INFLUENCE OF MAMMALIAN HERBIVORY ON WOODY PLANTS DYNAMICS AND ECOSYSTEM SERVICES IN A SEMI-ARID SAVANNA

Staline Kibet

BSc. (UON), MSc.(JKUAT)

Thesis submitted in partial fulfillment for the Degree of Doctor of Philosophy in Dryland Resource Management

Department of Land Resource Management and Agricultural Technology

Faculty of Agriculture

University of Nairobi.

DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

Staline Kibet (MSc.)

Department of Land Resources Management & Agricultural Technology

University of Nairobi

Sign…………………………………………...Date……………………..….

This thesis has been submitted with our approval as university supervisors

Prof. Moses M. Nyangito, PhD

Department of Land Resources Management & Agricultural Technology

University of Nairobi

Sign……….…………………………………Date……………………………..

Dr. David Kenfack, PhD

Smithsonian Tropical Research Institute

Sign………………………………………..Date…………………………

DEDICATIONS

I dedicate this thesis to my family; my lovely wife Joyce, my children Teddy, Kevo, Joshman and Malkia and all those who have tirelessly walked with me in this journey.

ACKNOWLEDGEMENTS

This study would not have been accomplished without generous financial support from Smithsonian Tropical Research Institute/Levinson Fellowship and Center for Sustainable Dryland Ecosystem and Societies (CSDES) for which they are acknowledged. Special gratitude goes to my supervisor Professor Moses Nyangito for his tireless assistance even when I seemed to be making minimal progress. He patiently and persistently guided me whenever I got stuck. I appreciate help I received from Dr. David Kenfack, and Dr. Laban MacOpiyo. Their scientific input and editorial support was invaluable. I got encouragement and support from members of the department and colleagues for which I am grateful. Special mentions include Prof. Nancy Karanja, Prof. Charles Gachene, Dr. Judith Mbau, Prof. Robinson Kinuthia, Dr. Oliver Wasonga, Dr. Oscar Koech, Grace, Esther, Tirop, and Charles Ikutwa. I acknowledge logistical support I received during field data collection from Mpala research Centre staff. I thank Goffrey Metiaki and all Il Motiok people for accepting me into their community and sharing their knowledge. This study would not have been successful without the help I received from my field assistants; Agnes, Jacob, Daniel, Peter, and Timothy from Il Motiok. Thank you all. I also acknowledge support from the CTFS team working on the long-term monitoring plot at Mpala ranch lead by Kimani Ndung'u, David Melly, Solomon Kipkoech and Augustine Wabuyele.

Lastly, I wish to appreciate the encouragement I received from my wife Joyce, my children Teddy, Kevin, Joshua and Malkia. You guys are amazing and you have given me reasons to be a better person each day. I share my happiness with you.

When all have been said and done, it was God that made everything possible. Glory and Honor goes to Him.

TABLE OF CONTENTS

List of Figures

Tables

ACRONYMS

AAS	Atomic Absorption Spectrophotometer
CCA	Canonical Correspondence Analysis
CTFS	Center for Tropical Forest Science
CV	Coefficient of Variance
DKH	Diameter at Knee Height
FGD	Focus Group Discussion
FTEA	Flora of Tropical East Africa
GOK	Government of Kenya
GR	Group Ranch
KII	Key Informants Interviews
LA	Leaf Area
LDMC	Leaf Dry Matter Content
LNC	Leaf Nitrogen Content
LPC	Leaf Phosphorus Content
NGOs	Non-Governmental Organizations
PR	Private Ranch
SES	Socio-ecological System
SLA	Specific Leaf Area
TLU	Tropical Livestock Unit

DEFINITION OF TERMS

Plant functional traits - can be defined as morphological or physiological characters that influence species responses to different environmental conditions

Functional diversity - Is the value and range of functional traits of the organisms present in a given ecosystem that influence the ecosystem functioning or simply the range and distribution of traits values in a community.

Morpho-Functional traits – Are plant functional traits whose response to disturbance are reflected from changes in their morphology e.g. Leaf size.

Community weighted means - the mean of trait values in the community, weighted by the relative abundance of the species carrying each value

Homogenization – changes that make all parts to be similar or the same especially in a way that is not desirable

Browsers – Herbivores that predominantly feed on woody plants

Grazers – Herbivores that predominantly feed on grass

Mixed feeders – Herbivores that feed on grass and browse woody plants depending on the seasons e.g. Elephant. Impala

Habitat invasibility - This refer to habitat susceptibility to invasive species

Herbivory – The consumption of plant tissue by animals

Weeds – plants growing where they are not wanted

Sadomasochistic – Enjoyment of hurting others and being hurt

Hour-glass – a device that was used to measure the passing of an hour with two round glass sections linked by a narrow channel.

Browse biomass – Edible portion of palatable plants (i.e. leaves, young twigs/shoot, fruits)

Increaser type 1 – Invader species associated with over-grazed areas

Increaser type II – Invader species associated with under-grazed areas

ABSTRACT

In Kenya, woody plants encroachment has been witnessed in many parts of the rangelands. In the study area (Laikipia county) shrub encroachment in the last half of the Century has increased by more than 25% has been blamed on the management systems in place. This has affected the landscapes' ability to provide critical ecosystem services e.g. forages, habitats for wildlife and ecosystem ability to resist invasion among others. This study investigated the effects of livestock browsing intensities on plant traits such as specific leaf area (SLA), leaf dry matter content (LDMC), leaf phosphorus and nitrogen content (LPC & LNC), canopy height (H) among others, functional diversity and ecosystem services (biomass production and habitat invasibility) under lightly browsed private commercial (PR) and intensely browsed pastoral group ranching schemes (GR). Innovations on natural and social capital assets management within pastoral group ranch system were also evaluated.

The vegetation and sites data was collected in 421 plots of 20x20 m each, nested in three transect lines of 3 km long in each ranch, while plant traits and leaf biomass where collected from four predetermined species that were dominant and palatable based on reconnaissance survey. They included; *Acacia brevispica*, *A. tortilis*, *A. etbaica*, and *Acacia mellifera*. Structural diversity between sites was determined based on coefficient of variation (CV) of vegetation structural attributes such as mean canopy crown cover, mean height etc. calculated as standard deviation divided by mean. Functional traits diversity and Simpson species diversity was calculated using Rao coefficient index formula $\boldsymbol{FD = \sum_{i-1}^{s} \sum_{j=1}^{s} d_{ij} p_i p_j}$ while Traits Community Weighted Means (CWM) was calculated using the formula $\boldsymbol{CWM = \sum_{i=1}^{s} pi\, x\, trait_i}$**.** Pearson correlation analysis was done to compare biotic and/or abiotic factors that may have influenced abundance and distribution of invasive species. Mann Whitney U - test and Z – test were used to test for significance between management systems. The findings show that key innovations in the management of natural capital assets in the pastoral system included establishment of small-scale cultivation, shift in herd species composition to maximize on changing forage resource (more browsers –goats than grazers – cattle), introduction of drought tolerant breeds (e.g. Galla goats) and species (camels), harnessing of wildlife and culture based tourism (Conservancies establishments), leasing and hiring of pastures, expansion of traditional enclosures (*Olokerii*) among others. Among social capital assets, the establishment of new networks such as business associations (e.g. Bee-keepers), self-help groups governed by by-laws, norms and sanctions replaced weakening traditional networks that were based on clans and age-sets. Vegetative traits varied between the two management systems. Contrary to expectation, aggregated mean values for diameter at knee height (DKH), height (H_c) and crown (CRWN) were larger ($Z= 98.3$, $p<0.05$; $Z = 98.5$, $p<0.05$; $Z= 37.7$, $p<0.05$) in GR than PR respectively. On the other hand, leaf traits recorded variable results. Aggregated mean for specific leaf area (SLA) and Leaf nitrogen content (LNC) were not different between sites ($Z = 0.66$, $p<0.43$ and $Z=0.44$, $p<0.76$) in GR and PR respectively while leaf area (LA) and leaf phosphorus content (LPC) recorded higher values ($Z = 4.9$, $p<0.05$; $Z=3.9$, $p<0.05$) in PR than GR respectively. Leaf dry matter content (LDMC) values were higher in GR than PR ($Z = 5.46$, $p<0.05$). The PR was more functionally diverse than GR based on Rao coefficient index for binary, categorical and quantitative data. Functional diversity for CRWN, H_c and DKH for the three PR species was more variable than same set of traits in GR species. The three species recorded low FD values for most of the analyzed traits except LA an indication of traits homogenization. The GR though higher in leaf production was low in structural diversity and species composition. The highest variation in structural diversity between sites was noted in basal area, canopy volume and canopy area while least variation was noted in herb cover and canopy depth. The GR was low in species composition although majorities were of high forage value. The site recorded high leaf biomass production analogous to 'browsing lawn' which was attributed to dominance of browsing-tolerant *A. mellifera* species known to easily replace lost biomass through compensatory growth. On the other hand, PR had higher diversity of species but with a significant presence of evergreen unpalatable species such as *Euclea divinorum* and *Croton dichogamus* an aspect attributable to high herbivores forage selection. Furthermore, PR was five times more woody compared to GR making it least suitable for open grassland wildlife species. The two management systems varied in invasive (native and nonnative) species abundance. Pastoral system had higher relative invasive species abundance compared to private commercial ranch. The GR was invaded by the following species; *Sansevieria sp, Ipomoea kituensis, Opuntia stricta, O. subalata,* and *Acacia reficiens.* There was a positive relationship between abundance of *Ipomoea kituensis* species with proximity to homestead while *Sansevieria volkensii* increase away from homestead. The most dominant invasive species at the PR was evergreen *Euclea divinorum* and was weakly associated with high species rich plots. In conclusion, innovative approaches currently being applied in the management of natural and social assets management have both positive and negative socio-ecological effects. The increasing shift from keeping more grazers (e.g. cattle) to more of browsers (e.g. goats and camels) among the Laikipia Maasai was informed by their higher survivorship during drought events but also to increasing availability of browse forage. Intense browsing in GR was effective in keeping check on browsing-sensitive woody species in the absence of fire. This implies that management of livestock browsing intensity can be used to manipulate species composition,density as well as functional diversity. Habitat invasibility is influenced by browsing but mediated by other factors such as soil properties (e.g. soil texture, nutrients etc.). The study findings suggest that group ranching is more socio-ecologically resilient than private ranching and policy options should be explored to strengthen its adaptive capacity.

CHAPTER ONE

GENERAL INTRODUCTION

1.0 Background

Savannas constitute major biome on the earth surface, covering an estimated area of 33 million square kilometres and support a large population of humans, livestock and a wide diversity of wildlife (Sankaran & Anderson, 2009). The biome is characterised by the co-existence of two life-forms (scattered trees and grasses) that exist in a continuum from woodland savanna to open grassland depending on prevailing climatic conditions (e.g. plant available moisture), soil conditions as well as fire and herbivory (Huenneke & Noble 1996; Sankaran et al. 2005; Sankaran & Anderson 2009). The tree-grass co-existence has been a subject of research for many decades (Belsky 1990; Scholes & Archer 1997; Sankaran et al. 2004) and to-date, major contributing factor to changes from woody to open grassland and vice versa is still debatable (Riginos & Young 2007; Kambatuku et al. 2011).

The African savannas have witnessed an increase in woody plant encroachment in the recent past (Angassa & Oba 2010; Mengistu et al. 2005), raising the questions on what it advance with respect to land degradation, desertification, ecological functions and global change (Asner et al. 2004; Eldridge et al. 2011; Sankaran & Anderson 2009). Is woody plant encroachment ecologically and/or economically good or bad?

The woody vegetation encroachment in Kenyan rangelands (Augustine and McNaughton, 2004, Riginos et al 2012), is raising concerns on the ability of these landscapes to provide unique services associated with these ecosystems such as provision of forages for livestock and wildlife, quality habitat for wildlife, habitat's ability to resists invasion among others. A study of savanna herbivores dynamics in Laikipia county, northern Kenya observed that population of some wildlife species were declining, despite concerted efforts to conserve them. Increased predation was suggested as possible lead cause for the decline of these species (Georgiadis, Ihwagi, et al. 2007). Ironically, private ranches (PRs) where more resources have been committed to wildlife conservation experienced the highest decline in wildlife population. Riginos and Grace (2008) working in the same region observed that with the exception of elephants, other wild herbivores preferred areas with low tree density for ease of visibility and avoidance of predation. Increase in woody plants density was possibly responsible for the decline of some species. The region and particularly pastoral group ranches (GRs) experiences frequent shortages of forages for livestock that could be attributed to effects of climate variability and change but also impacts of management style (Hauck, 2013; Huho et al., 2010; Ojwang et al., 2010; Zwaagstra et al., 2010). It is therefore logical to suggest that both PRs and GRs were unable to provide optimum ecosystem services, and as such there was need to understand the effects of land use on vegetation dynamics.

This study investigated woody plant responses to different levels of mammalian herbivory. Light to moderately browsed/grazed Mpala PR and adjacent heavily browsed Ilmotiok GR was selected for sampling following 'natural experiment' approach (Western et al. 2009).

1.1. Problem Statement

Increasingly GRs in Laikipia county are becoming more vulnerable to climate variability (especially drought) compared to PRs within similar bioclimatic zone. Whereas the livestock mobility has been maintained under GR as it were prior to 1976 when they were first established, the area available for mobility has reduced and therefore, the grazing pattern has changed from high intensity - low frequency to high intensity- high frequency. This has led to persistent forage shortages even during mild drought situation and in some cases significant increase in invasion by both native and alien plant species. Camels and small stock (particularly goats) are increasingly being promoted as a strategy to cope with climate variability (Desta & Coppock 2004; Huho et al. 2011; Gezahegn 2006) in arid and semi arid regions of Kenya and Ethiopia. Sheep and goats contribute about 30% of the red meat consumed in the country (Kiptarus, 2005) and therefore this sector will continue to be important sector in the country's economy into the future yet impact of their increase on environment is unknown.

The PRs known to be pro-wildlife conservation on the other hand have also lost valuable services due to woody plants encroachment (Riginos et al. 2008, 2012). Notable impact for lost ecosystem services is the decline in numbers of wildlife species in over at least a decade. Major declines have been noted among Waterbuck *Kobus ellipsiprymnus*, Thomson's gazelle *Gazella thomsoni*, Buffalo *Syncerus caffer*, Eland *Taurotragus oryx*, and Hartebeest *Alcelaphus buselaphus*). Declines on pro-wildlife properties were particularly severe, amounting to 37% of total wild herbivore biomass (excluding elephants) between 1990 and

2005 (Georgiadis, Ihwagi, et al. 2007). This situation necessitate deeper understanding of browse-browser interactions so as to inform management strategies for enhance ecosystem services.

1.2.Justification

In the last half century, Laikipia county has witnessed increase in woody vegetation due to wild fire suppression. Ten years ago, it was estimated that 28% cover in north-central Laikipia rangeland had been encroached by woody plants (Augustine, 2003). This has direct impact on the availability of grass forage for grazers but also an opportunity for browsers. The region is experiencing land use changes; from nomadic to agro-pastoral, increased sedentirisation, introduction of camels and more shoats and there is limited knowledge on impacts of the same on vegetation as well as ecosystem services they provide. The impacts of increasing small stock in Laikipia county on vegetation and ecosystem functions are unknown (Georgiadis et al., 2008; Kinnaird, 2012). The importance of browsers effects on woody plants dynamics remains unclear in African savanna (Augustine & McNaughton, 2004).

The selection of the two study sites was informed by the fact that both occur within the same bioclimatic zone and adjacent to each other. Additionally, Mpala PR hosts a long-term permanently marked monitoring plot under “FOREST-GEO Center of Tropical Forest Science (CTFS) Network” whose objective among others is to understand savanna vegetation dynamics over time. The role of past, present and future management of the ranch in term of vegetation dynamics is not clear and therefore, this study complements this effort by highlighting the role of management in vegetation dynamics. It also provides an opportunity to interrogate management shift that needs to be embraced to enhance ecosystem services from such savanna ecosystems. Furthermore, GRs in the region perceives PRs as ideal management option and have in the recent past incorporated wildlife conservation as part of their management objectives. Understanding the two systems and their challenges would better inform future management decisions. Additionally, the region is experiencing an increase of both alien and native invasive species linked to land management system (Strum et al. 2015). There is need to investigate mechanism through which invasive species spread with an aim of controlling them.

1.3. Broad objective

To generate knowledge on the impacts of mammalian herbivory on vegetation dynamics and long term provisioning of ecosystem services in semi-arid savanna for effective management.

1.3.1. Specific objectives

1. To assess transformation in the management of natural and social capital assets under pastoral group ranching.
2. To determine the effects of varying intensity of herbivory on palatable woody plants functional traits diversity
3. To determine the effects of mammalian herbivory on species composition, structural diversity and browse biomass production
4. To evaluate influence of mammalian herbivory on habitat invasibility

Research Hypotheses

H_0 – Variation in the level of herbivory has no effect on functional traits diversity of dominant palatable plants

H_0 – Species diversity, structure and composition of the study sites are not influenced by level of herbivory

H_0 – Level of herbivory has no influence on habitat invasibility by both native and non-native plants species.

1.4. Conceptual Framework

The savanna ecosystem determinants include soils, climate, fire and herbivory as shown in the conceptual framework (figure 1). Among the four determinants; fire and herbivory have an inverse relationship whereby high herbivory reduces incidences of fire and the reverse is true represented by two – way arrows. In this study herbivory is looked at within a controlled system where livestock are herded. The two ranches are interested in livestock production and in the conservation of wildlife and environment and therefore elements of management such as stocking rates (livestock densities), herding pattern, and grazing frequency are crucial and this has an influence on herbivory. Herbivory also indirectly affects the quantity and quality of some ecosystem services by influencing ecosystem properties such as soil nutrients but also directly through modification of vegetation abundance and composition.

These interactions were evaluated at different scales from individual species (traits) to community level (species diversity, structure). Vegetation structures, composition as well as the unique species traits have influence on the ecosystem services. Thick arrows indicate strong and narrow weak influence. This study addressed two ecosystem services; browse biomass production and ecosystem resistance to invasion by invasive plant species. Erosion control though critical was acknowledged but not investigated and indicated by dotted box. Besides herbivory and fire, soils and topography affect vegetation structure, composition and production and this was factored in the sampling design and data analysis.

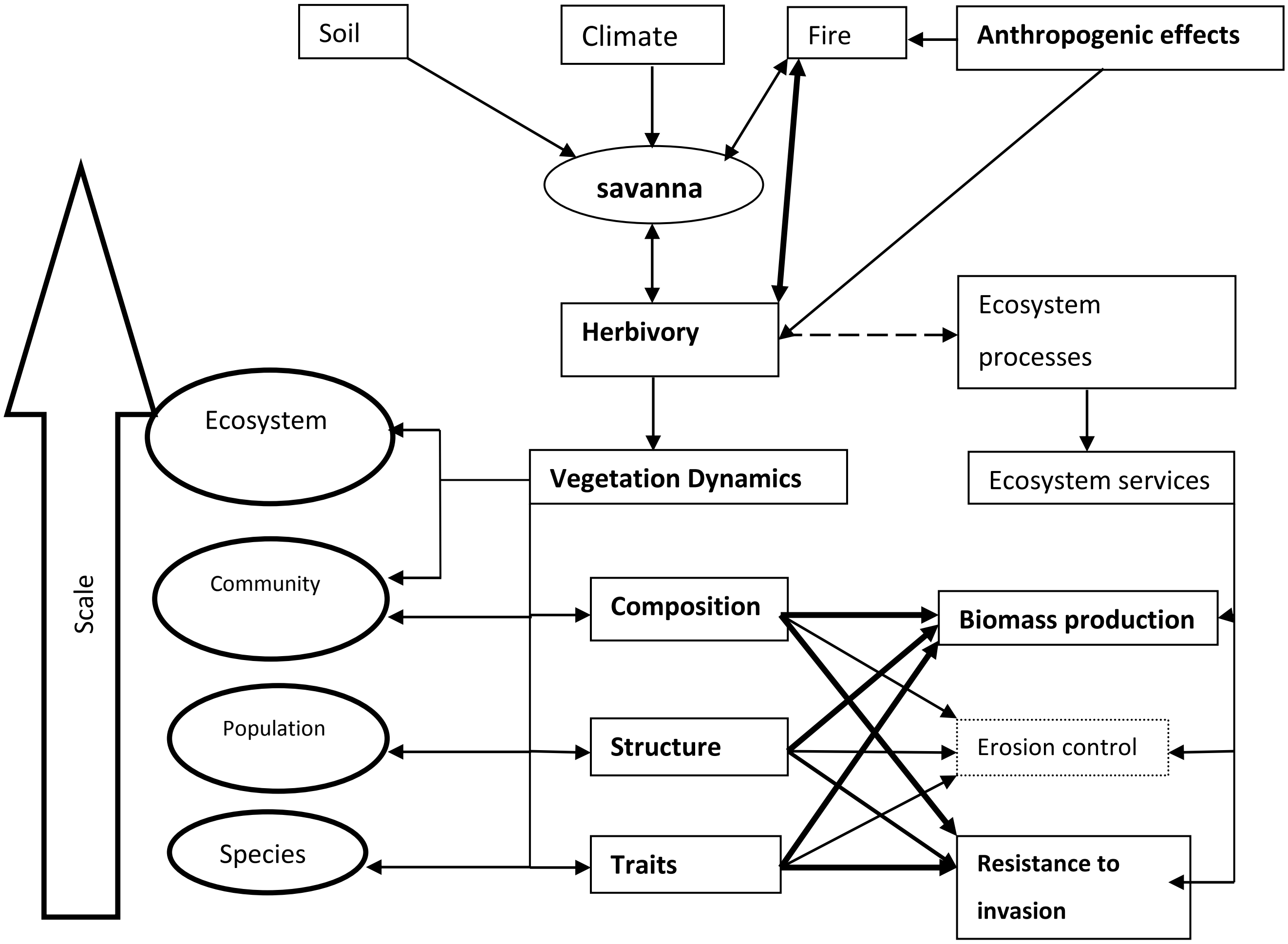

Figure 1-1. The study conceptual framework

CHAPTER TWO

GENERAL METHODS

2.1. Study Site

2.1.1. Geography and topography

Laikipia county lies across the Equator between latitude (0^0 17’ S) and (0^0 45’N) and longitude $36^0$15’E and $37^0$20’ E (figure 2). The county occupies an area of 9500 km^2 forming part of the wider 56,000 Km^2 Ewaso Ecosystem stretching from the slopes of Mt. Kenya (5199 m) in the South East to the edge of the Great Rift Valley in the West. Its escarpment descends into the arid land of northern Kenya (Boy, 2011). The altitude ranges between 1200 to 2845 m above sea level with majority of the area falling with the Laikipia plateau (1800 to 2100 m above sea level). The plateau is characterized by undulating and rolling topography with outcrops of hills and minor scarps (Ngigi 2006).

2.1.2. Rainfall

Laikipia county experiences a weak trimodal rainfall pattern with the long rain expected in April – May while the short rains come in August and October and January – March is the dry season (Augustine & McNaughton 2006). The rain is however highly variable and might fall any other time within the year. The rainfall experience in Laikipia is relief type with lots of influence from Mt. Kenya and the Nyandarua Ranges (Aberdare Ranges). The rainfall varies between 750 to 300 mm per annum from south to the arid north respectively (Gichuki et al., 1998).

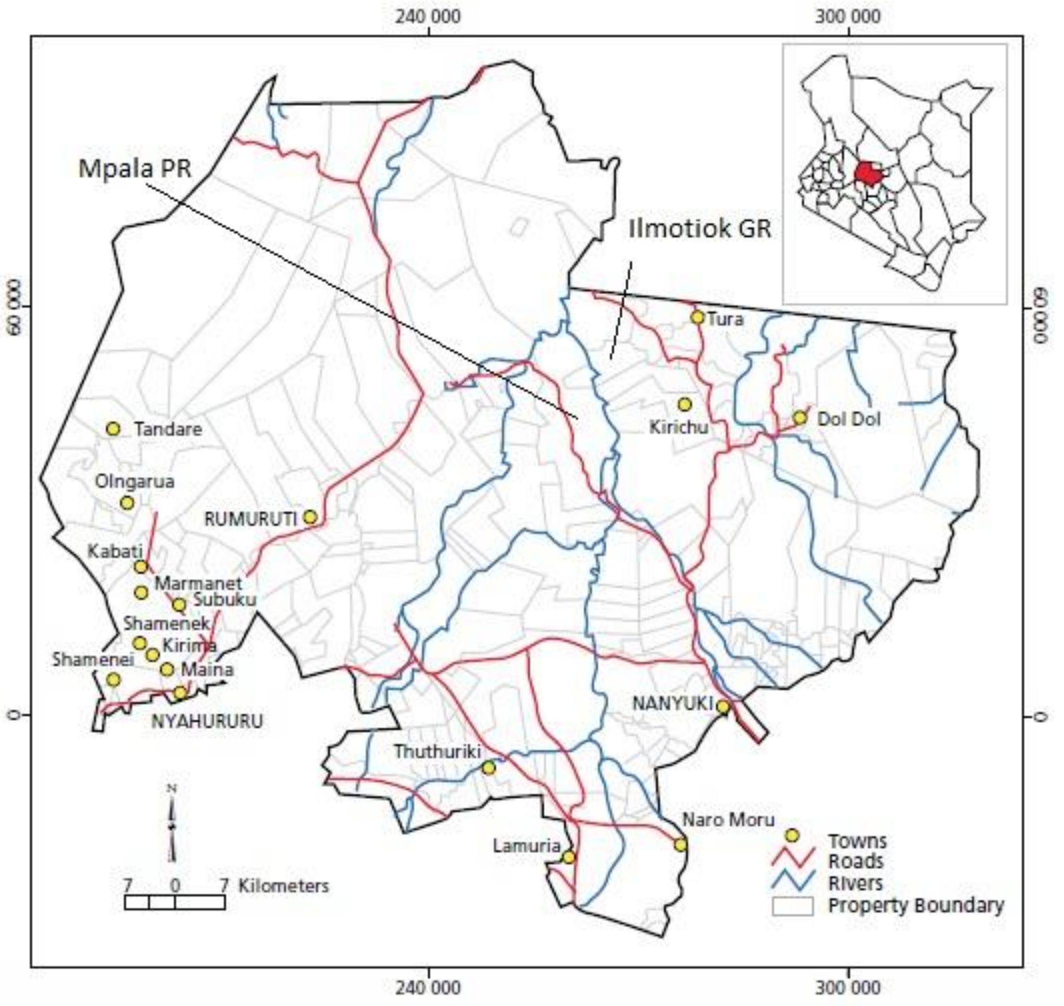

Figure 2-1. Map of Kenya showing position of Laikipia County (inset) County map showing land properties and position of study sites (Mpala PR and Il Motiok GR). Adopted from Ojwang et al., 2010

2.1.3. Temperature

The county means annual temperature is estimated at between 16^{0}C and 26^{0}C. The average duration of sunshine is between six and eight hours daily while the western and southern parts of the district have cooler temperatures. January and February are the hottest months while October is the coolest (Ojwang et al. 2010).

2.1.4. Soils

The study site is based within the Laikipia Plateau pockets of imperfectly drained grey to black clay – vertisols and planosols and expanding into the lowland comprising of metamorphic rocks of gneisses and migmatites with well drained to excessively drained soils which are mainly dark reddish brown in colour consisting of ferric and chromic luvisols (Ngigi 2006; Thenya 2001).

2.1.5. Fauna

Laikipia County is rich with classic sananna wildlife. Commonly sighted species include elephants, giraffes, zebras (common & grevy's), buffaloes, hippos, lions, leopards, cheetahs, hyena, wild dogs, and several species of antelope family (oryx, impala, gazelles, eland, dikdik, bushbuck, waterbuck, hartebeest among others). Among the endangered fauna, the County boasts of half of Kenya's Black rhinos population, two-third of world population of grevy's zebras, and the six world's largest population of wild dogs (Boy, 2011). According to WRI et al., (2007) Laikipia County is one among four Counties in the country that witnessed an increase in wildlife and livestock population between 1977/8 and 1994/6, with wildlife population increasing by up to 80% (measured using tropical livestock units). Conservation effort spearheaded by private and communal land owners is credited this increase.

2.1.6. Flora

The establishment of large scale ranching in many ways may have influenced the current vegetation mosaic. Firstly, the destocking of livestock within the Laikipia plateau and secondly, the reduction of deliberate burning could have contributed to the expansion of Acacia woodland (Augustine & Mcnaughton 2004a). Currently, Laikipia vegetation is a mosaic of dry forests, woodland, wooded grassland and grasslands a reflection of rainfall, soil, topographical gradients and human activities. The vertisols and planosols support grassland interspersed by *Acacia drepanolobium* Sjostedt and scattered *Balanites aegyptiaca* (L.) Delile, *B. glaber* Mildbr. & Schltr. and *Acacia mellifera* (Vahl) Benth, while ferric and chromic luvisol (reddish brown soils) support a mixture of *Acacia etbaica* Schweinf., *Acacia brevispica* Harms, *Acacia tortilis* (Forssk.) Hayne, *Grewia spp*, and *Boscia spp*. Areas previous occupied by dry woodland is currently covered by evergreen *Euclea divinorum* Hiern and *Acokanthera schimperi* (A.DC.) Schweinf. while riverine ecosystems have scattered *Acacia xanthophloea* Benth. believed to be declining in number due to damage from elephants (Boy, 2011;Wahungu et al., 2012). Plant nomenclature follows herein Flora of Tropical East Africa (FTEA, 1954-).

2.1.7. Water resource

Water resource used in the economic activities within the county is of particular interest. Rain fed agriculture, irrigated agriculture, pastoralism, and ranching, utilizes water from different sources. There has been a 10 folds increase in level of water abstraction from the main rivers draining Laikipia county since 1970s to present due to increased irrigated agriculture. Major drainage lines in the county are the Ewaso Nyiro and Ewaso Narok River and their tributaries. In a long term study (1970s and 1980s), Laikipia county was noted as seriously deficient in water resource and the use of river water by different land uses was impacting negatively on the ecosystem (Wiesmann and Kiteme, 1998).

2.1.8. Land use and economic activities

The variety of land holdings in Laikipia is influenced by the complex history of human settlement and the rainfall gradient. Prior to the arrival of the European settlers in the early 1900, Nomadic pastoralism was the main economic activity in the county and land was communally owned. The Maasai community roam the expanse of the county as well as neighbouring counties of Samburu, Isiolo, Baringo and Meru as they graze their livestock in some form of cyclical patterns based on seasons and availability of pastures and water. The colonial government in Kenya annexed a big chunk of land previously used by the Maasai community to form the "White Highlands" for commercial ranching consequently changing the grazing pattern, intensity and frequency. Soon after Kenya attained its independence in 1963, some of the commercial ranches owned by white settlers were sold out to locals who began to change land use once more.

Currently, there are several land use types in Laikipia county namely; ranching, ranching & wildlife, cultivation, pastoralism and cultivation, pastoralism and wildlife, forests, swamps and urban centres. The wetter southern parts of the county is largely occupied by small scale arable farmers, intermediate areas are used by commercial cattle ranchers while the drier north by pastoralists (Boy 2011; Ojwang' et al. 2010). The pastoral communal lands were consolidated into group ranches in the 1970s as a measure to (1) improve land productivity and earning capacity and (2) assign rights and responsibilities to a particular pastoral group to reverse land degradation and prevent possible landlessness among the Maasai (Coldham, 1982). Presently, over 40% of the county is occupied by large scale ranches involved in cattle keeping for beef production, wildlife conservation, and tourism.

2.1.9. The selection of study sites

To determine the influence of mammalian herbivory on vegetation dynamics, a natural experiment approach (Fornara & Du Toit 2008; Western et al. 2009) was followed whereby two adjacent ranches with different management systems were compared. These sites were; Mpala PR practicing livestock ranching and wildlife conservation, and Ilmotiok communal GR practicing pastoralism and wildlife conservation (see figure 2-1). The major difference between the two sites was the stocking densities (see table 2-1).

2.2. Methods

2.2.1. Second order cybernetic, key informants interviews (KII) and focus group discussions (FGD)

To evaluate innovations and transformations in natural and social capital assets management in pastoral group ranch, three approaches were used. They included second order cybernetic, key informant interviews (KII) and focus group discussions (FGDs). Details on how each of these approaches was applied are provided in chapter four.

2.2.2. Level of mammalian herbivory

Intensity of herbivory between PR and GR was estimated based on livestock and wildlife abundance as well as livestock stocking rates per ranch. Abundance of grazers and browsers were estimated based on surveys and peer reviewed publications (See Table 2-1). The GR stocking rate fluctuates intermittently depending on prevailing weather conditions with high stocking rates during rainy seasons when pastures and water are plenty and low stocking rates shortly after major droughts when livestock die or driven out to far off grazing areas outside the group ranch. Mpala however has maintained a stocking rate of 10-12 TLU[1]/km^2 in the last three decades soon after incorporating wildlife conservation as part of the ranch management objectives.

Table 2-1. Difference in abundance of livestock and wildlife between the two study sites (Private and group ranch) in Laikipia county, Kenya

Variables	**Weight per unit (kg)**	**Private ranch**	**Group ranch**
Land Area (Ha)		19000	3651
Stocking rate TLU/Km^2		10 -12	>25
Total cattle biomass (TLU)	207	2070	377
Total sheep & goats (TLU) (B)	19	4	320
Camel* (TLU) (B)	250		200
Total Livestock Biomass(TLU)		**2074**	**897**
Wildlife (TLU)			
Plain zebra (G)	166.3	602	5
Grevy’s zebra (G)	408	79	0
Thomson gazelle (G)	21	10	0.14
Hartebeest (G)	110.2	31	0
Buffalo (G)	388.6	199	2.5
Waterbuck (G)	158.1	44	0.3
Total biomass (grazers)		**965**	**7.94**
Eland (M)	295.3	160	4
Dik dik (B)	5	526	383
Impala (M)	40	618	36
Gerenuk (B)	38	0	1.52
Giraffe (B)	736	230	5
Elephants (M)**	3944.6	XX	XX
Total biomass (browsers)***		1537.7	950

---

[1] Tropical Livestock Unit (TLU) is equivalent to live weight of 250 Kg. camel = 1TLU, cattle = 0.7 TLU, sheep/goat = 0.1 TLU (source FAO, 1986).

Area availability for browsers (ha/TLU)	**12.6**	**3.8**
Total livestock & wildlife (TLU)	4572.7	1334.4
Densities of both wildlife & livestock (TLU/Km^2)	24	37

Data sources (Augustine 2003a; Georgiadis, et al. 2007; Kinnaird & O'Brien 2012; Ngene et al. 2013; Kaye-zwiebel & King 2014). (M) Mixed feeders, (browse and graze), (B) browsers, (G) grazers.

* Camels were introduced in Mpala in 2011 as part of an experiment and were highly regulated. Camel TLU was therefore not added to total livestock TLU.

** Laikipia county is a closed system for wildlife herbivores except elephants capable of migrating and out of the county seasonally. Elephants biomass were therefore omitted from this analysis because they are highly mobile, and tend to unduly skew biomass densities(Georgiadis, Olwero, et al. 2007).

*** The values for goats/sheep and camels were included.

Mixed feeders and browsers constitute the most effective biomass as far as woody plants herbivory are concern and this makes GR three times heavily browsed than PR

2.2.3. Vegetation sampling (Line transects with nested plots)

Vegetation sampling was done to investigate objective two, three and four. To compare effects of mammalian herbivory on vegetation dynamics, a permanent large plot measuring 0.5 x 3 km established at the PR (Mpala) in 2011 was used as a control plot (low to moderate intensity of herbivory) and a similar plot was established in the GR (high intensity of herbivory). To minimise differences on abiotic variables between sites (soils, elevation, and topography), the site for laying the GR plot was purposely selected. In each large plot (0.5 x 3 km) per site, three line transects (each 3 km long) were established. The first transect was randomly selected and the other two laid parallel at 200 m apart. In each site all woody species with stem diameters of at least 10 mm and more measured at 0.5 m above the ground – diameter at knee height (DKH) were enumerated using (20 x 20 m) subplots nested in each transects, modified from Young et al, (1998). Each transect had 75 subplots making a total of

225 subplots per site. From the line transects, vegetation data collected, methods and tools used are summarised in table 2-2.

Table 2-1. Structural parameters measured, units of measurement and tools used in the study

Parameter	**code**	**Units**	**How and Tools used**
Stem diameter	DKH	cm	Used a diameter tape
Height	H	Metre (m)	Dynamic Telescopic measuring rod
Crown diameter	CRWN	metres	Averaged two perpendicular measurements. Tape measure
Crown depth	CD	metres	Difference between maximum height (H) and the height of the lowest leafy branch. Used Dynamic Telescopic measuring rod
Basal area			Calculated as $\pi * r^2$ where r is radius of stem
Species abundance			Woody plant densities in 20 x 20 m subplots were used as indicators of species abundance. All individual plant species that qualifies based on cut-off criterial were counted and their numbers divided by unit area.
Species frequencies			Calculated as a percent based on the number of subplots a species occur in all the subplots sampled.
Species relative density			Calculated as percent based on the number of individual of a given species per plot divided by all individuals.
Tree cover	TC	% area	Visual estimate based on the (20x20 m) subplot area
Shrub cover	SC	% area	Visual estimate based on the (20x20 m) subplot area
Herb cover	HC	% area	Visual estimate based on the (20x20 m) subplot area
Bare ground	BG	% area	Visual estimate based on the (20x20 m) subplot area
Invasive species abundance			The cover estimate for invasive species was based on AFOR system (Abundant, Frequent, Occasional and Rare). The vegetation subplots were subdivided by drawing diagonal lines to create 8 units. The abundance ranking was as follows; **A**≥7/8, 6/8 ≥**F**≤5/8, 4/8≥**O**≤3/8, **R**≤2/8.

Species composition was evaluated based on the sampling subplots described above where all woody individuals were identified to species level and grouped into families per site. Species diversity was calculated using Shannon Weiner formula, $H' = -\Sigma \{(ni/N) \log (ni/N)\}$.

2.2.4. Functional traits measurement

To determine functional traits diversity, procedures provided by Cornelissen et al., (2003) were followed in measuring and analysing functional traits parameters. The species selected for traits analysis were those reported as highly acceptable (palatable) to browsing animals (goats & camels) used as surrogate for all other browsers in the study site) based on interviews with the members of the local community and from published literature (Lusigi et al. 1984). Three most acceptable and fairly dominant species selected included *Acacia etbaica*, *Acacia brevispica* and *A. mellifera* for Mpala and *A. etbaica*, *A. mellifera* and *A. tortilis* for Ilmotiok. Details of the methodology are provided in chapter five.

2.2.5. Browse biomass (Double sampling branch method)

This biomass estimates were done for only target species identified in 2.2.4 above given that they were the most dominant palatable species and therefore made significant contribution to available forage. The biomass was estimated using double sampling method as described by Foroughbakch et al., (2008). Details are provided in chapter six.

2.2.6. Soil sampling

Whereas care was taken to minimize variation in abiotic factors between sites, soils samples were collected from each for comparison. Soil data was used in chapter five to isolate edaphic factors that may have influence plant traits, in canonical correspondence analysis (CCA) in chapter six to decipher their effects on species distribution as well as in chapter seven on invasive species abundance and spread. Forty five soil samples were collected per site to make 90 samples in total. The subplots where soils were sampled were purposely selected to encompass various soil texture, colour and vegetation types. In each subplot, 5 subsamples were augured 0-30 cm deep from each of the four corners and at the centre and lumped into one composite sample. The composite samples were sun-dried and later transported in labelled zip-lock bags to National Agricultural Research Laboratories, Nairobi for further processing and analysis. Soil texture was tested using feel flow chart system (Vagen et al., 2010). The field sampling, handling and testing followed procedures expounded by Anderson and Ingram (1993); Vagen et al., (2010) and Okalebo et al (1993).

Standard methods were followed in macro-nutrients chemical analysis as follows;

Available nutrient elements (P, K, Na, Ca, Mg and Mn): The Mehlich Double Acid Method was used (Mehlich, 1984). The oven - dry soil samples were extracted in a 1:5 ratio (w/v) with a mixture of 0.1 N HCl and 0.025 N H_2SO_4. The elements; Na, Ca and K were determined using a flame photometer and P, Mg and Mn using a spectrophotometer.

Total organic carbon: Calorimetric method was used (Murphy and Riley, 1962): All organic C in the soil sample was oxidized by acidified dichromate at 150^0C for 30 minutes to ensure complete oxidation. Barium chloride was then added to the cool digests. After mixing thoroughly digests were left to stand overnight. The C concentration was then read on the spectrophotometer at 600 nm.

Total nitrogen: Kjeldahl method was used (Benton, 1991); Soil samples was digested with concentrated sulphuric acid containing potassium sulphate, selenium and copper sulphate hydrated at approximately 350^0C. Total N was determined by distillation followed by titration with H_2SO_4.

Soil pH and EC was determined in a 1:1 (w/v) soil – water suspension with pH – meter and conductivity meter respectively.

Available trace elements: Extraction with 0.1 M HCl: The oven - dry soil samples were extracted for trace elements (Fe, Zn & Cu) in a 1:10 ratio (w/v) with 0.1 M HCl. Elements amounts available were determined with Atomic Absorption Spectrophotometer (Black et al., 1965) .

Extractable Phosphorus: Olsen method (Olsen et al., 1954) (for soils with pH 7.0 and above was used): The dried soil samples were extracted in a 1:5 ratio (w/v) with 0.5M sodium bicarbonate solution at pH 8.5. Extractable phosphorus was determined spectrophotometrically.

2.2.7. Topography (% slope and elevation)

Percentage slope was estimated using clinometer and dynamic telescopic measuring rod, while elevation was measured using GPS receiver. This was done per subplot.

2.3. Data Analysis

Different analyses were done for the various chapters (see chapters 4, 5, 6, and 7 for specific analysis).

CHAPTER THREE

LITERATURE REVIEW

3.0. Introduction

The determinants of savanna are acknowledged as climatic factors, soil, fire and herbivory (Sankaran & Anderson, 2009; Sankaran et al., 2005). Rainfall and temperature (climatic) and soil properties are considered key determinants of savanna biomes while fire and herbivory are considered modifiers (Sankaran & Anderson, 2009). It has been argued that disturbances from fire and grazing play a major role in shaping changes on the savanna vegetation especially in environments receiving mean annual precipitation above 650 mm (Sankaran et al. 2005; Staver et al. 2009). A number of studies have been carried out to investigate the impact of grazing/herbivory on vegetation, however, the results have often been contradictory (see Anderson and Hoffman 2007; Allred et al. 2012; Arévalo et al. 2011; Hayes and Holl 2003). Some studies have shown a positive feedback mechanism where increase in grazing promoted species abundance, richness and/or diversity (Arévalo et al. 2011; Herrera, 2011; Papanikolaou et al. 2011). Conversely, other studies have observed a negative relationship where increase in herbivory resulted in decline in species abundance, diversity or loss of some functional types (Keya 1998; Moolman & Cowling 1994; Staver et al. 2009).

Previous reviews have greatly improved our understanding of the subject however some have either been too broad-based and global in nature (Asner et al. 2004) thus concealing localised unique variations or actors at play. Moreover, contradicting opinions within same geographic region makes such generalisation difficult to implement (Belay et al. 2013; Tefera et al. 2007;

Yusuf et al. 2011). Given the many varying views on the subject, conservationists and range managers have been left with no clear message on which steps to take in managing biodiversity as well as range productivity. Most countries in Eastern Africa banned the use of fire in management of rangelands, a policy directive currently blamed for the increase in woody species encroachment (Angassa & Oba 2008; Augustine & Mcnaughton 2004; Belay et al. 2013). Similarly, goats are considered destructive to forests/shrubland in Kenya and therefore not allowed into government protected areas (e.g. Forest Reserves) a cue followed by several private ranch managers in the country. Intense herbivory has been blamed for a host of environmental ills such as shifts from perennial grasses to annuals (Anderson & Hoffman 2007; Cornelius & Schultka 1997; Fynn and Connor 2000); soil compaction and increase in soil erosion (Cingolani et al. 2003; Tanentzap & Coomes 2012; Wardle 1999); decline in palatable species and increase in non-palatable species (Al-rowaily, et al. 2012); aids exotic plants invasion, establishment and spread (Vavra et al. 2007) and increase in woody plants encroachment thus reducing available grass to grazing livestock (Asner et al. 2004; Moleele & Perkins 1998; Moleele et al. 2002; Moolman & Cowling 1994; Skarpe, 1990).

Despite negative undertones, woody plants form a critical component of the semi-arid savanna (Belsky et al. 1989; Belsky & Canham 1994; Hagos & Smit 2005; Sankaran et al. 2004; Tredte et al. 2007, 2010). Woody plants provide habitats, shade and forage for ungulates and other animals yet the browse–browser interactions that regulates heterogeneity of the savanna systems remains unclear (Augustine & Mcnaughton 2004b; Levick & Rogers

2008; Staver et al. 2009). Plant responses to herbivory could be (a) mechanical/structural such as establishments of spines, pubescence, sclorophylly, prostrate habit among others to resist herbivory (b) chemical such as production of secondary metabolites e.g. phenolics, alkaloids etc. (c) phenological where plants avoid damage to sensitive organs by altering the life cycles e.g. early flowering or (d) recruitment of herbivores natural enemies (Hanley et al. 2007; Kessler & Heil 2011; Rasmann & Agrawal 2009). This synthesis restricted itself to analysis on woody plants mechanical response to ungulate herbivory. The basis for this analysis was to answer three questions (1) what are the morpho-functional traits changes attributable to ungulate herbivory? (2) What are herbivory-induced changes at community level - species composition and structure? (3) What role do ungulate herbivory have on habitat invasion by both native and non-native plant species?

The type of defence employed by a given plant is dictated by the size of herbivore most likely to attack (Hanley et al. 2007) and in this regard, only traits linked to large herbivores (> 5 kg) were reviewed because of high diversity and density of ungulates in the savanna (Sankaran & Anderson 2009). The unresolved ‘savanna problem’ debate on tree-grass co-existence and shifting paradigms between equilibrium, non-equilibrium, dis-equilibrium or a combination of states has featured prominently in ‘the herbivory factor’ (Accatino et al. 2010; Kambatuku et al. 2011; Meyer et al. 2008; 2009; Sankaran et al. 2004; Buitenwerf et al. 2012). In the absence of fire, herbivory shall remain sole critical modifier to savanna determinants.

To undertake this review, publications with the terms such as, “herbivory”, “ungulate herbivory”, “browsing”, “woody plants grazing”, “savanna”, semi-arid, was searched using ISI search, Google Scholar, Wiley Online Library and Science Direct. A total of 335 relevant publications were derived, majority consisting of studies done within tropical and sub-tropical savanna. The Africa savanna literature was dominated by studies from Southern Africa. Currently there is increasing acceptance that functional traits and functional types are better predictors of disturbance impacts under varying ecosystems than species-based approach (Díaz et al. 2001; Rusch et al. 2003). The proponents of functional-traits approach have gone ahead and built a database and taxonomy of traits with high predictive ability to various types and levels of disturbances (Kattge et al. 2011).

3.1. Morpho-functional traits response to herbivory

Herbivory affects plants directly through reduction of biomass during consumption, or indirectly by altering competitive balance between individuals or abiotic environment such as soil temperature via modification of vegetation structure (Gabay et al. 2011). Induced response from herbivory could entail regrowth, death of tissue and loss of fitness, or morphological modifications that lead to increased tolerance or resistance (Augustine & Mcnaughton 1998; Karban & Myers 1989). Morpho-functional traits modifications due to herbivory of woody plants has however received little attention perhaps partly due to the implicit assumption that woody plants are inherently lower in their compensatory potential as compared to herbs or due to the fact woody plants have long lifespan and therefore responses may take several years to emerge (Haukioja & Koricheva 2001).

3.1.1. Tolerance to herbivory

Tolerance refers to a plant's ability to minimise the impact of herbivore damage on plant fitness and this is reflected in traits such as intrinsic growth rate, storage capacity, and flexibility in nutrient uptake, photosynthetic rate and development (Hanley et al. 2007). Tropical savannas have co-evolved with fire and herbivory. It is logical therefore that plant species in these ecosystems have found ways through which to tolerate these two forms of disturbances. Africa savannas are dominated by the "Acacias" species and it comes as no surprise that the bulk of the ungulate forage comprises these highly nutritious plants. Accordingly, many savanna species have evolved high tolerance traits to cope with persistent defoliation. Some of the strategies include high regrowth abilities in shoots and leaves, high annual branch growth rates, extensive tree branching and internal N translocation thus allowing for compensation or overcompensation for the lost tissues as seen in *Acacia nigrescens* (Du Toit et al. 1990; Fornara & du Toit 2007).; Similar observation noted among *A. tortilis* (Oba & Post 1998; Oba & Post 1999), *A. karoo* and *A. nilotica* (Tsumelele et al 2009), and *Acacia erubescens* (Dangerfield & Modukanele 1996). Interestingly, palatability of some of these tolerant species improves with increased herbivory thus promoting repeated browsing (Du Toit et al. 1990).

It is also true that some species in these systems record under-compensation or experienced tissue death as a result of herbivory. Severe damage or mortality solely due to defoliation or in combination with other factors such as fire, rainfall, or ontology have also been reported among *Sclerocarya birrea ssp. Caffra* (Helm, et al 2011) and S*edera hirsuta* (Oba 1992).

3.1.2. Resistance to herbivory

Species that come under constant attack from herbivores and have no tolerance traits may acquire induced or constitutive traits for avoidance to browsing that are either structural (e.g. spines, prickles, thorns, sclerophylly, trichomes or pubescent leaves) or chemical (Hanley et al. 2007; Karban & Myers 1989) yet some have indirect defense where plants attract herbivores' natural enemies (Kessler & Heil 2011) . Some of these strategies have been successful in keeping off herbivory while some herbivores have evolved to counter plants protective traits (Sebata 2013).

Leaf morpho-functional traits concomitant with grazing response supported in a number of studies include leaf area (LA), specific leaf area (SLA), Leaf dry matter content (LDMC), and trichomes (Cornelissen et al. 2003; Hanley et al. 2007; Meers et al. 2008 ; Lavorel et al. 2007 ; Louault et al. 2005 ; Rusch et al. 2003).. Low values of SLA are associated with high investment in defence mechanism and thus increasing intensity of herbivory corresponds with declining values. A similar trend is expected with leaf area (LA). On the contrary, high LDMC values are associated with high leaf toughness (sclerophylly) and would exhibit a positive relationship with heavy grazing (Rusch et al. 2009). Emergence of tough leaves deter herbivores from browsing them because of high energy required to chew or tear, or reduces palatability and digestibility with increase in lignified substances (Hanley et al. 2007). The predictive power of SLA response to herbivory though supported by Meers et al. (2008) has been challenged (Díaz et al. 2001; Rusch et al. 2009). Plant trichomes are straight, spiral, hooked or glandular hair-like appendages occurring on leaves, stems, and sometimes fruits. Its evolutionary function is thought to include protection from excessive heat and water loss, UV light radiation, resistance to drought conditions or facilitation of seed dispersal (Gondard et al. 2003; Hanley et al. 2007). It has also been established that pubescence confer plants protection against herbivory from insects.

Beside leaf morpho-functional traits, whole plant traits such as growth form, plant height, and spinescence have been associated with defense against herbivory (Cornelissen et al. 2003; Sebata 2013; Young et al. 2003). Growth form, plant height and phenology (e.g. time of flowering) has shown consistent reliability in predicting impact of herbivory (Rusch et al. 2009). Woody plant responses to intense herbivory are also portrayed in the changes in reproduction and germination success. Herbivory may suppress reproduction in a number of ways, (1) feeding on the immature fruits (2) removal of photosynthesizing shoots/biomass (3) inducing costly defence thus diverting energy meant for reproduction (Young & Augustine 2007). In an exclusion experiment done in a Kenya savanna, it was observed that *A. drepanolobium* trees were twice as likely to reproduce and those that reproduced produced a greater biomass of seeds in the absence of native herbivores. This observation was attributed to physical removal of biomass as in 1 and 2 above but also due to costly investment in defence through establishment of large thorns exemplified by negative relationship between length of spines and reproduction (Goheen et al. 2007). Seed dormancy, a trait common in a number of savanna plants is useful in protection against predation and adverse climatic condition but present challenges during seed germination. Some species of Acacia genus have synchronised their fruiting and seed set to coincide with the dry season perhaps as a phenological strategy to avoid immature pods being browsed during the growth period (wet season) or to facilitate seed dispersal and germination. This strategy may be evolutionary in nature. When Seeds are ingested and go through animal digestive system without being harmed is a novelty that has undoubtedly promoted the undisputed dominance of this genus in many African savanna ecosystems.

3.2. Herbivory-induced changes in species composition and structure

The impacts of ungulate herbivory on woody plants structure and composition are particularly crucial debate at the present given the increasing role played by browsers (goats and camels) in pastoralists' economy in eastern Africa savanna as climate variability and change evolves. Camels and small stock (particularly goats) are being promoted as a strategy to adapt with climate variability (Desta & Coppock 2004; Huho et al. 2011; Gezahegn 2006; Ojwang' et al. 2010) in arid and semi-arid regions of Kenya and Ethiopia. Moreover, there is unprecedented increase in woody species (both native and non-native) in eastern and southern Africa savanna blamed on 'the no burning policy' and heavy grazing (Augustine & Mcnaughton 2004b ; Angassa & Oba 2010; Gemedo et al. 2006; Moleele et al. 2002; Yusuf et al. 2011) or most recently increase in carbon dioxide attributed to climate change (Buitenwerf et al. 2012).

To put in perspective, we scrutinized studies looking at livestock ungulate in managed systems where herbivory is supervised through herding. A comparative study on the effects of goat and elephant browsing in succulent thickets in South Africa noted reduced cover and diversity of endemic geophytes and succulent shrubs under goats and moderate change under elephants (Moolman & Cowling 1994). Congruent to this observation, Mills et al. (2005) stated that intensive goats pastoralism transformed semi-arid thicket from dense vegetation to open landscape dominated by ephemeral grass and forbs. These contradict findings from four goats exclusion experiments done in different regions (Fernández-Lugo et al. 2009; Hester et al. 2006; Oba 1998; Riggs & Urness 1999) where they all concluded that there were no significant changes in species composition between browsed and un-browsed sites except for variation in species growth rate and production.

Given the contrasting views, the question then is; do goats destroy forest? The answer to this question would be in the affirmative given that policy regulations prohibits grazing of goats in government forests and other protected areas in a number of eastern Africa countries. In the recent past a number of studies have somehow contested this perception (Allred et al. 2012; Mancilla-Leyton and Vicente 2011; Mancilla-Leytón, et al. 2013). In their views, there is no direct positive relationship between increase goats browsing and degradation but certainly, goats can preserve forest by reducing fire incidence through reduction of flammable materials and weeds encroachment (Jáuregui et al. 2009; Lu 1988). Though not entirely mutualistic relationship, ungulate herbivory has been credited as promoting increase abundance and richness of some plant species directly by tilting biotic competition or indirectly by modifying abiotic environments. Herbivores browse selectively for plants with high nutritive contents and low levels of structural or chemical defences (Mysterud 2006) thus affecting competitive process between palatable and non-palatable species (Augustine & Mcnaughton 1998) or woody plant and grass (Goheen et al. 2010). Herbivory causes removal of sizeable proportion of plant biomass thus altering resource requirement to damaged plants. Changes in relative abundance of preferred species due to herbivory are subject to relative degree and temporal pattern of tissue loss and how each response to defoliation in term of survivorship, regrowth, reproduction and competitive ability (Augustine & Mcnaughton 1998). In situation where the preferred plants are rare, heavy browsing may cause local extinction lowering species richness in the short term or reduction in seed production that built into the seed bank changing future species composition (Tessema et al. 2012).

Beside direct impact on defoliated plants, herbivores increases soil nutrients from accumulation of dung and urine especially from livestock ungulate around kraals (Augustine 2004; Ellis and Swift 1988; Reid and Ellis 1995; Riginos and Herrick 2010). Enhanced soils nutrients facilitate growth of species that would otherwise would not occur thus changing species composition. Abiotic environment is also modified by browsing of tree canopies by livestock or wildlife (e.g. by goats or giraffes) and in the process reduces their densities hence improve light penetration and soil temperature at the surface (Gabay et al. 2011). Improvements in light penetration accelerate growth of shade intolerant species beneath the canopies. Additionally, herbivory suppresses tree densities by imposing a demographic bottleneck on the maturation of saplings to adults and this allow grasses to grow and co-exist with woody plants (Fornara & Du Toit 2008; Higgins et al. 2000; Staver et al. 2009). This process alters the vegetation structure given that saplings of some species are maintained at certain browsing height, canopy area and diameter for many years awaiting the opportune time to advance into mature stage (Noumi et al. 2010).

3.3. Factors influencing herbivory response

A number of studies have indicated that vegetation response to disturbances be it from fire or herbivory is dictated by prevailing biotic or abiotic environment or both (Aarrestad et al. 2011 ; Fornara & Du Toit 2008 ; Hanley et al. 2007 ; Scogings & Mopipi 2008 ; Scogings & Mopipi 2008). According to Gabay et al. (2011), goats browsing impacted herbaceous vegetation directly from consumption but also indirectly through modification of woody plants structure above them. Browsing of woody plants reduced their canopy densities thus enabling more light into the soil surface and improves growing conditions for species that are shade intolerant. Responses to goat's grazing was also affected by species composition itself whether majority existing plant species were grazing averse or grazing tolerant (Jáuregui et al. 2009; Navarro et al. 2006). The herbivore species and habitat also affect the outcome of herbivory. Plants tend to be vulnerable to attack from various herbivores at different stages of their growth depending on preferred grazing height. For instant, elephants are known to prefer browsing on plants taller than 2.5 m (Augustine & Mcnaughton 2004a), yet this is escape height against herbivory from most of browsing ungulates such as goats, impala, eland, etc. The herbivore type also dictates the extent of damages caused from browsing as well as response to the same (Bergström et al. 2000). Debarking, stripping, and stem breakage common with elephants causes more damage to woody plants and may result in death of individuals when compared with biting of leaves and young shoots. Death may result from inability by the plant to photosynthesise due to excessive removal of above ground biomass, inability to transport water and minerals from the soil due to damage of xylem tissues from debarking or from "secondary aggressions" such as attacks from fungi, insects on damaged tissues and/or tilt competition in favour of non-browsed neighbouring plants. Frequency of herbivory, nutrients availability and damage timing also influence the plants induced responses (Scogings et al. 2013). Presence of grazers is yet another modifier to browsing induced-species assemblages. In a rather idiosyncratic relationship, Goheen et al. (2010) observed that *A. drepanolobium* seedlings establishment were indirectly facilitated by hervivory by large mammals (wild and domestic) through suppression of rodents who are major predators of seeds and seedlings, talk of attracting the enemy or a mere coincidence? Cattle (predominantly grazers) were observed to promote *A. drepanolobium* seedlings growth by reducing competition from grass while browsing wildlife suppresses growth. This means *A. drepanolobium* persistence in an ecosystem is subject to the net effect of browsers and grazers (Goheen et al. 2010; Riginos & Young 2007).

Herbivory in resources limited environment has been shown to triggers increase in carbon relative to nitrogen and this promote production of tannins that limits herbivory while in the opposite conditions, C decline relative to N resulting in suppressed tannin levels (Scogings et al. 2013). A review paper by Vesk and Westoby (2001) concluded that species were more likely to decrease under grazing in lower rainfall than at higher rainfall regimes. This compares with Teague et al (2004), where they observed that species richness and diversity decreased with increasing soil nutrients and level of herbivory among herbaceous and woody plants less than 50 cm in height (see Aarrestad, et al. 2011). There is a strong interaction between soil and light availability and herbivory in their influence on composition, species richness and structure (ibid).

3.4. Influence of herbivory on habitat invasion

The causes of shrub or woody plant encroachment in semiarid grasslands throughout the world have been much debated. Most often cited as reasons include; climate change, chronic high levels of herbivory, change in fire frequency, changes in grass competitive ability, spread of seed by livestock, small mammal populations, elevated levels of CO2, and combinations of these factors (Auken 2000). Unfortunately, many situations present a case of “chicken and egg” which come first. Climate change is predicted to drive the process of biodiversity loss, bush encroachment, spread of invasive species, degradation and desertification at the same time land-use and management has also been cited (Wigley et al. 2009; 2010). Herbivory together with prevailing climatic conditions have also been linked to bush encroachment and non-native species invasion (Eckhardt et al. 2000; Moleele & Perkins 1998; Vavra et al. 2007; Yusuf et al. 2011). There are four possible avenues through which invasion/encroachment is enhanced by herbivory (1) modification of abiotic environment through trampling and movement making it suitable for the establishment of invader species (2) tilt competition in favour of non-palatable species and (3) facilitate propagules via endozoochory and epizoochory means (Chytry et al. 2008; Jorg et al. 2004; Vavra et al. 2007), and (4) most important is the tolerance traits to herbivory where tolerant thrive over non-tolerant species (Fornoni 2011; Sebata 2013). Admittedly, species invasion modifies vegetation composition and structure however; it is unclear whether both native and non-native invader species undergo similar stages of invasion, establishment and expansion. Compared to non-native species invasion, there is limited literature on native species “invasion” or invader or encroaching species.

Notwithstanding the benefits associated with bush encroachment as expounded by Eldridge et al. (2011) increased density of woody plants reduces the quality of land for animal production (Asner et al. 2004) and negatively affects habitat quality for some wildlife species e.g. open savanna specialists (Riginos & Grace 2008). Furthermore, recent correlation between bush encroachment and rise in carbon dioxide in the atmosphere associated with climate change (Buitenwerf et al. 2012) put existing policies in management of the same back to the drawing board. There is need therefore to isolate management issues that compound process of bush encroachment and species invasion.

3.5. Conclusions and research gaps

There is a general agreement among scientists on traits concomitant with grazing as well as their responses to herbivory though predictive strength among morpho-functional traits may vary. Herbivory- induced changes in species composition and structure are modified by prevailing biotic and abiotic factors and thus making recommendations site specific. Due to herbivores selective behaviour and high variation in responses to herbivory, it is imperative that net ecological costs for mechanical responses at community level are determined. To this effect this study proposed that future studies investigating browser – browse interactions must select species that are palatable and contribute the most biomass to the community in line with Grime (1998) biomass ratio hypothesis to capture major ecosystem changes both biotic and abiotic. More studies are needed to elucidate cost effectiveness of combining tolerance and resistance defense a ubiquitous strategy among savanna plants. There are limited studies looking at effects of woody plants herbivory on ecosystem services such as forage production (quality and quantity), nutrients cycling, and habitat invasibility/bush encroachment.

CHAPTER FOUR

TRACING INNOVATION PATHWAYS IN THE MANAGEMENT OF NATURAL AND SOCIAL CAPITAL ON LAIKIPIA MAASAI GROUP RANCHES, KENYA

Paper published in Pastoralism: Research, Policy and Practice (2016) 6:16

Abstract

Group ranches (GRs) were established in Kenya in the 1960s and 1970s; their objectives included the increase of pastoral land productivity and the control of land degradation. Since their establishment, GRs have evolved and new trends have emerged in resource management with significant impact on socio-ecological systems (SESs). Little is known about these changes on the GRs in Laikipia County. The central thesis for this study was that GR level-driven and/or collective action innovations are socio-ecologically more resilient compared to household/individual-level strategies. This study investigated emerging innovations, their drivers and perceived and felt impacts, using Il Motiok GR as a case study. Tools used included semi-structured interviews, key informant interviews, focus group discussions and second order cybernetics. Qualitative analysis using SPSS software was done. The results showed that emerging innovations could be divided into either household/individual- or community-level-driven processes. Some of the innovations in natural capital management included the trading of grazing rights, expansion of traditional enclosures, adoption of 'new' livestock species and/or breeds, and crop cultivation. Household-level-driven innovations were influenced by wealth status, age and level of education. Economic returns and to some extent the greater good influenced community-driven initiatives. Formal groupings such as self-help groups and business associations were replacing declining traditional social

networks based on clans and age sets/groups. Climate change, development agencies, cultural and technological change and neighbourhood social learning are perceived as having inspired the innovations. Innovations that fragmented natural and social capital were inclined to limit socio-ecological resilience. Implementation of new interventions among communities must factor in the possibilities of transformation and/or emergence of new innovations beyond those initially conceptualised as implementation progresses. Supportive policies that recognise the increasing complexity of common property use are needed to address emerging 'new' land use changes. Furthermore, there is need to nurture emergent promising innovations and stop those considered detrimental to the sustainability of SESs.

4.0. Introduction

Pastoralism in eastern Africa has faced many challenges in recent decades, including an increase in climate variability and subsequent effects on forage and water availability, the declining authority of traditional institutions that effectively managed range resources in the past (Bekure et al. 1991; Sundstrom et al. 2012), reduced access to grazing land attributable to changes in tenure systems and other policies (Thornton et al., 2006), as well as the increase in human population (Bekure et al., 1991; Kiteme, et al., 1998). The devastating drought events of 1969, the 1970s and the 1980s, with significant reliance on international food aid, together with the initiation of range development trials increased the vulnerability of pastoral communities (Oba 1994). Experiments with range development projects such as range enclosures, block grazing, group ranches, range improvement and rehabilitation were implemented across the eastern African rangelands with the goal of building or restoring the resilience of ecosystems. At the same time, alternative economies to pastoralism that involved sedentarization (for example dryland farming, irrigated agriculture and fisheries) were also introduced, often with minimal success (Oba 1994). The establishment of group ranches (GR) seems to have received more attention than other policies. There is an extensive literature on the establishment of GRs, pointing out some of the inherent problems of the model as well as challenges to their implementation (Bekure et al 1991; Coldham 1982; Galaty, 1994; Kimani et al 1998; Ngethe, 1992; Peacock 1987). In the last decade, several studies have focused on impacts of the subdivision of GRs subdivision to plots held under individual freehold tenure. Such impacts are may be on wildlife (Wayumba et al. 2006; Western et al. 2009); on the livelihood of agro-pastoral households (Burnsilver & Mwangi, 2007; Thornton et al. 2006); on livestock populations (Boone et al. 2005), and on social capital and traditional management systems (Sundstrom et al. 2012). A recent development in transformation of GRs has been the establishment of grazing associations, in which friends or neighbours agree to graze their privately owned land jointly, with the aim of increasing livestock mobility and thus avoiding land degradation from year-round grazing (Burnsilver & Mwangi 2007). Significant amount of research have been done on Maasai GRs, but most of these studies focused largely on the southern Kenya rangelands, particularly those in Kajiado and Narok Counties. Fewer studies have been done on the Laikipia Maasai GRs (Hauck, 2013).

Despite the underlying similarity of objectives and circumstances among most GRs at their establishment, since then the southern and northern rangelands GRs have differed in their evolutionary paths. One notable divergence between them is the increased individualisation of operations in southern GRs, compared to the retention of fairly collective actions in the north. At the time of writing, the northern GRs have yet to subdivide their land into individual freehold parcels. In the recent past nine GRs have ‘consolidated’ their land parcels for wildlife management and conservation under an umbrella body, Naibunga Wildlife Conservancy. These efforts seemed to have paid off in view of the fact that the region has the second largest population of wildlife outside the protected areas of Kenya, with equally increasing livestock populations (Kinnaird, et al. 2012; Ngene et al. 2013; WRI et al., 2007).

The central thesis in this study is that group ranch-level driven and/or collective action-based innovations in management of livelihood assets are more social-ecologically resilient in comparison with household/individual driven innovations. Despite being on the receiving end of a number of significant negative forces, including the loss of large areas of grazing land through the 1904 ad 1911 treaties imposed by the colonial government (Keen, 1962), the land fragmentation that accompanied the GR policy, and broader forces associated with increased globalisation, the socio-ecological systems of the Laikipia Maasai have survived fairly well.

Social-ecological system (SeS) in this context is used to refer to a GR made up of nature (e.g. water, pastures), and humans (e.g. their beliefs and practices), as well as combined human-nature systems that are shown in co-evolved systems of management (adopted from Holling, 2001). The capacity of these SESs to absorb disturbance and reorganize while undergoing change but still retain essentially the same function, structure, and feedbacks indicates some level of resilience of the fundamental livelihood assets. Livelihood assets are people's strengths (capital endowments) that can be converted into livelihood outcomes (DFID, 1999). They may be tangible (e.g. trees, land etc.) or intangible (e.g. access to education, information, etc.). Nurturing and combining a range of these assets (such as natural, financial, human, social, or physical) in innovative ways enables people to achieve positive livelihood outcomes.

Livelihood diversification and land use change in the arid and semi-arid lands of eastern Africa (including Laikipia) have been the subject of many studies (Campbell et al. 2003; Desta & Coppock 2004; Galvin 2009; Jillo et al. 2006; Olson et al. 2004). Different concepts have been put forward as inspiring livelihood diversification in arid and semi-arid regions. Among the Turkana for example; impacts of drought, increasing insecurity and famine that has forced sedentarization of once pure nomadic and semi-nomadic pastoralists to explore alternative livelihoods (Watson & Binsbergen, 2008). There are examples of movement to non-pastoral livelihoods such as tourism, petty trades, fishing, wage employment and cultivation. Alongside livelihood diversification debate is the aspect of climate change and its impact on pastoral livelihood. Some scholars perceive pastoralists as vulnerable to climate change while others view them as as the most capable to adapt to climate change, since pastoral livelihoods are shaped to deal with scarce and variable natural resources (Nori & Davies, 2007).

This study aimed at understanding innovative pathways in the management of pastoral livelihood assets among the GRs in Laikipia County. Il Motiok GR was used as a case study to investigate the unpredicted ‘innovations’ in the management of natural and social capital. Key questions that were addressed included the following: what are emergent innovations in GR management of natural and social capital at both household and larger community level among the Laikipia Maasai? What drives the innovations; and What are the perceived and felt impacts of the innovations on the resilience of the socio-ecological system (SES)?

4.1 Conceptual framework

All traditional resource management systems are under constant change in response to stress, hazards, risks or opportunities and can be said to be in a form of adaptive cycle (Berkes et al. 2000; Walker et al. 2004). This study contends that in the absence of colonial and post-colonial intervention, the Laikipia Maasai (like other pastoralists) would have continued with their constant change in managing their livelihood assets in response to the uncertainty and unpredictability of their ecosystems due largely to climate dynamics. It is hypothesized that the creation of GRs and the accompanying policies altered the trajectory and probably also the rate of that change. Innovations in the management of natural and social capital and resultant resiliency are perceived as a function of climatic variables (e.g. rainfall frequency and amounts), government policy directives and the social learning gained from neighbours and other sources. Other less direct drivers may include prevailing economic trends (market trends), population dynamics (unprecedented increase in population), as well as advances in science and technology (e.g. Mobile phone technology) and, all of which have combined with other forces to cause significant cultural change (figure 4-1).

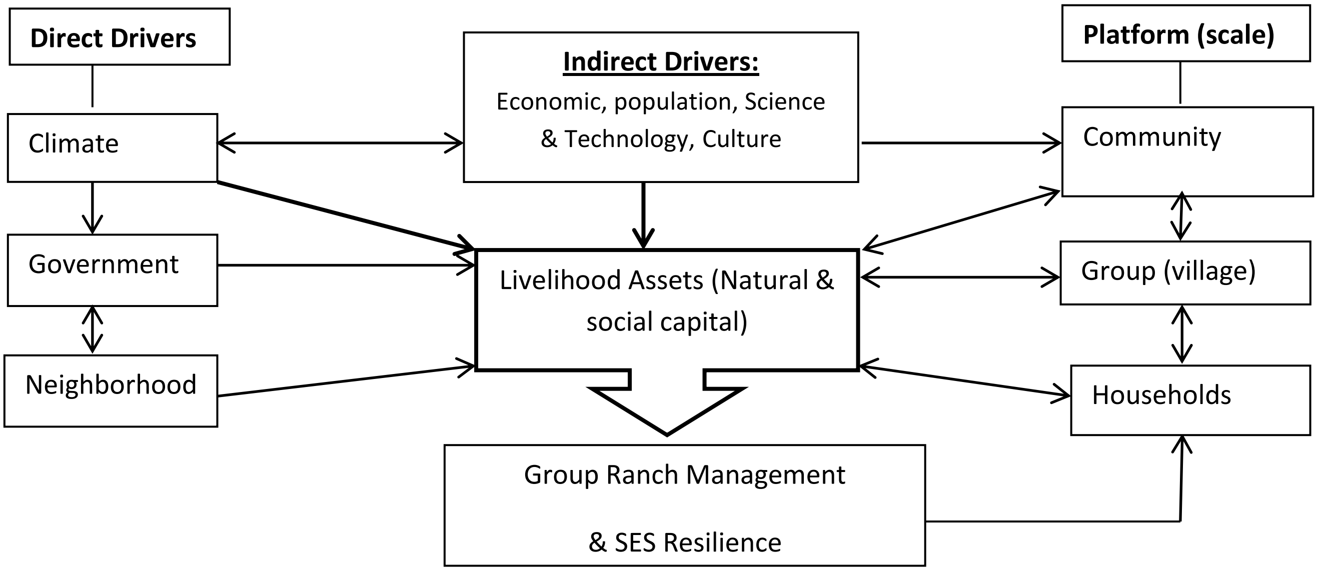

Figure 4-1. **Conceptual framework showing innovations in the SES of GRs**

It is also hypothesized that strategies adopted range from the household level (microsystem) to the level of the extended community (landscape). A previous study has shown that the level of vulnerability of households to climatic, economic and other shocks and the range of options they can access to address such shocks differs between wealthier and poorer households because of their capital endowment (Hauck, 2013). It is however too early to predict future sustainability of the emerging innovations but it is possible to speculate on their potential long-term effect on the resilience of SES. The term resilience is used to mean the capacity of an SES to sustain a desired set of ecosystem services in the face of disturbance and ongoing evolution and change (Biggs et al. 2012). The assumptions in this conceptual framework are that no external inputs get into the system and that no one among the population is transiting out of pastoral production system.

4.2. Study site

Laikipia county lies between latitudes 0^{o}18” South and 0 ^{o}51” North and between longitude 36^{o}11” and 37^{o}24” East. It covers an area of 9,462 km^{2}. Il Motiok GR is one of the 11 GRs in the region, lying in the northernmost part of the county. The GR covers an area of 3,651 ha and borders Mpala and Soita Nyiro private ranches to the west, Koija GR to the north, Tie Mamut GR to the east and Mukogodo private ranch to the south (see figure 2-1). The elevation ranges from 1550 to 1700 metres, with gentle undulating terrain. The ranch lies between two major drainage lines; Ewaso Nyiro River (permanent) and Losupukiai (seasonal river). The two drainage lines largely influence the use of the ranch with wet season grazing occurring towards Losupukiai and dry season zones towards River Ewaso Nyiro side because of access to permanent water.

Il Motiok GR lies on the Laikipia Plateau, a classical savanna ecosystem with a mosaic of clay, sandy and transitional soils. The county is rich in large savanna mammals such as elephants, giraffes, buffaloes, zebra, and several species of carnivores among others. Among the endangered fauna in this county are half of Kenya’s black rhino population, two-third of the world population of Grevy zebras, and the world’s sixth largest population of wild dogs (Boy 2011). The vegetation of the area is wooded savanna dominated by several species of acacia.

The county has a variety of land tenure and land use types. The biggest area of land (>50% of County land area) is categorized as large-scale ranching and farms. They are owned by individuals, companies, and state or government parastatals. A sizeable area was previously held under a 999 years lease which was later revised to 99 years (Kenya Constitution, 2010). Common land use types under this category include commercial livestock production, a combination of livestock production and wildlife conservation, and pure wildlife conservation (Conservancies). Small but expanding land use types in the county are the small-holder farms. These include parcels of land awarded during government resettlement programmes following Kenya's independence in 1963 together with privately acquired lands. They are mainly found in the south and south western parts of the county and their dominant forms of land use are crop cultivation and agro-pastoralism. Pastoralism is yet another category, practiced on land held under communal ownership with livestock production as the main economic activity. Communal group ranches that are the focus of this study fall within pastoralism land use category. Laikipia county also contains government forests, wetlands and rapidly growing urban settlements (Kiteme et al. 1998).

The study site has about 110 households with approximately 1000 inhabitants (Kaye-zwiebel & King 2014) spread across four villages namely; Nasirian, Lorupai, Losiagi and Il Motiok. The community keep cattle, sheep, goats and donkeys, and most recently have adopted camels and poultry. The livestock stocking rates vary greatly following seasonal fluctuations that dictate availability of pastures and water. In the recent past, active wildlife conservation has been introduced.

4.3. Methods

This study was conducted between April 2012 and March 2014. The data collected included emerging innovations in natural and social capital, factors motivating these innovations and felt and/or perceived impacts of the new strategies on sustainability of pastoral livelihood. Natural capital was considered to include pastures, wildlife, livestock, minerals, and vegetation while social capital included networks, gifting, reciprocity, employment, education, and wage remittance by relatives. Both primary and secondary data were used in this study. Strategies used to collect primary data included semi-structure questionnaires, key informant interviews (KII), focus group discussions (FGDs), and participants' direct observations through transect walks and photography. Both KII and FGDs purposely targeted men and women older than 40 years who had consistently lived in the area for more than 25 years, in order to benefit from their long-term experience. Key informant interviews were carried out both in Il Motiok and Mpala PR. Mpala ranch has had long term collaboration with Il Motiok and a number of its employees are residents of the ranch. Key informants included GR management committee officials, self-help groups' leaders, experienced herders and elders, and those in wage employment. In Mpala the management and long-serving staff were targeted. Twenty six KIIs were undertaken, six in Mpala ranch and the rest in Il motiok GR. Eight focus group discussions (FGDs), 2 in each village, were held in which 4 to 6 people participated. Separate FGDs were held for both genders to avoid male dominance in the discussions. Interviews and FGDs were held in the local Maa language with assistance from one woman and three young men, all fluent in both English and Maa languages. A total of 105, face to face interviews were carried out (targeting both men and women) making up

10.5% of the total GR population. Fifty two percent of the interviewee was women and the rest was men.

To appreciate household-driven initiatives and how those initiatives differed with level of wealth, two households, one ‘relatively rich’ household (with 35 TLU) and one relatively poor household (with 7 TLU) were selected. This poverty ranking was based on a household economy assessment undertaken in North East Turkana, Kenya (Levine & Crosskey, 2006). In this assessment, they observed that for a pastoral family to be able to feed its members and survive drought, each adult need 6 tropical livestock unit (TLU). Using second order cybernetic, the two households were observed for one season. Second order cybernetic is a tool not based on determining the facts on the ground but on observing the observer. For a second order observation, the question is not "What is there?" but "How does the observer construct what he constructs. It asks the questions “what are the distinctions that are used by the observed-observer?”(see Kaufmann, 2007). In the context of this study, we aimed at isolating information derived by the observer (household head) by observing ‘signals’ transmitted by trait carriers (livestock or environmental attributes) that interested him (those ‘signals’ that made meaning to him). Observing animals’ behaviors, or range conditions, send ‘signals’ about declining or improving quality and/or quantity of pastures and the need for the observer to take certain actions. This was done mainly through observing and recording the observer’s daily decisions and actions. Photography and transect walks guided by a community person were also done. Five Google earth maps (Image ©2014 Digital Globe) for 2007 to 2013 were used to observe land use changes and also to estimate the increase of land under cultivation and traditional enclosures locally known as *Olokerii*. The data was qualitatively analysed by coding recurring concepts and frequencies calculated using SPSS software version 15.0 (SPSS Inc. 1989-2006).

4.4. Results

The key innovations that were observed among the Laikipia Maasai are provided in table 1. Some of the innovations were either household-level-driven initiatives or at the group ranch level and commissioned by elected officials. Natural and social capital innovations have been addressed separately although they are discussed jointly in the next section because of their interconnectedness. It should be noted that some of the innovations may not be entirely attributed to GR formation but to other, broader aspects of development such as globalisation of economies, advancement in science, and cultural dynamics among others.

Table 4-1. Emergent innovations in the management of natural and social capital among group ranch pastoral communities in Laikipia, Kenya

Livelihood Assets		**Emergent innovation**	**Citations (n= 105)**	**Percent frequency**
Natural Capital	Pasture swap	Trading grazing rights to non – members (Agistment)	42	40
		Private Ranch - GR Alliance	38	36
		Expansion of *Olokerii* enclosures[1]		
	Resource use Diversification	Sand Mining	63	60
		Wildlife & tourism	38	36
		Cultivation Manure sale	29 19	28 18
		Charcoal making	17	16[2]

	Livestock dynamics	Buying & selling of Livestock	82	78
		Rearing of camels	13	12
		Increasing small stock (sheep & goats)	84	80
		Rearing of poultry	23	22
Social capital	Human	Children formal Schooling	82	78
		Hiring of Scouts/rangers	32	30
		Wage remittance by salaried relatives	19	18
	networks	Associations & self-help groups	48	46
	Businesses/trade	Eco-tourism related	13	12
		Others	29	28

[1] *Olokerii* enclosures were not part of citations but a critical observation made during field surveys. [2] charcoal making was officially banned in the GR in 2009.

4.4.1. Innovations in natural capital resource use

Two broad categories of natural resource management strategies linked to the GR model were observed; pasture swap and use diversification.

4.4.1.1. Pasture swap

Pasture is a critical resource and because of the uncertainty and unpredictability of the ecosystems in which they operate, pastoral communities go exceptional lengths to manage it. Two types of pasture swaps were recorded namely; 'cooperation' between private ranches (PRs) and GRs, and trading in pastures or pasture leasing.

Private-GR pasture alliances emerged in the early 2000s out of simmering tensions between pastoralists and large-scale ranch owners over access to pastures during dry seasons. To promote cohesion, PRs agreed to permit pastoral groups access to pastures during times of forage scarcity, subject to meeting some conditions. Below are some of the conditions set by Mpala private ranch;

(i) Livestock owners meet the costs of ecto-parasites control for their animals as well as for hired herder(s) while grazing in Mpala. In 2013 and 2014 the rate was Kshs 150 (approx. US $ 1.5) per head of cattle per month.

(ii) Each GR allowed access must organise to have all their cattle herded jointly for ease of controlling grazing pattern,, thus the need for hired herder in (i) above. GR nominated person(s) to be hired to herd their livestock.

(iii) Only cattle were allowed admission and sheep only under special situations. Goats were not permitted at all due to the perception that they degrade the rangeland.

(iv) Each PR set the maximum number of cattle to be admitted at any given time to avoid overgrazing. For example, Mpala ranch allowed a maximum of 800 cattle at any given time, principally from Il Motiok, Koija and Tie Mamut GRs.

Trading grazing rights (Pasture leasing/agistment)

Trading grazing rights to non-members of the GRs (mostly Somali camel herders) was yet another land use innovation that began in 2001. The Somali herders purchased grazing rights to fatten their camels before selling or during times of forage scarcity. Payment rate for grazing one camel per month in 2013 was Kshs 300 (approx. US $ 3.4). Between March and August 2013; there were 170 camels in the ranch (Godffrey Metiaki, 2013 GR Chairman, pers. communication).

Expansion of *Olokerii* enclosures

Expansion in structure and function of traditional enclosures (*Olokerii*) was observed through transect walks as well as using satellite maps. Between 2007 and 2013, the enclosures increased by 38% from 26 to 36 and their average size per enclosure tripled from approximate 1 to 3.2 acres.

4.4.1.2. Diversification in natural resource use

Besides, livestock production, the community has been experimenting with new livelihood options, using resources available but has hardly been exploited in the past. Some of these include:

Charcoal making

Between 2001 and 2009, Il Motiok community experimented with the charcoal making business, but thenabandoned it. This was cited by 16% of the informants, who said they had participated in the business as charcoal makers, buyers, sellers or brokers. This was a group ranch level decision and was sanctioned by management committee on behalf of the community.

Crop Cultivation

Crop cultivation in Il Motiok GR began in 2007. In the last seven years (to the end of 2013), the land under cultivation increased from about 8 acres to approximately 30 acres. Crop cultivation was concentrated along the Ewaso Nyiro River and in 2014 more than 20% of the households were involved. The majority of those involved in cultivation were people aged below 45 years with at least basic primary education. In household that had cultivation field, both men and women were involved in the farm activities. In the five years that cultivation has taken place on the ranch, successful harvests have been reaped only twice due to limited rainfall, so it is hard to understand why individuals continue with this activity

Harnessing tourism potential

To benefit from the potential of tourism, GRs have been encouraged to set aside portion of their land as Wildlife Conservancies. Nine GRs have set aside part of their land for purpose of promoting wildlife conservation and tourism. In Il Motiok, a tenth of its land was set aside for wildlife conservation, and a women's group has established an eco-lodge facility for tourists, with help from a donor agency. Thirty six percent of the informants cited tourism as a major source of income for the GR and households involved in businesses related to tourism (e.g. supply of food, beadworks etc.).

Mining of sand and stones

Sand and stone mining started in Il Motiok GR in the year 2000. These activities occur along flood plains and dry riverbeds (locally referred to as luggas). Sixty percent of the informants cited sand mining as a major income earner for the GR. In 2014, seven tonnes of sand was worth Kshs 4000 (approx. US $ 45) and employed 2 local persons for loading and paid Ksh 400 each for labour. Sand harvesting and selling was a group ranch level initiative and those directly involved were mainly young men.

4.4.1.2. Change in species composition, breeds and trade in livestock

The change in the composition of livestock species owned by households, and the significance of each species in meeting family requirements, showed a major shift in livestock production. More than 80% of the respondents indicated that they have increase the number of small stock (goats and sheep) relative to cattle which was the main livestock species historically. A livestock census done on the ranch in 2010 shortly after a severe drought tallied; cattle 207, shoats 3197, camels 20 and poultry 651. Twelve percent of the households have introduced camels, while 22% of households have introduced poultry. Less than five percent of households have introduced new breeds of goats and sheep, primarily Galla and Dorper respectively.

4.4.1.3. Trade in livestock manure.

Only nineteen percent of our informants mentioned manure sale as supplementing their household income, although in our home visits, we observed that most if not all households collect and preserve manure for sale. The value of a lorry full of manure was Kshs 10,000 (approx. US $ 115, 2014 rate).

4.4.2. Dynamics in management of social capital

The sedentarization of households was an inevitable outcome of the establishment of GRs. One reason is that the land for nomadic pastoralism was heavily constricted by the establishment of boundaries. Secondly, the creation of permanent infrastructure such as water sources (e.g. dams) and schools made household mobility less appealing. Members of Il Motiok GR settled in four villages (Nasirian, Lorupai, Losiagi and Il Motiok). Community members were free to choose where to settle in any of the villages. Historically, the maasai settled in a group of Kraal-camps that tends to gather around a dry-season water supply. Such a group locally known as enkutoto a ‘settlement association’ and was a fairly a stable political unit with their own governance structures (Coldman 1982).

Increased reliance on purchased goods and services from the marketplace by households has limited gifting and sharing to special occasions such as weddings, circumcisions.

4.4.2.1. The existence of Scout/Rangers

This was a new institution established to address challenges such as cattle raids, poaching of wildlife and enforcement of grazing protocols. The local youth (men only) were recruited and trained with help from Northern Rangeland Trusts (an NGO operating in the region) to scout for signs of security breach and on how to use modern technologies such as high frequency radios, binoculars, among others skills. The rangers were paid by the GRs through Naibunga Wildlife Conservancy Trust.

4.4.2.2. New social networks

New social networks requiring member to join more formalized groups governed by mutually-agreed or commonly accepted rules, norms, by-laws and sanctions were observed. Examples are the Nalepo women’s self-help group (that managed the Ol Gaboli Eco-lodge) and a beekeepers association.

4.4.2.3. Wage remittance

About 20% of respondents cited employment as critical source of their household income. Among 11 persons interviewed on wage employment, only one was a woman. Most of those employed were within the neighbouring private ranches and occasionally visit the family within the month.

4.4.2.4. Religion

Although not cited by many as playing any role in the re-organisation of social capital, it featured during FGD session as influencing the future life of the community. The Christian converts in the area believed that Christianity will instil new values as well as provide solutions to societal problems such as low literacy level among women, poverty, cattle raids, and female genital mutilation among others. As at 2014, two churches had been constructed in the ranch. The extent of Christianity among the population was beyond the scope of this study.

4.5. Discussions

The GR as a model for managing rangeland resources has evolved over time and has given birth to new innovations some of which are far from the path envisaged at its conception. Some of the emergent approaches in the management of natural and social capital assets were modifications of previously existing strategies; others were completely new ones. Household-driven initiatives may have evolved as part of a wider diversification of livelihood strategies. They were individualised in their nature and their benefits accrued to individual households. Innovations implemented at community level were collective actions and mean to provide common good to GR members. Operationalization of these innovations was confined by GR boundaries. Notable among them were the trading of grazing rights, eco-tourism, charcoal-making and sand mining.

Vulnerabilities (stresses) attributed to climate variability and changes, as well as trends such as government policies, markets; social learning and overall changing lifestyles could have inspired some of the current innovations. Initiatives that brought immediate benefits such as sand mining, eco-tourism and trading of grazing rights were popular even though their long-term sustainability was unknown.

4.5.1. Pasture swap

The establishment of PRs during the colonial period and GRs in post independent Kenya fragmented pastoral grazing land. Access to heterogeneity of landscapes is an important attribute of pastoral grazing landscape and therefore land fragmentation limits options for people and animals to access resources in a temporally and spatially heterogeneous environment (Hobbs et al. 2008). Dry season grazing areas, access routes to water, migration routes among other utilities were disrupted by GR model, thus jeopardizing the flexibility needed in the utilisation of drylands. This was however not unique to Laikipia Maasai. What is unique here is how GR model have survived for four decades while a number in the southern rangelands barely lasted 10 years (Veit 2011). The pasture-use co-operation (alliance) between PRs and GRs is one innovation that has given a lifeline to Laikipia GRs. Traditionally, pastoral communities in Africa and elsewhere practiced reciprocity with neighbouring communities, under which pastures were shared during hard times (Eriksen & Lind 2009; Fernandez-gimenez 2000). Partnership with private ranches is fairly new. The persistent and frequent scarcity of forage on the GRs compared to their neighbouring PRs had been a source of tensions in Laikipia. During the droughts of the 1990s and 2000s pastoral groups in the county, out of desperation and as a result of political machinations, trespassed into PRs. This provocative action, instead of ending up in the courts, led to a negotiated grazing agreement between the two parties. Besides easing tensions, the need for enhanced collaboration in areas of wildlife conservation and security in the region informed this strategy.

A notable impact of the pasture-use alliance between PRs and GRs was increased collaboration in area of security, wildlife conservation and promotion of eco-tourism through Laikipia Wildlife Forum and Naibunga Wildlife Conservancy. This agreement provided a window for increased livestock mobility, an opportunity for vegetation to regenerate and connectivity of people and habitats, which is an essential element in range resilience (Biggs et al. 2012). Furthermore, the conditional joint herding proposed under negotiated grazing agreements between PR and GRs has promoted cohesion amongst members of the GR. The members have to come together when making decision concerning their livestock herding strategies. These attributes promote SeS resilience through collective actions (Coppock & Desta 2013).

4.5.1.1. Trading of grazing rights (agistments)

Trading of grazing rights or agistments as referred to by (Robert & Mcallister 2010) involves allowing non-members of a ranch to graze their livestock at a fee. This was one of the community-level initiatives and was directly linked to GR status as knowledge of ranch boundaries by lessee was essential to avoid conflicts with neighbours. The motivation for leasing land to non-members (particularly Somali camel herders) was economic benefits. The money earned makes it possible for the GR to support education for members' children as well as improve social amenities (e.g. buying of desks in schools). Declining grass resource and perceived encroachment by woody plants on the ranch could have also inspired the undertaking to increase browsing as a control measure. Unlike the non-pastoralists currently viewed as a threat to Maasai pastoral livelihoods in Kajiado and Narok (Sundstrom et al. 2012), camel herders in Laikipia have in the immediate past created some form of symbiotic relationship, which is addressed later in this paper. Unfortunately, the GR did not have means to estimate sustainable stocking rate to avoid potential land degradation and possible conflicts as have been reported from other parts of Kenya (see http://www.the-star.co.ke/news/article-163109/herders-and-ranchers-clash-taita-taveta/, http://countypress.co.ke/somali-camel-herders-evicted-from-kajiado/). Trading in grazing rights has not only provided income but also promoted social capital; there has been some transformation of relationships by which existing collaboration has fostered establishment of new relationships.

4.5.1.2. Olokerii enclosures

These 'privately owned' enclosures were traditionally used for nursing sick animals, as postpartum recovery wing for livestock and nursery for young calves and kids or restraining newly acquired livestock (Kibet and Oyieke, 2009). It is not clear whether there was an accepted size of *Olokerii*, however, majority of was less than 1 acre. *Olokerii* was 'owned' by individual households and therefore access by non-household members was through permission. The structure and functions of these enclosures have however been transforming over time. Alongside the traditional use, *Olokerii* are currently used as dry season grazing reserve, a strategy driven by individual household desires.

Motivations for expansion of *Olokerii* enclosures were varied. Decline in availability of household labour, increased individualization of pastoral operations, decline in number of livestock to sustain mobility, and increased sedentarization are some of the factors. Notable impacts of *Olokerii* expansion were the upsurge in tree felling for fencing and maintenance; a decline in acreage of land under common use thus increasing grazing pressure on plants in “Common access” areas and the expansion of invasive species (*Opuntia subalata*) previously used as a live fence on these enclosures. Although fencing has not reduced available habitat, it has limited connectivity and access to micro-habitats such as floodplains known to host more diverse plant species. On a positive note, plant species susceptible to heavy grazing were likely to get refuge in the enclosures and minimise potential local extinction as observed in Ethiopia (Mengistu et al. 2005). Habitat fragmentation and limited connectivity depresses SES resilience.

4.5.2. Diversification of livelihood

Cultivation along River Ewaso Nyiro was one of the household-based emergent strategies aimed at diversifying livelihood options. Influence from NGOs operating in the area as well as neighbours (such as Koija GR where cultivation begun earlier) may have triggered the emergence of crop production in Il Motiok GR. Cultivation, like charcoal making, is a new type of land use. Shifting cultivation as well as fencing reduces riverine forest cover and more importantly, destroys dry season grazing pastures. Similar to *Olokerii* enclosures, and may heighten tensions and/or conflicts due to possible trespasses. This was likely to increase herding labour in future, weaken community cohesion and increase agitation for land subdivision into freehold as noted elsewhere in the country (Mwangi 2005; Sundstrom et al. 2012). A study by Kaye-zwiebel & King, (2014) on five GRs in the region, noted on four of the ranches (Koija GR was the exception), the majority of individuals surveyed did not favour land subdivision into individual titles. This was surprising observation given that the Koija community appears to have the strongest social assets (in terms of food sharing, livestock lending and sanctioning) necessary for maintaining a resilient communally based pastoral livelihood. Increased 'individualisation' of land through cultivation could have motivated this position. Between 2007 and 2014 there was over 200% increase in the area under cultivation and homesteads built near cultivated fields increased from one to eight. Increased cultivation is also likely to escalate water stress downstream. Studies on natural flow on the major rivers in the region indicate a gradual decline over the years due to increase upstream abstractions for irrigated agriculture with increasing conflicts between farmers upstream and pastoral communities downstream (Mungai et al. 2004; Ngigi 2006).

Presence of large population of wildlife in the region (WRI et al. 2007) and widespread crop-raiding by elephants within small-scale cultivated farms in southern Laikipia (Graham 2006) are warnings of escalating future confrontations. Moreover, cultivation in itself is inconsistent with the earlier investments in wildlife conservancy and a tourist facility (eco-lodge). Livestock trespassing into crop fields was also inevitable and this would strain relationship between neighbours. Experience from other regions indicates that cultivation in fragile ecosystem such as Il Motiok, compromises on habitats connectivity, species diversity, and may also strain communities' cohesiveness between those with crop fields and those more interested in livestock well-being (Biggs et al. 2012; Galvin 2009; Sundstrom et al. 2012).

Charcoal making initially commenced as a measure to control bush encroachment on the ranch. Perceived increase in the density of trees on the ranch was seen as posing risks of wildlife attacks due to declining visibility, particularly from elephants. Felling of woody plants along access paths was therefore commissioned by GR officials for the purpose of improving the safety of residents, particularly school-going children. It was also seen as an opportunity to generate income from charcoal sale. Charcoal making was initially spearheaded by non-Maasai, however through social interactions; residents of the ranch acquired skills and got involved in the business. As more people participated in the business, guidelines set earlier were flouted. Tree felling went far beyond the designated areas. After eight years of wanton felling of trees, targeting most valuable forage species such as *Acacia tortilis* and *Acacia mellifera,* it became evident that the practice was not sustainable and it was officially stopped. The high number of livestock lost as an aftermath of the 2009/2010 severe drought may have informed the decision. Selective harvesting of certain species of Acacia threatened both forages for livestock especially the browsers (e.g. goats and camels) and weakened the ecological insurance (functional redundancy and response diversity) that the harvested species provide during extreme weather events (Kahmen et al. 2005; Walker et al. 2004). Recognizing that SESs are complex adaptive systems presupposes that experimentation and learning are necessary for societal learning and enhance resilience (Biggs et al. 2012). Valuable lessons derived from the charcoal making experiment are that active adaptive management still forms part of this GR's management style (Fazey et al. 2005) and that collective action can be an effective means of group problem solving (Coppock & Desta 2013).

Sand and stone Mining

Increasing sedentarization and expanding urban centres in the region caused increased demand for building sands. With the establishment of county governments in the country, there has been unprecedented growth of urban centres and Nanyuki town is recognized as a major consumer of building sand from the GRs in the region. Sand mining is fairly recent in Il Motiok compared to the neighbouring GRs of Il Polei and Tie Mamut. This activity was motivated by the need to raise income and, like charcoal making; the business was commissioned as a GR initiative. The community seemed highly excited about sand harvesting given the high percentage of those who support it. Although sand mining is currently minimal it is affecting critical habitats – the floodplains and dry riverbeds (locally called luggas). These sites provides important ecosystem services such as soil erosion regulations, provision of water, dry season grazing pastures, habitat for wildlife and cultural values. These services will be compromised in the long-term. Some of the already felt impacts from sand mining include; increased erosion along the paths used by heavy Lorries ferrying sand as exemplified by deep gullies and frequently changing pathways on the ranch; emergence of conflicts between members of neighbouring GRs over ownership of sand resources on shared boundaries and also within GR members competing for sand loading jobs. For example inn 2013 elders of Tie Mamut and Il Motiok had to agree on a formula to share income and jobs from the sand on their shared boundary (Losupukiai lugga) after hostilities occurred. The spread of invasive species is a potential threat, given the large distances covered by lorries ferrying the sand. This study therefore foresee that increase sand mining will cause loss of dry season grazing areas, decline in community cohesion between neighbours, together with enhanced soil erosion are all likely to increase vulnerability to environmental shocks, thus weakening SES resilience.

4.5.3. Changes in herd composition, species and breeds

Traditionally, cattle formed the dominant herd in the Maasai households relative to sheep and goats (jointly shoats) but this was seen to be changing. The acquisition of new breeds of goats and sheep was associated with wealthier households. The following were reasons cited by the community for increase adoption of camels and shoats (i) Both camels and goats have higher tolerance to water and forage shortages (ii) Goats: ease of acquiring breeding stock and faster multiplication rate after losses, and availability of ready market (iii) Camels: continue to produce milk even during dry season when most lactating livestock dries up.

The Il Motiok community as landlord relied heavily on camel milk supplied by their Somali tenants during and shortly after the severe drought of 2009/2010 as most of their livestock were either dry or had been driven to graze out of the ranch. This experience could have influenced the rising adoption of camels. The role of camel milk as a source of food and family income is likely to rise with increase in climate variability (Elhadi et al. 2015). Increased trade in livestock, facilitated by proximity to two markets (Kimanjo and Oldo Ng'iro) where livestock is the main trade commodity, will influence livestock dynamics in future. Acquisition of new species and adoption of new breeds increases diversity at species and genetic level respectively. This enhances SES resilience by increasing diversity response as well as functional redundancy against adverse events such as drought (Biggs et al. 2012).

4.5.4. Re-organisation of social and human capital

Following sedentarization of pastoral households, settlement villages replaced traditional *inkutot* (settlement associations) as the smallest formal political segment of the Maasai (Coldham 1982). The established villages became the smallest units of GR administration; since officials are elected based on these units. The new institution imposed by the GR policy replaced the traditional institutions where natural resources were managed by council of elders (Coldham 1982). Based on observations made during the study and information from informants, Il Motiok GR committee have largely been effective in their 'foreign policy', which can be exemplified by dealings that involve non-members such as negotiating grazing agreements and employment opportunities for their members with the adjacent large private ranches, leasing agreements with charcoal makers and sand merchants. However, enforcement of internal regulations addressing natural resources use was facing challenges. Social sanctions play an important role in the provision of public good (Miguel & Gugerty 2004) and its effective administration of social sanctions demonstrates the capacity of a community for self-governance. Weakness in enforcing rules governing natural resources was noted to vary, with some ranches in the region seen as more effective than others (Kaye-zwiebel & King 2014). Grazing protocols and expansion enclosures (*olokerii* and crop fields) were not being regulated by the GR committee officials on Il Motiok ranch and were blamed by community members although effective management demand collective action by all members.

Herding is crucial in the debate about sustainability of pastoral livelihood because of centrality of livestock mobility in the production system (Butt 2011; Coppolillo 2000; Oba

1994). In the past herding among the Maasai community was a shared activity amongst relatives, friends and /or neighbours (Bekure et al. 1991). This has change with declined in number of livestock, increase individualisation of production and labour shortage. Additionally, government policies that encourage schooling of children and sedentarization by pastoral communities are transforming livestock management and society in general. Most children (both boys and girls) of school going-age attend school and livestock herding is carried out either by hired person(s) for rich households or by adult women in poorer households. Shortage of herding labour is reflected in the violations of grazing protocols in Il Motiok GR as women would combine herding and other household chores by grazing livestock near homes. During this study some GRs were experimenting on joint herding with the help of PRs and a local NGO. Hired labour was used to regulate grazing inside PRs as well as within the GR where Holistic Management experimental trials had been initiated. Although its full potential was yet unknown some households were already excited about the strategy.

The importance of traditional social networks among Il Motiok community seemed to be breaking down as exemplified by increased income inequality among households and insignificant gifting or exchanges between rich and poor (Hauck, 2013) see also (Bekure et al. 1991; Kaye-zwiebel & King 2014). New social networks have emerged to boost dwindling social capital. Some of these networks are beekeepers and beadwork associations for negotiating better prices for goods and services. Table banking where women save and loan money to members was taking over gifting/reciprocity as a way to support the recovery of people who had lost their livelihood. Emergence of these networks promotes collective action was not unique to Il Motiok GR and was seen to fortify social and human capital (Coppock & Desta 2013) and thus enhance SES resilience. Another important observation with social re-organization among the Il Motiok community was the social barriers surmounted by adoption of innovation. The majority of the married women in the community did not participate in off-ranch employment. However, the formation of home-based economic activities, (e.g. Ol Gaboli Eco-lodge) for tourists offered women opportunities to work as cooks, cleaners, or waiters without restrictions from their husbands. In addition, women make beaded jewelry, weave mats, supply foodstuff and even get paid to entertain tourists through songs and dance.

A number of policy implications can be drawn from this study. Whereas it is a well-established fact that livestock mobility is central in promoting sustainable pastoralism from accessing spatially and temporally heterogeneous resources, not much is being done to achieve the same. Increasing complexity of land use types in previously dominant pastoral land suggests the need for responsive policy change to ensure that fragile ecosystems are not overly exposed to irreversible degradation. There are opportunities provided by community to community social learning to adapt to unpredictable and uncertain environment and positive elements derived from such knowledge should be recognised and if necessary promoted. Policy initiatives therefore should seek to above issues as well as means to promote collective actions.

4.6. Conclusions

It is evident from the results that the GR model has shown unpredictable innovations pathways in the management of natural and social assets, not envisaged at its inception. These innovations consist of both new and modified forms of traditionally known practices, some of which were households and/or community level driven processes. There are many factors that may have influenced the emergence of new innovations; climate change, development agents (e.g. government, NGOs), and social learning from neighbours as part of a wider change in lifestyle are likely to have been some of the important ones. People interviewed on the ranch were mostly positive about innovations that were seen as bringing in immediate tangible benefits/income (e.g. sand mining, manure sale, crop cultivation etc.). However they did not often show awareness that the potential long-term effects on socio-ecological system resilience could be negative.

Official abandoning of charcoal making as a diversification strategy after it had been in operation for five years indicates that adaptive learning still dictates management strategies the community adopts. It is indicative from this study that interventions such as the Group Ranch model evolves in space and time and we suggest that flexibility both in funding and policies is needed to allow unintended or unpredicted innovations to emerge as implementation progresses.

Increasing complexity of common property use requires responsive policies to address emerging “new” land use changes (e.g. tourism, cultivation, sand mining and others) in previously purely pastoral grazing land. Equally important would be to initiate/strengthen policies that would promote collective action. In Kenya, policies such as Youth Development Fund where prerequisite for government support is the formation of a formal cohesive group can be customised to suit pastoral communities and encourage collective action. Similarly, it is imperative that pastoral land remain as common property given that further fragmentation is considered detrimental to socio-ecological systems sustainability.

CHAPTER FIVE

BROWSE-BROWSER INTERACTIONS: EFFECTS ON TRAITS, FUNCTIONAL DIVERSITY AND IMPLICATIONS FOR SEMI-ARID SAVANNA MANAGEMENT

Abstract

Woody plants in savanna systems play an important ecosystem function yet browser-woody plants interaction that regulates heterogeneity of the systems remains unclear. This study investigated how different browsing levels affected woody plants species diversity, and functional traits diversity of dominant palatable species. Plant traits; leaf area, specific leaf area, leaf dry matter content, canopy height, stem diameter and spines of four species in two adjacent ranches; private commercial ranch (PR) with light browsing and pastoral group ranch (GR) with intense browsing were evaluated. Rao index and Shannon index were used to calculate functional traits diversity and taxonomic diversity respectively. Whitney U-test and Z-test were used to evaluate traits values while Pearson correlation was done to explore relationship between soil properties and functional traits diversity. The study findings indicate that intense browsing diminishes both woody species and functional traits diversity. Low woody species diversity in intensely browsed site (pastoral system) suggests that palatable and less palatable browsing-sensitive species may have been suppressed and/or outcompeted by more tolerant species. Persistence of dominant-palatable species under intense browsing are supported by investment in browsing-tolerant traits (e.g. high canopy diameter, height, and multiple stems) as well as defense (e.g. high leaf dry matter content, high density of spines and low leaf area) with minimal effects of reproduction. We deduce that intense browsing causes ‘traits homogenization’ given the low functional traits diversity

in pastoral ranch. This makes ecosystems vulnerable to perturbations due to reduced response diversity. Manipulation of livestock stocking rate as well as the mix of livestock species kept can be used as a tool to manage species diversity and woody plants encroachment

5.0. Introduction

Woody cover is a chief determinant of properties of savanna ecosystems (Sankaran et al. 2005). They form a critical component of the semi-arid savanna (Belsky et al. 1989; Hagos & Smit 2005; Treydte et al. 2007; 2010). Woody plants provide habitats, shade and forages to ungulates and other animals yet the browser-woody plants interactions that regulates heterogeneity of the savanna systems remains unclear (Augustine & Mcnaughton 2004a; Levick & Rogers 2008; Staver et al. 2009). A number of studies have shown that selective browsing increased dominance of unpalatable plant species (Al-rowaily et al. 2012; Gordijn et al. 2012). Contrary opinion has also been demonstrated whereby long-term intensive browsing does not lead to dominance of unpalatable species (Augustine & Mcnaughton 1998; Díaz et al. 2001) and may at times even promote increase in highly palatable species (Cromsigt & Kuijper 2011). It has also been suggested that intense livestock herbivory could decrease functional diversity (FD) at community level by filtering out species that lack resistance/tolerant traits such as low stature and/or short life cycle to persist in grazed habitats (Díaz et al. 2001). This implies that intensely grazed/browsed ecosystems are likely to be dominated by functionally similar species. It could also mean persistence of dominant-palatable species in intensely browsed habitats are supported by heavy investment on browsing tolerant traits and/or browsing avoidance traits (Fornara & du Toit 2007). The relationship between species and FD remains an open question (Hooper et al 2005). Dissimilarity in trait space when weighted by the species' abundance, gives FD index comparable to generalized Simpson's index of species diversity. Whereas this index can provide a measure of relationship between FD and species diversity, little efforts have been done in calculating this index with real species' traits matrices and for assemblages under different environmental conditions (de Bello et al. 2006).

This study investigated effects of varying intensity of browsing on woody plants species diversity and functional traits diversity under livestock managed semi-arid savanna ecosystem in Kenya. This was motivated by the following reasons; firstly, diversity within a single trait is often the most ecologically relevant information (de Bello et al. 2006). Secondly, there are evidence that domestic browsers (goats and camels) are increasing in the study area, a fact linked to climate change adaptation (Georgiadis et al. 2007; Huho et al. 2011) and therefore, there is need to understand potential impacts of increased browsing in the long term. Thirdly, the region is experiencing an upsurge of invasive species and livestock grazing/browsing was identified as one of the contributing factor hence the need to explore possible mediating factors given that diversity of functional traits of resident species influences invasive species spread (Drenovsky & James 2010; Strum et al. 2015).

To investigate the effects of livestock browsing on woody plants under managed systems, two adjacent ranches (private commercial ranch –PR and a pastoral community group ranch - GR) with varying browsing intensities based on livestock stocking rates and livestock species kept were selected. The following hypotheses were tested;

1. There was no difference in species diversity between intensely and lightly browsed sites given their close proximity and similarity in bioclimatic conditions.
2. The persistence of palatable species in intensely browsed site was mediated by overabundance of browsing-tolerant and/or browsing-avoidance traits.
3. Intensely browsed ranch has low traits FD due to filtering out of browse –intolerant species causing traits ‘homogenization’.

5.1. Methods

5.1.1. Study site and sampling design

The study was conducted within two adjacent ranches Mpala PR and Il Motiok GR under different management and grazing intensity. Details are provided in chapter 2. The above hypotheses were tested by sampling naturally browsed trees in the two ranches following the ‘‘natural experiment’’ approach used in other studies (Fornara & du Toit 2008; Homewood et al. 2001; Western et al. 2009). The Ilmotiok group ranch was used as the experimental treatment to test the impact of intense browsing and Mpala ranch was used as the control representing lightly grazed ecosystem (Augustine 2003a). The two ranches differed in their livestock management system. The PR has maintained livestock stocking rate of 10 – 12 TLU/km^2 mainly cattle and sheep in the last three decades while the GR on the other hand, stocking rate fluctuates depending on prevailing weather conditions with high stocking rates during rainy seasons when pastures and water are plenty and low shortly after major droughts.

The effects associated with wildlife that dominate the area when put under consideration (see table 2-1), indicated that GR had more stocking rate although certain species such as elephants, eland, giraffe and grevy zebra spend more time in Mpala than Ilmotiok perhaps due to high human presence in the later (Kinaird and O'Brien 2012). On average GR stocking rate range between 25-39 TLU/km^2.

5.1.2. Determination of taxonomic diversity

An inventory of all woody plants with 10 mm stem diameter at knee height (DKH) approximately 50 cm above ground was undertaken and identified them to species and/or genus level using 20 x 20 m subplots nested in three kilometer long transects, approximately 200 m apart in each ranch. In total 225 and 196 subplots were sampled in GR and PR respectively. The subplots were systematically arranged at 40 m intervals in an alternating manner within the line transect. Triplicate copies of specimen for each species were collected for re-distribution between East African Herbarium, Mpala Research Center collection and Smithsonian Institution, Natural History Museums Herbarium.

5.1.3. Browsing on Traits and functional diversity

The species that contributed significant biomass in line with mass-ratio-hypothesis (Díaz et al. 2007) and rated as highly palatable (based on literature and interviews with members from the local community) were selected for traits analysis. In PR, *Acacia mellifera, A. brevispica*, and *A. etbaica* were selected while in GR; *A. mellifera*, *A. etbaica* and *A. tortilis* were picked. Cumulatively these species contributed more than 60% of plant biomass in PR and over 80% in GR respectively.

5.1.4. Traits sampled and analyzed

Three types of traits data were collected; binary, categorical (nominal) and quantitative. Examples of binary data include nitrogen fixing verses non-nitrogen fixing species, those species with or without spines. For such data a score of 1 with spines and 0 without spine was assigned. Categorical (nominal) data had more than two classes. Example of such data can be found with leaf lifespan; evergreen; semi-evergreen and deciduous or aspect such as palatability (much desired, desired, not desired). Binary and categorical data were collected from all woody species inventoried in the subplots. Lastly, quantitative data were collected only from the four dominant species in the study sites.

For each species specific leaf area (SLA), leaf area (LA), leaf dry matter content (LDMC), leaf phosphorus content (LPC), leaf nitrogen content (LNC), density of spines (thorns or spines) (SPINES), number of multiple stems per ramet (STMs), DKH, canopy height (H_c), and crown/canopy diameter (CRWN) were measured based on standardized protocol developed by Cornelissen et al. (2003).

One transect described earlier was randomly selected per site and in each, 30 individuals' trees for each of the three target browsed species were systematically selected at every 100 m intervals in the GR and 60 m intervals in PR, whenever targeted individual did not occur at the pre-determined interval, a nearby individual of target species was selected. In each tree, a fully exposed twig with fully expanded photosynthesizing leaves with no obvious damage was cut and kept in a ziplock bag and stored in a cool box at temperatures below 4˚C to avoid contraction. Twigs were collected early morning between 8 and 10 am and in the afternoon from 4 to 6 pm when the temperatures were cooler. All twigs were collected from the height of 2 m and below to avoid sampling beyond the browsing height of majority of browsing animals. In total 90 twigs were collected, 30 per target species in PR and in GR, a total of 30 twigs were collected; 10 per target species. The discrepancy on the number of twigs collected for the two sites was caused by the long distance covered by road to reach Il motiok GR and therefore less time was available per day in the morning and late evening sampling. SLA calculated as one-sided area of a fresh leaf divided by its oven-dry mass, expressed in mm^2 mg^{-1}, while LA – as one-sided projected surface area in mm^2. For SLA and LA trait measurement, 2 leaves per twig per species were randomly picked to make a total of 60 and 20 leaves replicates per species in PR and GR respectively. All water droplets on leaf surface were wiped with absorbent tissue paper thereafter they were scanned using Epson Scanner perfection v350 and kept in well labelled envelops. The areas of scanned leaves were determined with the use ImageJ 1.46r software (Rasband, 1972-2012).

For LDMC measurement similar number of leaves was used as in SLA per site. LDMC was calculated as the oven-dry mass (mg) of a leaf divided by its water-saturated fresh mass (g), expressed in mg g^{-1}. The area measurements for the two leaves per twig were later averaged. Leaf phosphorus content and LNC both expressed in mg g^{-1}were determined by selecting 10 composite samples each containing 20 randomly plucked leaves per species from the 10 twigs in PR and 8 composite samples with 20 leaves each from 8 twigs in GR site. Density of SPINES calculated as number of spines per 30 cm shoot measured from the growing point backward, number of STMS calculated as a density of branches per unit of vertical plant height, Stem diameter (in cm) was measured using diameter tape at knee height. Canopy height (in meters) was measured using a Dynamic Telescopic Measuring Rod while crown diameter was determined by averaging two readings done in north-south, east-west direction across the canopy at the widest point and both readings given in meters. All samples were kept in labelled envelopes thereafter all the samples were transported to East Africa Herbarium (Nairobi) where they were oven dried at 80˚C for 48 hours and re-weigh to get dry mass for SLA and LDMC calculation. Processing and analysis for LPC and LNC followed Cornelissen et al. (2003) protocol.

Two FD indices were measured for comparison purpose. They include Rao index of functional traits diversity, and Community Weighted Means (CWM) defined as the mean of values present in the community weighted by the relative abundance of taxa bearing each value (Lavorel et al. 2008). All the indices were calculated using Macro excel file; "FunctDiv.exl" freely available online http://botanika.bf.jcu.cz/suspa/FunctDiv.php . Rao's index of functional diversity was calculated based on the formula below (Leps et al 2006);

$$FD = \sum_{i-1}^{s} \sum_{j=1}^{s} d_{ij} p_i p_j$$

Where S is the number of species in the community, p_i is the proportion of i^{th} species and p_j is the proportion of j^{th} species and d_{ij} is the dissimilarity distance between species *i* and species *j* and varies from 0 (two species have exact the same traits) to 1 (two species have different traits). This analysis provide two indices (Rao coefficient index and Simpson diversity index) which provided an opportunity to test relationship between FD and species diversity (de Bello et al. 2006). In this test we controlled species richness (component of species diversity) by intentionally selecting three dominant palatable species per site.

Community weighted means was calculated using the formula below (Garnier et al. 2004)

$$CWM = \sum_{i=1}^{s} pi\ x\ trait_i$$

Where pi is the relative contribution of species i to the community, and trait$_i$ is the trait value of species i.

5.1.5. Traits and distance from homesteads

In Ilmotiok ranch, presence of sedentarized households provided an obvious grazing gradient (Butt 2010) which was tested. Intense grazing/browsing was expected near homesteads and light browsing distance away from homesteads. Individual treesused to collectquantitative traits data were geo-referenced relative to nearby homesteads and distances between them calculated. Regression was then done between distance and traits values.

5.1.6. Effects of soil properties on plant traits

To be able to isolate effects attributable to edaphic factors, 45 soil samples were collected per site taken from 45; (20 x 20 m subplots) in a stratified random manner using the vegetation sampling subplots described above. In each subplot, 5 subsamples were augured at 0-30 cm deep from each of the four corners and at the center and lumped into composite sample. The composite samples were sun-dried and later transported in labelled zip-lock bags to National Agricultural Research Laboratories, Nairobi for further processing and analysis. Standard methods were followed in macro-nutrients chemical analysis (see chapter two for details)

5.2. Data Analyses

Shannon diversity index was used to calculate taxonomic diversity between the two study sites using the formula described by Magurran (1988).

$$H' = - \overset{s}{\underset{i=1}{}} p_i ln_{pi}$$

Where S is the number of species in the community, p_i is the proportion of i species to the community and $\ln_{pi}$ is the natural logarithm of p_i.

5.2.1. Soil and herbivore effects on taxonomic and functional diversity

To examine the effects of browsing on traits two approaches were used. First approach used aggregated means values for all traits measured and significant differences tested using Mann-Whitney U-test given that traits values were not normally distributed. Second approached used CWM whereby trait values were weighted based on species abundance per site and significance difference tested using z-test. Correlation analysis was done to explore relationship between soil properties and FD. Z-test was used to test significant variation in functional traits diversity (Rao coefficient index values) per site. To test relationship between traits FD and taxonomic diversity, Rao coefficient index and Simpson diversity index were compared. Microsoft excels based Q1 Macros Software version 2014.12 (KnowWare International Inc. 1996-2014) was used for all the tests.

5.2.2. Traits response along browsing gradient

Ilmotiok ranch had an herbivory gradient from near homestead (year round grazing/browsing) to 2 km away (seasonally grazed/browsed) based on well-established knowledge on “sacrificial zones” effects of herbivory on vegetation (Butt 2010). This was explored using linear regression between distance and log transformed values for LA, SLA and LDMC. Both aggregated mean values and individual species response were tested. Relative densities of target species were also used to understand individual species response as well as effect on community as reflected by the key dominant species.

5.3. Results

5.3.1. Browsing effects on taxonomic diversity

Mpala ranch was taxonomically more diverse than Ilmotiok ranch with Shannon Weiner index of 1.95 and 1.01 respectively. A total of 40 and 12 woody species were collected in Mpala and Ilmotiok respectively. Some species were solely confined to one ranch though some overlapped. *A. brevispica* which was the most dominant species in Mpala in terms of density did not occur in Ilmotiok ranch. Similarly *A. tortilis* (third most dominant species in terms of density) and *A. reficiens* occurred in Ilmotiok yet did not appear in the sampled subplots in Mpala. *A. drepanolobium* was well represented in Mpala with more than 1500 individuals while only 2 individuals were recorded in Ilmotiok. Several evergreen/semi-evergreen (unpalatable species) occurred in Mpala namely; *E. divinorum, C. dichogamus, A. schimperi, pysdrax sp,* and *Phyllanthus sp*. The *E. divinorum* and *C.dichogamus* jointly contributed relative density of 25%. Twenty other species contributed cumulative relative density of only 1% meaning the species evenness was low.

5.3.2. Browsing effects on traits

Vegetative traits varied between sites. Contrary to expectation, aggregated mean values for DKH, H_c and CRWN were larger (Z= 98.3, $p<0.05$; Z = 98.5, $p<0.05$; Z= 37.7, $p<0.05$) in intensely browsed site (Ilmotiok) than in Mpala ranch respectively (table 5-1). Mpala recorded more multiple stems (Z=418.7, $p<0.05$) and more spines density (Z=1.855, $p<0.06$) than Ilmotiok. On the other hand, leaf traits recorded variable results. Aggregated mean for SLA and LNC did not differ between sites (Z = 0.66, $p<0.43$ and Z=0.44, $p<0.76$) respectively while LA and LPC recorded higher values (Z = 4.9, $p<0.05$; Z=3.9, $p<0.05$) respectively in Mpala than Ilmotiok. LDMC values were higher in Ilmotiok than Mpala (Z = 5.46, $p<0.05$).

Table 5-1. Aggregated traits mean values for four dominant browse species in lightly browsed (PR) and intensely browsed (GR).

Traits	**Mpala**	***n***	**Lmotiok**	***n***	***z***	***p-value***
Vegetative traits						
CRWN	1.7(±133)	3562	3.4(±1.4)	1622	37.7	***
DKH	3.8(±4)	3562	7.7(±3.8)	1625	98.3	***
H_c	2.1(±1.02)	3562	2.9(±1.1)	1625	98.5	***
STM	5.2(±5.6)	1078	4.9(±2.1)	1297	418.7	***
Spines	26(±11)	68	23(±6.7)	31	5.4	0.06
Leaf traits						
LNC	0.64(±0.3)	10	0.7(±0.33)	8	0.44	0.76
LPC	0.26(±0.07)	10	0.19(±0.02)	8	3.915	***
LA	971 (±661)	60	400(±292)	30	4.9	***
LDMC	416(±60)	60	487(±78)	30	5.46	***
SLA	11.4(±3.9)	60	11.5(±5.1)	30	0.43	0.66

Whitney U-test statistic and level of significance given at <0.05, n is the number of samples used; values in parentheses are standard deviation from mean while z represent critical values.

SLA and LDMC showed a negative relationship with distance away from homesteads for all the three species. However, only *A. tortilis* LDMC and SLA were significant ($r^2_{adj} = 0.63$, $p<0.004$; $r^2_{adj} = 0.339$, $p<0.045$) respectively. LDMC for *A. etbaica* was slightly significant with distance (figure 5-1). Leaf area (LA) for all the three species did not differ with increasing distance away from homesteads although; all showed a negative relationship.

5.3.3. Community Weighted Mean (CWM)

Community weighted means for all traits measured varied except the number of STMS between sites. Intensely browsed site had larger and taller individuals with wide canopies on average compared to lightly browsed site (Table 5-2). Comparable to aggregate traits means values, CWM for LDMC and SLA were greater in Ilmotiok than Mpala, while CWM for LA was lower in intensely browsed sites as per expectation. Contrary to expectations, individuals in Mpala had higher spine densities per shoot on average than those in Ilmotiok.

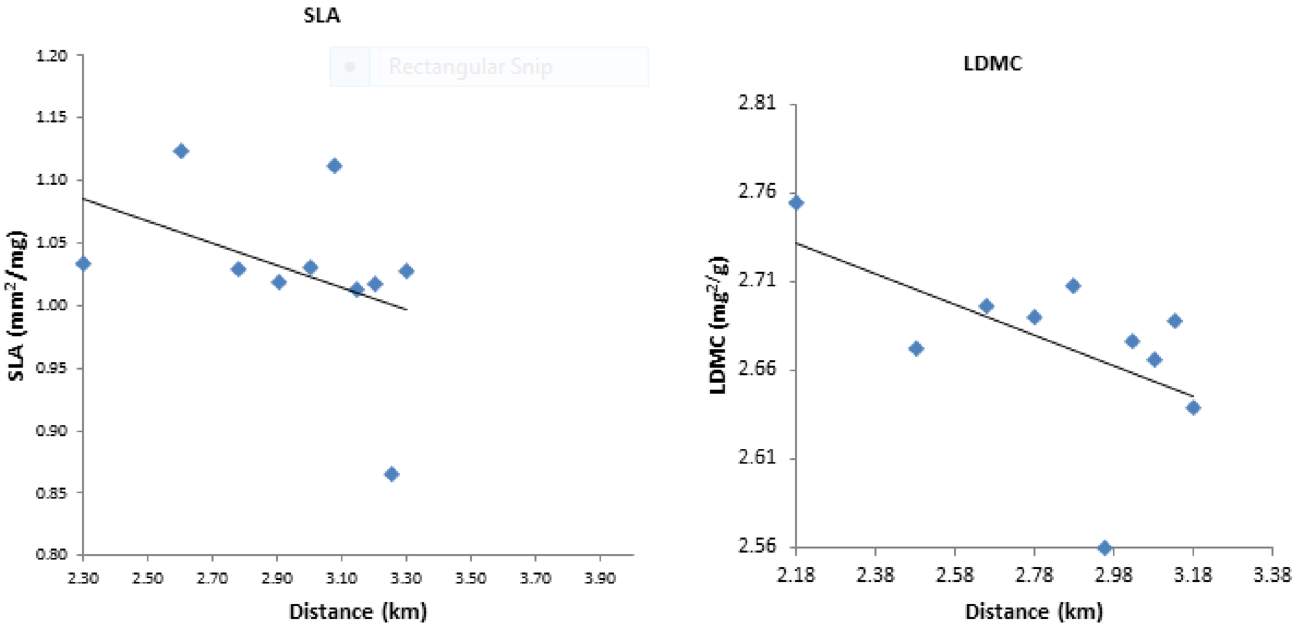

Figure 5-1. Linear regression for specific leaf area (SLA) and leaf dry matter content (LDMC) for three species *A. mellifera, A. etbaica* and *A. tortilis* against distance away from homesteads in Il Motiok GR

Table 5-2. Community weighted means (CWM) for four dominant forage between lightly browsed (PR) and intensely browsed (GR).

Traits	**Mpala**	**Lmotiok**	***p* value**
DKH	0.55	0.84	0
H_c	0.31	0.43	0
CRWN	0.2	0.5	0
Spines	1.4	1.32	0
STMS	0.54	0.54	0.79
LA	3.08	2.6	0
LDMC	2.63	2.67	0
SLA	0.96	1.07	0

Statistical significance level at $p<0.05$, ns - not significant

5.3.4. Responses per species to herbivory

The two species that common on the two sites *A. etbaica* and *A. mellifera* were compared (Table 5-3). *Acacia etbaica* CWM for DKH, H_c, LDMC, and STMS showed variation between individuals in lightly and intensely browsed sites. Unlike in the aggregated mean (Table 5-1) CWM for DKH and H_c recorded higher values in the PR than in GR ($Z=2.27$, $p<0.023$; $Z=5.22$, $p<0.05$) respectively. As anticipated *A. etbaica* LDMC-CWM and STMS-CWM values were larger in Ilmotiok than Mpala ($Z = -4.67$, $p<0.05$; $Z = -5.74$, $p<0.05$) respectively. Similarly LA-CWM were larger for individuals in Mpala ($Z=3.6$, $p<0.05$). *A. mellifera* individuals in the GR were taller, larger in diameter and had wider crowns than those from PR. LA-CWM differed between sites ($Z = 2.79$, $p<0.005$) with PR trees having larger leaves however LDMC-CWM and SLA-CWM did not differ ($Z = -0.245$, $p<0.806$; $Z=0.211$, $p<0.833$) between sites respectively.

Table 5-3. Log transformed mean traits values for four dominant species measured in PR and GR sites

	Mpala (PR)			Ilmotiok (GR)		
Traits	ACACME	ACACET	ACABR	ACACME	ACACET	ACACTO
CRWN	0.4±0.25*	0.38±0.3*	0.006±0.3	0.53±0.16*	0.42±0.17*	0.49±0.19
DKH	0.77±0.27*	1.82±0.24*	1.33±0.13	0.84±0.19*	0.8±0.26*	0.82±0.27
STMS	0.49±0.36	0.15±0.21*	0.68±0.39	0.63±0.22	0.39±0.25*	0.46±0.21
H_c	0.36±0.23*	0.46±0.2*	0.23±0.17	0.48±0.15*	0.39±0.19*	0.34±0.34
Spines	1.21±0.07	1.41±0.08	1.53±0.16	1.26±0.1	1.35±0.06	1.45±0.12
LA	3.01±0.1*	2.5±0.13*	3.29±0.1	2.84±0.14*	2.3±0.07*	2.3±0.13
LDMC	2.65 ± 0.02^{NS}	2.58±0.03*	2.62±0.04	2.66 ± 0.12^{NS}	2.67±0.05*	2.7±0.05
SLA	1.158 ± 0.06^{NS}	1.07 ± 0.09^{NS}	0.79±0.03	1.144 ± 0.2^{NS}	$1.0750.05^{NS}$	0.86±0.05
LNC	-0.24±0.2	-0.3±0.17	-0.18±0.2	-0.25±0.16	-0.11±0.18	0.18±0.26
LPC	-0.64±0.07	-0.64±0.103	-0.5±0.1	-0.69±0.02	-0.73±0.1	0.76±0.07

The Z-test on means values p value followed by asterisk are significant (*) and NS –Not significant; P<0.05, ACACME – *Acacia mellifera*, ACACET – *Acacia etbaica*, ACACBR – *Acacia brevispia*, ACACTO – *Acacia tortilis*

5.3.5. Browsing effects on functional traits and taxonomic diversity

Lightly browsed site was more functionally diverse than intensely browsed site based on Rao coefficient index for all types of data. Simpson index of diversity was marginally low in Mpala compared to Ilmotiok. This contrasted with Shannon index where Mpala showed higher species diversity (Table 5-4).

Table 5-4. Functional traits diversity (Rao coefficient index) and species diversity (Simpson & Shannon index) for PR and GR

Indices	Data type	Site		*p* Value
		Mpala	Lmotiok	
Rao index	Binary	0.23	0.14	0
	Category	0.29	0.16	0
	Quantitative	0.21	0.17	0
Simpson Index	Quantitative	0.34	0.39	0.058
Shannon index		1.95	1.01	

Rao and Simpson indices used data from plots with two or all the target species (*A. mellifera*, *A. tortilis*, *A. brevispica*, and *A. etbaica*) were considered in the analysis of Rao and Simpson indices. Shannon Weiner index was based on 40 species in PR and 12 in GR. Significant values at $p<0.05$.

Single trait FD values between the sites varied in vegetative traits such as CRWN, DKH, and H_c however, diversity of leaf traits; LA and SLA were not different. LDMC-FD in lightly browsed site was marginally more diverse (Table 5-5).

Functional diversity for CRWN, H_c and DKH for the three PR species was more variable than same set of traits in GR species. The three species recorded low FD values for most of the analyzed traits except LA an indication of traits homogenization.

Table 5-5 Functional trait Diversity (FD) values between PR and GR based on four palatable forage species (*Acacia brevispica, A. etbaica, A. mellifera and A. tortilis*).

Traits	Mpala	Ilmotiok	*p*
CRWN	0.15(±0.09)	0.07(±0.03)	**0.001**
DKH	0.23(±0.147)	0.06(±0.1)	**0.001**
H_c	0.12(±0.08)	0.09(±0.001)	**0.001**
LDMC	0.17(±0.11)	0.15(±0.02)	0.09
SLA	0.31(±0.19)	0.29(±0.04)	0.13
LA	0.32(±0.19)	0.35(±0.11)	0.13
Spines	0.22(±0.15)	0.22(±0.04)	0.76
STMS	0.15(±0.11)	0.12(±0.01)	0.49

Z-Test with *p* values in bold indicating those significant at $p<0.05$

5.3.6. Soil and herbivory effects on taxonomic and functional diversity

There was no significant variation in macro-nutrients values (Total N, total C, P, K, Mg, Ca, and Na) as well as PH between PR and GR. Correlation analysis between traits FD and soil chemical and physical properties and Pearson correlation coefficient did not show correlations (data shown as appendix 3).

5.4. Discussions

The results indicate that intense browsing diminishes both taxonomic and functional traits diversity. Low woody species diversity in intensely browsed site (pastoral system) suggest that palatable and less palatable browse-sensitive species may have been suppressed and/or outcompeted by more tolerant species when subjected to similar level of disturbance. These findings agree with observations in similar studies undertaken in semi-arid Succulent Karoo biome and in Mediterranean shrubland whereby sustained heavy grazing resulted in decline of woody species (Anderson & Hoffman 2007; Papanikolaou et al. 2011). Intense browsing further promotes investment in browsing-tolerant as well as defense traits amongst persistent dominant- palatable species. This was typified by higher values for canopy diameter, canopy height, and multiple stems, all associated with compensatory photosynthesis and growth rate. They also had high LDMC, spines and low LA values associated with avoidance strategies (defensive traits). These strategies were reflected at the scale of individual species as well as at the community level (see chapter six). The findings further indicate that intense browsing decreases traits FD and this may have implication on ecosystem processes. Whereas the above observations were made, it should be noted that conclusions derived thereof are based on sampling from only one site –albeit large ones each at the PR and GR.

5.4.1. Browsing effects on plant taxonomic diversity

The mechanism behind low diversity could be associated with direct impacts such as death due to intense defoliation of biomass or increase competition from non-browsed individuals (El-Keblawy et al. 2009; Hulme 1996). It could also be through indirect effect such as increased susceptibility to pests and disease infestation (Haukioja & Koricheva 2001), or decline in fitness causing low seed production and finally low seedlings recruitment (Fornara & du Toit 2007).

Interestingly, species with high abundance in the intensely browsed site (except one) were of medium to high palatability based on Lusigi et al. (1984) implying that majority were either tolerant or resistant to browsing. *Acacia reficiens* considered an invader of low palatability and associated with heavy browsing (Cornelius & Schultka 1997; Ward 2005) does not exist in PR and is said to be a recent entrant to the GR (Metiaki pers. Communication). This is a typical example of invader species taking advantage of changing competitive environment and/or resource availability.

Although the study sites had fairly similar bioclimatic properties, it was surprising to find that *A. drepanolobium* represented by more than 1500 individuals in private ranch was represented by only 2 individuals in the sampled plots within pastoral group ranch. A study on the species (Goheen et al. 2007) noted that browsing induced establishment of spines whose length was significantly and negatively related to magnitude of reproduction. The species is also associated with clay soils with impeded drainage and therefore there is need to understand whether intense herbivory could have in anyway affected eco-hydrological dynamics of the area. Canonical correspondence analysis of dominant species in PR indicated that the species was positively related with high soil fertility (see fig 6-1).

Lightly browsed site was more species rich although with low species evenness. The site had significantly higher abundance of unpalatable evergreen species primarily *E. divinorum* and *Croton dichogamus* perhaps due to high forage selectivity among the herbivores and resultant higher competitive edge of the unbrowsed individuals (Augustine & Mcnaughton 1998; Wahungu et al. 2013). Besides competitive edge of the unbrowsed species, absence of historical fire regime that was previously used in management of the savanna may have played a role in shaping present vegetation structure and composition.

5.4.2. Browsing effects on plants traits

The dominant palatable species have evolved over time to tolerate and/or resist defoliation in the savanna ecosystem. This study confirmed that majority of the dominant palatable species employ both tolerance and/or avoidance strategies to minimize negative effects of browsing (Fornara & du Toit 2007). Of the 12 woody species represented in intensely browsed site, all except one were spinescent (with thorns, spines or corky protective twigs).

This study findings contradicted Fornara & du Toit (2008) and Noumi et al. (2010) observations, where intense browsing was linked to reduction in canopy cover, canopy diameter and longer internodes. The higher traits values (crown/canopy diameter, stem diameter, canopy height) observed in the intensely browsed site was associated with compensatory growth (Sebata 2013) however morphology of the selected species may have also played a role. For example, *A. brevispica*, which contributed 30% of stem density in the private ranch, is a shrub with relatively small stem diameter (~2.2 cm on average) and 90% of individuals sampled had been browsed. This implies its canopy heights and canopy cover was below optimum and might be responsible for low mean values. The above limitation was overcome by comparing trait values for similar species that occurred across sites. It was possible to confirm the aspect of browsing lawn typified by wider crown canopies, and more multiple stems that facilitated browsing, compensatory photosynthesis and re-browsing within pastoral ranch (Cromsigt & Kuijper 2011; Du Toit et al. 1990; Sebata 2013; Staver et al. 2012). This was particularly true for *A. mellifera* which coincidentally was the most abundant in term of stem density. The species further recorded higher edible biomass in GR than PR (see chapter 6). This observation perhaps explains why the species has been reported as invader in overgrazed sites (Gemedo et al. 2006; Hagos & Smit 2005; Kraaij & Ward 2006; Skarpe 1990). It is unclear however why *A. mellifera* allocate so much energy on thorns/spines yet browsing seem to increase it fitness.

On the contrary *A. etbaica* on average had smaller canopies within intensely browsed site similar to observation made by Noumi et al. (2010) and Fornara & du Toit (2008) among *Acacia tortilis* and *Acacia nigrescens* species respectively. Low LA and high LDMC observed in intensely browsed site affect instantaneous intake rates through their effects on bite size and bite rate. These observations imply that *A. mellifera* and *A. etbaica* employs tolerance and avoidance strategies to herbivory respectively.

5.4.3. Functional diversity and browsing

Generally all traits except LA recorded low FD values in intensely browsed site. Like overgrazing, heavy browsing causes decline in FD (Díaz et al. 2001) and subsequent reduction in ecosystem function (Emmerson & Raffaelli 2000). Functionally, DKH, CRWN and H_c traits were more diverse in lightly browsed site (private ranch). One possible explanation to this observation is that heavy browsing caused traits homogenization by filtering out species intolerant to browsing leaving behind tolerant and/or resistant species. This suggests that intense browsing induces 'look alike' morphology among species. Another possible explanation is the abundance of two species with different lifeforms (*A. brevispica* ashrub and *A. etbaica* atree) in Mpala thus increases diverse traits. Conversely, all target species in pastoral ranch were all trees with relatively comparable sizes. They displayed similar architecture with respect to canopy height, crown and stem diameter implying low functional traits diversity, which may have cascading consequences for biodiversity and subsequent ecosystem functioning (Smit et al. 2010). For example rates of water, nutrient, and energy cycling through ecosystems are dependent on the horizontal and vertical structural features of primary producers (Blench & Sommer 1999).

5.5. Conclusions

These findings suggest that management of livestock browsing levels can be used to manipulate species diversity, and functional traits diversity. Extremely low stocking rates may promote proliferation of unpalatable species such as *E. divinorum* while overstocking may result in decline and/or complete loss of some species which in turn may facilitate encroachment by invasive species. High browsing tolerant species such as *A. mellifera* is likely to increase in abundance in the intensely browsed site due to its potential for compensatory photosynthesis and presence of spines to minimize defoliation damage. This is likely to exacerbate shortage of grasses for grazing animals as well as general loss of biodiversity through increased encroachment of the range. Similarly, intense browsing is likely to promote traits homogenization thus making ecosystems vulnerable to perturbations by diminishing their functional redundancy and response diversity. This means that ecosystems become vulnerable to disturbances/stress because the response diversity needed for their stability is lost through traits homogenization. Traits homogenization will also interfere with ecosystem processes such as energy flux.

CHAPTER SIX

BROWSING EFFECTS ON SPECIES COMPOSITION, STRUCTURAL DIVERSITY AND BIOMASS PRODUCTION UNDER PASTORAL AND COMMERCIAL RANCHING IN SEMI-ARID SAVANNA, NORTHERN KENYA

Abstract

The role of herbivory in woody plant dynamics within the savanna has been a subject for investigation for many years but limited studies have looked at managed systems dominated by wildlife and domestic herbivores. This study sampled vegetation using 421 square plots of 400m^2 nested on three transects (each 3 km long) per site that is; a lightly browsed private commercial ranch and intensely browsed pastoral group ranch to understand effects of mammalian herbivory. The data was subjected to Canonical Correspondence Analysis (CCA) to isolate environmental factors influencing vegetation dynamics from herbivory effects. Kruskal-Wallis analysis of variance was used to test variation between transects per site while non-parametric Mann-Whitney U-test was used for significance test. There was significant ($P<0.05$) difference in species diversity between sites. Intense herbivory mediated by soil nutrients diminishes woody species richness and abundance. Unpalatable woody species dominated lightly browse ranch. Intense herbivory diminishes vegetation heterogeneity but does enhances biomass production of browsing-tolerant species through compensatory re-growth and/or perhaps through reduced competition. Compensatory re-growth dampens once the species escape ‘browsing trap’ zone and therefore to sustain enhanced biomass production in the landscape; browsing-tolerant species should be regularly pruned at the average height of dominant herbivore species kept. The functional properties of ecosystem that are maintained by migratory behavior of major herbivores on savanna may have been lost by

high frequency high intensity grazing due to limited mobility in GR while low frequency, low intensity grazing in PR perhaps explains increase in unpalatable species in both ranches.

6.0. Introduction

The savanna systems covers more than half the area of the African continent and support a large fraction of its human population, majority of its rangeland and livestock biomass, and are home to the greatest density of wild herbivores and carnivores of any ecosystem on Earth (Sankaran & Anderson 2009). Besides their obvious socioeconomic importance, several savanna grazing systems have been noted to suffer from woody/bush encroachment; in Southern Africa (Moleele et al. 2002; Roques et al. 2001; Trollope et al. 1998), and Eastern Africa (Angassa 2014; Dalle et al. 2006). Bush encroachment has been associated with decline in grass resource for livestock (Macharia and Ekaya 2005; Moleele *et al.* 2002), decrease in soil carbon (Hudak et al. 2003), decline in biodiversity (Angassa 2014; Gordijn et al. 2012), and proliferation of invasive species (Alofs and Fowler 2007).

Several causal factors have been brought forward to explain mechanisms behind woody plants encroachment and key among them include; grazing, fire, browsing and rainfall (Angassa 2012; Dalle et al. 2006; Roques et al. 2001; Trollope et al. 1998). The role of browsers in the woody plants dynamics however remains controversial. A study by Mills et al. (2005) in South Africa noted that intensive goat production transformed semi-arid thicket with dense shrubby vegetation into open landscape dominated by ephemeral species. Conversely, Roques et al. (2001) observed that browsing pressure had significant but minor impact on the woody plants dynamic only at the early stages of encroachment. Elsewhere outside Africa, browsing goats were observed to have had no negative effects on species richness (Arévalo et al. 2011; Mancilla-Leytón et al. 2012; Papanikolaou et al. 2011) and at times browsing helped maintain species diversity (Arevalo et al. 2011; Oba 1998). Earlier studies blamed bush/woody encroachment on selective ungulates herbivory that leads to proliferation of unpalatable and/or chemically defended species that outcompete defoliated palatable species.

However other studies have also shown that grazing/browsing tolerant palatable species often increase with increase in herbivory (Augustine & Mcnaughton 1998; Hulme 1996; Skarpe 1990). It is also true that effects of herbivory on species composition and structure to a large extent are ameliorated by other prevailing environmental conditions such as rainfall, presence of fire, quality of soils, amount of biomass loss, and/or ability of affected species to recover (Augustine & Mcnaughton, 1998; Midgley et al. 2010; Roques et al. 2001). In this study the effects of varying intensity of mammalian herbivory on the dynamics of woody vegetation in semi-arid savanna in Kenya under similar bioclimatic conditions were evaluated. Woody plants encroachment in the Country has been observed in northern rangelands (Augustine 2003b; Okello et al. 2001; Wahungu et al. 2013) and in the southern rangelands (Macharia and Ekaya 2005). Augustine & Mcnaughton (2004) observed that woody cover in Laikipia county (northern Rangeland) had increased substantially in the last 50 years to stand at about 28% as at 1998 a fact they attributed to suppression of wildfires. This scenario is reflected by higher woody encroachment of lightly grazed private ranches compared to intensely grazed communal land. Ironically, intensely grazed communal pastoral ranches with low fuel load to support meaningful fire has remained fairly open even in areas with no human settlements when expectations would have been an increase in woody plants (Smit et al. 2010). In the absence of fire, herbivory remains the major modifier of savanna vegetation (Sankaran et al. 2005). It is against the above background that this study investigated effects of browsers on woody species composition, structural diversity and browse biomass. This was undertaken using square plots (400 m^2) sampled from two management systems; Private commercial ranch (lightly grazed) and intensely grazed communal pastoral group ranching.

6.1. Methods

6.1.1. Study Site

The study was conducted in Mpala PR and adjacent Ilmotiok GR in Laikipia county, Kenya (details provided in chapter two).

6.1.2. Browsing intensity

Livestock stocking rates as well as native herbivore densities per site were used as surrogate for variation in browsing intensity. Herbivores densities were derived from published and grey literature largely wildlife long-term surveys from the study region. The PR has maintained low livestock stocking rate of 10 – 12 TLU/km^2 mainly cattle and sheep in the last three decades. The GR stocking rates on the other hand fluctuates depending on prevailing weather conditions with high stocking rates during rainy seasons when pastures and water are plenty and low shortly after major droughts. The GR is estimated to be stocking at more than 25 TLU/Km^2 (Georgiadis et al. 2007; Kaye-zwiebel & King 2014; Kinnaird & O'Brien 2012; Kinnaird et al. 2012) . In the GR the grazers kept included cattle, sheep, and donkeys and browsers are mainly goats and camels.

Wildlife movement is unrestricted in most of the land properties (ranches) in the region given that there are no fences except those used to restrict movement of rhinos (Georgiadis et al. 2007). However, wildlife densities and occupancy time for non-resident wild animals (e.g. elephants) which uses the ecosystem at different seasons was more in PR than GR.

This however notwithstanding, average estimates of grazing and browsing wildlife and domestic animals in the region (1985 -2012) indicates that GR still had higher densities than PR at 43 TLU/Km^2 and 28 TLU/Km^2 respectively. Browsing domestic and wild herbivores considered the most effective TLUs in woody plant dynamics was estimated at 26 TLU/Km^2 and 8 TLU/Km^2 for GR and PR respectively (Augustine 2003a; Kaye-zwiebel & King 2014; Kinnaird & O'Brien 2012; Kinnaird et al. 2012).

6.1.3. Vegetation data

Sampling design for Structural and species composition data

Three transect lines; each 3 km long, approximately 200 m apart were purposively established per site to ensure similarity in soils types and topography. The altitude in the whole study region varied between 1500 and 1800 m above sea level. In each transect, subplots measuring 20 x 20 m were systematically laid in alternating manner at 20 m intervals to make 75 subplots per transect and a total of 225 per site. Whenever a plot fell in an area with signs of human disturbances (e.g. abandoned charcoal kiln, abandoned homestead, tree harvesting etc.) an alternative nearby site was selected. However 29 subplots were not sampled in PR due to wildlife threat during fieldwork. In each subplots the following attributes were recorded; percent vegetation cover, bare grounds (through visual estimate), percent slope, elevation, evidence of fire, and soil texture determined in the field based on feel flow chart system (Vagen *et al.* 2010). Forty five soil samples were collected per site taken from (20 x 20 m) subplots in a stratified random as described in section 2.2.6.

In each subplot all woody species with stem diameter of 1.0 cm at approximately 50 cm above ground were identified and the following measurements taken; DKH, height, canopy depth and crown diameter/canopy diameter (CRWN). Crown diameter was derived from measuring two perpendicular readings of the crown at the longest and shortest distance then measurements averaged to give one value per individual tree. Non woody invader species were also recorded and their abundance cover estimated. Botanical nomenclature followed Flora of Tropical East Africa (1954 -).

6.1.4. Structural diversity

Structural heterogeneity was assessed based on four dominant – palatable species identified earlier. The *A. etbaica* and *A. mellifera* occurred across study sites and provided opportunity to compare browsing effect. Structural variables measured included tree heights, canopy diameter, and canopy depth. Canopy volumes, Canopy area, and canopy density per subplot was then calculated using the formulas provided below.

a. Canopy Area (CA) = $\pi D1D2/4$

Where D_1 and D_2 are the two diameters measured in the field –the long length and the shorter distance of the crown when projected on the ground. This formula does not assume symmetry of the crown. In this case the radius (r) used is as per the length of the diameter, meaning the longer side will have higher r value while the shorter side will have a smaller value of r.

b. Canopy volume (Canvol) = $2/3\pi H_D$ ($D_1/2$ x $D_2/2$) derived from ellipsoid volume formula, where H_D is the length of canopy depth, while D1 and D2 are the two perpendicular canopy diameter readings (Thorne *et al*. 2002).

c. Canopy density (CD) per subplot = Σ canopy area of individual tree/400 m^2 *100 multiply by 100 to express as a percentage (Manila 2007).

6.1.5. Browse biomass

The browse biomass (leaves and young shoots) estimates were done for four target species earlier identified most dominant palatable species and therefore made significant contribution to available forage. The browse biomass was estimated using double sampling method as described by Foroughbakch *et al.* (2008). Fifteen to twenty six individuals per species were systematically selected for biomass measurement at 60 m intervals in the study plots in PR and 100 m interval in GR. At every pre-determined point, the nearest target species without signs of damage and/or browsing was selected for measurement. One representative branch was chosen and its diameter was then measured at the base using a diameter tape and later it was cut off the tree and all its leaves and young shoots harvested, oven dried at 70˚C for 3 days and weighed. A regression equation based on basal branch diameter and browse biomass was then derived and used to estimate edible biomass per hectare per site. The following equations were derived: A. *etbaica* $y = 56.24x-78.981$, $r^2 = 0.685$; *A. mellifera*, $y = 131.76x – 265.6$, $r^2 = 0.714$; *A. brevispica* $y = 48.74x - 41.17$, $r^2 = 0.24$ and *A. tortilis* $y = 53.5x – 103.5$; $r^2 = 0.75$ where y is the edible (browsable) biomass and x is branch base diameter.

6.1.6. Piospheric effects

To elucidate the observations made between sites, piospheric effects were tested using GR with apparent grazing/browsing gradient based on two focal points (homesteads and temporary watering point) that receive higher grazing intensity compared to the rest of the ranch. Near homesteads receive year round grazing/browsing while watering point receive higher intensity of grazing compared to distance further away. This was achieved by undertaking polynomial regression between distance from homesteads to the end of transects (near watering point) and plant densities per subplots.

6.2. Data analysis

Vegetation data was subjected to Canonical Correspondence Analysis (CCA) to decipher possible linkages between species and environmental variables from those associated with browsing. This analysis was performed using PC-ORD version 5.19 (McCune and Mefford, 2006). Variation within transects (vegetation and soil properties) were tested using Kruskal-Wallis test while Mann-Whitney U-tests were used to compare structural data between the two sites. Coefficients of variation (CV) were calculated to estimate structural diversity between sites. The CV was calculated as standard deviation divided by mean where higher values represented higher variation/diversity and vice versa. Correlation analysis between browse biomass and vegetation structure was done. Q1 Macros Software version 2014.12 was used in all the analysis (KnowWare International Inc. 1996-2014).

6.3. Results

6.3.1. Species composition

A total of 7412 woody plants were sampled; 1619 in GR and 5793 in PR. Species diversity varied between sites (Shannon index 1.95 and 1.01 for PR and GR respectively). Forty five species belonging to 24 families and 33 genera were identified in the study sites (Table 6-1).

Table 6-1. Floristic composition between PR and GR in Laikipia County, Kenya

Parameter	Private ranch	Group Ranch
Number of woody plants	5793	1619
Families	20	7
Genera	30	6
Species	40	15
Shannon diversity index	1.95	1.01
Similarity index	26%	

The two sites differed in species richness with 40 species in 20 families and 15 species in 7 families found in PR and GR respectively (Appendix 1). Despite relatively higher diversity in PR compared to GR, species evenness was low with 6 species contributing more than 85% of all individuals. Fabaceae family dominated the two sites with eight species represented in each site mainly from Acacia genus. Fifty seven percent of all species in GR belonged to Fabaceae family. Similarity index for the sites was 26%.

Some species were solely confined to one ranch though some overlapped. *A. brevispica* which was the most abundant species (in terms of density) in PR did not occur in GR. Similarly *A. tortilis* (third most dominant species in terms of density) and *A. reficiens* occurred in GR yet did not appear in all the sampled plots in PR. *A. drepanolobium* was well represented in PR with more than 1500 individuals while only 2 individuals were recorded in GR. Several evergreen/semi-evergreen (unpalatable) species occurred in PR and none in GR. They included *E. divinorum, C. dichogamus, A. schimperi, pysdrax sp,* and *Phyllanthus sp*. Similarly GR had abundance of invader species such as *I. kituensis, S. volkensii,* and *O. stricta*.

6.3.2. Woody community structure

Density of woody species between the two sites varied ($p<0.05$) with mean of 739 and 180 trees ha^{-1} for PR and GR respectively. The three most abundant species in PR in terms of density were; *Acacia brevispica*, *A. drepanolobium* and *Croton dichogamus* contributing 30.1, 18.1 and 15.3 percent densities respectively. Twenty six species had less than one percent relative density, six of which were represented by only one individual. The three most dominant-palatable species (*A. brevispica, A. mellifera* and *A. etbaica*) contributed relative density of 43.1%. Similarly, species densities in GR were highly skewed with the three most dominant species *A. tortilis, A. etbaica* and *A. mellifera* cumulatively contributing more than 97% density (Appendix 1).

Mean values for structural data varied between PR (lightly browsed) and GR (intensely browsed site) for all parameters measured. Trees on GR, on average had larger stems, crown diameters and heights. In absence of small-sized, this translated into larger mean values for basal area, canopy area and canopy volume ($Z = 39.5$, $p< 0.001$; $Z = 40$, $p < 0.001$ and $Z = 39.3$, $p < 0.001$) respectively (Table 6-2). Whereas fire could have contributed in shaping the vegetation structure in GR in the past, high level of grazing had reduce herbaceous biomass that can support high intensity fire due to shorter grazing intervals as indicated by higher bare ground in table 6-2. No evidence of fire was noted during subplots characterization.

Table 6-2. Mann-Whitney U-test results comparing mean values of structural parameters for four dominant-palatable species (*Acacia mellifera, A. brevispica, A. etbaica,* and *A. tortilis*) within private and group ranches.

Paramenters	**PR**	**GR**	**Z value**	***p* value**
DKH (cm)	3.8 (±4)	7.7 (±3.9)	39.5	*
Basal Area (cm^2)	24 (±94)	58 (±70)	39.5	***
Height (m)	2.1 (±1)	3 (±1.1)	26	***
Canopy Volume (m^3)	4.9 (±11)	18.4 (±24)	39.3	***
Crown Diameter (m)	1.7 (±1.2)	3.4 (±1.4)	39.8	***
Canopy Depth (m)	1.3 (±0.8)	2.1 (±0.9)	30.4	***
Canopy area (m^2)	3.5 (±5.6)	11 (±9)	40	***
Density (ha^{-1})	1175	175		***
Bare ground	20 (±20)	29 (±23)		*

Statistical significance level indicated *p<0.05, ** p<0.01, ***p<0.05. Standard deviation in parentheses

Due to this rather unexpected outcome, canopy diameter and height values for two species that that are common in the two sites (*A. mellifera* and *A. etbaica*) were compared. *A. mellifera* canopy diameter (CRWN) and height varied (mean 3.1 *cf* 2.6; $Z = 5.87$, $p<0.05$

and mean 3.6 *cf* 2.9; Z = 5.65, p<0.05) for GR and PR respectively. The *A. etbaica* canopy and height equally differed (P<0.05) between sites, individuals in PR were wider (mean 3.1 m) and taller (3.4 m) against 2.8 and 2.7 m for GR respectively Kruskal-Wallis test for variables in PR showed no variation between transects, however, soil PH, nitrogen, carbon, and magnesium individually differed among GR transects (table 6-3).

Table 6-3. Kruskal-Wallis analysis of variance test results for transects in group and private ranch

Parameters	Group Ranch		Private ranch	
	x^2	p	x^2	p
Soil texture	0.36	0.84	0.016	0.99
Percent slope	0.26	0.88	1.77	0.41
Density	3	0.22	2.11	0.35
PH	8.67	**0.013**	0.95	0.62
Nitrogen	9.7	**0.008**	2.35	0.31
Carbon	8.84	**0.012**	2.38	0.3
Calcium	4.84	0.09	1.25	0.53
Magnesium	14.53	**0.001**	0.002	0.99

The figures in bold are significant, p<0.05, df = 2.

Abiotic factors

Canonical Correspondence Analysis (CCA) ordination brought to fore, the environmental variables that may have influenced vegetation structuring. Distance away from homesteads was used as surrogate for declining herbivory intensity. As anticipated, soil fertility decline away from homestead as a result of declining dung and urine concentration from livestock. This occurrence seemed to positively favour *Sansevieria volkensii* (SANSVO) as they increased in abundance with distance (Dis), while *Ipomoea kituiensis* (IPOMKI) had opposite effect. First axis eigenvalue was 0.375 and did explained 23% of the variance. Monte carlo test results were not significant. Although Kruskal-Wallis test showed that PR transects did not differ, *Acacia brevispica* (ACACBR), *A. etbaica* (ACACET), and *Croton dichogamus* (CROTDI) were associated with plots on lower elevation with sandy soils. *Acacia dreponolobium* (ACACDR) dominated vertisols high in macro-nutrients (N, Mg, and Ca) and PH while *Pyrostria phyllanthoides* (PYROPH) were abundant on sloppy areas (Figure 6-1). Monte Carlo test results for species –environmental variables was significant ($p<0.002$) for 500 runs. Thirty one percent of variance was explained by the first axis.

When size class distribution of the two overlapping species based on stem diameters were compared, they differed significantly between sites. *A. mellifera* in GR showed a course-grained dome-shaped distribution curve with fewer individuals having stem diameter less than 4.9 cm but increase to peak at 7-8.9 cm diameter class before declining as diameter increased. At the PR the species had relatively fine-grained reverse J-shaped curve with more smaller sized individuals that decline gradually with increase in trees diameters. *Acacia etbaica* followed a similar pattern as *A. mellifera* in GR although in a less dramatic manner (Fig.6-2). The individuals with 1 - 2.9 cm stem diameters were fewer compared to those in 3 - 4.9 cm category.

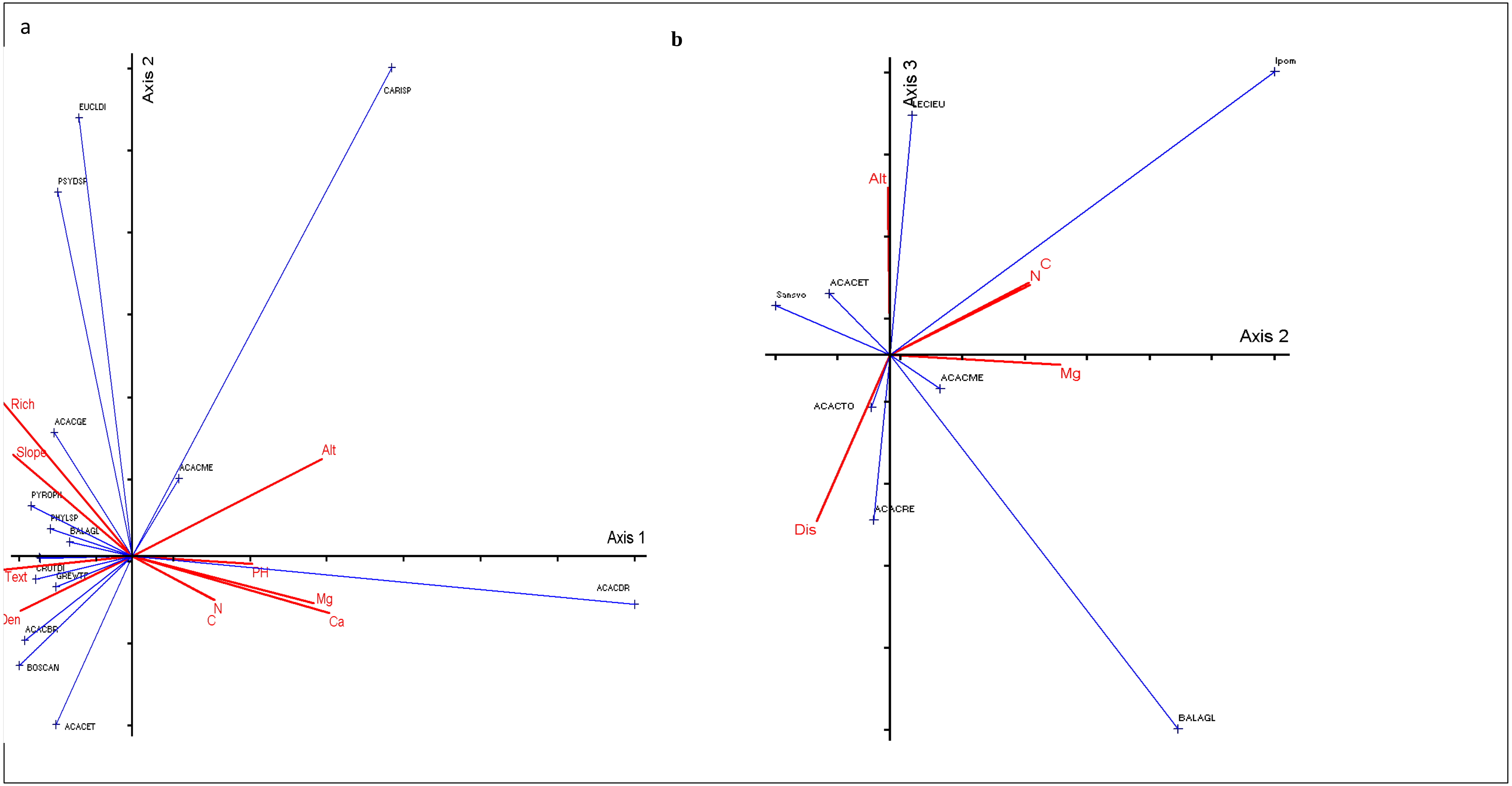

Figure 6-1 results (a) Mpala and (b) Il Motiok showing effects of soil nutrients, slope, elevation (Alt), soil text (Text), spp richness (Rich) and distance (Dis) on vegetation distribution. EUCDI – *E.divinorum*, ACACGE – *Acacia gerradii*, ACACME – *A, mellifera*, ACACET – *A, etbaica*, ACACTO – *A. tortilis*, *Sanvo – S. volkensii*, Ipom – *I. kituensis*,

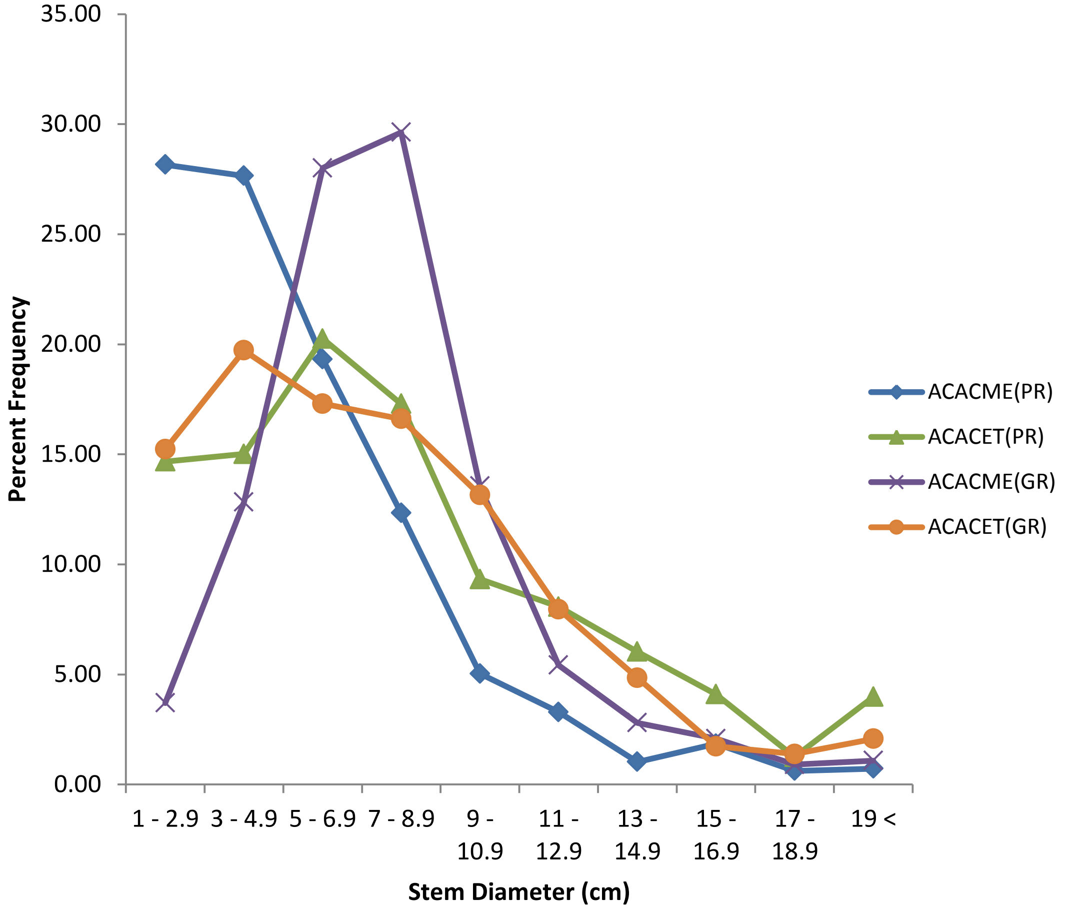

Figure 6-2. Size class distribution of two overlapping species A. mellifera (ACACME) and A. etbaica (ACACET) for PR and GR respectively.

Piospheric effects

Mean polynomial regression for the three transects between distance (x) from homesteads and plant density (y) was derived as ($y = -0.1779x^2 + 2.6561x - 1.5535$; $R^2 = 0.9067$) indicating increasing tree density with increase in distance away from homesteads. This trend however change after 2.3 km when further increase in distance resulted in decline in tree densities (Fig. 6-3). All the three transects showed similar trend, however only two had coefficient of determination above 0.5

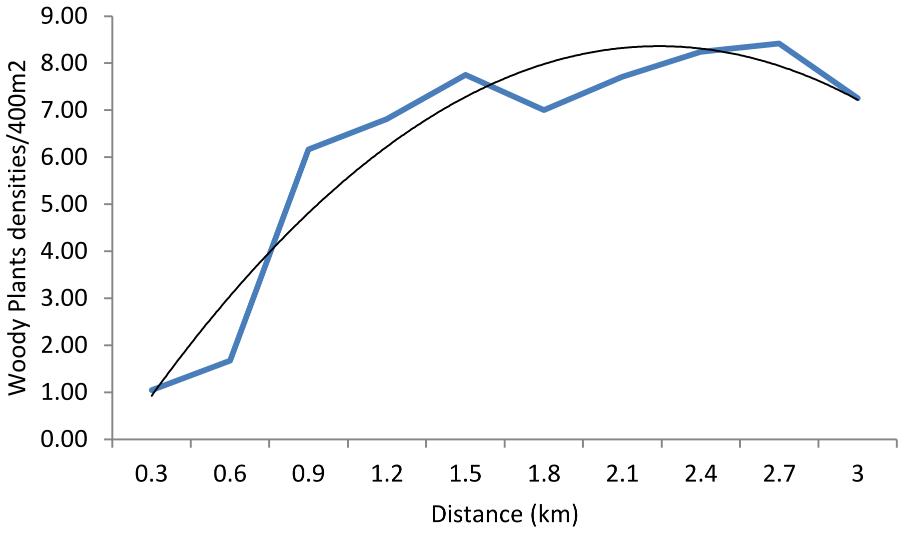

Figure 6-3. Mean polynomial regression results indicating actual values and line of best fit between distances from homesteads to watering point in GR

6.3.3. Structural diversity

Communal ranch recorded higher structural mean values in all variables measured (Table 6-1) however, in terms of structural heterogeneity; the site was less diverse compared to PR. The coefficient of variation (CV) for basal area and herbaceous cover was 270% and 30% compared to 390% and 20% for GR and PR respectively. The greatest difference between sites was in basal area, canopy volume and canopy area with a CV difference of 270%, 90% and 70% respectively. The least difference in structural diversity was noted in herbaceous cover and canopy depth with CV difference of 10% and 20% respectively. Private ranch recorded higher occurrence frequency per height class per hectare when the two sites were compared except in height class 3.1 – 4 m where GR had more individuals.

6.3.4. Browse biomass production

Cumulative biomass varied ($p<0.05$) between GR and PR. The three target species in GR produced cumulative browse biomass of 2775.5Kg DM and a mean of 308Kg DM ha^{-1} while PR produced 2131kg DM with a mean of 276Kg DMha^{-1} ($z = 89$, $p< 0.05$). In terms of browse production potential per species, *A. mellifera, A. etbaica* and *A. tortilis* produced 267.2, 19.35 and 16.13Kg DM ha^{-1} respectively in GR while *A. mellifera, A. etbaica* and *A. brevispica* in PR, produced 109.7, 53.8 and 108 Kg DM ha^{-1} respectively. This indicates that A. *mellifera* produced more biomass per unit area in the GR than PR whereas *A. etbaica* performed better in PR than GR. Similarly, *A. mellifera* individuals in GR produced more biomass (z = 125, p < 0.05) mean of 481g DM stem^{-1} compared to mean of 407g DM stem^{-1} in PR while *A.etbaica* had the opposite effect (Table 6-4). Herbivory had profound effect on *A. mellifera* biomass production at all size classes with intensely browsed GR posting more biomass than PR. Biomass production by *A. etbaica* between sites though generally higher for PR, was not consistent in all size classes. There was no difference in biomass within ≤1 and 1.1-2.0 m size classes between sites (z = 0.31, *p* = 0.76 and z = 1.3, p = 0.19 respectively).

Table 6-4. Browse biomass mean values (gDM) per species per height class in group (GR) private ranch (PR) in semi-arid savanna, northern Kenya.

Height class	**GR**	**PR**	**Z**	***p* values**
A. mellifera				
≤ 1	78±232	-80± 52	6.5	**0.001**
1.1 – 2.0	224±285	216±369	3.11	**0.001**
2.1 – 3.0	393±285	348±389	4.43	**0.001**
3.1 – 4.0	501±306	633±880	0.64	0.52
≥ 4.1	729±461	702±579	1.49	0.13
Mean	481	407	125	**0.001**
Acacia etbaica				
≤ 1	112 ±179	112±239	0.31	0.76
1.1 – 2.0	62±46	128±246	1.3	0.19
2.1 – 3.0	203±190	250±204	2.64	**0.01**
3.1 – 4.0	327±202	381±245	2.4	**0.02**
≥ 4.1	487±251	414±338	2.39	**0.02**
Mean	215	301	7.3	**0.001**

The U-test significant values are indicated in bold. Note A. tortilis and A. brevispica did not occur across the ranches.

6.4. Discussions

This study shows that herbivory exerts pressure on species composition, structure, structural diversity and subsequently impacts on biomass production as an ecosystem process. Intense herbivory caused shift in species diversity; whereby some species disappear, while other may appear depending on their levels of tolerance and/or resistance as well as suitability of emergent environment (Table 6-1). Furthermore intense herbivory facilitates formation of course grained vegetation structure (as exemplified by figure 6-2), diminishes structural diversity and this had implication on biomass production (table 4). Some of the effects of herbivory were mediated by environmental factors such as nutrients, elevation, and soil texture.

6.4.1. Species composition

Differences in level of herbivory caused marked difference in woody species composition between PR and GR. The intensely browsed site (GR) was less rich in woody species compared to PR although there were 26% similar with PR. Under intense browsing, species selection is low and therefore both palatable and less palatable species are browsed (Augustine and Mcnaughton 1998) and browsing-tolerant species will thrive under such circumstances to the detriment of less tolerant species. Low species diversity in GR may indicate a case of filtering out of species intolerant to heavy browsing (Díaz et al. 2001) or declining competitiveness resulting in low reproduction ability (Fornara and du Toit 2007). Using *A. drepanolobium* as an example, it's low density in GR could be attributed to re-allocation of resources for the development of defensive traits at the expense of reproduction (Goheen et al. 2007). Over time few seedlings are recruited in the system and even fewer ever survive to maturity stage due to biotic and non-biotic constrains and may eventually get locally extinct.

Beside tolerance/resistance evolutionary traits acquired by palatable species to persist under intense browsing, intensity of biomass removed and soil nutrients availability could ultimately determine species composition in the long-term (Augustine and Mcnaughton 1998; Mysterud 2006). Notably, species with high abundance in the GR except one were of medium to high palatability (Lusigi et al. 1984) implying these species have evolved with herbivory and have developed browsing tolerant and/or browsing resistant strategies to persist sustained biomass. This observation contradicts findings that intense herbivory causes increase in unpalatable species (Riginos and Hoffman 2003). Though not significant, *A.mellifera* was positively associated with sites with higher nitrogen and carbon at the GR. Similarly, *Ipomoea kituensis* was abundant in areas close to homestead with higher nutrients level.

Occurrence of non-palatable species such as *S. volkensii, I. kituensis* and *A. reficiens* in GR suggest potential increase in resource availability associated with low intensity of competition (Alpert et al. 2000) and/or existence of unoccupied ecological niche (Schellberg and Pontes 2013). *Ipomoea kituensis* decrease in abundance with distance away from homesteads, and was positively associated with increase in soil fertility linked to enhanced dung and urine concentration. The species has been associated with overgrazing in southern Kenya rangeland (Kidake et al. 2015; Macharia and Ekaya 2005). Beside reduction in competition from palatable species, hooves actions may also be playing a role in their proliferation.

Species selection in PR is high due to low stocking rate and as such only highly palatable species are repeatedly defoliated. If targeted species are browsing-intolerant, they will decline or disappear thus availing extra resources to un-browsed non-palatable species and a more competitive edge especially in areas with nutritionally poor soils (Augustine and Mcnaughton 1998). Dominance of unpalatable species such as *C. dichogamus* and *E. divinorum* which can be classified as increaser type II (Reed and Dougill 2010) could support this position. Moreover, absence of fire and low level of defoliation gives unpalatable species a competitive edge over palatable species.

6.4.2. Woody community Structure

In GR there was relatively low woody plants density contrary to commonly held position that in the absence of fire, woody plants proliferates. In the absence of fire in the management of both PR and GR, herbivory seemed to be the only major modifier of vegetation dynamics (Sankaran et al. 2005). Low woody plants density (175 trees/ha) in GR suggest possible poor recruitment of seedlings over the years. This interpretation was confirmed by size class distribution analysis for *A. mellifera* and *A. etbaica* whereby both species produced dome-shaped curves showing fewer smaller and larger sized compared to medium-sized individuals. Possible explanations for the observations include; low seed development associated with declining fitness of heavily defoliated plants (Fornara & du Toit 2008), increase reallocation of resources to induced defense traits instead of reproduction (Goheen et al. 2007) or death of younger individuals attributed to heavy consumption and trampling by browsers (Augustine & Mcnaughton 2004; van Langevelde et al. 2003). All the three persuasions can apply however; the last argument is more plausible to our study site. Individual trees below 3 m are accessible to majority of animals (sheep from ground level up to 0.87, goats at 2 and camels up to 3 m high). This means smaller individuals suffered more defoliation than taller individuals (Rutagwenda et al. 1989). Augustine and Mcnaughton (2004) observed that browsing at dikdik's (*Madoqua kirkii*) height (i.e. < 0.5 m) had more profound effect on the recruitment of *A. mellifera,* and *A. etbaica* species to 0.5 -1.5 m height class. This observation does not however explains why, the three target species (*A. mellifera*, *A. etbaica* and *A. tortilis*) continues to remain dominant contributing more than 80% of woody plants relative density within GR. Dominant palatable species in GR may be employing tolerance and/or avoidance strategies to remain dominant amid higher level of herbivory. Significantly higher mean values for stems, crown diameters and height for individuals in GR are indicative of faster growth rate to achieve ‘safe height’ beyond browsing line. Fast replacement of lost biomass through compensatory photosynthetic process (Sebata 2013) are some the strategies common with browsing tolerant-species to minimize negative effect of defoliation.

High density of trees in PR was attributed to high occurrence of clustered *A. brevispica* species as well as abundance of unpalatable species (*C. dichogamus, Phyllanthus sp,* and *E. divinorum*). Suckering traits associated with the species (Beentje, 1994) as well as sampling effect could have also contributed to this observation. Herbivory might have contributed indirectly through selective feeding giving competitive edge to unpalatable over palatable species (Augustine and Mcnaughton 1998) however CCA showed that soil properties and percent slope played a role on vegetation structuring. Fertile clay soils that occupied a third of the sampled area in PR was low in species diversity as well as tree densities while sloppy area though with relatively low fertile transitional soils, had higher tree densities. Decline in some wildlife species in pro-wildlife ranches (including Mpala) attributed to increase predation (Georgiadis et al. 2007) could be linked to bush encroachment and decline in visibility.

6.4.3. Structural diversity

Heterogeneity in vegetation structure influences functioning of African savannas, providing habitat for a wide variety of plants and animals (Asner et al. 2009). Structural diversity besides showing how height mean values deferred between sites it also indicated how different height classes varied within and between sites. High structural diversity in PR over GR indicates that intense herbivory tends to create uniformity in vegetation architecture and as such GR had little variation in structure between species. High livestock stocking rate reduces species selection during feeding and this may promote establishment of 'browsing lawn' (Cromsigt & Kuijper 2011; Fornara and du Toit 2007) where species are browsed to a certain constant height depending on the dominant herbivore and maintained through constant re-browsing. Whereas this phenomena tends to increase available resource to herbivores, it does reduces the structural heterogeneity that enhances the habitat available for a wide range of organisms beyond the herbivore communities as well as alters ecological processes as nutrient cycling, seed dispersal, and germination (Asner et al. 2009).

Structural diversity measurement indicates specific height classes that are under intense pressure from herbivory, which otherwise would not have been observed if structural mean values only were used. It is clear from this study that recruitment of seedlings/saplings in the recent years has been constrained in both regimes, though GR seemed worst affected. High structural diversity observed in PR may not entirely be attributable to browsing alone but also variability of lifeforms of target species. Two of the species (*A. mellifera* and *A. etbaica*) are trees while *A. brevispica* is commonly a shrub (rarely a tree) and this may have caused the observed high CV for canopy volume and canopy area for PR target species. Whereas variation in structural diversity maybe attributed to herbivory, different herbivore species may have different effects on woody plants, therefore attributing the observed variation between the two sites to cumulative effects of both domestic and wild herbivores equally is a limitation of this study. Though Elephants and Impalas are both mixed feeders (graze and/or browse depending on seasons) their effects on vegetation do vary. Similarly effects of domestic livestock and native herbivores often vary because the former are often herded while the later are free ranging.

6.4.4. Edible biomass **(Browse)**

Broadly, intense herbivory enhanced biomass production within GR per unit plant and subsequently per unit area and this was mainly linked to enhanced growth of *A. mellifera*. Intense browsing in GR seemed to have had a positive effect on *A. mellifera* biomass production for individuals with 1 to 3m high. This was demonstrated by more multiple stems per ramet and wider crown canopies associated with breaking up of apical dominance, and increase in growth of lateral buds. Secondly, individuals taller than 3 m did not differ significantly between sites because they were subjected to light browsing. Except camels, most domestic herbivores browse below 3 m height (Rutagwenda et al. 1989) and therefore taller individuals within GR though subjected to higher stocking rate escape intense browsing. Compensatory re-growths among browsing tolerant species have been noted in other studies; *Acacia tortilis* by Oba and Post (1999); *A. nilotica* and *A. karroo* (Sebata 2013); *A. nigressens* (Fornara and du Toit 2007) and *Indigofera spinosa* by (Oba et al. 2000).

Browsing enhances biomass production of browsing-tolerant species through increased photosynthesis, cell division and reduction in rate of leaves senescence (Sebata 2013).

Ironically, more than 60% of the biomass occurred beyond the browsing height of majority of domestic herbivores. This implies that palatable species are able to survive intense browsing by strategically investing resources for faster growth rate to escape the browsing 'trap'. Formation of 'hourglass - shaped' architecture is one such strategy where browsed seedlings/saplings initially forms a 'browsing lawn' at the height of about 1 m that spreads horizontally thus creating a buffer/safe zone for shoots at the middle to grow faster and achieve a height beyond 3 m (Fig. 6-4). Once the trees are fully established the lower branches senescence out and the individuals escape browsing altogether in the absence of larger herbivores such as elephants and giraffes. This suggest that whereas GR may have more biomass per unit area, it may become unavailable if majority of the trees are taller than 3 m. Presence of elephants in the region may however make such biomass available to smaller mammals by pushing-over large trees (Kohi et al. 2010).

Unlike *A. mellifera*, intense browsing generally had negative effect on *A. etbaica* biomass production typified by fewer lateral stems and smaller canopy diameters. The absence of significant difference in biomass between sites for individuals with height below 2 m remains unclear. Possibly the species is effective in resisting herbivory at seedling and/or sapling stage than later in life stage and thus receive low defoliation irrespective of stocking rate.

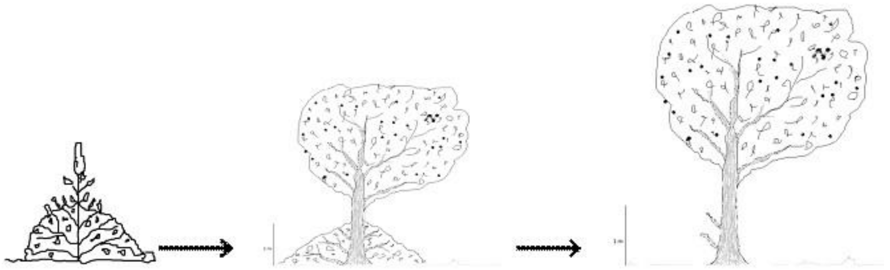

Figure 6-4. Hourglass structural architecture created by browsing mammals among browsing tolerant species

Mammalian herbivores show a strong preference for mature compared to juvenile tissues in woody plants because chemical defense is enhanced at the seedling stage (Barton and Koricheva 2010). A study by Augustine & Mcnaughton (2004) observed that browsers had more severe effects for *A. mellifera*, which possesses only short, recurved thorns, than for *A. etbaica*, which is defended by long straight thorns and recurved thorns. In both study sites, there was significant positive correlation between biomass values and numbers of individuals and canopy volume per hectare.

6.5. Conclusions

Herbivory modifies vegetation directly through alteration of composition and structure and also indirectly through modification of growing environment such as enhanced nutrients levels, trampling and compaction of soil near kraals and watering points. Intense browsing is thought to alter species composition whereby browsing-sensitive species decline; browsing-tolerant species increases and/or invader species emerge. Herbivory in nutrient-poor soils is predicted to promote the upsurge of herbivory-tolerant species but also those adapted to grow in poor soils. Defoliation of browsing-tolerant species causes the establishment of ‘temporary browsing lawn’ where browsed individuals quickly replace lost biomass, increase biomass production and promotes re-browsing. Strangely, the species also enhances the plants defensive strategies against herbivory in a ‘sado-masochistic-like[2]’ behavior. The growth vigour associated with browsed individuals is thought to be part of a strategy to escape herbivory given that compensatory growth ceases once the individuals escape the ‘browsing trap’ zone. This implies that, to increase browse biomass for livestock within a landscape would demand that browse –tolerant species canopies are maintained within browsing height of the dominant herbivore species kept. However, if the management objective is to promote species diversity (both flora and fauna) then, the strategy would be to promote structural diversity instead by maintaining a stocking rate below 25 TLU/Km^2 and above 12 TLU/Km^2.

Whereas browsing wild ungulates move freely between the private and group ranch, high presence of human population in GR may have greatly reduced the occupancy time by some animals such as eland, giraffes and impala and therefore individuals’ species contribution to the observed variations between sites may not have been fully accounted for. Finally, amalgamating effects of all herbivores stifles ability to know species specific effects as well as the role of native wildlife from domestic herbivores in vegetation dynamics.

---

[2] Sadomasochism is the enjoyment of inflicting pain and receiving pain

CHAPTER SEVEN

HABITAT INVASION AND THE ROLE OF MAMMALIAN HERBIVORY IN A SEMI-ARID ENVIRONMENT.

Abstract

Invasive species spread and bush encroachments constitute two major challenges facing savanna landscape management for livestock production. Whereas extensive work has been done to investigate mechanisms through which non-native invasive species spread and their effects on ecosystems, little attention has been given to native ‘invasive’ species. This study investigated the role of mammalian herbivory on the distribution and abundance of native invasive/invader/increaser species. Two adjacent management systems (private ranch- PR and Group ranch – GR) with different stocking rates were compared using plots nested on three line transects per site. In addition to ecological data, semi-structure questionnaires was administered among the members of the local community to find out species they consider invasive, the effect the species has had on their livelihood and what control measures they have undertaken. Pearson correlation and multiple regression analysis were done to establish linkages between the invader species abundance/distribution with abiotic and/or biotic factors to be able to rule out other compounding factors. The results indicate that intense herbivory facilitated proliferation of *Sansevieria volkensii* and *Ipomoea kituensis* and this may be linked to availability of ecological niche space due to decline in species richness and abundance. It was also linked to modification of soil properties such as flashes of nutrients associated with livestock movement and concentration of dung and urine and hooves actions. Proliferation of *E. divinorum* and *C. dichogamus* in lightly grazed may have occurred due to prolong absence of fire which previously shaped the area vegetation. Selective browsing of palatable

species could have occurred and may have advantaged the invader species. However, close positive relationship between invader species and high species diversity cannot be explained by the level of herbivory but by other factors (such as absence of fire over prolong period). In conclusion, mammalian herbivory's role in the invader species spread occurred by titling the competitive environment in favour of invading species by increase mortality of sensitive species or reducing their growth vigour. It is recommended that frequent selective harvesting of increaser type II species (for charcoal, firewood or any other use) be promoted while type I invader species be controlled by promoting increase in species diversity (e.g. reducing stocking rate).

7.0. Introduction

Woody plants encroachment (bush encroachment or weedy wood encroachment) remains a serious challenge in the management of several savanna grasslands in Africa and elsewhere (Gemedo et al. 2006; Gordijn et al. 2012; Wahungu et al. 2013; Wigley et al. 2009). Some of the problems associated with increase in woody lifeforms in grasslands include; (1)suppression of grass productivity through altering soil moisture and nutrients regimes thus affecting livestock production (Roques et al. 2001), (2) decline in habitat integrity and possible loss of species diversity (Hester et al. 2006; Riginos & Grace 2008), (3) decline in palatable and increase in unpalatable species (Gordijn et al. 2012; Yusuf et al. 2011), and (4) promote indirectly invasive grass species (Alofs & Fowler 2007) among others.

Bush encroachment has been a subject of investigation for decades yet there is limited consensus among scholars on causal factors (Auken 2000). Grazing and/or browsing intensity, fire regime, rainfall amount and frequency, soil nutrients, drought, and most recent increase in atmospheric carbon dioxide (Co_2) have been suggested as being behind bush encroachment in savanna ecosystems (Gordijn et al. 2012; Moleele & Perkins 1998; Moleele et al. 2002; Wahungu et al. 2013; Ward 2005). Ward (2005) believes that past efforts to control bush encroachment have been futile because interventions have been premised on wrong understanding of how encroachment occurs. He rejected the view that overgrazing induces encroachment of woody species by limiting fire frequency and/or intensity or by tilting tree–grass competition following two–layer Walter's theory on moisture levels. To support his position, he highlighted that some lightly grazed areas and those known to have only single soil layer have not been spared from bush encroachment. A study by Belay et al. (2013) working in Ethiopia semi-arid savanna concluded that bush encroachment was not positively related to neither human activities nor livestock grazing intensity. Areas far away from human settlement and with low density of grazers were experiencing more woody encroachment. Other studies (see Augustine 2004; Augustine et al. 2011; van der Waal et al. 2011) have established that nutrients rich glades created from abandoned cattle kraals have remained open (without bush encroachment) for several decades long after being vacated contrary to the believe that resource availability increases bush encroachment (Wiegand et al. 2006). Whereas there seem to be some consensus that herbivory has something to do with bush encroachment, the mechanisms involved are still not well understood, and the rates, dynamics, patterns, and successional processes are not well defined (Auken 2000). Additionally, though woody weeds spread follows similar pattern as alien invasive species (Meiners et al. 2004) limited knowledge exist on ecosystem invasibility (Catford et al. 2012).

In Laikipia county, central Kenya, woody cover increased substantially in the last five decades and by the year 2000, more than 28% of the landscape had been encroached, a phenomenon attributed to banning of fire in land use management (Augustine 2003b). It is however unclear why bush encroachment varies in terms of density and species depending on land use type. Private commercial ranches in the region seemed to have more bush encroachment compared to pastoral group ranches yet all occur under similar bioclimatic conditions and have not experienced fire incidence in recent times. Wahungu et al. (2013) working in the county, observed that *E. divinorum* seedlings densities increased by 27% annually over a period of five years largely within grassland habitat in Ol Pejeta Conservancy where livestock ranching and wildlife conservation are major land use. The study linked *E. divinorum* seedlings recruitment to rainfall frequency and amount. Strum et al. (2015) working in the same region, attributed recent upsurge in spread of *Opuntia stricta* to land use change (i.e. increased sedentirization by pastoral communities) contrary to past nomadic pastoralism.

In view of previously contradicting findings on causes of bush encroachment, there is need to identifying the factors that influences such variation in invader species, abundance and distribution patterns as a prerequisite for understanding the present and potential future extent of native plant infestations and, in turn, develop appropriate management programs. Unlike alien species invasion whereby relative alien species richness and abundance provides fairly indicative of contribution that alien species make in a community and the trajectory of invasion over time (Catford et al 2012), practical measure for native invader species is in eastern Africa is lacking. The presence of adjacent land properties under different management with varying ungulates densities provided a natural field experiment to investigate (Western et al. 2009). The study specifically sought to establish invader species associated with high and low intensity of mammalian herbivory and secondly, to evaluate factors influencing invader weeds distribution and abundance. This study hypothesize that level of herbivory alters plant competition, disturbance regimes and levels of environmental stress, especially resource availability that dictate habitats invasibility. On the basis of the above statement, species diversity (richness and evenness), densities and types are construed as good indicators of the changes as well as changes in soil properties especially nutrients. High environmental stress (e.g. low soil nutrients) may promote expansion of species with mechanisms to make efficient use of limited resource. Additionally, herbivory may diminish certain functional groups thus providing empty ecological niche to encroaching species.

7.1. Methods

Study sites are as described in chapter two.

7.1.1. Intensity of mammalian herbivory

Wildlife movement was unrestricted in most of the land properties in the region given that there are no fences except those used in Conservancies to restrict movement of rhinos (Georgiadis, Ihwagi, et al. 2007). However, wildlife densities and occupancy time for migratory animals was more in PR than GR. This notwithstanding, densities of common wild grazers and browsers (e.g. elephants, giraffes, eland, impalas, zebras, dikdik, waterbuck, and bushbuck) and livestock when combined, GR still had higher stocking rate than PR at 2.3 ha/TLU and 3.5 ha/TLU respectively (Augustine 2003a; Kaye-zwiebel & King 2014; Kinnaird & O'Brien 2012;Ngene et al. 2013). Beside differences in level of herbivory, both PR and GR practiced traditional livestock herding practices whereby animals were grazed on one site for a couple of days then moved elsewhere in a cyclical pattern. Due to the difference in stocking densities of the two adjacent properties, it provided an opportunity to undertake a natural experiment by comparing them. Fire may previously have been an important factor in the savanna management, but has been subdued for several decades. In the study sites, no large-scale fires have been witnessed in either PR or GR in the recent decades (Augustine 2003a). Herbivory effects addressed in this paper are cumulative effects of defoliation (grazing and browsing), trampling of seedlings, hooves effects on soil, as well as nutrients cycling.

7.1.2. Invader weeds species

Invader weeds were determined based on published literature and interviews with members of the two ranches. Using a semi-structured questionnaire, 105 residents of the GR and 10 long-term service employees and management of PR were asked to list invader weeds they believed have increased in abundance over the years in order of magnitude of invasion (how widespread) based on their understanding of the local environment. They were also asked to state whether any effort had been made in the past to eradicate or control them. From literature, evergreen *E. divinorum*, *Tarconanthus camphoratus* and *Acokanthera schimperi* are said to be increasing in the region taking over previously grasslands areas of Laikipia County (Boy 2011, Wahungu et al. 2013). The term invader weeds was used to refer to those species the land owners thought to have increased in abundance in the recent times but are of limited forage value. Plant nomenclature followed (Bentje 1994).

7.1.3. Invader weeds distribution and abundance

To determine the distribution and abundance of invader weeds obtained from interviews, 421 plots (20 x 20 m) nested in three 3km long transects per ranch were sampled. The first plot in each transect was selected randomly and the subsequent plots placed systematically at 20 m intervals to make 75 plots per transect (Yusuf et al. 2011). In each plot the following data was collected; soil texture, percent slope; geo-reference location using GARMIN *etrex* 10 handheld GPS Receiver (Taiwan), visual estimates of tree, shrub and herb cover and bare ground. In GR, plots' distance to nearest homesteads was also determined using GPS receiver. Invader weeds occupancy was determined based on presence/absence of target species while abundance was based on percent cover per plot. To derive the abundance values of weedy species, the plots were subdivided into eight equal triangular subplots (Fig. 7-1) and visually estimated area covered by target species.

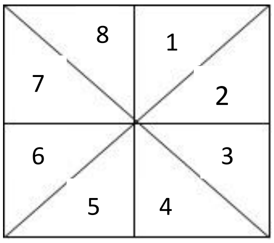

Figure 7-1. Subplots design used to estimate vegetation cover

Presence of target species on $\frac{7}{8}$ or $\frac{8}{8}$ of the grids was given a score of 87% cover, $\frac{5}{8}$ or $\frac{6}{8}$ a score of 62%, $\frac{3}{8}$ or $\frac{4}{8}$ a score of 37.5% and $\frac{1}{8}$ or $\frac{2}{8}$ a score of 12.5% cover of the subplots. This method was found appropriate instead of using species densities/abundance given that identification of a ramet for some target species was difficult (see Fig. 7-2).

Sansevieria volkensii *Ipomoea kituensis*

Figure 7-2. Growth habits of common weeds (*Sansevieria volkensii and Ipomoea kituensis*) in Imotiok group ranch.

The distribution of *Acacia mellifera*, a species that occurred across the ranches with more than 50% occupancy and also reported as invading in GR was used to analyze the role of abiotic factors in the spread of species within the two ranches. This was done by correlating *A. mellifera* abundance with soil nutrients, texture, percent slope, and elevation. In addition, chemical soil properties were evaluated for 45 representative plots per ranch (see chapter two).

7.2. Data Analyses

Descriptive analysis was done on the data derived from questionnaires whereby percentage scores were assigned per species based on citation frequencies. The higher the citations per species, the higher the score assigned. Similarly, the proportion of invader weeds in relation to the other species was determined both in terms of occupancy (presence/absence) as well as their abundance. Correlation analysis was done to establish linkages between invader weeds abundance and associated plot properties to evaluate factors that best describe the pattern of the species spread within each of the two ranches. Spearman rank test was used to test significance of the linkages. Soil chemical analysis results did not vary significantly between sites and were expunged from further analysis. Q1 Macros (excel based statistical software) version 2014.12 was used in the analysis (KnowWare International Inc, 1996-2014).

7.3. Results

7.3.1. Woody weeds

Respondents in the GR listed seven key species as having increased in the recent past. They were *Opuntia stricta* and *O. subulata* (exotic species), *Sansevieria volkensii, Ipomoea kituensis*, *A. reficiens*, Olperintai and Mpalek. Other species such as *Acacia mellifera* (Munishoi), Lesayiet, Elusubei and Laimerruak were cited less than five times (Table 7-1). In PR, *Opuntia stricta* was cited as single most problematic species though general bush encroachment was acknowledge especially by evergreen species *Euclea divinorum* and *Croton dichogamus*.

Table 7-1. Species perceived to have increase in abundance in recent times in the GR.

Species	**Local name**	**Status**	**Citation** *N=105*	**Percent**
Opuntia subulata	Kurasi	exotic	104	99
Sansevieria volkensii	Oldupai	native	104	99
Opuntia stricta	Matundai	exotic	103	98
Ipomoea kituensis	Lokiteng	native	36	34
	Olperintai*	native	33	31
	Mpalek*	native	14	13
Acacia reficiens	Enchurai	native	8	8
Others	Munishoi,Lesayiet*, Esulubei*	native	<5	

*Some species with only local names are short-lived perennial and/or annuals and were not available during the fieldwork for identification.

Absence of Olperintai, Mpalek, Lesayiet and Esulubei records in the field, low actual occurrence of *A. reficiens*, the uncertainty with respect to propagule pressure of exotic species and the fact that some were introduced as live fences in recent times, led to their exclusion from further analysis. *A. mellifera* (Munishoi) though believed to have significantly increased in abundance in GR, was not considered by the community as a weed because of its importance as a source of forage for livestock and was therefore excluded from invader weeds analysis.

Except for *O. stricta* where attempts have been made to control its spread, no measures have been taken to curb other species. Some of the methods used to control spread included; cutting and burning, cutting and placing on rocky surfaces or atop of tree branches to dry. In PR, experimental control effort included harvesting the species and placing them on access roads so that passing vehicles could run over, crush and hopefully kill them. Biological control trials by use of cochineal bugs (*Dactylopius opuntiae* “stricta”), sap sucking insects are currently underway in the region (Mutinda, 2015). Based on the above observations, *S. volkensii* and *I. kituensis* were selected as primary woody weeds in GR while *E. divinorum* and *C. dichogamus* were selected for PR ranch for further analyses. While *O. stricta* was thought to be increasing at faster rate, it was only found once in PR and in eight plots in GR. *Sansevieria volkensii* and *I. kituensis* had 50% and 7% occupancy and 29% and 1.6% relative abundance respectively in GR. In PR, both *S. volkensii* and *I. kituensis* did occur but not within the sampled plots however *E. divinorum* and *Akocanthera schimperi* had 32.1% and 1% occupancy and relative abundance of 10% and <1% respectively. *Croton dichogamus* had 45% occupancy and 15.1% relative abundance. This meant that *E. divinorum* and *C. dichogamus* contributed the biggest percentage of non-palatable species in PR.

7.3.2. Factors influencing invader weeds distribution and abundance

In the GR, there was positive ($p<0.05$) correlation between *Ipomoea kituensis* species and soil texture with higher abundance in areas with sandy-clay soils. There was also weak correlation between the species' abundance and elevation and shrub cover. Weak negative correlation was observed between the species and increasing distance away from homesteads (Table 7-2).

The distribution of *C. dichogamus* in PR was partly influenced by soil texture, plant densities and species richness ($r^2 = 0.64$). *Euclea divinorum* on the other hand showed positive correlation ($p<0.05$) with species richness but with low coefficient of determination ($r^2 = 0.33$). Cumulative effects of elevation, species richness and plant densities explained 43% of the *E. divinorum* distribution within the private ranch (Table 7-3). Neither *E. divinorum* nor *C. dichogamus* occurred in sampled plots within GR.

Table 7-2. Pearson correlation matrix of invader species *S. volkensii* and *I. kituensis* against habitat properties in GR. Significant values (p<0.05) are given in bold.

CORREL	Sansevieria	Ipomoea	soil text	% Slope	Elevation	Distance	Spp. Density	Spp. Richness	Tree cover	Shrub cover
Sansevieria	1									
Ipomoea	#DIV/0!	1								
soil text	-0.16	**0.51**	1.00							
% Slope	-0.01	-0.20	0.02	1.00						
Elevation	0.24	**0.38**	0.05	0.04	1.00					
Distance	-0.10	**-0.37**	-0.06	-0.05	-0.56	1.00				
Spp. Density	0.00	-0.25	-0.03	0.07	-0.04	0.20	1.00			
Spp. Richness	-0.09	-0.05	-0.12	0.15	-0.10	0.24	0.42	1.00		
Tree cover	-0.20	**-0.41**	-0.06	0.03	-0.16	0.16	0.52	0.22	1.00	
Shrub cover	-0.16	**0.47**	0.00	0.06	0.02	0.08	0.01	0.10	0.05	1.00

Table 7-3. Pearson correlation matrix of invader species *C. dichogamus and E. divinorum* against habitat properties in GR. Significant values (p<0.05) are given in bold

CORREL	Croton	Euclea	soil text	Slope	Elevation	Spp Density	Richness
Croton	1.000						
Euclea	0.395	1.000					
soil text	**0.362**	0.254	1.000				
Slope	0.162	**0.351**	0.680	1.000			
Elevation	-0.296	-0.109	-0.877	-0.396	1.000		
Spp Density	**0.740**	**0.339**	0.402	0.160	-0.472	1.000	
Richness	**0.474**	**0.580**	0.685	0.535	-0.586	0.517	1.000

7.3. Discussions

Level of herbivory had a significant effect on vegetation dynamics and overall habitat invasion. Both intense and light herbivory facilitated bush encroachment however, different species were involved. Intense herbivory elevated growth of *S. volkensii* and *I. kituensis* among other species while light herbivory enhanced growth of *E. divinorum* and *C. dichogamus*. The local community perception about encroaching species was corroborated by field inventories although not in their order of magnitude of invasion. Although *Opuntia subalata* was present in both PR and GR and rated as most widespread encroaching species, the species was not found in any of the sampled plots. Similarly, *O. stricta* was rated highly as encroaching species in both ranches yet it was only found once and in 8 plots in PR and GR respectively. Four possible reasons that may explain high rating of the two invasive species could be (i) that the species though recently introduced has covered significant area of the ranches in the shortest time (ii) that the rating was influenced by increasing debate in local media about negative effects of the invasive alien species (Akumu, 2015) or (iii) that increased awareness on the species negative effects based on experiences from neighboring ranches where invasion was first recorded after its introduction into the area by the colonial administration in 1950s (Strum et al. 2015), and lastly, sites where the species occurred within the two ranches, their abundance was high, an aspect that could be attributed to their dispersal mode. According to Strum et al. (2015), *O. stricta* densities are higher near Baboon sleeping sites, near homesteads and along elephants' trails a phenomenon attributable to agents of seeds dispersal; baboons, people, livestock and elephants. Whether the negative effects associated with the species are apparent or not, the community's fear is seen from efforts already made to control further spread through harvesting and burning or harvesting and drying in GR and harvesting and crushing in PR.

7.3.1. Invader species

According to Pratt and Gywne (1977), invader species in rangeland could either be increaser type I associated with areas experiencing overgrazing or type II associated with under-grazed zones. *Sansevieria volkensii* is a succulent species with low palatability and common on sandy soils in drylands in association with *Acacia spp*. The species proliferate more in areas with intense grazing (increaser type I) especially within encrusted soils in water run-on zones where growth of new shoots is common (King and Franz, undated). Mature leaves of this succulent contain on average 75% water, with run-on sites having higher water content (ibib). The species is chewed by elephants, goats and baboons to draw water from the leaves during dry seasons giving the species a nickname of elephant ice-cream. The species regenerate predominantly from underground rhizomes (see fig. 7-2).

Ipomoea kituensis is an increaser species common in overgrazed areas (Kidake et al. 2015; Macharia & Ekaya 2005) and is of low forage value (Lusigi et al. 1984). The species is fast growing and readily blooms during the wet season releasing several seeds into the environment every season. It also regenerates vegetatively from underground tissues. Although the species is broad-leaved, it has capability to remain green long into the dry season in semi-arid environment. The possible mechanisms for *S. volkensii* and *I. kituensis* proliferation in intensely grazed zones include; ability to outcompete heavily grazed palatable species, ability to utilized limited moisture by using well developed rooting system, the use of underground storage organs and ability to grow in compacted soils.

Euclea divinorum and *C. dichogamus* are increaser type II species and proliferate under light herbivory. They are evergreen and of low forage value especially to cattle (Lusigi et al. 1984). *Euclea divinorum* is dioecious and the seeds are often dispersed by birds. It is common in bush, dry forest margins, thornscrub, anthills, river banks and open woodlands in association with *Acacia spp*. (Bentje, 1994). Inter-specific competition between *E. divinorum* and *Acacia spp* is thought to leads to conversion of open grasslands to densely vegetated woodlands (Orwa et al. 2009). Browsing of *Acacia spp.* by large mammals seemed to facilitate *Acacia-Euclea* savannas successional dynamics. Under light herbivory, feeding selectivity is high (Augustine & Mcnaughton 1998) thus increasing loss of tissues from palatable species thus giving *E. divinorum* competitive advantage over scarce resources. Furthermore, the species has remarkable coppicing and root suckering and tends to weediness, dominating pasture to the detriment of wildlife and pastoralism if not curbed (Orwa et al 2009).

Croton dichogamus is a tree or a shrub 1-7 m tall common in dry forest, bushland and thicket, on rocky ground, lava, limestone and porous soils. It is known to occasionally form thick stand at elevation between 550 – 1500 m a.s.l. (http://www.ville-ge.ch/musinfo/bd/cjb/africa/recherche.php).

7.3.2. Factors influencing Invader weeds distribution and abundance

Both lightly and intensely grazed zones were invaded though by different species. Abiotic factors (soil texture, slope and elevation) had minimal influence on the distribution of majority of increaser species in the study sites. The correlation coefficients for *S. volkensii* against the habitats' properties in GR, was very low. This may indicate that the species distribution was driven by other factors (e.g. propagule pressure). The observations that *S. volkensii* and *I. kituensis* level of abundance differed across the ranches suggests that land management practices (such as stocking rates) between the ranches played a role for higher proliferation within heavily grazed GR. Intense herbivory causes decline in species diversity and abundance through decline of browsing/grazing sensitive species (Louhaichi et al. 2012; Zhao et al. 2007) and therefore proliferation of *S. volkensii* and *I. kituensis* may have been boosted by absence of intense competition as well as availability of under-utilised resources as noted elsewhere (Alpert et al. 2000).

Loss of grazing-intolerant palatable species and other sensitive species may interfere with species interactions (e.g. competition, mutualism) and may have tipped the ecological balance. Positive correlation between *I. kituensis,* intense herbivory and sandy soil congruent to findings by Kidake et al. (2015) that attribute the outcome to soil crusting. A mixture of sandy and clay soils common in the study sites are prone to crusting and compaction when exposed to heavy grazing and may have influence physical soil properties. We suggest therefore that *I. kituensis* proliferation under intensely grazed site has to do with its ability to thrive in compacted soil possibly with low moisture compared to other species.

Contrary to mode of invasion by nonnative species where areas of low species diversity are first encroached (Ruijven et al. 2003)*, E. divinorum* were more abundance in plots with higher species richness. This positive association could be attributed to a number of palatable species escaping browsing due to dominance of *E. divinorum* species making some of these sites undesirable foraging areas. However proliferation of *E. divinorum* can be explained by its own attributes such as ability to regenerate vegetatively as well as from seeds, high re-coppicing and capacity to grow in highly diverse micro-habitats. Besides attributes that could promote its invasive nature, herbivory of palatable *Acacia spp* may indirectly promote the increaser species through a mechanism of competition and facilitation. Herbivory enhanced growth of some browsing-tolerant palatable species (e.g. *A. mellifera*) through a process of compensatory photosynthetic growth (Sebata 2013). During times of full recovery and increased biomass production after defoliation, there is increased competition between *Acacia spp* and the increaser species. However, whenever *Acacia spp* losses its biomass through defoliation and growth declines, excess nutrients are made available to facilitate invader species growth. Furthermore, *Acacia spp* are deciduous meaning occasional increase of nutrients are expected from decomposing leaves from seasonal leaf shedding and dormant leafless phase. It should be noted that this phenomenon is not unique to *E. divinorum*, however, such a scenario may only work for species with invasive traits and thus able to take due advantage limiting resources. Facilitation and competition phenomena have been noted to occur between grazing Bovids and Equids depending on the season (Odadi et al. 2011) and this may promote co-existence of species.

7.4. Conclusions

Herbivory plays a role in woody weeds encroachment however direct and indirect mechanisms may be involved. Higher level of disturbances in GR attributed to grazing, trampling, compaction and destruction of soil crust played a role in the proliferation and distribution of invader species by modifying the soil attributes. This had the effect of reducing species richness and abundance in general thus availing resources to invader species, and possibly by facilitating germination of invader seeds through the hoof action. Proliferation could have also been boosted by invader species' own traits such as extensive rhizomatous tissues and succulent leaves thus able to survive under low moisture regimes. Increaser type II (*E. divinorum* and *C. dichogamus*) increases could have benefitted from absence of fire that could have put the species on check previously.

To control increaser type I species from invading the environment, species diversity should be increase to ensure all ecological niches are occupied and that there was no under-utilized resources. Increaser type II spread may be controlled by selective harvesting for use in fencing, building, charcoal, fuelwood, medicinal and other household requirements. There is need for further controlled experiments to isolate specific factors that influences non-native species invasion.

CHAPTER EIGHT

GENERAL DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

8.0. Introduction

The interest in savanna ecosystems have in the recent past increased due to recognition of expanded valuable good and services they provided. Additionally, there is increase understanding on the important linkage between the actions of range managers and the mix of ecosystem services available and also due to the fact that a significant percentage of the world poorest inhabit these regions. Several savanna ecosystems are dominated by native vegetation and are largely managed without intensive inputs. These ecosystems provide unique irreplaceable ecosystem services. However, the rapid growth of human population in the tropics has contributed to rapid transformation of savanna landscapes resulting in land degradation; reduce productivity, invasive species spread, loss of species and declining provision of ecosystem services.

Bush encroachment and invasive species spread in Kenyan savanna is raising concerns on the ability of these landscapes to provide unique ecosystem services particularly provision of forages for livestock and wildlife, quality habitat for wildlife, and the habitat’s ability to resists invasion among other associated services. Land use and management practices have been blamed for these problems and a number of interventions have been undertaken to reverse the trend with minimal success. To understand the mechanism behind bush encroachment and habitat invasion, this study compared two adjacent ranches (private commercial ranch-PR and pastoral group ranch-GR) under different management in Laikipia County. The major difference between the two ranches was livestock stoking rate, with the former having maintained stocking rate of 10 -12 TLU/Km^2 over the last three decades, while the later on average more than 25 TLU/Km^2 (Kaye-zwiebel & King 2014) but also were physiognomically different. Due to close proximity of the ranches it was assumed that there was no significant variation on bioclimatic condition between them and hypothetically should have similar vegetation type. This study therefore investigated the role of mammalian herbivory given that the two ranches indicated different level of bush encroachment. The research questions included the following; (1) How does historical management system affected vegetation dynamics? (2) How does intense herbivory of woody plants affect traits of dominant palatable species? and (3) How does mammalian herbivory influence habitat species invasion?

The main aim of this study was to generate knowledge on the impacts of mammalian herbivory on vegetation dynamics and long term provisioning of ecosystem services in semi-arid savanna. The specific objectives included the following;

1. To assess transformation in the management of natural and social capital assets under pastoral group ranching system.
2. To determine effects of varying intensity of herbivory on palatable woody plants functional traits diversity
3. To determine the effects of mammalian herbivory on species composition, structural diversity and browse biomass production and
4. To evaluate influence of mammalian herbivory on habitat invasibility

8.1. Transformation in management of natural and social capital

There have been significant changes in the management of natural and social capital within the pastoral group ranches since the establishment of group ranching in the mid-1970s which may have impacted on the vegetation. Group ranch formation provided new opportunities as well as challenges to land owners that may have triggered innovations in the management of the resources. These innovations were either completely new or modification of pre-existing traditional practices; household-level-driven initiatives or group ranch level commissioned by elected officials. It should be noted that some of the innovations may not be entirely attributed to GR formation but other aspects of development such as government policies, globalisation of economies, advancement in science, and cultural dynamics among others. Key innovations in the management of natural capital in the pastoral system included; establishment of small-scale cultivation, shift in species composition to maximize on changing forage resource (more browsers – goats than grazers – cattle), introduction of drought tolerant breeds (Galla goats) and species (camels), harnessing of wildlife and culture based tourism (Conservancies establishments), leasing and hiring of pastures, expansion of traditional enclosures (*Olokerii*) among others.

Among social capital assets, the establishment of new networks such as business associations (e.g. Bee-keepers), and self-help groups governed by by-laws, norms and sanctions replaced weakening traditional networks that were based on clans and age-sets. These findings compares well with observation from other studies (Huho et al. 2011; Coppock & Desta 2013; Kaye-zwiebel & King 2014). Long-term sustainability for some of the innovations remains unknown however; increase in number of browsers from residents in addition to those from lessees is likely to have increased pressure on woody vegetation. Similarly, expansion of 'privately-owned' traditional enclosures (olokerii), as well as land under cultivation could increasingly fragment the grazing land, diminish available land for common use and reduce community socio-ecological resilience. Increase adoption of camels and shoats, a strategy motivated either by increasing aridity or increasing bush encroachment or both may not only cushion the community from declining fortunes from cattle but also help in controlling spread of woody plants (Mills et al. 2005; Moolman & Cowling 1994). The effects of intense browsing experienced in GR and attributed to high stocking rate, increased land fragmentation and diminishing 'Commons' were reflected both at species and community level and if not checked, could undermine the natural capital and provision of ecosystem services in the long-run. This calls for flexibility in funding regime for community projects, close monitoring to identify and nurture emerging good innovations. Furthermore there is need for enactment of policies responsive to changing complexity in land use in arid and semi-arid environments.

8.2. Browsing effects on traits and functional diversity

Effects of increased browsing at individual species level (functional traits), community level, as well as its influence on ecosystem services biomass production and habitat resistance to invasion were investigated. Functional traits (leaf dry matter content-LDMC, leaf area-LA, and specific leaf area-SLA) of four palatable dominant species differed between individuals on lightly and heavily browsed sites. The four species included *Acacia mellifera, A. brevispica, Acacia tortilis* and *A. etbaica*. High LDMC, low LA, and low SLA associated with intense herbivory were common among individuals in GR. High LDMC influences the physical toughness and digestibility of plants thus reduces intake rates (Sebata 2013). Intense herbivory further diminish functional and taxonomic diversity. This occurred through a process of traits homogenization; diminishing divergence within and between individual plants functional traits. Traits homogenization makes ecosystem vulnerable to perturbations by diminishing functional redundancy and response diversity required for resiliency.

8.3. Browsing effects on species composition, structural diversity and biomass production

Similar to trends observed at species level; species composition, structural diversity and browse biomass production at community level differed significantly between sites. Intensely browsed site (GR) had low structural diversity compared to PR however; it had higher browse biomass production attributed to overcompensation by abundant browsing-tolerant species. These findings were supported by significant investment on browsing-tolerant traits such as larger canopies, height and multiple stems among individuals in GR compared to those in PR. It is also important to note that overcompensation due to heavy browsing diminishes once the tree grow beyond browsing height of majority of browsing herbivores. Low structural diversity at GR was attributed to establishment of ‘browsing lawn’ where individual trees were pruned at almost similar height. This implied reduction in potential habitats for other species to thrive.

Persistence of dominant-palatable species under intense browsing was supported by investment in browsing-tolerant traits (e.g. high canopy diameter, height, and multiple stems) as well as defense (e.g. high leaf dry matter content, high density of spines and low leaf area) with minimal effects of reproduction. Low functional, taxonomic, and structural diversity as well as low species abundance within GR could make the system ecologically unstable and susceptible to species invasion due to existence of underutilized resources and empty ecological niches.

8.4. Effects of herbivory on habitat invasion

There was no clear linkage between level of herbivory between sites and level of invasion. Intensely browsed site (GR) was invaded largely by *Sansevieria volkensii* and *Ipomoea kituensis* while PR was encroached by *Euclea divinorum* and *Croton dichogamus* a scenario of increaser type I and type II, respectively. There was no direct linkage between abundance of invader species and species density, and any other structural parameters measured in GR that included canopy cover, canopy depth, basal area etc. Species richness, density, and slope showed significant positive correlation with *E.divinorum's* abundance at PR. It was therefore difficult to isolate role of herbivory on their proliferation without controlling for other co-factor at play such as soil moisture level, seed dispersal mode, and propagule pressure per site. It was clear from this study that both intensely and lightly to moderately grazed/browsed ecosystem are equally prone to encroachment albeit by different species. It is recommended that controlled experiment be undertaken to isolate mechanism behind non-native species encroachment. It is also recommended that business cases be explored where invader species provide raw materials for tradable products as a means of controlling their spread e.g. charcoal making.

8.5. Recommendations

Based on the study findings, the following recommendations can be made;

1. Natural and social innovations that arise from management interventions should be monitored and evaluated so that those that promote socio-ecological resilience are promoted and those with negative effects are discouraged.
2. Manipulation of livestock stocking rate as well as the mix of livestock species kept can be used as a tool to manage species diversity and woody plants encroachment.
3. To sustain enhanced biomass production associated with compensatory growth of browsing-tolerant species, regular pruning of the species at average height of dominant herbivore species kept should be done or else the beneficial outcome will be lost once the tree grows beyond the browsing height.
4. Further research is recommended in the following areas;
    a. Change of traits values within an individual species subjected to different levels of herbivory.
    b. Controlled experiment to isolate factors responsible for non-native species invasion and spread

REFERENCES

Akumu, C. (2015). Kenya: Invading Cactus a Big Threat to Livestock in Laikipia. Available at www.allafrica.com/stories/201501290806.html. Accessed *on 27th January 2015.*

Anderson J.M. and Ingram J.S.I. (1993). Tropical soil biology and fertility, A handbook of methods 2nd Ed. CAB International, Wallingford UK

Aarrestad, P. A., Masunga, G. S., Hytteborn, H., Pitlagano, M. L., Marokane, W., and Skarpe, C. (2011). Influence of soil, tree cover and large herbivores on field layer vegetation along a savanna landscape gradient in northern Botswana. *Journal of Arid Environments*, *75*(3), 290–297.

Accatino, F., De Michele, C., Vezzoli, R., Donzelli, D., and Scholes, R. J. (2010). Tree-grass co-existence in savanna: Interactions of rain and fire. *Journal of Theoretical Biology*, *267*(2), 235–42.

Allred, B. W., Fuhlendorf, S. D., Smeins, F. E., and Taylor, C. A. (2012). Herbivore species and grazing intensity regulate community composition and an encroaching woody plant in semi-arid rangeland. *Basic and Applied Ecology, 13*, 149–158.

Alofs, K. M., and Fowler, N. L. (2007). Woody plant encroachment indirectly facilitates the establishment of an invasive grass by reducing species richness.

Alpert, P., Bone, E., and Holzapfel, C. (2000). Invasiveness , invasibility and the role of environmental stress in the spread of non-native plants. *Perspectives in Plant Ecology, Evolution and Systematics*, *3*(1), 52–66.

Al-rowaily, S. L., El-bana, M. I., and Al-dujain, F. A. R. (2012). Changes in vegetation composition and diversity in relation to morphometry , soil and grazing on a hyper-arid watershed in the central Saudi Arabia. *Catena*, *97*, 41–49.

Anderson, P. M., and Hoffman, M. T. (2007). The impacts of sustained heavy grazing on plant diversity and composition in lowland and upland habitats across the Kamiesberg mountain range in the Succulent Karoo , South Africa. *Journal of Arid Environments, 70*, 686–700.

Anderson, R. C., Nelson, D., Anderson, M. R., and Rickey, M. A. (2005). White-tailed Deer (Odocoileus virginianus Zimmermann) Browsing Effects on Tallgrass Prairie Forbs : Diversity and Species Abundances. *Natural Areas Journal*, *25*(1), 19–25.

Angassa, A. (2014). Effects of Grazing Intensity and Bush Encroachment on Herbaceous Species and Rangeland Condition in Southern Ethiopia. *Land Degradation and Development*, Vol. 25(5), 438-451

Angassa, A., and Oba, G. (2008). Bush encroachment control demonstrations in southern Ethiopia: 1. Woody species survival strategies with implications for herder land management. *Africa Journal of Ecology*, *47*, 63–76.

Angassa, A., and Oba, G. (2010). Effects of grazing pressure, age of enclosures and seasonality on bush cover dynamics and vegetation composition in southern Ethiopia. *Journal of Arid Environments*, *74*(1), 111–120.

Arévalo, J. R., de Nascimento, L., Fernández-lugo, S., Mata, J., and Bermejo, L. (2011). Grazing effects on species composition in different vegetation types (La Palma , Canary Islands). *Acta Oecologica*, *37*(3), 230–238.

Arevalo, J. R., De Nascimento, L., Fernandez-Lugo, S., Saro, I., Camacho, a., Mata, J., and Bermejo, L. (2011). Effects of abandoning long-term goat grazing on species composition and species richness of pastures at La Gomera, Canary Islands. *Spanish Journal of Agricultural Research*, *9*(1), 113–123.

Asner, G. P., Elmore, A. J., Olander, L. P., Martin, R. E., and Harris, A. T. (2004). Grazing Systems, Ecosystem Responses, and Global Change. *Annual Review of Environment and Resources*, *29*(1), 261–299.

Asner, G. P., Levick, S. R., Kennedy-bowdoin, T., Knapp, D. E., Emerson, R., Jacobson, J., … Martin, R. E. (2009). Large-scale impacts of herbivores on the structural diversity of African savannas. *Proceedings of the National Academy of Sciences*, *106*, 4947–4952.

Augustine, D. J. (2003a). Long-term , livestock-mediated redistribution of nitrogen and phosphorus in an East African savanna. *Journal of Applied Ecology*, *40*, 137–149.

Augustine, D. J. (2003b). Spatial heterogeneity in the herbaceous layer of a semi-arid savanna ecosystem. *Plant Ecology*, *167*, 319–332.

Augustine, D. J. (2004). Influence of Cattle Management on Habitat Selection by Impala on Central Kenyan Rangeland. *Journal of Wildlife Management*, *68*, 916–923.

Augustine, D. J., and Mcnaughton, S. J. (1998). Ungulates effects on the functional species composition of plant communities: Herbivore selectivity and plant tolerance. *Journal of Wildlife Management*, *62*(4), 1165–1183.

Augustine, D. J., and Mcnaughton, S. J. (2004a). Regulation of shrub dynamics by native browsing ungulates on East African rangeland. *Journal of Applied Ecology*, *41*, 45–58.

Augustine, D. J., and Mcnaughton, S. J. (2004b). Regulation of shrub dynamics by native browsing ungulates on East African rangeland. *Journal of Applied Ecology*, *41*, 45–58.

Augustine, D. J., and McNaughton, S. J. (2006). Interactive Effects of Ungulate Herbivores, Soil Fertility, and Variable Rainfall on Ecosystem Processes in a Semi-arid Savanna. *Ecosystems, 9*, 1242–1256.

Augustine, D. J., Veblen, K. E., Goheen, J. R., Riginos, C., and Young, T. P. (2011). Pathways for positive Cattle-Wildlife Interactions in Semi-arid Rangelands. In N. J. Georgiadis (Ed.), *Conserving Wildlife in African Landscapes; Kenya's Ewaso Ecosystem* (pp. 55–71). Washington, DC: Smithsonian Institution Scholarly Press.

Auken, O. W. Van. (2000). Shrub invasions of North American Semiarid Grasslands. *Ann. Rev. Ecol. Syst.*, *31*, 197–215.

Barton, K. E., and Koricheva, J. (2010). The ontogeny of plant defense and herbivory: characterizing general patterns using meta-analysis. *The American Naturalist*, *175*(4), 481–93.

Bekure, S., de Leeuw, P., Grandin, B., and Neate, P. (1991). The Maasai: Social-Historical context and Group Ranches. In S. Bekure, P. de Leeuw, Grandin BE, and N. PJ (Eds.), *Maasai herding: An analysis of the livestock production system of Maasai pastoralists in eastern Kajiado District, Kenya*. Addis Ababa: International Livestock Research Institute.

Belay, T. A., Totland, Ø., and Moe, S. R. (2013). Woody vegetation dynamics in the rangelands of lower Omo region , southwestern Ethiopia. *Journal of Arid Environments*, *89*, 94–102.

Belsky, A. J. (1990). Tree / Grass Ratios in East African Savannas : A Comparison of Existing Models. *Journal of Biogeography*, *17*(4/5), 483–489.

Belsky, A. J., Amundson, R. G., Duxbury, J. M., Riha, S. J., Ali, A. R., and Mwonga, S. M. (1989). The Effects of Trees on Their Physical , Chemical and Biological Environments in a Semi-Arid Savanna in Kenya. *Journal of Applied Ecology*, *26*(3), 1005–1024.

Belsky, A. J., and Canham, C. . (1994). Forest Gaps and isolated Savanna Trees. *Bioscience*, *44*(2), 77–84.

Benton, J. J. 1991. Kjeldahl method for nitrogen determination. Micro-Macro Publishing, Athens, Georgia, USA.

Bergström, R., Skarpe, C., and Kjell, D. (2000). Plant responses and herbivory following simulated browsing and stem cutting of Combretum apiculatum. *Journal of Vegetation Science*, *11*, 409–414.

Berkes, F., Colding, J., and Folke, C. (2000). Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications*, *10*(5), 1251–1262.Biggs, R., M. Schlüter, D. Biggs, E.L. Bohensky, S. BurnSilver, G. Cundill, and

P.C. West. (2012). Toward principles for enhancing the resilience of ecosystem services. Annual Review of Environment and Resources 37(1): 421–448.

Black, C.A., Evans, D.D., White, J.L., Ensminger, L.E., Clark, F.E. (1965). Methods of Soil analysis. Part 1. Physical and Mineralogical Properties Including Statistics of Measurement and Sampling. Am. Soc. Agro. Inc., Madison, Wisconsin.

Blench, R., and Sommer, F. (1999). *Understanding Rangeland Biodiversity* (No. 121) (pp. 1–51). London.

Boone, R. B., Burnsilver, S. B., Thornton, P. K., Worden, J. S., and Galvin, K. (2005). A Quantifying Declines in Livestock Due to Land Subdivision. Rangeland Ecology & Management 58: 523–532.

Boy, G. (2011). Laikipia- A Natural History Guide. Laikipia Wildlife Forum publication, Nanyuki, Kenya.

Buitenwerf, R., Bond, W. J., Stevens, N., and Trollope, W. S. W. (2012). Increased tree densities in South African savannas: >50 years of data suggests CO2 as a driver. *Global Change Biology*, *18*(2), 675–684.

Burnsilver, S., and Mwangi, E. (2007). *Beyond Group Ranch Subdivision : Collective Action for Livestock Mobility , Ecological Viability , and Livelihoods* (No. 66). Washington, DC.

Butt, B. (2010). Pastoral resource access and utilization: Quantifying the spatial and temporal relationships between livestock mobility, density and biomass availability in southern Kenya. *Land Degradation and Development*, *21*(6), 520–539.

Butt, B. (2011). Coping with Uncertainty and Variability: The Influence of Protected Areas on Pastoral Herding Strategies in East Africa. *Human Ecology*, *39*(3), 289–307.

Campbell, D. J, Gichohi, H., Mwangi, A., Smucker, T. (2003). Globalization and Local Heterogeneity: An Overview of Diversity in Land Use and Development Issues in Loitokitok Division, Kajiado District , Kenya. Land Use Change Impacts and Dynamics (LUCID) Project. Working Paper 21.Nairobi, Kenya: International Livestock Research Institute.

Catford, J. A., Vesk, P. A., Richardson, D. M., and Pysek, P. (2012). Quantifying levels of biological invasion : towards the objective classification of invaded and invasible ecosystems. *Global Change Biology*, *18*, 44–62.

Chytry, M., Jarosik, V., Pysek, P., Hajek, O., Knollova, I., Tichy, L., and Danihelka, J. (2008). Separating habitat invasibility by alien plants from actual level of invasion. *Ecology*, *89*(6), 1541–1553.

Cingolani, A. M., Cabido, M. R., Renison, D., and Solís Neffa, V. (2003). Combined effects of environment and grazing on vegetation structure in Argentine granite grasslands. *Journal of Vegetation Science*, *14*(2), 223.

Coldham, S. (1982). The registration of group ranches among the Maasai of Kenya - some legal problems. *Journal of Legal Pluralism*, *20*, 1–16.

Coppock, D. L., and Desta, S. (2013). Collective Action, Innovation, and Wealth Generation Among Settled Pastoral Women in Northern Kenya. *Range Ecology and Management*, *66*, 95–105.

Coppolillo, P. B. (2000). The Landscape Ecology of Pastoral Herding : Spatial Analysis of Land Use and Livestock Production in East Africa. *Human Ecology*, *28*(4).

Cornelissen, J. H. C., Lavorel, S., Garnier, E., Díaz, S., Buchmann, N., Gurvich, D. E., … Poorter, H. (2003). A handbook of protocols for standardised and easy measurement of plant functional traits worldwide. *Australian Journal of Botany*, *51*(4), 335.

Cornelius, R., and Schultka, W. (1997). Vegetation structure of a heavily grazed range in northern Kenya: tree and shrub canopy. *Journal of Arid Environments*, *36*(2), 291–306.

Cromsigt, J. P. G. M., and Kuijper, D. P. J. (2011). Revisiting the browsing lawn concept : Evolutionary Interactions or pruning herbivores ? *Journal of PPEES*, *13*(3), 207–215.

Dangerfield, J. M., and Modukanele, B. (1996). Over compensation by Acacia erubescens in response to simulated browsing. *Journal of Tropical Ecology*, *12*(06), 905–908.

De Bello, F., Leps, J., and Sebastia, M. (2006). Variations in species and functional plant diversity along climatic and grazing gradients. *Ecography*, *29*, 801–810.

Desta, S., and Coppock, D. L. (2004). Pastoralism Under Pressure: Tracking System Change in Southern Ethiopia. *Human Ecology*, *32*(4), 465–486.

DFID (DEPARTMENT FOR INTERNATIONAL DEVELOPMENT) (1999) Sustainable Livelihoods Guidance Sheets. Overseas Development Institute, UK.

Díaz, S., Lavorel, S., de Bello, F., Quétier, F., Grigulis, K., and Robson, T. M. (2007). Incorporating plant functional diversity effects in ecosystem service assessments. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(52), 20684–9.

Díaz, S., Noy-meir, I., and Cabido, M. (2001). Can grazing response of herbaceous plants be predicted from simple vegetative traits ? *Journal of Applied Ecology*, *38*, 497–508.

Drenovsky, R. E., and James, J. J. (2010). Designing Invasion-Resistant Plant Communities : The Role of Plant Functional Traits. *Rangelands*, *32*(1), 32–37.

Du Toit, J. T., Bryant, J. P., and Frisby, K. (1990). Regrowth and palatability of Acacia shoots following pruning by African Savanna browsers. *Ecology*, *71*(1), 149–154.

Eckhardt, H. C., Wilgen, B. W. Van, and Biggs, H. C. (2000). Trends in woody vegetation cover in the Kruger National Park , South Africa , between 1940 and 1998. *Africa Journal of Ecology*, *38*, 108–115.

Eldridge, D. J., Bowker, M. a, Maestre, F. T., Roger, E., Reynolds, J. F., and Whitford, W. G. (2011). Impacts of shrub encroachment on ecosystem structure and functioning: towards a global synthesis. *Ecology Letters*, *14*(7), 709–22.

Elhadi, Y.A., Nyariki, D.M. & Wasonga, O. V. (2015). Role of camel milk in pastoral livelihoods in Kenya : contribution to household diet and income. *Pastoralism: Research, Policy and Practice*, 5(8).

El-Keblawy, A., Ksiksi, T., and El Alqamy, H. (2009). Camel grazing affects species diversity and community structure in the deserts of the UAE. *Journal of Arid Environments*, *73*(3), 347–354.

Ellis, J. E., and Swift, D. M. (1988). Stability of African pastoral ecosystems : Alternate para- digms and implications for development. *Journal of Range Management*, *41*(6), 450–459.

Eriksen, S. & Lind, J. (2009). Adaptation as a political process: adjusting to drought and conflict in Kenya’s drylands. *Environmental management*, 43(5), pp.817–35. Available at: http://www.ncbi.nlm.nih.gov/pubmed/18726051 [Accessed September 21, 2013].

Emmerson, M. C., and Raffaelli, D. G. (2000). Detecting the effects of diversity on measures of ecosystem function : experimental design, null models and empirical obserUations. *Oikos*, *91*(1), 195–203.

FAO (1986). Production yearbook 1985: No. 39. Rome: FAO

Fernández-Lugo, S., de Nascimento, L., Mellado, M., Bermejo, L. a., and Arévalo, J. R. (2009). Vegetation change and chemical soil composition after 4 years of goat grazing exclusion in a Canary Islands pasture. *Agriculture, Ecosystems and Environment*, *132*(3-4), 276–282.

Fazey, I., Fazey, J.A. & Fazey, D.M.A., 2005. Learning More Effectively from Experience. *Ecology and Society*, 10(2), p.4.

Fernandez-gimenez, M.E., 2000. The Role of Mongolian Nomadic Pastoralists ' Ecological Knowledge in Rangeland Management. *Ecological Applications*, 10(5), pp.1318–1326.

Fornara, D. A., and du Toit, J. T. (2007). Browsing Lawns ? Responses of Acacia nigrescens to Ungulate Browsing in an African Savanna. *Ecology*, *88*(1), 200–209.

Fornara, D. A., and du Toit, J. T. (2008). Community-level interactions between ungulate browsers and woody plants in an African savanna dominated by palatable-spinescent Acacia trees. *Journal of Arid Environments, 72*, 534–545.

Fornara, D., and Du Toit, J. T. (2008). Responses of woody saplings exposed to chronic mammalian herbivory in an African savanna. *Ecosciences*, *15*(1), 129–135.

Fornoni, J. (2011). Ecological and evolutionary implications of plant tolerance to herbivory. *Functional Ecology*, *25*(2), 399–407.

Fynn, R. W. S., and Connor, T. G. O. (2000). Effect of stocking rate and rainfall on rangeland dynamics and cattle performance in a semi-arid savanna , South Africa. *Journal of Applied Ecology*, *37*, 491–507.

Gabay, O., Perevolotsky, a., Bar Massada, a., Carmel, Y., and Shachak, M. (2011). Differential effects of goat browsing on herbaceous plant community in a two-phase mosaic. *Plant Ecology*, *212*(10), 1643–1653.

Galaty, J. (1982). being “Maasai” being “people of cattle” ethnic shifters in East Africa. *American Ethnologist*, 1–20.

Galvin, K. A. (2009). Transitions: Pastoralists Living with Change. *Annual Review of Anthropology*, *38*(1), 185–198. doi:10.1146/annurev-anthro-091908-164442

Garnier, E., Cortez, J., Billes, G., Navas, M.L., Roumet, C., Debussche, M., Laurent, G., Blanchard, A., Aubry, D., Bellmann, A., Neill, C., & Toussaint, J.P. (2004). Plant functional markers capture ecosystem properties during secondary succession. *Ecology* 85: 2630- 2637.

Gemedo, D., Maass, B. L., and Isselstein, J. (2006). Encroachment of woody plants and its impact on pastoral livestock production in the Borana lowlands , southern Oromia, Ethiopia. *Africa Journal of Ecology*, *44*(2), 237–246.

Georgiadis, N. J., Ihwagi, F., Olwero, J. G. N., and Romañach, S. S. (2007). Savanna herbivore dynamics in a livestock-dominated landscape: II. Ecological, conservation, and management implications of predator restoration. *Biological Conservation, 137*, 473–483.

Georgiadis, N. J., Olwero, J. G. N., Ojwang', G., and Romañach, S. S. (2007). Savanna herbivore dynamics in a livestock-dominated landscape: I. Dependence on land use, rainfall, density, and time. *Biological Conservation*, *137*(3), 461–472.

Gezahegn, A. K. (2006). *Characterization of rangeland resources and dynamics of the pastoral production systems in the Somali region of eastern Ethiopia*. University of Free State.

Goheen, J. R., Palmer, T. M., Keesing, F., Riginos, C., Young, T. P., and Truman, P. (2010). Large herbivores facilitate savanna tree establishment via diverse and indirect pathways. *Journal of Animal Ecology*, *79*(2), 372–382.

Goheen, J. R., Young, T. P., Keesing, F., and Palmer, T. M. (2007). Consequences of herbivory by native ungulates for the reproduction of a savanna tree. *Journal of Ecology*, *95*(1), 129–138.

Gondard, H., Jauffret, S., Aronson, J., and Lavorel, S. (2003). Plant functional types : a promising tool for management and restoration of degraded lands. *Applied Vegetation Science*, *6*(2), 223–234.

Gordijn, P. J., Rice, E., and Ward, D. (2012). The effects of fire on woody plant encroachment are exacerbated by succession of trees of decreased palatability. *Perspectives in Plant Ecology, Evolution and Systematics*, *14*(6), 411–422.

Graham, M. (2006). *Coexistence in a land use mosaic ? Land use , risk and elephant ecology in Laikipia District , Kenya*. Cambridge.

Hagos, M. G., and Smit, G. N. (2005). Soil enrichment by Acacia mellifera subsp . detinens on nutrient poor sandy soil in a semi-arid southern African savanna. *Journal of Arid Environments*, *61*, 47–59.

Hanley, M. E., Lamont, B. B., Fairbanks, M. M., and Rafferty, C. M. (2007). Plant structural traits and their role in anti-herbivore defence. *Journal of PPEES*, *8*, 157–178.

Hauck, S. (2013). Pastoralist societies in flux: The impact of ecology, markets, and governmental assistance on the Mukugodo Maasai of Kenya. Unpublished PhD Dissertation submitted to Department of Ecology and Evolutionary Biology, Princeton University, USA.

Haukioja, E., and Koricheva, J. (2001). Tolerance to herbivory in woody vs . herbaceous plants. *Evolutionary Ecology*, *14*(4-6), 551–562.

Hayes, G. F., and Holl, K. D. (2003). Cattle Grazing Impacts on Annual Forbs and Vegetation Composition of Mesic Grasslands in California. *Conservation Ecology*, *17*(6), 1694–1702.

Helm, C., Wilson, G., Midgley, J., Kruger, L., and Witkowski, E. T. F. (2011). Investigating the vulnerability of an African savanna tree (Sclerocarya birrea ssp. caffra) to fire and herbivory. *Austral Ecology*, *36*(8), 964–973.

Herrera, A. (2011). *Changes in spatial structure of woody savanna vegetation after 11 years of exclusion of large herbivores*. MSc Thesis submitted to Biology Education Centre and Department of Ecology and Genetics, Plant Ecology and Evolution, Uppsala University.

Hester, A. J., Scogings, P. F., and Trollope, W. S. W. (2006). Long-term impacts of goat browsing on bush-clump dynamics in a semi-arid subtropical savanna. *Plant Ecology*, *183*(2), 277–290.

Higgins, S. I., Bond, W. J., Winston, S., and Trollope, W. (2000). Fire , resprouting and variability : a recipe for grass - tree coexistence in savanna. *Journal of Ecology*, *88*, 213–229.

Hobbs, N. T., Galvin, K. a., Stokes, C. J., Lackett, J. M., Ash, A. J., Boone, R. B., … Thornton, P. K. (2008). Fragmentation of rangelands: Implications for humans, animals, and landscapes. *Global Environmental Change*, *18*(4), 776–785.

Holling, C.S., 2001. Understanding Complexity of Economic , Ecological , and Social Systems. *Ecosystems*, 4(5), pp.390–405.

Homewood, K., Lambin, E. F., Coast, E., Kariuki, a, Kikula, I., Kivelia, J., … Thompson, M. (2001). Long-term changes in Serengeti-Mara wildebeest and land cover: pastoralism, population, or policies? *Proceedings of the National Academy of Sciences of the United States of America*, *98*(22), 12544–9.

Hudak, A. T., Wessman, C. A., and Seastedt, T. R. (2003). Woody overstorey effects on soil carbon and nitrogen pools in South African savanna. *Austral Ecology*, *28*, 173–181.

Huenneke, L. F., and Noble, I. (1996). Ecosystem Function of biodiversity in Arid ecosystems. In H. A. Mooney, J. H. Cushman, E. Medina, O. . Sala, and E. . Schulze (Eds.), *Functional Roles of Biodiversity: A Global Perspective* (pp. 99–128). John Wiley and Sons Ltd.

Huho, J. M., Ngaira, J. K. W., and Ogindo, H. O. (2011). Living with drought : the case of the Maasai pastoralists of northern Kenya. *Educational Research* *2*(1), 779–789.

Hulme, P. E. (1996). Herbivory, plant regeneration and species coexistence. *Journal of Ecology*, *84*(4), 609–615.

Jáuregui, B. M., García, U., Osoro, K., Celaya, R., Ja, B. M., and Garcı, U. (2009). Sheep and Goat Grazing Effects on Three Atlantic Heathland Types. *Range Ecology and Management*, *62*(2), 119–126.

Jillo, A., Aboud, A.A. & Coppock, D.L. (2006). *From herd diversification to livelihood diversification as aresponse to poverty: The case of the Waso Boran of Northern Kenya*, Davis, USA.

Jorg, T., Frank, S., and Florian, J. (2004). Seed dispersal by cattle may cause shrub encroachment of Grewia flava on southern Kalahari rangelands. *Applied Vegetation Science, 7*, 89–102.

Kahmen, A., Perner, J. & Buchmann, N. (2005). Diversity-dependent productivity in semi-natural grasslands following climate perturbations. *Functional Ecology*, 19, pp.594–601.

Kambatuku, J. R., Cramer, M. D., and Ward, D. (2011). Savanna tree-grass competition is modified by substrate type and herbivory. *Journal of Vegetation Science*, *22*(2), 225–237.

Karban, R., and Myers, J. H. (1989). Induced Plant Responses to Herbivory. *Annu. Rev. Ecol. Syst.*, *20*, 331–348.

Kaufmann, B. (2007). Cybernetic Analysis of Socio-biological Systems: The Case of Livestock Management in Resource-Poor Environments. Margraf Publishers GmbH, Scientific books, 2007 Kanalstraße 21; D-97990 Weikersheim

Kattge, J., Díaz, S., Lavorel, S., Prentice, I. C., Leadley, P., Bönisch, G., … Wirth, C. (2011). TRY - a global database of plant traits. *Global Change Biology*, *17*(9), 2905–2935.

Kaye-zwiebel, E., and King, E. (2014). Kenyan pastoralist societies in transition : varying perceptions of the value of ecosystem services. *Ecology and Society*, *19*(3), 17.

Kessler, A., and Heil, M. (2011). The multiple faces of indirect defences and their agents of natural selection. *Functional Ecology*, *25*(2), 348–357.

Keya, G. a. (1998). Herbaceous layer production and utilization by herbivores under different ecological conditions in an arid savanna of Kenya. *Agriculture, Ecosystems and Environment*, *69*(1), 55–67.

Kidake, K. B., Manyeki, K. J., Kirwa, C. E., Ngetich, R., Nenkari, H., and Mnene, N. W. (2015). Key Informant Perceptions on the Invasive Ipomoea Plant Species in Kajiado County , South Eastern Kenya. *Agriculture, Forestry and Fisheries*, *4*(4), 195–199.

Kimani, K., and Pickard, J. (1998). Recent trends and implications of Group Ranch sub-division and fragmentation in Kajiado District , Kenya. *The Geographical Journal*, *164*(2), 202–213.

Kinnaird, M. F., and O'Brien, T. G. (2012). Effects of Private-Land Use , Livestock Management , and Human Tolerance on Diversity , Distribution , and Abundance of Large African Mammals. *Conservation Biology*.

Kinnaird, M., O'Brien, T., and Ojwang', G. (2012). *Sample Count Aerial Surveys as a Monitoring Tool for Wildlife and Livestock : a Case Study from Laikipia County*. Nanyuki, Kenya.

Kiptarus, J.K. (2005). Focus on livestock sector: supply policy framework strategies status and links with value addition presented at workshop on value asses food & export investmen 3rd March 2005, Nairobi

Kiteme, B P., Wiesmann, U., Kúnzi, E., and Mathuva, J M. (1998). A Highland- Lowland System under Transitional Pressure: A Spatio-Temporal Analysis. Eastern and Southern Journal of Geography vol. 8 Special number, September 1998.

KnowWare International Inc. 1996-2014. Q1 Macros Software version 2014.12.

Kohi, E. M., Boer, W. F. De, Peel, M. J. S., Slotow, R., Waal, C. Van Der, Skidmore, A., … Prins, H. H. T. (2010). African Elephants Loxodonta africana Amplify Browse Heterogeneity in African Savanna. *Biotropica*, 1–11.

Kraaij, T., and Ward, D. (2006). Effects of rain, nitrogen, fire and grazing on tree recruitment and early survival in bush-encroached savanna , South Africa. *Plant Ecology*, *186*, 235–246.

Lavorel, S., Díaz, S., Cornelissen, J. H. C., Garnier, E., Harrison, S. P., Mcintyre, S., … Carlos, R. (2007). Plant Functional Types : Are We Getting Any Closer to the Holy Grail ? In J. G. Canadell and L. Pataki (Eds.), *Terrestrial Ecosystems in a changing Wolrd.* (pp. 149–160). Springer-Verlag Berlin Heidelberg.

Lavorel, S., Grigulis, K., Mcintyre, S., Williams, N. S. G., Garden, D., Dorrough, J., … Bonis, A. (2008). Assessing functional diversity in the field – methodology matters! *Functional Ecology*, *22*, 134–147.

Levick, S., and Rogers, K. (2008). Patch and species specific responses of savanna woody vegetation to browser exclusion. *Biological Conservation*, *141*, 489–498.

Levine, S. & Crosskey, A. (2006). *Household Economy Assessment of North East Turkana*. Kenya

Louault, A. F., Pillar, V. D., Aufrère, J., Garnier, E., and Soussana, J. (2005). Plant traits and functional types in response to reduced disturbance in a semi- natural grassland. *Journal of Vegetation Science*, *16*(2), 151–160.

Louhaichi, M., Ghassali, F., Salkini, a. K., and Petersen, S. L. (2012). Effect of sheep grazing on rangeland plant communities: Case study of landscape depressions within Syrian arid steppes. *Journal of Arid Environments*, *79*, 101–106.

Lu, C. D. (1988). Grazing behavior and diet selection of goats. *Small Ruminant Research*, *1*(3), 205–216.

Lusigi, W. J., Nkurunziza, E. R., and Masheti, S. (1984). Forage Preferences of Livestock in the Arid Lands of Northern Kenya. *Journal of Range Management*, *37*(November), 542–548.

Macharia, P. N., and Ekaya, W. N. (2005). The Impact of Rangeland Condition and Trend to the Grazing Resources of a Semi-arid Environment in Kenya. *Journal of Human Ecology*, *17*(2), 143–147.

Magurran, A. E. (1988). Ecological Diversity and its Measurement. Princeton University Press, Princeton, N.J

Manila, M. R. (2007). Forest Canopy Density mapping for forest climate change mitigation, FLR and SFM: Philippine experience. Available at: http://www.cifor.org/publications/pdf_files/cop/session bali-2-7-4-forest canopy-denr philippines.pdf, Assessed on 21 May 2015.

Mancilla-Leytón, J. M., Pino Mejías, R., and Martín Vicente, A. (2013). Do goats preserve the forest? Evaluating the effects of grazing goats on combustible Mediterranean scrub. *Applied Vegetation Science*, vol. 16(1) 63-73

Mancilla-Leyton, J. M., and Vicente, A. M. (2011). Goat grazing silviculture for the prevention of forest fires in Doñana Natural Park. *Options Mediterraneennes - Serie Seminaires*, *100*, 169–172.

Manila, M. R. (2007). Forest Canopy Density mapping for forest climate change mitigation, FLR and SFM: Philippine experience.

Meers, T. L., Bell, T. L., Enright, N. J., and Kasel, S. (2008). Role of plant functional traits in determining vegetation composition of abandoned grazing land in north-eastern Victoria, Australia. *Journal of Vegetation Science*, *19*(4), 515–524. doi:10.3170/2008-8-18401

Mehlich A. (1984). Mehlich 3 soil test extractant: a modification of Mehlich 2 extractant. Commun Soil Sci Plant Anal 15:1409– 16.

Meiners, S. J., Cadenasso, Mary, L., and Pickett, S. T. A. (2004). Beyond biodiversity : individualistic controls of invasion in a self-assembled community. *Ecology Letters*, *7*, 121–126.

Mengistu, T., Teketay, D., Hulten, H., and Yemshaw, Y. (2005). The role of enclosures in the recovery of woody vegetation in degraded dryland hillsides of central and northern Ethiopia. *Journal of Arid Environments, 60*(2), 259–281.

Meyer, K. M., Ward, D., Wiegand, K., and Moustakas, A. (2008). Multi-proxy evidence for competition between savanna woody species. *Perspectives in Plant Ecology, Evolution and Systematics, 10,* 63–72.

Meyer, K. M., Wiegand, K., and Ward, D. (2009). Patch dynamics integrate mechanisms for savanna tree – grass coexistence. *Basic and Applied Ecology, 10*(6), 1–9.

Midgley, J., Lawes, M. J., and Chamaillé-jammes, S. (2010). Savanna woody plant dynamics : the role of fire and herbivory , separately and synergistically. *Australian Journal of Botany, 58*(19), 1–11.

Miguel, E. & Gugerty, M.K. (2004). Ethnic Diversity , Social Sanctions , and Public Goods in Kenya.

Mills, A. J., Cowling, R. M., Fey, M. V., Kerley, G. I. H., Donaldson, J. S., Lechmere-Oertel, R. G., … Rundel, P. (2005). Effects of goat pastoralism on ecosystem carbon storage in semiarid thicket, Eastern Cape, South Africa. *Austral Ecology, 30*(7), 797–804.

Moleele, N. M. M., and Perkins, J. S. S. (1998). Encroaching woody plant species and boreholes : is cattle density the main driving factor in the Olifants Drift communal grazing lands , south-eastern Botswana ? *Journal of Arid Environments, 40*(3), 245–253.

Moleele, N. M., and Perkins, J. S. (1998). Encroaching woody plant species and boreholes : is cattle density the main driving factor in the Olifants Drift communal grazing lands , south-eastern Botswana ? *Journal of Arid Environments, 40,* 245–253.

Moleele, N. M., Ringrose, S., Matheson, W., and Vanderpost, C. (2002). More woody plants ? the status of bush encroachment in Botswana ' s grazing areas. *Journal of Environmental Management, 64,* 3–11.

Moolman, H. J., and Cowling, R. M. (1994). The impact of elephant and goat grazing on the endemic flora of South African succulent thicket. *Biological Conservation, 68*(1), 53–61.

Mueller-Dombois, D., and Ellenberg, H. (1974). Aims and Methods of Vegetation Ecology. Sydney: John Wiley and Sons.

Mungai, D. N., Ong, C. K., Kiteme, B., Elkaduwa, W., and Sakthivadivel, R. (2004). Lessons from two long-term hydrological studies in Kenya and Sri Lanka, *104,* 135–143.

Murphy, J., and Riley, J.P. (1962). A modified single solution method for the determination of phosphate in natural waters. Analyt. Chim. Acta 27, 31–39.

Mwangi, E. (2005). *The Transformation of property rights in Kenya's Maasailand: Triggers and Motivations* (No. 35). Washington, DC.

Mwangi, E. (2007). The Puzzle of Group Ranch Subdivision in Kenya's Maasailand. *Development and Change*, *38*(5), 889–910.

Mysterud, A. (2006). The concept of overgrazing and its role in management of large herbivores. *Wildlife Biology*, *12*(2), 129–141.

Navarro, T., Alados, C. L., and Cabezudo, B. (2006). Changes in plant functional types in response to goat and sheep grazing in two semi-arid shrublands of SE Spain. *Journal of Arid Environments*, *64*(2), 298–322.

Ngene, S., J. Mukeka, F. Ihwagi, J. Mathenge, A. Wandera, G. Anyona, T. Nyumba, L. Kawira, I. Muthuku, J. Kathiwa, P. Gacheru, Z. Davidson, J. King, and Omondi, P. (2013). Total aerial count of elephants, Grevy's zebra and other large mammals in Laikipia-Samburu-Marsabit ecosystem in (November 2012). Nairobi

Ng'ethe, J.C. 1992. Group ranch concept and practice in Kenya with special emphasis on Kajiado District. In Kategile J. A. and Mubi S. eds); Future of livestock industries in East and southern Africa. Proceedings of a workshop held at Kadoma Ranch Hotel, Zimbabwe, 20–23 July 1992. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia. 227 pp.

Ngigi, S. N. (2006). *Hydrological impacts of land use changes on water resources management and socio-economic development of upper ewaso ng'iro river basin in Kenya*. Delft University of Technology.

Nori, M., and Davies, J. (2007). Change of wind or wind of change? Climate change, adaptation and pastoralism. The World Initiative for Sustainable Pastoralism (WISP). Nairobi: IUCN.

Noumi, Z., Touzard, B., Michalet, R., and Chaieb, M. (2010). The effects of browsing on the structure of Acacia tortilis (Forssk.) Hayne ssp. raddiana (Savi) Brenan along a gradient of water availability in arid zones of Tunisia. *Journal of Arid Environments*, *74*(6), 625–631.

Ntiati, P. (2002). *Group Ranches Subdivision Study in Loitokitok Division of Kajiado District , Kenya* (No. 7). Nairobi, Kenya.

Oba, G. (1992). Effects of Controlled Grazing on a Degraded Dwarf Shrub, Annual Grass Semi-desert Vegetation Type of North western Kenya. *Land Degradation and Development*, *3*(April), 199–213.

Oba, G. (1994). *The Role of Indigenous Range Management Knowledge for Desertification Control in northern Kenya* (pp. 1–38). Uppsala, Sweden.

Oba, G. (1998). Effects of excluding goat herbivory on Acacia tortilis woodland around pastoralist settlements in northwest Kenya. *Acta Oecologica*, *19*(4), 395–404.

Oba, G., Mengistu, Z., and Stenseth, N. C. (2000). Compensatory Growth of the African Dwarf Shrub Indigofera spinosa Following Simulated Herbivory. *Ecological Applications*, *10*(4), 1133–1146.

Oba, G., and Post, E. (1999). Browse production and offtake by free-ranging goats in an arid zone , Kenya. *Journal of Arid Environments*, *43*, 183–195.

Odadi, W. O., Karachi, M. M. K., Abdulrazak, S. A., and Young, T. P. (2011). African wild ungulates compete with or facilitate cattle depending on season. *Science*, *333*(6050), 1753–5.

Ojwang', G., Agatsiva, J., and Situma, C. (2010). *Analysis of Climate Change and Variability Risks in the smallholder Sector; Case studies of the Laikipia and Narok Districts representing major agro-ecological zones in Kenya*. Rome, Italy: FAO.

Okello, B. D., O'Connor, T. G., and Young, T. P. (2001). Growth, biomass estimates, and charcoal production of Acacia drepanolobium in Laikipia, Kenya. *Forest Ecology and Management*, *142*(1-3), 143–153.

Olsen, S.R., Cole, C.V., Watanabe, F.S., Dean, L.A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonet. US Department of Agriculture. Cir. 939, USDA.

Papanikolaou, A. D., Fyllas, N. M., Mazaris, A. D., and Pantis, J. D. (2011). Grazing effects on plant functional group diversity in Mediterranean shrublands. *Biodiversity Conservation*.

Peacock, C. (1987). Herd movement on a Maasai group ranch in relation to traditional organisation and livestock development. Agricultural Administration and Extension, vol 27(2): 61–74.

Oba, G. (1994). *The Role of Indigenous Range Management Knowledge for Desertification Control in northern Kenya*, Uppsala, Sweden.Ojwang', G., Agatsiva, J. and Situma, C. (2010). Analysis of Climate Change and Variability Risks in the smallholder Sector; Case studies of the Laikipia and Narok Districts representing major agro-ecological zones in Kenya. FAO, Rome, Italy.

Olson, J.M., S. Misana, D.J. Campbell, M. Mbonile, and Mugisha, S. (2004). The spatial patterns and root causes of land use change in East Africa. (No. 47).

Rasmann, S., and Agrawal, A. A. (2009). Plant defense against herbivory : progress in identifying synergism , redundancy , and antagonism between resistance traits. *Current Opinion in Plant Biology*, *12,* 473–478.

Reed, M. S., and Dougill, A. J. (2010). Linking degradation assessment to sustainable land management: A decision support system for Kalahari pastoralists. *Journal of Arid Environments, 74*(1), 149–155.

Reid, R. S., and Ellis, J. E. (1995). Impacts of Pastoralists on Woodlands in South Turkana , Kenya : Livestock- Mediated Tree Recruitment. *Ecological Applications*, *5*(4), 978–992.

Riggs, R. A., and Urness, P. J. (1999). Effects of goat browsingon gambel oak communities in northern Utah. *Journal of Range Management*, *42*(5), 354–360.

Riginos, B. C., and Herrick, J. (2010). *Monitoring Rangeland Health A Guide for Pastoralist Communities and other Land Managers in Eastern Africa*.

Riginos, C., and Grace, J. B. (2008). Savanna tree density, herbivores, and the herbaceous community: bottom-up vs. top-down effects. *Ecology*, *89*(8), 2228–38. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/18724733

Riginos, C., and Hoffman, M. T. (2003). Changes in population biology of two succulent shrubs along a grazing gradient. *Journal of Applied Ecology*, *40*, 615–625.

Riginos, C., and Young, T. P. (2007). Positive and negative effects of grass, cattle, and wild herbivores on Acacia saplings in an East African savanna. *Oecologia*, *153*(4), 985–95.

Roba, H. G., and Oba, G. (2009). Efficacy of Integrating Herder Knowledge and Ecological Methods for Monitoring Rangeland Degradation in Northern Kenya. *Journal of Environmental Management*, *90*(2), 589–612.

Robert, R. and Mcallister, J. (2010). Livestock mobility in arid and semi- arid Australia : escaping variability in space. *Pastoralism*, 1(1), pp.37–54.

Robinson, L. W., and Berkes, F. (2010). Applying Resilience Thinking to Questions of Policy for Pastoralist Systems : Lessons from the Gabra of Northern Kenya. *Human Ecology*, *38*(3), 335–350.

Roques, K. G., O’Connor, T. G., and Watkinson, A. R. (2001). Dynamics of shrub encroachment in an African savanna : relative influences of fire , herbivory , rainfall and density. *Journal of Applied Ecology, 38*, 268–280.

Ruijven, J., De Deyn, G. B., and Berendse, F. (2003). Diversity reduces invasibility in experimental plant communities: the role of plant species. *Ecology Letters*, *6*(10), 910–918.

Rusch, G. . M., Pausas, J. G., and Leps, J. (2003). Plant Functional Types in relation to disturbance and land use : Introduction. *Journal of Vegetation Science*, *14*, 307–310.

Rusch, G. M. Ã., Skarpe, C., and Halley, D. J. (2009). Plant traits link hypothesis about resource-use and response to herbivory. *Basic and Applied Ecology*, *10*(5), 466–474.

Rutagwenda, T., Kaske, M., Engelhardt, W. V, Schultka, W., and Schwartz, H. J. (1989). Adaptation Strategies of camels on a thornbush savannah pasture : comparison with other domestic animals. *Options Mediterraneennes - Serie Seminaires*, 69–73.

Sankaran, M., and Anderson, T. M. (2009). Management and Restoration in African Savannas: Interactions and Feedbacks. In R. J. Hobbs and N. Suding, Katharine (Eds.), *New Models for Ecosystem Dynamics and Restoration.* (pp. 136–155). Island Press.

Sankaran, M., Hanan, N. P., Scholes, R. J., Ratnam, J., Augustine, D. J., Cade, B. S., … Zambatis, N. (2005). Determinants of woody cover in African savannas. *Nature*, *438*(7069), 846–9.

Sankaran, M., Ratnam, J., and Hanan, P. (2004). Tree – grass coexistence in savannas revisited – insights from an examination of assumptions and mechanisms invoked in existing models. *Ecology Letters*, *7*, 480–490.

Schellberg, J., and Pontes, L. S. (2013). Plant functional traits and nutrient gradients on grassland. *Grassland Science in Europe*, *67*, 305–319.

Scholes, R. J., and Archer, S. R. (1997). Tree-Grass interactions in Savannas. *Annu. Rev. Ecol. Syst.*, *28*, 517–544.

Scogings, P. F. F., Hjältén, J., and Skarpe, C. (2013). Does large herbivore removal affect secondary metabolites, nutrients and shoot length in woody species in semi-arid savannas? *Journal of Arid Environments*, *88*, 4–8.

Scogings, P. F., Mamashela, T. C., and Zobolo, A. M. (2012). Deciduous sapling responses to season and large herbivores in a semi-arid African savanna. *Austral Ecology*, n/a–n/a.

Scogings, P. F., and Mopipi, K. (2008). Effects of water , grass and N on responses of Acacia karroo seedlings to early wet season simulated browsing : Leaf N , fibre and tannin concentrations. *Journal of Arid Environments*, *72*, 1666–1674.

Scoones, I. (1995). Exploiting heterogeneity:habitat use by cattle in dryland Zimbabwe. *Journal of Arid Environments*, *29*(2), 221–237.

Sebata, A. (2013). Woody Plant-Herbivore Interactions in Semi-Arid Savanna Ecosystems (pp. 1–16). INTECH Open science, Open minds.

Skarpe, C. (1990). Structure of the woody vegetation in disturbed and undisturbed arid savanna, Botswana. *Vegetatio*, *87*(1), 11–18.

Smit, I. P. J., Asner, G. P., Govender, N., Kennedy-Bowdoin, T., Knapp, D. E., and Jacobson, J. (2010). Effects of fire on woody vegetation structure in African savanna. *Ecological Applications*, *20*(7), 1865–1875.

Solbrig, O. T., Medina, E., and Silvia, J. F. (1996). Biodiversity and tropcal savanna properties: A Global view. In H. A. Mooney, J. H. Cushman, E. Medina, O. E. Sala, and E. D. Schulze (Eds.), *Functional Roles of Biodiversity: A Global Perspective* (pp. 185–211). John Wiley and Sons Ltd.

Staver, A. C., Bond, W. J., Cramer, M. D., and Wakeling, J. L. (2012). Top-down determinants of niche structure and adaptation among African Acacias. *Ecology Letters*, *15*, 673–679.

Staver, A. C., Bond, W. J., Stock, William, D., van Rensburg, S. J., Waldram, M. S., and Africa, S. (2009). Browsing and fire interact to suppress tree density in an African savanna. *Ecological Applications*, *19*(7), 1909–1919.

Strum, S. C., Stirling, G., and Kalusi, S. (2015). The perfect storm : Land use change promotes Opuntia stricta ' s invasion of pastoral rangelands in Kenya. *Journal of Arid Environments*, *118*, 37–47.

Sundstrom, S., Tynon, J. F., and Western, D. (2012). Rangeland Privatization and the Maasai Experience: Social Capital and the Implications for Traditional Resource Management in Southern Kenya. *Society and Natural Resources*, *25*(5), 483–498.

Tanentzap, A. J., and Coomes, D. a. (2012). Carbon storage in terrestrial ecosystems: do browsing and grazing herbivores matter? *Biological Reviews of the Cambridge Philosophical Society*, *87*(1), 72–94.

Tefera, S., Snyman, H. A., and Smit, G. N. (2007). Rangeland dynamics of southern Ethiopia : (2). Assessment of woody vegetation structure in relation to land use and distance from water in semi-arid Borana rangelands. *Journal of Arid Environments*, *85*(2), 443–452.

Tessema, Z. K., Boer, W. F. De, Baars, R. M. T., and Prins, H. H. T. (2012). Influence of Grazing on Soil Seed Banks Determines the Restoration Potential of Aboveground Vegetation in a Semi-arid Savanna of Ethiopia. *Biotropica*, *44*(2), 211–219.

Thenya, T. (2001). Challenges of conservation of dryland shallow waters , Ewaso Narok swamp , Laikipia District , Kenya. *Hydrobiologia*, *458*, 107–119.

Thorne, M. S., Skinner, Q. D., Smith, M. A., Rodgers, J. D., Laycock, W. A., and Cerekci, S. A. (2002). Evaluation of a technique for measuring canopy volume of shrubs. *Journal of Range Management*, *55*(May), 235–241.

Thornton, P.K., BurnSilver, S.B., Boone, R.B, and Galvin, K.A. (2006). Modelling the impacts of group ranch subdivision on agro-pastoral households in Kajiado, Kenya. Agricultural Systems 87: 331–356.

Treydte, A. C., Heitkönig, I. M. a., Prins, H. H. T., and Ludwig, F. (2007). Trees improve grass quality for herbivores in African savannas. *Perspectives in Plant Ecology, Evolution and Systematics*, *8*(4), 197–205.

Treydte, A. C., Riginos, C., and Jeltsch, F. (2010). Enhanced use of beneath-canopy vegetation by grazing ungulates in African savannahs. *Journal of Arid Environments*, *74*(12), 1597–1603.

Trollope, W. S. W., Trollope, L. A., Biggs, H. C., Pienaar, D., and Potgieter, A. L. F. (1998). Long-term changes in woody vegetation of the Kruger National Park, with special reference to the effects of elephants and fire. *Koedoe*, *41*(2), 103–112.

Vagen, T., L. Winowiecki, L.T. Desta and Tondoh, J.E. (2010). Field Guide. The Land Degradation Surveillance Framework, World Agroforestry Centre, ICRAF, Nairobi.

Van der Waal, C., Kool, A., Meijer, S. S., Kohi, E., Heitkönig, I. M. A, de Boer, W. F., … de Kroon, H. (2011). Large herbivores may alter vegetation structure of semi-arid savannas through soil nutrient mediation. *Oecologia*, *165*(4), 1095–107.

Van Langevelde, F., van de Viljver, C. A. D. M., Kumar, L., van de Koppel, J., de Ridder, N., van Andel, J., … Rietkerk, M. (2003). Effects of fire and herbivory on the stability of Savanna ecosystems. *Ecology*, *84*(2), 337–350.

Vavra, M., Parks, C. G., and Wisdom, M. J. (2007). Biodiversity, exotic plant species, and herbivory: The good, the bad, and the ungulate. *Forest Ecology and Management*, *246*(1), 66–72.

Veit, P. (2011). The Rise and fall of Group Ranches in Kenya. Focus on Land in Africa , (March).

Wahungu, G. M., Gichohi, N. W., Onyango, I. A., Mureu, L. K., Kamaru, D., Mutisya, S., … Kimuyu, D. M. (2013). Encroachment of open grasslands and Acacia drepanolobium Harms ex B.Y.Sjostedt habitats by Euclea divinorum Hiern in Ol Pejeta Conservancy , Kenya. *Africa Journal of Ecology*, *51*, 130–138.

Walker, B., Holling, C. S., Carpenter, S. R., and Kinzig, A. (2004). Resilience , Adaptability and Transformability in Social – ecological Systems. *Ecology and Society*, *9*(2).

Ward, D. (2005). Do we understand the causes of bush encroachment in African savannas ? *African Journal of Range and Forage Science*, *22*(2), 101–105.

Wardle, D. A. (1999). Biodiversity , ecosystems and interactions. *Trends in Ecology and Evolution*, *14*(4), 125–127.

Watson, DJ, and Van Binsbergen, J. (2008). Livelihood diversification opportunities for pastoralists in Turkana, Kenya, ILRI Research Report 5. ILRI (International Livestock Research Institute), Nairobi, Kenya, 43.

Wayumba, R. N. and Mwenda, J. N. (2006). The Impact of Changing Land Tenure and Land Use on Wildlife Migration within Group Ranches in Kenya: A Case Study of the Amboseli Ecosystem The Impact of Changing Land Tenure and Land Use on Wildlife Migration within Group Ranches in Kenya: A Case Study of the Amboseli Ecosystem. Promoting Land Administration and Good Governance 5th FIG Regional Conference Proceedings, Accra, Ghana 8-11th March 2006

Western, D., Groom, R., and Worden, J. (2009). The impact of subdivision and sedentarization of pastoral lands on wildlife in an African savanna ecosystem. *Biological Conservation*, *142*(11), 2538–2546.

Wiegand, K., Saltz, D., and Ward, D. (2006). A patch-dynamics approach to savanna dynamics and woody plant encroachment – Insights from an arid savanna. *Journal of PPEES Sources*, *7*, 229–242.

Wigley, B. J., Bond, W. J., and Hoffman, M. T. (2009). Bush encroachment under three contrasting land-use practices in a mesic South African savanna. *Africa Journal of Ecology*, *47*, 62–70.

Wigley, B. J., Bond, W. J., and Hoffman, M. T. (2010). Thicket expansion in a South African savanna under divergent land use: local vs. global drivers? *Global Change Biology*, *16*(3), 964–976.

World Resources Institute, Department of Resource Surveys and Remote Sensing Ministry of Environment and Natural Resources, K., Central Bureau of Statistics, Ministry of Planning and National Development, K., and International Livestock Research institute. (2007). *Nature ' s Benefits in Kenya, An Atlas of Ecosystems and Human Well-Being*. Washington, DC and Nairobi: World Resources Institute.

Young, T. P., and Augustine, D. J. (2007). Interspecific Variation in the Reproductive Response of Acacia Species to Protection from Large Mammalian Herbivores. *Biotropica*, *39*(4), 559–561.

Yusuf, H., Treydte, A. C., Demissew, S., and Woldu, Z. (2011). Assessment of woody species encroachment in the grasslands of Nechisar National Park , Ethiopia. *Africa Journal of Ecology*, *49*, 397–409.

Zhao, W. Y., Li, J. L., and Qi, J. G. (2007). Changes in vegetation diversity and structure in response to heavy grazing pressure in the northern Tianshan Mountains , China. *Journal of Arid Environments*, *68*, 465–479.

Zwaagstra, L., Sharif, Z., Wambile, A., de Leeuw, J., Said, MY., Johnson, N., Njuki, J., Ericksen, P., and Herrero, M. 2010. *An assessment of the response to the 2008- 2009 drought in Kenya. A report to European Union Delegation to the Republic of Kenya*, ILRI, Nairobi.

APPENDIX 1.

Percent frequencies and densities for all species found in the study sites

		PR		GR	
Species	**Family**	**% Freq.**	**% Den**	**%Freq.**	**%Den**
Acokanthera oppositifolia	Apocynaceae	0.5	0.0	-	-
Acokanthera schimperi	Apocynaceae	1.0	0.1	-	-
Balanites aegyptiaca	Balanitaceae	0.5	0.0		
Balanites glaber	Balanitaceae	22.4	1.1	3.1	0.6
Boscia angustifolia	Capparaceae	27.0	0.8	-	-
Cadaba farinose	Capparaceae	2.6	0.1	2.7	0.4
Canthium sp	Rubiaceae	19.4	1.0	-	-
Carissa spinarum	Apocynaceae	7.1	0.8	-	-
Commiphora sp	Burseraceae	-	-	0.4	0.1
Cordia sinensis	Boraginaceae	2.0	0.1	-	-
Croton dichogamus	Euphorbiaceae	45.4	15.1	-	-
Euclea divinorum	Sapindaceae	32.1	9.9	-	-
Grewia similis	Malvaceae S.l	47.4	4.0	-	-
Grewia tenax	Malvaceae S.l	4.6	0.5	-	-
Ipomoea kituensis	Convulvulaceae			xx	xx
Lycium europeaum	Solanaceae	1.0	0.0	2.2	0.6
Maerua angolensis	Capparaceae	1.0	0.1	-	-
Maerua triphylla	Capparaceae	1.5	0.1	-	-
Mystroxylon aethiopicum	Celastraceae	4.6	0.1	-	-
Ocimum sp	Lamiaceae	0.5	0.0	-	-
Opuntia stricta	Cactaceae	0.5	0.0	-	-
Ormocarpum sp	Fabaceae	0.5	0.0	-	-
Pappea capensis		1.0	0.1	-	-
Pavetta gardenifolia	Rubiaceae	4.1	0.1	-	-

Phyllanthus sp	Euphorbiaceae	6.1	0.6	-	-
Psiadia punctata	Asteraceae	0.5	0.0	-	-
Psydrax sp	Rubiaceae	8.7	0.3	-	-
Pyrostria phyllanthoides	Rubiaceae	24.5	1.1	-	-
Rhamnus staddo	Rhamnaceae	1.5	0.0	-	-
Rhus natalensis	Anacardiaceae	7.7	0.2	-	-
Sansevieria volkensii	Draceanaceae	-	-		
Scutia myritina	Flacourtiaceae	7.7	0.3	-	-
Schlebera alata	Oleaceae	0.5	0.0	-	-
Acacia mellifera	Fabaceae	53.1	5.0	55.6	68.3
Tinnea aethiopicum	Labiatea	4.6	0.4	-	-
Acacia brevispica	Fabaceae	58.7	30.3	-	-
Acacia drepanolobium	Fabaceae	38.3	18.1	0.9	0.1
Acacia elatior	Fabaceae	-	-	0.4	0.1
Acacia etbaica	Fabaceae	39.3	8.0	43.1	17.8
Acacia gerradii	Fabaceae	22.4	1.5	-	-
Acacia nilotica	Fabaceae	8.2	0.2	1.3	0.2
Acacia reficiens	Fabaceae	-	-	3.1	0.4
Acacia seyal	Fabaceae	0.5	0.0	1.8	0.2
Acacia tortilis	Fabaceae	-	-	28.9	11.2
Ziziphus mucronata	Flacourtiaceae??	1.0	0.0	-	-

APPENDIX 2:

Questionnaire

Name of informant (optional) ……………………………………Age…………

Gender……………………………Ranch………………………………….

1. What are the objectives of the ranch?
2. What type of enterprise(s) are you involved in?
3. How long have you been in the current enterprise(s)?
4. What major change has occurred in your management/running of the ranch?
5. What are the mix of livestock species in your ranch and why?
6. What factors influence the choice of species?
7. How has the numbers of livestock change over the last 40 years?
8. How has the different species (cattle, sheep, camels, goats, donkeys etc) numbers change over the last 40 years?
9. What are your strategies to cope with forage shortages over the years?
10. How have these strategies change over time?
11. In your view, what are some of the notable changes in your ranch in the last 20 years?
12. In your views, has there been unprecedented increase in some plant species within your ranch? If your answer is yes;
    a. Which species are they?
    b. How have they affected your enterprises?
    c. What have you done about it?
13. Have you got any question with respect to this interview?

APPENDIX 3

Soil chemical analysis results for Mpala and Il Motiok ranches

Mpala soils														
S-Plot	**Soil pH**	**N**	**C**	**P(M)***	**P (O)**	**K**	**Ca**	**Mg**	**Mn**	**Co**	**Fe**	**Zn**	**Na**	**CEC**
MT101	6.43	0.07	1.51	65		1.96	6.1	4.59	0.24	1.64	60.1	4.05	0.42	
MT102	6.02	0.16	1.53	20		0.98	4.3	4.63	0.37	1.64	24.9	3.17	0.38	
MT103	5.80	0.12	0.79	15		0.86	2.7	4.28	0.47	1.37	23.0	2.67	0.20	
MT104	5.88	0.07	0.66	15		0.60	2.0	3.44	0.39	1.41	33.0	3.66	0.18	
MT105	6.15	0.12	1.14	30		1.00	2.7	4.50	0.48	1.51	122.0	3.86	0.18	
MT106	5.99	0.09	0.77	10		0.48	5.5	3.36	0.18	1.47	22.2	1.80	0.54	
MT107	5.92	0.11	0.84	10		0.66	2.2	3.57	0.29	1.44	28.7	2.96	0.20	
MT108	6.15	0.10	0.73	15		0.48	2.0	3.04	0.29	1.48	27.7	2.58	0.12	
MT109	6.01	0.09	0.86	35		0.62	2.0	3.77	0.38	1.48	31.1	3.34	0.12	
MT110	7.34	0.10	1.40		0.1	1.20	3.5	5.73	0.50	1.54	36.1	3.84	0.22	0.29
MT111	6.84	0.07	0.77	15		0.66	2.2	6.24	0.51	1.75	43.3	2.20	0.18	
MT112	6.21	0.09	1.72	15		1.04	2.7	5.92	0.69	1.54	51.1	3.16	0.20	
MT113	7.35	0.11	1.18		0.1	0.68	17.1	7.19	0.41	1.25	57.8	2.06	1.79	0.08
MT114	6.53	0.08	1.30	40		0.96	12.9	7.49	0.37	1.67	60.1	3.07	1.35	
MT115	6.78	0.11	1.54	35		0.90	12.9	7.49	0.36	3.93	13.3	18.2	1.31	
MT201	6.09	0.12	0.97	20		0.92	2.7	3.84	0.29	6.53	124	5.73	0.20	
MT202	5.69	0.18	0.95	10		0.60	2.0	3.71	0.21	1.54	23.8	3.28	0.16	
MT203	6.24	0.11	0.88	60		0.42	2.2	2.80	0.48	1.31	31.9	2.69	0.12	
MT204	5.44	0.12	0.77	35		0.56	1.2	3.44	0.46	1.70	20.9	2.66	0.12	
MT205	6.85	0.10	1.57	30		0.84	4.1	5.49	0.36	1.60	28.8	3.67	0.40	
MT206	6.41	0.11	1.25	60		0.62	3.3	5.53	0.75	2.00	49.9	3.65	0.28	
MT207	5.21	0.08	0.69	65		0.38	1.4	3.67	0.44	1.53	34.1	2.44	0.08	
MT208	5.44	0.06	0.62	15		0.60	2.0	3.47	0.33	1.94	24.4	2.60	0.12	
MT209	5.59	0.07	0.90	10		0.46	1.6	3.83	0.36	1.00	13.4	1.51	0.10	
MT210	5.58	0.10	0.86	10		0.32	1.2	2.63	0.51	1.57	34.9	2.34	0.08	
MT211	7.92	0.08	1.31		0.1	0.38	2.9	6.43	0.52	1.54	23.4	2.75	0.24	0.13
MT212	6.54	0.05	1.46	20		0.78	11.3	8.42	0.45	1.31	48.5	2.31	1.14	
MT213	6.68	0.07	0.99	30		0.80	11.9	7.98	0.50	1.48	58.7	3.12	1.18	
MT214	7.20	0.08	1.10		0.1	0.76	15.1	7.95	0.71	1.47	26.3	2.81	1.53	0.52
MT215	7.11	0.05	1.05		0.1	0.68	15.4	7.64	0.42	1.43	41.0	2.12	1.57	0.11
MT301	5.43	0.04	0.79	20		0.60	2.2	4.42	0.53	1.65	31.5	2.40	0.16	
MT302	5.95	0.10	1.01	20		0.64	2.2	5.13	0.38	1.75	32.3	4.11	0.14	
MT303	5.76	0.09	0.75	15		0.52	3.7	3.36	0.31	1.55	23.9	2.14	0.10	
MT304	6.29	0.06	0.90	25		0.46	2.0	4.14	0.48	1.77	21.1	2.41	0.12	
MT305	6.03	0.07	0.51	15		0.46	2.0	3.78	0.47	1.59	24.1	1.94	0.12	
MT306	5.81	0.06	0.62	15		0.26	1.4	4.24	0.30	1.97	30.1	2.21	0.10	

MT307	6.21	0.06	0.75	85		0.56	2.0	5.76	0.59	2.08	32.2	2.84	0.14	
MT308	5.77	0.10	0.67	10		0.80	2.2	3.48	0.53	2.12	26.5	3.64	0.16	
MT309	6.20	0.05	0.45	10		0.82	2.4	3.75	0.47	3.23	23.7	2.74	0.16	
MT310	4.83	0.06	0.38	15		0.44	1.4	2.40	0.43	1.41	40.2	2.02	0.10	
MT311	5.26	0.09	0.83	15		0.16	2.0	4.55	0.61	1.81	161	3.37	0.20	
MT312	7.97	0.15	1.45		0.1	0.52	2.7	6.51	0.18	1.93	58.7	25.1	0.22	0.40
MT313	6.88	0.14	1.41	25		0.76	13.1	7.66	0.30	1.65	41.4	23.8	1.37	
MT314	6.85	0.15	1.44	20		0.76	15.9	7.38	0.50	4.76	24.8	17.5	1.67	
MT315	6.72	0.11	1.09	30		0.80	18.9	7.08	0.56	1.60	79.6	2.95	1.95	
Ilmotiok Soils														
Plot	**Soil pH**	**Tot. N**	**Tot. C**	**P(Meh)**	**P (Ols)**	**K**	**Ca**	**Mg**	**Mn**	**Co**	**Fe**	**Zn**	**Na**	**CEC**
LT101	6.03	0.07	0.63	75		0.40	1.4	1.33	0.15	1.00	25.9	2.14	0.12	
LT102	7.54	0.16	1.59		2	1.80	5.5	6.37	0.29	0.88	48.8	8.40	0.38	0.69
LT103	8.17	0.12	1.12		0.1	0.58	13.5	4.69	0.28	1.24	29.4	3.08	1.49	0.82
LT104	8.51	0.07	0.62		0.2	0.32	15.5	3.82	0.33	1.42	31.1	2.74	1.63	0.73
LT105	8.31	0.12	1.17		0.1	0.34	15.9	3.75	0.16	1.19	19.9	3.18	1.71	0.69
LT106	6.24	0.09	0.91	30		0.84	5.7	5.37	0.25	1.52	37.6	1.91	0.50	
LT107	7.87	0.11	1.04		0.1	0.58	7.7	4.72	0.30	1.44	34.4	2.42	0.72	0.44
LT108	8.49	0.10	0.95		0.1	0.32	13.3	4.04	0.06	1.33	30.6	2.97	1.41	0.72
LT109	6.13	0.09	0.85	30		0.48	3.9	3.36	0.34	1.63	27.6	1.50	0.38	
LT110	6.38	0.10	0.93	20		0.56	2.9	4.00	0.30	1.87	37.9	1.56	0.26	
LT111	7.70	0.07	0.70		0.2	0.42	9.7	4.71	0.37	1.56	49.2	1.71	1.00	0.35
LT112	7.56	0.09	0.83		0.1	0.50	4.5	4.99	0.20	1.53	33.1	2.05	0.44	0.43
LT113	6.52	0.11	1.05	30		0.50	2.0	3.77	0.19	1.37	31.2	1.95	0.18	
LT114	6.65	0.08	0.78	50		0.80	2.4	3.44	0.19	1.34	33.5	3.15	0.16	
LT115	6.08	0.11	1.08	35		0.68	2.2	3.11	0.20	1.46	28.9	2.39	0.16	
LT201	7.20	0.12	1.12		0.2	0.52	5.3	5.50	0.32	1.78	14.2	7.25	0.54	0.15
LT202	8.22	0.18	1.80		0.5	0.46	8.9	3.73	0.12	1.57	54.4	15.4	0.90	0.77
LT203	8.58	0.11	1.11		0.3	0.24	16.9	2.07	0.06	1.63	112	6.31	1.82	0.54
LT204	8.22	0.12	1.16		0.3	1.14	9.7	3.99	0.06	4.33	59.4	5.00	0.98	0.71
LT205	6.87	0.10	0.93	40		0.78	3.9	2.77	0.47	1.81	48.6	5.91	0.38	
LT206	5.76	0.11	1.06	25		0.56	2.4	2.46	0.37	1.92	56.8	13.3	0.20	
LT207	5.82	0.08	0.81	30		0.90	2.7	1.38	0.35	1.92	51.1	11.1	0.22	
LT208	5.70	0.06	0.54	25		0.60	2.0	1.21	0.37	1.80	21.7	11.2	0.18	
LT209	5.55	0.07	0.67	20		0.80	2.9	1.99	0.52	1.76	17.4	7.24	0.24	
LT210	5.67	0.10	0.95	15		0.74	2.9	1.78	0.28	1.84	13.9	2.97	0.26	
LT211	6.17	0.08	0.80	15		0.64	2.5	2.69	0.30	2.41	20.1	23.3	0.20	
LT212	5.82	0.05	0.43	15		0.62	2.2	1.90	0.26	1.88	21.3	21.8	0.19	
LT213	5.50	0.07	0.69	20		0.44	2.0	1.66	0.62	1.53	129	21.1	0.16	
LT214	6.03	0.08	0.76	20		0.58	3.7	3.90	0.43	1.93	115	22.7	0.38	
LT215	8.37	0.05	0.49		0.2	0.48	2.9	3.02	0.41	1.88	54.8	6.46	0.30	0.63

LT301	NA													
LT302	NA													
LT303	NA													
LT304	NA													
LT305	NA													
LT306	5.94	0.04	0.39	150		0.78	2.9	1.15	0.38	2.91	55.8	28.0	0.26	
LT307	5.69	0.10	0.96	45		0.78	2.7	1.48	0.32	1.85	61.1	20.6	0.26	
LT308	5.75	0.09	0.83	20		0.62	2.4	1.85	0.42	1.64	90.5	20.8	0.20	
LT309	5.55	0.06	0.60	25		0.46	3.1	1.14	0.29	2.72	102	16.7	0.30	
LT310	6.15	0.07	0.63	55		0.74	3.5	1.61	0.32	2.16	51.6	22.6	0.32	
LT311	6.37	0.06	0.58	30		0.90	2.7	1.03	0.46	1.90	39.5	11.5	0.28	
LT312	6.20	0.06	0.61	25		0.50	2.5	3.19	0.43	2.22	34.8	3.32	0.26	
LT313	5.92	0.10	1.01	20		0.66	3.3	2.93	0.63	5.11	61.9	12.2	0.32	
LT314	7.09	0.05	0.50		1	0.90	2.9	3.13	0.33	2.26	43.8	3.75	0.28	0.14
LT315	7.89	0.06	0.53		1	1.32	5.1	4.65	0.43	2.40	42.5	3.52	0.44	0.34

*P(M) – measure of phosphorus using Mehlich method in soils with PH lower than 7.0 while P(O) measure of phosphorus using Olsen method for soils with PH higher than 7.0.