type (i.e., free versus pay) and location (i.e., local versus distant) were influenced by different factors (Table 3.12 and Table 3.13). During the 2009 drought, proximity to a water source and the availability of social capital affected the choice of water source type in more than one village, whereas grazing availability and perceived herd size affected decisions about water source location. Grazing was a relevant factor for the choice of local versus distant sources in all villages during the 2009 drought, but not during historical droughts. Several factors were associated with resource-use decisions during historical droughts but not during the 2009 drought: conflict at the used source and other sources, cultivation around other sources, and disease at other locations.

**Table 3.12.** Factors associated with decisions about water source location (L) and cost (C) during the 2009 drought

| | *Loiborsoit* | *Sukuro* | *Terrat* |
|---|---|---|---|
| Household Location | L | | C |
| Cost | | L | |
| Disease | | L | |
| Grazing | L | C&L | L |
| Herd size | L | | L |
| Labor | | | L |
| Nearest Available | C | | C |
| Social capital | C&L | C | |
| Social capital at alt. source | C | | |
| Waiting | | | C |

**Table 3.13.** Factors associated with decisions about water source location (L) and cost (C) during historical droughts

| | *Emboreet* | *Terrat* |
|---|---|---|
| Conflict | | L |
| Conflict at other sources | | C |
| Cultivation at other sources | | L |
| Disease at other locations | C&L | L |
| Herd size | L | C |
| Labor | C | |
| Nearest Available | C | C |
| Waiting | C&L | L |

## *3.5. Discussion*

### *3.5.1. Household Demographics & Economics*

Median per capita livestock holdings were relatively low (3.5 TLU/capita) considering that about 4.5 TLU/capita are required to sustain pastoral livelihoods in arid environments (Pratt and Gwynne 1977, Fratkin and Roth 1990). Although these estimates do not account for other food sources, and crops such as maize and beans are increasingly important sources of income and food for Maasai households, harvests are susceptible to the unpredictable timing and quantity of rainfall and many households are vulnerable to food insecurity during drought years. Smaller perceived herd sizes in 2009 compared to historical droughts are consistent with declines in livestock per capita among Maasai in Ngorongoro Conservation Area (McCabe 2003).

*3.5.2. Resource-Use Decision Making*

Herders often preferred watering their livestock at dams and standing rainwater, but most dams dried up during droughts and many boreholes became crowded or broke. The apparent increase in the proportion of respondents from Emboreet using pay sources was due to several boreholes switching from free to pay sources in the recent past. In Sukuro, the same pattern was likely due to the development of a new borehole within the village coupled with a lack of water in the Sukuro Dam during the 2009 drought, which did not always dry up during past droughts. Rivers became dry during many droughts, but the availability of surface water in rivers was not significantly correlated with use. Many households used the Kikoti River during the 2009 drought even though it did not have surface water. The increase in the proportion of respondents who used distant sources, such as Kikoti River, and the finding that fewer people were using the nearest *available* source in 2009 compared to the past suggests that something other than water availability has influenced changes in mobility. It appears that this pattern was largely a consequence of grazing availability.

QCA results demonstrated that the choice of water source location was related to perceived herd size and grazing availability/quality, and to a lesser extent labor, cost, disease, social capital, and household location. Grazing was a relevant factor for the choice of local versus distant sources in all villages during the 2009 drought, but not during historical droughts. Herd size and grazing availability are closely related because having a large herd increases the amount of fodder that a herder must find for his animals. The finding that the majority of people who watered livestock at distant sources during the 2009 drought used rivers (73%; n=22) may also be related to lower likelihood of finding grazing near developed sources, which are often located closer to village centers and are generally more likely to be surrounded by overgrazed pasture.

The choice of free versus pay sources was dependent on proximity to the household and social capital, and to a lesser extent waiting times, household location, and grazing. Respondents were more likely to report knowing a friend or family member who owned a well in a river than someone who served on a borehole committee. This was partly because there are a larger number of river wells compared to boreholes, and because clan affiliation[18] can determine which wells a herder is able to use. Clan membership can give a herder priority access to a river well, but is less effective for gaining faster access to boreholes that are controlled by formal village committees, which crosscut clan and family ties.

Some decision-making factors were unique to a particular village. For respondents in Terrat during the 2009 drought, labor availability was relevant to the choice of water source location, and waiting times and household location affected the choice of source type. The influence of labor availability on herding decisions in Terrat should be interpreted with caution since the implicant explained the decision of only one of two individuals that used distant water sources. Nonetheless, it is possible that increasing children's school attendance or wage labor migration of other household members have affected the number of people in the household that are available to help

[18]Clans are patrilineal groups which constrain marriage opportunities and access to hand-dug wells, and provide geographically dispersed social support networks (Homewood & Rodgers 1991; Spear & Waller 1993)

herd. Of the Terrat residents who used boreholes, a greater proportion reported short waiting times compared to the other villages (Terrat=88%; Sukuro=10%; Loiborsoit=25%; Emboreet=33%). Similarly, waiting times and grazing availability were not cited as major problems in Emboreet, and Emboreet respondents used boreholes almost exclusively during droughts. This could be the result of effective resource management practices, lower total demand on water and grazing resources, higher rainfall in that village, or a combination of several factors.

Conflict, disease, and cultivation were factors that affected decision-making during historical droughts but not in 2009. Disease may be perceived as less of a problem in recent years because of improved access to veterinary medicine, and better mediation of conflict and land use plans. However, comparing decision-model results for recent and historical droughts is problematic because of the aggregation of drought years that had different social and physical conditions. For instance, some sources (i.e., boreholes) changed from free to pay sources. Additionally, the role of social capital in resource access has changed over time. Many people were able to use dams during past droughts, and access to dams is largely unregulated other than broader restrictions on access to the village or territory. In terms of boreholes, village-based committees were regulating access to most boreholes in 2009, but this was not always the case in the past when some boreholes had no regulatory committee, or people from outside of the village operated them.

### *3.5.3. Resource Use & Tarangire National Park*

Perhaps the most surprising finding from this study is the absence of respondents who used sites that are now within TNP (i.e., Silalo Swamp and Tarangire River) and that have been described by other scholars as critical DRAs for Simanjiro Maasai during historical droughts. I see three possible explanations for this finding: the people most affected by this change emigrated or left the pastoral sector (and were therefore omitted from my sample), the sample of people who recalled droughts that occurred prior to TNP was not large enough to capture people who used those sites, or the importance of these DRAs has been misunderstood. I cannot rule out the first possibility, and the second seems unlikely given the supposed importance of these resource areas. Group interviews are consistent with the third possibility, and shed light on the possible reasons for this surprising finding.

When asked about resource use during droughts that occurred before the establishment of TNP, it was uncommon for people to mention the use of the Silalo Swamp or Tarangire River without being prompted. Most people relied on wells in rivers within Simanjiro. Residents of Emboreet (who live especially close to TNP) stated that most livestock used the Terrat River and some used the Loiborsiret River before the colonial government drilled two boreholes and built 2 dams in the 1950s. A few respondents went so far as to say that Maasai simply were not using sites within the park.

When asked specifically about their use of Silalo Swamp, respondents often stated that it was a good grazing area for small stock, but they also cited concerns about livestock disease and water availability. Silalo is dependent on rainfall for surface water and it was difficult to dig large enough wells to supply sufficient water to cattle during droughts. Moreover, Silalo was a problem area for tick-borne livestock diseases (e.g., East Coast fever) and tsetse flies that transmit trypanosomiasis to people and animals, which would have been of particular concern during periods with little access to cattle dips, veterinary medicine, and clinics. Some people would take their animals to TNP at the beginning of the rains in order to avoid bovine malignant catarrhal fever that is spread by wildebeest calving in the Simanjiro Plains during the wet-season.

When asked about the Tarangire River, people cited concerns about wildlife, water quality (high salinity), and the presence of other ethnic groups. Barabaig herders were living on the far side of the Tarangire River and Silalo Swamp, so using these areas would have meant an increased risk of conflict and cattle raiding. Dorobo hunters and gatherers were also living in and using the TNP area, but this was not a concern in terms of conflict, presumably because Maasai and Dorobo "…communities have exchanged populations in the long run, and that the distinction between them is essentially an economic one, reinforced by other social boundaries." (Galaty 1993: 186) Dorobo is a Maasai word meaning "'poor' – by inference, those without cattle." (Sutton 1993: 50) The presence of Dorobo hunter-gatherers within TNP is consistent with the idea that the area was not ideal for livestock keeping due to wildlife and disease risks.

TNP was a useful grazing area for smallstock during certain dry periods and an area that could be used to avoid diseases like malignant catarrhal fever during the wet season. The use of Silalo Swamp and Tarangire River were limited due to risks from diseases such as East Coast Fever and trypanosomiasis, and interactions with other ethnic groups. This is consistent with the notion that pastoralist herding strategies are generally a balance of resource needs and risks (McCabe 2004), but contrasts with the claims of other scholars that these sites were historically important DRAs (Igoe 2002, 2004, Sachedina 2006) and that the effects of losing access to these sites are still being felt during more recent droughts: "The loss of Silalo was profoundly felt during the drought of 1993-1994. At this time, over 30 households in the village of Loibor Sirret (located on the boundary of the park) were forced to migrate to an area south of Tarangire in search of pasture and water." (Igoe 2004: 62) The discrepancy between my findings and those of previous scholars may be due to changes in perceptions about resource availability; Maasai may now perceive sites within TNP as valuable potential DRAs due to increased pressure on resources outside of the park and improved access to veterinary medicines that would reduce the disease risks associated with using those sites. In other words, the perceived value of Silalo Swamp and Tarangire River as DRAs may reflect broader changes in resource availability in Simanjiro, rather than a historical reliance on these sites.

#### *3.5.4. Conservation Implications of Resource Use Practices*

Rivers are key resource areas, and the Kikoti, Loiborsiret, and Terrat Rivers are some of the most important DRAs in the region. During the 2009 drought, herders from as far away as southern Kenya brought their livestock to Simanjiro for grazing and water, and Kikoti was one of the most widely used resource areas in the study villages. Rivers and their associated network of wells allow access for larger numbers of people and livestock at any one time compared to boreholes, and the distribution of individuals along a waterway can spread resource demand and perhaps grazing impacts as well. Rivers generally do not require payment and allow for negotiated access, but this is changing in some villages, such as Loiborsiret, where well-owners have started using household generators to pump water out of hand-dug wells and requesting payment of diesel in exchange for watering animals.

Although agriculture is an increasingly common aspect of Maasai livelihoods, cultivation is also a concern among many residents due to its influence on resource access and sedimentation of rivers and dams. Some respondents stated that grazing availability was being compromised by large tracts of cultivated land. Land use configuration is a problem in some sub-villages, particularly in the northeastern part of the study area, where agriculture is reportedly restricting livestock herding routes. This is mainly an issue prior to harvests (when livestock could destroy crops), and problems with cultivation were often viewed as stemming from immigrant landowners and large-scale commercial agriculture. The influence of cultivation on erosion and hydrology was mentioned by some respondents, and is explored in greater detail in the following chapter.

*3.5.5. Limitations*

This research yielded a number of substantive findings, but, like all studies of complex, real-world phenomena, it suffered from several limitations. First, this research focused on male heads of household. I recognize that human-environment interactions are gendered; men and women have different environmental knowledge, rights, levels of involvement in management, and day-to-day responsibilities (Robbins 2004b). In the case of Maasai, men typically water livestock and women are responsible for household water needs (Homewood and Rodgers 1991). As a result, changes in resource availability would likely have differential implications for men and women. For instance, the development of a new borehole might decrease the labor for men who previously dug wells in dry river beds to access subsurface water, but this development might increase the distance that women must walk to obtain water since they frequently gather water where the men water livestock. Other factors are relevant to women's water use choices, such as the availability of donkeys, which can improve household welfare by reducing the substantial time and energy spent carrying water, and freeing up some wives to participate in other activities such as wage labor, work in gardens/farms, and childcare. During fieldwork I collected 65 surveys from women regarding decision-making about water gathering during the 2009 drought and historical droughts. In the future, I will use these data to explore gender differences by comparing the factors associated with women's and men's resource-use decisions.

Second, dichotomization is not a very precise way to operationalize measures of rather complex social and environmental variables. In future studies, it would be useful to include continuous or categorical variables for measures of wealth, waiting times, and water source locations, and to analyze these data using multi-value or fuzzy set QCA. For instance, the variable of perceived herd size could be tested against a categorical wealth variable representing poor, middle, and wealthy households. Additionally, my measure of waiting times could be improved by having respondents rank perceived waiting times at each available source, or by collecting estimated waiting times at each source. Similarly, more detailed information about the distances between household and resource locations would be useful. I could also account for different types of conflict. For example, conflict during the 2009 drought was generally not violent, or severe; rather, arguments were arbitrated by others in the community such as elders or committee members. This is distinct from conflict that may have occurred during historical droughts involving cattle raids or violent confrontations between ethnic groups.

Third, I did not test the predictive capacity of these models on another sample of individuals from the study villages because of a lack of data. This would provide an indication of the models' internal validity, which is the typical form of validation for ethnographic decision models (Ryan and Bernard 2006).

Finally, there was potential for recall error, especially for droughts that were further in the past. However, I am confident in the accuracy of respondents' recollections of herding practices during historical droughts, even ones in the 1940s, because of the importance of these memories for avoiding disaster during subsequent years. Such herding successes and failures are so important that they can even be transmitted across generations through oral history.

### *3.6. Conclusion*

The selection of livestock watering sites during drought depends on two choices – water source location and type. These resource-use decisions are complex and are affected by both contextual factors (e.g., disease, conflict, water cost, waiting times, and grazing) and household factors (e.g., social capital, labor, herd size). Results supported my expectation that decisions regarding where to water livestock during droughts before and after TNP was established vary by village, but I cannot demonstrate that this variation was due to proximity to TNP. On the contrary, this variation is more closely related to levels of water development and proximity to the primary natural water sources in Simanjiro. Changes in grazing availability are also central to these decisions.

The social effects of TNP appear less dramatic than stated by other scholars. Contrary to expectations based upon previous studies, I found little evidence of people relying on Tarangire River and Silalo Swamp as key resource areas during historical droughts. Rather, these places were more heavily used as grazing areas for smallstock and wet-season grazing areas for cattle to avoid disease carried by calving wildebeest. Although Silalo Swamp maintains green vegetation during periods of low rainfall, Maasai often cited risks from disease and conflict, and insufficient water availability. Rivers, and later dams and boreholes, outside of the park have been important water sources during recent and historical droughts.

Small rivers and even ephemeral streams continue to serve as critical DRAs. Rivers are also valuable for their accessibility to individuals who lack the money required to access boreholes. Droughts have served as impetus for finding other natural water sources, such as wells in the Kikoti River, which have become important water sources for residents of Simanjiro as well as livestock herders from as far away as southern Kenya during recent droughts. There have been threats to pastoralist access to Kikoti from private safari companies seeking to establish an area that is free of herders and livestock. Fortunately, the Loiborsoit village council negotiated the terms of the proposed contract and maintained access for herders. More broadly, villages are currently debating the terms of shared grazing areas throughout Simanjiro.

The study villages are undergoing substantial changes in land use and development (Baird 2012). Future water development projects should plan for settlement in the immediate area of these projects before they are implemented, and account for the need of households to both water animals and gather water. It is important to install separate water taps and livestock troughs in order to partition livestock and household water use, and thereby reduce waiting times, increase women's autonomy, and improve sanitation. Water developments are having substantial positive impacts on household water security, but boreholes are prone to overcrowding and breaking, so increased dependence on developed water sources could increase vulnerability to severe droughts.

It is imperative that rivers and streams remain accessible and productive resource areas. The configuration of land uses is especially relevant to this objective because cultivation is disrupting access routes to both grazing and water resources in some communities, and appears to be affecting water and sediment supply (see following chapter). Managing and restoring natural water sources in is essential for supporting pastoralist livelihoods both within Simanjiro and beyond, because Simanjiro itself is an important drought resource area for households across the region.

**CHAPTER 4**

# RANGELAND MANAGEMENT AND FLUVIAL GEOMORPHOLOGY IN THE SIMANJIRO PLAINS

## *4.1. Introduction*

"*No one can own water. Water is here for the community.*"
– Resident of Loiborsiret

Understanding the ways in which livelihood decisions affect the environment has great practical importance for maintaining ecosystem function and resource availability. However, detecting degradation and identifying its links to particular livelihood decisions is challenging, especially because resource use rules often mediate the relationships between people and the environment. Failure to recognize these institutions their relationship to resource use decisions can result in substantial misunderstandings of the processes driving environmental change. The goal of this chapter is to shed light on the connections between resource management institutions, land use, and rivers in Simanjiro.

Rivers are especially valued features of arid and semi-arid rangelands due to the ecosystem services they provide and the biodiversity they sustain. East African rivers support vegetation communities and wildlife assemblages that are distinct from the surrounding landscape mosaic (Medley and Hughes 1996). Dry-season water and forage availability make them important habitats for consumers, and the spatial distribution of these resources structures wild ungulate migrations (Western 1975) as well as livestock movements (Coppolillo 2000). Yet East African rivers face threats from agriculture, resource extraction, damming, and settlement (Stave et al. 2001, Stave et al. 2003, Stave et al. 2007, Mango et al. 2011). These land use changes, and their effects on rivers, are mitigated by both customary and governmental resource management institutions. In East Africa, top-down rangeland management policies have, in many cases, marginalized traditional land tenure arrangements and land use patterns, often to the detriment of rangeland condition and local land users. In particular, government interventions have eroded systems of exchange, access, and mobility that had previously governed livestock distributions and range condition (e.g., Sandford 1983, Fratkin 1997, Homann et al. 2008, Mwangi and Ostrom 2009). Local systems for regulating riparian resource use have also been threatened by national policies that ignore indigenous knowledge and tenure arrangements (Stave et al. 2001, Stave et al. 2007). There have been recent efforts to recognize group property rights and to decentralize land administration, but this too has been met with substantial challenges. In many places there are overlapping claims of tenure and conflicting resource demands across groups, and within groups there are problems related to power sharing, accountability, and equitability (Mwangi 2009).

Although researchers have independently documented threats to customary resource management institutions and river systems in East Africa, there is a lack of research on the relationships between them. This gap in our understanding of the proximate and more distal drivers of river change limits our ability to effectively manage rangeland watersheds. As a result, this study asks: how do communities in Simanjiro manage water resources, and what are the implications for river systems?

## *4.2. Background*

### *4.2.1. Fluvial Geomorphology*

There are conflicting findings about the impact of livestock on East African woodlands and riparian forests, with studies reporting negative grazing and browsing impacts (Mathooko and Kariuki 2000), positive influences on tree regeneration and browse production (Reid and Ellis 1995, Oba 1998), and inconclusive results (Stave et al. 2001). These mixed findings may be artifacts of inconsistent or poorly designed livestock exclosure research, which have yielded uncertainty in studies of western U.S. riparian systems (Sarr 2002). Moreover, as pastoralist livelihoods diversify and change, and the relative influence of livestock on the environment also change, studies of riparian vegetation may not be sufficient to capture the effects of broader changes in land use on river systems.

An alternative means of assessing the effects of land use changes on waterways is to analyze river channel form and structure. River channels adjust to water and sediment supply from within their catchment, and can thereby reflect changes in land use through their morphology. Moreover, geomorphic processes form the physical template that constrains the distribution of riparian vegetation communities (Hupp and Osterkamp 1996). Riparian vegetation responds to changes in fluvial geomorphology such as channelization, and as a result, vegetation changes can lag behind river channel adjustments (Hupp 1992). In light of the lag effects associated with riparian vegetation, the shortcomings of livestock exclosure research (including the difficulty of isolating the grazing/browsing effects of livestock from those of wildlife), and the lack of gauging stations and hydrologic data for the study region, geomorphology offers a means of assessing the influence of land use changes on rivers.

The effects of human activities on river channel geomorphology are well-studied (Gregory 2006), and sediment size distributions and channel dimensions are common metrics for assessing river channel response to disturbances. Comparing these metrics across multiple rivers can illustrate the environmental effects of different types or levels of land use change, while downstream trends reflect temporal changes in water and sediment supply from the surrounding landscape and can thus aid in reconstructing the historical effects of land use changes on channel morphology. For instance, reverse channel morphology (i.e., a downstream decrease in channel area) is the result of an initial period of increased sediment supply followed by a period of decreased sediment supply; evaluating the presence and magnitude of such downstream trends across catchments can demonstrate the environmental effects of different land use histories and help forecast future changes to river systems (Clark and Wilcock 2000).

Channel width, depth, and area are frequently used to describe river channels. These dimensions are typically measured relative to bankfull stage, or the height of the active floodplain. Bankfull discharge is of interest because it is a correlate of effective discharge – that is, the flow rate with the greatest influence on long-term sediment transport and channel morphology (Wolman and Miller 1960). Width to depth ratios (W:D) for dryland rivers ranges widely (3.8 to 255, Schumm 1961, 16 to 340, Shaw and Cooper 2008). Lower order streams and smaller drainages typically exhibit low W:D (Shaw and Cooper 2008), and W:D is also inversely related to weighted mean percent silt-clay in the channel perimeter (Schumm 1961).

Channel dimensions can be affected by changes in land use that alter water and sediment supply from the surrounding landscape. The conversion of land to agriculture is associated with increases in flood magnitude (Knox 1977), and additional loss of forest in the Mara River watershed (Kenya) is projected to decrease low flows and increase peak flows (Mango et al. 2011). Increased peak discharge yields more erosive stream flows that cause channel incision, especially in areas with fine, loose soils (Fu 1989). Channel incision can then initiate a sequence of changes, wherein increased channel depth weakens riparian vegetation and stream banks, and can eventually lead to channel widening (Bull 1997). Grazing is also a source of geomorphic change and has been associated with channel widening (Platts 1991); similarly, livestock exclosure has been linked to decreased width, increased depth, and decreased W:D (McDowell and Magilligan 1997).

Changes in land use not only impact water supply, but also affect erosion and sediment transport. Cultivation and rural roadways are significant sources of sediment in East African river catchments (Dunne 1979). Measuring the sediment size distributions of riverbeds provides information on changes in sediment supply and transport capacity. Bedload sediment is commonly described using the particle sizes associated with the 84$^{th}$, 50$^{th}$, and 16$^{th}$ percentiles of the sediment size distribution (referred to as $D_{84}$, $D_{50}$, and $D_{16}$, respectively).

Metrics of sediment size and channel dimensions can be combined in order to calculate non-dimensional critical shear stress for a discharge of height *h* (i.e., Shields stress, $\tau^*$):

$$\tau^* = \gamma hs / \left[ D_{50} \left( \gamma_s - \gamma \right) \right]$$

where $\gamma$ is the unit weight of water; $h$ is channel height, approximated as bankfull depth; $s$ is bed slope; $D_{50}$ is median grain size; and $\gamma_s$ is the unit weight of sediment (Shields 1936). Shields stress can be used to gauge whether or not bankfull flows are sufficient for mobilizing sediment; a value above about 0.06 indicates that sediment is mobilized during bankfull flows. Particle size typically decreases in the downstream direction (Knighton 1998), and shear stress increases downstream in small- and medium-sized entrenched dryland streams (Graf 1988).

Detecting the effects of land use on channel morphology can be confounded by shifts in precipitation; however, East African precipitation shows no distinct trends over the past 100 years despite interannual fluctuations (Hulme et al. 2001). Moreover, climate and land use changes affect erosion of dryland rivers at different scales; variations in climate affect erosion at large scales, while land uses such as grazing control erosion in smaller catchments such as those studied here (Graf 1988).

*4.2.2. Study Area & Population*

The Simanjiro Plains are semi-arid with an average annual rainfall of about 600 mm. The vegetation consists of short grassland and smaller areas of woodland, bushland, and bushed grassland that is seasonally water-logged (Kahurananga 1979). These savanna communities intergrade with riparian zones, which support remnants of tropical rainforest that became isolated and fragmentary due to climatic drying around 4000 YBP (Medley and Hughes 1996). The soils of the Simanjiro Plains range from dark red sandy clay loam in the grasslands, to black clay in the depressions (Kahurananga 1981).

At the beginning of the wet season, wildlife – especially zebra and wildebeest – migrate from Tarangire National Park (TNP) to the Simanjiro Plains (Kahurananga 1981, Kahurananga and Silkiluwasha 1997). As the dry-season progresses, much of the wildlife migrates from Simanjiro back into TNP. Wildlife distributions are partly structured by water quality (particularly salinity; Gereta 2004) and habitat and food preferences (Lamprey 1963), but they are also attracted to TNP by surface water in the Tarangire River and the Silalo Swamp.

Water is a primary concern for Maasai pastoralists living in Simanjiro during both drought and non-drought years. Streams and rivers are widely used water sources, particularly during times of water scarcity when boreholes break or become crowded, and dams dry up. When surface water is no longer available in rivers, hand-dug wells are used to access water for livestock, households, and even schools. Rivers and riparian zones are used for a variety of other purposes including washing, bathing, grazing, honey production, charcoal production, brick-making, and as a source of building materials. This study focuses on 4 rivers in Simanjiro: the Kikoti, Kiti Engare, Loiborsiret, and Terrat Rivers (Figure 4.1).

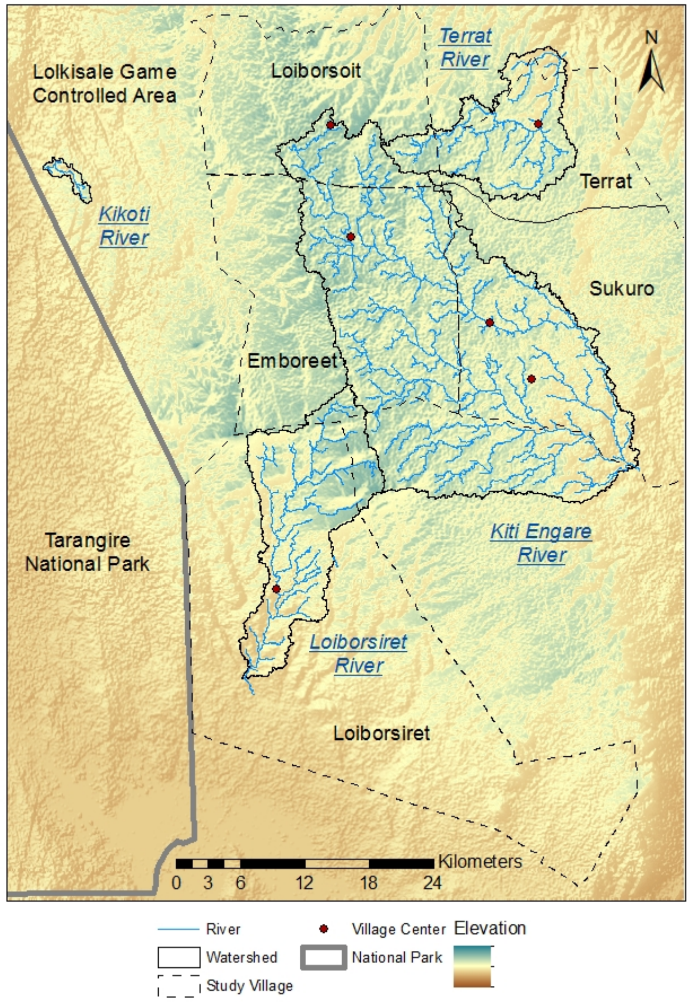


**Figure 4.1.** Watersheds of the four study rivers and village boundaries[19]

Preliminary fieldwork in 2009 and 2010 indicated that the Terrat River has been subject to the highest levels of land use change, with cultivation across large parts of its catchment, settlement and roadways near the river, and ineffective regulation of grazing and resource extraction in the riparian zone. Kikoti is the most remote river, and has also been managed as part of a grazing reserve. Loiborsiret and Kiti Engare have functioning riparian management institutions and intermediate levels of land use change;

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[19]Village boundaries are from the Tanzania National Bureau of Statistics for the 2002 Census, and were downloaded from http://openmicrodata.wordpress.com/2010/12/16/tanzania-shapefiles-for-eas-villages-districts-and-regions/

Loiborsiret's village center and main access road are located adjacent to the river, and there has been more intense grazing pressure in this area, but its watershed has been subject to less cultivation than Kiti Engare.

Based on these preliminary observations, I anticipate that the Terrat River will exhibit the most pronounced changes in channel dimensions and sediment, and Kikoti River the least. In particular, higher levels of land use change have been associated with channel incision in other systems, so I expect Terrat to have the greatest depth, followed by Kiti Engare, Loiborsiret, and Kikoti. I also anticipate that rivers with higher grazing intensity in riparian areas (Terrat and Loiborsiret) to exhibit higher width. I expect that the Terrat River's channel area will decrease downstream due to scour upstream and deposition downstream. Kiti Engare and Loiborsiret will show some initial signs of this reverse channel morphology. Sediment size should decrease downstream for all rivers. Since these are sand-/gravel-bed rivers, and the parent-material is mostly fine-grained sands and clays (Kahurananga 1981), I expect that much of the moderately-fine sediment has been washed out of the upstream reaches of rivers that have been subject to more extensive land use changes. This should yield finer bedload sediment in Terrat, Kiti Engare, and Loiborsiret as compared to Kikoti.

### *4.3. Methods*

#### *4.3.1. Resource Management Institutions*

In order to compare the various institutions managing the four study rivers, I conducted 35 semi-structured interviews with village leaders, key informants, and other community members from March to November 2011. Interviews were collected with the assistance of two Tanzanian field assistants who have worked with advisor Leslie and colleagues for more than 10 years, and who are fluent in English, Kiswahili, and Maasai.

My assessment of institutions was guided by the design principles of long-lived common property resource institutions outlined by Ostrom (1990: 90): clearly defined boundaries; congruence between appropriation and provision rules and local conditions; collective-choice arrangements that allow most individuals affected by the rules to participate in modifying them; effective monitoring by individuals who are part of or accountable to the resource users; graduated sanctions for users who do not respect community rules; conflict-resolution mechanisms which are cheap and easy of access; minimal recognition of rights to organize (e.g., by the government); and in case of larger common pool resources, organization in the form of multiple layers of nested enterprises. Interviews also addressed institutional responses to contextual and livelihood changes (Appendix V). A subset of interviews focused specifically on drought histories and changes in the use, management, and characteristics of the study rivers (Appendix VI).

### *4.3.2. Fluvial Geomorpohology*

Preliminary observations of the study river catchments indicated that they varied in terms of land use change, but were comparable in other respects. To more rigorously ascertain the biophysical similarity of the study rivers and their capacity for channel adjustment I borrowed methods from Stages 1 and 2 of the river styles framework (Brierley and Fryirs 2005), classifying the rivers based on their landscape units, elevation profiles, and levels of confinement. I derived elevation profiles, slope estimates, and drainage areas from a 30m digital elevation model (ASTER Global DEM) using the *TauDEM* extension for *ArcGIS 10.0*.

I also collected a total of 104 cross-sectional measures of river channel dimensions and 81 sediment samples within representative stream reaches across the four study rivers. Due to Kikoti's small drainage area and short length, I was able to collect samples along nearly its entire length, whereas sampling of the other rivers was more restricted to their upper reaches. In terms of landscape units, all sampled reaches were in the uplands and foothills.

I used the active floodplain as the reference height for field measurements of channel width and depth. I identified the active floodplain by the presence of depositional features (e.g., break in bank slope, presence of perennial vegetation species, flat floodplain surface)[20], and then used a tape measure and measuring rod to determine width and depth. I calculated cross-sectional areas from these width and depth measurements. I estimated sediment size distributions using the Wolman pebble count procedure, whereby particles are sampled along transects running perpendicular to the channel, measured along their intermediate axis, and tallied using Wentworth size classes (Wolman 1954). I then compared channel dimensions and sediment size distributions both across rivers and in terms of their downstream trends.

Lastly, I approximated sediment supply for each watershed using the Pacific Southwest Inter-Agency Committee (PSIAC) method of predicting watershed sediment-yields (PSIAC 1968). This method is similar to the Universal Soil Loss Equation but was designed for arid and semi-arid conditions of the Southwest U.S. (Graf 1988). It has

[20]This technique is described online at http://stream.fs.fed.us/publications/bankfull_west.html

proven to be a reasonable estimator of sediment yield for various catchments in the Southwest (Renard and Stone 1982, Woida and Clark 2001) and drylands elsewhere in the world (Safamanesh et al. 2006, Tangestani 2006, de Vente 2009). I collected GPS locations and rated nine factors (geology, soils, climate, runoff, topography, ground cover, land use, upland erosion, and channel erosion and sediment transport) at representative locations within major land cover types in each of the four watersheds. For each sample location, the sum of these nine rankings was entered as *x* into the equation

$$SY = 0.0816e^{0.0353x}$$

where *SY* is the annual sediment yield rate (acre ft $mi^{-2}$). I calculated mean sediment yield for each land use type within each watershed, and then estimated the sediment yield for each watershed by calculating an average weighted by the area of the different land cover types. Land cover classifications were derived from satellite imagery using a supervised classification method (see Chapter 2 for details). Sediment yield estimates were not intended to be interpreted as precise values, but rather approximations that allowed me to compare relative differences in land use across sites.

## ***4.4. Results***

### *4.4.1. Resource Management Institutions*

Both formal and customary institutions regulate natural resource use in Simanjiro. In terms of customary institutions, Maasai communities regulate the use of specific water sources through nested access rules. Sections are social and political units that regulate access to large territories, and thereby limit the use of grazing areas and water resources to people within broad geographical areas (Homewood and Rodgers 1991). Clan (patrilineal group) membership regulates access to particular hand-dug wells that are "owned" by individuals or households.

Wells are located in river channels or in the adjacent floodplain, and can be quite deep (>10m), sometimes passing through layers of bedrock. Although wells fill with sediment each rainy-season, people remember the specific location of their well and excavate the infilled sediment every year. Well owners have priority access to water. People who do not own a well or who are from outside of the area typically use wells that are owned by individuals from the same clan. Non-owners must request permission in order to use the well, and are assigned a day and time that they may use it. Livestock are typically watered every other day, and well users establish an order of use for each day that is based on clan-membership, village affiliation, and household location. In some cases, clans may alternate the days that they use a particular well. Respondents generally viewed these institutions as effective at ensuring fair access to water, and respected their processes and regulations. Establishing and following a specified watering schedule is particularly important because wells may take several hours to recharge after a group of livestock is watered. *Laigwenak* (age-set spokesmen) and other leaders may be called upon to settle disputes associated with well use.

Formal institutions govern rivers at the broadest scale through national laws; for instance, people must cultivate at least 50m away from rivers. However, the village is the most relevant scale of government in terms of the specific rules, monitoring approaches, and levels of sanctions that relate to daily household activities. Each village has three main committees: development, safety/security, and finance. These committees consist of up to 25 members, including the village chairman, village executive officer, and sub-village chairmen. Committee members are from the village council, whose members are elected by the general assembly[21]. The district council oversees village government decisions, but village-level rules are established through a process in which subvillage leaders collect recommendations from residents and bring them to the village council to formalize rules. These rules are then brought to the general assembly for final approval.

The three main village committees are composed of sub-committees (e.g., environment, health, school, wildlife, livestock, water) and the village assembly appoints members to these committees every 3 years. There is substantial variation in the number and types of sub-committees in each village, and not all villages have water or environmental committees. Particular regulations also vary by village, and the governance structures associated with each of the four study rivers is described in greater detail below.

#### *4.4.1.1. Kikoti River*

The Kikoti River is located within Lolkisale Game Controlled Area (GCA). GCAs regulate hunting, but settlement, grazing, and timber extraction are permitted within their boundaries (Caro et al. 1998). The management of Kikoti River falls under the jurisdiction of Loiborsoit village, which has an environmental committee and a water committee. The water committee is mainly responsible for the management of boreholes while the environment committee is in charge of a broader set of natural resources. Loiborsoit also established a sub-committee of the environmental committee, in May 2011, known as the livestock committee. Their role is to regulate people bringing

[21]The general assembly consists of all residents of a village over the age of 18. This body elects a village council every 5 years. These councils can own property and engage in legal contracts (Nelson 2007).

livestock into the village from elsewhere, mitigate environmental impacts form immigration and settlement, and to ensure that the village benefits financially from these visitors. The creation of the livestock committee was initially motivated by perceived environmental impacts from people from outside of the village bringing livestock to Loiborsoit during the 2009 drought. In particular, village leaders expressed concerns about environmental damage such as tree-cutting associated with building *enkang* (compounds that contain a collection of households), charcoal making, and outside businesspeople who were using village land to fatten livestock and then taking the animals back to urban areas (e.g., Arusha) for sale.

People from outside of the village are only allowed to graze animals in Loiborsoit from October 1 until March 15. They are allowed to move their animals through the village before October 1 but are required to herd livestock along the road in an effort to prevent visitors from constructing *enkang* in more remote parts of the village without permission. For those who enter the village during the grazing period, newcomers must ask permission to build *enkang*, and the committee selects the site of the temporary settlement. These individuals will also have to move their animals once the grass in their area is depleted and the committee assigns them a new location. The first reserve for grazing and temporary settlement is Lokono Hill toward Karbol Swamp, and the second grazing reserve is near Kikoti River.

Residents of Loiborsoit are also not permitted to use these grazing areas before approval by the committee. The village general assembly agrees upon a date when households should move their livestock to more distant grazing areas in order to conserve fodder near settlements for calves and smallstock. This differs from historical practices, when households would make such herding decisions themselves. The timing of opening the grazing reserves varies by year. In 2011, people moved from Lokono Hill to Kikoti in mid-July. This decision was largely driven by water availability; Lokono depends on small dams and swamps and there was not enough rain this year for people and their livestock to stay in that area past July. If there is sufficient water and grazing at Lokono during a given year, then people may not have to move to Kikoti at all. If someone moves into these areas without permission they are fined and removed. Activities such as charcoal making are also illegal, and if someone is caught making charcoal he/she is brought to the village office, their charcoal is confiscated[22], and they are fined by the village office. The committee occasionally monitors Kikoti, but because of its distance from the village center, they mostly depend on reports from other villagers living in adjacent subvillages. It is believed that everyone has a responsibility to report unlawful activities to the committee, and that community members will help monitor for violations because the resource-use rules were approved by the general assembly.

The effectiveness of this monitoring strategy is questionable, and the committee faces substantial challenges with regulating access to Kikoti River. According to the committee, several people were caught and fined for rule violations in 2011, and this deterred others from breaking laws. They also claimed that grazing availability around Kikoti River has improved due to these regulations. There were independent reports of rule enforcement, but there were also many people from outside of Loiborsoit (e.g., Kisongo, Lolkisale, and Meserani) using Kikoti before October 1. One visitor had been there since June and had been coming to Kikoti for all of the last 4 dry-seasons. By and

[22]The committee takes the charcoal and sells it to villagers and the money goes to the village office.

large the most significant problem facing the management of the Kikoti River is its remoteness from the village center. On a few occasions the committee has hired a vehicle for monitoring purposes, but the cost of doing so on a regular basis is prohibitive. There were also instances of rule violations associated with other rivers and streams in in Loiborsoit. For instance, people are required to establish households at least 200m from rivers throughout the village, but, in the words of one respondent, “some people listen, and some do not.”

*4.4.1.2. Kiti Engare River*

Although Kiti Engare has a large watershed that spans multiple villages, the active channel of the river is almost exclusively within the Kiti Engare subvillage of Sukuro. At the time of fieldwork, Kiti Engare was in the process of transitioning from a subvillage of Sukuro to an independent village with its own governance structures. It still shared some operations with Sukuro, and people from outside of the village were required to ask permission from the village council in order to access water sources. Kiti Engare did not yet have an environmental committee but was planning to establish one. This transitional period made the assessment of formal institutions difficult, partly due to tension among residents regarding the Kiti Engare’s split from Sukuro.

*4.4.1.3. Loiborsiret River*

Similar to Loiborsoit, Loiborsiret has an environmental committee that is responsible for managing natural resources, including forests, mining operations, and pasture. The environmental committee also provides the livestock committee with recommendations about grazing schedules and the placement of *enkang*, and monitors for poaching in collaboration with the wildlife committee. The livestock committee was established in 2009 in order to manage visitors and their resource use. The committee sets aside areas for visitors to establish *enkang* (near the mountains in the north and Oldule swamp in the south), and started collecting "donations" from outsiders in 2011, asking each herder for $200,000 TSH (approximately $125 USD). Four people from the village that are not on the committee collect this money. The village says that the money will be used for improving the secondary school, building water tanks at the dispensary, and other development projects. As of mid-July 2011, they had already received 58 herds, totaling about 18,000 livestock, mostly from Monduli District.

The environmental committee is the primary body in charge of managing the Loiborsiret River and it has established a number of use regulations, for example: settlement is prohibited within 100m of the Loiborsiret River; livestock cannot walk into the river and must use the livestock trough; livestock may not graze on particular species of plants in the riparian zone; and people must bathe and wash clothing at certain locations. The environmental committee is responsible for monitoring for rule violations, and the village office makes decisions regarding punishment and sanctions for violators. As in other villages, all community members are considered part of the monitoring effort since everyone is aware of the rules. It is expected by the committee that if a citizen finds someone violating the rules, they should bring the offender to the village office, which is responsible for punishing violators. However, offenders are sometimes taken to *laigwenak*, and sometimes to the village council depending on the severity of the violation. For minor infractions, compromise can be sought with the committee or leaders, but for more serious violations (e.g., those involving violence) cases are taken up with the village office. The committee claimed to be collaborating with both *laigwenak* and non-Maasai representatives.

In terms of effectiveness of these institutions, herders generally followed the established order for watering their livestock at wells, keeping their animals in makeshift corrals until it was their turn to be watered. They also prevented livestock from grazing near the river. Yet despite these efforts, most of the grass in the riparian zone was depleted, either due to trampling by the thousands of livestock using wells in the river, or from grazing by donkeys that were allowed to roam freely. Moreover, when the river is flowing people may simply water their animals when and where they wish, and the committee does not play much of a role in resource management during those periods. According to respondents, the committee faces challenges with visitors violating village rules, conflicts related to the order of watering animals, and preventing charcoal making. Multiple community members expressed the view that although the committee was making an effort to sustainably manage the river, people continued to break the laws.

*4.4.1.4. Terrat River*

The Terrat environmental committee is responsible for managing the Terrat River and surrounding environments. This committee was formally created in 2000, but the village implemented measures to collectively manage the river as early as 1978, when people (especially warriors) were appointed to guard the river and establish a specific area for watering livestock. They also planted sisal in an effort to protect part of the river from overuse. Their primary role is to monitor for infractions such as tree-cutting, brickand charcoal-making, the removal of gravel from the river bed, and bathing and washing in certain areas of the river.

Violators are brought to the village office or the primary court for punishment. However, community members expressed concerns that the village council and the court do not assign sanctions that are commensurate with rule infractions identified by the committee, and, as a result, the authority of the committee is limited. There were reports of people being caught illegally grazing their animals in the riparian zone who did not receive any punishment. I also observed charcoal and brickmaking in several locations near the river, and gravel/sand extraction from the river channel itself. Problems with rule enforcement, largely stemming from poor coordination with the village council and court, have discouraged the committee from meeting frequently and fulfilling their duties.

The committee also has little agency in managing resources on land that has been allocated to households. The environmental committee is not responsible for land use planning – which is the purview of the land committee – and therefore cannot punish people for clearing forest on their land. The disconnect between environmental management and land use planning was also evident on a broader scale; people stated that the problems with the Terrat River were not from the management of the river itself, but the tributaries, which extend beyond the village boundaries where much of the land has been allocated and cultivated. Despite attempts to work with neighboring villages on land use planning, people often felt that there was simply too much demand for land and people need to cultivate. So although people in Terrat generally follow the rule that settlements must be at least 70 meters from the river, this buffer zone is "…not enough to bring as much water as it used to."

Other organizations have become involved in managing the Terrat River. The Ujamaa Community Resource Trust[23] is a non-governmental organization that has held trainings for the environmental committee and is independently monitoring a conservation easement within the village. Tanzania Natural Resource Forum is also working with the village to limit the degradation of riparian forests near the village center. People generally protect large trees because they recognize the benefit of trees for producing building materials, charcoal, seedpods for feeding small stock, and water production; however, there were reports of people surreptitiously using these areas by grazing their animals at night.

### *4.4.2. River Styles*

Before assessing differences in fluvial geomorphology across these rivers, it is necessary to account for the possibility that underlying biophysical variation across rivers could amplify or attenuate anthropogenic impacts on channel form. For instance, a confined bedrock river reach would likely have a lower channel width than an unconfined alluvial reach with the same level of human disturbance, because bedrock reaches have less capacity for adjustment and are more resistant to change (Brierley and Fryirs 2005). The most remote study river (Kikoti) was also one of the least confined, which suggests that comparing its channel geometry to that of other study rivers with the same relief and landscape position would provide a conservative estimate of differences in anthropogenic impact on channel form.

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[23]UCRT is part of the Dorobo Fund (501(c)(3)). Their mission is "t*o promote and enhance community capacity to improve their livelihoods and sustainably manage their natural resources." (http://dorobofund.squarespace.com/ucrt/)*

The four study rivers exhibited similar slopes and starting elevations, and sampling sites were located along a similar range of elevations in the rivers' profiles (Figure 4.2). All rivers exhibited low slope angles (0.008 to 0.016), and relatively low sinuosity. All rivers had a single active channel with predominantly sand/gravel bed material. Surprisingly, the drainage areas (calculated for the most downstream sampling points in each river) varied more widely; Kikoti River's drainage area was much smaller (about 6km$^2$) than the other three study rivers (125 to 630km$^2$).

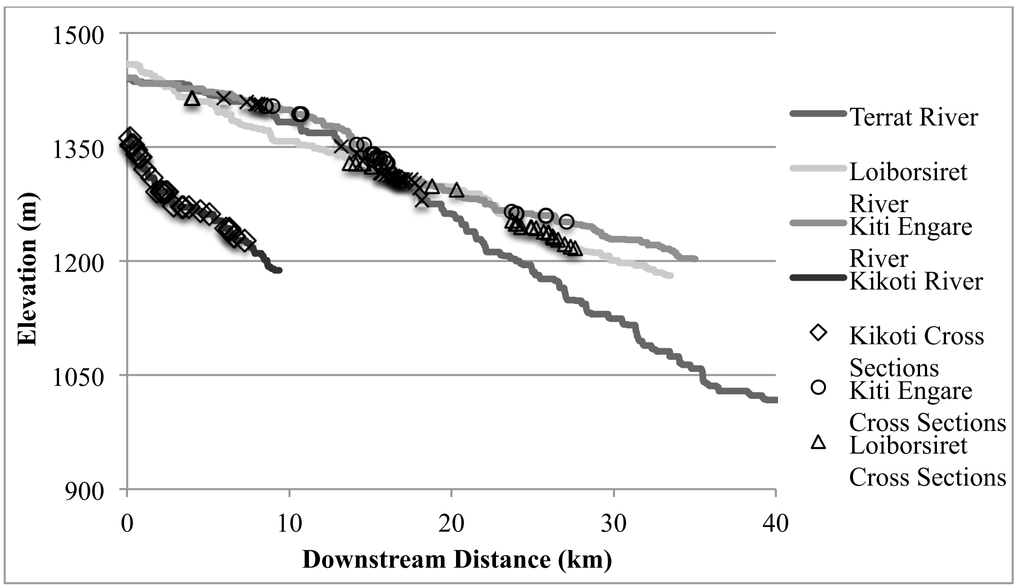

**Figure 4.2.** River elevation profiles and sampling sites

The Kikoti River is ephemeral and has slightly higher sinuosity than the other rivers, low confinement, limited signs of incision (except in a few reaches), and gravel/sand bed material. It has a moderately well-developed floodplain in all but the upstream reaches, which is bordered by bushland in the upper reaches and grassland with scattered *Acacia*, *Ficus*, and *Kigelia africana* trees farther downstream. In the late dry-season of 2011, grazing was still available in the area around Kikoti. There were approximately 35-40 actively used hand-dug wells in the channel and the adjacent floodplain for watering livestock, and there were at least as many that were not in use. Some wells had not been used since the 2009 drought, and some were simply abandoned because they did not yield water. A single well could water approximately 250 cattle per day during the late dry-season: about 200 in the morning and about 50 in the evening. There was also ample evidence of elephants in the river channel and riparian zone.

Kiti Engare flows for limited periods of time during the wet-season. The Maasai phrase "Kiti Engare" translates to "little water" which may be an indication of the reliability of water there, but community members stated that the name was meant as a trick to discourage outsiders from coming there. The channel has low to moderate confinement, stable banks covered in vegetation, occasional sandbars, and a few reaches dominated by boulders. Kiti Engare has a relatively well-developed floodplain covered in bushland and open woodland in the upper reaches, and scattered trees farther downstream. There was little evidence of erosion or incision in most reaches, excluding the main access point, and one of the most downstream study reaches. There were several hand-dug wells both in the floodplain and in the river channel, and one functional hand-pump in the floodplain near the main access point. There was ample evidence of wildlife, including lion, elephant, and buffalo, especially in the downstream reaches.

The Loiborsiret River sustains pools of standing water throughout the year, but only in a limited number of locations. According to local people, the river flows for about 6 hours after rainfall, and floods its banks every 4 or 5 years. It has moderate confinement in the middle reaches, but prevalent sandbars and low to moderate incision along most of its length (except in the upper reaches). The channel material mostly consists of silt/sand near the headwaters, and sand/gravel downstream of a boulder-strewn reach near the village. The floodplain is relatively well developed, but difficult to discern near the village center due to road crossings and many livestock/wildlife paths. The floodplain is dominated by bushland along the upper reaches, and then transitions to *Acacia*, *Ficus*, and *Kigelia africana* riparian woodland farther downstream. There were about eight to ten wells in the floodplain near the village that were approximately three to five meters in diameter, and five to ten meters deep. Water was extracted from several wells using diesel-powered generator pumps[24]. There were also three hand pumps along river, and one concrete barrier in the river channel that was meant to funnel water into a livestock trough; however, the upriver side of the barrier was infilled with sediment. There were signs of elephants, buffalo, and other wildlife.

The Terrat River is similar to the Loiborsiret River in terms of water availability, but slightly less productive, flowing during and shortly after the rains. The channel has moderate confinement, poorly developed sandbars, and moderate incision with steep cut-banks in the upper reaches. The bed material consists of silt/sand near the headwaters, and transitions to sand/gravel farther downstream. The floodplain is poorly developed in the upper reaches, and populated by dense bushland, but is more evident in downstream reaches where there is a more substantial riparian forest. It also had fewer signs of wildlife than the other rivers.

### *4.4.3. Channel Dimensions & Bedload Material*

There were no clear differences in channel geometry (Figure 4.3). The Loiborsiret River had somewhat higher width, depth, and area compared to the other study rivers,

[24]Herders were paying one to two liters of diesel to water 50 to 200 cows.

especially in the upstream reaches, but mean W:D was similar for the four rivers (Kikoti=10.0; Kiti Engare=12.8; Loiborsiret=9.5; Terrat=13.0). The Kikoti River exhibited the most clear downstream trends in channel dimensions, but all rivers exhibited a downstream increase in channel dimensions. The relatively wide scatter of the data inhibits more detailed comparisons.

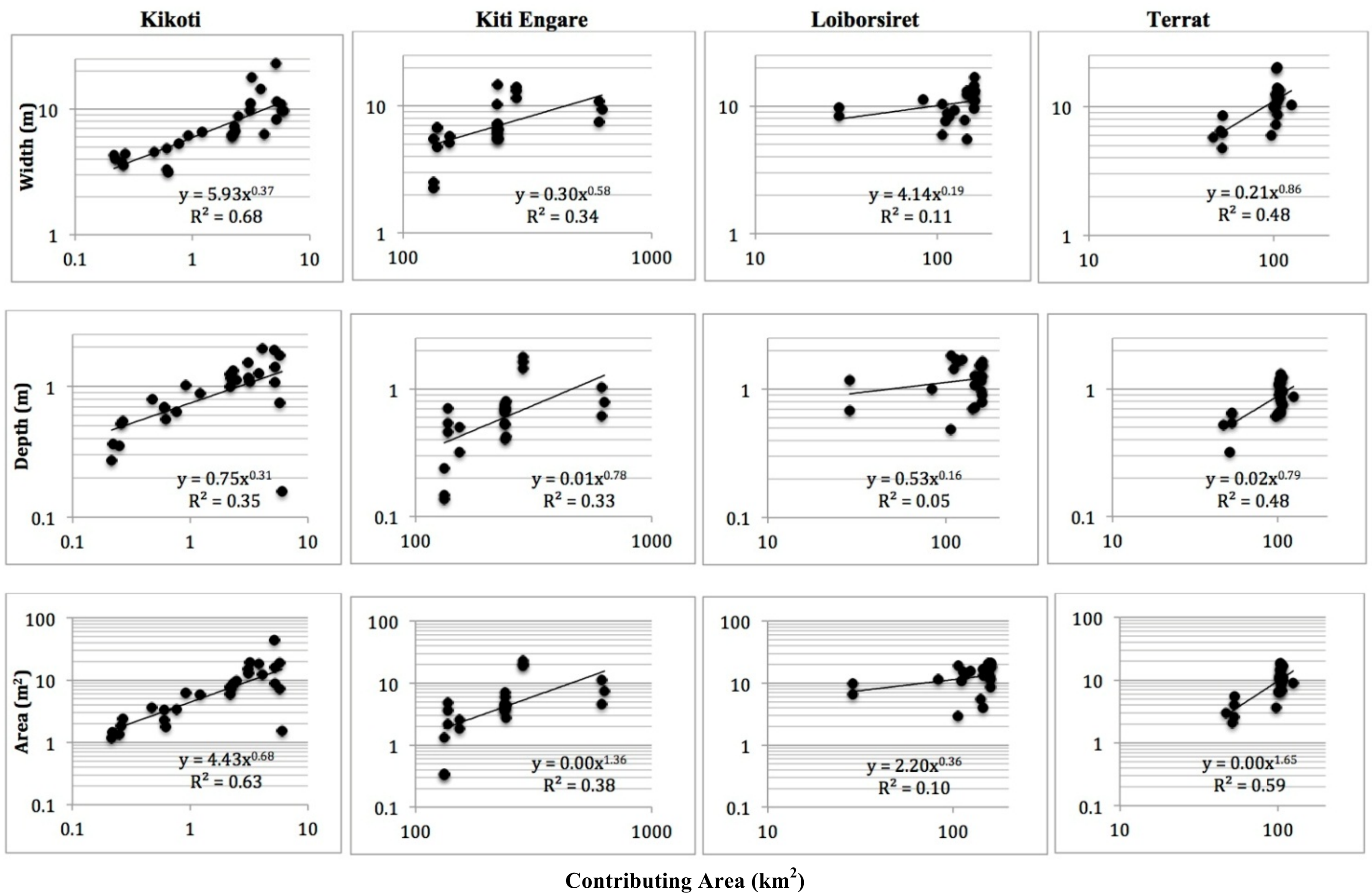


**Figure 4.3.** Downstream trends in channel dimensions for the four study rivers. Note the different x-axis scales for each river

Shields stress was above the critical threshold for bedload movement (0.06) in nearly all cross-sections of all rivers (Figure 4.4). There were no discernable differences in downstream trends in Shields Stress.

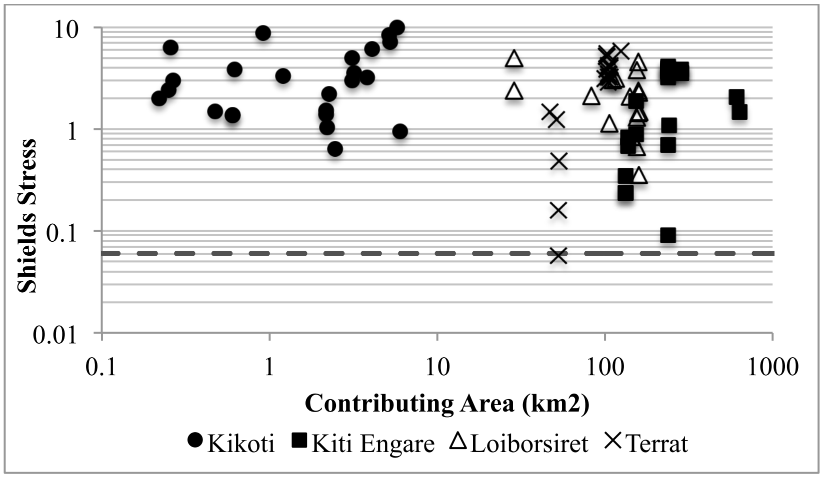


**Figure 4.4.** Non-dimensional shear stress. The dashed line indicates the approximate threshold of sediment mobility (0.06) for particles of median grain size ($D_{50}$)

The Kikoti River exhibited higher values of aggregate $D_{84}$, $D_{50}$, and $D_{16}$ compared to the other study rivers (Figure 4.5). However, only the sampling distributions of $D_{16}$ and $D_{50}$ were significantly different across the four rivers ($p<0.05$, Kruskal-Wallis equality-of-populations test). In particular, the $D_{16}$ sampling distributions from Kikoti were significantly different than each of the other three study rivers ($p<0.05$, two-sample Wilcoxon/Mann-Whitney rank-sum test). The $D_{50}$ samples from Kikoti were also significantly different than those from Kiti Engare and Terrat at the $p<0.05$ level, and significantly different from Loiborsiret at the $p<0.1$ level. Moreover, Kiti Engare, Terrat, and Loiborsiret did not have significantly different sediment samples compared to one another.

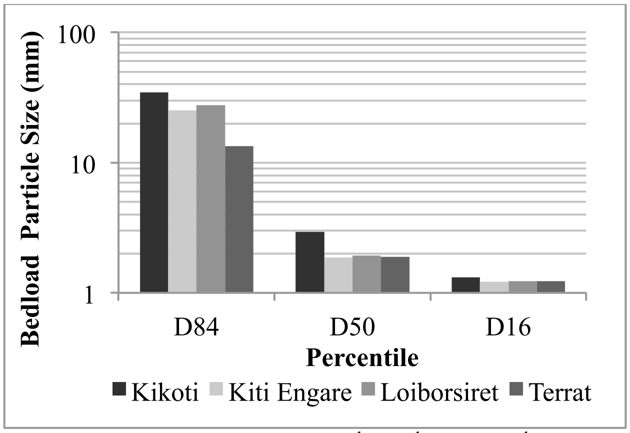


**Figure 4.5.** Bedload particle size associated with 84th, 50th, and 16th percentiles

Rivers had significantly different distributions of sediment across the Wentworth size classes ($p<0.01$, chi-squared test) (Figure 4.6). The proportion of sand and gravel in samples from Kikoti were significantly different than samples from each of the other three study rivers ($p<0.05$, two-sample Wilcoxon/Mann-Whitney rank-sum test). Pairwise comparisons of the other three rivers indicated that their sediment distributions were not significantly different from one another.

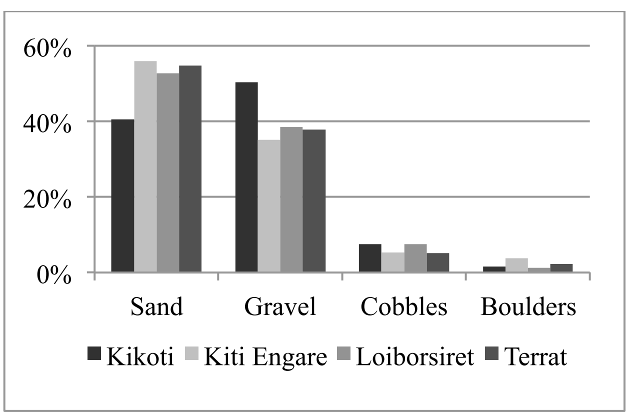


**Figure 4.6.** Proportion of bedload material in each size class

There was a relatively clear pattern of downstream sediment fining in Kikoti, but this pattern was less pronounced for the other rivers. A comparison of the proportion of sediment in the 2-4mm size class suggested that the presence of villages, road-crossings, and cattle access points influence downstream patterns of sediment size, but this relationship was confounded by changes in bed slope (Figure 4.7).

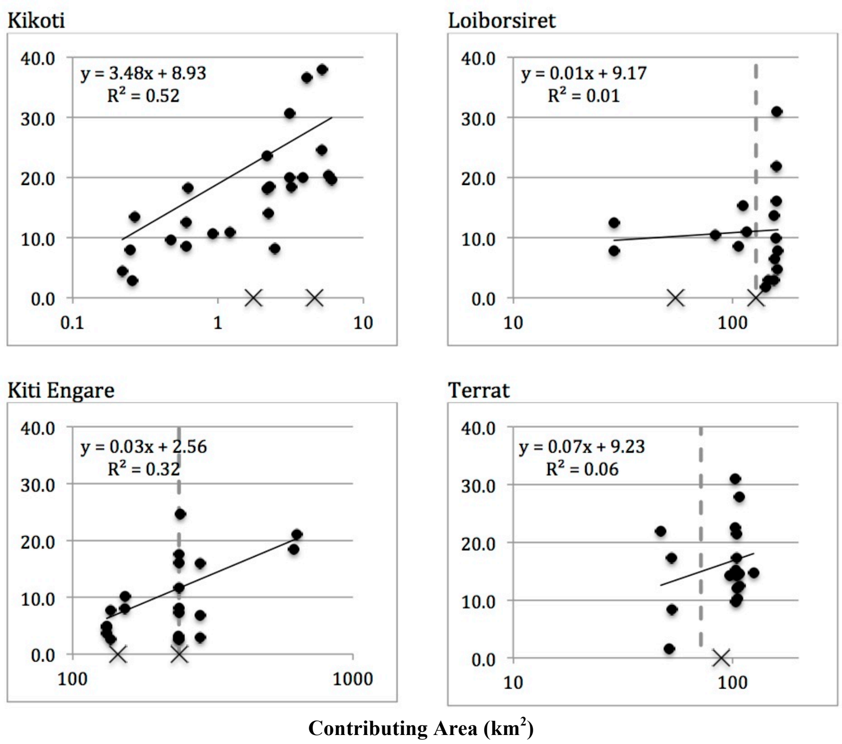


**Figure 4.7.** Proportion of sediment in the 2-4mm size class as a function of drainage area. Dashed lines indicate the location of villages, road crossings, and main access points; X's indicate the location of substantial changes in bed slope

*4.4.4. Sediment Yield*

The watersheds differed markedly in terms of the proportion of land cover in each land use class, and in the mean sediment yield of each class (Table 4.1). Additionally, the weighted mean sediment yield of each catchment was inversely correlated with $D_{84}$ sediment size (Table 4.2).

**Table 4.1.** Area ($km^2$) and estimated sediment yield (S.Y.; $m^3/km^2$) of each land use/land cover type within each river catchment

| | ***Kikoti*** | | ***Kiti Engare*** | | ***Loiborsiret*** | | ***Terrat*** | |
|---|---|---|---|---|---|---|---|---|
| | *Land Cover* | *Mean S.Y.* | *Land Cover* | *Mean S.Y.* | *Land Cover* | *Mean S.Y.* | *Land Cover* | *Mean S.Y.* |
| Rangeland | 93.67% (6.00) | 134.64 | 50.54% (336.38) | 170.03 | 71.4% (121.20) | 182.76 | 56.7% (74.62) | 235.17 |
| Forest | 0.55% (0.04) | 65.99 | 43.54% (289.77) | 177.31 | 26.6% (45.18) | 181.54 | 19.2% (25.25) | 317.46 |
| Cultivated | 0.65% (0.04) | 177.31 | 3.35% (22.28) | 252.38 | 1.6% (2.73) | 193.67 | 7.1% (9.36) | 421.06 |
| Bare | 5.13% (0.33) | 194.81 | 2.50% (16.64) | 255.36 | 0.4% (0.65) | 476.43 | 17.0% (22.32) | 609.97 |
| Water | 0.00% (0.00) | 0.00 | 0.07% (0.45) | 0.00 | 0.00% (0.01) | 0.00 | 0.00% (0.01) | 0.00 |
| Total | 100% (6.41) | | 100% (665.51) | | 100% (169.78) | | 100% (131.57) | |

**Table 4.2.** Correlation between weighted mean sediment yield and sediment size by river

| | *Weighted mean SY ($m^3/km^2$)* | *$log(D_{84})$* | *$log(D_{50})$* | *$log(D_{16})$* |
|---|---|---|---|---|
| Kikoti | 137.62 | 1.54 | 0.47 | 0.12 |
| Kiti Engare | 177.98 | 1.40 | 0.27 | 0.09 |
| Loiborsiret | 183.73 | 1.44 | 0.29 | 0.09 |
| Terrat | 327.75 | 1.13 | 0.27 | 0.09 |
| Pearson correlation | | -0.99** | -0.59 | -0.55 |

**Significant at the p<0.01 level

## *4.5. Discussion*

### *4.5.1. Resource Management Institutions*

Communities in Simanjiro manage rivers through both customary (e.g., clan-based access rules) and government institutions (e.g., environmental committees). Customary institutions facilitate negotiated access to resources, and effectively limit disputes and resolve conflicts. The government institutions managing rivers in Simanjiro have arrangements that allow most individuals to participate in crafting rules; however, the roles of environmental committees were very broadly defined, and they had low capacity for monitoring and enforcement.

Resource-use rules structure property rights (Schlager and Ostrom 1992), and the mixture of government and customary institutions described above structure the rights of residents of the study villages, as well as herders from outside the villages who bring their animals in search of water and fodder. Herders from outside of a village can obtain authorization from government institutions to access rivers and withdraw resources, whereas village residents not only have de jure (legal) rights of use, but they can also participate in resource management through rule-creation and modification.

At the same time, Maasai hold de facto rights to resources within their section's territory, regardless of their village membership. Within these territories, particular river wells are managed by households or groups of households that decide who is included/excluded from resource access and withdrawal. Non-owners can negotiate the right to use a well, but as water becomes scarce, some of people may be excluded from use based on clan or household location; this exclusion may be direct (i.e., explicit denial of access) or indirect (e.g., long waiting times). Clearly, de facto and de jure rights to rivers in Simanjiro overlap. Maasai sections and clans grant certain rights to some users, but villages may grant different rights to a different set of users. This suggests that government and customary institutions are not effectively coordinating their efforts.

Moreover, formal institutions are emerging that are taking on the roles of customary institutions (e.g., livestock committees are regulating herders from outside the village, which was previously the purview of Maasai sections). The effectiveness of these new institutions is limited by the mismatch between administrative and ecological boundaries, and some community members continue to hold more respect for the authority of traditional leaders (e.g., *laigwenak*) than that of elected officials (e.g., subvillage chairs). These findings are consistent with studies from elsewhere in Tanzania and Kenya which have found that the institutions responsible for managing the environment have diversified and are at times at odds with traditional rules (Southgate and Hulme 2000, Sokile et al. 2005).

The nested nature of Maasai customary institutions more closely match resource boundaries, and could provide a useful framework for managing resources across subvillage and village boundaries. The territories of Maasai sections are often closely related to geographical features such as watershed boundaries (Homewood & Rodgers 1991). Moreover, the influence of *laigwenak* crosscuts administrative boundaries, which means they are in a position to coordinate the management of rivers and watersheds that extend beyond subvillage and village boundaries. Kiti Engare's current transition from a sub-village to a village offers an especially valuable opportunity to establish formal governance structures that draw upon the strengths of existing customary institutions.

The institutions managing the four study rivers face unique challenges. Access to Kikoti is regulated based on the time of year and grazing conditions in other parts of the village, it therefore has the greatest congruence between appropriation and provision rules and local conditions. However, monitoring of Kikoti is a substantial challenge because of its remoteness. The size of the Kiti Engare watershed raises concerns about the difficulty of managing land use impacts over a large area that spans multiple villages. In Loiborsiret, there is some coordination between customary and formal resource management institutions, but the influx of a large number of people and livestock into the village during drought years makes monitoring a challenge. Moreover, punishment for violators is being decided on a case-by-case basis rather than through an established set of graduated sanctions. The environmental committee in Terrat has multiple problems associated with its role in monitoring and enforcement. There was no formal process for monitoring the river; sanctions were inconsistent; there was poor coordination with the wider village government; and there was a substantial disconnect between private land use and watershed management.

*4.5.2. Geomorphology & Oral Histories of River Change*

Each of the study rivers faces unique management challenges, but the differences in their resource management policies and practices were fairly subtle in terms of their influence on riparian resource use. The more clear differences were found at broader scales; the four watersheds exhibited substantial differences in land cover change and sediment yield associated with the location of settlements, roadways, and cultivation. So although it is not particularly surprising that the relatively subtle variation in river management was not associated with clear patterns in river morphology, it is interesting that the more substantial variation in land use across the four watersheds also did not yield more dramatic differences in channel geometry.

There was little evidence of channel incision or different downstream trends in channel geometry. The W:D of the study rivers (9.5 to 13) were in the lower ranges identified by several previous studies of dryland rivers (3.8 to 255, Schumm 1961, 16 to 340, Shaw and Cooper 2008). Low W:D is typical for lower order streams and smaller drainages (Shaw and Cooper 2008), but given that grazing has been associated with channel widening in other systems (Platts 1991), it is surprising that all of the study channels exhibited low W:D despite widespread grazing and variation in grazing intensity.

I suspect that the absence of a clear relationship between land use change and channel dimensions is related to the long history of grazing by wild and domestic ungulates. Rivers in East African rangelands may have adjusted to the long-term presence of large mammals, and their associated effects on water and sediment discharge, making channels less sensitive to recent changes in land use. This resistance to land use changes would make it especially difficult to detect differences in river channel morphology across watersheds with relatively minor differences in resource management.

At this point in the system's trajectory, differences in bedload material appear to be more useful for detecting the influence of land use changes on rivers in Simanjiro. The sampling distributions of $D_{50}$ and $D_{16}$ were significantly different for the four rivers, and there was a significantly lower proportion of sand and a higher proportion of gravel in Kikoti River. These differences in sediment size may be indicative of the rivers' potential for more substantial shifts in geomorphology.

Trends in the water and sediment transport capacity of the study rivers can be explored by integrating data on channel dimensions, sediment size, and sediment yield. In particular, these data can be combined using the relationship

$$S_2/S_1 = (q_1/q_2)\,(q_{s2}/q_{s1})^{1/2}\,(D_2/D_1)^{3/4}$$

where $S$ is bed slope, $q$ is water discharge, $q_s$ is sediment discharge, and $D$ is sediment size at times, or in this case, locations 1 and 2 (Clark and Wilcock 2000). A value of <1 indicates degradation (i.e., lowering of bed slope due to channel scour associated with increased water discharge, decreased sediment supply, and/or decreased sediment size), and >1 indicates aggradation (i.e., increased bed slope due to sediment deposition associated with decreased water discharge, increased sediment supply, and/or increased sediment size).

I present this relationship as a plot of $D_2/D_1$ versus $q_{s2}/q_{s1}$ with constant $q_2/q_1$[25] (Figure 4.8). I use Kikoti as the reference site (i.e., location 1) for each of the other three study rivers and a hypothetical scenario (i.e., location 2). This space-for-time substitution approach has limitations (Pickett 1989), but in the absence of historical data it is the best available means of assessing river responses to land use changes in the study area. Moreover, this is a general relationship that is intended to make broad comparisons of sediment supply and transport across river catchments.

Kiti Engare, Loiborsiret, and Terrat had higher sediment supply ($q_{s2}/q_{s1} > 1$) and lower sediment size ($D_2/D_1 < 1$) relative to Kikoti. This combination of changes could allow the transport capacity of the rivers to remain relatively stable, and yield little evidence of aggradation or degradation across the study rivers ($S_2 = S_1$; “Kiti Engare”, “Loiborsiret”, and “Terrat” data points in Figure 4.8). However, if sediment supply increases further without dramatic changes in sediment size or water discharge (which both seem improbable), the channel likely will aggrade ($S_2 > S_1$; “Scenario” in Figure 4.8). Slope could also increase through a decrease in sinuosity, which is possible in rivers with relatively weak channel margins (Clark and Wilcock 2000).

[25] This is distinct from Clark and Wilcock’s (2000) plot of $q_{s2}/q_{s1}$ versus $q_2/q_1$ with constant $D_2/D_1$. I deviated from their example because I collected data on sediment size, but did not have data on water discharge.

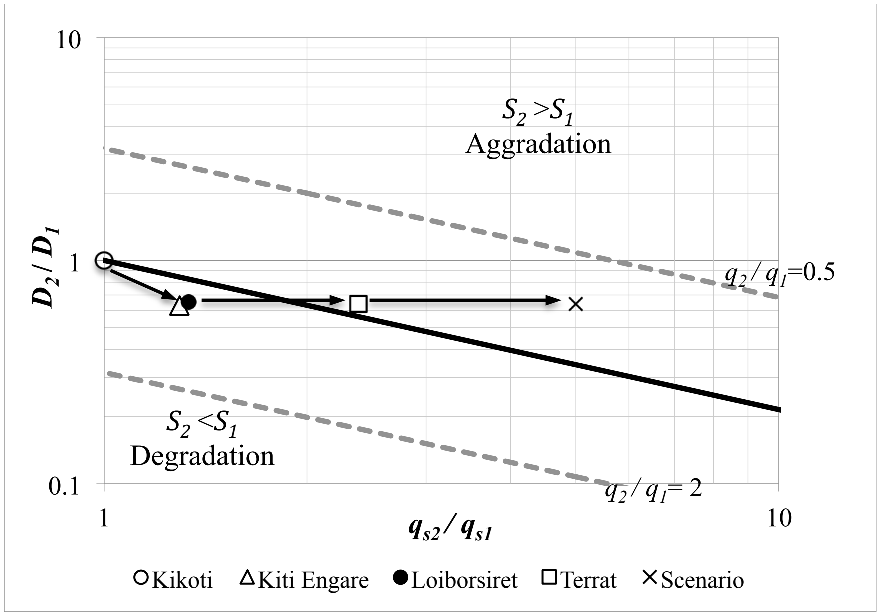


**Figure 4.8.** Plot of sediment size and sediment discharge of Kiti Engare, Loiborsiret, Terrat, and a hypothetical scenario relative to Kikoti River. The solid line represents no difference in water discharge between locations 1 and 2. Dashed lines indicate differences in water discharge by a factor of 2. Points above or to the right of the line would steepen through upstream deposition and points below or to the left would degrade through channel scour. The arrows indicate a hypothetical trajectory of change from one state to another.

Oral histories from key informants and other residents of the study villages support this evidence for decreased sediment size and increased sediment supply, and are informative for reconstructing changes in land use and hydrology. The Terrat River has reportedly undergone a decrease in sediment size and a substantial decline in water discharge. In the past, the river was flowing throughout the year and now it only flows following heavy rainfall. Even during particularly dry years such as 1967 ("the year of the sun"), water could still be found on the surface of the river. Now people need to dig wells or move farther downstream in order to find enough water. The following paraphrased statement[26] from one community leader describes these changes:

[26] These are not direct quotes, but rather, paraphrased statements. I was not able to tape-record interviews, so interviews were translated and transcribed as accurately as possible at the time of the interview.

*"There has been a big change in the Terrat River. When I was young it was flowing all year round, up to the road crossing. Now we have to go downstream, and there's not as much water. Even during droughts it was like the Loiborsiret River. There has been environmental destruction – cutting trees close to the river, cutting too many trees, not taking good care of the river – and the weather has changed. There is less rainfall. In the past people had to take livestock to certain places, now people come in wherever they want and walk in rivers. People aren't cultivating right around the Terrat River, but we depend on korongos to bring in water from other areas, and there is lots of cultivation in areas around these branches. The river is fed by three korongos that you can dig wells in... The river used to have sand in the branches, and now it's just mud; when it rains it brings mud… It's unusual to have mud; we expect to see sand, based on how it used to be. The branches are bringing sediment from farms. It's a problem along the whole river. There are also more people and more animals."*

Declines in water availability were also reported for several other small drainages (e.g., Nyorit, Lorosorutia & Sinya) and for the Loiborsiret River. According to one elder, there was a period of time when elders were young (specifically, when the Seuri ageset became warriors) that the Loiborsiret River "started" flowing:

*"When Seuri were young it wasn't flowing and people were just digging wells. Then water started seeping out and we didn't stop getting water. There were good and bad years, but never stopped again like in the past. It started flowing when Seuri became warriors and water spread along the river. Even Kiti Engare started flowing even though it was usually flowing only when it would rain. The Laibon[27] did that to help people. The original spring was near the village center, then water spread along the river; in bad years the area of the river having water reduces from downstream to where the original spring was. In 2009 there was a big demand for water and stated using wells like in the past. It's still a big problem; people are settling, there is increased population, and there is not enough water for people."*

Perceived reductions in the amount of surface water may be related to relative declines in rainfall as well as changes in land use. The increased flow when Seuri were young and the subsequent declines in rainfall are consistent with a period of unusually high rainfall in the late 1950s and early 1960s (Figure 1.5 in chapter 1; Miller et al. 2008). However, changes in climate were not always viewed as the sole source of

[27] *Laibon* are spiritual leaders and ritual experts (Homewood & Rodgers 1991)

declines in water availability. Respondents often mentioned an increased number of people and livestock and land use changes as factors influencing the amount of water and sediment in rivers. For instance, people in Terrat pointed specifically to settlement and livestock watering sites near the village center; in the words of one man, "it now it looks like a livestock kraal." Similarly, a group in Loiborsoit said that in the past there were large trees covered in moss that collected water, but people cut these trees and, as a result, rain was no longer collected and the sun dried out the ground. Following deforestation, more people started settling nearer to rivers. Some respondents also noted that increases in the amount of cultivated land had reduced the amount of water in some rivers. Although the cultivation of small plots (especially in old *enkang* sites) has been a common practice for many years, the government's villagization program and the associated increase in land ownership were viewed as factors driving recent increases in cultivated land area.

These changes in water availability and sediment size may both be the result of changes in water discharge similar to those observed in urbanizing systems. Urbanization can lead to "…increased volumes of runoff, decreased lag time between precipitation and runoff, and increased flashiness of flow (or increased kurtosis) of the runoff hydrograph." (Graf 1988: 286) Road building, cultivation, and settlement may have affected the study rivers in a similar fashion; land use changes could have led to more flashy flows (i.e., more contracted hydrograph with a higher peak discharge) that were capable of transporting larger sediment downstream while smaller sediment continued to be produced by fine-grained parent material (sandy clay loam in the grasslands and clay in depressions; Kahurananga 1981). This explanation is not only consistent with the inverse relationship between sediment size and land use change in my study catchments, but also matches reports of decreased water availability. If water is now passing through the system more quickly than in the past (even given the same total amount of rainfall), it would appear as though rivers no longer flow for as much of the year as they used to.

A major challenge in managing the study rivers, and rivers in general, is the definition of resource units. Rivers are not only affected by resource use within the river channel, or even in the riparian zone, but instead are affected (via changes in water and sediment supply) by activities that take place throughout their catchments. Of the four rivers, Kikoti was the most clearly defined resource area because of its small size and geographic isolation from permanent settlements, whereas the watersheds of the other study rivers spanned multiple villages and encompassed areas of permanent settlement. The institutions that are responsible for managing these rivers must coordinate their efforts with broader land use plans if they are to be successful at preventing substantial changes in river geomorphology.

### *4.5.3. Limitations*

These findings should be interpreted in light of several limitations. First, the analyses of river channel geomorphology may have been complicated by different sampling extents. The short length of the Kikoti River allowed me to sample nearly the entire length of the channel, but I could only sample the upstream reaches of the other rivers. The selection of sampling sites was restricted by terrain, road access, dense vegetation, and the presence of potentially dangerous wild animals. Second, the surprising similarity of the Kikoti River's channel characteristics to those of the other rivers despite its very small catchment area suggests that Kikoti may be unique in other respects that I did not control for (e.g., underlying geology, groundwater hydrology). Third, lag times may hinder the ability to detect the effects of recent land use changes on river geomorphology, especially in semi-arid environments were ephemeral channels only flow for brief periods of time each year. Finally, the Wentworth scale that I used for sampling sediment size distributions did not sufficiently capture variation in the finer sediments and did not allow me to compare the proportion of silts, clays, and sand.

### *4.6. Conclusion*

Despite extensive grazing and more recent land use changes, rivers in Simanjiro have not responded as expected based on studies of other rivers. The long history of grazing by domestic and wild ungulates may have influenced water and sediment supplies such that river channel dimensions are actually more resistant to changes in land use (i.e., settlement, road building, and agriculture) than in other systems. This would suggest that not all rivers will have the anticipated responses to contemporary land use changes due to historical land use patterns, and it is possible that, over long time scales, the presence of grazers may actually increase the ability of rivers to withstand changes in land use.

However, the lack of evidence for a dramatic effect of contemporary land use change on river channel geomorphology in Simanjiro does not guarantee that these rivers will be resistant to further anthropogenic environmental effects. To date, reductions in sediment size may have counteracted the influence of increased sediment supply on bed aggradation/degradation, but continued increases in sediment supply in catchments like the Terrat River watershed are likely to lead to more pronounced changes in bed slope. Dryland rivers and ephemeral streams are dynamic, and there is a need for further study of shifts between different system states (Graf 1988, Bull 1997). My findings show that this is especially true in regions with a long history of grazing, and a relatively recent increase in non-irrigated agriculture.

Maintaining the productivity of the four study rivers requires particular attention to different aspects of their management. Maintaining the Kikoti River as a drought reserve is crucial, and its remoteness from the village center necessitates increased capacity for monitoring. The Kiti Engare watershed spans multiple villages, and will require broad coordination of land use planning, which could be facilitated by traditional leaders. Since Kiti Engare is splitting from Sukuro and becoming an independent village, it presents an opportunity to better integrate land use planning with river management. A large number of people and livestock converge on the Loiborsiret River during droughts, which necessitates a system for monitoring changes in resource availability during these periods, coupled with a consistent set of sanctions for rule violators. The efforts of Terrat's environmental committee are hampered by a lack of cooperation from other government organizations, and land use changes occurring on private land and beyond the village boundaries. The role and authority of the environmental committee in Terrat should be more clearly defined and coordinated with land use planning in Terrat and neighboring villages.

A common challenge in managing these rivers, and rivers in general, is the mismatch between the boundaries of watersheds and those of administrative units (e.g., villages). This mismatch necessitates collaborative approaches to land management.

National laws and local rules regarding buffer zones around rivers are important, but not sufficient for managing water and sediment discharge. There is a need for discussions within and between villages about the collective influence of individual land use decisions on river systems, especially in light of the widely held view in the study area that people may do what they wish on private land. Formal institutions also require better resources and more clear protocols for monitoring, enforcement, and coordination across multiple committees.

As village committees take on increasingly larger and more diverse roles in resource management, it is important that they coordinate their efforts with customary institutions, which are widely respected and provide a consistent set of rules across administrative boundaries. However, the resource management practices of other ethnic groups and the needs of multiple stakeholders in the region will have to be balanced. Organizations such as the Ujamaa Community Resource Trust, and Tanzania Natural Resource Forum are in a good position to facilitate the coordination of customary and government rangeland management institutions.

**CHAPTER 5**

# SYNTHESIS AND CONCLUSION

## *5.1. Introduction*

*"You can move livestock to where the rain is, but you can't move farms."*
– Resident of Loiborsoit

The establishment of conservation areas is a widespread strategy for protecting the environment from human activities. It is clear that conservation areas, such as national parks, also have a variety of consequences for human communities (e.g., resettlement, resource dislocation, jobs, income), but the ways in which these social effects of conservation then translate into environmental impacts are less-well studied (Miller et al. 2012). More fully understanding these social dynamics is essential for improving conservation outcomes and resolving conflict with human communities. Through this dissertation, I have illustrated one approach to studying these conservation-community feedbacks.

I focused on drought resources in East Africa, which are of particular importance in a region that is dominated by arid and semi-arid rangelands and occupied by large numbers of people who rely directly upon natural resources for their livelihoods (i.e., subsistence farmers and herders). Reports of conservation areas limiting the access of Maasai pastoralists to drought resources led me to ask: <u>how does the management of drought resources interact with Maasai livelihoods?</u> I used the sustainable livelihoods framework (Scoones 1998) as a guide for parsing this overarching question into three more specific sub-questions:

1) What is the spatial distribution of drought resrouce areas (DRAs) in relation to conservation areas and agriculture development?

2) How have changes in access to DRAs influenced pastoralist livelihood decisions?

3) In the face of these livelihood decisions, how do Maasai communities manage available water resources, and what are the consequences for river systems?

I then drew upon theory and methods from landscape, human, and political ecology to design and implement three studies aimed at addressing these sub-questions. The previous chapters detail how I identified patterns of resource access at multiple scales (Chapter 2), assessed the effects of changes in resource access on household livelihood decisions (Chapter 3), and evaluated the relationships between livelihoods and the environment (Chapter 4). In this final chapter, I synthesize and interpreting my findings in terms of conservation-community feedbacks, and how these relate to the broader social-ecological resilience of the study system.

## *5.2. Findings & Relevance to the Literature*

### *5.2.1. Three Ecologies*

My use of analytical approaches from landscape, political, and human ecology in combination has yielded a more comprehensive picture of resource use than I could have obtained by using any one alone. Landscape ecology directed attention to the spatial and temporal variation in drought resources, political ecology underscored the role of conservation and political context on resource availability, and human ecology shed light on household resource-use decisions and their environmental consequences. Each of the previous chapters not only used theory and methods from these three ecologies, but my findings also contribute to these bodies of literature in distinct ways.

In Chapter 2 (*The Distribution of Drought Resource Areas in East Africa and Implications for Pastoralist Livelihoods*), I found that access to DRAs in East Africa has changed in recent decades due to both environmental conservation efforts and land use changes, and these phenomena have had different amounts of influence on DRA accessibility at different scales. This multi-scale approach yielded a broader picture of resource access than previous studies of individual conservation initiatives, which have dominated the literature on the social effects of conservation areas in East Africa (Ngorongoro Conservation Area - Homewood and Rodgers 1991, e.g., Mkomazi Game Reserve - Brockington and Homewood 2001, Tarangire NP - Igoe 2002, Amboseli NP - Western and Manzolillo-Nightingale 2004). These specific case studies provide rich detail, and my multi-scale geospatial analysis serves to complement this body of literature rather than dispute it, illustrating larger-scale patterns and dynamics that indicate the representativeness of the social effects of any one conservation initiative. This is similar to Moran & Brondizio's (1998) support for combining remote sensing and ethnographic methods for analyzing land use change.

In order to gain a more detailed picture of the social effects of conservation in my study area, I analyzed the influence of Tarangire National Park (TNP) on four Maasai communities in Simanjiro (Chapter 3, *Coping with Natural Hazards in a Conservation*

*Context: Resource-Use Decisions of Maasai Households During Recent and Historical Droughts*). Interview and survey data regarding livestock herding practices during recent and historical droughts suggest that the social effects of the establishment of TNP were less dramatic than previously thought. This discrepancy is likely due to changing perceptions of resource availability and the complexity of resource-use decisions, which are affected by household factors (e.g., social capital, labor, herd size) and contextual factors (e.g., disease, conflict, cost, waiting times, grazing), rather than just the size or reliability of a given resource area. These findings are consistent with resource-use patterns of other pastoralist groups (McCabe 2004), and also highlight two main benefits of decision-making analysis.

First, decision-making analysis provided a structured way to identify the factors affecting household livelihood decisions, thereby avoiding the pitfall, identified by Vayda and Walters (1999), of assuming that political influences (such as national conservation programs) are always important. Second, it demonstrated that although the physical and social characteristics of a given community influence resource-use decisions, it is informative to consider how these community-level characteristics translate into specific opportunities, constraints, and perceptions at the household-level. The approach that I used in Chapter 3 allowed me to account for the diversity of community and household characteristics by identifying factors that were necessary and those that were sufficient to produce a given outcome, rather than averaging the cases in order to identify the most "influential" variables (as in regression analysis). In other words, although communities are useful analytical units for describing the broader social effects of conservation initiatives, it is the interplay of community and household characteristics that affect how individuals actually respond to changes in resource access and thereby affect the environment.

In Chapter 4 (*Rangeland Management and Fluvial Geomorphology in Simanjiro*) I described how differences in land use across four different river catchments did not yield the expected environmental effects. I believe that this finding was due to the historical effects of wild and domestic ungulates, which have influenced water and sediment supplies over sufficient time periods to increaes the resistance of rivers in the study area to recent land use changes. Studies of fluvial geomorphology should account for such historical effects on the characteristics and responses of rangeland river systems.

### *5.2.2. Conservation-Community Feedbacks*

What do these chapters tell us about feedbacks between conservation initiatives and human communities? Conservation and development are affecting the DRA availability at broad scales. In Simanjiro, the direct effects of conservation on resource access are less pronounced, and Maasai households have continued to use small drainages and even found new locations (e.g., Kikoti) for acquiring resources during droughts. At the same time, pastoralist livelihoods have been changing through the adoption of agriculture. These land use changes have not yet had dramatic impacts on river systems in Simanjiro, but I anticipate that continued alterations in water and sediment supply will be problematic for some waterways such as the Terrat River. Overall, these results do not paint a clear picture of a feedback pathway between the establishment of TNP, changes in resource use, and changes in river systems. This is not surprising, considering that I did not measure the full range of social and environmental variables that could have been affected by the establishment of TNP, and other concurrent phenomena could have confounded the effects of TNP.

Although somewhat beyond the scope of the research presented here, I can propose a more clear feedback pathway that appears to be operating in Simanjiro related to the perceived risk of TNP expansion, cultivation, and wildlife migration. Many residents living near TNP are concerned that its borders might one day be expanded to encompass village lands. Some households have responded to this perceived risk of losing their land to TNP by cultivating, thereby making a visible claim on land for which they could potentially receive compensation if the park were to expand (Baird et al. 2009). At the same time, cultivation is affecting wildlife migration routes between Simanjiro and TNP (Msoffe et al. 2011a, Msoffe et al. 2011b). This land use change has raised concerns among conservationists, whose appeals to either expand the park or impose land use restrictions on communities in Simanjiro could heighten the perceived risk of local communities losing land to an expanded TNP.

Whether or not this feedback is actually operating in Simanjiro is an open question, but in this and most other conceivable scenarios, livelihoods occupy a central role in the feedbacks between conservation initiatives and social-ecological systems. My work indicates that decision-making analysis is a particularly powerful tool for identifying the most relevant factors influencing people's livelihood choices. Identifying these factors and describing their relationship to household and environmental outcomes is a necessary step toward modeling system resilience more broadly.

*5.2.3. Social-Ecological Resilience*

The identification of relevant system components, relationships, elements of continuity, and sources of innovation has proven insightful for obtaining a general picture of the resilience of other rangeland systems (Robinson and Berkes 2010). In the process of answering the above study question I have generated information on a number of study system components (i.e., drought resources, management institutions), relationships (e.g., resource use rules and enforcement, livelihood choices), elements of continuity (e.g., reliance on livestock and ecosystem services), and sources of innovation (e.g., changes in herding practices, the adoption of agriculture).

Although many Maasai households in Simanjiro are participating in multiple livelihoods, many also continue to rely on transhumant herding practices. During droughts, when there are shortfalls in grazing or water availability near settlements, many households use traditional coping mechanisms of leaving some stock at boma and moving most others to more distant pastures. In fact, some have become more mobile during recent droughts; for example, some survey respondents who watered livestock at local rivers during historical droughts moved their animals to more distant sources such as Kikoti River or Kimotorok Swamp in 2009. These areas in Simanjiro also serve as drought resource areas for herders from throughout the region, and as far away as southern Kenya. During the 2009 drought, village leaders estimated that Loiborsoit received 65,000 livestock from outside of the village, and Loiborsiret received 33,000. These herding practices demonstrate the importance of Simanjiro's drought resources, as well as Simanjiro's institutional and environmental resilience to large fluctuations in user membership and resource demand that occur during droughts.

Traditional systems of mobility and herd division have proven useful for households to cope with changes in resource access and land use; however, many households are in a tenuous position between limited grazing resources near their settlement and inaccessible grazing reserves in distant locations. Landscape fragmentation and resource dislocation from large-scale cultivation and private conservation easements threaten to limit livestock mobility and access to more distant resource areas (refer to the following section for details). Since many households already appear to be suffering from insufficient livestock production (Chapter 3), the loss of access to widely used DRAs such as Kikoti River could shift the system into an alternate state of poverty and dependence. A similar transition is occurring in northern Kenya, where a large number of households have become less mobile, settled near permanent water sources, degraded pastures, and thus made it more difficult to support themselves through livestock-based livelihoods (Robinson and Berkes 2010).

In terms of the eco-hydrologic system, evidence suggests that the long history of grazing by domestic and wild ungulates has influenced water and sediment supplies such that river channels have been resistant to recent changes in land use (i.e., settlement, road building, and agriculture). In other systems, these kinds of land use changes have caused rivers to transition to a state dominated by feedbacks wherein reduced vegetation cover leads to more erosive stream flows that cause channel entrenchment, which weaken riparian vegetation, inhibit regrowth, and further increase runoff speeds (Bull 1997). The study rivers appear to be in a state in which flood regimes continue to sustain riparian vegetation and maintain channel form. Yet the lack of evidence for a dramatic effect of land use change on river channel geomorphology does not guarantee that these rivers will be resilient to further changes in land use and will not transition to an entrenched state.

Shifts between river system states can be nonlinear, wherein erosional or depositional processes have few obvious effects on river form until a threshold is reached at which there is a rapid shift in channel morphology (e.g., gullying, decreased sinuosity) (Schumm 1973, 1979). The existence of nonlinearities in river systems "…implies that changes in state may be abrupt and difficult to reverse, particularly when hydrology and geomorphology are involved… managers should always consider the potential from transitions between multiple states, as systems that appear to be changing slowly may nonetheless be on a trajectory to a sudden shift. The most problematic threshold responses are those that result in irreversible negative changes. Management efforts should focus on prevention of such events." (Dent et al. 2002: 642-643) For instance, it is relatively easy to maintain an unentrenched state through soil and vegetation conservation measures, compared to the difficult task of restoring entrenched rivers (Dent et al. 2002).

More broadly, finding ways to empirically measure the resilience of social-ecological systems is a major challenge. Doing so requires the measurement of thresholds, which can only be detected by crossing them – a relatively rare and unexpected occurrence, and a potentially unpredictable, extreme, and irreversible form of experimentation on large, complex systems (Carpenter et al. 2005). Computer-based simulations such as agent-based models are a promising means of exploring thresholds and system states while still accounting for finer scale variation in the characteristics of households or individuals.

Agent-based models (ABMs) have been promoted as tools for studying properties of complex-adaptive systems such as feedbacks and emergence [see the special issue in PNAS (Berry et al. 2002)], and recent studies suggest that they are also useful for assessing resilience (e.g., Schluter and Pahl-Wostl 2007, Schluter et al. 2009, Schouten et al. 2013). ABMs can include sufficient detail regarding resource-use decision making, but also reflect uncertainty particular variables or processes (e.g., climate and population projections). Moreover, they can be used for participatory research; scenario building in conjunction with a variety of stakeholders can identify plausible future states and key social and biophysical metrics (Cumming et al. 2005, Erlien et al. 2006), which can be used to parameterize the ABM. The final model can then be applied to the exploration of policy and management scenarios and the identification of system thresholds.

Like all social-ecological systems, Simanjiro's resilience is affected by a large set dynamics (e.g., immigration/emigration, wildlife migrations), livelihood options (e.g., wage labor, agriculture), and power relations (e.g., property rights, costs and benefits associated with conservation) (Leslie and McCabe 2013). Measuring all of these facets of system resilience requires long-term coordinated efforts from numerous scholars. The Savanna Land Use Project (being led by advisor Leslie and colleagues) is undertaking this effort, and my dissertation contributes to the growing body of research from this multi-institutional collaborative project. The following section outlines several opportunities for additional research.

### *5.3. Opportunities for Further Research*

Cultivation in Simanjiro has implications for wildlife migration routes, resource access, and land tenure, and there is a need for additional study of the drivers and spatial structure of agricultural land use change. The relative influence of household and commercial agriculture on land cover change is still unclear. Additionally, community members in several subvillages have expressed concerns that the expansion of cultivated areas is restricting cattle paths and reducing grazing areas. More detailed information on landscape fragmentation – including the identification of key pathways for livestock and wildlife, and opportunities for increasing landscape connectivity – would be useful for inter-village land use planning. In particular, this information could be given to governmental and traditional leaders from across Simanjiro who have begun convening meetings to try and coordinate land use plans.

Women's roles in Maasai society have oftentimes been ignored or marginalized by development initiatives (Hodgson 2001), but should be an integral part of land use planning and making decisions about future water developments. Women play a key role in making decisions about acquiring water for the household, and therefore play a large role in human health and sanitation. The factors influencing women's decisions about water acquisition are likely to be distinct from the factors affecting men's livestock watering decisions, and as a result, changes in resource availability are likely to have differential implications for men and women. I collected interview and survey data on women's water-gathering decisions, and plan to analyze these data in the future.

There are also a number of opportunities for further study of dryland rivers in the region. Several rivers in Simanjiro flow through or near village centers, and as these communities develop their water infrastructure it is worth carefully considering the effects that boreholes will have on water tables and river baseflow. There are multiple boreholes in Terrat, and some are located in the river channel and in the riparian zone. Some community members expressed concern that boreholes in the immediate area of the river are negatively affecting water availability. In the western U.S., groundwater extraction has affected streamflow and water tables, and as a result, negatively affected riparian vegetation (Patten 1998). There is a pressing need for information on the effects of boreholes on river baseflow, water tables, and riparian vegetation in villages such as Terrat.

It would also be useful to conduct analyses of river channel morphology, similar to the ones I have presented here, in other catchments in the region that have undergone more dramatic changes in land use. These studies would be useful for describing possible system futures, and to understand more about the susceptibility of rangeland rivers to land use changes.

### *5.4. Practical Relevance & Closing Thoughts*

Finding ways to enhance the resilience of rangelands to drought is particularly relevant in the context of climate change, which is expected to alter the distribution of natural resources both within and beyond protected areas, and to increase the severity and frequency of natural disasters in many parts of the world. The extent and severity of drought in East Africa in 2009, and in the U.S. in 2012 underscored concerns about the effects of climate change on the environment and economy. Such droughts have wide-ranging impacts on society and direct consequences for the livelihoods of local land users, whose ability to cope with disasters can be heavily dependent upon their access to natural resources.

In Simanjiro, resource availability is being affected by conservation initiatives, infrastructure development, land use changes, and demographic processes. Despite changes in resource access, many Maasai households have proven resilient to recurring droughts. Small rivers and ephemeral streams continue to serve as critical resource areas during periods of low-rainfall. Maintaining the productivity and accessibility of these sites is central to the viability of livestock-based livelihoods in the study area. Several changes in resource management, land tenure, and infrastructure development could contribute to this effort and foster the resilience of Simanjiro to future droughts.

First, it is essential that resource management institutions account for resource variability and accommodate mobility through landscape connectivity, flexibility in user membership, and resource monitoring. Arid and semi-arid rangelands exhibit substantial spatial and temporal variation in primary production, and even the most productive parts of the landscape can vary from drought to drought. This variability underscores the need for large areas of connected land in order to ensure that livestock and wildlife will have continued access to productive DRAs, especially as climate changes. Maintaining resource access will require cooperative land use planning across communities, and better communication between customary and governmental management institutions. Customary institutions are well placed to facilitate intervillage planning because they are widely respected and operate at multiple scales, often crosscutting administrative boundaries. These institutions are also adept at allowing for flexibility in user membership, which is essential for mobile populations who utilize spatially and temporally variable resources; attempting to specify and set user groups or resources may be less effective than strengthening the rules for negotiating resource access (Turner 1999). It is important that the land use plans themselves also remain flexible and be developed in conjunction with more comprehensive monitoring efforts, especially because it is yet unclear when and how rivers in Simanjiro might respond to additional changes in land use.

Second, providing residents with more secure land tenure and governmental recognition of group property rights would reduce perceived risks associated with living near TNP, and may slow land use changes. More secure land tenure could stem some of the precautionary cultivation described by Baird et al. (2009) and strengthen the ability of communities to retain rights to communal grazing areas, which can be vulnerable to land grabbing by private safari companies and commercial agriculture operations. At the same time, supporting good farming practices and increasing education and employment opportunities would serve to increase productivity of the land in cultivation and provide alternative streams of income (Cooke 2007).

Third, there is a need for improved infrastructure development in the form of better access to livestock markets, veterinary care, and clean water. Improved access to livestock markets and veterinary care appear to be essential elements for maintaining the viability of pastoralism (Fratkin 1997). Traditionally, large herds buffer households from fluctuations in livestock populations associated with droughts and disease epidemics, but evidence suggests that livestock populations are not keeping pace with human population increases. Improving the condition of herds would dampen the effects of drought and livestock disease on human well-being, and improved market access allow households to strategically convert livestock to other forms of capital (Robinson and Berkes 2010). Finally, the vast majority of households in Simanjiro do not have reliable and easy access to clean water. Yet residents recognize that water development is a double-edged sword; it is a first step in establishing other facilities (schools, village offices, etc.), but it also attracts more people and encourages settlement in locations that might be important grazing areas. Water development projects should be carefully placed relative to rivers and key grazing areas, and accompanied by land use plans that account for these secondary effects.

Ultimately, developing long-terms solutions to the conflicts between conservation and development requires finding common ground between stakeholders. This is especially true in places like Simanjiro, which is both an important wildlife dispersal area and home to thousands of people. Rivers offer a starting point for establishing this common ground. Maintaining the productivity of dryland rivers is in the interests of both parties; rivers support wildlife populations and distinct vegetation communities, and also provide ecosystem services for human communities. I am optimistic about the prospect of establishing access rights and management strategies that maintain ecosystem function and resource availability, especially because livestock herders are gradually gaining recognition as valuable conservation partners (Curtin 2002a, Western 2002, Sayre 2005). It is my hope that the research presented here will contribute to the endeavor to connect conservation goals and outcomes through socially responsible and environmentally effective resource management strategies.

**APPENDIX I.** Thematic Land Cover Classification Error Analysis Results

1) ***Unsupervised IsoData Classification*** [1-10 classes, 5% change threshold, maximum class standard deviation = 1.0]
   a) ***Watershed (2010)***
      Overall Accuracy = (30756/48880) 62.92%
      Kappa Coefficient[28] = 0.4636

2) ***Maximum Likelihood Classification***
   a) ***Watershed (2010)***
      OverallAccuracy = (24475/27661) 88.48%
      Kappa Coefficient = 0.615

Confusion matrix (pixels)

| | *Rangeland* | *Forest* | *Agriculture* | *Bare* | *Water* | *Total* |
|---|---|---|---|---|---|---|
| *Rangeland* | 21457 | 55 | 264 | 0 | 0 | 21776 |
| *Forest* | 263 | 1062 | 0 | 0 | 1 | 1326 |
| *Agriculture* | 2558 | 0 | 950 | 0 | 0 | 3508 |
| *Bare* | 44 | 1 | 0 | 95 | 0 | 140 |
| *Water* | 0 | 0 | 0 | 0 | 911 | 911 |
| *Total* | 24322 | 1118 | 1214 | 95 | 912 | 27661 |

Confusion matrix (percent)

| | *Rangeland* | *Forest* | *Agriculture* | *Bare* | *Water* | *Total* |
|---|---|---|---|---|---|---|
| *Rangeland* | 88.2 | 4.9 | 21.7 | 0.0 | 0.0 | 114.9 |
| *Forest* | 1.1 | 95.0 | 0.0 | 0.0 | 0.1 | 96.2 |
| *Agriculture* | 10.5 | 0.0 | 78.3 | 0.0 | 0.0 | 88.8 |
| *Bare* | 0.2 | 0.1 | 0.0 | 100.0 | 0.0 | 100.3 |
| *Water* | 0.0 | 0.0 | 0.0 | 0.0 | 99.9 | 99.9 |
| *Total* | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | |

| | *Commission (Percent)* | *Omission (Percent)* | *Commission (Pixels)* | *Omission (Pixels)* |
|---|---|---|---|---|
| *Rangeland* | 1.46 | 11.78 | 319/21776 | 2865/24322 |
| *Forest* | 19.91 | 5.01 | 264/1326 | 56/1118 |
| *Agriculture* | 72.92 | 21.75 | 2558/3508 | 264/1214 |
| *Bare* | 32.14 | 0.00 | 45/140 | 0/95 |
| *Water* | 0.00 | 0.11 | 0/911 | 1/912 |

[28] Kappa coefficients represent “the proportion of agreement obtained after removing the proportion of agreement that could be expected to occur by chance.” (Foody 1992: 1459)

| | *Producer Accuracy (Percent)* | *User Accuracy (Percent)* | *Producer Accuracy (Pixels)* | *User Accuracy (Pixels)* |
|---|---|---|---|---|
| *Rangeland* | 88.22 | 98.54 | 21457/24322 | 21457/21776 |
| *Forest* | 94.99 | 80.09 | 1062/1118 | 1062/1326 |
| *Agriculture* | 78.25 | 27.08 | 950/1214 | 950/3508 |
| *Bare* | 100.00 | 67.86 | 95/95 | 95/140 |
| *Water* | 99.89 | 100.00 | 911/912 | 911/911 |

***b) Simanjiro (2010)***

OverallAccuracy = (22606/27327) 82.72%

Kappa Coefficient = 0.4776

Confusion matrix (pixels)

| | *Rangeland* | *Forest* | *Agriculture* | *Bare* | *Water* | *Total* |
|---|---|---|---|---|---|---|
| *Rangeland* | 19924 | 54 | 258 | 9 | 0 | 20245 |
| *Forest* | 328 | 1064 | 0 | 0 | 0 | 1392 |
| *Agriculture* | 3558 | 0 | 954 | 0 | 0 | 4512 |
| *Bare* | 511 | 0 | 2 | 104 | 1 | 618 |
| *Water* | 0 | 0 | 0 | 0 | 560 | 560 |
| *Total* | 24321 | 1118 | 1214 | 113 | 561 | 27327 |

Confusion matrix (percent)

| | *Rangeland* | *Forest* | *Agriculture* | *Bare* | *Water* | *Total* |
|---|---|---|---|---|---|---|
| *Rangeland* | 81.9 | 4.8 | 21.3 | 8.0 | 0.0 | 116.0 |
| *Forest* | 1.3 | 95.2 | 0.0 | 0.0 | 0.0 | 96.5 |
| *Agriculture* | 14.6 | 0.0 | 78.6 | 0.0 | 0.0 | 93.2 |
| *Bare* | 2.1 | 0.0 | 0.2 | 92.0 | 0.2 | 94.5 |
| *Water* | 0.0 | 0.0 | 0.0 | 0.0 | 99.8 | 99.8 |
| *Total* | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | |

| | *Commission (Percent)* | *Omission (Percent)* | *Commission (Pixels)* | *Omission (Pixels)* |
|---|---|---|---|---|
| *Rangeland* | 1.59 | 18.08 | 321/20245 | 4397/24321 |
| *Forest* | 23.56 | 4.83 | 328/1392 | 54/1118 |
| *Agriculture* | 78.86 | 21.42 | 3558/4512 | 260/1214 |
| *Bare* | 83.17 | 7.96 | 514/618 | 9/113 |
| *Water* | 0.00 | 0.18 | 0/560 | 1/561 |

| | *Producer Accuracy* (Percent) | *User Accuracy* (Percent) | *Producer Accuracy* (Pixels) | *User Accuracy* (Pixels) |
|---|---|---|---|---|
| *Rangeland* | 81.92 | 98.41 | 19924/24321 | 19924/20245 |
| *Forest* | 95.17 | 76.44 | 1064/1118 | 1064/1392 |
| *Agriculture* | 78.58 | 21.14 | 954/1214 | 954/4512 |
| *Bare* | 92.04 | 16.83 | 104/113 | 104/618 |
| *Water* | 99.82 | 100 | 560/561 | 560/560 |

## **APPENDIX II.** Group Interview Guide

Date: ________ Village:____________________ Sub-village: ______________________________
# People: _____ Age-sets: _______________________________________________________
Names:_______________________________________________________________________

***Resource History***

When you were children, where did you [men: take livestock] [women: obtain resources] during droughts? _______________________________________________________________________
Water? ____________________________ Fodder? ___________________Fuelwood? ___________
Were there places that provided several resources? ________________________________________
_______________________________________________________________________________
Were there restrictions or rules on using these places? ____________________________________
_______________________________________________________________________________
_______________________________________________________________________________
_______________________________________________________________________________

***Changes & Responses***

In what ways have the drought resources themselves changed since you were children? Amount? Quality?__________________________________________________________________________
_______________________________________________________________________________
_______________________________________________________________________________
_______________________________________________________________________________
What caused these changes? ___________________________________________________________
_______________________________________________________________________________
_______________________________________________________________________________
_______________________________________________________________________________
How have these changes influenced where you herd or get water? __________________________
_______________________________________________________________________________
_______________________________________________________________________________
_______________________________________________________________________________
Have changes the quantity or quality of drought resources influenced your decision to cultivate?__
_______________________________________________________________________________
_______________________________________________________________________________
Do you remember the est. of Tarangire NP? ____ Where did your family [men: water livestock] [women: gather water] during droughts before the NP? ____________________________________
_______________________________________________________________________________
When and why did you use that area? ______________________________________________________
_______________________________________________________________________________
_______________________________________________________________________________
Why _________(e.g., the Silalo Swamp) instead of ___________(e.g., the river)? ______________
_______________________________________________________________________________
_______________________________________________________________________________
Why _________(e.g., the Silalo Swamp) instead of ___________(e.g., the dam)? ______________
_______________________________________________________________________________
_______________________________________________________________________________
Do you or people you know still use this area? ___________________________________________
_______________________________________________________________________________
Where did you [men: water livestock] [women: gather water] during the last drought? __________
_______________________________________________________________________________
Why did you use that area? ____________________________________________________________
_______________________________________________________________________________

Why _________(e.g., the river) instead of ____________(e.g., the borehole)? ________________
______________________________________________________________________________
______________________________________________________________________________

Why _________(e.g., the river) instead of ____________(e.g., the dam)? ___________________
______________________________________________________________________________
______________________________________________________________________________

Why _________(e.g., the river) instead of ____________(e.g., the spring)? _________________
______________________________________________________________________________
______________________________________________________________________________

Have water development projects impacted the quality and/or quantity of grazing or water resources? ___________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

How have they influenced where you herd or get water? ____________________________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

How has agriculture impacted the quality and/or quantity of grazing or water resources? ________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

How has it influenced where you herd or get water? ______________________________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

How are communities dealing with problems related to drought resources?___________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

In your opinion, are these solutions working? _____________________________________________
______________________________________________________________________________

***Scenarios & Suggestions***

What do you think drought areas and water resources will be like in the future? _______________
______________________________________________________________________________
______________________________________________________________________________

Do you have suggestions for how to improve things? _______________________________________
______________________________________________________________________________

***Additional/Alternate Questions***

What other concerns do you have about drought resources? _________________________________
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

Is anyone addressing these concerns?  Who establishes the water rules and regulations? ________
______________________________________________________________________________

What are the +/- impacts of water rules and regulations on you and other people? ______________
______________________________________________________________________________

Has the government (village, district, or national) been involved in managing/regulating drought resources? ___________________________________________________________________

What are the +/- impacts of this involvement? _____________________________________________
______________________________________________________________________________

## **APPENDIX III.** Household Survey

### A. PARTICIPANT IDENTIFICATION

**1.** Date of interview: ___________________
**2.** Interviewer(s):______________________
**3.** Participant Name (Household Head):___________________________________
**4.** Village: ___________________________
**5.** Sub-village:________________________
**6.** Participant's Approximate Age: ________
**7.** Do you consider your boma to be near or far from the village center? ***Near*** ***Far***

### B. HOUSEHOLD CHARACTERISTICS

**8.** How much land were you allocated? ________________
**9.** Number of acres rented/leased to others _____________
- **a.** Relation to owner _________________________
- **b.** Ethnic group of renter ______________________

**10.** When was your field plowed (try to be as specific as possible) ____________________
**11.** When did you plant your crops (again try to be specific)
- **a.** Maize ______________________________________________________________
- **b.** Beans ______________________________________________________________

**12.** Number of acres cultivated by owner for maize ________________________________
**13.** Number of acres cultivated by owner for beans ________________________________
**14.** Are maize and beans planted separately or together? __________________________
**15.** This year's harvest for maize _____________________________________________
**16.** This year's harvest for beans _____________________________________________
**17.** During the last year what were the major problems with cultivation? ______________
_____________________________________________________________________________
_____________________________________________________________________________

**18.** At this time how many of each animal species do you have
- **a.** Bulls ______________________________________________________________
- **b.** Castrated males _____________________________________________________
- **c.** Adult females _______________________________________________________
- **d.** Heifers ____________________________________________________________
- **e.** Immature males _____________________________________________________
- **f.** Calves _____________________________________________________________
- **g.** Sheep _____________________________________________________________
- **h.** Goats _____________________________________________________________

**19.** Since we talked to you last year how many of each animal has been born or bought (specify)

- **a.** Cattle ______
- **b.** Sheep ______
- **c.** Goats ______

**20.** Since we talked to you last year how many of each animal has died and for what reasons.

- **a.** Cattle ______
- **b.** Sheep ______
- **c.** Goats ______

For each wife list the following for people living at home now

**21.** Wife 1

- **a.** Adult male (over 15) ______
- **b.** Adult female (over 15) ______
- **c.** Boys 11-15 ______
- **d.** Girls 11-15 ______
- **e.** Boys 6-10 ______
- **f.** Girls 6-10 ______
- **g.** Boys 0-5 ______
- **h.** Girls 0-5 ______

**22.** Wife 2 (for others list on the back of the page)

- **a.** Adult male (over 15) ______
- **b.** Adult female (over 15) ______
- **c.** Boys 11-15 ______
- **d.** Girls 11-15 ______
- **e.** Boys 6-10 ______
- **f.** Girls 6-10 ______
- **g.** Boys 0-5 ______
- **h.** Girls 0-5 ______

**23.** Others living in the olmari: ______

______

______

**24.** Are any family members working away from home – if so who, where are they, what are they doing and do they send or bring money back home (about how much each year)? ______

______

**25.** Anything else that you think are important changes from last year? ______

______

## C. WATER USE PREFERENCES

**26.** Where is your household currently watering cattle and smallstock?

- **a.** Cattle: ______________________________
- **b.** Goats: ______________________________
- **c.** Sheep: ______________________________

**27.** If you could water cattle at any water source, including those available during the rainy season, what would be your first choice? ______________________

- **a.** Why do you prefer that location? ______________________________
______________________________

**28.** If your first choice is not available, then what is your second choice for watering cattle? ______________________________

- **a.** In what situations do you use it instead of your first choice?__________
______________________________

**29.** If your first two choices are not available, then what is your third choice for watering cattle?______________________________

- **a.** In what situations do you use it instead of your second choice?__________
______________________________

**30.** What location provides the best quality water for your cattle? ______________

- **a.** Why is it best? ______________________________

## D. THE YEAR 2009 (Questions 31-53 refer to the year 2009)

**31.** During the long rains in 2009, what were the water sources for livestock in order of increasing distance from your boma? (Be sure to record the names of the nearest dam and river)

| | |
|---|---|
| 1) Closest: ______________ | 4) ______________ |
| 2) ______________ | 5) ______________ |
| 3) ______________ | 6) ______________ |

**32.** During the 2009 drought, who decided where to water livestock?

| | |
|---|---|
| ***Participant*** | ***Uncle*** |
| ***Brother*** | ***Mother*** |
| ***Father*** | ***Other:*** ______________ |

**33.** During the 2009 drought, did your household have a big herd of livestock? ***Yes*** ***No***

- **a.** About how many? Cattle: __________ Goats:__________ Sheep:______

**34.** During the worst part of the 2009 drought, were there enough people to help water livestock? ***Yes*** ***No***

- **a.** Were children helping water livestock? ***Yes*** ***No***
- **b.** Was your household hiring anyone to help herd livestock? ***Yes*** ***No***

**35.** During the worst part of the 2009 drought, where did your household water livestock? (If more than one source, list all sources and circle the one that was used most for each species)

**a.** Cattle: ________________________________________________

**b.** Goats: ________________________________________________

**c.** Sheep: ________________________________________________

**36.** Why did your household use that/those location(s) during the worst part of the 2009 drought? ________________________________________________

________________________________________________

________________________________________________

**37.** Why didn't your household take livestock to the other water sources you listed (see question **31**)? ________________________________________________

________________________________________________

________________________________________________

**38.** From your boma, about how far away is the location where you watered cattle (see **35.a.**) during the worst part of the 2009 drought? *Distance:*________________

*Walking time (with cattle):*________

**39.** Was there grazing/grass in the area where you watered cattle during the worst part of the 2009 drought? ***Yes*** ***No***

If *No*: Where did you graze livestock?________________________________________

**40.** Were people able to establish temporary bomas in the area where you watered cattle during the worst part of the 2009 drought? ***Yes*** ***No***

**If participant WAS NOT watering cattle at a borehole (see 35.a.), go to question 42**

**41.** At the borehole you were using during the worst part of the 2009 drought:

**a.** Did it have a livestock trough? ***Yes*** ***No***

**b.** Did you have to wait a long time to water cattle? ***Yes*** ***No***

**c.** About how long did you have to wait? ________________________________

**d.** Did people have to pay diesel or money to water cattle there? ***Yes*** ***No***

If *Yes*: How much? *Money:* ______________ *Diesel:* ____________

**e.** Were you, a friend, or a relative on the committee for that borehole?

***Yes*** ***No*** ***N/A-there was no committee***

If *Yes*: Specify (circle all that apply)

***Participant*** ***Family (specify):***________

***Friend*** ***Other:*** ________________

***Clan Relative***

**f.** Was this the nearest borehole to your boma? ***Yes*** ***No***

If *Yes*: Go to question **43** If *No*: Go to the next question

**42.** During the worst part of the 2009 drought, was the borehole nearest to your boma working? ***Yes*** ***No***

If *No*: Why wasn't it working? ____________________

If *Yes*:

**a.** Did it have a livestock trough? ***Yes*** ***No***

**b.** If you had taken cattle to the nearest borehole during the worst part of the 2009 drought, would you have waited a long time to use it? ***Yes*** ***No***

About how long? ____________________

**c.** At that time, did people have to pay diesel or money to use the nearest borehole? ***Yes*** ***No***

If *Yes*: How much? *Money:* __________ *Diesel:* __________

**d.** At that time, were you, a friend, or a relative on the committee of the nearest borehole? ***Yes*** ***No*** ***N/A-there was no committee***

If *Yes*: Who (circle all that apply)?

***Participant*** ***Family:*** __________

***Friend*** ***Other:*** __________

***Clan Relative***

**43.** During the worst part of the 2009 drought, was there surface water in the river/korongo you were using (if he was not using a river/korongo to water cattle at that time, then refer to the nearest river/korongo and write down its name)? ***Yes*** ***No***

If *No*:

**a.** When did the surface water in the river dry up in 2009? __________

**b.** Did wells in the river/korongo have water during the worst part of the 2009 drought? ***Yes*** ***No***

**44.** In 2009, did the river/korongo and its wells have less, the same, or more water compared to similar drought years in the past?

***Less*** ***Same*** ***More***

If *More* or *Less*: What do you think caused the change? ____________________

____________________

**45.** During the worst part of the 2009 drought, did you or someone you know own a well in the river/korongo? ***Yes*** ***No***

If *Yes*: Who (circle all that apply)?

***Participant*** ***Family:*** __________

***Friend*** ***Other:*** __________

***Clan Relative***

**46.** During the worst part of the 2009 drought, was there water in the nearest dam?
***Yes*** ***No***

If *No*: When did the dam dry up in 2009? ____________________

**47.** During the worst part of the 2009 drought, was cultivation affecting your access to the place where you watered cattle (see **35.a.**)? ***Yes*** ***No***

If *Yes*: Describe: ____________________

____________________

**48.** At that time, was there conflict (e.g., fighting or arguing) between people where you watered cattle (see **35.a.**)? ***Yes*** ***No***

If *Yes*: Describe: ____________________

____________________

**49.** During the worst part of the 2009 drought, was livestock disease a problem in the area where you watered cattle (see **35.a.**) more so than in other places? ***Yes*** ***No***

If *Yes*: Describe: ____________________

____________________

**50.** At that time, was cultivation affecting your access to other water sources?
***Yes*** ***No***

If *Yes*: Describe: ____________________

____________________

**51.** During the worst part of the 2009 drought, was there conflict (e.g., fighting or arguing) between people at other water sources? ***Yes*** ***No***

If *Yes*: Describe: ____________________

____________________

**52.** At that time, was livestock disease a problem around any other water sources in particular? ***Yes*** ***No***

If *Yes*: Describe: ____________________

____________________

**53.** During the worst part of the 2009 drought, were there rules that restricted your access to any water sources? ***Yes*** ***No***

If *Yes*: Describe: ____________________

____________________

**E. PAST DROUGHTS (Questions 54-78 refer to the drought when participant was young)**

**54.** What is the earliest drought that you can remember (write down)? ________________

If participant has difficulty remembering, mention the following droughts:

*1940's: "Red Bone Marrow Year," Meshuki were initiated*

*1952-54: "People Moved From Their Homes," Meshuki were warriors*

*1960-63: "Red Grass Year," Seuri were warriors*

*1974-77: Seuri had Olng'esher, Makaa were junior warriors*

*1983-84: Makaa were warriors*

*1993-94: Landess were warriors*

**55.** At that time, were you living in this sub-village? ***Yes*** ***No***

If *No*: Which village and sub-village were you living in? ________________________

**56.** At that time when you were young, did your household have a garden, farm, both, or neither? ***Garden*** ***Farm*** ***Both*** ***Neither***

**57.** During the long rains of that year, what were the water sources for livestock in order of increasing distance from your boma? (Include the names of the nearest dam and river)

1) Closest: ______________________

2) ______________________________

3) ______________________________

4) ______________________________

5) ______________________________

6) ______________________________

**58.** During the drought you mentioned that happened when you were young, who decided where to water livestock?

***Participant*** ***Brother*** ***Father*** ***Uncle*** ***Mother*** ***Other:*** ___________________

**59.** During the drought you mentioned, did your household have a big herd of livestock? ***Yes*** ***No***

**a.** About how many? Cattle: ____________ Goats:____________ Sheep:______

**60.** During the worst part of the drought you mentioned, were there enough people to help water livestock? ***Yes*** ***No***

**a.** Were children helping water livestock? ***Yes*** ***No***

**b.** Was your household hiring anyone to help herd livestock? ***Yes*** ***No***

**c.** How many people were in your household, including you?_________________

**d.** How many people were in your boma, including those in your household?____

**e.** About how many bomas were in the village?____________________________

**61.** During the worst part of the drought you mentioned, where did your household water livestock? (If more than one source, list all sources and circle the one that was used most for each species)

**a.** Cattle: ______________________________

**b.** Goats: ______________________________

**c.** Sheep: ______________________________

**62.** Why did your household use that/those location(s) during the worst part of that drought? ______________________________

______________________________

______________________________

**63.** Why didn't your household take livestock to the other water sources you listed (see **57**)? ______________________________

______________________________

**64.** From your boma, about how far away is the location where you watered cattle (see **61.a.**) during the worst part of the drought you mentioned? *Distance:*__________

*Walking time (with cattle):*__________

**65.** Was there grazing/grass in the area where you watered cattle during the worst part of the drought you mentioned? ***Yes*** ***No***

If *No*: Where did you graze livestock?______________________________

**66.** Were people able to establish temporary bomas in the area where you were watering cattle during the worst part of the drought you mentioned? ***Yes*** ***No***

**If participant WAS NOT watering cattle at a borehole (see 61.a.), go to question 68**

**67.** At the borehole you were using during the worst part of the drought you mentioned:

**a.** Did it have a livestock trough? ***Yes*** ***No***

**b.** Did you have to wait a long time to water cattle? ***Yes*** ***No***

**c.** About how long did you have to wait? ______________________________

**d.** Did people have to pay diesel or money to water cattle there? ***Yes*** ***No***

If *Yes*: How much? *Money:* ______________ *Diesel:* ______________

**e.** Were you, a friend, or a relative on the committee for that borehole?

***Yes*** ***No*** ***N/A-there was no committee***

If *Yes*: Specify (circle all that apply)

***Participant*** ***Family (specify):*** ______________

***Friend*** ***Other:*** ______________

***Clan Relative***

**f.** Was this the nearest borehole to your boma? ***Yes*** ***No***

If *Yes*: Go to question **69** If *No*: Go to the next question

**68.** During the worst part of the drought you mentioned, was the <u>borehole nearest to your boma</u> working? ***Yes*** ***No*** ***N/A - none built yet***

<u>If *N/A*</u>: Go to question **69**

<u>If *No*</u>: Why wasn't it working? ____________________________________________

<u>If *Yes*</u>:

**a.** Did it have a livestock trough? ***Yes*** ***No***

**b.** If you had taken cattle to the <u>nearest borehole</u> during the worst part of the drought you mentioned, would you have waited a long time to use it? ***Yes*** ***No***

About how long? ______________________________________________

**c.** At that time, did people have to pay diesel or money to use the nearest borehole? ***Yes*** ***No***

<u>If *Yes*</u>: How much? *Money:* __________________ *Diesel:* ___________

**d.** At that time, were you, a friend, or a relative on the committee of the <u>nearest borehole</u>? ***Yes*** ***No*** ***N/A-there was no committee***

<u>If *Yes*</u>: Who (circle all that apply)?

***Participant*** ***Family:*** _________________

***Friend*** ***Other:*** __________________

***Clan Relative***

**69.** During the worst part of the drought you mentioned, was there surface water in the river/korongo you were using (<u>if he was not using a river/korongo to water cattle at that time, then refer to the nearest river/korongo and write down its name)</u>? ***Yes*** ***No***

<u>If *No*</u>:

**a.** When did <u>the surface water</u> in the river dry up that year? _______________

**b.** Did <u>wells</u> in the river/korongo have water during the worst part of that drought? ***Yes*** ***No***

**70.** During the worst part of the drought you mentioned, did you or someone you know own a well in the river/korongo? ***Yes*** ***No***

<u>If *Yes*</u>: Who (circle all that apply)?

***Participant*** ***Family:*** _________________

***Friend*** ***Other:*** __________________

***Clan Relative***

**71.** During the worst part of the drought you mentioned, was there water in the <u>nearest dam</u>? ***Yes*** ***No*** ***N/A-none built yet***

<u>If *No*</u>: When did the dam dry up that year? ___________________________________

**73.** During the worst part of the drought you mentioned, was cultivation affecting your access to the place where your household watered cattle (see **61.a.**)?

***Yes*** ***No***

If *Yes*: Describe: ______________________________________________

______________________________________________________________

**74.** At that time, was there conflict (e.g., fighting or arguing) between people where you were watering cattle (see **61.a.**)? ***Yes*** ***No***

If *Yes*: Describe: ______________________________________________

______________________________________________________________

**75.** During the worst part of the drought you mentioned, was livestock disease a problem around the area where you watered cattle (see **61.a.**) more so than in other places?

***Yes*** ***No***

If *Yes*: Describe: ______________________________________________

______________________________________________________________

**76.** At that time, was cultivation affecting your access to other water sources?

***Yes*** ***No***

If *Yes*: Describe: ______________________________________________

______________________________________________________________

**77.** During the worst part of the drought you mentioned, was there conflict (e.g., fighting or arguing) between people at other water sources? ***Yes*** ***No***

If *Yes*: Describe: ______________________________________________

______________________________________________________________

**78.** At that time, was livestock disease a problem around any other water sources in particular? ***Yes*** ***No***

If *Yes*: Describe: ______________________________________________

______________________________________________________________

**79.** During the worst part of the drought you mentioned, were there rules that restricted your access to any water sources? ***Yes*** ***No***

If *Yes*: Describe: ______________________________________________

______________________________________________________________

**Thank you for answering my questions. Do you have any questions for me?**

**APPENDIX IV.** Hydrologic Event Calendar

| *Reporting Village(s)* | Loiborsoit | Terrat | Terrat | Emboreet, Sukuro, Terrat | Sukuro, Loiborsoit | Emboreet | Sukuro | Emboreet, Terrat | Loiborsoit | Sukuro | Emboreet, Terrat | Loiborsoit, Emboreet, Terrat, Sukuro | Terrat | Sukuro, Terrat, Emboreet, Loiborsoit | Loiborsoit, Terrat | Loiborsoit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Event* | D | D/Dis | D | D | W | W | D | D | R | H | D | D | W | D/Dis | D | W |
| *Year and/or Social Landmark* | 1886 | 1894-1898 (Ituati were warriors) | 1944-47 (Nderito were warriors) | 1952-54 (Meshuki were warriors; Iseuri ~12 years old ) | 1954 | 1957 | 1961 (2 years after Meshuki finished Olengesher*; Iseuri were jr. warriors ) | 1964-67 | 1968 | 1968 (Seuri became warriors) | 1971-72 | 1974-77 (Iseuri Olengesher) | 1981 | 1982-85 | 1987 | 1990 |
| *Description* | "The year that people ate donkey meat" | *Emutai;* disease and drought throughout East Africa | Red bone marrow disease | There was water in the Terrat River, but people moved to Loiborsiret because of rain and grass | Sukuro Dam and Loiborsoit borehole were built by the colonial government | Red Dam and Emboreet Borehole built | "The Red Grass Year;" people moved from Sukuro to Kisongo and Manyara | "The year of the sun;" people ate cow hides; some in Terrat consider this the worst drought in memory | "The year of water" good rains followed by elevated water table for several years, the Sinya River was flowing | Loiborsiret and Kiti Engare Rivers "started" flowing | | People moved to Loiborsiret and beyond to Kiteto and Kondoa because of a lack of grass | Government built a borehole | Rinderpest outbreak; a lot of dead wildebeest; U.S. brought food aid | | Borehole and dam built |

| *Reporting Village(s)* | Sukuro, Terrat | Loiborsoit | Emboreet, Loiborsoit, Sukuro, Terrat | Sukuro | Sukuro, Loiborsoit, Terrat, Emboreet | Emboreet, Sukuro, Terrat | Sukuro; Emboreet, Terrat | Sukuro | Sukuro, Terrat | Sukuro | Emboreet | Sukuro, Loiborsoit, Terrat | Sukuro, Emboreet, Loiborsoit, Terrat | Sukuro, Terrat | Loiborsoit. Emboreet, Terrat |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Event* | D | W | D | W | D | D | D | W | D | W | W | W | H, D | W | W |
| *Year and/or Social Landmark* | 1990-91 | 1992 | 1993-94 | 1996 | 1997-98 | 1999-2000 | 2002-03 | 2003 | 2005-06 | 2007 | 2008 | 2009 | 2009 | 2010 | 2011 |
| *Description* | | People discovered water by digging wells in the Kikoti River | People moved to Sukuro from Kondoa | 2 hand pumps built near the Kiti Engare river | People moved into Loiborsiret; people in Loiborsoit were using the Kikoti River wells | | | Windmill borehole built | People took their animals toward the park and even into the park | District govt. built dam in Loiborsiret; hunting co. built cement barriers in Kiti Engare river to collect water and attract wildlife | Dam built in Emboreet | Borehole built in Sukuro by village; windmill borehole built in Loiborsoit; borehole built in Terrat | People brought livestock to Simanjiro from across the region; first time people came from Kenya | 3 boreholes built in Kiti Engare; 2 boreholes built in Terrat | 4 boreholes being built in Loiborsoit; 2 in Emboreet; 1 in Terrat |

D=drought, Dis=disease outbreaks, W=water development, R=rainfall, and H=other hydrologic events

*Olengesher is a meat eating ceremony that signifies the transition of an ageset from senior warriors to elder

## **APPENDIX V.** Institutional Interview Guide

Date: _________ Village (SV):______________(_____________) Organization name: _________
_____________________ Est.: ______ Interviewee(s): _______________________________________
_____________________________________________________________________________________

***Resources***

What are the major water sources in your village and how long do they provide resources each year? _______________________________________________________________________

Rivers:___________________________________Boreholes:________________________________

Dams: ___________________________________Springs: __________________________________

Have there been changes in drought resource quantity or quality? ___________________________
_____________________________________________________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________

What caused these changes? _________________________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________

How are people affecting them (now and in the past)?_____________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________

***Institutional Characteristics***

Tell me about the history of your organization: ___________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________

What role does it play in managing drought resources such as water and fodder? _______________
_____________________________________________________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________

How does it establish rules? _________________________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________

Who enforces the rules? _____________________________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________

How are rules enforced? Is this effective?_______________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________

***Institutional Changes & Responses***

Do you remember the est. of Tarangire NP? ___________ How did it affect the resources you manage? ____________________________________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________

How did your organization respond? ___________________________________________________
_____________________________________________________________________________________
_____________________________________________________________________________________

Has ag. influenced drought resources or the availability of water? ______________________________

How is your organization responding? ______________________________

Describe your relationship with local people: ______________________________

Are there problems? How do you resolve conflicts? ______________________________

Do you interact with other (local, village, district, regional, etc) organizations?______________________________

What role do they play in managing drought resources, especially water? ______________________________

How do they affect your org.?______________________________

***Scenarios & Suggestions***

What do you think water resources will be like in the future? ______________________________

Do you have suggestions for how to improve things? ______________________________

**APPENDIX VI**. Drought and River History Interview Guide

Date: ________ Village:___________________ Sub-village: ____________________________
# People: _____ Age-sets: ____________________________________________________

What is the earliest drought you remember? ________________________________________
____________________________________________________________________________

What other droughts do you remember? ___________________________________________
____________________________________________________________________________
____________________________________________________________________________

Do you remember any of the following droughts (circle all that apply):

*1952-54 (Meshuki were warriors)*
*1960-61 (Iseuri were junior warriors)*
*1973-74 (Makaa were junior warriors)*
*1983-85 (Makaa were warriors)*
*1993-94 (Landess were warriors)*

Are these dates correct? _____________________________________________________
____________________________________________________________________________

Are the ageset descriptions correct? ____________________________________________
____________________________________________________________________________

Do these droughts have names? ________________________________________________
____________________________________________________________________________

What happened during these droughts? ___________________________________________
____________________________________________________________________________

Which droughts were especially bad and what was bad about them? ________________________
____________________________________________________________________________

What is the worst drought you remember and why was it the worst? _______________________
____________________________________________________________________________
____________________________________________________________________________

What was the river like during the 2009 drought?_________________________________
____________________________________________________________________________
____________________________________________________________________________

Did it have surface water? _____________________________________________________
How much water was in the wells (how long did it take to water animals)? __________________
____________________________________________________________________________

About how deep were they? ____________________________________________________
About how many wells were there? ______________________________________________
Number of livestock and people using the river and wells each day? _____________________
____________________________________________________________________________

Where were these people from? _________________________________________________
What rules were there about using the wells and the area around the river? _______________
____________________________________________________________________________
____________________________________________________________________________
____________________________________________________________________________

What was the river like during the earliest drought you remember? ______________________
____________________________________________________________________________
____________________________________________________________________________

Did it have surface water? _____________________________________________________
How much water was in the wells (how long did it take to water animals)? __________________
____________________________________________________________________________

About how deep were they? ____________________________________________________

About how many wells were there? ______________________________
Number of people using the river and wells? ______________________________
Where were these people from? ______________________________
What rules were there about using the wells and the area around the river? ____________
______________________________
______________________________
______________________________

Tell me about changes in the river (floods, water, grazing, wells, sediment, number of people, rules of use) during the following periods.

*Nderito were warriors:*
*Meshuki were warriors:*
*Seuri were warriors:*
*Makaa were warriors:*
*Landis were warriors:*
*Since Korianga became warriors:*

Has the width of the river channel changed since you were young? ____________
______________________________
Has the depth of the river channel changed? ______________________________
______________________________

During good times of year (the rainy season), have there been changes in the following since you were young?

The amount of water in the river: ______________________________
______________________________
______________________________
The number of people using the river or the area around the river: ____________
______________________________
How often it floods: ______________________________
______________________________
Sediment size or color: ______________________________
______________________________
Rules of use: ______________________________
______________________________
______________________________
______________________________
______________________________

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