EFFECTS OF LAND USE AND SEASONALITY ON THE RESPONSES OF WILD UNGULATES TO LIVESTOCK GRAZING IN LAIKIPIA RANGELAND, KENYA

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EGERTON UNIVERSITY

MARCH 2019

DECLARATION AND RECOMMENDATION

DECLARATION

This thesis is my original work and has not wholly or in part been submitted for examination in any other University.

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RECOMMENDATION

This thesis has been submitted for examination with our approval as University supervisors.

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DEDICATION

This work is dedicated to my lovely daughter Tiffany Nyaruai.

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ABSTRACT

Tropical savannas occur prevalently in Africa and they are important for wildlife conservation and human livelihoods. Wild and domestic ungulates often co-occur and share forage and water resources in these savannas. This situation is prevalent in areas with minimal coverage of protected areas like Laikipia. Habitat sharing can result to varied ecological interactions, including competition and facilitation depending on season. This study assessed the responses of wild ungulates to livestock grazing in three livestock-based land-use types in Laikipia savanna ecosystem, and whether these responses are influenced by seasonal changes. Census data were obtained from the Department of Resource Survey and Remote Sensing (DRSRS) for censuses conducted in February 2001, February 2003 and February 2005 (dry periods) and June 1997, February 2010 and November 2012 (wet periods). Wild ungulates abundance was estimated using Jolly's method 2 while species diversity (α-diversity) was calculated using Simpson's diversity index in each census grid. Mean diversity index ($\bar{\alpha}$-diversity) was also calculated for each land-use type. The β and γ diversity were also calculated. Analysis of variance (ANOVA) and Kruskal-Wallis were used to test for differences in wild ungulates abundance and species diversity. Regression analysis was used to assess the relationship between livestock densities and wild ungulates abundance and diversity across land-use types in different seasons. Significant differences were accepted at $p < 0.05$. Wild ungulates-cattle spatial relationship was analyzed using Ripley's bivariate K_{12} function. Livestock driven land-use type significantly affected nine ungulate species, four wild ungulate guilds and both the α and β-diversity. Seasonality had minimal effect on wild ungulates. Waterbucks and Gerenuk were neither significantly affected by land-use type nor by seasonality. Seasonality did not affect the α and β diversity significantly. Cattle and various wild herbivore guilds exhibited different spatial relationships (attraction or repulsion) at various scales of distance. The departure of L_{12} function from complete spatial randomness (CSR) was generally low in PR than in TRL and PGA; implying better co-existence in PR than in TRL and PGA. For effective wildlife conservation in Laikipia and similar savanna landscapes, restoration of native vegetation in degraded areas especially in TRL and PGA is important. More importantly, the local communities need to be sensitized on the need to maintain the proper livestock density which may not negatively impact on native wild herbivore. Research should be done to establish the correct stocking density that if exceeded, it can impact negatively on the native wild ungulates.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ASAL	Arid and Semi-Arid Lands
AVHRR	Advanced Very High Resolution Radiometer
CSR	Complete Spatial Randomness
DRSRS	Department of Resource Survey and Remote Sensing
ECF	East Coast Fever
GLM	General Linear Model
HSD	Honest Significance Difference
LWF	Laikipia Wildlife Forum
MODIS	Moderate Resolution Imaging Spectroradiometer
MSA	Mean Species Abundance
NDVI	Normalized Difference Vegetation Index
PA(s)	Protected Areas
PGA(s)	Pastoral Grazing Areas
PR	Private Ranches
SE	Standard Error
SRF	Systematic Reconnaissance Flight
TRL	Transitional Land

CHAPTER ONE

INTRODUCTION

1.1 Background information

Tropical savannas are characterized by continuous grass layer occurring together with varying densities of woody vegetation under a climatic regime comprising distinct wet and dry seasons (Walker and NoyMeir, 1982; Walter, 1971). These savannas occupy the transitional zones between equatorial rainforests and the deserts of the higher northern and lower southern latitudes, and cover nearly a third of the earth's total land surface (Gottsberger and Silberbauer-Gottsberger, 2009). Tropical savannas occur more extensively in Africa than in any other continent, it is estimated that approximately 50% of Africa's land surface area is covered by savannas (Gottsberger and Silberbauer-Gottsberger, 2009; Macedo, 1997; Sangeda and Malole, 2014). In Africa, savannas are broadly categorized as either moist-dystrophic or arid-eutrophic depending on moisture (Fig.1.1), or broad-leafed or fine-leafed depending on vegetation leaf type (Du Toit and Cumming, 1999; Huntley *et al.*, 1982; Justice *et al.*, 1994).

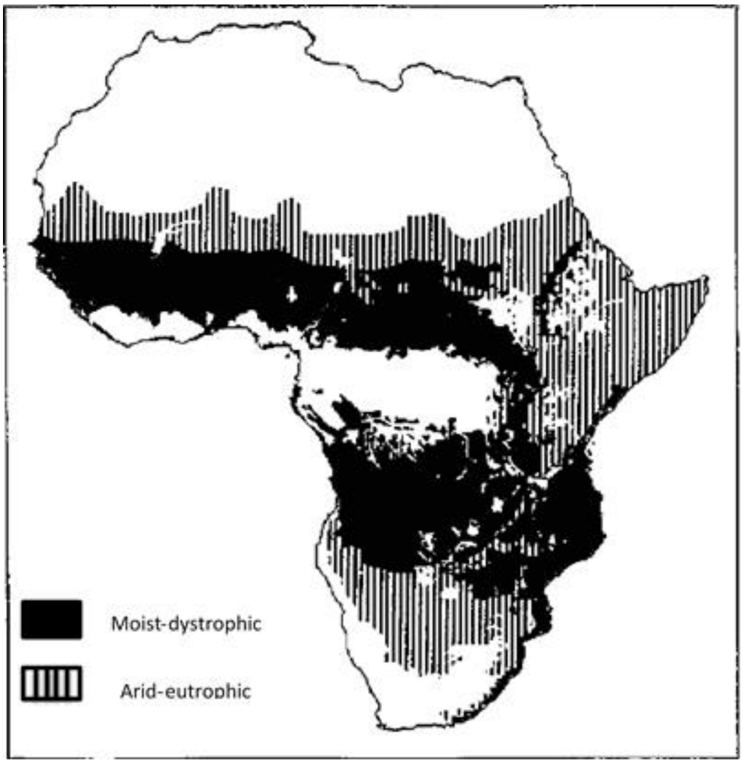


Figure 1.1: Distribution of Savanna ecosystems in Africa.

Source: (Du Toit and Cumming, 1999)

African savannas are important both ecologically and socio-economically. Specifically, these landscapes are important for biodiversity conservation and provision of habitats for many wildlife species. These savanna landscapes are known to harbour the earth's highest diversity of ungulates (Du Toit and Cumming, 1999; Owen-Smith and Cumming, 1993). Previous studies show that extant ungulates endemic to African savanna number 46 species with approximately 80% of these belonging to the family *Bovidae* (Du Toit and Cumming, 1999). This high diversity of ungulates is linked to high spatial heterogeneity in the savanna landscapes. In addition to their biodiversity conservation value, African savannas are important for livestock production through ranching, pastoralism and agro-pastoralism, and thus support high densities of livestock (Rosen, 2000). The sub-Saharan Africa hosts approximately 36.7 million head of cattle in the pastoral and agro-pastoral farming system and 55.5 million head of cattle in the mixed extensive farming systems (Robinson *et al.*, 2011). East Africa has higher cattle density compared to other regions in the continent. The average density of cattle, sheep and goats in East Africa has been found to be approximately $14/km^2$, $6/km^2$, and $9/km^2$ respectively (Sebastian, 2014). Kenya hosts approximately 11.5 million cattle and 18.7 million sheep and goats combined while the Tanzania's savannas host approximately 19.5 million cattle and 17.5 million sheep and goats combined (FAO, 2005; Sangeda and Malole, 2014). Laikipia hosts an estimated 149,910 head of cattle, and 380,312 sheep and goats combined (Kinnaird *et al.*, 2012).

Tropical savannas also act as important carbon sinks. It is estimated that African savannas store approximately 59% of the regional carbon stock (Emg, 2011; Rosen, 2000). African savannas, given their rich biodiversity; also provide excellent sceneries for tourism and recreational activities including wildlife viewing, photography and sport hunting. Because of the important ecosystem services they provide, African savannas support approximately 162 million people, some of them among the world's poor livestock keepers (Kruska *et al.*, 2003).

Some of the most ecologically and socio-economically important African savannas are found in East Africa. These savannas host some of the most spectacular, diverse and abundant wild ungulate assemblages in the world (Du Toit and Cumming, 1999). While numerous protected areas have been established across East African savannas for the purpose of conserving wildlife populations, large proportions of these populations frequently occur outside protected areas (Western *et al.*, 2009) where they share habitat with livestock. This situation is prevalent in landscapes with minimal coverage of protected areas such as the Laikipia rangeland. The Laikipia rangeland is one of the most biodiversity-rich savanna landscapes in

Africa, with over 95 species of mammals, 540 species of birds, over 700 plant species and over 1,000 invertebrate species (LWF, 2012), and approximately 40,000 individuals of focal ungulate species (Kinnaird *et al.*, 2012). However, despite the high biological richness and wild ungulate abundance, Laikipia is largely unprotected with just approximately 2.1% of the landscape currently falling under formal government protection for conservation purposes (Georgiadis *et al.*, 2007). Consequently, a large proportion of wild ungulates in this ecosystem co-occur with livestock in the unfenced communal areas, transitional, and private lands.

When wild ungulates share habitats with livestock, their populations can be affected through different pathways (Nayak *et al.*, 2013; Odadi *et al.*, 2011; Young *et al.*, 2005). Wild ungulates may be affected by the actual presence of livestock and their herders or indirectly through livestock driven habitat alteration. The strength of the effects of livestock on wild ungulates may vary across different land use types and seasonal conditions. Therefore, developing conservation strategies for continued survival of wildlife populations in livestock dominated savanna landscapes such as Laikipia requires thorough understanding of the effects of land use types, and seasonality on the response of wild ungulates' community attributes (abundance, distribution, diversity and spatial relationship) to livestock grazing.

1.2 Statement of the problem

East African savanna rangelands are known for their diverse and abundant assemblage of wild ungulate populations. Large proportions of these populations are found outside protected areas, especially on privately owned unfenced livestock ranches, communal grazing areas and transitional areas (land changing from large-scale ranches to small-scale mixed farming). Consequently, these wild ungulates share habitats with domestic ungulates (livestock). To enhance wildlife conservation in these savanna rangelands, thorough understanding of the effects of land use types, and seasonality on wild ungulates community attributes (abundance, distribution, diversity and spatial relationship) in the different livestock based land uses was important. This was particularly critical for savanna landscapes with minimal coverage of protected areas such as Laikipia. However, such an assessment has rarely been carried out in such livestock-dominated savanna landscapes.

1.3 Objectives

1.3.1 Broad objective

To assess the effects of land use and seasonality on the response of wild ungulates to livestock in Laikipia savanna rangelands with a view to contributing towards enhanced wildlife-livestock co-existence in human occupied landscapes.

1.3.2 Specific objectives

1. To evaluate forage availability across the different land-use types in different seasons.
2. To map the spatial distribution of wild ungulates and livestock across different land-use types in different seasons.
3. To assess the effects of land-use type on the abundance and species diversity of wild ungulates in different seasons.
4. To assess the effects of land-use type on the spatial relationship between different wild ungulate guilds and cattle herds.

1.4 Hypotheses

1. H_o: Forage availability is the same across the different land-use types and it does not vary between the wet and the dry season.
2. H_o: Wild ungulates and livestock are uniformly distributed across the different land use types both in wet and dry season.
3. H_o: Wild ungulates abundance and diversity is the same across the different land use types during the wet and dry season.
4. H_o: Wild ungulate guilds and cattle herds are randomly distributed in the different land use types.

1.5 Significance of the study

This study was motivated by the conservation and ecological significance of the Laikipia savanna rangeland and similar livestock-dominated landscapes with high wildlife species diversity and abundance occurring in different land use types. This study generated information on the effects of land use and seasonality on the abundance, species diversity and distribution of wild ungulates and on the spatial relationship between these ungulates and livestock. The information generated is useful to wildlife and natural resource managers, local communities, and policy makers keen on finding ways of fostering compatibility between livestock production and wildlife conservation especially in areas where wildlife and livestock co-occur in varying densities. Specifically, the findings of this study could provide insights into the implications of different livestock-based land-use types on wildlife conservation. Lastly, this work contributes to the general pool of knowledge in the field of wildlife and rangeland management as well as land use planning.

1.6 Assumptions

During this study, it was assumed all that ungulates present in the study area were located, identified and counted accurately during the aerial surveys.

1.7 Scope and limitations of the study

The study was carried out within the geographical boundaries of Laikipia County and used previously collected aerial animal census data covering both wet and dry periods. Specifically, the study used data from aerial surveys conducted in February 2001, February 2003 and February 2005 (dry periods) and June 1997, February 2010 and November 2012 (wet periods). DRSRS has monitored wild herbivore and livestock populations in Kenya since 1977, however, the data in the years used in this study was preferred because firstly; the mean monthly rainfall was very distinct and secondly; the corresponding NDVI data was readily available thus making it easier to segregate between dry and wet survey periods. The study focused on the three broad wildlife-livestock based land use types namely: the private ranches, pastoral grazing areas and transitional lands. The abiotic ecological factors like the topography, solar radiation, temperatures and soil factors of the study area were not considered in this study though they may have a direct or indirect influence on dependent variables. The abundance of rhino and the Cape buffalo (*Syncerus caffer*) was not analyzed because these two species exclusively occurred in PR in all census years used in this study; also, the abundance of Reticulated giraffe *(Giraffa camelopardalis reticulata),* Greater kudu *(Tragelaphus strepsiceros)*, Lesser kudu *(Tragelaphus imberbis)* and Reedbuck (*Rudanca rudanca*) was not analyzed due to lack of sufficient data. The major limitation to this study was the acquisition of high resolution satellite imagery for seasonal vegetation characterization that coincided with the period when the censuses were done. However, moderate resolution satellite imageries with a resolution of 250 x 250 metres, and 0.05° x 0.05° were used.

1.8 Operational definition of terms

Abundance: The total number of individuals of a particular species occupying a specific area at a given time.

Agro-pastoralism: Land use type where a land parcel is either on crop farming (during wet season) or on livestock production (during dry periods).

Distribution: Occurrence in terms of intensity of wild and domestic ungulates.

Diversity: Total variety or variability of distinct component species in a specific place and time.

Group ranch: A section of community land registered in the name of group representatives and managed by a committee of locals.

Land use: The function or functions that humans apply on the land available to them.

Livestock: Are domestic ungulates including cattle, sheep, goats, camels and donkeys.

Mixed farming: Land use type where crop farming and livestock keeping is done on the same parcel of land concurrently.

Pastoral grazing areas: Land accessed freely and used purely by the local pastoral community for livestock grazing.

Private ranches: Refers to individually or company owned livestock ranches that are also accommodative of wildlife conservation.

Response: Community adjustments of wild ungulates to livestock grazing in different land use types expressed by differences in certain measured wild ungulate community attributes (abundance, distribution, diversity and spatial relationship).

Savanna: Ecosystems dominated by grasses and non-graminoid herbaceous species and varying density of trees.

Savanna rangelands: Ecosystems dominated by graminoid and non-graminoid species which are naturally grazed or browsed by native wild ungulates.

Seasonality: Variability in weather patterns for over a period of one year, usually characterized by rainy (wet) or dry periods.

Spatial relationship: The relationship in space between two or more objects which are geographically referenced.

Species diversity: The average rarity of a species within a community

Transitional land: Refers to parcels of land changing from large-scale ranching to small-scale agro-pastoralism and/or mixed farming.

Wild ungulates: Refers to hoofed wild herbivores belonging to the order Artiodactyla (even-toed), Perissodactyla (odd-toed), and Proboscidea (elephants) all of which have their feet modified as hooves of various types.

Wild ungulates' species diversity: The variability in species within a community of wild ungulates.

Wild ungulate guilds: Groupings of wild ungulates based on either body size or feeding style.

CHAPTER TWO
LITERATURE REVIEW

2.1 Distribution of savanna ecosystems

Tropical savannas are the dominant rangeland ecosystem in equatorial region (Kauffman and Pyke, 2001). Tropical savanna covers nearly a third of the world's land surface, over 50% of Africa and Australia and approximately 45% of South America. In India and South East Asia, tropical savanna covers approximately 10% (Gottsberger and Silberbauer-Gottsberger, 2009; Macedo, 1997) while in South America, savanna occur in Brazil, Colombia and Venezuela and cover approximately 2.5 million square kilometers. Additionally, savannas dominate the Northern part of Australia, and they cover almost a half of the sub-Saharan Africa. In Africa, tropical savannas are distributes across West Africa, Central Africa, Southern Africa and East African region and are found in two distinct types namely the moist-dystrophic and the arid-eutrophic (Du Toit and Cumming, 1999; Huntley *et al.*, 1982).

The nutrient-rich arid-eutrophic savannas predominate the East Africa especially Tanzania and Kenyan landscape (Huntley *et al.*, 1982). These savannas are conspicuous and include the Serengeti plains in Tanzania and the Mara ecosystem and Laikipia plateau in Kenya. In Kenya; savannas cover about three quarters of the total land surface (Western, 1989) thus become an important ecosystem. Laikipia plateau is among the Kenya's arid-eutrophic savanna rangelands with heterogeneous land uses; some integrating wildlife and livestock in fenced ranches, unfenced ranches, transitional lands and open pastoral community grazing areas. Dystrophic savannas dominate the Southern and Western Africa and are characterized by nutrient poor vegetation thus low carrying capacity (Huntley *et al.*, 1982; Kruska *et al.*, 2003).

2.2 Characteristics of tropical savannas

The tropical savanna biome includes those ecosystems that are characterized by continuous grass layer, non-graminoid herbaceous plants and tree occurring together in varying densities under a climatic regime of distinct wet and dry seasons. Vegetation is largely comprised of widely scattered thorny trees and grasses. Trees are spaced widely because of insufficiency of soil moisture especially during the dry season to support a full tree cover (Strahler, 2013). Trees in the tropical savanna ecosystems are of medium height, with either flattened or umbrella-shaped crowns, and with trunks having thick and rough bark. Grasses turn green and grow tall during the wet season and leaves develop on trees. During the dry season, grasses wither and turn brown while trees shed their leaves (Arbogast, 2011). These ecosystems are rich in biodiversity and very prone to disturbance resulting from heavy grazing and browsing, and fires especially during dry season. There is also a high diversity of large grazing mammals which attract a variety of predators in African savanna (Strahler, 2013). Average annual precipitation is from 9 cm to 150 cm and average monthly temperatures is greater than 18°C (Arbogast, 2011). Tropical savannas are classified as either broad-leafed/moist-dystrophic or fine-leafed/arid-eutrophic savanna (Du Toit and Cumming, 1999; Walker and NoyMeir, 1982; Walter, 1971).

2.3 Importance of tropical savannas

Tropical savannas provide a wide range of ecological, biological, social-economic and cultural goods and services. They act as habitat for wildlife and soil life; most wildlife is found on natural grazing lands and includes big game, small mammals, upland game birds and predators (Williams *et al.*, 1968). Tropical savanna rangelands have high species diversity compared to other rangelands and act as home to significant concentrations of large mammals and plants with a high value in ecological, leisure and scientific terms to human populations (Blench and Sommer, 1999; Solbrig *et al.*, 1996). Soils of well managed natural grazing land serve as prime habitat for countless unseen microorganisms such as bacteria, fungi, algae, protozoa and also shelter beneficial insects, earthworms and various burrowing animals.

Tropical savannas also serve as watersheds that receive precipitation which eventually drain into rivers and small streams or sink into the soil to replenish springs and ground-water reservoirs thus influencing water cycling (Hill *et al.*, 2010; Solbrig *et al.*, 1996). A healthy cover of natural vegetation provides an effective cover for soil and water conservation, the vegetation contribute significantly to primary production, carbon sequestration and cycling (Hill *et al.*, 2010; Rosen, 2000). It is estimated that savanna ecosystems store an above ground carbon stock of between 1.8 t C^{-1} in areas where trees are absent to 30 t C^{-1} in areas with substantial tree cover (Grace *et al.*, 2006). Tropical savanna rangelands are a source of food and proteins for the human population. This is as a result of these ecosystems supporting huge proportion of meat producing domestic animals for instance cattle, goats and camel which predominantly form the basic source of proteins to human beings (Williams *et al.*, 1968). Tropical savannas are also a source of fuel and low value commercial timber and building materials for the human population inhabiting this ecosystem especially in the developing countries. Other importances of tropical savannas include provision of medicine and industrial compounds which originate from natural vegetation including: nuts, seeds, turpentine, rubber, quinine and poisons for control of insects and parasites. Tropical savannas have also been found to possess minerals and building materials which are largely used by man in various industrial processing; for instance limestone, uranium, granite and phosphorous (Williams *et al.*, 1968). Additionally, these ecosystems are important for recreation, research and education.

2.4 Land-use types in tropical savannas

Over the years; mankind has used the savannas differently throughout the world. Savannas have been used for wildlife conservation, pastoralism, small scale and large scale crop farming and subsistence mixed farming among other land uses. This has led to massive conversion of rangelands of the world. Approximately 19.1% of the savannas in Africa have been converted into cropland while 0.4% have been converted into urban centres (Rosen, 2000).

2.4.1 Wildlife conservation

African savanna boost of rich wildlife abundance and diversity. A high diversity of indigenous mammals (>5kg) is a natural feature of African savannas (Huntley *et al.*, 1982; Huxley, 1961). This high diversity is broadly attributed to the spatial heterogeneity inherent in the savanna biome. However, this wildlife assemblage is either in protected areas or outside protected areas. In Kenya, savanna rangelands cover over 75% and all except a small proportion of the large herbivore populations (Western *et al.*, 2009). In Laikipia, private wildlife conservation enterprises appear to have been remarkably successful. Laikipia harbour high diversity of large mammals than Serengeti National park in Tanzania and Kruger National park in South Africa which are among the most famous protected areas in Africa (Sundaresan and Riginos, 2010). Laikipia is also second in wildlife abundance after the Mara-Serengeti ecosystem despite only 2.1% of the land in privately fenced reserves being set aside exclusively for wildlife conservation, otherwise wildlife share the largely unfenced landscape with livestock (Georgiadis *et al.*, 2007). Wildlife conservation in Laikipia takes two approaches. Firstly is the wildlife conservation in the pro-wildlife ranches where a total of 29 ranches in Laikipia are managed in favour of wildlife conservation (LWF, 2012). The ranches are privately owned by individuals who have leased them from the government. These ranches are owned and managed by people who feel there is an intrinsic value in wildlife conservation (Sundaresan and Riginos, 2010), livestock is also kept in these properties in most cases. Secondly, wildlife conservation is passively practiced in the community group ranches (pastoral areas) that are managed as a collective resource. These areas are occupied by large numbers of families from local community and their livestock and wildlife wander freely in these pastoral areas (LWF, 2012).

2.4.2 Pastoralism and ranching

Livestock was introduced in Africa about 7000-8000 years ago from the Arabian Peninsula (Du Toit and Cumming, 1999) and then spread across the Sahelian zone in West Africa about 6000 years ago and to South Africa about 2000 years ago. Livestock now dominates the ungulate biomass in Africa with indigenous wild ungulates now contributing less than 10% (Cumming, 1982). Pastoralism has been for many years the traditional land use in the Arid and Semi-Arid Lands (ASAL) zones of Kenya. ASAL comprise over 75% of the Kenya's land mass and accommodates around 28% of the total human population (Aligula *et al.*, 1998). Livestock products have been the primary source of food for these pastoral populations; however, due to the steady increase in population of the pastoral communities, livestock has been unable to meet their food requirements forcing them to transform their land use to the direction of agro-pastoralism (Aligula *et al.*, 1998). In Laikipia, pastoralism is predominant in the Northern region in the communally owned group ranches within Mukogodo and some privately owned small holdings. About 45% of Laikipia land mass (3118km^2) is under informal grazing by the semi-nomadic pastoralists (LWF, 2012). In 1994; the ratio of livestock to wildlife in Laikipia was approximately 4:1 and this rose to 11:1 in 2003. There are 48 large-scale ranches in Laikipia that are greater than 2000 acres covering approximately 39% of the total land mass, with exception of only two; all ranches are used for commercial livestock production with 16 of these engaging in some form of wildlife based enterprises.

2.4.3 Agro-pastoralism and mixed farming

Agro-pastoralism and mixed farming are dominant land use types in the world; mixed farming occupy slightly more than 30% while agro-pastoralism and pastoralism occupy slightly above 46% of the global land area (Robinson *et al.*, 2011). In sub-Saharan Africa; agro-pastoralism and pastoralism occupy approximately 38% while mixed farming occupies nearly 28%. In east Africa; 5.5 million square kilometres of land are under agro-pastoralism and pastoralism while 1.7 million square kilometres are under mixed farming (Fig. 2.1).

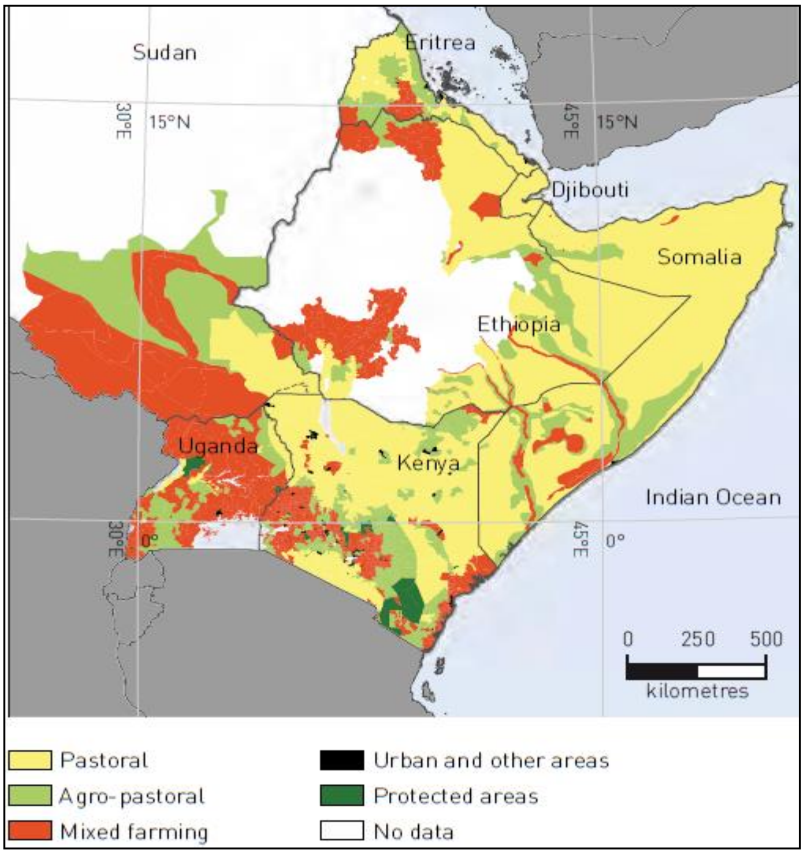


Figure 2.1: Distribution of livestock production systems land-use in Eastern Africa in 2010

Source: (Robinson et al., 2011)

In Laikipia, agro-pastoralism and mixed farming is widely practiced in the transitional properties where land parcels range from 1-10 ha; and the land tenure is freehold. Approximately 2103km^2 is under small-scale and commercial agriculture. This include rain-fed cultivation, irrigated cultivation along the permanent rivers combined with some subsistence livestock production especially in the marginal areas of settled smallholders (LWF, 2012). Varying levels of transitioning occur across vast parcels which are often grazed by livestock. Diverse wildlife species also occur in the transitional properties at varying densities (Georgiadis *et al.*, 2007).

2.5 Ecological interactions between wild and domestic ungulates

2.5.1 Competition

Competition is an ecological process which occurs between two or more individuals of same species or different species which vie or seek to exploit a common resource which is in short supply thus resulting to one individual or species being adversely affected. In order for competition to occur, three conditions must be fulfilled; they include resources sharing by populations of the different species, these resources must be limited, and finally the joint exploitation of those resources and/or interference interactions related to the resources must negatively affect the performance of either or both species (Butt and Turner, 2012). Competition can be through interference or exploitation. Interference occurs when resources are denied to individuals aggressively by other individuals while exploitation occur when limiting resources become scarcer as in the case of grazing (Butt and Turner, 2012). Competition over shared resources has been shown to occur in African savannas particularly in Laikipia between livestock and different wild ungulate guilds that are morphologically similar especially during dry season (Odadi *et al.*, 2011; Prins *et al.*, 2000). Odadi *et al* (2011) observed that cattle had depressed weight during dry season when they shared foraging area with wild ungulates which is an indication of competition.

2.5.2 Facilitation

Facilitation is said to occur when use of a resource by an animal or a group of animals increases the availability of resources for another animal or a group of animals (Gordon, 1988). Numerous studies have shown that different ungulate groups have the grazing facilitation effect on each other. Cattle through their non-selective grazing have been found to alter the structure and composition of vegetation which in return maintains vegetation diversity which is preferred by the Red deer (Gordon, 1988). It was observed that areas which were grazed by cattle in winter contained a significantly higher standing crop of green matter which is preferred by the Red deer. An increase in the calf: hind ratio in areas grazed by cattle than in areas not grazed by cattle has also been observed. Also, the stags body weight was found to be higher in plots where cattle had grazed during winter than in plots which had not been grazed (Gordon, 1988). In a study done in Laikipia, cattle exhibited increased performance in shared foraging areas during the wet season (facilitation) and depressed body weight in shared foraging areas during dry season (competition) (Odadi *et al.*, 2011).

2.5.3 Diseases and parasites transmission

Studies have shown that contacts between livestock and wildlife can be quite common, especially when livestock herds are unguarded or close to forested and/or protected areas. Wild ungulates such as buffaloes and warthogs are natural hosts of ticks which are vector for various diseases which are transmitted to livestock (Maleko *et al.*, 2012). Wild ungulates are revealed to be carrier of most of the diseases that are fatal to livestock for instance; east coast fever (ECF). Though there might be some physical displacement existing between wild ungulates and livestock; this displacement might not preclude disease-relevant interactions (zu Dohna *et al.*, 2013).

2.6 Wild ungulates community attributes

2.6.1 Wild ungulates abundance

Abundance is a key parameter in understanding wildlife population dynamics. It is used by managers and other stakeholders for effective and sustainable management and conservation of wildlife populations (Milner-Gulland and Rowcliffe, 2007). Studies show that wildlife population has been on a decline globally. Among mammals which population trends are known, more than 50% of species are declining (Schipper *et al.*, 2008). The abundance of large mammals declined by 59% between 1970 and 2005 in Africa's PAs with a decline of 52% in Eastern Africa (Craigie *et al.*, 2010). Ungulates generally dominate these large mammal population assemblages.

In Kenya, most wild ungulates whose comparable long-term data has been available shows decline between 1977-1997 (Ottichilo *et al.*, 2000). In this study, the total non-migratory wildlife population in the Kenya's Serengeti-Mara Ecosystem declined by 58%. Giraffe, Topi, Buffalo, and Warthog decreased by 73-88%. Waterbuck, Thomson's gazelle, Kongoni, Grant's gazelle, and Eland reduced by 60%, however; Impala, Elephant and Ostrich showed no decline (Ottichilo *et al.*, 2000). Laikipia is known for its high abundances of mammals than any other protected or unprotected landscape in Kenya (LWF, 2012). Laikipia contains half of the Kenya's black rhino population (*Diceros bicornis*) and the second largest population of African elephant (*Loxodonta africana*), besides Laikipia and Samburu act as home for over 80% of the world's remaining Grevy's zebra (*Equus grevyi*) population and Laikipia alone contains over two thirds of world population of reticulated giraffe (*Giraffa camelopardalis reticulata*).

2.6.2 Wild ungulates species diversity

Species diversity is related to the probability of interspecific encounters (Patil and Taillie, 1982), it is a measure of the number of component species and their abundance at a specified point in time (Rosenzweig, 1995). Species diversity is a characteristic unique to the specific community level and it expresses the community structure (Brower *et al.*, 1990). A community has a high species diversity if many equally or nearly equally abundant species are present. On a given resource gradient for instance light intensity, prey size and forage materials; species evolve to use different parts of the gradient in attempt to reduce competition (Whittaker, 1972). He referred to the extent of differentiation of communities along a habitat gradient as beta diversity (β-diversity). The diversity of communities depend on non-extreme conditions, stable conditions, evolutional and successional time and the kind of community development over time (Whittaker, 1972).

African savannas carry the earth's greatest diversity of ungulates and has sustained multispecies animal production for a long time (Du Toit and Cumming, 1999). High diversity of indigenous large mammals (>5kg) is a natural feature of African savannas (Huntley *et al.*, 1982; Huxley, 1961). Extant ungulates endemic to African savanna biome numbers to 46 species of which about 80% belong to one family along the Bovidae (Du Toit and Cumming, 1999). The distribution of ungulates diversity in Africa is clearly associated with the distribution of savanna biome with a particular concentration of species in the topographically diverse Rift valley region in the East African savanna (Turpie and Crowe, 1994). The high ungulates diversity in African savanna is linked directly to the spatial heterogeneity inherent in the savanna biome. At a finer scale (ungulate habitats), marked seasonality and spatial variation in plants, available moisture and soil nutrients create patchiness in the quality and quantity of savanna vegetation (Bell, 1986). Laikipia has high species diversity. There are around 95 mammal species, 540 bird species, 87 species of amphibians and reptiles, around 1000 species of invertebrate and approximately 700 plant species (LWF, 2012). This makes Laikipia one of the most important conservation areas in East Africa.

2.6.3 Wild ungulates distribution

Large numbers of vertebrates and invertebrates including a diverse combination of native and domestic ungulates occur in the tropical savanna ecosystems as well as the polar regions (Kauffman and Pyke, 2001). Wild ungulates are either uniformly or randomly distributed, or clumped in an ecosystem or a habitat depending on resources availability or other biological factors like competition (Brower *et al.*, 1990). Accurate distribution of ungulates over time and space may help managers regulate densities and understand effects of specific ungulates on ecosystem process (Coe *et al.*, 2004). Seasonal distribution of both domestic and wild ungulates may be influenced by vegetation composition, topography and distance to water source (Peek and Krausman, 1996). Ungulates have also been found to distribute themselves in response to disturbance for example: traffic, hunting and logging (Johnson *et al.*, 2005; Pederson *et al.*, 1980; Rowland *et al.*, 2000) and presence of inter- and intraspecific influence from animals (Bowyer *et al.*, 1997).

Wild ungulates for instance the pronghorn (*Antilocapra americana*), elk (*Cervus elaphus*) and deer (*Odocoileus spp*.) are the most widely distributed in North America. In the Arctic, the dominant native ungulates include Caribou (*Rangifer tarandus*) and Musk ox (*Ovibos maschatos*). A few native ungulates occur in small herds in Northern Asia and include: gazelle (*Procarpa* or *Gazella spp*.), Wild horse (*Equus przewalskii*) and Bactrian camel (*Camelus bactrianus*), Southern Asia is more diverse in native ungulates. In Australian grasslands, large grazing animals are represented by marsupials (euros and kangaroos, *Macropus spp*.; wallabies, *Petrogale spp.*) (Kauffman and Pyke, 2001). In Africa, wild ungulates consist of three taxonomic orders. They include the proboscidea (African elephant), perrisodactyla (rhinos and zebras) and the artiodactyla which comprises five families namely: suidae, hippopotamidae, tragulidae, giraffidae and bovidae (Kauffman and Pyke, 2001). These wild ungulates are distributed in grasslands, savannas, woodlands, riverine and wetlands.

In Kenya, savanna rangelands are approximately three quarters of total land mass (Western *et al.*, 2009) and they are home to a large proportion of wild ungulates. Over 70% of Kenya's wildlife occurs outside protected areas (Aligula *et al.*, 1998) where wildlife has to compete for resources. For many years, pastoralism has been the traditional land-use activity in the savanna rangelands due to the fact that livestock products form the primary source of food for the increasing pastoral population (Aligula *et al.*, 1998). Livestock, particularly cattle has been shown to competitively utilize forage resources that are also utilized by other wild ungulates. In a study by Riginos *et al* (2012) in Laikipia, it was found that cattle suppress a broad spectrum of wild herbivore species presumably through competition for shared forage resources. Cattle diet has also been observed to constitute up to 15% forbs implying that they not only competitively suppress grazers but also mixed feeders (Odadi *et al.*, 2007).

2.7 Effects of livestock on wild ungulates population attributes

2.7.1 Effects on abundance

One of the proximate drivers of ungulate population decline is habitat loss and degradation by changes inside the PAs through encroachment by livestock (Scholte, 2011). Though controversial; competition over natural resources between domestic livestock and wildlife has been broadly discussed (Butt and Turner, 2012). Some studies have suggested or implied that domestic livestock compete with wildlife (Averbeck *et al.*, 2009; Low *et al.*, 2009; Voeten and Prins, 1999; Young *et al.*, 2005). Other researchers have argued that livestock facilitate wildlife (Gordon, 1988) while (Homewood *et al.*, 2001; Sitters *et al.*, 2009) proposes that livestock coexist with wildlife without competition. Another school of thought states that livestock both facilitate and compete with wildlife depending on season (Odadi *et al.*, 2011). Habitat and diet overlap has been cited as the primary mechanism by which competition occurs (Beck and Peek, 2005). Wildlife-livestock competition therefore raises basic ecological and evolutionary issues of reduced fitness, competitive exclusion and population decline (Odadi *et al.*, 2011; Ogutu *et al.*, 2011; Stewart *et al.*, 2002). Increased livestock stocking rates in the Kenya's rangelands has been blamed for the decline in wildlife resources (Aligula *et al.*, 1998).

Cattle presence has been shown to suppress the presence of zebra and other wild ungulates. In a study conducted in a savanna ecosystem in the Laikipia rangeland; it was shown that exclusion of cattle led to between 44% - 79% increase in zebra presence depending on whether megaherbivores (elephants and giraffes) were excluded (Young *et al.*, 2005). In addition, cattle also suppressed a broad spectrum of other wild herbivores including Grant's gazelle, elands, and the oryx presumably through competition for shared forage resources (Riginos *et al.*, 2012). A study carried out in Maasai Mara National Reserve analyzed population trend data of seven ungulate species between 1989-2003; it was observed that the overall abundance of four resident grazers declined due to competition from livestock alongside other factors (Ogutu *et al.*, 2009). A decline in giraffe numbers was also observed and was associated with the disturbance and displacement of wildlife by illegal livestock grazing. The displacement of giraffes which are purely browsers and thus have minimal dietary overlap with domestic grazers is an indication that the mechanism through which livestock affects wildlife abundance extends beyond competition for forage resources.

2.7.2 Effects on species diversity

Grazing livestock in the rangelands cause removal and replacement of wild grazers due to the combined effects depending on: extent of rangeland grazed by livestock, grazing intensity, native vegetation type and land management (Alkemade *et al.*, 2013). Livestock grazing has been found to have profound impact on the Mean Species Abundance (MSA) of native species assemblages in the savannas. Assuming 1 to be the highest possible value of MSA; five categories of varying grazing intensities showed a value statistically significant below the highest possible value of 1. MSA values decreased with increased grazing intensity from 0.6 in moderately used rangelands to 0.3 in man-made grasslands (Alkemade *et al.*, 2013).

Wildlife habitats have been impacted on in various ways by livestock grazing. Trampling and alteration of plant composition and structure are directly linked to qualities of wildlife habitats. As much as livestock grazing can affect vegetation characteristics, it will also affect wildlife habitat structure and productivity (Krausman *et al.*, 2009). Substantial annual consumption of herbaceous vegetation in native rangeland settings that leaves only remnant covers is detrimental to many wildlife species. Krausman *et al* (2009) observed that livestock grazing is detrimental to songbirds' diversity and the bull trout (*Salvelinos confluentus*) in the riparian areas. In a study in Pannsylvania; grazing exclosures were erected as wildlife habitat enhancement projects along riparian areas which had continuously been grazed and it was found that within 1-2 years of rest, the small mammals abundance and species diversity had approximately doubled (Krausman *et al.*, 2009). This observation was attributed to enhanced combination of food and cover depending on particular species of small mammals.

2.7.3 Effects on spatial relationship

Different wild ungulates species exhibit varying spatial relationship in presence of livestock. Wild ungulate species which are ecologically and morphologically similar to domestic ungulates in terms of body mass and diet are supposed to be more sensitive to resources depletion by livestock and would be separated to a larger extent (Hibert *et al.*, 2010). This separation could be attributed to competition arising from resources depletion by livestock. In a study in "W" Regional Park in West Africa; various wild ungulate species exhibited different spatial relationship with cattle at different scales of distance. Buffaloes were observed to be significantly separated from herds of cattle at a large scale (> 10km). Defassa waterbuck and Hartebeest also tended to separate from cattle at large scale too. Smaller grazers like Buffon's Kob and Bohor reedbuck were observed to have significant separation from cattle at smaller scale (< 10km). Elephants showed significant separation at larger scale of between 12km-14.5 km. Browsing ungulates like Bushback and Grey duiker showed significant aggregation with cattle at small scales and large scale respectively (Hibert *et al.*, 2010).

2.8 Forage assessment (using NDVI as a proxy for primary productivity)

Normalized Difference Vegetation Index (NDVI) has been used to indicate and describe the greenness (relative density and health of vegetation) for each pixel in a satellite image by measuring reflectance from the visible region of the electromagnetic spectrum; particularly the red and the near-infrared region (Myneni *et al.*, 1995). Healthy vegetation absorbs most of the visible light (red) reaching it and reflects most of the near-infrared light while unhealthy or sparse vegetation reflects more visible light (red) and less near-infrared light thus being a good indicator and predictor of vegetation productivity (Pettorelli *et al.*, 2011). The NDVI values range from -1.0 to +1.0 and the higher the value the more green or healthy the vegetation is. Areas of barren land, sand or snow usually show very low NDVI value while sparse vegetation such as shrubs, grasslands or senescing crops show moderate values, high NDVI values correspond to dense vegetation (Pettorelli *et al.*, 2011). NDVI is defined by the equation: $NDVI = NIR - R/NIR + R$, where NIR and R is the reflectance at near infrared and the red region of the electromagnetic spectrum respectively (Gao *et al.*, 2000; Myneni *et al.*, 1995). However, the use of NDVI as a proxy for vegetation productivity faces the challenge of NDVI values saturation in high biomass conditions, and also NDVI is insensitive to changes in understory vegetation under closed canopy (Gao *et al.*, 2000; Sellers, 1985).

2.9 Wildlife conservation and management legal and policy framework in Kenya

Wildlife conservation and management in Kenya is principally guided by Wildlife Conservation and Management Act 1976; chapter 376 alongside other relevant laws. Section 3 (1) of the Act provides for the establishment of the Kenya Wildlife Service (KWS) while section 3A highlights the various functions of KWS. Section 3A (a) mandates the KWS with formulation of policies regarding the conservation, management and utilization of all types of fauna (with exception of domestic animals) and flora (RoK, 2012). This implies that KWS is therefore in charge of all wildlife in Kenya whether in communal, government or private land. The Act also provides the guidelines for the establishment of national parks, national reserves and local sanctuaries under section 6, 18 and 19 respectively.

2.10 Conceptual framework

Land use types and seasonality are hypothesized to determining how wild ungulates respond in terms of their abundance, distribution, species diversity and spatial relationship (attraction or repulsion) to livestock grazing (Fig.2.2). Land use type and seasonality determines the amount of forage available for both wild and domestic ungulates which in return determines the carrying capacity in the particular land use type. Private ranches practicing wildlife enterprises are expected to have huge quantity of forage that is higher in quality compared to communal grazing area and transitional lands where there is common access to foraging resources thus land tend to be degraded. Seasonal conditions specifically rainfall also determines forage availability across the different land use types. During rainy seasons, there is increased forage production than during dry seasons and this tends to reduce competitive pressure over forage among the ungulate guilds; this may therefore result in high abundance and species diversity of wild ungulates and more random distribution between wild ungulates and livestock. The spatial separation between the domestic and wild ungulate guilds is also expected to reduce across land uses during the rainy season as compared to dry season due to reduced exploitative competition over forage.

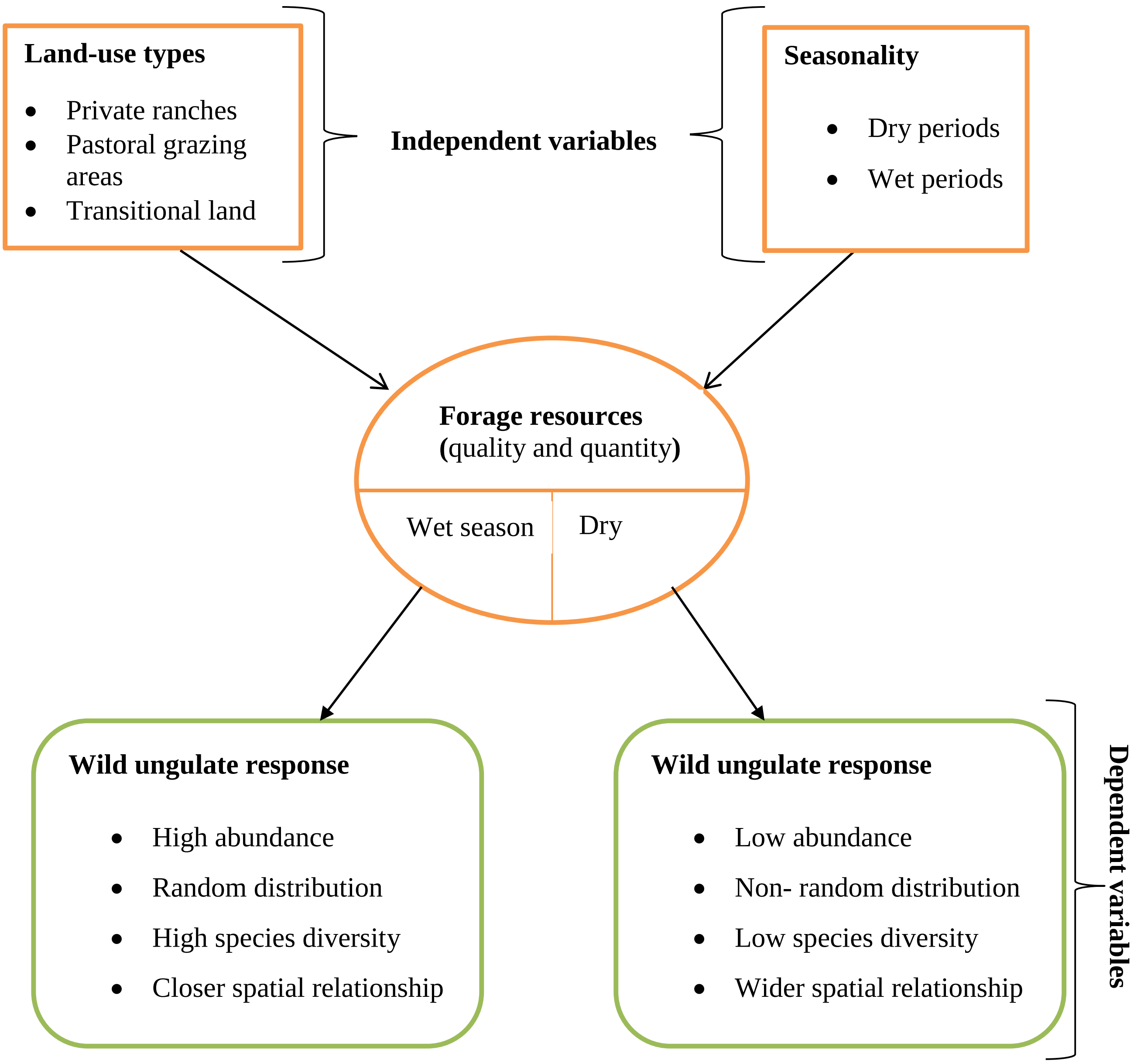


Figure 2.2: Conceptual framework showing independent and dependent variables

CHAPTER THREE
MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location and Size

The study was conducted in the Laikipia savanna ecosystem in Laikipia County (longitude 36˚13'E-37˚23'E and latitude 0˚17'S-0˚52'N) in Kenya (Figure 3.1).

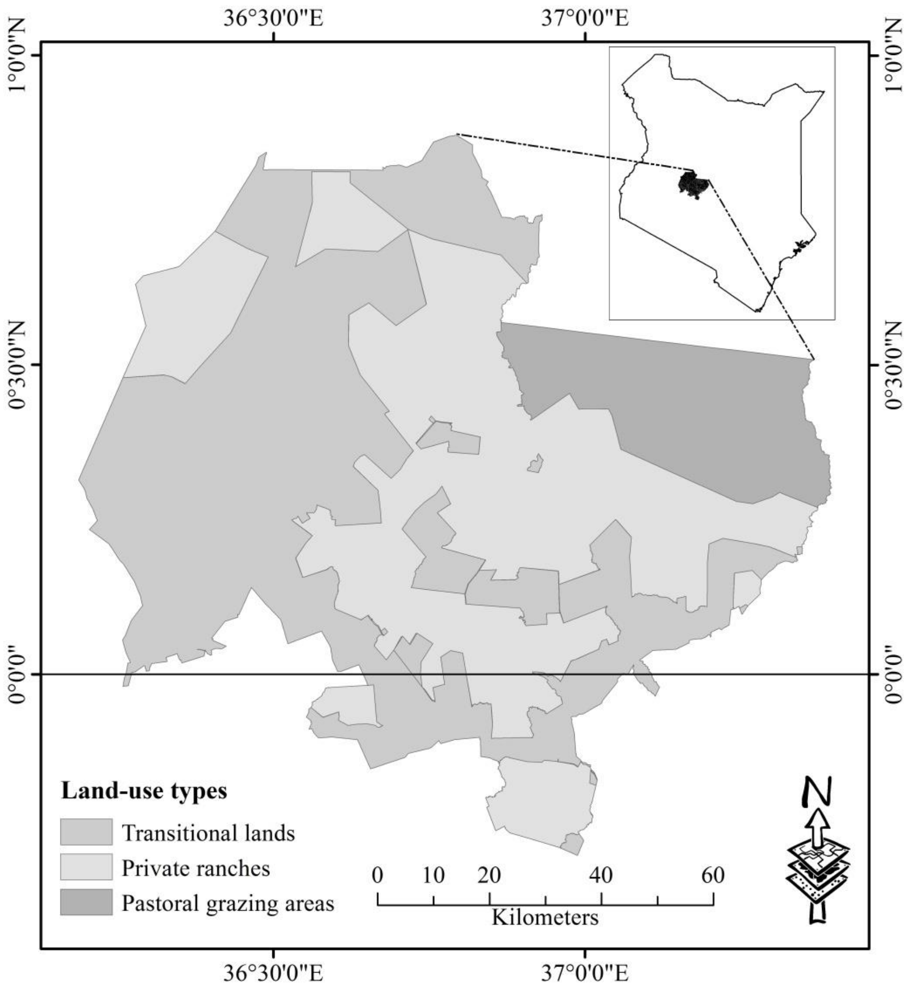


Figure 3.1: A map of Laikipia County showing the three broad land-use types

Source: (*LWF 2012*)

Laikipia County covers approximately 9666km^2. It is located centrally in Kenya with a larger portion of its area falling to the northern of the equator. Laikipia County boarders Samburu to the north, Meru and Isiolo to the east, Nyandarua and Nakuru to the south west, Baringo to the west and Nyeri to the south. To the south-west is part of Aberdare ranges while to the south-east is Mt. Kenya thus creating a climatic gradient in Laikipia savanna rangeland (Georgiadis *et al.*, 2007).

3.1.2 Climate, hydrology and soils

Laikipia vastly lies within the semi-arid agro-ecological zone (Anonymous, 2018). Rainfall is erratic and usually bimodal with long rains being experienced between March and May and short rains between October and December. The mean annual rainfall ranges between 450mm and 750mm (Sundaresan and Riginos, 2010). Laikipia lies between altitudes 1600-2300 meters above sea level and the mean temperatures ranges 17.5˚C with daily amplitude of 1.4˚C but may fall drastically at night (Ojwang, 2000). From Mt. Kenya and the Aberdare are numerous streams which flow through Laikipia plateau and then join to form two perennial rivers: Ewaso N'giro, and Ewaso Narok which flow northward to Samburu (Georgiadis *et al.*, 2007). Natural springs occur in the west and southern region of the county, artificial water-holes are common and wide spread depressions which fill with water during the rainy season (Ojwang, 2000), there are also two major swamps in the study area. Laikipia has varying soil types; dark grey to black clay vertisoils and planosols occur broadly in the plateau. The red brown sandy clay loam luvisoils are found on the foot of Mt. Kenya and north of Abardare. The reddish clay loam and dark brown clay loam phaezoms occur on hills and minor scarps, and low ridges of the plateau respectively.

3.1.3 Vegetation

Laikipia has diverse vegetation type which defines the various habitats. In the grassland and open woodlands; the whistling thorn (*Acacia drepanolobium*), *Acacia mellifera* and *Acacia seyal* and various graminoid species dominate (LWF, 2012). *Acacia* and *Commiphora* woodland is predominant in the dry central and the northern part of Laikipia, *Acacia mellifera* is the dominant species in this habitat type. In the dry upland forest habitat type; African olive (*Olea africana*) and cedar (*Juniperus procera*) dominate. In the evergreen bushland forest, the dominant vegetation type is *Euclea divinorum* with *Akokanthera schimperi* and *Carissa spinosa* also being present. In the west Laikipia and along the escarpments is *Leleshwa* (*Tarconanthus camphoratus*) bushes and the Sand olive (*Dodonaea angustifolia*) especially in the overgrazed areas. The Yellow fever trees (*Acacia xanthophloea*) dominate along the riverines and papyrus dominates in the wetlands (LWF, 2012).

3.1.4 Wild animals

Laikipia harbours higher large mammals' diversity than Serengeti National park in Tanzania or Kruger National park in South Africa (Sundaresan and Riginos, 2010). Laikipia is also home to the second highest abundance of wildlife in East Africa after Mara-Serengeti ecosystem. There is higher wildlife species-richness including 25 ungulate species and numerous carnivores. They include: Plains zebra (*Equus burchelli*), Impala (*Aepyceros melampus*), Dikdik (*Madoqua kirkii*), Grant's gazelle (*Gazella granti*), African elephant (*Loxodonta africana*), Coke's hartebeest (*Alcelaphus buselaphus*), Oryx (*Oryx beisa*), Eland (*Taurotragus oryx*), Giraffe (*Giraffa camelopardalis*), Buffalo (*Syncerus caffer*), Gerenuk (*Litocranius walleri*), and Waterbuck (*Kobus ellipsiprymnus*). Common carnivores are Lion (*Panthera leo*), Cheetah (*Acionyx jubatus*), Leopard (*Panthera pardus*), and Spotted hyena (*Crocuta crocuta*). Laikipia also harbour a number of important threatened animal species including the Black rhino (*Diceros bicornis*), Grevy's zebra (*Equus grevyi*), African wild dog (*Lycaon pictus*), Lion and African elephant (Sundaresan and Riginos, 2010). Laikipia plateau is suitable for a wide range of herbivores from the small sized ungulates to the megaherbivores due to availability of large cover of dry savanna grassland and bushland vegetation type mostly at the lower elevation.

3.1.5 Land ownership and land uses in Laikipia

Land in Laikipia is held under private, communal and government ownership. There are 48 large scale ranches that are greater than 2000 acres in size under private ownership covering 39% of Laikipia. Sub-divided ranches for small holder settlement under varying degree of occupancy cover 34% and eleven communally owned group ranches in the north of Laikipia covering 7% of the land (LWF, 2012). A part of Laikipia is also under government ownership and comprises of National Forest Reserve, large-scale government ranches, veterinary outspans and land bought by the government settlement trust fund and swamps approximated to 1549km^2, the rest is covered by urban centers. Most of the ranches are engaged in commercial livestock production with sixteen of these properties practicing some form of wildlife-based enterprises. Pastoralism is a major economic activity in Laikipia; most of the northern part of Laikipia is dominated by the Maasai community who are majorly nomadic pastoralists with only a few practicing sedentary type of pastoralism. Sundaresan and Riginos (2010) observed that livestock in Laikipia's pastoral areas have grown rapidly over time since independence effectively excluding wildlife from these areas. Agro-pastoralism and small-scale mixed farming is also common in Laikipia especially in the small land holding. The different land tenures in Laikipia have led to a mosaic of land uses in the County.

3.2 Study design and data processing

3.2.1 Laikipia land-use delineation

The study adopted land-use delineation developed by the Laikipia Wildlife Forum (LWF) (2012). The land-use types considered were: Private Ranches (PR), Pastoralists Grazing Areas (PGA) and Transitional Land (TRL). These land-use types were extracted using ArcGIS 10.2 from the Laikipia land-use map developed by LWF (LWF 2012). After delineation of the various livestock-based land use types; livestock and wild ungulates spatial data were then added for analysis.

3.2.2 Distribution, mapping and grouping wild ungulates

The distribution of wild ungulates and livestock groups was mapped using geo-referenced aerial census data obtained from Department of Resource Surveying and Remote Sensing (DRSRS). Only complete census grids and those that 85% and above of their total land mass occurred in a specific land-use type were considered to belong to that land-use type thus used in the analysis. Wild ungulate grouping was done based on feeding habits and body size. Based on body size, wild ungulates were grouped into two i.e. megaherbivores (those whose individuals may weigh over 1000 kg) and include the African elephants (*Loxodonta africana*), rhino (*Diceros bicornis & Ceratotherium simum*) and giraffe (*Giraffa camelopardalis*) (Fritz *et al.*, 2002; Odadi *et al.*, 2011). Medium-sized ungulates comprised wild ungulates weighing above 20 kg (Odadi *et al.*, 2011). They include: burchell's zebra (*Equus burchelli*), grevy's zebra (*Equus grevyi*), thomson's gazelle (*Gazella thomsoni*), grant's gazelle (*Gazella granti*), hartebeest (*Alcelaphus buselaphus*), impala (*Aepyceros melampus*), cape buffalo (*Syncerus caffer*), eland (*Taurotragus oryx*), warthog (*Phacochoerus aethiopicus*), beisa oryx (*Oryx gazella beisa*), greater kudu (*Tragelaphus strepsiceros*), lesser kudu (*Tragelaphus imberbis*), waterbuck (*Kobus ellipsiprymnus*), reedbuck (*Rudanca rudanca*), and gerenuk (*Litocranius walleri*).

Based on feeding, three groups namely: grazers, browsers and mixed-feeders were identified. Grazers referred to wild ungulates which consumed herbaceous plants including grass, grass-like plants and forbs while browsers were those wild ungulates that consumed leaves, twigs or reproductive parts of shrubs, woody-vines or trees (Kauffman and Pyke, 2001). The grazers comprised of: Burchell's zebra (*Equus burchelli*), Grevy's zebra (*Equus grevyi*), Thomson's gazelle (*Gazella thomsoni*), Grant's gazelle (*Gazella granti*), Coke's hartebeest (*Alcelaphus buselaphus*), Cape buffalo (*Syncerus caffer)*, Warthog *(Phacochoerus aethiopicus)*, Waterbuck *(Kobus ellipsiprymnus)* and Reedbuck *(Rudanca rudanca)*. The browsers included: Reticulated giraffe *(Giraffa camelopardalis reticulata)*, Maasai giraffe *(Giraffa camelopardalis)*, Greater kudu *(Tragelaphus strepsiceros)*, Lesser kudu *(Tragelaphus imberbis)* and Gerenuk *(Litocranius walleri)*. The mixed-feeders comprised of: African elephant (*Loxodonta africana*), Impala (*Aepyceros melampus*), Eland (*Taurotragus oryx*) and Beisa oryx *(Oryx gazella beisa)*.

3.2.3 Data acquisition and processing

Georeferenced Terra MODIS (MOD13Q1) 16-day composite satellite image data with a spatial resolution of 250 meters and AVHRR NDVI data with spatial resolution of 0.05° x 0.05° were downloaded from (https://ladsweb.modaps.eosdis.nasa.gov). This data was used in the computation of mean NDVI for the study area for the months coinciding with when ungulates' aerial surveys were done. This acted as an indicator of forage resource quantity available in the study area during the different seasons. Rainfall data from various gauging stations in Laikipia was obtained from the Kenya Meteorological Department and the daily, monthly and annual rainfall calculated for each survey period. Mean monthly rainfall data was calculated from all gauging stations in Laikipia and this was taken to be the total rainfall for that particular month in the study area.

Wild ungulates and livestock aerial census data was obtained from the Kenya's Department of Resource Survey and Remote Sensing (DRSRS) which has been conducting census for both wild and domestic ungulates using Systematic Reconnaissance Flight (SRF) (Norton-Griffiths, 1978) since 1977. Specifically, this study used aerial census data collected in February 2001, February 2003 and February 2005 (dry period) and June 1997, February 2010 and November 2012 (wet period). These years were found appropriate for use in this study because corresponding Normalized Difference Vegetation Index (NDVI) data was readily available from Terra Moderate Resolution Imaging Spectroradiometer (MODIS) except for June 1997 where Advance Very High Resolution Radiometer (AVHRR) data was used.

3.3 Estimation of ungulates population attributes

3.3.1 Estimation of wild ungulate abundance

Jolly's method 2 (Jolly, 1969) was used to estimate the abundance of wild ungulates and livestock in each census grid. The population estimate (Y) was given by the equation $Y = Z * R$ where: $R = \frac{\sum yi}{\sum zi}$. The quantity yi was the number of animals counted in the i^{th} unit, zi was the size of i^{th} sample unit and Z was the size of the survey area (km^2). Summations of ungulates of the same species within a land-use type formed the abundance of that species in the respective land-use type. This was repeated for all wild ungulate species encountered during the aerial animal census across the three land-use types. Abundance was analyzed at individual species level and at ungulate group level (based on body size and feeding style).

3.3.2 Estimation of wild ungulate species diversity

The population estimated in each census grid was used in calculating species diversity. The Simpson's diversity index was used to estimate species diversity in each census grid (2.5 km x 5 km) and this was considered to be the alpha (α) diversity; the mean species diversity of the various grids within a specific land-use type was considered to be the wild ungulate's diversity in that land-use type ($\bar{\alpha}$-diversity). Wild ungulate diversity was also estimated in totality in the study area and this was taken to be the gamma diversity (γ). Simpson's diversity index was preferred because it not only uses the number of species (s) and the total number of individuals (*N*) but also the proportion of the total that occurs in each species (Brower *et al.*, 1990). This measure is also advantageous in that it does not depend on the log-series or any other abundance distribution (Rosenzweig, 1995). Alpha species diversity (α– diversity) is defined by the equation: $Ds = 1 - l$ where the quantity l is a measure of dominance and is given by equation

$$l = \frac{\Sigma ni(ni - 1)}{N(N - 1)}$$

where: *Ds* is the Simpson's diversity index, *l* is the Simpson's dominance, *ni* is the number of individuals in species *i*, and *N* is the total number of individuals in a census grid.

The rate of change in the wild ungulates diversity (*β*-diversity) was also estimated across different land-use types using the equation:

$$\beta = \frac{\gamma - \bar{\alpha}}{\gamma} = 1 - \frac{\bar{\alpha}}{\gamma}$$

where: γ- diversity is the Simpson's diversity index (*Ds*) for the whole study area and $\bar{\alpha}$- is the mean diversity index within a particular land-use type.

3.3.3 Estimation of cattle - wild ungulates spatial relationships

To assess the wild ungulate-cattle spatial relationship in the study area, the Ripley's bivariate K_{12} function (Lotwick and Silverman, 1982) was used.

$$K_{12}(s) = \frac{1}{\lambda_2} E(N_{2S})$$

$$\lambda_2 = \frac{N_2}{A}$$

Where: N_{2s} = number of Type 2 events within a distance *s* of an arbitrary Type 1 event

λ_2 = is the intensity of the Type 2 events

N_2 = number of groups of Type 2 events

A = unit area occupied by Type 2 individuals

s = distance of Type 2 events from Type 1 events (radius)

The bivariate K_{12} function shows the spatial relationship between individual wild ungulate species or groups and individual domestic ungulates or groups to examine whether the different guilds are segregated, independently distributed or aggregated (Hibert *et al.*, 2010). This function measures the average number of groups located within a distance (*s*) of a randomly chosen domestic ungulate group/herd, divided by the overall density of the wild species' groups. To enable the graphical interpretation of the relationship between specific domestic ungulate groups and wild species groups, the linearized corresponding L_{12} (Lotwick and Silverman, 1982) was used.

$$L_{12} = \sqrt{\frac{K_{12}(s)}{\pi}} - s$$

3.4 Data analysis

Parametric and non-parametric methods of data analysis were used depending on normality of the data of individual ungulate species and the ungulate groups. The data for African elephant, Maasai giraffe, Grevy's zebra, Coke's hartebeest, Impala, Eland, Warthog, Oryx, Waterbuck and browsers was log transformed to attain normality and two-way ANOVA used for analysis. Two-way ANOVA was used for the "balanced" cases while general linear model (GLM) was used for the "un-balanced" cases to examine for interaction effect and main effect of different levels of independent factors (land-use type and seasonality) on wild ungulate abundance, species diversity and spatial relationship among the three land-use systems (private ranches, pastoralists grazing areas and transitional land) and between seasons (wet and dry). Kruskal-Wallis test was used to analyze the data for Thomson's gazelle, megaherbivores, medium-sized ungulates and grazers because normality could not be attained even after log transformation. Interaction effects between levels of independent factors could not be established in Hartebeest, Waterbuck and Gerenuk due to lack of some data; however, the main effects were established.

Tukey's Honest Significance Difference (HSD) and Dunn-Bonferroni approach were used to separate means and median for multiple comparisons where significant interactions or main effect occurred for parametric and non-parametric data respectively. Linear regression analysis was used to examine the relationship between livestock numbers and individual wild ungulates species abundance. Also, it was used to assess the relationship between livestock and different wild ungulate groups, and wild ungulates' diversity in different seasons across the various land use types. Significant differences were accepted at $p < 0.05$

Table 3. 1: Summary of data analysis

Objective	Hypotheses	Measure of parameter	Analysis method
1. To evaluate forage availability across the different land-use types in different seasons.	H_o: Forage availability is the same across the different land-use types and it does not vary between the wet and the dry season.	NDVI analysis	ANOVA
2. To map the spatial distribution of wild ungulates and livestock across different land-use types in different seasons.	H_o: Wild ungulates and livestock are uniformly distributed across the different land use types both in wet and dry season.	Distribution	Descriptive statistics
3. To assess the effects of land-use type on the abundance and species diversity of wild ungulates in different seasons.	H_o: Wild ungulates abundance and diversity is the same across the different land use types during the wet and dry season.	Jolly's method 2 Simpson's diversity index	Two way - ANOVA/ GLM/Kruskal-Wallis Linear regression analysis
4. To assess the effects of land-use type on the spatial relationship between different wild ungulate guilds and cattle herds.	H_o: Wild ungulate guilds and cattle herds are randomly distributed in the different land use types.	Linearized L_{12} function	Ripley's bivariate K_{12} function

CHAPTER FOUR

RESULTS

4.1 Seasonal forage availability across land use types

Forage availability differed across the three land use types during the dry and wet survey periods. During the dry periods (Fig, 4.1), TRL had the highest forage with a mean NDVI value of 0.39 followed by PR with a mean of 0.37. The PGA had the lowest forage with a mean NDVI value of 0.34. However, the difference in the observed NDVI was not statistically significant ($F_{2,\ 2}$ = 2.08, p = 0.325).

PR **TRL** **PGA**

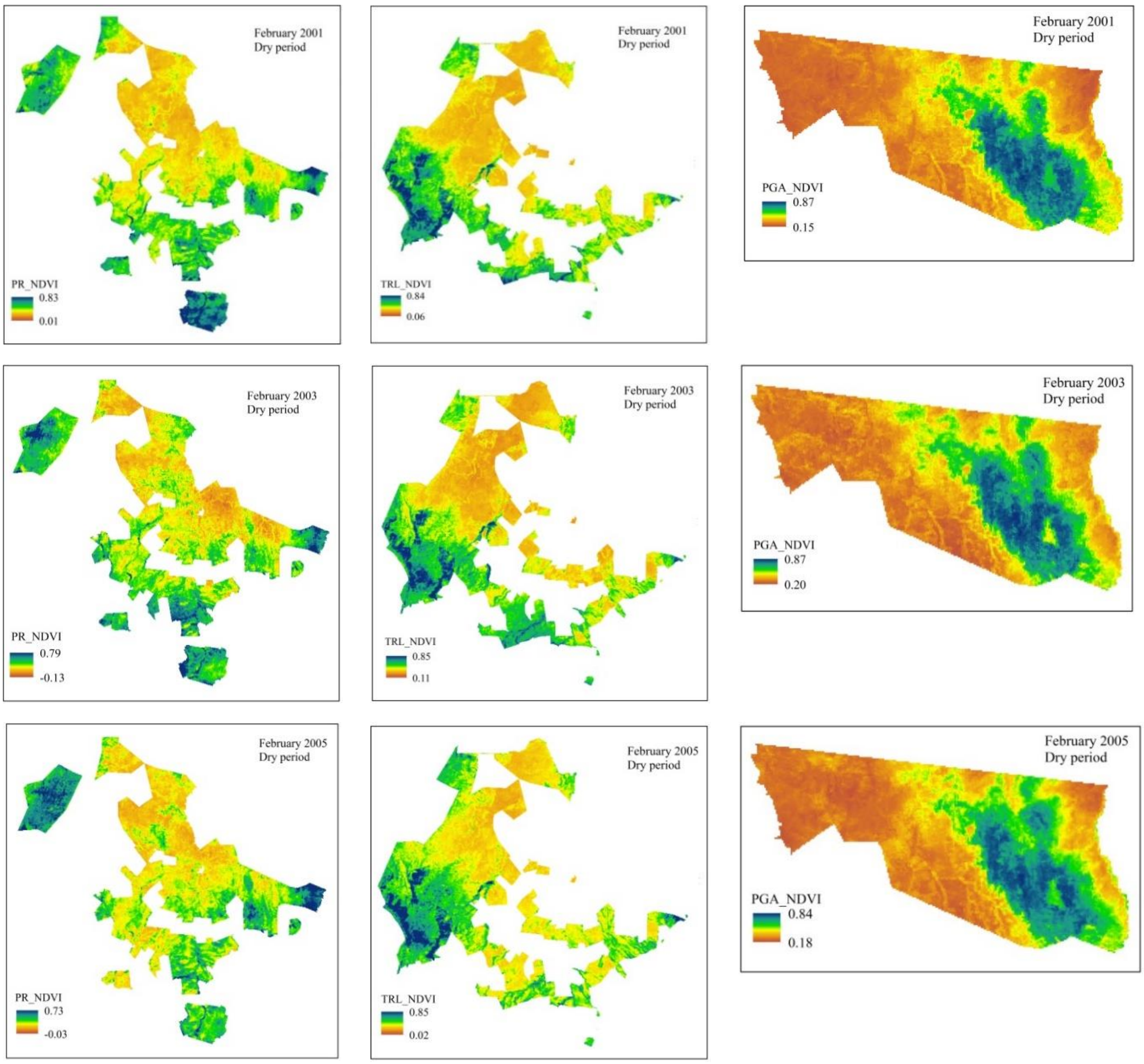


Figure 4.1 Dry period forage availability across different land use types

During wet periods (Fig. 4.2), TRL had higher forage with a mean NDVI value of 0.42 while both the PR and PGA had a mean NDVI value of 0.41. There was no significant difference in the observed NDVI values across land-use types during the wet season ($F_{2, 2} = 2.08$ $p = 0.325$).

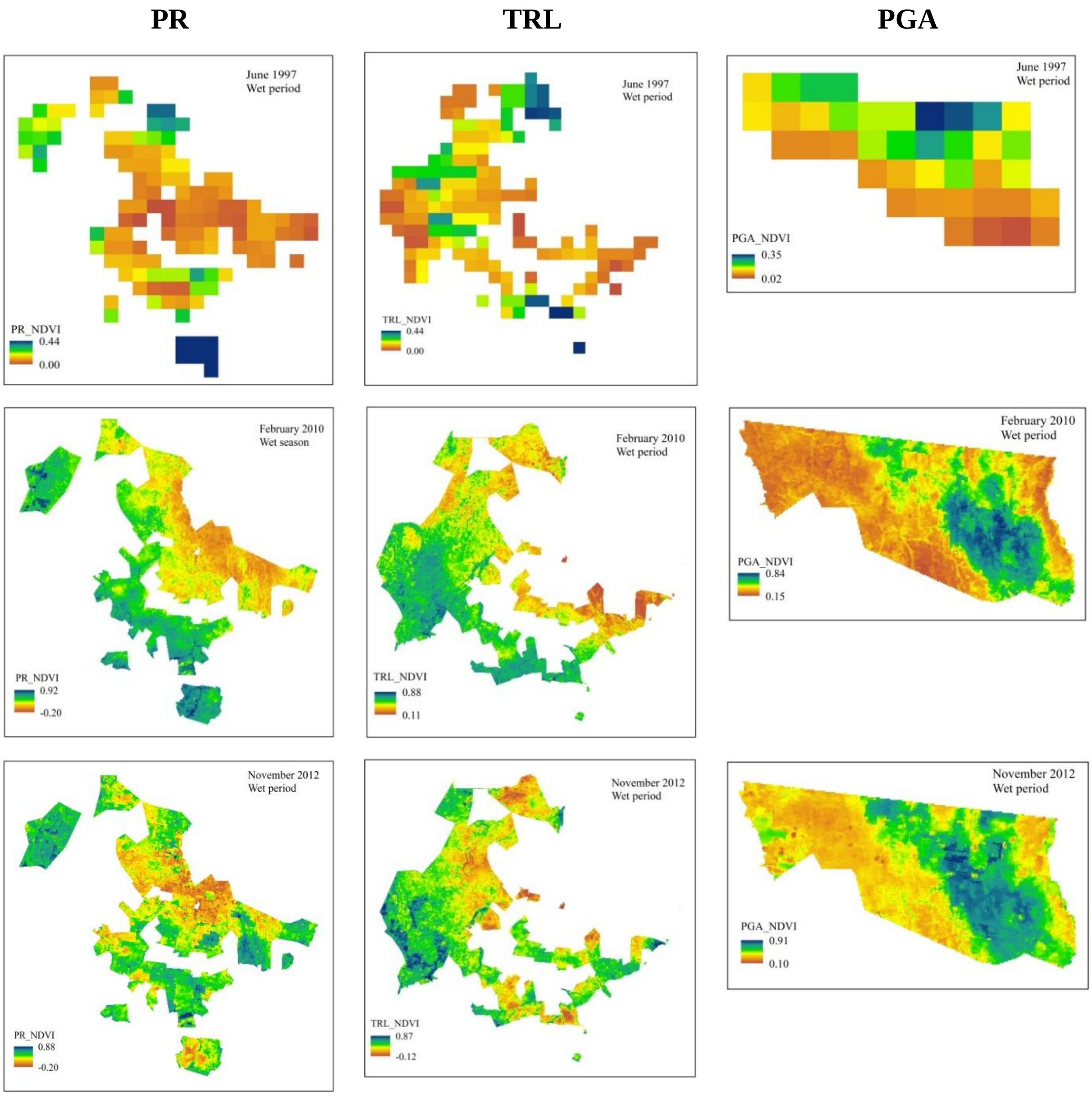


Figure 4.2: Wet period forage availability across different land use types

Forage was higher during wet seasons than in dry seasons. Figure 4.3 shows a graphical representation of seasonal variations in mean NDVI across the three land-use types. Notably, the variation in mean NDVI among the three land-use types was very small during the wet season unlike during the dry season. The difference in NDVI between wet and dry season was not statistically significant ($F_{1, 2} = 15.08$ $p = 0.06$). However, it was near significant.

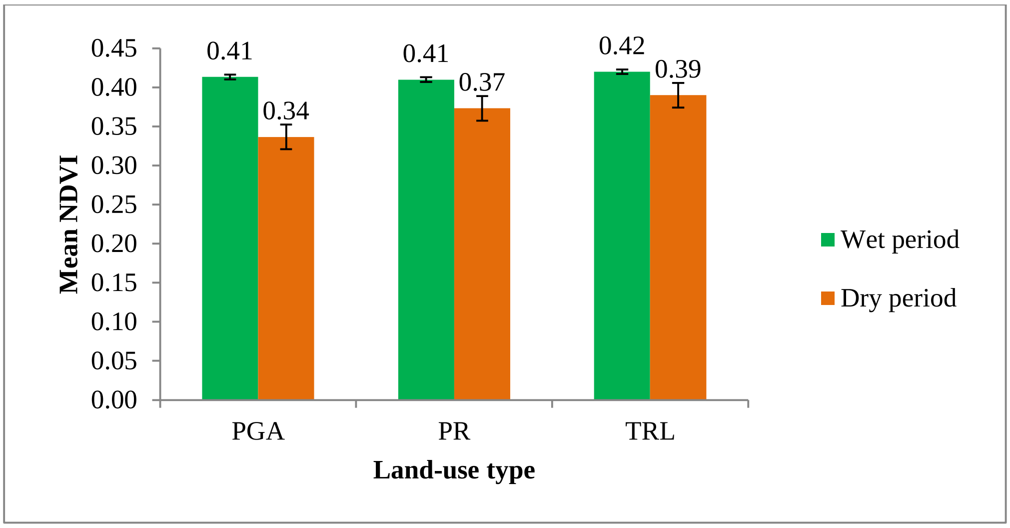


Figure 4.3: Seasonal Normalized Difference Vegetation Index (NDVI) across the three land-use types

4.2 Spatial distribution of wild and domestic ungulates

Out of the total area of Laikipia County (9663 km^2), pastoral grazing areas (PGA), private ranches (PR) and transitional lands (TRL) covered approximately 11.8% (1139.40 km^2), 40.3% (3891.60 km^2) and 47.8% (4618.80 km^2) respectively. In all sampled years, wild ungulates and livestock exhibited different distribution patterns driven by land-use type and seasonality (Figure 4.4 and Figure 4.5).

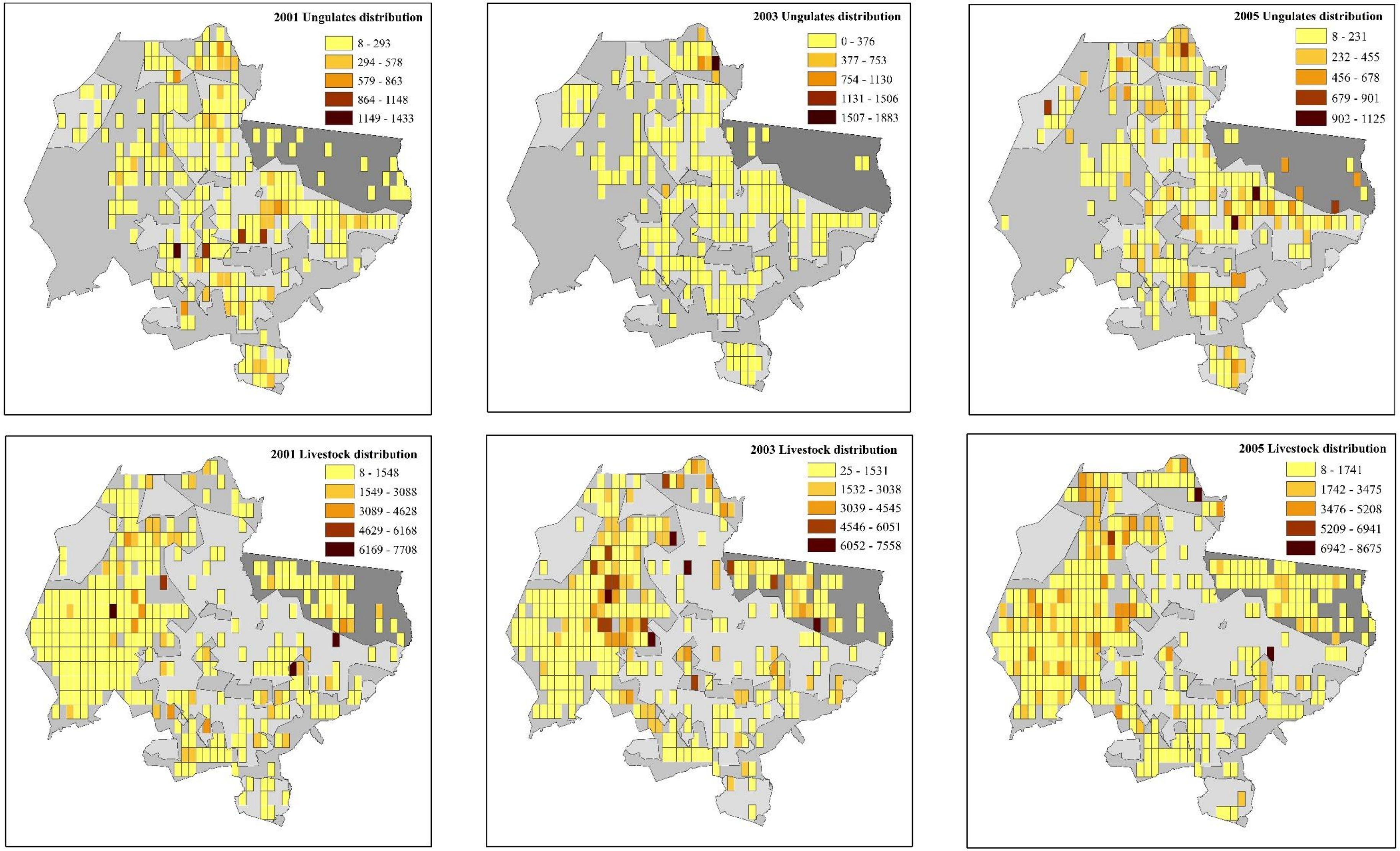


Figure 4.4: Distribution of wild ungulates (above) and livestock (below) in the three different land use types, (pastoral grazing areas, PGA- dark grey), (transitional lands, TRL-grey), and (private ranches, PR-light grey) during dry season census.

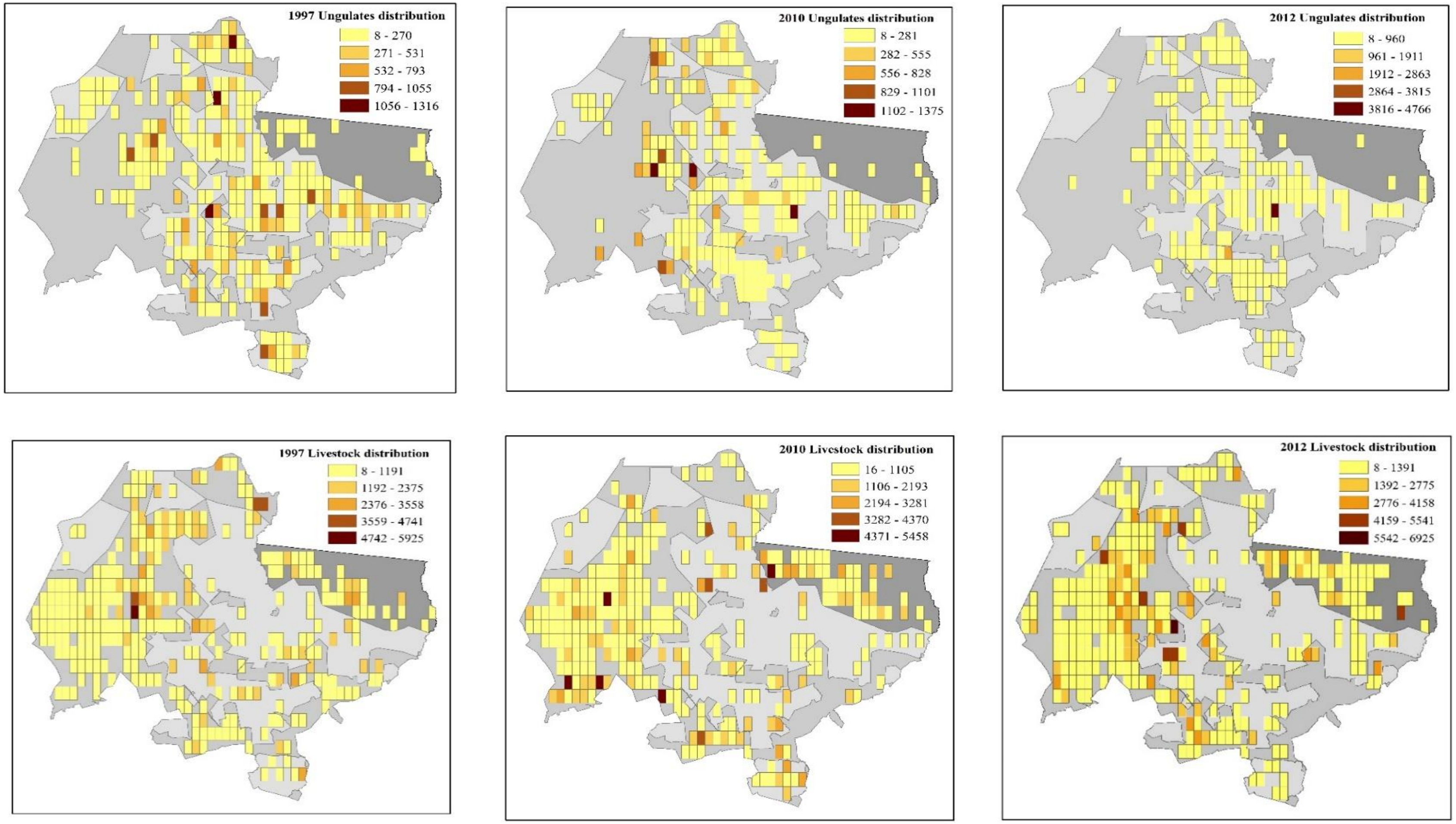


Figure 4.5: Distribution of wild ungulates (above) and livestock (below) in the three different land use types, (pastoral grazing areas, PGA- dark grey), (transitional lands, TRL-grey), and (private ranches, PR-light grey) during wet season census.

Specifically, wild ungulates dominated in PR followed by TRL and finally the PGA. On average, wild ungulates occupied 49.1%, 17.1%, 10.3% of the total land area in the PR, TRL and PGA respectively Table 4.1.

Table 4. 1: Occupancy of different land-use types by wild ungulates

	Wild ungulates					
Land-use type	PGA		PR		TRL	
	Km^2	%	Km^2	%	Km^2	%
Wet season	106.9 ± 33.1	9.4	1820.5 ± 177	46.8	786.5 ± 177	17.0
Dry season	127.6 ± 36.6	11.2	1998.7 ± 31.2	51.4	794.3 ± 83.8	17.2
Overall mean	117.3 ± 10.3	10.3	1909.6 ± 89.1	49.1	790.4 ± 3.9	17.1

Livestock dominated in the TRL and PGA occupying on average 57.5% and 46.1% of the total land area respectively (Table 4.2). Only 18.7% of PR was occupied by livestock (Table 4.2).

Table 4. 2: Occupancy of different land-use types by livestock

	Livestock					
	PGA		PR		TRL	
	Km^2	%	Km^2	%	Km^2	%
Wet season	500.6 ± 40.5	43.9	705.2 ± 16.8	18.1	2470.2 ± 35.9	53.5
Dry season	549.3 ± 77.5	48.2	752.5 ± 45.4	19.3	2838.2 ± 69.8	61.5
Overall mean	524.9 ± 24.4	46.1	728.9 ± 23.6	18.7	2654.2 ± 184	57.5

4.3 Effects of land-uses and season on abundance of individual wild ungulate species

4.3.1 African elephant *(Loxodonta africana)*

Elephants differed significantly in abundance among land-use type. ($F_{2, 12} = 10.52$ $p = 0.002$); they were significantly more abundant in PR than PGA, and TRL (Fig.4.6). However, there was no significant main effect of seasonality on the abundance elephants ($F_{1, 12} = 0.27$ $p = 0.610$).

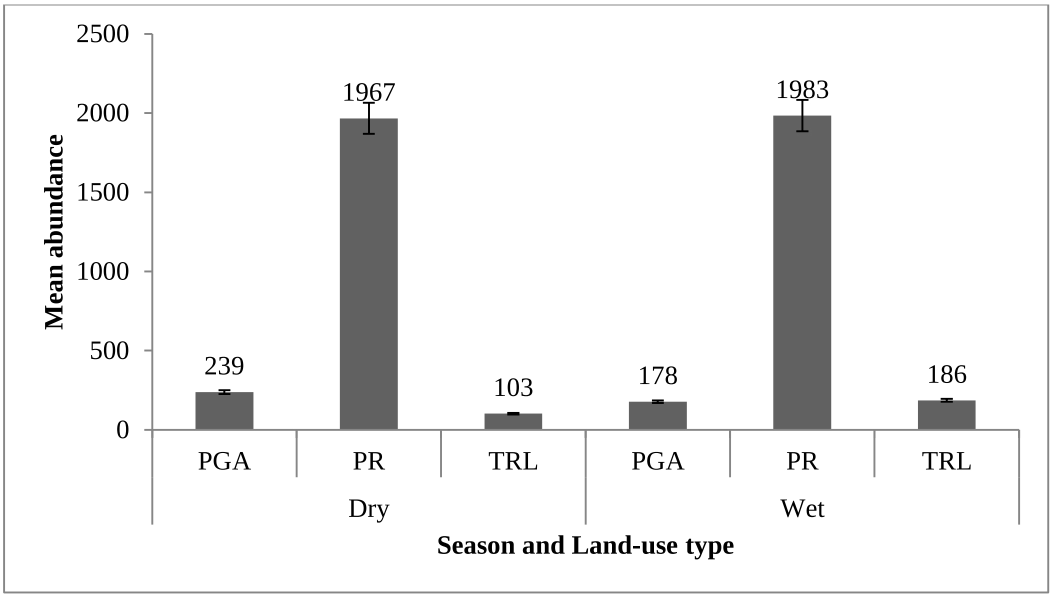


Figure 4.6: African elephant mean abundance across land-use types and between seasons

Additionally, there was a significant positive linear relationship between livestock density and elephant abundance in PR during the wet season (R^2 = 0.99; p = 0.05; Table 4.3)

Table 4. 3: Linear regression model of Livestock-Elephant relationship

Season	Land-use		Sum of Squares	df	Mean Square	F	Sig.
Wet	PGA	Regression	27044.63	1	27044.63	1.64	.42
		Residual	16448.03	1	16448.03		
		Total	43492.67	2			
	PR	Regression	733127.48	1	733127.48	152.19	.05*(+)
		Residual	4817.19	1	4817.19		
		Total	737944.67	2			
	TRL	Regression	9394.28	1	9394.28	.23	.71
		Residual	40309.72	1	40309.72		
		Total	49704.00	2			
Dry	PGA	Regression	30222.75	1	30222.75	.72	.55
		Residual	41969.92	1	41969.92		
		Total	72192.67	2			
	PR	Regression	1699222.03	1	1699222.03	3.66	.31
		Residual	464527.97	1	464527.97		
		Total	2163750.00	2			
	TRL	Regression	4449.83	1	4449.83	6.17	.24
		Residual	720.83	1	720.83		
		Total	5170.67	2			

*(+) significant positive linear relationship (p = 0.05)

4.3.2 Maasai Giraffe *(Giraffa camelopardalis)*

There was a significant interaction effect between seasons and land-use on abundance of Maasai giraffe ($F_{2,\ 9}$ = 6.09 p = 0.021). Specifically, Maasai giraffe abundance was significantly higher in PR during dry season than in TRL both during dry and wet season. Also, they were significantly abundant in PR during wet season than in TRL during wet season. Additionally, they were significantly less abundant in PGA during dry season than in PR during dry and wet season, further, they were significantly less in TRL during dry season than in PR during wet season (Fig.4.7)

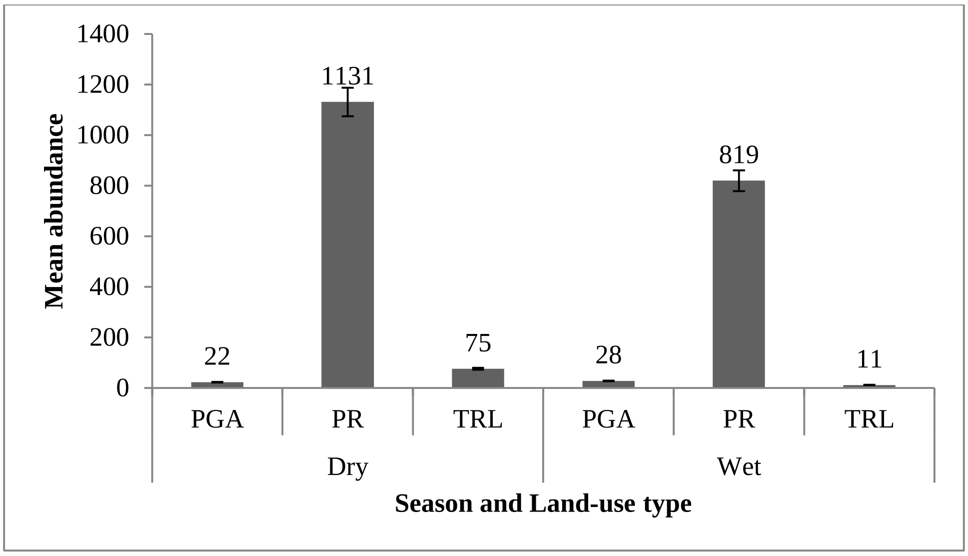


Figure 4.7: Maasai giraffe abundance across land-use types and between seasons

Table 4.4 shows significance levels between different combinations of independent/ interacting factors.

Table 4. 4: Factors interaction showing significance levels

Levels of factors interaction	***P*-value**
Dry PGA less than Dry PR	< 0.005
Dry PGA less than Wet PR	< 0.005
Dry PR greater than Dry TRL	< 0.05
Dry PR greater than Wet TRL	< 0.05
Dry TRL less than Wet PR	< 0.05
Wet PR greater than Wet TRL	< 0.05

Regression analysis showed there was no significant relationship between livestock density and the giraffe abundance in any of the land-use type at any season (Table 4.5)

Table 4. 5: Linear regression model of Livestock-Maasai giraffe relationship

Season	Land-use		Sum of Squares	df	Mean Square	F	Sig.
Wet	PGA	Regression	3223.982	1	3223.982	2.356	.368
		Residual	1368.685	1	1368.685		
		Total	4592.667	2			
	PR	Regression	37750.515	1	37750.515	.282	.689
		Residual	133670.151	1	133670.151		
		Total	171420.667	2			
	TRL	Regression	315.364	1	315.364	29.651	.116
		Residual	10.636	1	10.636		
		Total	326.000	2			
Dry	PGA	Regression	17.140	1	17.140	.112	.795
		Residual	153.527	1	153.527		
		Total	170.667	2			
	PR	Regression	8784.149	1	8784.149	1.083	.487
		Residual	8108.518	1	8108.518		
		Total	16892.667	2			
	TRL	Regression	3352.676	1	3352.676	1.302	.458
		Residual	2575.324	1	2575.324		
		Total	5928.000	2			

4.3.3 Burchell's Zebra *(Equus burchelli)*

Figure 4.8 shows Burchell's zebra abundances across the different land-use types in different seasons. There was a significant main effect of land-use type ($F_{2, 12} = 36.81$ $p < 0.0001$); with abundance being significantly higher in PR than in PGA ($p < 0.0001$) and TRL ($p = 0.0034$); and TRL having significantly higher abundance than PGA ($p = 0.0023$). There was no significant main effect of seasonality on Burchell's zebra abundance ($F_{1, 12} = 0.46$ $p = 0.512$).

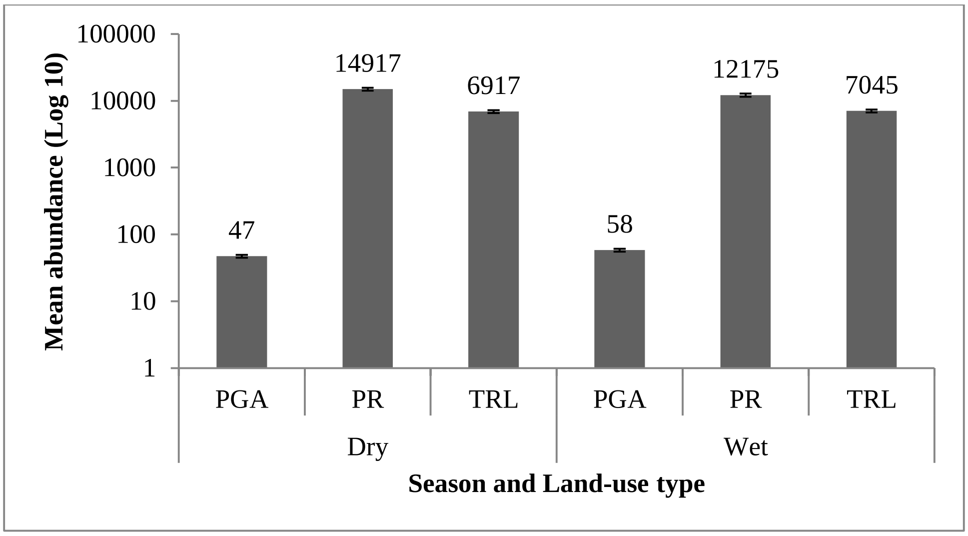


Figure 4.8: Burchell's zebra abundance across different land-use types and between seasons

A linear regression model showed there was no significant linear relationship between livestock density and Burchell's zebra (Table 4.6).

Table 4. 6: Linear regression model of Livestock-Burchell's zebra relationship

Season	Land-use		Sum of Squares	df	Mean Square	F	Sig.
Wet	PGA	Regression	561.57	1	561.565	.045	.866
		Residual	12355.10	1	12355.102		
		Total	12916.67	2			
	PR	Regression	6181221.58	1	6181221.584	.307	.678
		Residual	20120306.42	1	20120306.416		
		Total	26301528.00	2			
	TRL	Regression	20857742.24	1	20857742.244	.974	.504
		Residual	21424950.42	1	21424950.423		
		Total	42282692.67	2			
Dry	PGA	Regression	18.75	1	18.751	.784	.539
		Residual	23.92	1	23.915		
		Total	42.67	2			
	PR	Regression	328933.15	1	328933.151	.021	.908
		Residual	15597111.52	1	15597111.516		
		Total	15926044.67	2			
	TRL	Regression	2137962.22	1	2137962.224	.893	.518
		Residual	2394182.44	1	2394182.443		
		Total	4532144.67	2			

4.3.4 Grevy's Zebra *(Equus grevyi)*

The Grevy's zebra abundance varied across land-use types, being greatest in PR, intermediate in TRL and lowest in PGA (Fig.4.9). However, a GLM indicated that there was no significant interaction between seasonality and land-use type on Grevy's abundance ($F_{2,\ 9}$ = 0.96 p = 0.420). There was a significant main effect of seasonality on abundance of Grevy's zebra ($F_{1,\ 9}$ = 5.22 p = 0.048); being significantly higher during dry season than wet season ($p <$ 0.005). Land-use had no significant main effect on Grevy's zebra abundance ($F_{2,\ 9}$ = 2.30 p = 0.156).

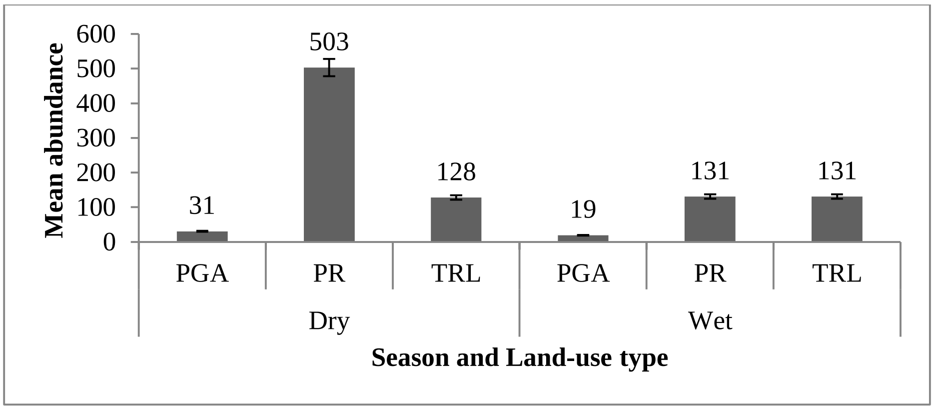


Figure 4.9: Grevy's zebra abundance in different land-use types at different seasons

There was no significant linear relationship revealed between Grevy's zebra and livestock density (Table 4.7)

Table 4. 7: Linear regression model of Grevy's zebra-Livestock relationship

Season	Land-use		Sum of Squares	df	Mean Square	F	Sig.
Wet	PGA	Regression	47.937	1	47.937	0.088	0.816
		Residual	544.73	1	544.73		
		Total	592.667	2			
	PR	Regression	22937.056	1	22937.056	3.593	0.309
		Residual	6383.611	1	6383.611		
		Total	29320.667	2			
	TRL	Regression	6781.812	1	6781.812	0.227	0.717
		Residual	29860.854	1	29860.854		
		Total	36642.667	2			
Dry	PGA	Regression	2479.843	1	2479.843	0.784	0.539
		Residual	3162.823	1	3162.823		
		Total	5642.667	2			
	PR	Regression	16675.325	1	16675.325	7.094	0.229
		Residual	2350.675	1	2350.675		
		Total	19026	2			
	TRL	Regression	488.835	1	488.835	1.21	0.47
		Residual	403.832	1	403.832		
		Total	892.667	2			

4.3.5 Thomson's gazelle *(Gazella thomsoni)*

A Kruskal-Wallis test showed significant differences in abundance of Thomson's gazelles across land-use types (H = 11.43 df = 2 p = 0.003) (Fig.4.10). A post-hoc test (Dunn-Bonferroni approach), revealed that Thomson's gazelles were significantly less abundant in PGA than PR (p = 0.002) and TRL (p < 0.002); the difference between PR and TRL was not significant (p > 0.05). However, Thomson's gazelle abundance did not differ significantly between seasons (H = 0.05 df = 1 p = 0.825).

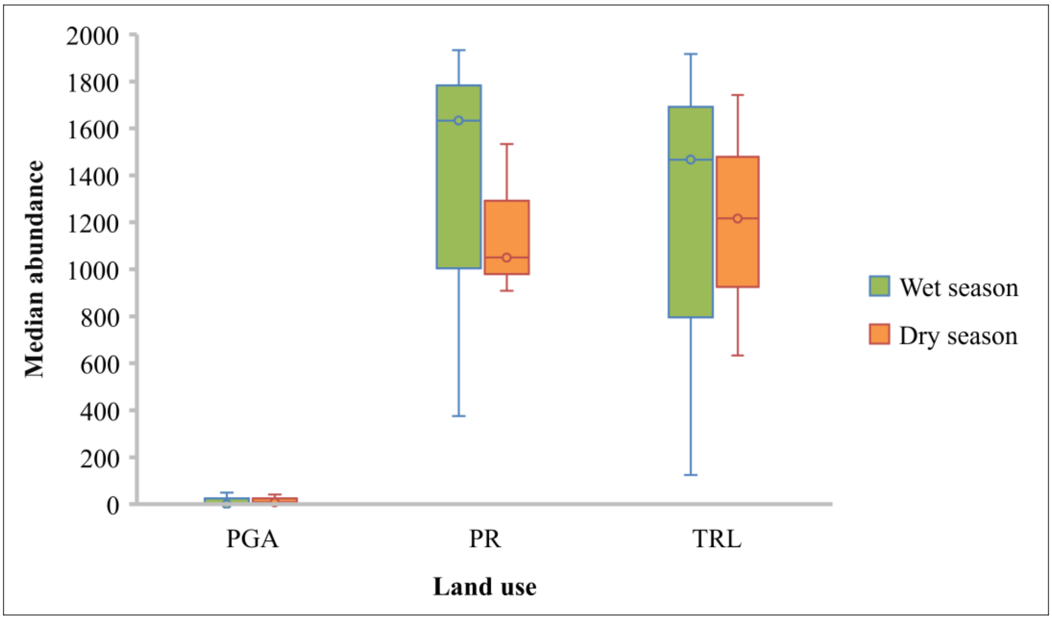


Figure 4.10: Thomson's gazelle abundance in different land-use types at different seasons

There was no significant linear relationship between Thomson's gazelle and livestock (Table 4.8)

Table 4. 8: Linear regression model of Thomson's gazelle-Livestock relationship

Season	Land-use		Sum of Squares	df	Mean Square	F	Sig.
Wet	PGA	Regression	1169.975	1	1169.975	2.356	.368
		Residual	496.692	1	496.692		
		Total	1666.667	2			
	PR	Regression	56669.760	1	56669.760	.043	.869
		Residual	1309972.906	1	1309972.906		
		Total	1366642.667	2			
	TRL	Regression	1718526.007	1	1718526.007	87.161	.068
		Residual	19716.660	1	19716.660		
		Total	1738242.667	2			
Dry	PGA	Regression	856.808	1	856.808	6.215	.243
		Residual	137.858	1	137.858		
		Total	994.667	2			
	PR	Regression	59201.010	1	59201.010	.381	.648
		Residual	155491.657	1	155491.657		
		Total	214692.667	2			
	TRL	Regression	251116.519	1	251116.519	.689	.559
		Residual	364404.148	1	364404.148		
		Total	615520.667	2			

4.3.6 Grant's gazelle *(Gazella granti)*

Private ranches had the highest abundance of Grant's gazelle followed by TRL, PGA had the least abundance. Figure 4.11 shows the abundance of Grant's gazelle.

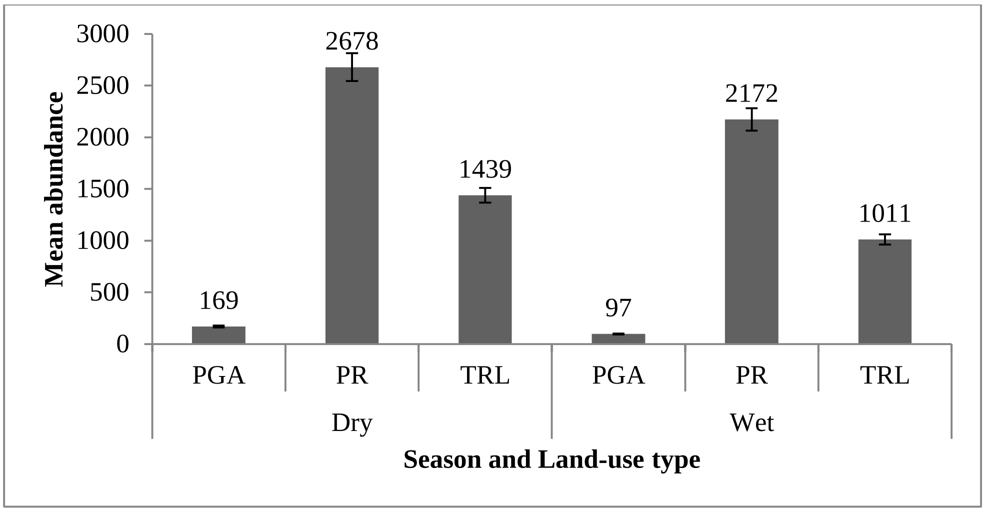


Figure 4.11: Grant's gazelle abundance across different land-use types and between seasons

A two-way ANOVA indicated significant main effect of land-use on Grant's gazelle abundance ($F_{2, 12}$ = 13.10 p = 0.001) with significantly higher abundance in PR than PGA (p < 0.005) and TRL (p = 0.049). Grant's gazelle abundance in TRL was higher than in PGA but not significant (p = 0.0746). Seasonality had no significant main effect ($F_{1, 12}$ = 0.84 p = 0.337). There was a significantly negative linear relationship between Grant's gazelle abundance and livestock density in PGA during the dry season (R^2 = 0.99; p < 0.05) as shown in Table 4.9

Table 4. 9: Linear regression model of Grant's gazelle-Livestock relationship

Season	Land-use		Sum of Squares	df	Mean Square	F	Sig.
Wet	PGA	Regression	16679.330	1	16679.330	1.045	.493
		Residual	15963.337	1	15963.337		
		Total	32642.667	2			
	PR	Regression	218399.976	1	218399.976	.069	.837
		Residual	3187020.691	1	3187020.691		
		Total	3405420.667	2			
	TRL	Regression	545177.257	1	545177.257	18.371	.146
		Residual	29676.743	1	29676.743		
		Total	574854.000	2			
Dry	PGA	Regression	85304.504	1	85304.504	252.259	.04*$^{(-)}$
		Residual	338.163	1	338.163		
		Total	85642.667	2			
	PR	Regression	126178.987	1	126178.987	.164	.755
		Residual	770813.680	1	770813.680		
		Total	896992.667	2			
	TRL	Regression	1842437.776	1	1842437.776	4.837	.272
		Residual	380888.224	1	380888.224		
		Total	2223326.000	2			

*$^{(-)}$ significant negative linear relationship (p < 0.05)

4.3.7 Hartebeest *(Alcelaphus buselaphus)*

Hartebeest occurred in PR in relatively high abundance compared to TRL and PGA (Fig.4.12).

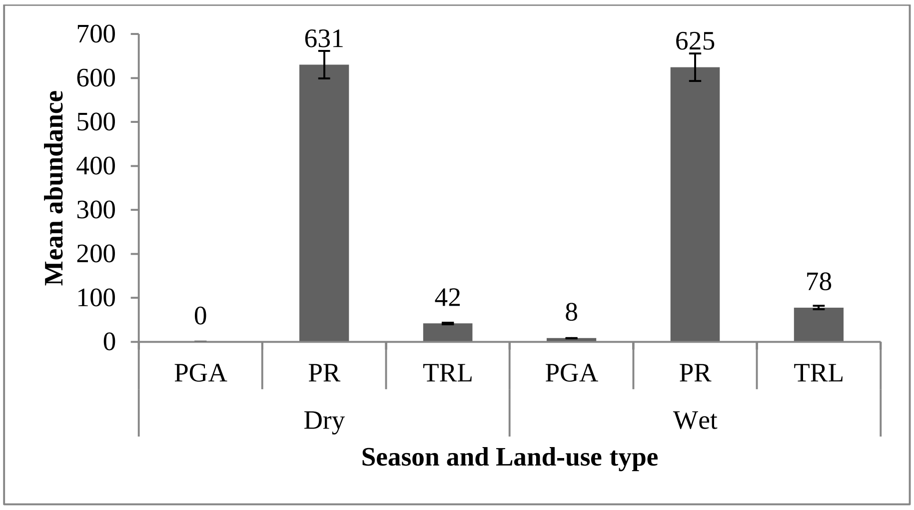


Figure 4.12: Hartebeest abundance in different land-use types and seasons

There was a significant main effect of land-use type on abundance of hartebeest ($F_{2, 8} = 7.16$ $p = 0.017$) with significantly higher abundance in PR than in TRL ($p = 0.0194$) and PGA ($p < 0.05$). Seasons had no significant main effect ($F_{1, 8} = 0.11$ $p = 0.747$). Hartebeest abundance and livestock density had no significant linear relationship across different land-use types between seasons (Table 4.10).

Table 4. 10: Linear regression model of Hartebeest-Livestock relationship

Season	Land-use		Sum of Squares	df	Mean Square	F	Sig.
Wet	PGA	Regression	292.494	1	292.494	2.356	.368
		Residual	124.173	1	124.173		
		Total	416.667	2			
	PR	Regression	281312.229	1	281312.229	.374	.651
		Residual	752265.771	1	752265.771		
		Total	1033578.000	2			
	TRL	Regression	1448.648	1	1448.648	.247	.707
		Residual	5872.018	1	5872.018		
		Total	7320.667	2			
Dry	PGA	Regression	0.000	0	-	-	-
		Residual	0.000	2	0.000		
		Total	0.000	2			
	PR	Regression	2443.144	1	2443.144	.034	.884
		Residual	71399.523	1	71399.523		
		Total	73842.667	2			
	TRL	Regression	18.966	1	18.966	.003	.966
		Residual	6725.700	1	6725.700		
		Total	6744.667	2			

- means no data

4.3.8 Impala *(Aepyceros melampus)*

Impalas were more abundant in PR followed by TRL. The PGA had least abundance of impala (Fig.4.13).

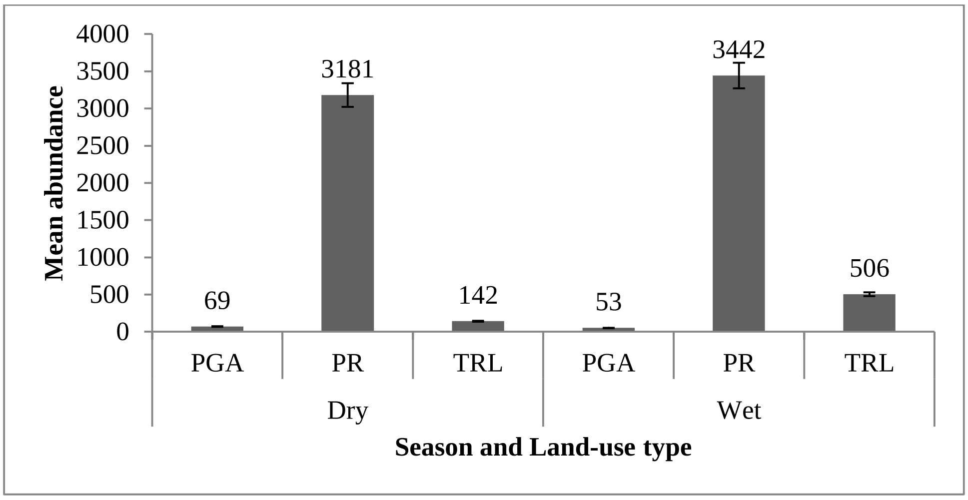


Figure 4.13: Impala abundance across different land-use types and between seasons

A GLM indicated significant main effect of land-use on impala abundance ($F_{2, 11} = 37.33$ $p < 0.001$); with significantly higher abundance in PR than PGA ($p < 0.0001$) and TRL ($p < 0.005$). There was no significant main effect of seasonality on impala abundance ($F_{1, 11} = 1.99$ $p = 0.186$). There was a significant negative linear relationship between the Hartebeest abundance and livestock density in PGA during wet ($R^2 = 0.99$ $p < 0.05$) (Table 4.11).

Table 4. 11: Linear regression model of Impala-Livestock relationship

Season	Land-use		Sum of Squares	Df	Mean Square	F	Sig.
Wet	PGA	Regression	5035.296	1	5035.296	683.143	.02*(-)
		Residual	7.371	1	7.371		
		Total	5042.667	2			
	PR	Regression	42700.275	1	42700.275	.007	.947
		Residual	6187716.391	1	6187716.391		
		Total	6230416.667	2			
	TRL	Regression	269751.421	1	269751.421	1.054	.492
		Residual	255869.246	1	255869.246		
		Total	525620.667	2			
Dry	PGA	Regression	2038.058	1	2038.058	.206	.729
		Residual	9882.609	1	9882.609		
		Total	11920.667	2			
	PR	Regression	34749.547	1	34749.547	1.669	.419
		Residual	20821.120	1	20821.120		
		Total	55570.667	2			
	TRL	Regression	16825.807	1	16825.807	1.668	.419
		Residual	10086.860	1	10086.860		
		Total	26912.667	2			

*(-) significant negative linear relationship ($p < 0.05$)

4.3.9 Eland *(Taurotragus oryx)*

Elands were more abundant in the PR than TRL (Figure 4.14). Notably, no elands were enumerated in the PGA during the censuses used in this study. A two-way ANOVA showed land-use type had a significant main effect on eland abundance ($F_{1, 8} = 8.41$ $p = 0.02$). They were significantly more abundant in PR than in TRL ($p = 0.019$). There was no significant main effect of seasonality on eland abundance ($F_{1, 8} = 0.02$ $p = 0.900$).

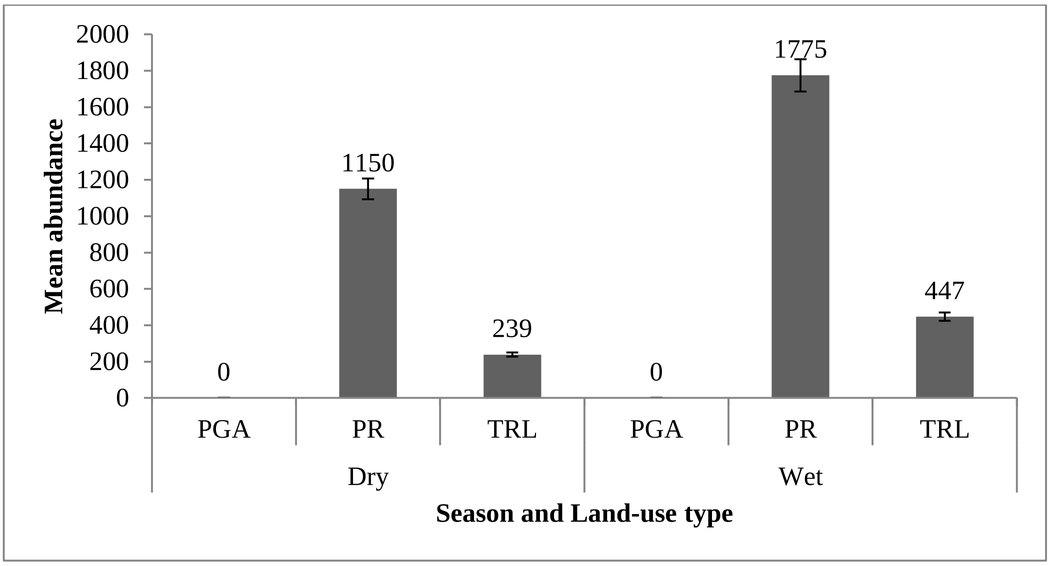


Figure 4.14: Eland abundance across different land-use types and between seasons

A linear regression analysis showed no significant relationship between Eland abundance and livestock density in all the three land-use type during wet or dry season (Table 4.12)

Table 4. 12: Linear regression model of Eland-Livestock relationship

Season	Land-use		Sum of Squares	df	Mean Square	F	Sig.
Wet	PGA	Regression	0.000	0	-	-	-
		Residual	0.000	2	0.000		
		Total	0.000	2			
	PR	Regression	1866471.800	1	1866471.800	1.351	.452
		Residual	1381606.200	1	1381606.200		
		Total	3248078.000	2			
	TRL	Regression	193481.046	1	193481.046	.346	.662
		Residual	559611.620	1	559611.620		
		Total	753092.667	2			
Dry	PGA	Regression	0.000	0	-	-	-
		Residual	0.000	2	0.000		
		Total	0.000	2			
	PR	Regression	11447.243	1	11447.243	1.338	.454
		Residual	8552.757	1	8552.757		
		Total	20000.000	2			
	TRL	Regression	37157.720	1	37157.720	.866	.523
		Residual	42896.280	1	42896.280		
		Total	80054.000	2			

- means no data

4.3.10 Warthog *(Phacochoerus aethiopicus)*

Warthog abundance differed significantly across land-use types ($F_{2,6}$ = 11.04 p = 0.010) (Fig 4.15) with significantly higher abundance in PR than in PGA (p < 0.05) and TRL (p < 0.05). Seasonality had no significant main effect on warthog abundance ($F_{1,6}$ = 0.78 p = 0.411).

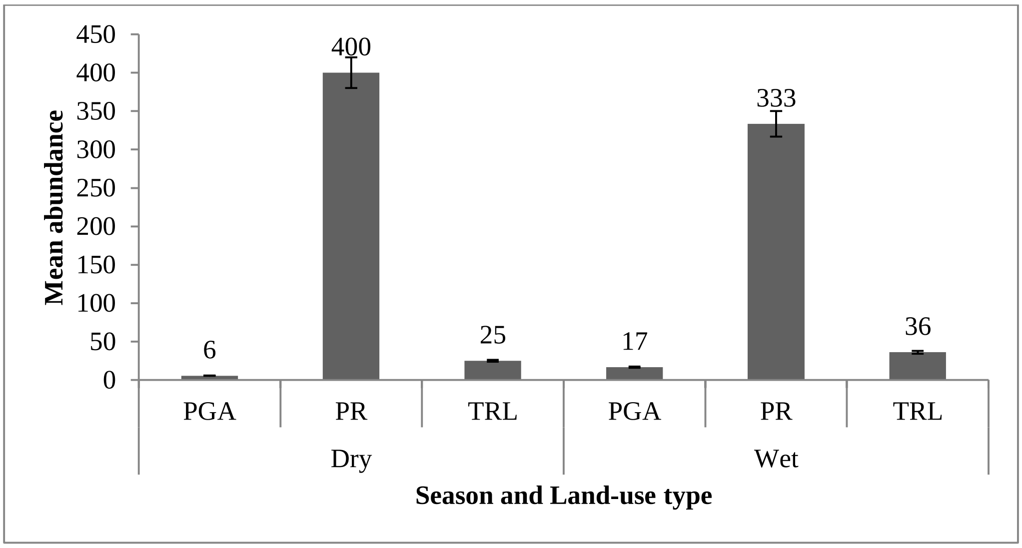


Figure 4.15: Warthog abundance in different land-use types and seasons

There was no significant linear relationship between warthog abundance and livestock density in any of the land-use type during wet or dry season (Table 4.13).

Table 4. 13: Linear regression model of Warthog-Livestock relationship

Season	Land-use		Sum of Squares	df	Mean Square	F	Sig.
Wet	PGA	Regression	4.833	1	4.833	.003	.966
		Residual	1661.834	1	1661.834		
		Total	1666.667	2			
	PR	Regression	22237.570	1	22237.570	14.755	.162
		Residual	1507.097	1	1507.097		
		Total	23744.667	2			
	TRL	Regression	1356.924	1	1356.924	.395	.643
		Residual	3435.743	1	3435.743		
		Total	4792.667	2			
Dry	PGA	Regression	184.977	1	184.977	24.056	.128
		Residual	7.690	1	7.690		
		Total	192.667	2			
	PR	Regression	34923.758	1	34923.758	.747	.546
		Residual	46742.909	1	46742.909		
		Total	81666.667	2			
	TRL	Regression	2557.091	1	2557.091	21.149	.136
		Residual	120.909	1	120.909		
		Total	2678.000	2			

4.3.11 Beisa Oryx *(Oryx gazella beisa)*

Figure 4.16 shows the abundance of Oryx across different land-use types and seasons. Notably, Oryx occurred in PR and TRL but not in PGA. There was a significant main effect of land-use type on Oryx abundance ($F_{1,\ 7}$ = 9.14 p = 0.019); with significantly higher abundance in PR than in TRL ($p < 0.05$). Seasonality had no significant effect on Oryx abundance ($F_{1,\ 7}$ = 0.30 p = 0.60).

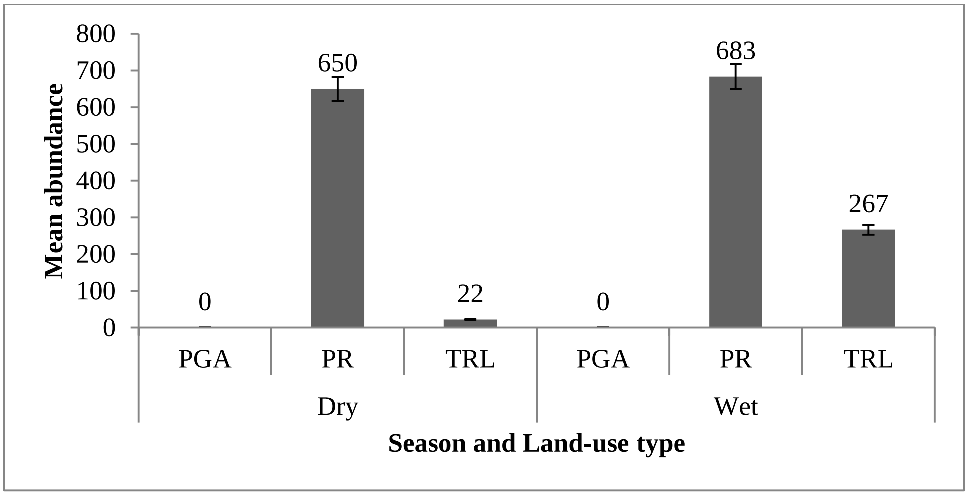


Figure 4.16: Oryx abundance in different land-use types and seasons

There was no significant linear relationship between Oryx abundance and livestock density in the three land-use types during the wet or dry season (Table 4.14).

Table 4. 14: Linear regression model of Oryx-Livestock relationship

Season	Land-use		Sum of Squares	df	Mean Square	F	Sig.
Wet	PGA	Regression	0.000	0	-	-	-
		Residual	0.000	2	0.000		
		Total	0.000	2			
	PR	Regression	163268.955	1	163268.955	.339	.664
		Residual	481731.045	1	481731.045		
		Total	645000.000	2			
	TRL	Regression	64033.144	1	64033.144	.277	.692
		Residual	231383.523	1	231383.523		
		Total	295416.667	2			
Dry	PGA	Regression	0.000	0	-	-	-
		Residual	0.000	2	0.000		
		Total	0.000	2			
	PR	Regression	14555.452	1	14555.452	.090	.814
		Residual	160861.214	1	160861.214		
		Total	175416.667	2			
	TRL	Regression	25.513	1	25.513	.020	.910
		Residual	1267.153	1	1267.153		
		Total	1292.667	2			

- means no data

4.3.12 Waterbuck *(Kobus ellipsiprymnus)*

Waterbucks tended to be more abundant in PR than in TRL and PGA (Fig.4.17), based on a two-way ANOVA, main effect of land-use type was not statistically significant ($F_{2, 5}$ = 4.78 p = 0.069). In addition, waterbuck abundance did not differ significantly between seasons ($F_{1, 5}$ = 0. 21 p = 0.668).

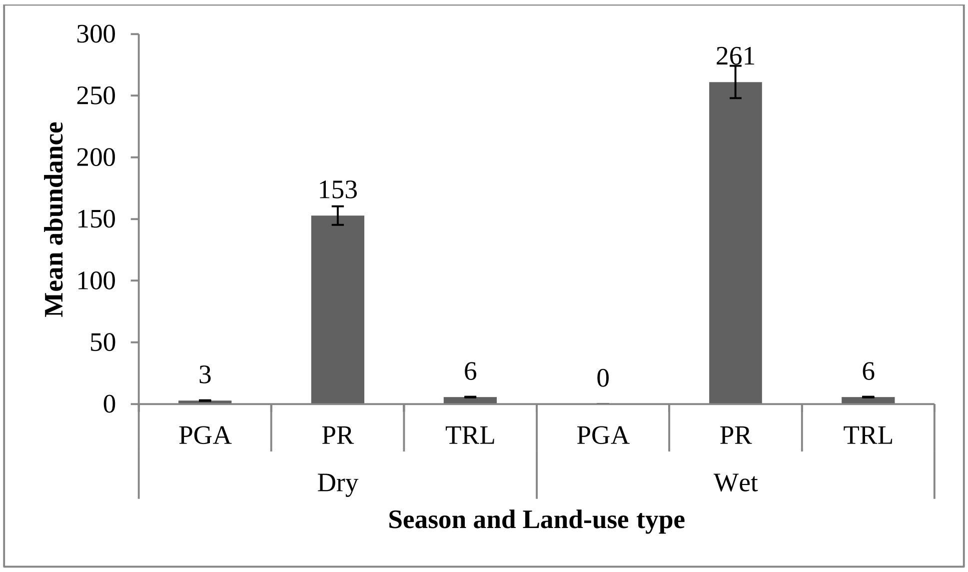


Figure 4.17: Waterbuck abundance in different land-use types and seasons

There was no significant linear relationship between Waterbuck abundance and livestock density in any of the three land-use types during wet or dry season (Table 4.15).

Table 4. 15: Linear regression model of Waterbuck-Livestock relationship

Season	Land-use		Sum of Squares	df	Mean Square	F	Sig.
Wet	PGA	Regression	0.000	0	-	-	-
		Residual	0.000	2	0.000		
		Total	0.000	2			
	PR	Regression	20335.879	1	20335.879	.179	.745
		Residual	113790.121	1	113790.121		
		Total	134126.000	2			
	TRL	Regression	72.547	1	72.547	.604	.579
		Residual	120.120	1	120.120		
		Total	192.667	2			
Dry	PGA	Regression	40.964	1	40.964	24.056	.128
		Residual	1.703	1	1.703		
		Total	42.667	2			
	PR	Regression	29333.905	1	29333.905	14.057	.166
		Residual	2086.761	1	2086.761		
		Total	31420.667	2			
	TRL	Regression	173.180	1	173.180	8.887	.206
		Residual	19.486	1	19.486		
		Total	192.667	2			

- means no data

4.3.13 Gerenuk *(Litocranius walleri)*

Although Gerenuks tended to be more abundant in PR than in any other land-use type (Fig.4.18), there was no statistically significant effect of land-use type on abundance of this ungulate species ($F_{2,\ 7}$ = 2.88 p = 0.122). Likewise, gerenuk abundance did not differ significantly between seasons ($F_{1,7}$ = 0.00 p = 0.976).

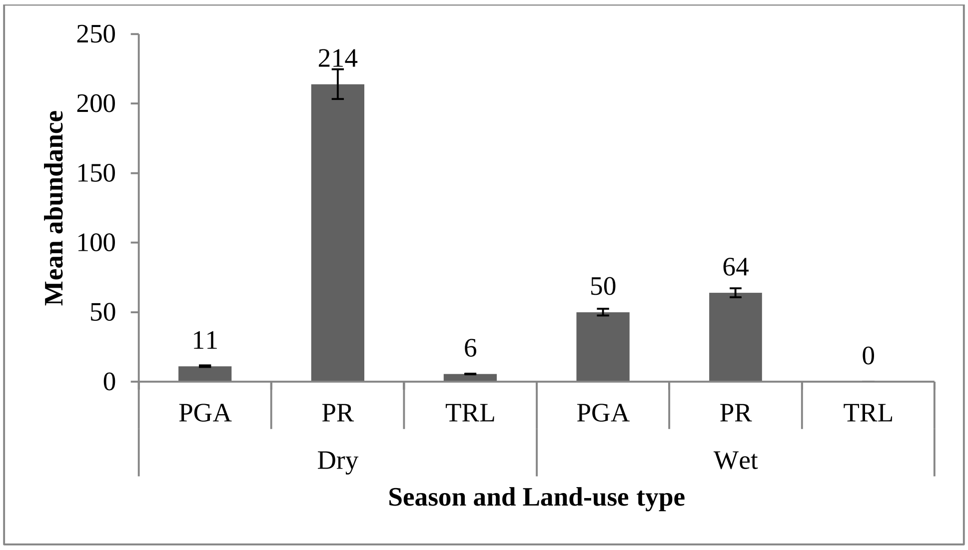


Figure 4.18: Gerenuk abundance across different land-use types and seasons

There was no significant linear relationship between Gerenuk abundance and livestock numbers in all the land-use types during the dry or wet season (Table 4.16).

Table 4. 16: Linear regression model of Gerenuk-Livestock relationship

Season	Land-use		Sum of Squares	df	Mean Square	F	Sig.
Wet	PGA	Regression	10529.772	1	10529.772	2.356	.368
		Residual	4470.228	1	4470.228		
		Total	15000.000	2			
	PR	Regression	1700.745	1	1700.745	2.873	.339
		Residual	591.922	1	591.922		
		Total	2292.667	2			
	TRL	Regression	0.000	0	-	-	-
		Residual	0.000	2	0.000		
		Total	0.000	2			
Dry	PGA	Regression	23.732	1	23.732	.784	.539
		Residual	30.268	1	30.268		
		Total	54.000	2			
	PR	Regression	17.951	1	17.951	.010	.935
		Residual	1736.049	1	1736.049		
		Total	1754.000	2			
	TRL	Regression	108.219	1	108.219	1.281	.461
		Residual	84.448	1	84.448		
		Total	192.667	2			

- means no data

4.4 Land-use and seasonal effects on abundance of wild ungulates based on body size

4.4.1 Megaherbivores

Megaherbivores (elephant, rhinos and giraffes) occurred across all the three land-use types but with highest abundance in PR (Fig.4.19)

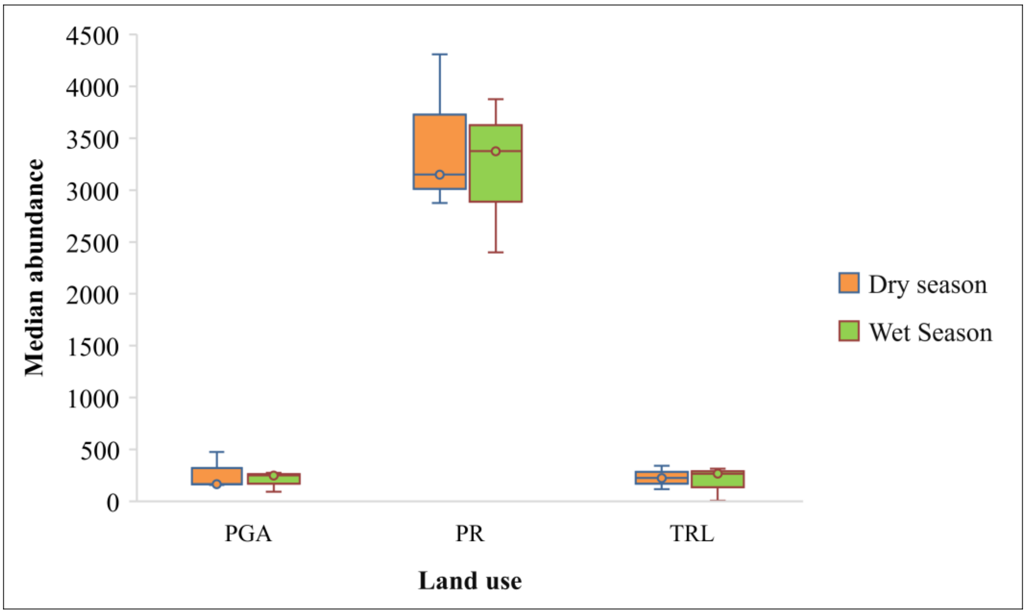


Figure 4.19: Number of Megaherbivores in different land-use types at different seasons

A Kruskal-Wallis test indicated significant variation in megaherbivore numbers across the three land-use types (H = 11.37 df = 2 p = 0.003) with abundance being significantly higher in PR than in PGA ($p < 0.005$) and TRL ($p < 0.005$). However, megaherbivore abundance did not differ significantly between seasons (H = 0.05 df = 1 p = 0.825). There was a significant positive linear relationship between Megaherbivore numbers and livestock density in PR during dry season (R^2 = 1 p = 0.005) (Table 4.17).

Table 4. 17: Linear regression model of Megaherbivores-Livestock relationship

Season	Land-use		Sum of Squares	df	Mean Square	F	Sig.
Wet	PGA	Regression	11446.498	1	11446.498	1.388	.448
		Residual	8246.169	1	8246.169		
		Total	19692.667	2			
	PR	Regression	1079356.869	1	1079356.869	23.434	.130
		Residual	46059.798	1	46059.798		
		Total	1125416.667	2			
	TRL	Regression	13081.589	1	13081.589	.312	.676
		Residual	41939.078	1	41939.078		
		Total	55020.667	2			
Dry	PGA	Regression	27022.870	1	27022.870	.709	.554
		Residual	38121.797	1	38121.797		
		Total	65144.667	2			
	PR	Regression	1156629.702	1	1156629.702	18369.536	.005*$^{(+)}$
		Residual	62.965	1	62.965		
		Total	1156692.667	2			
	TRL	Regression	11682.408	1	11682.408	.856	.525
		Residual	13643.592	1	13643.592		
		Total	25326.000	2			

*$^{(+)}$ significant positive linear relationship (p = 0.005)

4.4.2 Medium-sized ungulates

This group of ungulates comprised most of the individuals in the study area. They occurred across all the three land-use types but were more abundant in PR than in other land-use types (Fig.4.20).

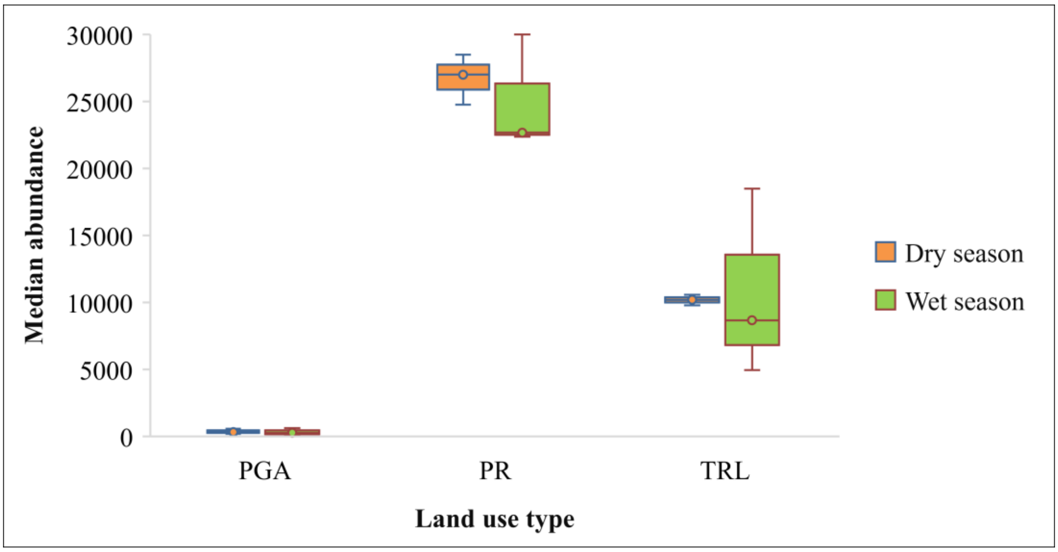


Figure 4.20: Number of medium-sized ungulates across land-use types and seasons

A Kruskal-Wallis test showed significant differences in the numbers of these ungulates among land-use types (H = 15.16 df = 2 p = 0.001). Specifically, these ungulates were significantly less abundant in PGA than in TRL ($p < 0.005$) and PR ($p < 0.005$). Also, they were significantly less abundant in TRL than in PR ($p < 0.005$). However, the abundance of these ungulates did not differ significantly between seasons (H = 0.10 df = 1 p = 0.757).

Table 4. 18: Linear regression model of medium-sized ungulates-Livestock relationship

Season	Land-use		Sum of Squares	Df	Mean Square	F	Sig.
Wet	PGA	Regression	139130.729	1	139130.729	15.306	.159
		Residual	9089.938	1	9089.938		
		Total	148220.667	2			
	PR	Regression	12773508.149	1	12773508.149	.518	.603
		Residual	24649336.518	1	24649336.518		
		Total	37422844.667	2			
	TRL	Regression	62762136.792	1	62762136.792	1.790	.409
		Residual	35060761.875	1	35060761.875		
		Total	97822898.667	2			
Dry	PGA	Regression	66770.167	1	66770.167	35.620	.106
		Residual	1874.500	1	1874.500		
		Total	68644.667	2			
	PR	Regression	41002.452	1	41002.452	.006	.951
		Residual	7016190.214	1	7016190.214		
		Total	7057192.667	2			
	TRL	Regression	284731.707	1	284731.707	17.920	.148
		Residual	15888.960	1	15888.960		
		Total	300620.667	2			

There was no significant relationship between medium-sized ungulate numbers and livestock densities in all the three land-use types during the dry or wet season (Table 4.18).

4.5 Land-use and seasonal effects on abundance of wild ungulates based on feeding habits

4.5.1 Grazers

The grazers occurred in varying abundance across different land-use types but with the highest abundance being observed in PR than in any other land-use type. Their numbers also varied seasonally though not significantly (Figure 4.21).

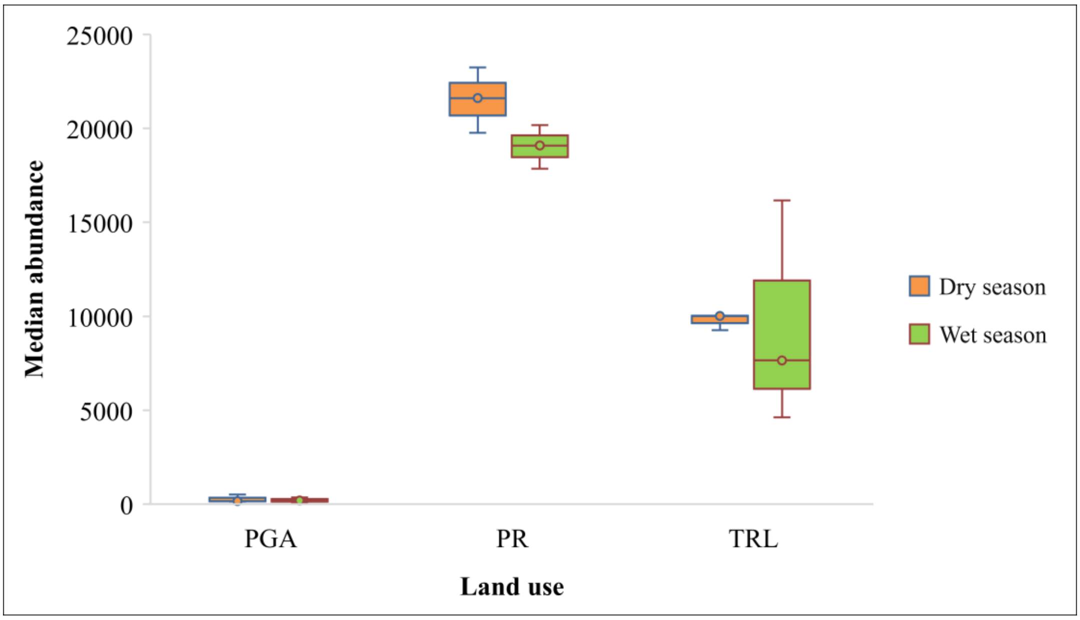


Figure 4.21: Number of grazers across land-use types and seasons

Based on a Kruskal-Wallis analysis, the numbers of grazers differed significantly among land-use type (H = 15.16 df = 2 p = 0.001); being significantly lower in PGA than TRL (p < 0.005) and PR (p < 0.005) and also being significantly lower in TRL than in PR (p < 0.005). There was no significant difference in grazers abundance between seasons (H = 0.24 df = 1 p = 0.627). There was no significant linear relationship between abundance of grazers and livestock density in all the three land-use types during the dry and wet season (Table 4.19)

Table 4. 19: Linear regression model of Grazers-Livestock relationship

Season	Land-use		Sum of Squares	df	Mean Square	F	Sig.
Wet	PGA	Regression	39771.456	1	39771.456	40.866	.099
		Residual	973.210	1	973.210		
		Total	40744.667	2			
	PR	Regression	2383504.674	1	2383504.674	7.388	.224
		Residual	322621.326	1	322621.326		
		Total	2706126.000	2			
	TRL	Regression	45023660.937	1	45023660.937	1.699	.417
		Residual	26505293.063	1	26505293.063		
		Total	71528954.000	2			
Dry	PGA	Regression	87541.305	1	87541.305	36.792	.104
		Residual	2379.361	1	2379.361		
		Total	89920.667	2			
	PR	Regression	143709.419	1	143709.419	.024	.901
		Residual	5901244.581	1	5901244.581		
		Total	6044954.000	2			
	TRL	Regression	227377.871	1	227377.871	1.379	.449
		Residual	164942.796	1	164942.796		
		Total	392320.667	2			

4.5.2 Browsers

This was the ungulate group with lowest number of individuals in the study area (Fig 4.22).

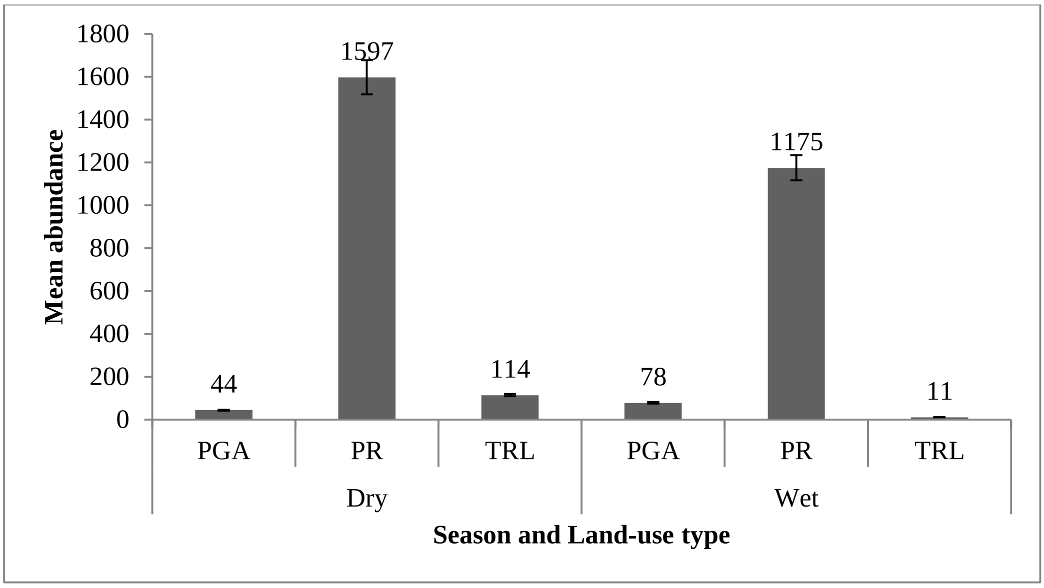


Figure 4.22: Number of browsers in different land-use types in different seasons

A two-way ANOVA showed a significant interaction effect between level of land-use type and seasons on browsers abundance ($F_{2,\,9}$ = 6.82 p = 0.016). Specifically, the abundance of browsers was significantly higher in PR during the dry season than in TRL during the wet and dry season. Also, browsers were significantly higher in PR during the wet season than in TRL and PGA during wet season. Additionally, browsers were significantly abundant in TRL during dry season than in PGA during dry season. Table 4.20 shows significance levels between different combinations of independent/interacting factors.

Table 4. 20: Factors interaction showing levels of significance

Levels of factor interaction	***P*-value**
Dry PGA less than Dry PR	< 0.005
Dry PGA less than Wet PR	< 0.005
Dry PR more than Dry TRL	< 0.005
Dry PR more than Wet TRL	< 0.0005
Dry TRL less than Wet PR	< 0.005
Wet PGA more than Wet TRL	< 0.05
Wet PR more than Wet TRL	< 0.0005

There was no significant linear relationship between abundance of browsers and livestock density in any of the land-use types during wet or dry season (Table 4.21).

Table 4. 21: Linear regression model of Browsers-Livestock relationship

Season	Land-use		Sum of Squares	df	Mean Square	F	Sig.
Wet	PGA	Regression	25406.701	1	25406.701	2.356	.368
		Residual	10785.965	1	10785.965		
		Total	36192.667	2			
	PR	Regression	40817.239	1	40817.239	.339	.664
		Residual	120432.761	1	120432.761		
		Total	161250.000	2			
	TRL	Regression	315.364	1	315.364	29.651	.116
		Residual	10.636	1	10.636		
		Total	326.000	2			
Dry	PGA	Regression	312.304	1	312.304	37.347	.103
		Residual	8.362	1	8.362		
		Total	320.667	2			
	PR	Regression	14015.464	1	14015.464	.045	.866
		Residual	309305.203	1	309305.203		
		Total	323320.667	2			
	TRL	Regression	15755.762	1	15755.762	2.162	.380
		Residual	7286.905	1	7286.905		
		Total	23042.667	2			

4.5.3 Mixed-feeders

This group of ungulates appeared in the various land-use types and seasons in varying proportions (Fig.4.23).

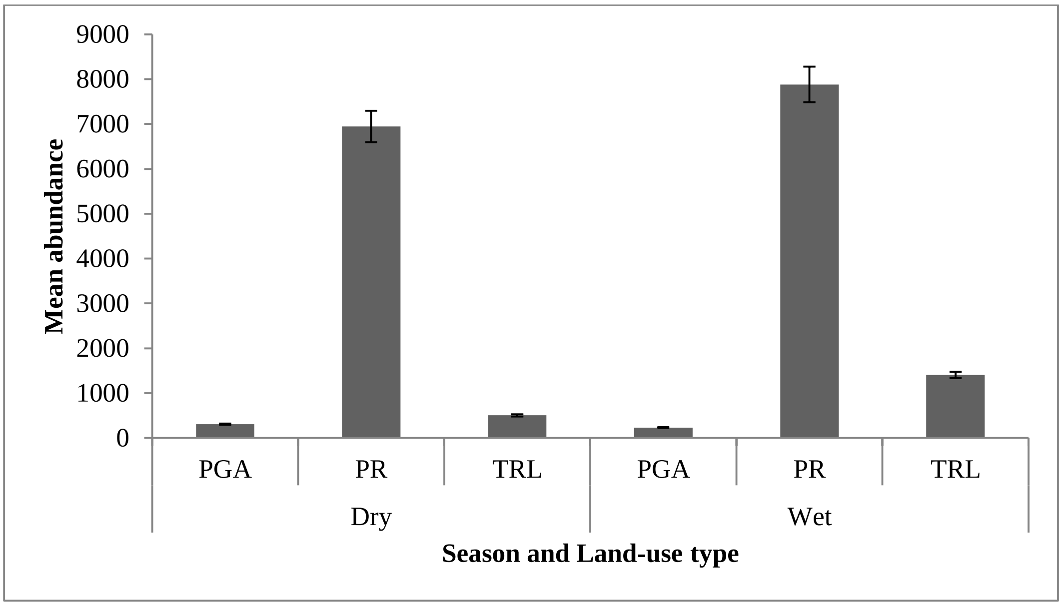


Figure 4.23: Number of mixed-feeders across land-use types at different seasons

A two-way ANOVA showed a significant main effect of land-use type on numbers of mixed-feeders ($F_{2, 12}$ = 64.73 p < 0.001); with significantly lower abundance in PGA than in PR (p < 0.0001) and TRL (p < 0.05); also their abundance was significantly lower in TRL than in PR (p < 0.0001). Seasonality had no significant influence on the numbers of mixed-feeders ($F_{1, 12}$

= 0.97 p = 0.345). There was no significant linear relationship between abundance of mixed-feeders and livestock density in all land-use types during the dry or wet season (Table 4.22)

Table 4. 22: Linear regression model of Mixed-feeders and Livestock relationship

Season	Land-use		Sum of Squares	df	Mean Square	F	Sig.
Wet	PGA	Regression	8740.886	1	8740.886	.510	.605
		Residual	17151.781	1	17151.781		
		Total	25892.667	2			
	PR	Regression	8023753.165	1	8023753.165	.437	.628
		Residual	18377913.502	1	18377913.502		
		Total	26401666.667	2			
	TRL	Regression	1244724.517	1	1244724.517	3.813	.301
		Residual	326446.149	1	326446.149		
		Total	1571170.667	2			
Dry	PGA	Regression	48194.756	1	48194.756	4.284	.287
		Residual	11249.911	1	11249.911		
		Total	59444.667	2			
	PR	Regression	2260838.832	1	2260838.832	3.160	.326
		Residual	715481.835	1	715481.835		
		Total	2976320.667	2			
	TRL	Regression	.024	1	.024	.000	1.000
		Residual	88970.643	1	88970.643		
		Total	88970.667	2			

4.6 Land-use and seasonal effects on diversity of wild ungulates

There were differences in the α-diversity index of wild ungulates among land-use types (Figures 4.24- 4.26)

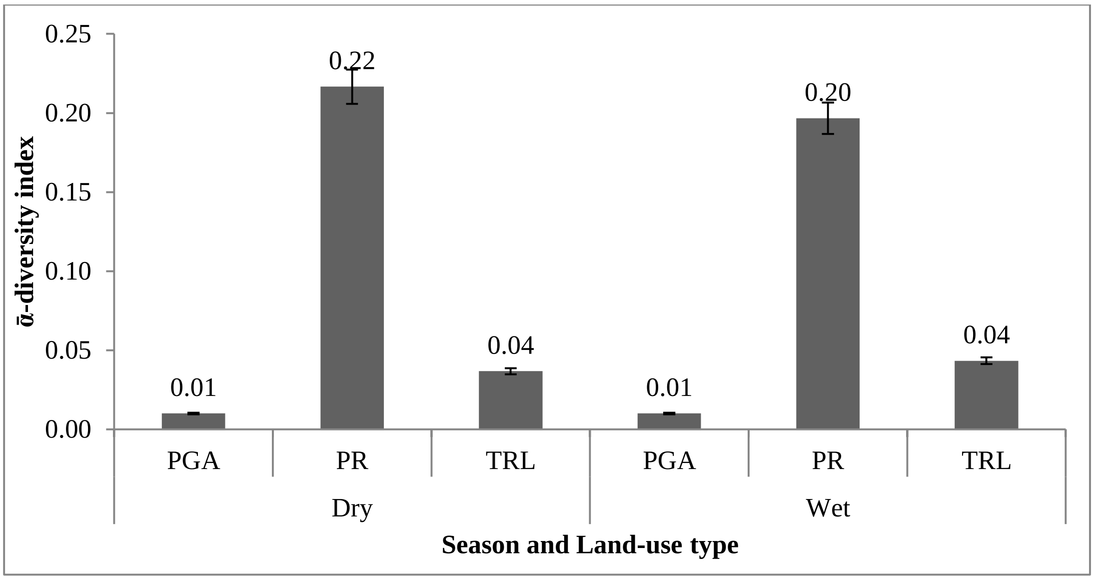


Figure 4.24: Mean ungulates diversity (ᾱ) per land-use type

Specifically, PR had the highest ᾱ-diversity index followed by TRL and PGA. A two-way ANOVA indicated that there was significant main effect of land-use type on ᾱ-diversity ($F_{2, 10}$ = 44.99; p < 0.001) with significantly lower ungulate diversity in PGA than PR (p < 0.0001) and TRL (p < 0.05). In addition, ungulate diversity was significantly lower in TRL than in PR (p = 0.0002). There was no significant effect of seasonality on the ᾱ-diversity of wild ungulates ($F_{1, 10}$ = 0.01; p = 0.95). A linear regression analysis showed there was a significant negative linear relationship between livestock and wild ungulates ᾱ-diversity in PGA during wet season (R^2 = 0.99, p < 0.05) (Table 4.23)

Table 4. 23: Linear regression model of livestock and wild ungulates ᾱ-diversity

Season	Land-use		Sum of Squares	df	Mean Square	F	Sig.
Wet	PGA	Regression	.000	1	.000	343.884	.034*(-)
		Residual	.000	1	.000		
		Total	.000	2			
	PR	Regression	.000	1	.000	.003	.966
		Residual	.007	1	.007		
		Total	.007	2			
	TRL	Regression	.001	1	.001	89.153	.067
		Residual	.000	1	.000		
		Total	.001	2			
Dry	PGA	Regression	.000	1	.000	1.275	.461
		Residual	.000	1	.000		
		Total	.000	2			
	PR	Regression	.001	1	.001	.387	.646
		Residual	.001	1	.001		
		Total	.002	2			
	TRL	Regression	.001	1	.001	2.475	.360
		Residual	.000	1	.000		
		Total	.001	2			

*(-) significant negative linear relationship (p < 0.05)

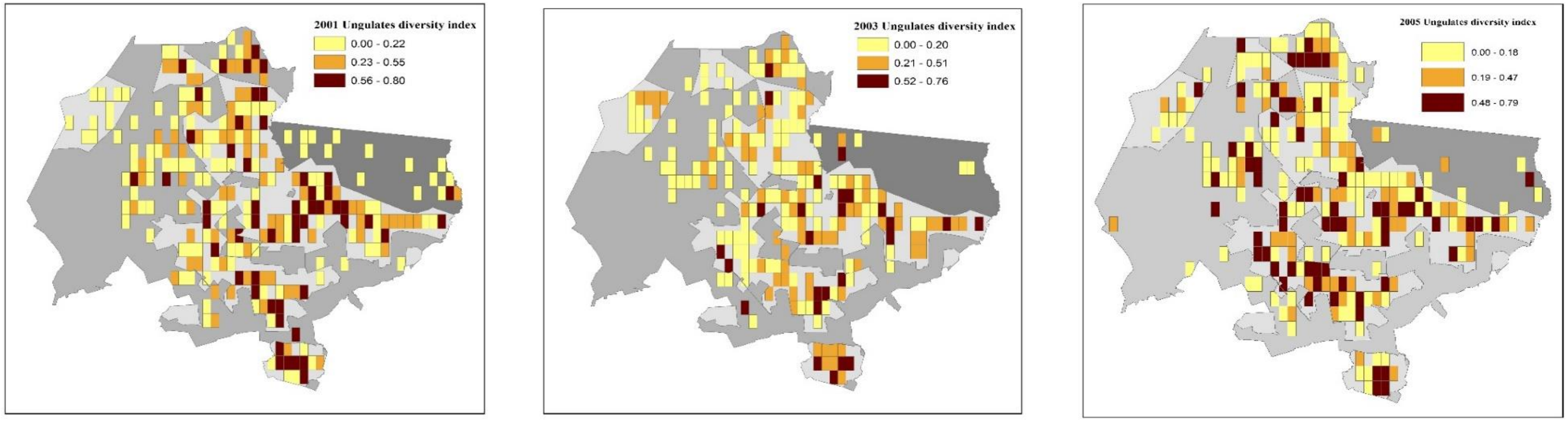


Figure 4.25: Wild ungulates α-diversity index in the three different land use types, (pastoral grazing areas, PGA- dark grey), (transitional lands, TRL-grey), and (private ranches, PR-light grey) during dry season census.

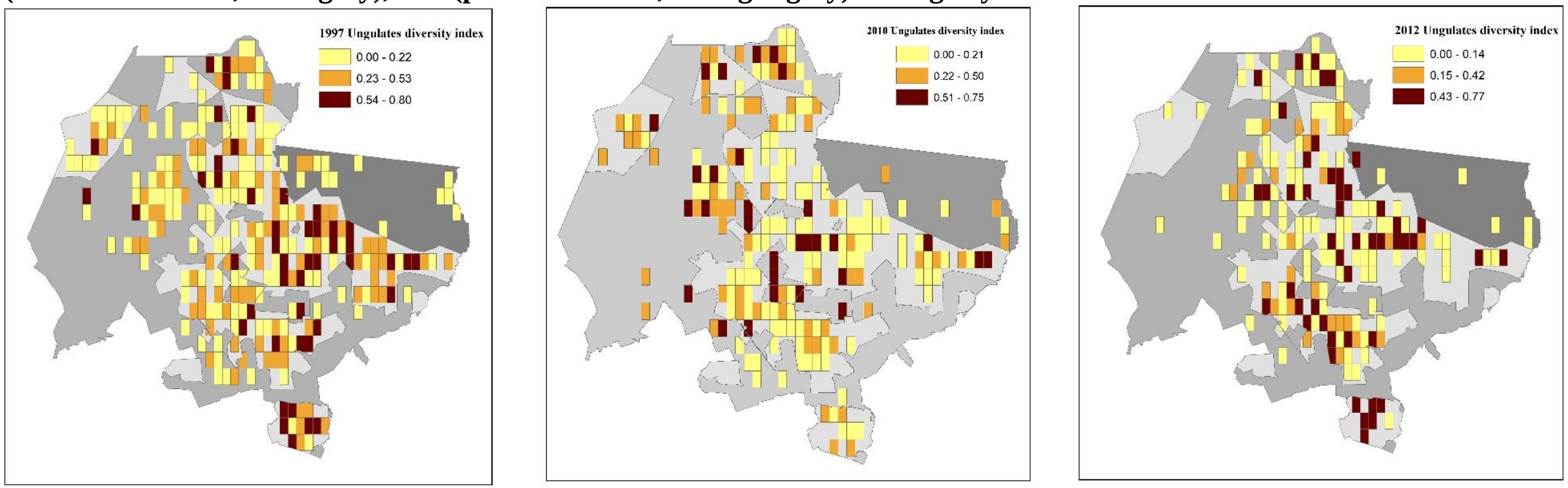


Figure 4.26: Wild ungulates α-diversity index in the three different land use types, (pastoral grazing areas, PGA- dark grey), (transitional lands, TRL-grey), and (private ranches, PR-light grey) during wet season census.

Figure 4.27 below shows variations in β-diversity of the wild herbivores across land-use types in different seasons.

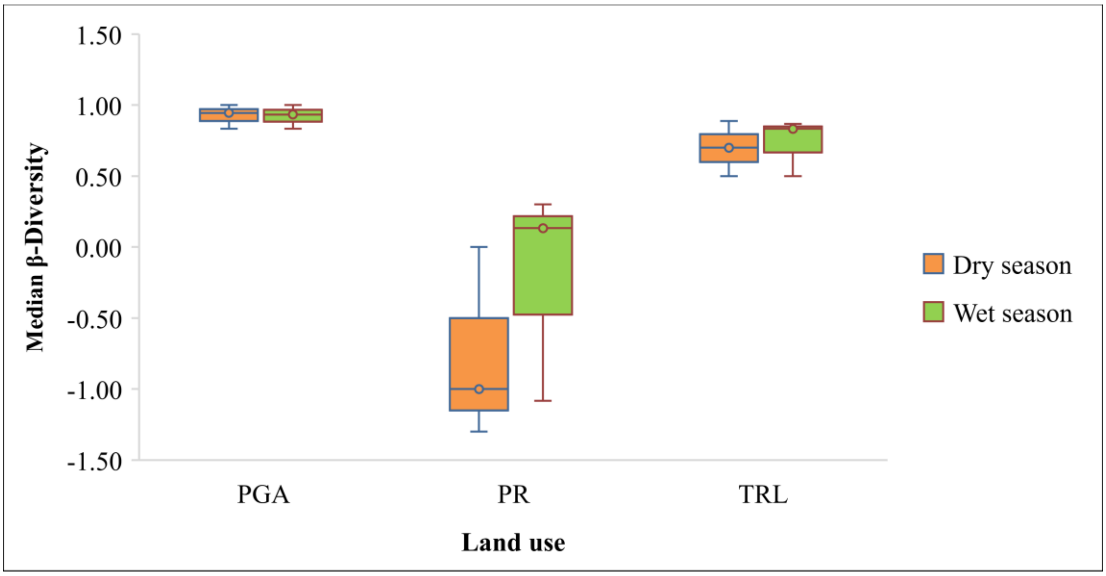


Figure 4.27: β-diversity of wild ungulates in different land-use type

A Kruskal-Wallis test indicated a significant main effect of land-use type on wild ungulates β-diversity (H = 13.43 df = 2 p = 0.001). Subsequent pairwise comparison revealed that β-diversity was significantly higher in PGA than PR ($p < 0.005$) and TRL ($p < 0.005$). There was no significant main effect of seasons on wild ungulates β-diversity (H = 0.05 df = 1 p = 0.825).

Table 4. 24: Linear regression model of livestock and wild ungulates β-diversity

Season	Land-use		Sum of Squares	df	Mean Square	F	Sig.
Wet	PGA	Regression	.014	1	.014	40.740	.099
		Residual	.000	1	.000		
		Total	.015	2			
	PR	Regression	.552	1	.552	.951	.508
		Residual	.580	1	.580		
		Total	1.132	2			
	TRL	Regression	.039	1	.039	.901	.517
		Residual	.043	1	.043		
		Total	.082	2			
Dry	PGA	Regression	.011	1	.011	2.584	.354
		Residual	.004	1	.004		
		Total	.015	2			
	PR	Regression	.600	1	.600	1.836	.405
		Residual	.327	1	.327		
		Total	.927	2			
	TRL	Regression	.034	1	.034	.828	.530
		Residual	.042	1	.042		
		Total	.076	2			

There was also no significant linear relationship between wild ungulate β-diversity and livestock density in all the land-use types during the wet or dry season (Table 4.24).

4.7 Land-use and spatial relationship between cattle and different wild ungulate guilds

Spatial relationship between cattle and different wild ungulate guilds exhibited departure from complete spatial randomness (CSR) across different land-use types at varying scales of distance. This assessment was done for a radial distance (*s*) of 10000 m at an interval of 250 m. The green line (Fig. 4.28 – Fig. 4.32) represents the L_{12} values of cattle and specific wild ungulate guild interaction while the dashed lines represent the upper and lower confidence envelope resulting from a random toroidal shift of 99 simulations of the particular wild ungulate guild (event 2) spatial data. The dotted line ($L_{12} = 0$) corresponds to CSR where the distribution of the two events (cattle/event 1, and wild ungulate guild/event 2) is independent of each other. Below this line ($L_{12} < 0$) is considered negative interaction/repulsion between events while above this line ($L_{12} > 0$) is considered positive interaction/attraction. Above the upper envelope, and below the lower envelope; the interactions are considered to be significant.

4.7.1 Cattle and wild grazers

There were 1025 events of wild grazers and 212 events of cattle in PR, 379 events of wild grazers and 399 events of cattle within the TRL and 23 events of wild grazers and 22 events of cattle in PGA. Cattle and wild grazers generally exhibited attraction in the three land-use types and especially in PR and TRL. In the PR, the attraction was significant from 0 up to approximately 5 km while in TRL, the attraction was significant from 0 up to approximately 4 km. In PGA, there was repulsion between the two guilds for short scale of distance between 0 and approximately 1.5 km; however, there was attraction between cattle and wild grazers in PGA beyond 3 km. Figure 4.28 shows the spatial distribution of cattle and wild grazers, and the graphical representation (L_{12} function) of their spatial relationship across the three land-use types.

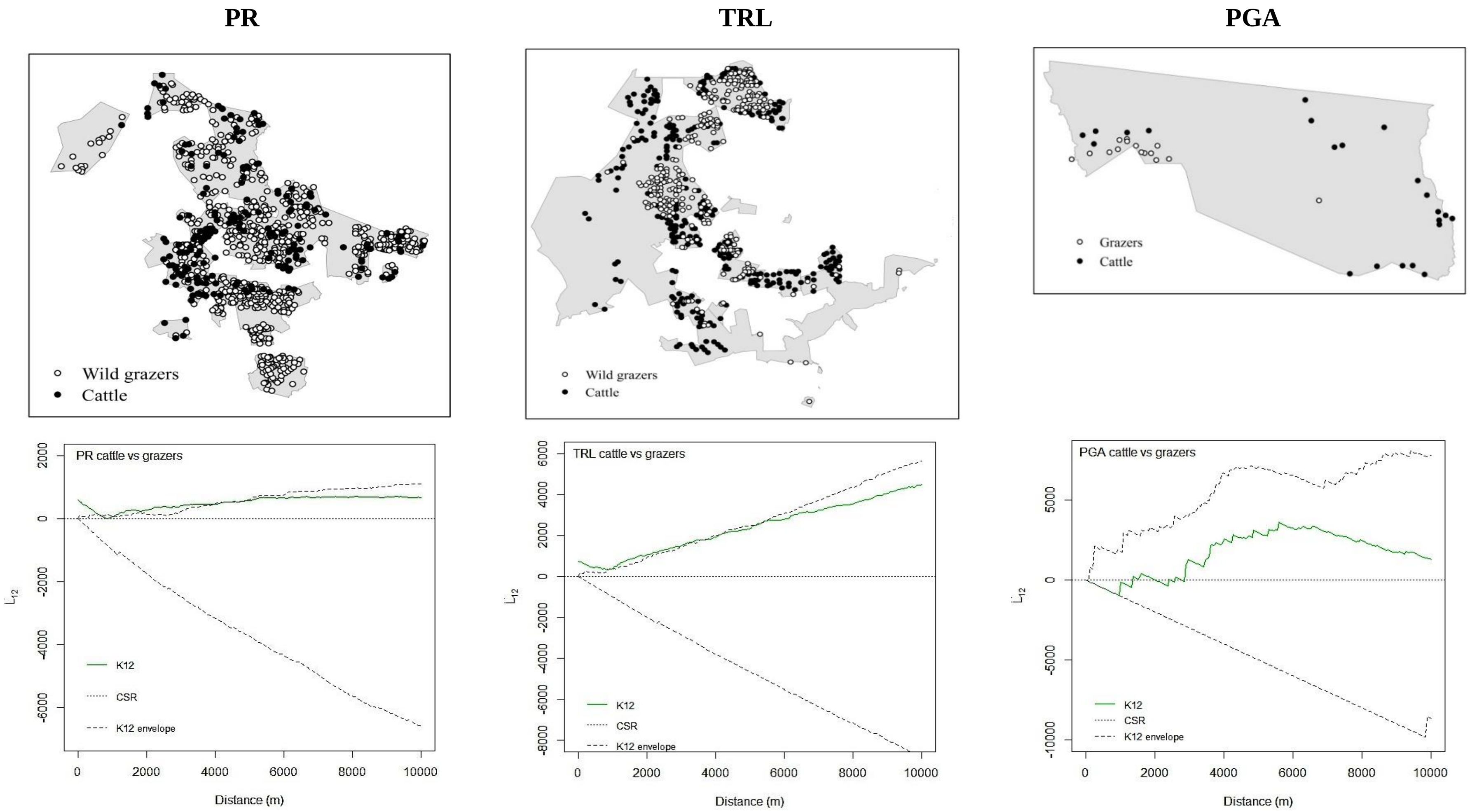


Figure 4.28: Spatial distribution of cattle and wild grazers (above), and a graphical representation of their spatial relationship as L_{12} function (below). The green line represents the L_{12} function, the dotted line represents the complete spatial randomness (CSR) while the dashed lines represents 95% confidence envelope.

4.7.2 Cattle and wild browsers

The browsers events comprised of 271 in PR, 28 in TRL and 6 in PGA while cattle events comprised of 212, 399 and 22 in PR, TRL and PGA respectively. Figure 4.29 shows the spatial distribution and a graphical representation of the distribution of the two events across the three land-use types. Browsers in PR exhibited attraction for distance between 0 and approximately 1 km, beyond this; the relationship largely remained repulsion though close to independent distribution up to around 7 km where the two guilds seemed to attract. In TRL, segregation behavior was observed up to close to 6 km from where the two guilds seemed to attract. In PGA, there was generally an attraction between cattle and browsers with the relationship being significant at very short distances (< 0.5 km).

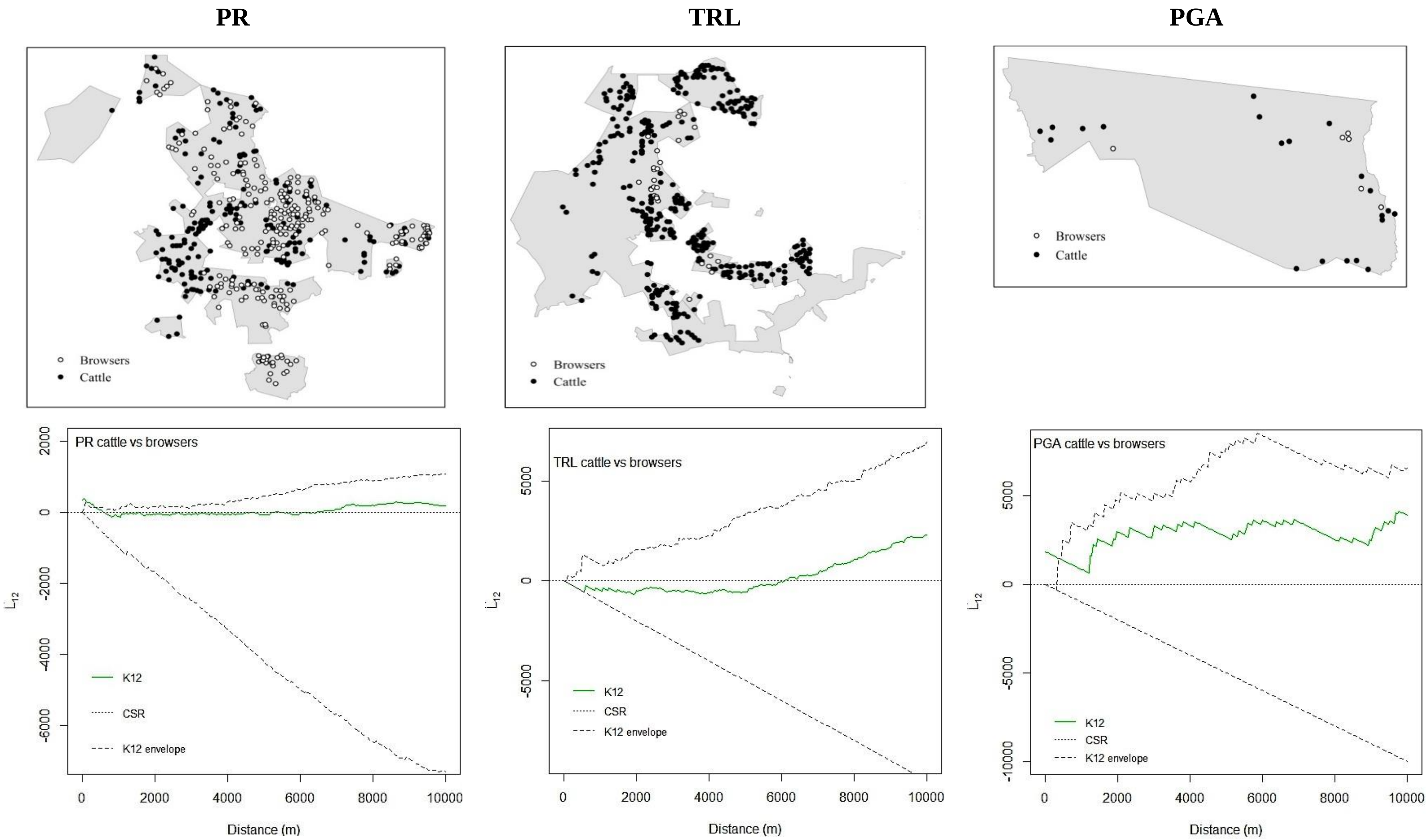


Figure 4.29: Spatial distribution of cattle and browsers (above), and a graphical representation of their spatial relationship as L_{12} function (below). The green line represents the L_{12} function, the dotted line represents the complete spatial randomness (CSR) while the dashed lines represents 95% confidence envelope.

4.7.3 Cattle and mixed-feeders

A total of 564, 57 and 24 events of mixed-feeders were observed in PR, TRL and PGA respectively while cattle consisted of 212 events in PR, 399 events in TRL and 22 groups in PGA. The two events seemed to generally attract in PR with the attraction being significant at very close distance (< 0.5 km). In TRL, significant attraction was observed at short scale of distance (< 0.5 km) followed by repulsion up to around 3 km and then an attraction behavior. In PGA, cattle and mixed-feeders showed repulsion at short distance (< 0.5 km) from where the two guilds showed attraction generally though significant at around 6 km. Figure 4.30 shows the spatial distribution and a linearized L_{12} function of the spatial relationship of the two guilds in different land-use type.

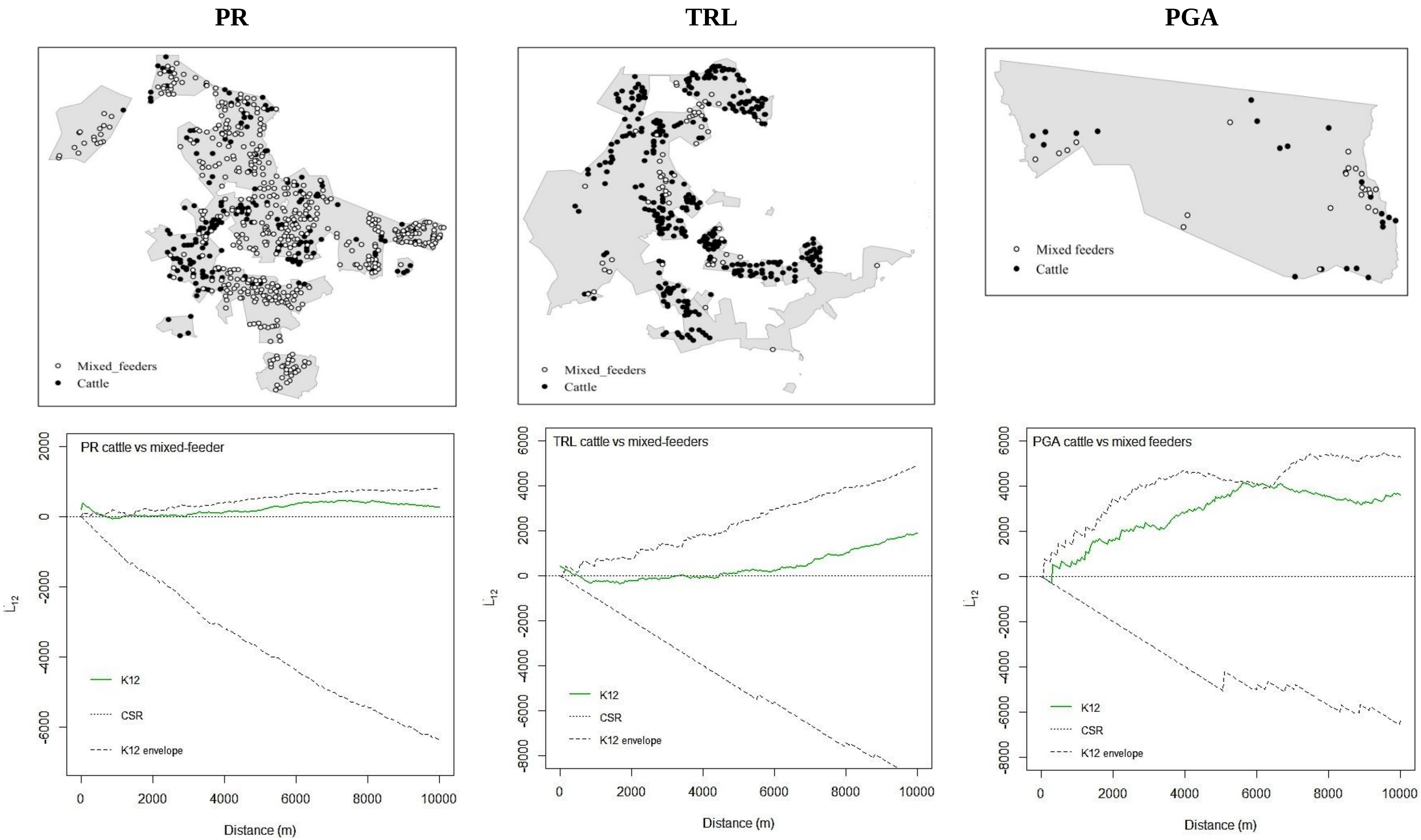


Figure 4.30: Spatial distribution of cattle and mixed-feeder (above), and a graphical representation of their spatial relationship as L_{12} function (below). The green line represents the L_{12} function, the dotted line represents the complete spatial randomness (CSR) while the dashed lines represents 95% confidence envelope.

4.7.4 Cattle and megaherbivores

Megaherbivores comprised of 460 events in PR, 45 in TRL and 22 in PGA while cattle comprised of and 212, 399 and 22 events in PR, TRL and PGA respectively. Megaherbivores in PR showed a significant aggregation with cattle at short distances of approximately (< 0.5 km). Beyond 0.5 km, there seems to have slight segregation between the two guilds. However, this interaction closely tracks independent distribution up to around 5 km where an aggregation is observed. In TRL, the two groups showed significant attraction at short distances (< 0.5 km) followed by repulsion up to approximately 6 km from where an attraction was observed. In PGA, a repulsion between the two guilds was observed at short distances (< 0.5 km) followed by attraction behavior (Fig 4.31).

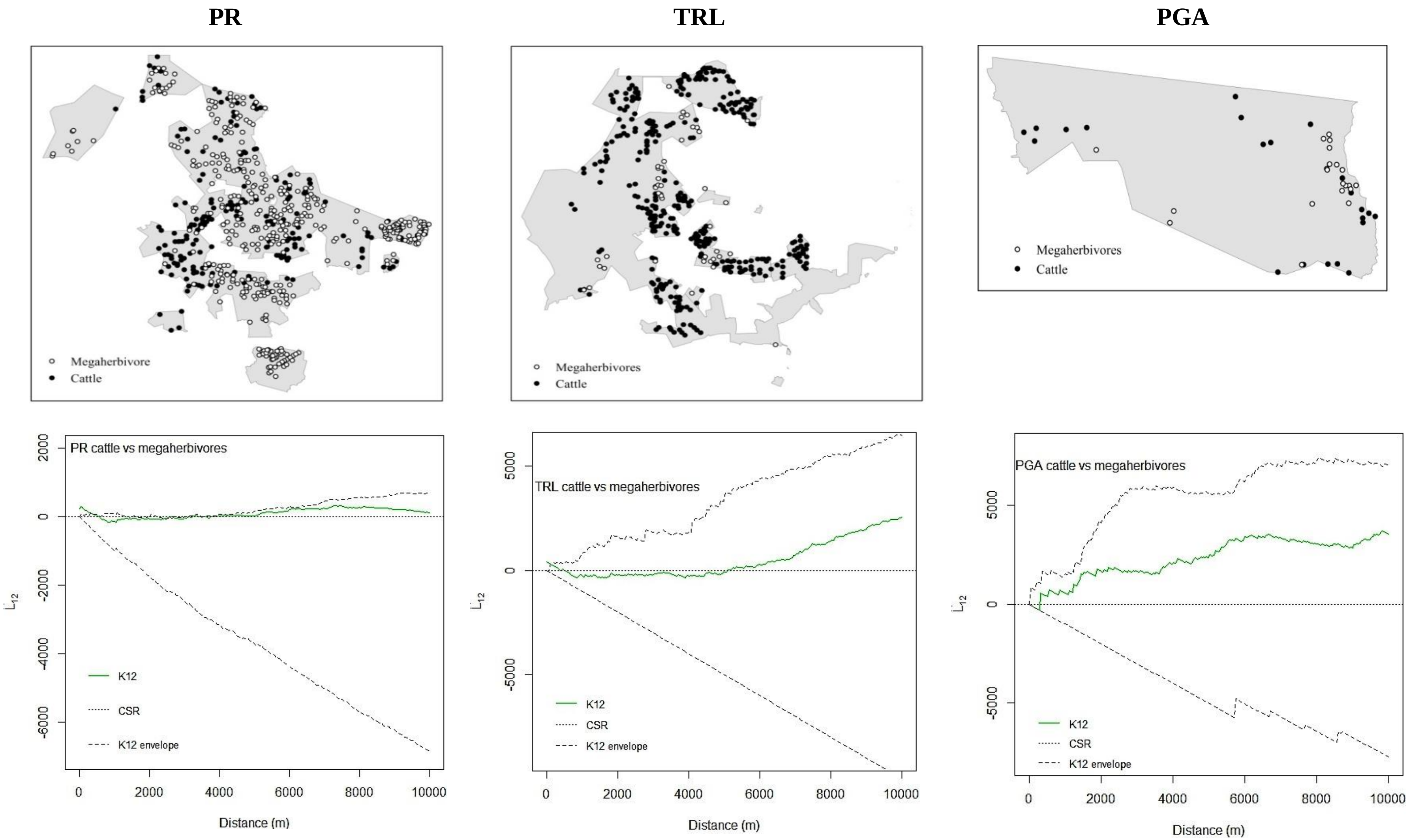


Figure 4.31: Spatial distribution of cattle and megaherbivores (above), and a graphical representation of their spatial relationship as L_{12} function (below). The green line represents the L_{12} function, the dotted line represents the complete spatial randomness (CSR) while the dashed lines represents 95% confidence envelope.

4.7.5 Cattle and medium sized ungulates

There were 1431 events of medium sized ungulates in PR, 421in TRL and 31 in PGA. Cattle comprised of 212 events in PR, 399 events in TRL and 22 events in PGA. The two guilds showed attraction generally in the different land-use types. Attraction was significant in PR from approximately 0-6 km while in TRL, significant attraction was from approximately 0-3 km. In PGA, there was evidence of repulsion between the two guilds at approximately 1.5 km though the behavior remained largely attraction (Fig. 4.32).

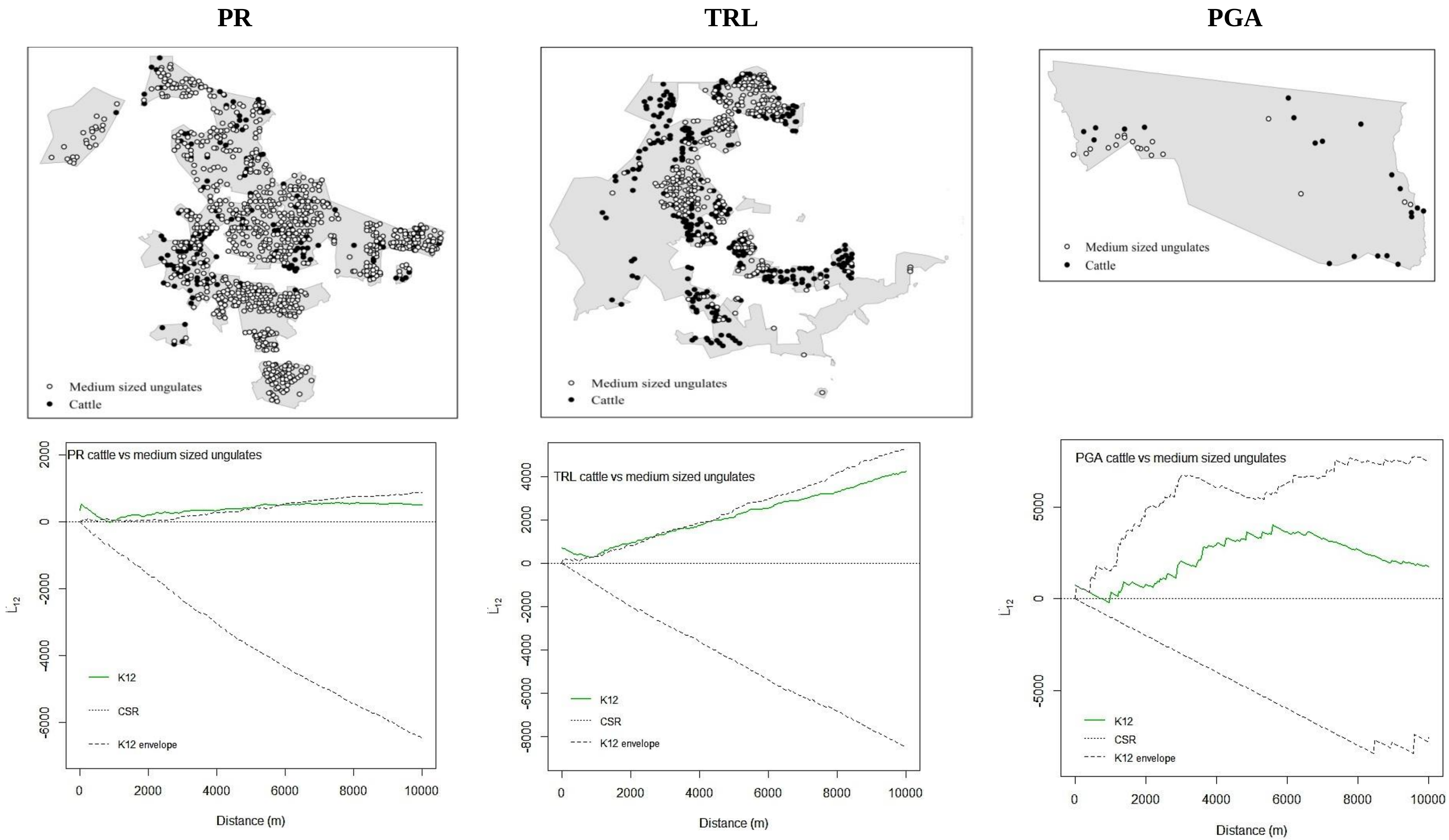


Figure 4.32: Spatial distribution of cattle and medium sized ungulates (above), and a graphical representation of their spatial relation as L_{12} function (below). The green line represents the L_{12} function, the dotted line represents the complete spatial randomness (CSR) while the dashed lines represents 95% confidence envelope.

CHAPTER FIVE

DISCUSSION

5.1 Differences in forage availability among land-use types

Analysis of Normalized Difference Vegetation Index (NDVI) across the three broad land-use types revealed that forage availability was higher in transitional lands (TRL) followed by private ranches (PR). The pastoral grazing areas (PGA) had the lowest forage resources available for domestic and wild ungulates. During the wet season, the variation in mean vegetation index across the three land-use types was very small unlike in the dry periods. The almost same mean vegetation index during the wet season could possibly be attributed to the uniform greening of the vegetation in the landscape due to rainfall.

5.2 Differences in wildlife abundance and diversity across land-use types and between seasons

Wild ungulates spatially dominated the PR (49.1%) while livestock dominated the TRL (57.5%); the spatial dominance of wild ungulates was low in PGA (10.3%). This observation is broadly consistent with (Georgiadis *et al.*, 2007) where the mean biomass density of total wild herbivores and total livestock was higher in PR and TRL respectively. Furthermore, the mean biomass density of wild ungulates was lowest in PGA.

Decline in wildlife in Laikipia rangelands has largely been associated with increased livestock alongside other factors (Aligula *et al.*, 1998). An analysis on abundance of individual wild herbivore species showed that in private ranches (PR) where livestock density was relatively low, the abundance of elephant, Burchell's zebra, Thomson's gazelle, Grant's gazelle, hartebeest, impala, eland, warthog and oryx was significantly higher compared to other land-use types; the Grevy's zebra, waterbuck and gerenuk abundance was equally higher in PR compared to TRL and PGA though the difference in abundance across the three land-use types was not statistically significant. The high abundance of individual species in PR compared to TRL and PGA is broadly attributed to the reduced potential adverse effects associated with livestock on native ungulates for instance habitat encroachment (Scholte, 2011) and possible competition resulting from habitat and dietary overlap especially to wild grazers (Beck and Peek, 2005; Odadi *et al.*, 2011; Ogutu *et al.*, 2009; Riginos *et al.*, 2012; Young *et al.*, 2005). The abundance of Maasai giraffe was also highest in PR, but unlike in other individual species where land-use had main effect in their abundance, a combined interaction effect of land-use type and seasonality seemed to affect its abundance. Although Maasai giraffe are browsers and thus face reduced or no competition over forage resources from livestock, the disturbance from livestock has been shown to cause a decline in giraffe abundance (Ogutu *et al.*, 2009).

Based on body size of wild herbivores, both the megaherbivores and medium sized ungulates numbers were significantly high in PR than in TRL and PGA. The high numbers of megaherbivores in PR could be as a result of reduced competition and disturbance from livestock. Also, management practices could be attributed to the higher number of megaherbivores particularly the rhinos which are almost exclusively found in sanctuaries within the PR due to their conservation status. Other megaherbivores for instance the elephants could be confining themselves in PR as a behavioral adjustment to cope with increasing human-based threats arising from poaching and other harmful activities as a result of human-elephant conflict especially in areas inhabited by humans like TRL and PGA (Wittemyer *et al.*, 2007). While the medium sized ungulates could have preferred the PR over TRL and PGA as a result of reduced competitive pressure and reduced disturbance from livestock, they could also be taking advantage of the facilitative effects by megaherbivores particularly the elephants. Previous studies have shown an increase in specific species of medium sized ungulates (zebra) in areas occupied by elephants (Young *et al.*, 2005).

Grazers and mixed-feeders were significantly more abundant in PR than in TRL and PGA, just like in the case of individual species analysis and ungulate analysis based on body size; reduced competition (especially in mixed-feeders), disturbance and habitat encroachment could be the key drivers of their high numbers in PR. Browsers abundance was equally high in PR but this was attributable to the interaction effect between land-use type and seasonality.

Presence of livestock has been associated with trampling and alteration of plant composition and structure thus affecting the quality of wildlife habitat and eventually the biodiversity (Krausman *et al.*, 2009). In this study, wild herbivores $\bar{\alpha}$-diversity index within land-use types was highest in PR followed by TRL and finally the PGA in both dry and wet season. Seasonal variation in $\bar{\alpha}$-diversity index was not significant. However, land-use had significant main effect on $\bar{\alpha}$-diversity of wild herbivores. This observation was broadly consistent with previous studies in savanna landscapes which showed livestock grazing affects the mean species abundance (MSA) of native species (Alkemade *et al.*, 2013). The effects of livestock on biodiversity have been found to be far reaching not only affecting wild ungulates but also bird and fish species. Furthermore, it has been shown that exclusion of livestock increases small mammals abundance and species diversity (Krausman *et al.*, 2009). The high ungulate β-diversity particularly in the PGA implies high ungulates species turnover associated largely with habitat and/or ecosystem instability due to disturbance (Worm and Duffy, 2003). Additionally, previous studies have indicated that species richness decrease with increase in negative disturbance (Dornelas, 2010). The high ᾱ-diversity in PR and the high β-diversity in PGA are therefore attributed partly to the relatively low livestock spatial dominance and density in PR, and the high rate of habitat disturbance, and forage resources shortage arising from livestock presence in PGA. However, other human related activities could also be contributing to the observed measures of ungulate diversity.

5.3 Differences in spatial interactions across different land-use types

Wild grazers largely exhibited attraction to livestock (cattle) in PR and TRL, in the PGA, cattle and wild grazers exhibited both repulsion and attraction. This observation was generally consistent with (Ego *et al.*, 2003; Voeten and Prins, 1999) where habitat and/or niche overlap between cattle and some wild grazers has been observed especially when forage resources are abundant. Conversely, in the PGA where forage resources were scarce, wild grazers and cattle repelled at short distances (≤ 1400 m) and this could be attributed to the differential resource use which is mostly associated with scarcity (Voeten and Prins, 1999). However, at moderate to large scales of distance; the two guilds showed attraction. The departure of the wild grazers' L_{12} function from CSR across the three land-use types clearly indicated that randomness in the distribution of wild grazers with respect to cattle herds was high in PR than in TRL and PGA; an indication that cattle presence had minimal influence on spatial distribution of wild grazers particularly in PR. This possibly indicated co-existence between cattle and wild grazers in PR.

Browsers showed attraction to cattle at short distances (≈ 1 km) in PR and PGA; however, the relationship changed to a weak repulsion in the PR up to around 7 km where again attraction was observed, the relationship in the PGA remained positive throughout. In TRL, browsers strongly repelled cattle at short distance; furthermore, the relationship remained negative up to approximately 6 km. The observed repulsion between cattle and browsers in PR and TRL could be attributed to lack of dietary niche overlap because the two guilds have different feeding styles as it has previously been observed (Fritz *et al.*, 1996). The observed attraction in the PGA could possibly be due to cattle and browsers occupying same resource patches even though utilizing different forage materials.

Mixed feeders exhibited different spatial relationships to cattle in all the land-use systems. In PR, significant attraction followed by a short stint of repulsion was observed at short distance; however, the general interaction was largely attraction although close to CSR. In TRL, significant attraction was observed at short distances followed by repulsion and then an attraction, while in PGA, a strong repulsion followed by attraction behavior was observed. The dynamics in the spatial relationship between cattle and mixed feeders can be attributed to the dynamic feeding style of mixed feeders, this observation is closely in conformity with (Hibert *et al.*, 2010) on three different species of mixed feeders.

Megaherbivores showed significant attraction to cattle at short distances (≤ 500 m) followed by repulsion up to around 5 km and 6 km in PR and TRL respectively, beyond this distance; the two guilds exhibited attraction to each other though not significant. In PGA, the spatial relationship was largely attraction although strong repulsion was evident at very short distances. The attraction and repulsion behavior as it was observed could be attributed to the two guilds utilization of different habitat types on one hand (as in the case of browsing megaherbivores) and seasonal habitat and/or dietary overlap (as in the case of mixed feeders megaherbivores).

The medium sized ungulates generally showed attraction behavior to cattle in all the three land-use systems. Significant attractions were observed from 0 to close to 6 km and from 0 to around 3 km in PR and TRL respectively. In PGA, the relationship was significant at short distances, however, at around 1.5 km, there was a short stint of repulsion between cattle and medium sized ungulates. The observed general attraction between the two guilds particularly in PR and TRL was thought to be due to the reduced competitive pressure because some individual species constituting this wild herbivore group browsed while others were mixed feeders.

There were observable differences in forage availability across the different land-use types in the study area; furthermore, these differences occurred even between seasons. Additionally, wild ungulates and livestock occupied the three land-use systems in varying proportions in different seasons. Previous studies have revealed that the densities of wild ungulates and livestock across various land use types in the study area differ (Georgiadis *et al.*, 2007). The observed dynamics in the measured wild ungulates community attributes (abundance, distribution, diversity and spatial relationship) could therefore be broadly attributed to: 1) forage resource availability and 2) livestock presence across different land-use types. Forage resource availability was largely determined by seasonality besides other land-use management practices carried out in the different land-use types. Pasture resources availability is a requisite conditional requirement for interspecific competition (which is thought to be the key ecological driver of the observed wild ungulates response to livestock presence) to occur between sympatric populations (Butt and Turner, 2012).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

6.1.1 Forage availability across land-use types in different seasons

Forage availability differed across the three broad land-use types. Forage was highest in the transitional land (TRL) followed by the private ranches (PR) and finally the pastoral grazing areas (PGA); however, these differences were not statistically significant. Furthermore, forage availability differed between seasons; it was high during wet season than during dry season. However, it is conspicuously notable that this seasonal variation in forage availability was not statistically significant.

6.1.2 Distribution of wild ungulates and livestock across land-use types and seasons

Wild herbivores spatially and numerically dominated the PR while livestock spatially and numerically dominated the TRL and the PGA. The distribution of wild ungulates and livestock seemed to largely have an inverse relationship in the different land-use types. This possibly implied that wild ungulates tended to restrict themselves to areas with no, or with minimal livestock density. With regard to seasonality, both wild herbivores and livestock spatially occupied larger areas in dry season compared to wet season. The range expansion during dry season could be driven by the need for the wild ungulates and livestock to forage wider to meet their constrained nutritional requirement especially during dry season.

6.1.3 Effects of land-use and seasonality on wild ungulates abundance and diversity

Land-use significantly affected the abundance of nine wild ungulate species but it did not affect the abundance of three wild herbivore species. Seasonality only affected significantly the abundance of Grevy’s zebra while interaction between land-use type and seasonality affected the abundance of Maasai giraffe. Based on ungulates groupings, land-use significantly affected the numbers of grazers, mixed feeders, megaherbivores and medium sized ungulates. Interaction between land-use and seasonality affected the number of browsers while seasonality did not affect any of these ungulate guilds significantly. Both measures of wild ungulate diversity ($\bar{\alpha}$-diversity and β-diversity) significantly varied across the land-use systems; however, seasonality did not affect ungulate diversity significantly. Livestock driven land-use type seems to have actual effect on abundance and diversity of wild herbivores while seasonal changes seems to have minimal effect on wild herbivore abundance and diversity.

6.1.4 Effects of land-use type on wild ungulate guilds and cattle spatial relationship

Different wild ungulate guilds exhibited varying spatial relationship with cattle at different scales of distance. This was possibly attributable to the habitat and/or dietary niche overlap amidst other biotic and abiotic factors. A notable observation from this study was the minimal departure of the L_{12} function curve from CSR in PR compared to the other two land-use types. This implied that distribution of different wild ungulate guilds in PR was more random unlike in TRL and PGA; this could be taken as an indicator of better co-existence between cattle and wild herbivore in PR. The general attraction behaviour observed in PGA while considering the relatively low primary productivity as shown by the low NDVI could be an indicator of high degree of habitat overlap between wild herbivores and cattle, a situation that can easily culminate into competition in exploitation of pasture resources.

6.2 Recommendations

Laikipia savanna rangeland has significant ecological and conservation importance owing to the huge number and diverse species of fauna and flora despite the small proportion of land that is formally protected for wildlife conservation. Wildlife management broadly involves management of: 1) wildlife populations, 2) wildlife habitats and 3) people (inside and outside conservation areas). To maintain a stable ecological and environmental balance, it is important that different stakeholders put concerted efforts in ensuring that wildlife populations and habitats as well as people living in Laikipia are in harmony.

6.2.1 Recommendations for land management

1. To ensure adequate and stable forage availability for wildlife and livestock, the degraded land areas should be rehabilitated by replanting native vegetation; either grasses or plants, or by allowing them enough time to facilitate natural regeneration especially in the TRL and PGAs. Additionally, the pastoralists inhabiting the PGA should be educated on the need to maintain sustainable livestock populations based on the carrying capacity of the ecosystems to prevent further degradation through overstocking.
2. The possibilities of rangeland manipulation in attempt to evenly redistribute forage resources for wildlife and livestock should be explored especially in the TRL and PGAs, this can be achieved by practicing organized grazing among others. Farm-forestry should also be encouraged particularly in the TRL to assist in improving provision of habitable habitats for some wild herbivore species.

3. To ensure that wild herbivore populations increase in the TRL and PGAs; land owners with big tracts of land should be encouraged to engage in land-use practices that are compatible with wildlife conservation. Also, further sub-division of land should be discouraged specifically in TRL.
4. The pastoral communities occupying the PGA, and also the herders in TRL should be sensitized on the need of maintaining sustainable populations of cattle based on the carrying capacity of the ecosystem to reduce or prevent potential competition over pasture resources utilization between cattle and wild herbivores. This can increase randomness in the spatial relationship between cattle and wild ungulates.

6.2.2 Recommendation for future studies

1. More studies should to be done particularly on wild and domestic ungulates spatial relationship with particular focus on specific focal wild herbivore species. Additionally, a differential study should be done to establish the primary productivity of browse and grazing material available for wild herbivores and livestock in all the land-use types.
2. Research should be done to establish the livestock stocking density threshold above which wild herbivores respond negatively to livestock presence.
3. Research on potential effects of predator presence, habitat type and other biotic and abiotic factors that may affect wild herbivore community and livestock in Laikipia should be enhanced.
4. Additional resources should be mobilized towards constant monitoring and periodic evaluation of wild herbivore abundance and diversity as well as livestock populations in order to inform wildlife conservation and management decisions in Laikipia.

REFERENCES

Aligula, H. M., Said, M. Y., Njuguna, E. C., de Leeuw, J., and Skidmore, A. K. (1998). *Geo-information for sustainable rangeland management*: Department of Resource Surveys and Remote Sensing.

Alkemade, R., Reid, R. S., van den Berg, M., de Leeuw, J., and Jeuken, M. (2013). Assessing the impacts of livestock production on biodiversity in rangeland ecosystems. *Proceedings of the National Academy of Sciences, 110*(52), 20900-20905.

Anonymous. (2018). AEZs: Kenya System. Retrieved from infonet-biovision.org/EnvironmentalHealth/AEZs-Kenya-System website:

Arbogast, A. F. (2011). *Discovering Physical geograPhy* (Second ed.). United States of America: Wiley.

Averbeck, C., Apio, A., Plath, M., and Wronski, T. (2009). Environmental parameters and anthropogenic effects predicting the spatial distribution of wild ungulates in the Akagera savannah ecosystem. *African Journal of Ecology, 47*(4), 756-766.

Beck, J. L., and Peek, J. M. (2005). Diet Composition, Forage Selection, and Potential for Forage Competition Among Elk, Deer, and Livestock on Aspen-Sagebrush Summer Range. *Rangeland Ecology & Management, 58*(2), 135-147. doi: http://srmjournals.org/doi/abs/10.2111/03-13.1

Bell, R. H. V. (1986). Soil-plant-herbivore interactions. *Conservation and wildlife management in Africa*, 107-130.

Blench, R., and Sommer, F. (1999). *Understanding rangeland biodiversity*: Overseas Development Institute London.

Bowyer, R. T., Van Ballenberghe, V., and Kie, J. G. (1997). The role of moose in landscape processes: effects of biogeography, population dynamics, and predation *Wildlife and Landscape Ecology* (pp. 265-287): Springer.

Brower, J. E., Zar, J. H., and Von Ende, C. N. (Eds.). (1990). *Field and Laboratory Methods for General Ecology* (Third Edition ed.). United States of America: Wm.C.Brown

Butt, B., and Turner, M. D. (2012). Clarifying competition: the case of wildlife and pastoral livestock in East Africa. *Pastoralism, 2*(1), 1-15.

Coe, P. K., Johnson, B. K., Stewart, K. M., and Kie, J. G. (2004). *Spatial and temporal interactions of elk, mule deer, and cattle.* Paper presented at the North American Wildlife and Natural Resources Conference.

Craigie, I. D., Baillie, J. E. M., Balmford, A., Carbone, C., Collen, B., Green, R. E., and Hutton, J. M. (2010). Large mammal population declines in Africa's protected areas. *Biological Conservation, 143*(9), 2221-2228.

Cumming, D. H. M. (1982). The influence of large herbivores on savanna structure in Africa. In B. J. Huntley and B. H. Walker (Eds.), *Ecology of Tropical Savannas* (pp. 217–245). Berlin: Springer-Verlag.

Dornelas, M. (2010). Disturbance and change in biodiversity. *Philosophical Transactions of the Royal Society B: Biological Sciences, 365,* 3719-3727. doi: doi:10.1098/rstb.2010.0295

Du Toit, J. T., and Cumming, D. H. M. (1999). Functional significance of ungulate diversity in African savannas and the ecological implications of the spread of pastoralism. *Biodiversity & Conservation, 8*(12), 1643-1661. doi: http://dx.doi.org/10.1023/A%3A1008959721342

Ego, W., Mbuvi, D., and Kibet, P. (2003). Dietary composition of wildebeest (Connochaetes taurinus) kongoni (Alcephalus buselaphus) and cattle (Bos indicus), grazing on a common ranch in south - central Kenya. *African Journal of Ecology, 41*(1), 83-92.

Emg, U. N. (2011). Global drylands: a UN system-wide response. *United Nations Environment Management Group, 131*.

FAO. (2005). Livestock Sector Brief *Livestock Information, Sector Analysis and Policy Branch*. Rome: Food and Agriculture Organisation.

Fritz, H., De Garine-Wichatitsky, M., and Letessier, G. (1996). Habitat Use by Sympatric Wild and Domestic Herbivores in an African Savanna Woodland: The Influence of Cattle Spatial Behaviour. *Journal of Applied Ecology, 33*(3), 589-598. doi: 10.2307/2404987

Fritz, H., Duncan, P., Gordon, I. J., and Illius, A. W. (2002). Megaherbivores influence trophic guilds structure in African ungulate communities. *Oecologia, 131*(4), 620-625.

Gao, X., Huete, A. R., Ni, W., and Miura, T. (2000). Optical–biophysical relationships of vegetation spectra without background contamination. *Remote Sensing of Environment, 74*(3), 609-620.

Georgiadis, N. J., Olwero, J. G. N., Ojwang, G., and Romaach, 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. doi: http://www.sciencedirect.com/science/article/pii/S0006320707001097

Gordon, I. J. (1988). Facilitation of red deer grazing by cattle and its impact on red deer performance. *Journal of Applied Ecology*, 1-9.

Gottsberger, G., and Silberbauer-Gottsberger, I. (2009). Tropical Savannas-Introduction. *Tropical Biology and Conservation Management., X*. www.eolss.net/sample-chapters/c20/e6-142-se-18.pdfdoi: www.eolss.net/sample-chapters/c20/e6-142-se-18.pdf

Grace, J., Jose, J. S., Meir, P., Miranda, H. S., and Montes, R. A. (2006). Productivity and carbon fluxes of tropical savannas. *Journal of Biogeography, 33*, 387-400.

Hibert, F., Calenge, C., Fritz, H., Maillard, D., Bouche, P., Ipavec, A., Convers, A., Ombredane, D., and de Visscher, M.-N. (2010). Spatial avoidance of invading pastoral cattle by wild ungulates: insights from using point process statistics. *Biodiversity and conservation, 19*(7), 2003-2024.

Hill, M. J., Henan, N. P., Hoffmann, W., Scholes, R., Prince, S., Ferwerda, J., Lucas, R. M., Baker, I., Arneth, A., Higgins, I., Barrett, D. J., Disney, M., and Hutley, L. (2010). *Remote Sensing and Modeling of Savannas: The State of the Dis-Union*. Colorado State University. 2-4 March 2010

Homewood, K., Lambin, E. F., Coast, E., Kariuki, A., Kikula, I., Kivelia, J., Said, M., Serneels, S., and Thompson, M. (2001). Long-term changes in Serengeti-Mara wildebeest and land cover: Pastoralism, population, or policies? *Proceedings of the National Academy of Sciences, 98*(22), 12544-12549. doi: 10.1073/pnas.221053998

Huntley, B., Walker, B., and Huntley, B. J. (1982). Southern African Savannas *Ecology of Tropical Savannas* (Vol. 42, pp. 101-119): Springer Berlin Heidelberg.

Huxley, J. (1961). The Wild Riches of Africa. *Published by the Observer for the Fauna Preservation Society, London*.

Johnson, B. K., Wisdom, M. J., and Cook, J. G. (2005). *Issues of elk productivity for research and management.* Paper presented at the The Starkey Project: a synthesis of long-term studies of elk and mule deer. Reprinted from the 2004 Transactions of the North American Wildlife and Natural Resources Conference, Aliance Communications Group, Lawrence, Kansas, USA.

Jolly, G. M. (1969). Sampling methods for aerial censuses of wildlife populations. *East Africa Agricultural Forestry Journal, 34*, 46-49.

Justice, C., Scholes, B., and Frost, P. (1994). African savannas and the global atmosphere. Research agenda. Report of a joint IGBP/START/IGAC/GCTE/GAIM/DIS workshop on African savannas, land use and global change: interactions of climate, productivity and emissions, 2-5 June 1993, Victoria Falls, Zimbabwe. *Global Change Report (Sweden)*.

Kauffman, J. B., and Pyke, D. A. (2001). Range ecology, global livestock influences. *Encyclopedia of biodiversity, 5*, 33-52.

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 *Report submitted to Laikipia Wildlife Forum, Nanyuki, Kenya*.

Krausman, P. R., Naugle, D. E., Frisina, M. R., Northrup, R., Bleich, V. C., Block, W. M., Wallace, M. C., and Wright, J. D. (2009). Livestock grazing, wildlife habitat, and rangeland values. *Rangelands, 31*(5), 15-19.

Kruska, R. L., Reid, R. S., Thornton, P. K., Henninger, N., and Kristjanson, P. M. (2003). Mapping livestock-oriented agricultural production systems for the developing world. *Agricultural systems, 77*(1), 39-63.

Lotwick, H. W., and Silverman, B. W. (1982). Methods for analysing spatial processes of several types of points. *Journal of the Royal Statistical Society. Series B (Methodological)*, 406-413.

Low, B., Sundaresan, S. R., Fischhoff, I. R., and Rubenstein, D. I. (2009). Partnering with local communities to identify conservation priorities for endangered Grevy's zebra. *Biological Conservation, 142*(7), 1548-1555. doi: http://www.sciencedirect.com/science/article/pii/S0006320709000779

LWF. (2012). A Wildlife Conservation Strategy for Laikipia County (2012-2030). Nanyuki: Laikipia Wildlife Forum.

Macedo, M. C. M. (1997). *Sustainability of pasture production in the savannas of tropical America*. Paper presented at the XVIII International Grassland Congress, Canada.

Maleko, D. D., Mbassa, G. N., Maanga, W. F., and Sisya, E. S. (2012). Impacts of Wildlife-Livestock Interactions in and around Arusha National Park, Tanzania. *Current Research Journal of Biological Sciences, 4*(4), 471-476.

Milner-Gulland, E. J., and Rowcliffe, J. M. (2007). *Conservation and sustainable use: a handbook of techniques*: Oxford University Press.

Myneni, R. B., Hall, F. G., Sellers, P. J., and Marshak, A. L. (1995). The interpretation of spectral vegetation indexes. *IEEE Transactions on Geoscience and Remote Sensing, 33*(2), 481-486.

Nayak, S., Jena, J., and Dave, C. (2013). Impact of Cattle Grazing on Wild Ungulate Habitat in Kanha-Pench Corridor, Madhya Pradesh. *World Journal of Zoology, 8*(4), 354-365.

Norton-Griffiths, M. (1978). *Counting Animals* (2^{nd} ed.). Nairobi, Kenya: African Wildlife Foundation,.

Odadi, W. O., Karachi, M. K., Abdulrazak, S. A., and Young, T. P. (2011). African wild ungulates compete with or facilitate cattle depending on season. *Science, 333*(6050), 1753-1755.

Odadi, W. O., Young, T. P., and Okeyo-Owuor, J. B. (2007). Effects of Wildlife on cattle in Laikipia Rangeland, Kenya. *Rangeland Ecology & Management, 60*, 179-185.

Ogutu, J. O., Owen Smith, N., Piepho, H. P., and Said, M. Y. (2011). Continuing wildlife population declines and range contraction in the Mara region of Kenya during 1977-2009. *Journal of Zoology, 285*(2), 99-109.

Ogutu, J. O., Piepho, H. P., Dublin, H. T., Bhola, N., and Reid, R. S. (2009). Dynamics of Mara Serengeti ungulates in relation to land use changes. *Journal of Zoology, 278*(1), 1-14.

Ojwang, G. O. (2000). *On sampling variability of wildlife cropping-quota allocated on the basis of airborne sample surveys.* MSc Thesis. ITC, Enschede.

Ottichilo, W. K., De Leeuw, J., Skidmore, A. K., Prins, H. H. T., and Said, M. Y. (2000). Population trends of large non-migratory wild herbivores and livestock in the Masai Mara ecosystem, Kenya, between 1977 and 1997. *African Journal of Ecology, 38*(3), 202-216.

Owen-Smith, N., and Cumming, D. H. M. (1993). *Comparative foraging strategies of grazing ungulates in African savanna grasslands.* Paper presented at the XVII International Grasslands Congress New Zealand.

Patil, G. P., and Taillie, C. (1982). Diversity as a concept and its measurement. *Journal of the American Statistical Association, 77*(379), 548-561.

Pederson, R. J., Adams, A. W., and Skovlin, J. M. (1980). *Elk habitat use in an unlogged and logged forest environment*: Oregon Department of Fish and Wildlife, Research and Development Section.

Peek, J. M., and Krausman, P. R. (1996). Grazing and mule deer. *Rangeland wildlife. Denver, CO: The Society for Range Management*, 183-192.

Pettorelli, N., Ryan, S., Mueller, T., Bunnefeld, N., Jędrzejewska, B., Lima, M., and Kausrud, K. (2011). The Normalized Difference Vegetation Index (NDVI): unforeseen successes in animal ecology. *Climate Research, 46*(1), 15-27.

Prins, H. H. T., Grootenhuis, J. G., and Dolan, T. T. (2000). *Wildlife conservation by sustainable use*: Kluwer Academic Publishers.

Riginos, C., Porensky, L. M., Veblen, K. E., Odadi, W. O., Sensenig, R. L., Kimuyu, D., Keesing, F., Wilkerson, M. L., and Young, T. P. (2012). Lessons on the relationship between livestock husbandry and biodiversity from the Kenya Long-term Exclosure Experiment (KLEE). *Pastoralism, 2*(1), 1-22.

Robinson, T., Thornton, P., Franceschini, G., Kruska, R., Chiozza, F., Notenbaert, A., Cecchi, G., Herrero, M., Epprecht, M., and Fritz, S. (2011). *Global livestock production systems*. Rome: Food and Agriculture Organization of the United Nations (FAO).

Wildlife (Conservation and Management) Act, Chapter 376 (2012).

Rosen, C. (2000). *World Resources 2000-2001: People and ecosystems: The fraying web of life*. Washington, DC 20002 USA: World Resources Institute.

Rosenzweig, M. L. (1995). *Species diversity in space and time*. Cambridge, UK: Cambridge University Press.

Rowland, M. M., Wisdom, M. J., Johnson, B. K., and Kie, J. G. (2000). Elk distribution and modeling in relation to roads. *The Journal of Wildlife Management*, 672-684.

Sangeda, A. Z., and Malole, J. L. (2014). Tanzanian rangelands in a changing climate: Impacts, adaptations and mitigation. *Net Journal of Agricultural Science, 2(1)*, 1-10.

Schipper, J., Chanson, J. S., Chiozza, F., Cox, N. A., Hoffmann, M., Katariya, V., Lamoreux, J., Rodrigues, A. S. L., Stuart, S. N., and Temple, H. J. (2008). The status of the world's land and marine mammals: diversity, threat, and knowledge. *Science, 322*(5899), 225-230.

Scholte, P. (2011). Towards understanding large mammal population declines in Africa's protected areas: A West-Central African perspective. *Tropical Conservation Science, 4*(1), 1-11.

Sebastian, K. (Ed.). (2014). *Atlas of African agriculture research and development: Revealing agriculture's place in Africa*. Washington, DC: International Food Policy Research Institute.

Sellers, P. J. (1985). Canopy reflectance, photosynthesis and transpiration. *International Journal of Remote Sensing, 6*(8), 1335-1372.

Sitters, J., Heitknig, I. M. A., Holmgren, M., and Ojwang, G. S. O. (2009). Herded cattle and wild grazers partition water but share forage resources during dry years in East African savannas. *Biological Conservation, 142*(4), 738-750. doi: http://www.sciencedirect.com/science/article/pii/S0006320708004746

Solbrig, O. T., Medina, E., and Silver, J. (1996). Biodiversity and Savanna Ecosystem Process: A Global Perspective. In H. A. Mooney ,J. H. Cushman ,E. Medina ,O. E. Sala and E. D. Schulze (Eds.), *Functional Roles of Biodiversity*. Berlin: John Wiley & Sons Ltd.

Stewart, K. M., Bowyer, R. T., Kie, J. G., Cimon, N. J., and Johnson, B. K. (2002). Temporospatial distributions of elk, mule deer, and cattle: resource partitioning and competitive displacement. *Journal of Mammalogy, 83*(1), 229-244.

Strahler, A. (2013). *Introducing Physical Geography* (Sixth ed.). United States of America: Wiley.

Sundaresan, S. R., and Riginos, C. (2010). Lessons learned from biodiversity conservation in the private lands of Laikipia, Kenya. *A Journal of Natural and Social Sciences, Paper 1081*.

Turpie, J. K., and Crowe, T. M. (1994). Patterns of distribution, diversity and endemism of larger African mammals. *South African Journal of Zoology, 29*(1), 19.

Voeten, M. M., and Prins, H. H. T. (1999). Resource partitioning between sympatric wild and domestic herbivores in the Tarangire region of Tanzania. *Oecologia, 120*(2), 287-294. doi: http://dx.doi.org/10.1007/s004420050860

Walker, B. H., and NoyMeir, I. (1982). Aspects of stability and resilience of savanna ecosystems. *Applied Ecology, 24*, 381-401.

Walter, H. (1971). *Ecology of Tropical and Subtropical Vegetation*. Edinburgh: Oliver Boyd.

Western, D. (1989). Conservation without parks: wildlife in the rural landscape. *Conservation for the Twenty-first Century*, 158-165.

Western, D., Russell, S., and Cuthill, I. (2009). The status of wildlife in protected areas compared to non-protected areas of Kenya. *PloS one, 4*(7), e6140.

Whittaker, R. H. (1972). Evolution and measurement of species diversity. *Taxon, 21*, 213-251.

Williams, R. E., Allred, B. W., Denio, R. M., and Paulsen Jr, H. A. (1968). Conservation, development, and use of the world's rangelands. *Journal of Range Management*, 355-360.

Wittemyer, G., Getz, W., Vollrath, F., and Douglas-Hamilton, I. (2007). Social dominance, seasonal movements, and spatial segregation in African elephants: a contribution to conservation behavior. *Behavioral Ecology and Sociobiology, 61*(12), 1919-1931.

Worm, B., and Duffy, J. E. (2003). Biodiversity, productivity and stability in real food webs. *Trends in Ecology & Evolution, 18*(12), 628-632. doi: http://www.sciencedirect.com/science/article/pii/S0169534703002799

Young, T. P., Palmer, T. M., and Gadd, M. E. (2005). Competition and compensation among cattle, zebras, and elephants in a semi-arid savanna in Laikipia, Kenya. *Biological Conservation, 122*(2), 351-359. doi: http://www.sciencedirect.com/science/article/pii/S0006320704003799

zu Dohna, H., Peck, D. E., Johnson, B. K., Reeves, A., and Schumaker, B. A. (2013). Wildlife-livestock interactions in a western rangeland setting: Quantifying disease-relevant contacts. *Preventive Veterinary Medicine, 113*(4), 447-456.

APPENDICES

APPENDIX 1: REQUEST LETTER FOR RESEARCH PERMIT

EGERTON UNIVERSITY

Tel: Pilot: 254-51-2217620
254-51-2217877
254-51-2217631
Dir. line/Fax: 254-51-2217847

P.O. Box 536 – 20115
Egerton, Njoro, Kenya
Email: bpgs@egerton.ac.ke
www.egerton.ac.ke

OFFICE OF THE DIRECTOR GRADUATE SCHOOL

REF: NM11/3682/13 **DATE:** 15th Nov. 2018

The Director General
National Commission for Science Technology and Innovation
P. O. Box 30623-00100
NAIROBI

Dear Sir,

RE: REQUEST FOR RESEARCH PERMIT – GEOFFREY WANGOMBE KINGA, REG. NO: NM11/3682/13

This is to introduce and confirm to you that the above named student is in the Department of Natural Resources, Egerton University.

He is a bonafide registered Masters student in this University. His research topic is entitled **"Effects of Land Use and Seasonality on the Response of Wild Ungulates to Livestock Grazing in Laikipia Rangeland, Kenya."**

He is at the stage of collecting field data. Please issue him with a research permit to enable him undertake the studies.

PROF. NZULA KITAKA
DIRECTOR, BOARD OF POSTGRADUATE STUDIES

DIRECTOR, BOARD OF POST GRADUATE STUDIES
15 NOV 2018
EGERTON UNIVERSITY, P.O. Box 536-20115 EGERTON

NK/ear

"Transforming Lives Through Quality Education"
Egerton University is ISO 9001:2008 Certified

APPENDIX 2: RESEARCH AUTHORIZATION LETTER

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

Telephone:+254-20-2213471, 2241349,3310571,2219420
Fax:+254-20-318245,318249
Email: dg@nacosti.go.ke
Website : www.nacosti.go.ke
When replying please quote

NACOSTI, Upper Kabete
Off Waiyaki Way
P.O. Box 30623-00100
NAIROBI-KENYA

Ref: No. **NACOSTI/P/18/38334/27183**

Date: **12th December, 2018**

Geoffrey Wangombe Kinga
Egerton University
P.O. Box 536-20115
NJORO

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"Assessment of the effects of land use and seasonality on the responses of wild ungulates to livestock grazing In Laikipia Rangeland, Kenya"*** I am pleased to inform you that you have been authorized to undertake research in **Laikipia County** for the period ending **12th December, 2019.**

You are advised to report to **the County Commissioner and the County Director of Education, Laikipia County** before embarking on the research project.

Kindly note that, as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit **a copy** of the final research report to the Commission within **one year** of completion. The soft copy of the same should be submitted through the Online Research Information System.

GKalerwa.

GODFREY P. KALERWA MSc., MBA, MKIM
FOR: DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Laikipia County.

The County Director of Education
Laikipia County.

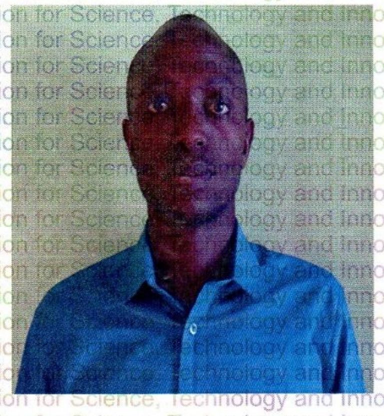
APPENDIX 3: RESEARCH PERMIT

THIS IS TO CERTIFY THAT:
MR. GEOFFREY WANGOMBE KINGA
of EGERTON UNIVERSITY, 0-10400
NANYUKI,has been permitted to conduct
research in *Laikipia County*

on the topic: *ASSESSMENT OF THE EFFECTS OF LAND USE AND SEASONALITY ON THE RESPONSES OF WILD UNGULATES TO LIVESTOCK GRAZING IN LAIKIPIA RANGELAND, KENYA*

for the period ending:
12th December,2019

Permit No : NACOSTI/P/18/38334/27183
Date Of Issue : 12th December,2018
Fee Recieved :Ksh 1000



....
Applicant's Signature

....
Director General
National Commission for Science, Technology & Innovation

APPENDIX 4: PUBLICATION EXCERPT

Hindawi
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Research Article

Analysis of the Spatial Relationship between Cattle and Wild Ungulates across Different Land-Use Systems in a Tropical Savanna Landscape

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In many African savanna landscapes, domestic and wild herbivores cooccur across different land-use systems, but the role of land-use in shaping their spatial relationship is poorly understood. We evaluated the spatial relationship between cattle and wild herbivores categorized by body sizes and feeding habits across different land-use types, namely, private ranches (PR), transitional lands (TRL), and pastoral grazing areas (PGA), in Laikipia County, Kenya. Cattle and wild herbivores spatial distribution data were obtained from Kenya's Department of Resources Survey and Remote Sensing (DRSRS). Spatial relationships between cattle and different wild herbivore guilds were analyzed using Ripley's bivariate K_{12} function. In PR, wild herbivore guilds showed significant attraction to cattle at short distances. In TRL, wild grazers, mixed feeders, megaherbivores, and medium-sized ungulates exhibited significant attraction to cattle. Additionally, repulsion was observed between cattle and browsers at short distances under this land-use system. In PGA, wild grazers, mixed feeders, and megaherbivores repelled strongly with cattle at short distances while browsers and medium-sized ungulates were significantly attracted to cattle. Cattle and wild herbivores were more randomly and independently distributed in PR than in TRL and PGA. These spatial relationships imply better coexistence between cattle and wild herbivores in PR than in TRL and PGA.