RANGELAND MANAGEMENT PRACTICES AND THEIR INFLUENCE ON SOIL PROPERTIES, VEGETATION METRICS AND WILDLIFE IN LEWA WILDLIFE CONSERVANCY, KENYA

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Rangeland management practices and their influence on soil properties, vegetation metrics and wildlife in Lewa Wildlife Conservancy, Kenya

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DECLARATION

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

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DEDICATION

I dedicate this dissertation to my parents and brothers, whose words of advice stirred me to complete this study. Also, to my colleagues in the Conservation and Wildlife Department of the Lewa Wildlife Conservancy, who persistently inquired, "When Are You Graduating?".

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LIST OF ABBREVIATIONS AND ACRONYMS

ADA	Animal Days per Acre
CMO	Control for Mowed Grassland
CPG	Control for Prescribed Grazing
CUG	Control for Unprescribed Grazing
EC	Electrical Conductivity
IUCN	International Union for Conservation of Nature
LandPKS	Land-Potential Knowledge System
LMD	Livestock Management Department
LWC	Lewa Wildlife Conservancy
MO	Mowing of grasslands and carrying away
NNFR	Ngare Ndare Forest Reserve
N, P, and K	Nitrogen, Phosphorus, and Potassium
PG	Prescribed Grazing
pH	Potential of hydrogen
TN	Total Nitrogen
UG	Unprescribed Grazing

ABSTRACT

Rangeland landscapes, comprising forbs, grasses, and shrubs, are primarily managed for wildlife and livestock grazing. These ecosystems, encompassing various vegetation types like shrublands, grasslands, and savannahs, cover a significant portion of the Earth's landmass. With low and unpredictable annual rainfall, rangelands contribute over 30% to terrestrial net primary productivity, playing a crucial role in natural ecosystems. Given their sensitivity to human activities, effective management interventions are essential for sustaining forage quality and quantity for wildlife. The uneven wildlife utilisation of Lewa Wildlife Conservancy (LWC) rangelands prompted the application of recognised improvement methods, yet their effects remain understudied. This research therefore investigated the impacts of mowing of grasslands and carrying away (MO), prescribed grazing (PG), and unprescribed grazing (UG) on select soil and vegetation chemical elements, above-ground biomass, basal gaps, diversity, and wildlife abundance across 62,000 acres of LWC rangeland in Meru County, Kenya. Data collection was undertaken 18 months after treatment for MO and PG, while UG was continuous. Treated blocks were selected in a random systematic way, where adjacent untreated plots that had the same physical soil and site characteristics as determined using the Land-Potential Knowledge System (LandPKS) application acted as controls. Blocks were divided into 100 m × 100 m grid cells using ArcGIS 10.8.1, where sampling plots were drawn. Data analysis, both descriptive and inferential statistics were done in the R version 4.2.2 environment, with a significance level set at 0.05 ($\alpha = 0.05$). A two-sample t-test was used for above-ground biomass, basal gaps, and soil and vegetation chemical elements data to discern variations between treatments and their controls. Additionally, a one-way analysis of variance (ANOVA) was utilized to assess the extent of change (treatment minus control) among treatments. Wilcoxon rank-sum test (WRST) was used on diversity data to compare differences between treatments and their controls while the Kruskal Wallis H test was used to compare the magnitude of change between treatments. Duncan's multiple-range test and Conover's all-pairs test were used as post hoc tests for one-way ANOVA and H test respectively. The vegetation P concentration was significantly higher in MO ($t = -2.5164$, $p = 0.0455$) but significantly lower in UG ($t = 2.6222$, $p = 0.0399$) compared to their controls. Vegetation K was significantly higher in PG compared to its control ($t = -3.6222$, $p = 0.0225$). The mean above-ground biomass was significantly lower in MO ($t = 4.8861$, $p = 0.0029$) and UG ($t = 5.4866$, $p = 0.0068$) compared to their controls while no significant difference was observed between PG and its control ($t = 1.1916$, $p = 0.2867$). The mean length of basal gaps of MO ($t = 7.0687$, $p = 0.0001$) and UG ($t = -4.0531$, $p = 0.0001$) was significantly lower and higher respectively compared to their controls. MO decreased mean basal gaps by a larger magnitude compared to UG where mean basal gaps increased ($p = 0.0008$). A significantly higher wildlife density was observed in MO compared to its control ($t = -4.6696$, $p = 0.0034$) as well as other treatments ($F_{(2, 9)} = 5.216$, $p = 0.0313$). In conclusion, this study establishes that various management practices exert distinct effects on rangelands. The significant rise in wildlife densities observed in MO, coupled with its positive impact on several metrics examined, positions it as the most favourable practice. Furthermore, the study recommends time series data be collected to understand changes in these metrics at time intervals and the time in which effects are neutralised.

CHAPTER ONE

INTRODUCTION

1.1 Background

Rangelands, which constitute shrublands, grasslands, and savannahs, comprise about 50% of the earth's landmass (Bailey, 1996; Getabalew and Alemneh, 2019). They are primarily arid and semi-arid lands, experiencing low and unpredictable annual rainfall regimes. Despite this, they form at least 30% of terrestrial net primary productivity (Field et al., 1998; Jackson and Prince, 2016). This makes rangelands important parts of many natural ecosystems, providing an array of ecosystem goods and services (Fox et al., 2009; Angerer et al., 2023), while remaining sensitive to internal and external factors such as anthropogenic activities (Yuanming et al., 2003; Brown and MacLeod, 2018). The quality of the goods and services provided is dependent on the level of the management practices put in place (Fox et al., 2009; Reed et al., 2015).

Rangelands are primarily dominated by large wild and domestic mammalian herbivores, more so than any other ecosystem (Ogutu et al., 2016). Wildlife in rangelands has been noted to be on the decline in the recent past (Geldmann et al., 2019; Rija et al., 2020) particularly in Africa due to rangeland degradation (Scholte, 2011; Ogutu et al., 2016). In response to this, ecologists have devised a wide range of management practices to maintain rangeland health and productivity for plant species diversity and wildlife abundance (Bailey et al., 2019) such as burning of grasslands, prescribed grazing, mowing of grasslands and carrying away, and establishment of exclusion zones. These management practices are meant to influence the chemical elements and structure of the soils as well as vegetation metrics.

In East African rangelands, grasses, and woody plants are the primary source of sustenance for livestock and wildlife (Tefera et al., 2007; Ayelew and Mulualem, 2018). The availability of this natural pasture is dependent on the complex interactions between ecosystem components such as water, climate, soils, plants, and animals (Azimi et al., 2013). In Kenyan rangelands, proper management practices are necessary considering that at least 65% of wildlife roams in communal and private lands (Western et al., 2009; Musyoki et al., 2012).

The Lewa Wildlife Conservancy (LWC) has undergone multiple land use and several different rangeland management practices (Giesen et al., 2017). In the 1970s and 1980s, LWC, formally known as Lewa Downs, was managed as a livestock ranch by the Craig family with some low-level informal wildlife tourism. During this time, there was a significant reduction in black rhinoceros numbers to just a few hundred, largely due to poaching in the mid-1980s. This led to the establishment of the fenced and guarded Ngare Sergoi Rhino Sanctuary, spanning approximately 2,024 hectares of land. The sanctuary was proposed by Anna Merz in 1983 to the Craig family (Giesen et al., 2017). To create habitat for wildlife and reduce grazing pressure, livestock were phased out which led to the increase in the population of various species, including zebras, elephants, impalas, and giraffes. Concurrently, in 1983-1984, there was a successful reintroduction of the critically endangered black rhinoceros and the near-threatened white rhinoceros to the area (Giesen et al., 2017). As a strategic measure, this wildlife conservation effort prompted the extension of the perimeter fence in 1994 to encompass Ngare Ndare Forest Reserve (NNFR). Furthermore, in the 1990s, an exclusion zone fencing initiative was implemented specifically to keep giraffes and elephants away, with the primary aim of meeting the habitat requirements of the black rhinoceros population.

LWC was officially registered as a non-profit making organization in 1995 (Giesen et al., 2017). Other management practices followed such as prescribed burning to deter fuel build-up, translocation of wildlife in and out of the Conservancy, and restoration of the existing swamp (Giesen et al., 2017). Currently, the management practices in place include prescribed grazing, unprescribed grazing, mowing of grasslands and carrying away, and establishment of browsing exclusion zones (Giesen et al., 2017). Prescribed grazing and mowing of grasslands are meant to diversify habitats by reducing the accumulation of the dominant increaser grass species namely *Cenchrus mezianus* and *Cenchrus stramineus* (Schulz et al., 2014) which are edible forage when growing but reduce in palatability when fully mature forming huge, long dry stands of grass (Odadi et al., 2011). However, studies on the effect of prescribed grazing on plant species diversity in Lewa Wildlife Conservancy have been inconclusive, with two studies showing differing results. Sargent, 2016 reported that mowing resulted in a reduction in vegetation quantity and an improvement in species diversity while prescribed grazing did not yield a clear advantage. On the other hand, Kariuki, 2010 reported a reduction in vegetation quantity only. Nevertheless, the grasslands in the conservancy become nutritionally poor during the prolonged dry period because of the accumulation of the two grass species (Giesen et al., 2017).

This study focused on the effects of rangeland management practices (prescribed grazing, unprescribed grazing, and mowing of grasslands and carrying away) on select soil chemical elements, vegetation metrics, and wildlife abundance. The focus on soil chemical elements was informed by their ability to be significantly influenced by rangeland management practices (Northup et al., 2019). The notable select soil chemical elements vital in forage production are total nitrogen (TN), phosphorus (P), and potassium (K) (Mathison and Peterson, 2011). The study also included pH and electrical conductivity (EC) since they are known to influence the availability of mineral elements (Mathison and Peterson, 2011; Northup et al., 2019). A portion of at least 380 acres of government land known as the Livestock Management Department (LMD) area falls within the Conservancy. This portion of land was accessible by surrounding communities for grazing their livestock throughout the year. This area represented unprescribed grazing since grazing was continuous and not controlled. The study focused on black cotton soils (vertisols) since they represent at least 85% of the Conservancy (Linsen and Giesen, 1983) and this is where the three management practices were undertaken.

1.2 Statement of the Problem

Rangeland management practices significantly impact soil chemical element levels, vegetation metrics, and wildlife abundance (Erfanzadeh, 2014; Bailey et al., 2019). The uneven utilization of LWC's rangelands by wildlife had led to an exploration of existing methods for rangeland improvement namely prescribed grazing (PG), unprescribed grazing (UG), and mowing of grasslands and carrying away (MO). However, the effects of these methods in the Conservancy, and whether they achieve the desired outcomes, have not been thoroughly researched. In LWC, a study by Kariuki (2010) showed that prescribed grazing reduced vegetation quantity but did not affect plant species diversity. In a comparable investigation conducted by Sargent (2016), it was found that mowing led to a decrease in the quantity of vegetation and an enhancement in species diversity, whereas prescribed grazing did not exhibit a distinct advantage. The two studies did not investigate the effects of rangeland management practices on select soil chemical elements (total nitrogen (TN), phosphorus (P), potassium (K), the potential of hydrogen (pH), and electrical conductivity (EC)) levels, and their relationships with select vegetation chemical element (nitrogen - N, phosphorus - P, and potassium - K) levels, diversity, basal gaps, biomass, and wildlife abundance in the management units they studied. Also, the two studies did not investigate unprescribed grazing as a rangeland management practice within the Conservancy. This study was therefore meant to address this gap at the same time advancing these studies by bringing in new variables. The study was also meant to inform the LWC management of the effects the rangeland management practices have had on select soil chemical elements and the relationships with vegetation metrics and wildlife abundance. In addition to the above, the study aimed to enhance scientific knowledge in the realm of landscape approaches to rangeland and wildlife management.

1.3 Justification

Historically, the LWC transitioned from a cattle ranch to first a Rhino Sanctuary and then to the current state of a Wildlife Conservancy. The Conservancy had undergone regimes of prescribed grazing, unprescribed grazing, mowing of grasslands and carrying away, prescribed burning, and exclusion zones to deter certain animals from accessing excluded blocks (Giesen et al., 2017). All these regimes imposed a significant effect on soil chemical elements concentration and availability influencing species composition, abundance, and vegetation chemical elements (Juice et al., 2006).

The Conservancy also forms a crucial habitat for wildlife and hosts among others the species of key conservation concern namely; the critically endangered Black rhinoceros (*Diceros bicornis* ssp. *michaeli*), the near-threatened Southern white rhinoceros (*Ceratotherium simum* ssp. *simum*), the endangered Grevy's zebra *(Equus grevyi)*, the endangered Beisa oryx (*Oryx beisa* ssp. *beisa*), the endangered Lelwel hartebeest (*Alcelaphus buselaphus* ssp. *lelwel*), and the critically endangered Pancake tortoise (*Malacochersus tornieri*) (IUCN, 2020).

The above information underscores the conservation importance of this landscape. However, little was known about the effect of various rangeland management practices on soil chemical elements and their relationships with wildlife and vegetation metrics, which are key to the survival of species of key conservation concern. This study was meant to inform the LWC management of the state of the blocks that had received different treatments and the recommendations thereof to guide future practices in habitat manipulation for conservation management. The scientific community was meant to benefit by understanding the effect of rangeland manipulation practices on select soil chemical element levels and the relationships between soil chemical element levels and vegetation metrics, and consequently on the wildlife abundance.

1.4 Objectives

1.4.1 Broad Objective

To determine the influence of rangeland management practices on the level of select soil chemical elements, vegetation metrics, and wildlife abundance in Lewa Wildlife Conservancy, Meru, Kenya for increased rangeland productivity and wildlife abundance.

1.4.2 Specific Objectives

1. To determine the effect of different rangeland management practices on the level of select soil chemical elements in Lewa Wildlife Conservancy.
2. To determine the influence of different rangeland management practices on vegetation metrics in Lewa Wildlife Conservancy.
3. To establish how different rangeland management practices influence wildlife abundance in Lewa Wildlife Conservancy.

1.5 Hypotheses

1. **H_0:** Different rangeland management practices have no effect on the level of select soil chemical elements in Lewa Wildlife Conservancy.
2. **H_0:** Vegetation metrics are not influenced by different rangeland management practices in Lewa Wildlife Conservancy.

3. **H_0:** Different rangeland management practices do not influence wildlife abundance in Lewa Wildlife Conservancy.

1.6 Scope of the Study

The study focused on black cotton soil (vertisols) sites because they form at least 85 per cent of Lewa Wildlife Conservancy's rangeland and were the only soil sites grazed in the year 2020. Further to this, the focus was on select soil chemical elements level (TN, P, K, pH, and EC), select vegetation metrics (N, P, and K, biomass, basal gaps, and diversity), and wildlife abundance. The study was also limited to the blocks that were subjected to the three management practices in June 2020, apart from unprescribed grazing that was continuous.

CHAPTER TWO

LITERATURE REVIEW

2.1 Soil and Vegetation Chemical Elements and Site Characteristics in Rangelands

Different forms of rangeland management practices have been noted to significantly influence soil chemical elements (Northup et al., 2019). Nitrogen, phosphorus, potassium, pH, and EC are identified as the primary soil elements vital in forage production (Mathison and Peterson, 2011). Plant species and precipitation have also been noted to control soil mineral chemical cycles (Erfanzadeh, 2014) in which the rate of input and loss closely balances in dry ecosystems (Riginos and Herrick, 2010). Bare ground causes a risk of soil mineral loss, soil erosion, species invasion, and a decrease in water infiltration because of the lack of organic matter necessary for stabilizing the soil structure (Riginos and Herrick, 2010). The deep coarse soils favour woody plant growth because they ease water percolation and mineral leaching whereas shallow soils and fine textured surface soils retain water and minerals close to the surface favouring grass growth (Hruska et al., 2017).

Soil pH affects nutrient availability in the soils for plant absorption (Thomas, 2010; Egeru et al., 2019). The optimal range for soil nutrients to be available to plants is between 6.5 and 7.5 (Thomas, 2010; Ch'ng et al., 2014). Nitrogen and potassium are less affected directly by soil pH although potassium is less available in acidic soil since it is usually leached out (Miller, 2016). However, phosphorus is directly affected because a greater pH value of more than 7.5 makes phosphate ions quickly react with magnesium and Calcium forming a less soluble compound (Thomas, 2010). Also, high acidic pH values make phosphate ions react with iron and aluminium to form less soluble compounds (Thomas, 2010).

Increased grazing pressure has an impact on soil properties, specifically increasing available nitrogen, total nitrogen, available phosphorus, and total phosphorus (Wei et al., 2011). Dung and urine disintegration alters soil electrical conductivity (EC), pH, and increases the nitrogen mineralization rate (Krounbi et al., 2018). Nitrogen increases and mineralization in the long run increases forage quantity in grasslands

(Egeru et al., 2019). Moderate grazing is advised as it helps attain a balance between nitrogen management and species diversity protection (Wei et al., 2011). However, a study by Mirdeilami et al. (2017) on the impacts of different grazing intensities on soil characteristics in the Inchebroun rangelands of Iran indicated that different grazing intensities have the same outcomes in terms of nutrient composition.

Mown and unmown plots differ in nitrogen levels. A study in Utah and Nevada in the USA on nutrient availability in rangeland soils noted that vegetation removal increases soil nitrogen because there is less or no vegetation available for nutrient uptake (Blank et al., 2007). In Shenandoah National Park, research by Christensen (1976) indicated that mowing does not affect the level of phosphate concentration unless in areas with high shrubs where concentration increases. Another study on the effects of mowing and burning on soil properties by Edwards et al. (2012) showed no impact of mowing on soil chemicals because of the lack of livestock dung to aid decomposition. Hu et al. (2015) noted that mowing repressed the chemical storage capacity of the rhizosphere decreasing the total nitrogen and available nitrogen in rhizosphere soil.

The use of organic substances in the soil such as manure significantly increases the electrical conductivity (EC) value of the soil (López-Cano et al., 2016). The established critical range for good vegetation growth is 750 µS cm-1 to 3,490 µS cm-1 (Abad et al., 2001). According to Hawkins et al. (2017), soil texture and soil moisture level influence the soil EC. Soils that have a large percentage of clay are fine textured and can hold a substantial amount of water increasing soil moisture and consequently increasing the soil EC (Hawkins et al., 2017).

While grazing has a positive impact on soil mineral concentration, grazed lands tend to have higher soil bulk density compared to ungrazed lands in semi-arid rangelands (Nyangito et al., 2009). This is because grazing livestock exposes lands to soil compaction and decreases soil aggregate stability (Kinyua et al., 2010). This lowers water infiltration and impedes the germination of seeds due to the soil surface forming a hard pan (Beukes and Cowling, 2003). The infiltration problem is even more pronounced in heavily grazed semi-arid rangeland grasslands (Mganga et al., 2011), affecting the soil chemical elements – vegetation metrics relationships (Beukes and Cowling, 2003).

Landscapes in which soils are collected and assessed have different characteristics. These differences in the formation of the landscape are called site characteristics. The commonly known site characteristics that influence soil physio-chemical properties are slope, aspect, landform, rockiness, and parent materials (Mirdeilami et al., 2017; Liu et al., 2020). Middle slopes and upper slopes have the highest and lowest records of physio-chemical properties respectively (Liu et al., 2020).

Phosphorus in the soil has a positive correlation with that in the plant compared to other chemical elements (FAO, 1982; Lizcano-Toledo, 2021). The positive correlation between the total soil nitrogen and plant nitrogen is equally good (FAO, 1982). Similarly, Soil potassium and vegetation potassium are positively correlated (FAO, 1982). The increase in pH increases exchangeable potassium in the soil but decreases in plants (FAO, 1982; Scanlan et al., 2017).

2.2 Vegetation Biomass, Basal Gaps, and Diversity

Species composition, abundance, and vegetation chemical elements are influenced by variations in soil cations concentration and soil chemical elements availability (Juice et al., 2006). Biomass production has been seen to be positively correlated with soil nitrogen and pH (Karltun et al., 2013). Soils influence habitat heterogeneity by impacting changes in plant diversity and vegetation structure (Rodrigues, 2018). In savannah ecosystems, vegetation structure and species diversity are more affected by soil variables (Rodrigues, 2018) underscoring their sensitivity (Yuanming et al., 2003). While abiotic conditions influence plant species diversity, biotic interactions being other ecosystem processes in play may also limit diversity if they limit the dispersal of seeds (Peña-Claros et al., 2012).

Rangeland management practices significantly influence above-ground biomass, vegetation height, and coverage. Zhang and Dong (2009), while studying the impact of topography, soils, and intensity of grazing on vegetation diversity, found that grazing intensity influences vegetation structure and composition. Overgrazing significantly influences vegetation composition and diversity (El-Khouly, 2004), while light grazing can promote an increase in plant diversity (Mligo, 2006). An increase in the intensity of grazing reduces the above-ground biomass, vegetation height, and coverage. Moderate grazing increases species richness. Prescribed grazing reduces plant basal gap resulting in a more herbaceous foliar cover which reduces the risk of land degradation caused by soil erosion (Odadi et al., 2017). Grazing pressure increases nitrogen storage which has a positive correlation with below-ground biomass increase. To balance soil nitrogen and species diversity, moderate grazing is necessary in the long term (Wei et al., 2011).

Mowing causes a significant change in species richness and diversity and increases the number of plant species. Further to this, Beltman et al. (2003) also noted that mowing twice per year increases the number of plant species significantly compared to mowing once. The unmown plots accumulate a significant amount of above-ground biomass compared to mown plots. This greater biomass in unmown plots may simply be explained as accumulation without removal by mowing (Beltman et al., 2003). Rainfall also contributes significantly to species abundance when an area is mowed (Kołos and Banaszuk, 2018).

There is a correlation between grass cover and abundance with the changes in the percentage of clay and the availability of nitrogen (Ben-Shahar, 1991). However, this correlation is to a lesser degree in soil phosphorus (Ben-Shahar, 1991). The variation in geomorphological structure has also been noted to strongly influence grass abundance (Li et al., 2010). It can easily be thought that the availability of chemical elements in the soils could influence the levels of chemical elements in grass species. However, studies by Ben-Shahar and Coe (1992) and Chrzan (2016) found no correlation between soil chemical element levels with that of grasses because grasses accrued higher chemical elements in soils with low levels of chemical elements compared to soils with a higher level of chemical elements. This, therefore, suggests that the immediate climate of an area, plant species attributes, and their associations could be the main factors influencing chemical element concentration in grasses (Ben-Shahar and Coe, 1992; Malhi et al., 2020).

2.3 Grazing and Mowing of Grasslands

Livestock shares the landscape with wildlife in the savannah ecosystem. This overlap means livestock share grass with wild grazers and mixed feeders on a varying scale

(Kimuyu et al., 2017). In unrestricted landscapes, habitat selection is resource-driven in relation to the surrounding matrix, and displacement of one species is based on resource depletion by one species (Kimuyu et al., 2017).

The concept of holistic management which involves grazing big herds in one area and moving to another on a rotational basis (Savory, 1991) is highly controversial. Some studies have associated the method with success through improving vegetation quality (Teague et al., 2011; Kimuyu et al., 2017; Odadi et al., 2017) while others have shown that it has no additional value to less intensive but continuous grazing strategies (Joseph et al., 2002; Carter et al., 2014). Sargent (2016) reports that at Lewa Wildlife Conservancy, Kenya, the cattle grazing program did not have clear advantages to the grassland and any advantages were short-lived.

Mowing on the other hand is presumed to yield similar results as grazing but is more costly (Schulz et al., 2014). Sargent (2016) indicates that mowing results are long-lived compared to grazing, with biomass reduction lasting over two years and grass species diversity increasing.

2.4 Wildlife Abundance in Response to Rangeland Management Practices

Wild ungulates have different nutritional needs depending on their gut morphology (ruminants and non–ruminants) influencing their food quality preference and abundance in the rangelands (Tyrrell et al., 2017). Ruminants such as impala and Grant's gazelle have four stomach compartments compared to one stomach compartment in non–ruminants such as Grevy's zebra and Plains zebra (Mackie, 2002). Ruminants require quality forage (Tyrrell et al., 2017) while non–ruminants will strive to eat enough forage without much care on the quality to meet their metabolic requirements (Russell et al., 2018). Low grass biomass especially when green is usually of high quality and is normally found in grazed and mowed areas (Mose et al., 2013). When an area is intensely grazed, it accumulates even more crude proteins further increasing the quality of grasslands (Anderson et al., 2010) for wildlife usage.

High grass biomass is generally of low quality because it has high level structural tissues required to support its heavy weight lowering its digestibility. Developing plants of low biomass have high nutrient levels and high digestibility attracting more ungulates (Ogutu et al., 2014). Despite the known concept that grazed areas have grass of high nutritional value (Mose et al., 2013), a study by Kimuyu et al. (2017) observed lower numbers of mesoherbivores in grazed zones than non–grazed zones. Cattle have been noted to consume a substantial amount of forbs in an area that has both forbs and grass (Odadi et al., 2007) which could contribute to overall biomass reduction which then reduces the use by grazers and mixed feeders even in moderately grazed areas (Kimuyu et al., 2017). Contrary to the above observation, Odadi et al. (2017), reported that grazing attracts more wild ungulates, particularly in prescribed grazing sites compared to unprescribed grazing sites.

Whereas habitat quality and the impact of rangeland management practices are noted to influence wild ungulates distribution, the distribution of the dominant predator has been noted to also influence the distribution of wild ungulates in protected areas by avoiding risky habitats to increase their survival (Thaker et al., 2011). Wild ungulates congregate in moderately flat areas and away from water sources decreasing their exposure to predation (Anderson et al., 2010). When conditions are moderate, wild ungulates prefer areas with low vegetation biomass which increases visibility for the avoidance of predators (Hopcraft et al., 2012). This is a clear predator avoidance response (Kie, 1999) as opposed to being driven by food quality and quantity. However, this may be compromised during the dry period when biomass is significantly reduced causing wild ungulates to congregate in a few areas with high biomass and areas around the swamps (Tyrrell et al., 2017).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Site

3.1.1 Location

The study was conducted at Lewa Wildlife Conservancy (LWC) located at latitude 0.20N and longitude 37.42E in Meru County in Kenya covering approximately 62,000 acres of land (Dupuis-Desormeaux et al., 2018) (Figure 3.1). The habitat can mostly be described as a savannah with at least 2% shrub and tree cover (Dupuis-Desormeaux et al., 2018).

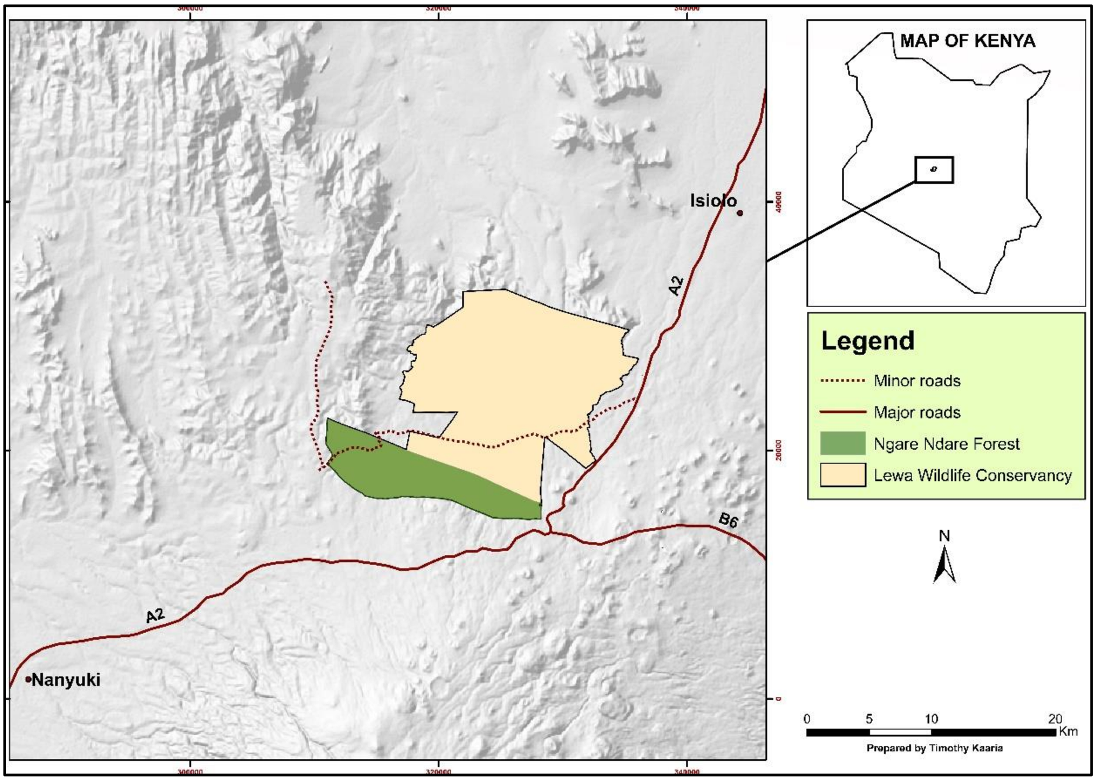

Figure 3.1: Location of Lewa Wildlife Conservancy in Kenya

3.1.2 Geology and Soils

Lewa exhibits two distinct geological rock formations identified by Botha (1999), as basement rocks and volcanic rocks. The basement system rocks comprise sedimentary deposits forming the foundational layer upon which the remaining rocks in the area sit. This system includes schists, granulites, and heterogeneous gneisses (Linsen and

Giesen, 1983), as well as volcanic rocks and subordinate sediments from the Mount Kenya volcanic series. The volcanic rocks consist of upper basalts overlaying lower basalts within the Mount Kenya volcanic series. Certain areas are covered by superficial Pleistocene deposits, predominantly volcanic ash or basement system gneisses.

Lewa features five dominant soil types namely nitisols, vertisols, solonetz, fluvisols, and gleysols, largely derived from the erosion of geological formations. A substantial portion of the Conservancy features the black cotton type of vertisol, known for its distinctive impeded drainage characteristics (Linsen and Giesen, 1983; Botha, 1999).

3.1.3 Climate and Biodiversity

The climate in the Lewa Wildlife Conservancy falls within the tropical savanna classification, as per the Koppen Climate Classification system (Koppen, 1936; Peel et al., 2007). It features two distinct wet seasons: long rains from March to May and short rains from October to December, occasionally interspersed with droughts (Kenya Meteorological Department, 2021). The daily maximum temperatures range from 24°C to 32°C, while daily minimum temperatures range from 8°C to 16°C (Linsen and Giesen, 1983; Kenya Meteorological Department, 2021).

The Conservancy encompasses four primary habitat types, categorized based on dominant plant species: plains (dominated by *Pennisetum* grasses and *Acacia* trees), forest (characterized by *Olea-Juniperus* forest), hills and rocky outcrops (marked by *Acacia*, *Commiphora*, and *Grewia*), and riverine habitats (Linsen and Giesen, 1983; Mwololo, 2011; Giesen et al., 2017).

Of significant conservation importance, the Conservancy is home to endangered and threatened wildlife species, including the critically endangered black rhinoceros (*Diceros bicornis*), endangered Grevy's zebra (*Equus grevyi*), and the endangered Beisa oryx (*Oryx beisa*), among others (Low et al., 2009; IUCN, 2020). Additionally, the Conservancy hosts a diverse large carnivore guild, including Spotted hyenas (*Crocuta crocuta*), lions (*Panthera leo*), cheetahs (*Acinonyx jubatus*), leopards

(*Panthera pardus*), striped hyenas (*Hyaena hyaena),* and occasionally, African wild dogs (*Lycaon pictus*).

3.2 Description of Treatments

Prescribed Grazing: Cattle were confined in blocks of known acreage between June and July 2020. The duration of stay, recognized as, the Animal Days per Acre (ADA) was 25 cows per day per acre, which translates to one cattle per acre for 25 days. This was the known patch size required to feed 25 adult cows for one day for the LWC (Butterfield et al., 2006; Schulz et al., 2014). Once the ADAs were exhausted, the cattle were moved to the next available block. In June 2020, three blocks were grazed namely, block 33 covering 296 acres using 224 cows for 33 days, block 28 covering 636 acres using 350 cows for 45 days, and block 47 covering 395 acres using 300 cows for 33 days (Figure 3.2). The following equation (Equation 3.1) was used to calculate the number of grazing days in a particular block;

Equation 3.1: Formula for Estimating the Number of Grazing Days in a Given Block

$$\boxed{\text{Number of Grazing Days} = \frac{\text{Number of cattle required per acre per day (ADA)} \times \text{Size (in acres) of the block to be grazed}}{\text{Number of cattle available for grazing}}}$$

Mowing of Grasslands and Carrying Away: A lawn mower was set at a height of 15 cm. The mower was towed by a tractor to cut grass on 120 acres of land on block 37 in June 2020 (Figure 3.2). The grass was then gathered by a hay rake, hays created by a baler, and carried away from the site. This activity took place in June 2020.

Unprescribed Grazing: This grazing program took place on approximately 502 acres of government land within the Conservancy known as the Livestock Management Department (LMD) area. The livestock (cattle and shoats) from the surrounding communities grazed on this block uncontrollably and considerably intensive throughout the year, including the study time. This area, designated as government-owned land under the Ministry of Livestock, has been utilized for grazing up to the present time. This block was divided into 2 portions: portion 13 covered 295 acres while portion 102 covered 207 acres (Figure 3.2). This LMD area was demarcated by public and private roads which were used by the Conservancy rangers to patrol and prevent livestock from accessing the Conservancy. In this case, the Conservancy's block adjacent to the LMD area was used as a control.

Control Blocks: These were neighbouring blocks to the selected ones that did not undergo any of the three treatments. These blocks exclusively experienced grazing by wildlife and, in addition to not being grazed by livestock, were expected to possess similar physical soil and site characteristics, verified using the Land-Potential Knowledge System (LandPKS) application (Herrick et al., 2017; Herrick et al., 2019; Kimiti et al., 2020a; Kimiti et al., 2020b).

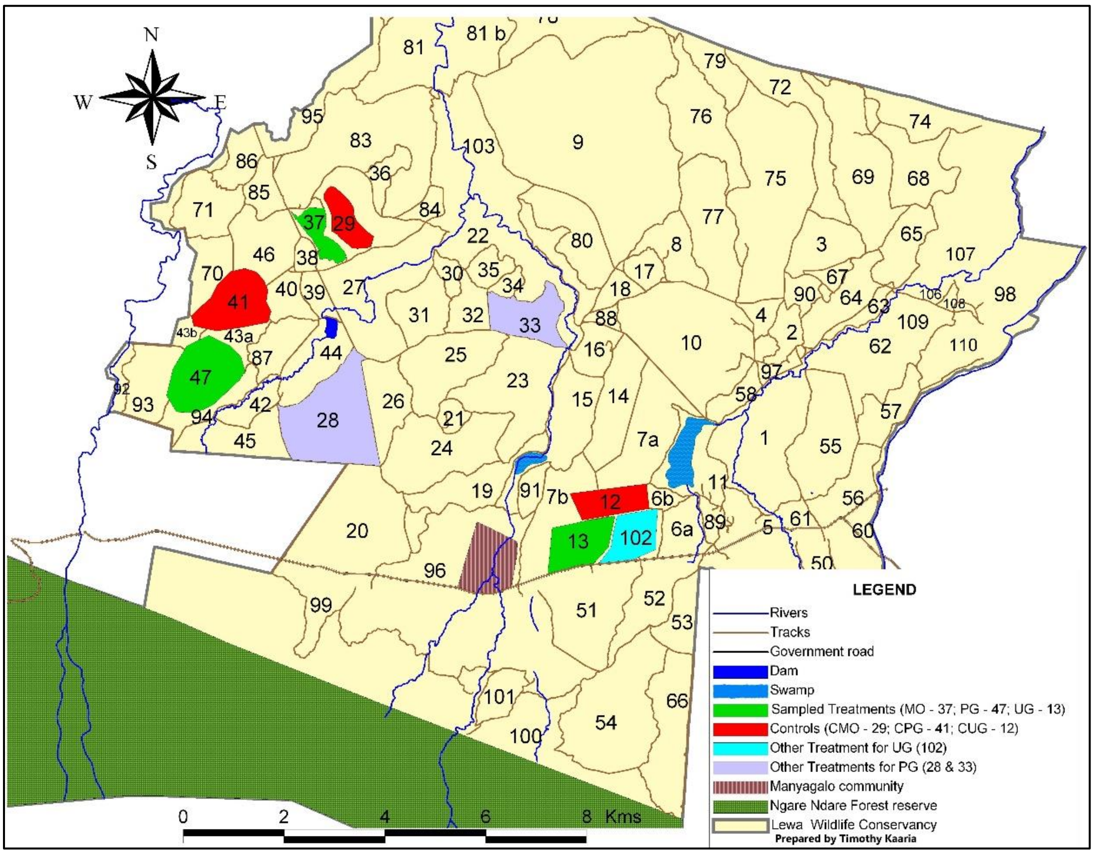

Figure 3.2: Blocks of the Lewa Wildlife Conservancy

3.3 Experimental Design and Sampling

Random systematic selection of the blocks was used (Mirdeilami et al., 2017). This was through assigning random numbers to each treatment separately to all the treated blocks in the year 2020. The adjacent untreated blocks that resembled the physical soil and site characteristics of each of the selected blocks acted as controls. This was determined using the Land-Potential Knowledge System (LandPKS) application that uses an inbuilt LandInfo module to predict soil type after keying in the slope, soil depth, rock fragments percentage, soil colour, land use, and texture of the soil (Herrick et al., 2017; Herrick et al., 2019; Kimiti et al., 2020a; Kimiti et al., 2020b). In instances where more than one potential control block exhibited similar characteristics, a random selection method was applied. The physical soil and site characteristics were important while determining the homogeneity of the study area because they affect vegetation and soil chemical properties (Liu et al., 2020). A 100 m × 100 m grid cells were developed using ArcGIS 10.8.1 to cover the selected blocks and their controls separately. All complete cells were numbered and four cells in each block were randomly selected to form the sampling plots (Mirdeilami et al., 2017; Kimiti et al., 2020a) (Figure 3.3). The study, therefore, adopted an informal experimental research design known as the 'after-only with control design' (Sahu, 2013). This is because observations were made after the application of treatments, which included prescribed grazing, unprescribed grazing, and mowing of grasslands and carrying away. The incorporation of control groups allowed for a comparative analysis to determine the effects of the applied treatments (Sahu, 2013).

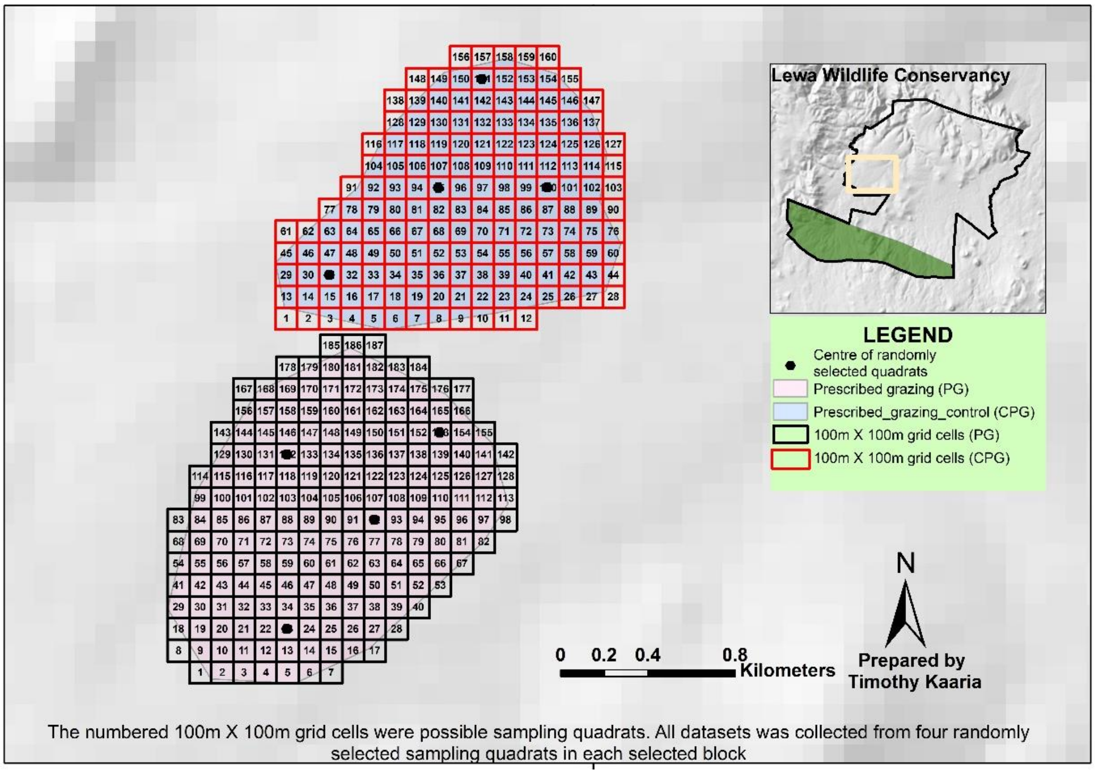

Figure 3.3: A Model Representing Experimental Design for the Selected Block of Prescribed Grazing and Control Blocks

3.4 Data Collection

Data was collected between December 2021 and January 2022 on all the metrics investigated by this study. During the last quarter (October, November, and December) of the year 2021, the region received below-average rainfall, characterised by uneven spatial distribution. The rainfall recorded during this quarter of the year was 186.9 mm, compared to 371.7 mm and 434.4 mm in 2020 and 2019, respectively (Kenya Meteorological Department, 2021; County Government of Isiolo, 2023).

3.4.1 Soil Sample Data Collection

At every sampling plot, soil samples were scooped with a clay auger using the zigzag method (Sabbe and Marx, 1987; Carter and Gregorich, 2007) at a depth of 10 cm, 30 cm, and 50 cm. These depths were chosen because they were within reach by plant roots for chemical elements absorption (Kimiti et al., 2020b). The sampling technique involved taking samples at six corners of a zigzag line within the sampling plot. This was important as it ensured that soil samples were collected from various locations within the field to capture any potential variability in soil properties (Sabbe and Marx, 1987). The soil samples in each sampling plot were mixed to get a composite sample that was then taken to Crop Nutrition Laboratory Services Limited for soil Total Nitrogen, Phosphorus, Potassium, the potential of hydrogen, and electrical conductivity chemical analysis (Kimiti et al., 2020a; Kimiti et al., 2020b).

3.4.2 Vegetation Data Collection

Basal Gaps: A 25 m line transect was established where the length of any gap between rooted vegetation was measured using a tape measure in centimetres. The cumulative length of all the basal gaps in each treatment was compared against its control to distinguish any significant disparities (Kimiti et al., 2020b).

Diversity: A modified line-point intercept was used (Herrick et al., 2017). At every five metres of a 25 m transect, a 50 cm × 50 cm quadrat was placed. All the different species within the quadrat were counted and identified. Unknown plant species were identified using the PlantNet application (Bonnet et al., 2020; PlantNet,2021). PlantNet is a mobile application created to streamline plant identification using image recognition technology. Photographs of unfamiliar plants were captured, emphasizing distinct features such as leaves, flowers, or fruits, which were then uploaded to the application. Upon submission, PlantNet analysed the images and generated a list of potential plant species with matching visual characteristics, enabling the narrowing down of identification to specific plant species.

The Shannon - Wiener Diversity Index (*H*) was calculated as follows (Shannon, 1948; Omayio et al., 2019);

$H = -\sum[PiLNPi]$, where Pi was the relative proportion achieved by dividing the number of an individual species by the total number of all species in a particular environment. $LNPi$ was the natural logarithm (LN) of the value Pi.Σ was the summation symbol of the outputs with the final value multiplied by a negative one(-1).

Biomass: After taking diversity metrics, the vegetation within the quadrats was clipped with grass shears, air-dried to achieve a constant weight, and then weighed using an electronic balance to record the final weight in grams, ultimately allowing the estimation of biomass in kilograms per acre of land (Kimiti et al., 2020b). The five sets of vegetation clipped per site were mixed to get a composite sample and taken to Crop Nutrition Laboratory Services Limited for plant Nitrogen, Phosphorus, and potassium chemical analysis.

3.4.3 Wildlife Abundance Data Collection

A measuring tape was used to establish a north-facing 4 m × 100 m line transect inside the sampling plots to count wildlife dung piles (Kimuyu et al., 2017). Data was collected by walking through the middle of the 100 m line transect counting the dung piles within 2 m on both sides of the transect (Figure 3.4). Each dung pile was regarded as one individual and the species responsible was identified using a field guide for wildlife tracks and signs by Stuart (2013) and in consultation with the Conservancy rangers. The dung piles count was repeated two times at an interval of two weeks. To circumvent recounting the dung piles during successive surveys, all the recorded dung piles were smashed each period the data was collected (Kimuyu et al., 2017). The dungs counted were used to estimate wildlife densities per acre of land using a modified formula by the National Research Council (1981) (Equation 3.2). The line transect method using dung counts is robust in studying wildlife abundance of large mammals (Kimuyu et al., 2017).

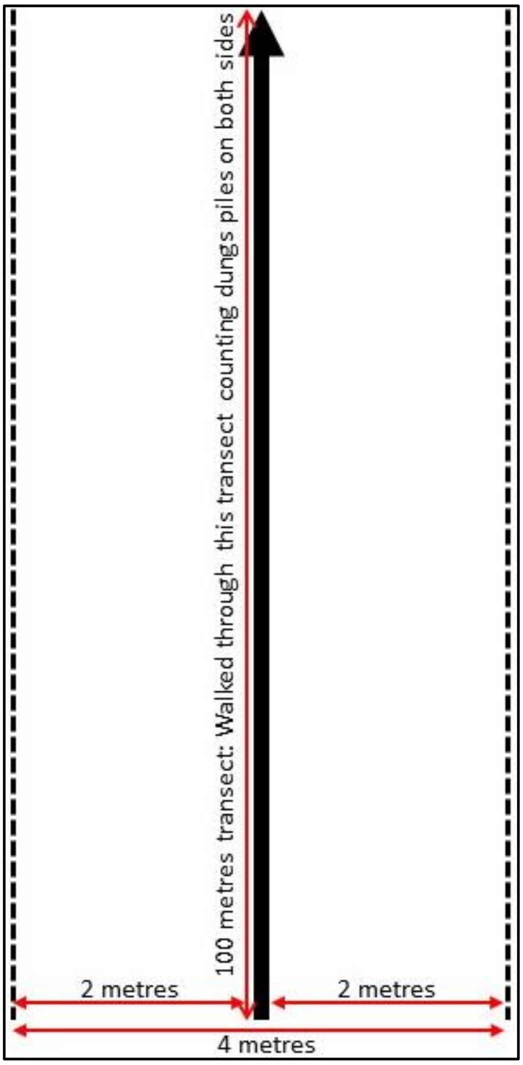

Figure 3.4: A Model Representing Line Transects for the Dung Survey

Equation 3.2: Formula for Estimating Wildlife Species Abundance

$$D = \frac{n}{lw} \times 4{,}046.86m^2$$

Where;

D = Density of dung piles of a species per acre

n = Number of dung piles per transect

l = Length of the transect in metres

w = Width of the transect in metres

m^2 = Metres squared

3.5 Data Analysis

Data analysis, both descriptive and inferential statistics, were done in the R version 4.2.2 environment (R Core Team, 2022). The significant level was set at 0.05 (α = 0.05). Two sample t-test was used on above-ground biomass, basal gaps, and soil and vegetation chemical elements data, to compare differences between treatments and controls while the one-way analysis of variance (ANOVA) test was used to compare the magnitude of change (treatment minus control) between treatments. Wilcoxon rank-sum test (WRST) was used on diversity data to compare differences between treatments and controls while the Kruskal Wallis H test was used to compare the magnitude of change between treatments. Where significance existed while implementing the one-way ANOVA test and Kruskal Wallis H test, Duncan's multiple-range test and Conover's all-pairs test respectively were used as post hoc tests. The magnitude of change was determined by subtracting control values from the treatment values for each specific treatment. Following this, a comparative analysis of the values from each treatment was undertaken to pinpoint the treatments that resulted in a notable and significant change.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Effects of Management Practices on Soil Chemical Elements (Soil N, P, K, pH, and EC)

The levels of soil TN, P, K, pH, and EC remained consistent across all the management practices when compared to their respective controls (Table 4.1).

Table 4.1:Changes in the Soil Nutrients (Soil Total Nitrogen – TN, Soil Phosphorus – P, Soil Potassium – K, Soil Potential of Hydrogen - pH, and Soil Electrical Conductivity - EC) Between Mowing of Grasslands and Carrying Away (MO) and its Control (CMO), Unprescribed Grazing (UG) and its Control (CUG), and Prescribed Grazing (PG) and its Control (CPG)

Chemical elements	Treatments versus their Controls	Mean ± SE	Two sample t-test	Significant increase (↑) or decrease (↓). Not significant (ns).
Soil TN (%)	UG	*0.1425±0.01*	$t = 0.5447, p = 0.6057$	ns
	CUG	*0.1500±0.01*		
	PG	*0.1800±0.02*	$t = -0.5774, p = 0.6042$	ns
	CPG	*0.1500±0.03*		
	MO	*0.1500±0.02*	$t = -0.3280, p = 0.7596$	ns
	CMO	*0.1425±0.01*		
Soil P (ppm)	UG	*10.6825±2.02*	$t = 2.8997, p = 0.0566$	ns
	CUG	*39.5500±9.75*		
	PG	*9.6950±5.62*	$t = -0.9406, p = 0.4126$	ns
	CPG	*4.3225±1.00*		
	MO	*1.5500±0.28*	$t = 0.7411, p = 0.4942$	ns
	CMO	*1.9875±0.52*		
Soil K (ppm)	UG	*865.2500±66.62*	$t = 2.6014, p = 0.0674$	ns
	CUG	*1455.0000±216.70*		
	PG	*1108.0000±199.98*	$t = -1.5010, p = 0.2219$	ns
	CPG	*800.0000±45.97*		
	MO	*675.5000±44.34*	$t = -0.9157, p = 0.4071$	ns
	CMO	*584.7500±88.63*		
Soil pH	UG	*8.1000±0.09*	$t = -1.1099, p = 0.3168$	ns
	CUG	*7.9200±0.14*		
	PG	*7.9650±0.14*	$t = 0.4904, p = 0.6413$	ns
	CPG	*8.0650±0.15*		
	MO	*8.1700±0.06*	$t = 1.2359, p = 0.2815$	ns
	CMO	*8.3600±0.14*		
Soil EC (uS/cm)	UG	*254.0000±30.67*	$t = 0.1191, p = 0.9100$	ns
	CUG	*261.2500±52.57*		
	PG	*241.0000±39.57*	$t = 0.4127, p = 0.6948$	ns
	CPG	*267.0000±49.02*		
	MO	*223.0000±10.73*	$t = 1.1077, p = 0.3106$	ns
	CMO	*240.5000±11.59*		

n=8

Further investigation of whether the magnitude of change (treatment minus its control) of each treatment in each chemical element was of material difference found that indeed there was a significant difference in the magnitude of change between the three treatments in P ($F_{(2,9)} = 5.687$, $p = 0.0253$) (Figure 4.1a) and K ($F_{(2,9)} = 7.798$, $p=0.0108$) (Figure 4.1b). However, no significant difference in magnitude was observed between the three treatments in TN level ($F_{(2,9)} = 0.271$, $p=0.7690$) (Figure 4.1c), pH level ($F_{(2,9)} = 1.476$, $p=0.2790$) (Figure 4.1d), and EC level ($F_{(2,9)} = 0.034$; $p=0.9670$) (Figure 4.1e).

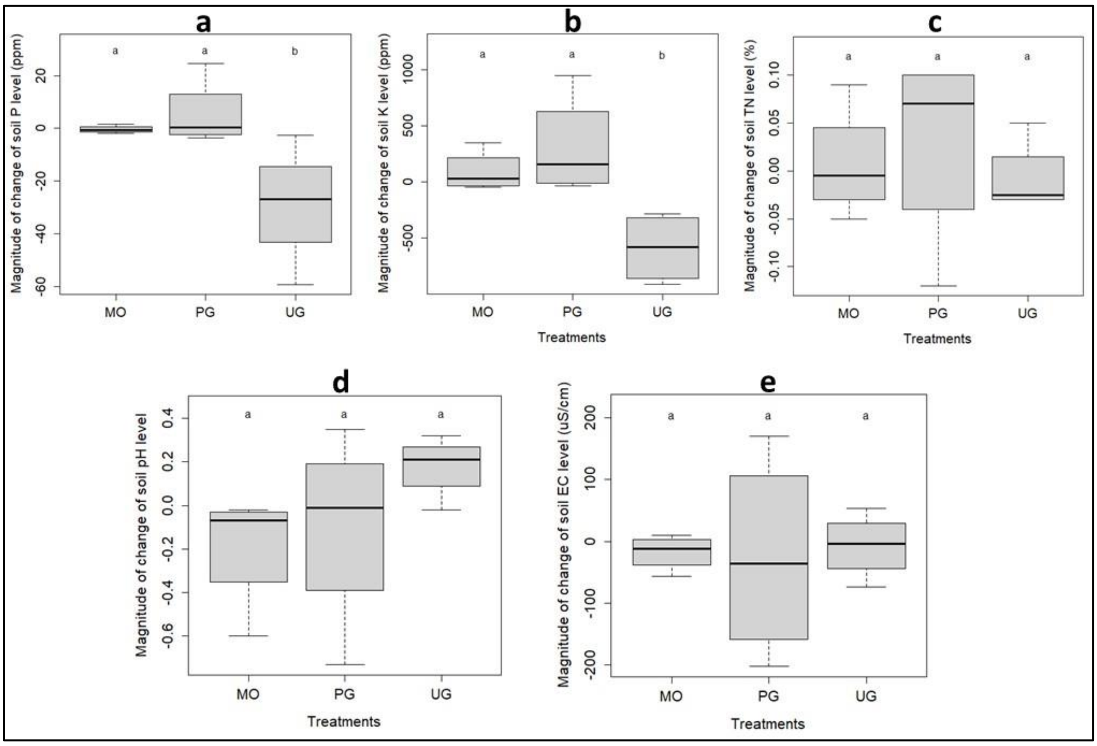

Figure 4.1: Magnitude of Change of Soil Nutrients, Derived from the Difference Between Each Treatment and its Control (Treatment Minus Control) of a) Soil Phosphorus (P); b) Soil Potassium (K); c) Soil Total Nitrogen (TN); d) Soil Potential of Hydrogen (pH) and e) Soil Electrical Conductivity (EC)

In the P level, Duncan's multiple-range test showed differences between UG and MO ($p = 0.0280$) and between UG and PG ($p = 0.0144$). UG decreased the P level to a higher magnitude compared to MO and PG where there was a slight increase. In the K level, Duncan's multiple-range test showed differences between UG and MO (p =

0.0185) and between UG and PG ($p = 0.0054$) where UG decreased K level and PG and MO slightly increased the levels (Table 4.2).

Table 4.2: One-Way ANOVA Test and Post Hoc Duncan's Multiple Range Test for the Magnitude of Change of Soil Nutrients, Derived from the Difference Between Each Treatment and its Control (Treatment Minus Control) of Soil Phosphorus (P), Soil Potassium (K), Soil Total Nitrogen (TN), Soil Potential of Hydrogen (pH), and Soil Electrical Conductivity (EC)

Chemical elements	*Magnitude of change (Mean ± SE)*			*F-test*	*Post hoc comparisons using Duncan's multiple-range test*		
	UG	*PG*	*MO*		*Treatments*	*q-value*	*p-value*
Soil TN (%)	-0.0075±0.02	0.0300±0.05	0.0075±0.03	$F_{(2,9)}$ = 0.271; p=0.7690	N/A	N/A	N/A
Soil P (ppm)	-28.8675±11.59	-5.3725±6.50	-0.4375±0.71	$F_{(2,9)}$ = 5.687; p=0.0253	PG versus MO	0.7560	0.6058
					UG versus MO	3.7000	0.0280 *
					UG versus PG	4.4560	0.0144 *
Soil K (ppm)	-589.7500±158.39	308.0000±226.06	90.7500±90.57	$F_{(2,9)}$ = 7.798; p=0.0108	PG versus MO	1.2950	0.3836
					UG versus MO	4.0570	0.0185 *
					UG versus PG	5.3530	0.0054 **
Soil pH	0.1800±0.07	-0.1000±0.23	-0.1900±0.14	$F_{(2,9)}$ = 1.476; p=0.2790	N/A	N/A	N/A
Soil EC (uS/cm)	-7.2500±26.25	-26.0000±82.70	-17.500±14.44	$F_{(2,9)}$ = 0.034; p=0.9670	N/A	N/A	N/A

n=12

Soil TN, P, K, pH, and EC are primary elements vital for forage production (Mathison and Peterson, 2011). Rangeland management practices are meant to influence soil chemistry in a manner that favours the growth of quality and diverse vegetation for wild ungulates. This potentially means an increased concentration of soil TN, soil P, and soil K enhances their absorption by plants (Wei et al., 2011; Bi et al., 2020).

This study documented a slight decrease in soil P levels under unprescribed grazing compared to its control. Even though the level of reduction of soil K under the same intervention was not noticeable, the magnitude of change was pronounced compared to other treatments. Since this grazing was uncontrolled and intensive, it might have induced negative effects due to excessive livestock excretions and trampling shielding the surface of the soil structure decreasing microbial processes and soil mineralization (Bardgett et al., 1998). Again, these sites had reduced above-ground biomass and increased basal gaps making them recipients of nutrient leaching and erosion reducing the soil nutrient concentration (Bi et al., 2020).

Many studies have different outcomes on the effect of prescribed grazing ranging from increased (Bi et al., 2020), decreased (Li et al., 2018; Hao and He 2019; Mihertu et al., 2021), to no change (Lin et al., 2010) in the primary chemical elements. Considering most of the parameters under this study remained unchanged in prescribed grazing, there is a possibility that the level of grazing was not enough to influence changes, or the changes were neutralized by the time the data was collected.

Mowing of grasslands and carrying away did not significantly influence soil chemical elements concurring with Edwards et al. (2012) findings, possibly due to lack of litter and livestock excrement that could increase soil nutrient concentration after decomposition.

4.2 Effects of Management Practices on Vegetation Chemical Elements (N, P, and K)

The P concentration in vegetation was significantly higher in MO, marginally higher in PG, and significantly lower in UG compared to their respective controls. Additionally, the K concentration in vegetation was significantly higher in PG compared to its control (Table 4.3).

Table 4.3: Changes in the Vegetation Nutrients (Vegetation Nitrogen – N, Vegetation Phosphorus – P, and Vegetation Potassium - K) Between Mowing of Grasslands and Carrying Away (MO) and its Control (CMO), Unprescribed Grazing (UG) and its Control (CUG), and Prescribed Grazing (PG) and its Control (CPG)

Chemical elements	Treatments versus their Controls	Mean ± SE	Two sample t-test	A significant increase (↑) or decrease (↓). Not significant (ns).
Vegetation N (%)	UG	0.7875±0.09	t = -0.2460, p = 0.8178	ns
	CUG	0.7625±0.04		
	PG	0.7225±0.03	t = -2.0273, p = 0.0900	ns
	CPG	0.6275±0.04		
	MO	0.6975±0.06	t = 1.0403, p = 0.3387	ns
	CMO	0.7900±0.07		
Vegetation P (%)	UG	0.0625±0.01	t = 2.6222, p = 0.0399	↓
	CUG	0.0815±0.00		
	PG	0.0785±0.01	t = -2.6369, p = 0.0541	ns
	CPG	0.0608±0.00		
	MO	0.0748±0.00	t = -2.5164, p = 0.0455	↑
	CMO	0.0658±0.00		
Vegetation K (%)	UG	0.3825±0.04	t = 1.9296, p = 0.1393	ns
	CUG	0.4700±0.01		
	PG	0.4750±0.04	t = -3.6222, p = 0.0225	↑
	CPG	0.3100±0.02		
	MO	0.4425±0.05	t = -0.2072, p = 0.8448	ns
	CMO	0.4300±0.03		

n=8

Further investigation on whether the magnitude of change (treatment minus its control) of each treatment in each chemical element was of material difference indicated a significant difference in the magnitude of change among the three treatments in P level ($F_{(2,9)} = 7.384$, $p = 0.0127$) (Figure 4.2a) and K level ($F_{(2,9)} = 5.829$, $p = 0.0238$) (Figure 4.2b). However, no significant difference in magnitude was observed in the N level among the three treatments ($F_{(2,9)} = 1.627$, $p = 0.2490$) (Figure 4.2c).

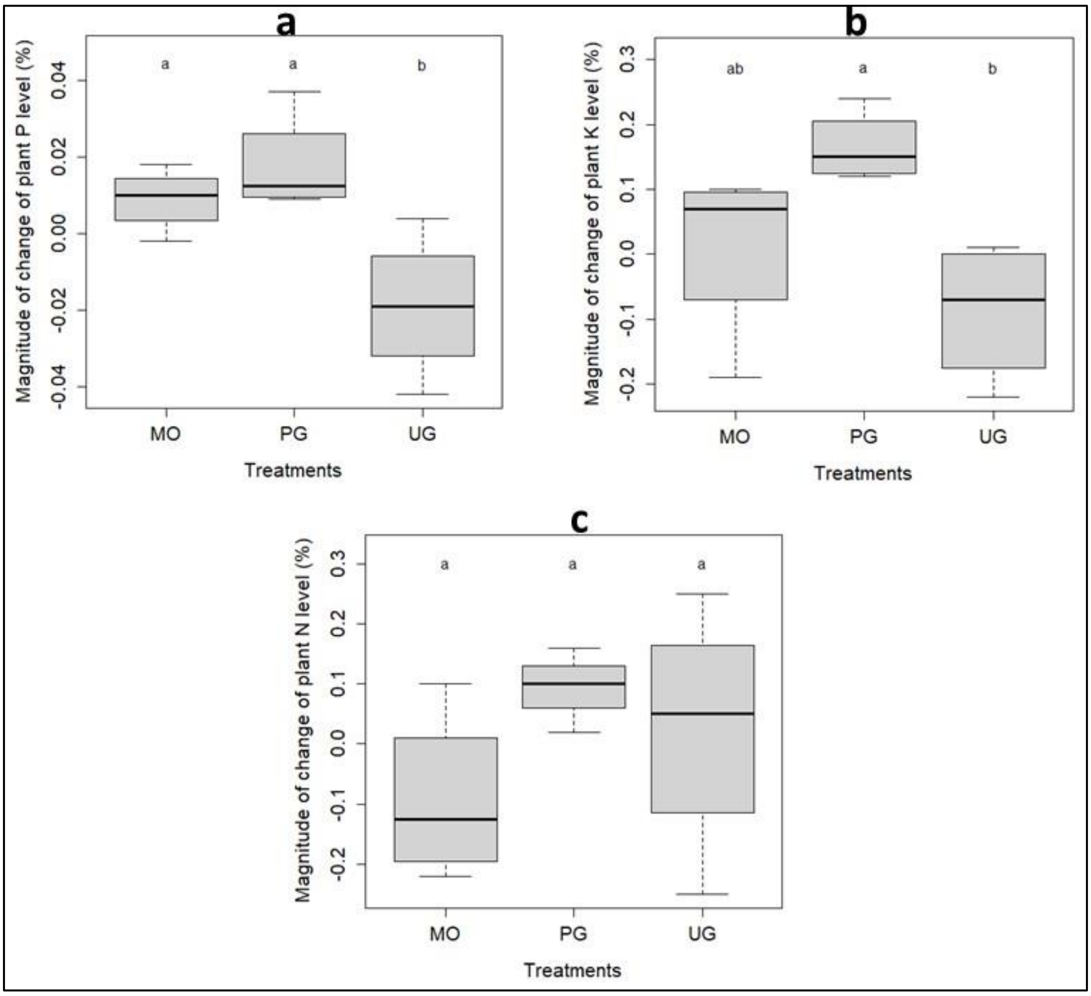

Figure 4.2: Magnitude of Change of Vegetation Nutrients, Derived from the Difference Between Each Treatment and its Control (Treatment Minus Control) of a) Vegetation Phosphorus (P); b) Vegetation Potassium (K); and c) Vegetation Nitrogen (N)

In the P level, Duncan's multiple range test showed differences between UG and MO ($p = 0.0206$) and between UG and PG ($p = 0.0064$). UG decreased the P level to a higher magnitude compared to MO and PG where there was a slight increase. In the K level, Duncan's multiple range test showed differences between UG and PG only ($p = 0.0099$) where UG decreased the K level and PG increased the level (Table 4.4).

Table 4.4: One-Way ANOVA Test and Post Hoc Duncan's Multiple Range Test for the Magnitude of Change of Vegetation Nutrients, Derived from the Difference Between Each Treatment and its Control (Treatment Minus Control) of Vegetation Phosphorus (P), Vegetation Potassium (K), and Vegetation Nitrogen (N)

Chemical elements	***UG***	***PG***	***MO***	***F-test***	***Post hoc comparisons using Duncan's multiple-range test***		
	Magnitude of change (Mean ± SE)				*Treatments*	*q-value*	*p-value*
Vegetation N (%)	0.0250±0.10	0.0950±0.03	-0.0925±0.07	$F_{(2,9)} = 1.627$; p=0.2490	N/A	N/A	N/A
Vegetation P (%)	-0.0190±0.01	0.0178±0.01	0.0090±0.00	$F_{(2,9)} = 7.384$; p=0.0127	PG versus MO	1.2390	0.4039
					UG versus MO	3.9630	0.0206 *
					UG versus PG	5.2020	0.0064 **
Vegetation K (%)	-0.0875±0.05	0.1650±0.03	0.0125±0.07	$F_{(2,9)} = 5.829$; p=0.0238	PG versus MO	2.8960	0.0709
					UG versus MO	1.8990	0.2123
					UG versus PG	4.7940	0.0099 **

n=12

Vegetation N, P, and K play a pivotal role in the growth and development of the plant as they contribute to the structural composition and functioning of the plant cells (Vitousek et al., 2010; Shrivastav et al., 2020). The ecological importance of rangeland interventions through the application of prescribed grazing, unprescribed grazing, and mowing is to improve the quality of rangeland for use by wildlife. This study observes variations across different scales, with prescribed grazing demonstrating notably higher concentrations of vegetation K, mowing of grasslands and removal displaying significantly higher P concentration, and unprescribed grazing exhibiting significantly lower vegetation P concentration. Even though some outcomes in this study recorded a miniature change, an increase or decrease in a particular soil nutrient corresponded with an increase or decrease of the same chemical element in vegetation respectively (Bi et al., 2020). This may indicate that for you to change chemometrics in the vegetation community, you need to apply a management intervention that can change the soil chemistry.

Whereas prescribed grazing resulted in significantly higher vegetation K concentration, intensive uncontrolled grazing compromised the effects by reducing vegetation P levels possibly due to excessive trampling forming a hardpan suppressing vegetation growth hindering nutrients uptake by plants (McNaughton, 1983; Bi et al., 2020).

Mowing of grasslands and carrying away influenced vegetation P concentration by increasing it. Mowing takes away nutrients and stimulates shoot regrowth improving nutrient recycling efficiency. Previous studies have recorded no effects on vegetation macronutrient concentrations because no nutrients were introduced into the soil as in the case of grazing (Edwards et al., 2012; Li et al., 2020; Liu et al., 2022).

4.3 Effects of Management Practices on the Above-Ground Biomass

Two sample t-test showed a significant reduction in the mean amounts of above-ground biomass between MO (649.1286 ± 106.91SE) and CMO (1335.4992 ± 91.12SE) ($t = 4.8861$, $p = 0.0029$) (Figure 4.3a) and between UG (1092.0590 ± 32.90SE) and CUG (1651.4196 ± 96.50SE) ($t = 5.4866$, $p = 0.0068$) (Figure 4.3b). No significant change was observed in the mean amounts of above-ground biomass between PG (1448.2633 ± 161.17SE) and CPG (1811.6478 ± 258.90SE) ($t = 1.1916$, $p = 0.2867$) (Figure 4.3c).

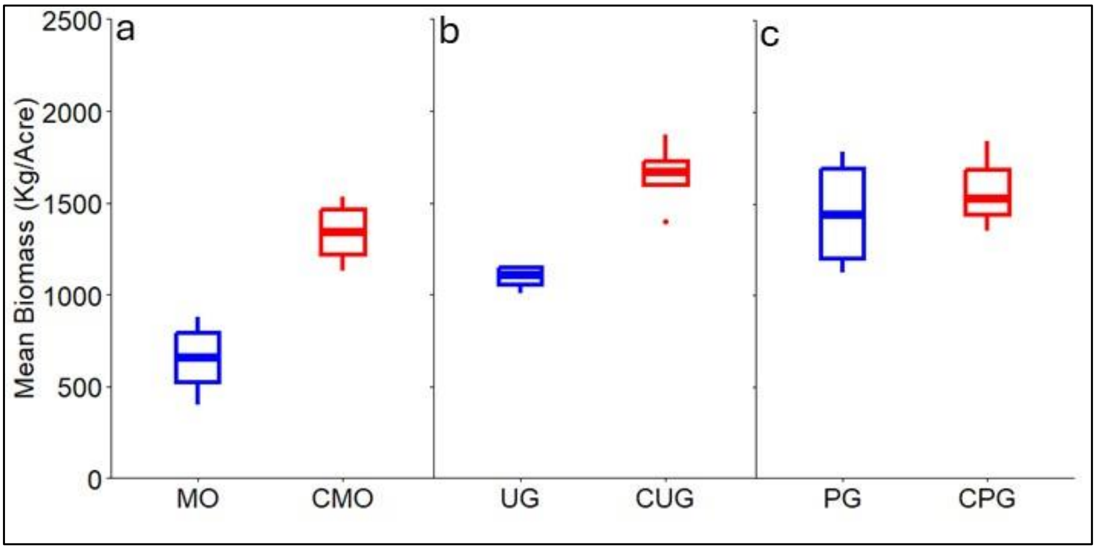

Figure 4.3: Change in Above-Ground Biomass Between a) Mowing of Grasslands and Carrying Away and its Control; b) Unprescribed Grazing and its Control; and c) Prescribed Grazing and its Control

One-way analysis of variance (ANOVA) test did not record a significant difference in the magnitude of change between UG (-559.3606 ± 145.74SE), PG (-363.3845 ± 173.86SE), and MO (-686.3706 ± 46.13SE) ($F_{(2, 57)} = 1.4820$, $p = 0.2360$) (Figure 4.4).

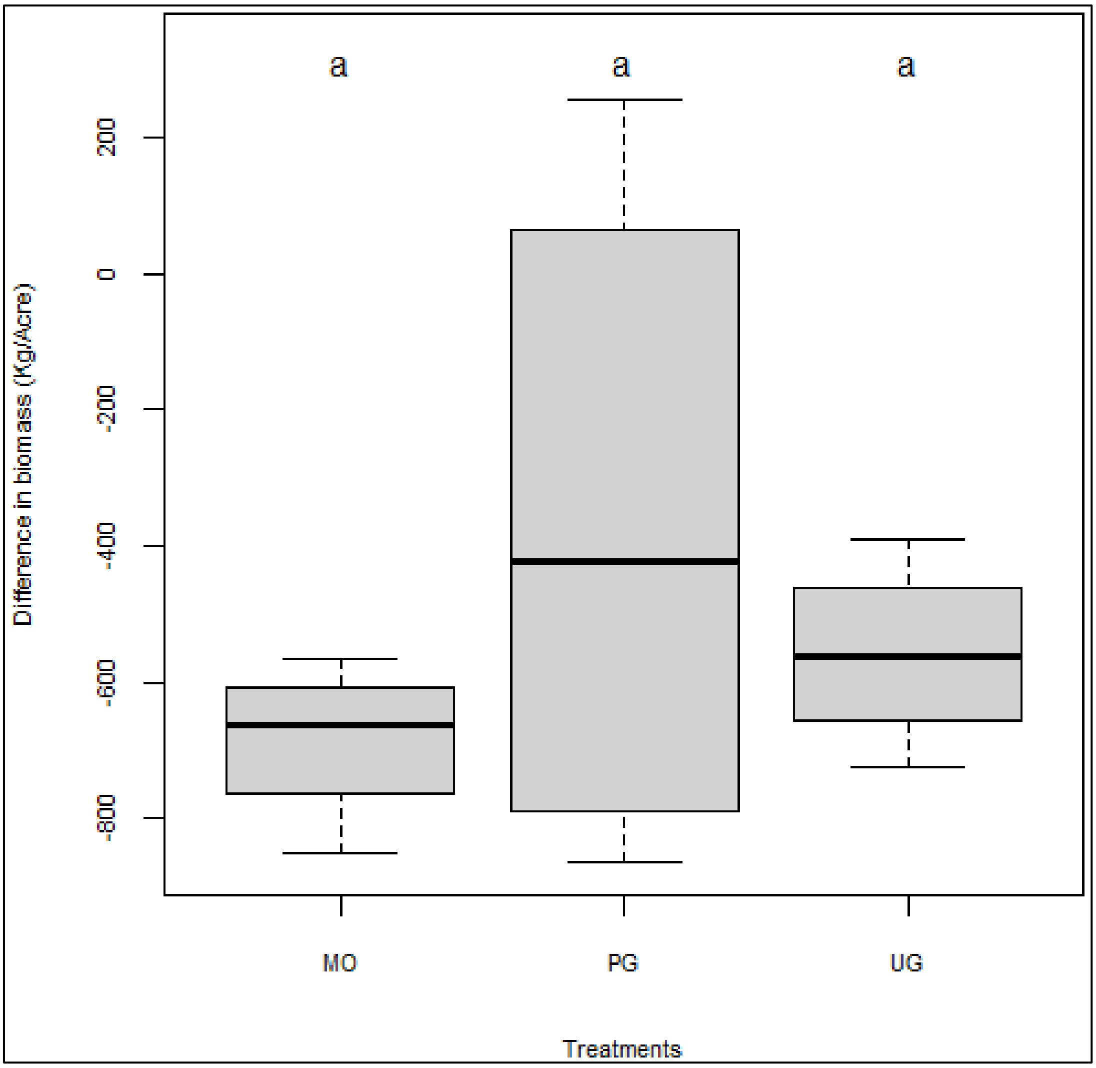

Figure 4.4: Magnitude of Change of Above-Ground Biomass among Treatments

The concept of rotational prescribed grazing of big herds, widely known as holistic management is highly controversial (Savory, 1991). Some studies have linked the method with success, noting that it reduced above-ground biomass and improved vegetation quality (Jacobo et al., 2006; Teague et al., 2011; Kimuyu et al., 2017; Odadi et al., 2017) while others did not record additional value when compared to less intensive but continuous grazing approaches (Joseph et al., 2002; Carter et al., 2014). On the other hand, while mowing has been documented to be costly, it has been recorded to yield similar results as grazing (Schulz et al., 2014).

Comparison of each treatment to its control indicates a significant disparity as a result of mowing of grasslands and carrying away as well as unprescribed grazing, while no significant difference was detected from prescribed grazing. The observed variations resulting from the first two practices were similar, making them the preferred recommendations for rangeland practitioners whose main goal is to reduce above-ground biomass. It is important to note that the magnitude of the difference in effects was not statistically significant between the three methods (Wang et al., 2019; Bi et al., 2020), which was most likely a result of the high variability in plot differences within both prescribed grazing and unprescribed grazing. With this variability within the prescribed grazing plots, it can be argued that the grazing rate of 25 cattle per acre per day was not enough to significantly influence the above-ground biomass in the long term. This further supports the perception that the number and assemblage of cattle in grazing schemes are crucial in influencing notable long-term changes (Sargent, 2016).

4.4 Effects of Management Practices on the Basal Gaps

Two sample t-test showed a significant decrease in the mean length of basal gaps between MO (19.4348 ± 1.01SE) and CMO (35.4912 ± 2.04SE) ($t = 7.0687$, $p = 0.0001$) (Figure 4.5a) but a significant increase between UG (32.8800 ± 2.43SE) and CUG (22.0280 ± 1.13SE) ($t = -4.0531$, $p = 0.0001$) (Figure 4.5b). No significant change was observed in the mean length of basal gaps between PG (28.0589 ± 1.40SE) and CPG (32.1736 ± 1.67SE) ($t = 1.8815$, $p = 0.0611$) (Figure 4.5c).

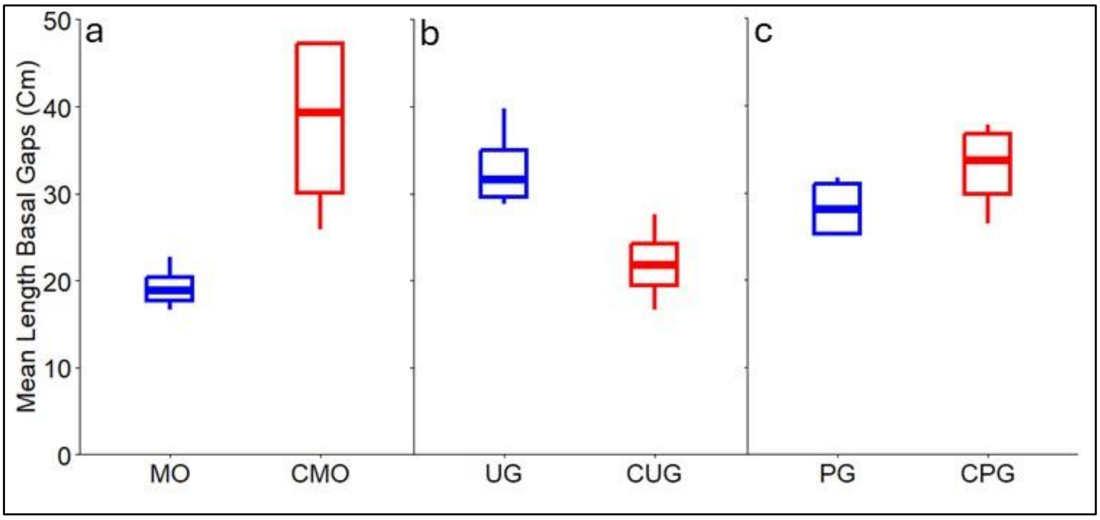

Figure 4.5: Change in Basal Gaps Between a) Mowing of Grasslands and Carrying Away and its Control; b) Unprescribed Grazing and its Control; and c) Prescribed Grazing and its Control

One-way analysis of variance (ANOVA) test recorded a significant difference in the magnitude of the group means between UG (10.9840 ± 3.29SE), PG (-4.6399 ± 4.24SE), and MO (-18.7276 ± 4.55SE) ($F_{(2, 9)} = 13.4000$, $p = 0.0020$) (Figure 4.6).

Post hoc pairwise comparisons using Duncan's multiple range test indicate differences between PG and MO ($p = 0.0366$), between UG and MO ($p = 0.0008$), and between UG and PG ($p = 0.0236$).

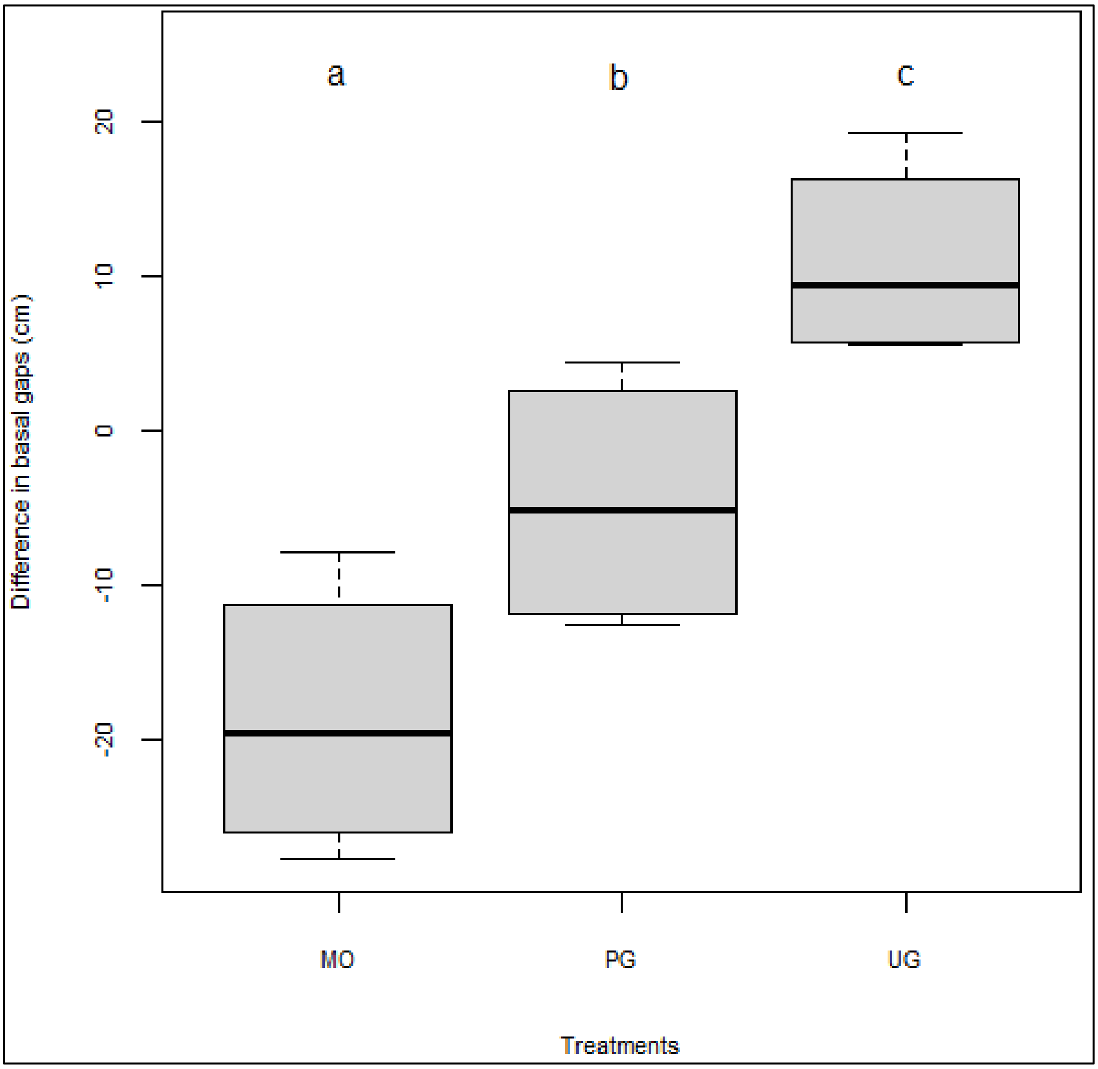

Figure 4.6: Magnitude of Change of Basal Gaps among Treatments

Conspicuous basal gaps increase runoff velocity, expose the land to erosion, and lead to degradation (Odadi et al., 2017; Kimiti et al., 2020b). The Lewa Wildlife Conservancy is dominated by *Cenchrus stramineus* and *Cenchrus mezianus* grasses which are only edible while growing but decrease in palatability when wholly mature forming huge stands of lignified grass. Reducing such huge stands of vegetation to 15 cm by mowing reduced competition for light by opening the canopies allowing other grasses and forbs to grow thus reducing the basal gaps (Williams et al., 2007; Odadi et al., 2011; Schulz et al., 2014).

Unprescribed grazing by its nature was intensive and non-stop, barely allowing existing vegetation to regenerate and new species to grow. This significantly reduced above-ground biomass without allowing recovery, therefore, increasing the basal gaps and subsequently exposing the ground to the peril of erosion and degradation (Kairis et al., 2015; Brenton, 2016; Bi et al., 2020).

Prescribed grazing aims to reduce the risk of land degradation triggered by soil erosion. This is because the previously exposed bare ground is instead occupied by a more herbaceous foliar cover (Odadi et al., 2017). The use of 25 Animal Days per Acre (ADA) in prescribed grazing in this study did not influence the basal gaps significantly. Sargent (2016) notes that this grazing scheme in LWC does not yield a clear advantage, and any advantage that may have been present was short-lived. On the magnitude of change, results indicate mowing of grasslands and carrying away as the best methods of reducing the basal gaps.

4.5 Effects of Management Practices on Vegetation Diversity

Wilcoxon Rank-Sum Test (WRST) indicated no significant difference in diversity between MO (Median = 1.2220) and CMO (Median = 1.2845) ($W = 6.0$, $p = 0.6631$) (Figure 4.7a), between UG (Median = 1.3170) and CUG (Median = 0.9180) ($W = 5.0$, $p = 0.4857$) (Figure 4.7b), and between PG (Median = 1.0890) and CPG (Median = 1.2860) ($W = 10.0$, $p = 0.6857$) (Figure 4.7c).

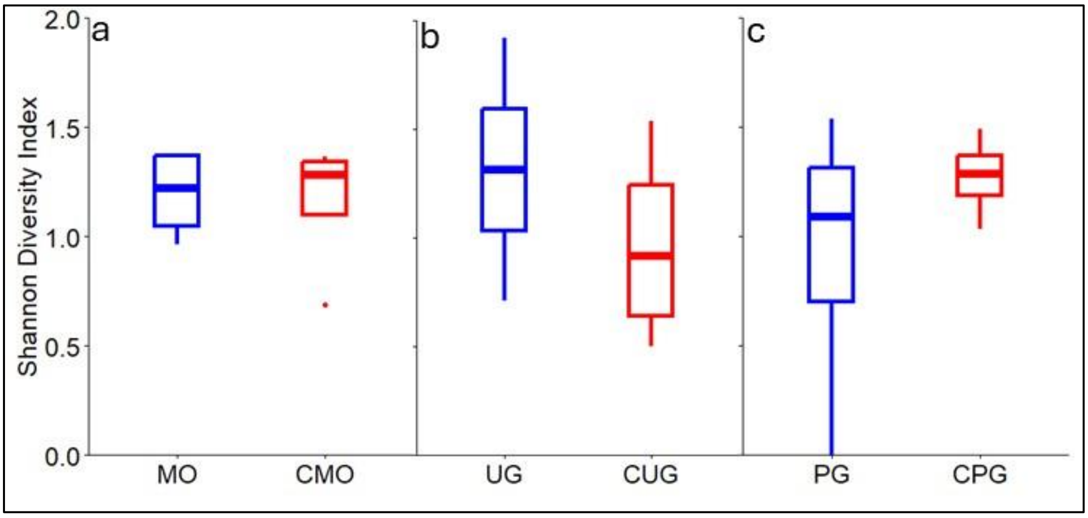

Figure 4.7: Change in Diversity Between a) Mowing of Grasslands and Carrying Away and its Control; b) Unprescribed Grazing and its Control; and c) Prescribed Grazing and its Control

Kruskal-Wallis test did not record a significant difference in the magnitude of the group medians between UG (Median = 0.2981), PG (Median = -0.2784), and MO (Median = 0.0210) (H (2) = 3.5000, p = 0.1738) (Figure 4.8).

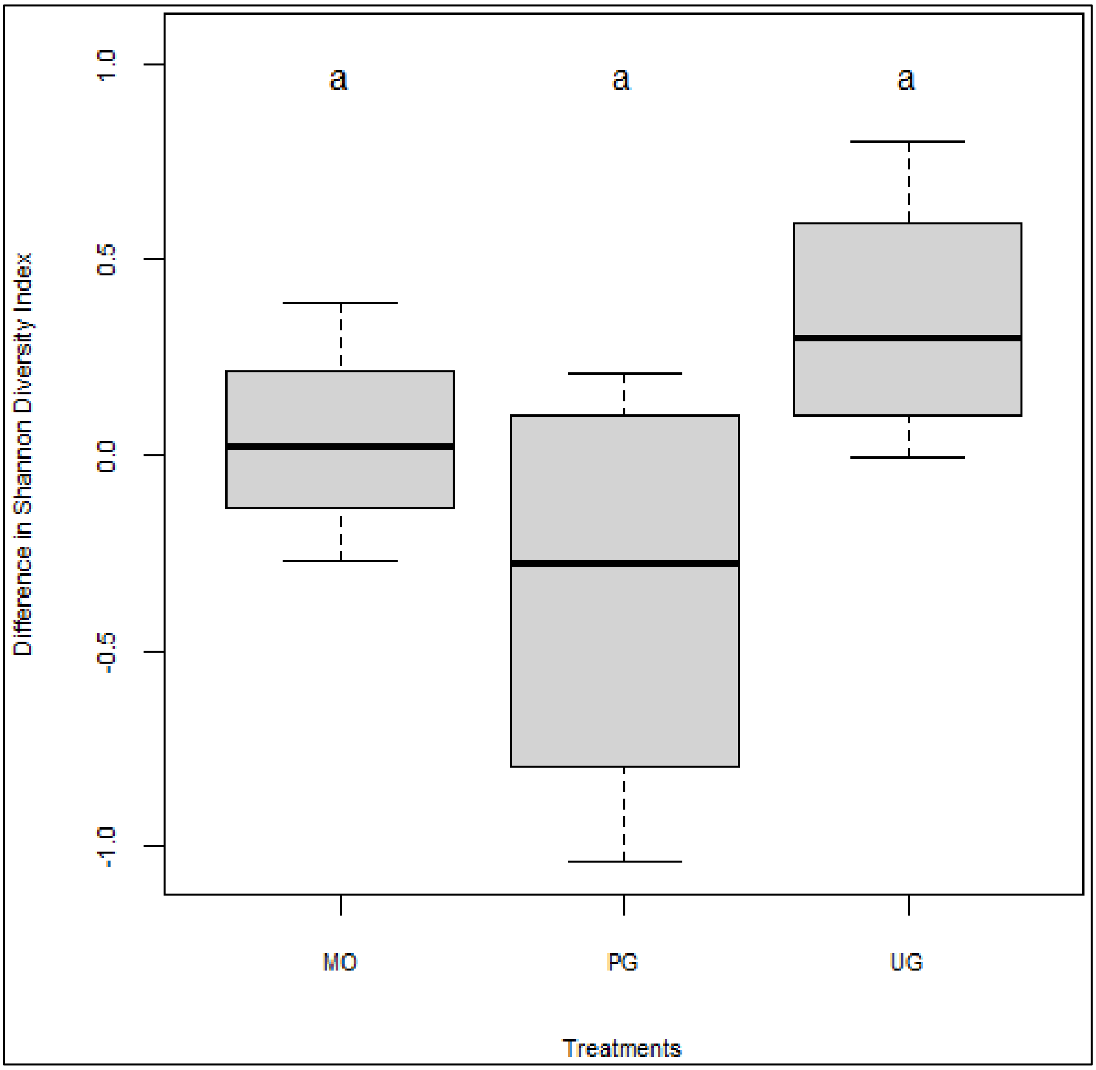

Figure 4.8: Magnitude of Change of Vegetation Diversity among Treatments

Species diversity is largely influenced by variations in soil cations concentration and soil chemical elements availability brought about by rangeland management activities (Juice et al., 2006; Niu et al., 2016).

This study did not record a significant change in species diversity in prescribed grazing concurring with Kariuki (2010). Also, no significant difference was observed in unprescribed grazing and mowing of grasslands and carrying away.

The Lewa Wildlife Conservancy rangeland is dominated by *Cenchrus stramineus* and *Cenchrus mezianus* which tend to increase and dominate when the range is selectively grazed or underutilized preventing other species from growing limiting species diversity (Trollope and Trollope, 1999; Angassa, 2014).

Under continuous and intensive grazing, biomass was continuously removed without giving ground time to recover limiting species growth and diversity (Kairis et al., 2015; Brenton, 2016; Bi et al., 2020).

Precipitation plays a critical role in improving nutrient availability allowing more species to grow and endure in water-constrained ecosystems (Xu et al., 2018). In 2021, the region received 187 mm of rainfall, a marked decrease from the historical annual range of 400 mm to 650 mm (Kenya Meteorological Department, 2021). This likely affected the parameters being investigated.

4.6 Effects of Management Practices on Wildlife Abundance

Two sample t-test showed significantly higher wildlife densities in MO (460.3303 ± 43.02SE) compared to CMO (171.9916 ± 44.29SE) ($t = -4.6696$, $p = 0.0034$) (Figure 4.9a). No significant difference was observed between UG (619.6754 ± 86.08SE) and CUG (584.2654 ± 104.44SE) ($t = -0.2616$, $p = 0.8027$) (Figure 4.9b), and between PG (275.6923 ± 48.23SE) and CPG (308.5731 ± 28.17SE) ($t = 0.5887$, $p = 0.5825$) (Figure 4.9c).

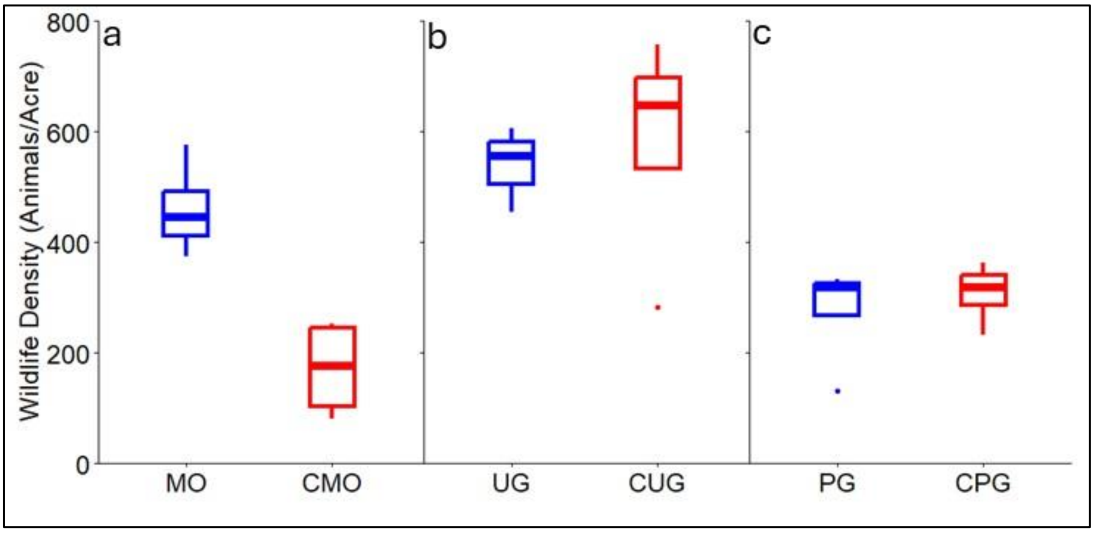

Figure 4.9: Change in Wildlife Densities Between a) Mowing of Grasslands and Carrying Away and its Control; b) Unprescribed Grazing and its Control; and c) Prescribed Grazing and its Control

One-way analysis of variance (ANOVA) test indicated a significant difference in the magnitude of the group means between UG (35.4100 ± 100.54SE), PG (-32.8807 ± 70.38SE), and MO (288.3388 ± 37.52SE) ($F_{(2, 9)} = 5.216$, $p = 0.0313$) (Figure 4.10).

Post hoc pairwise comparisons using Duncan's multiple range test indicate differences between PG and MO ($p = 0.0165$) and between UG and MO ($p = 0.0390$).

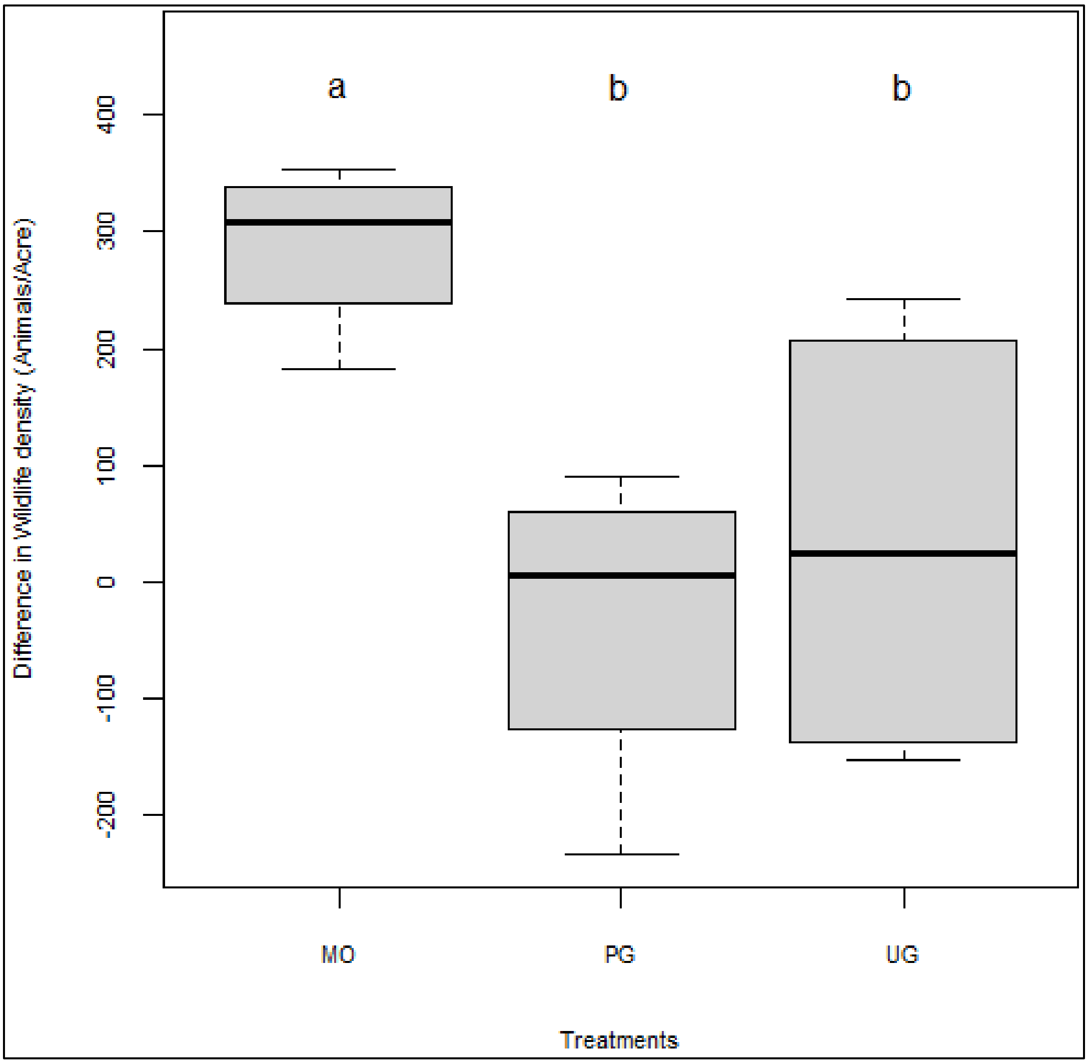

Figure 4.10: Magnitude of Change of Wildlife Densities among Treatments

In mowed (MO) and unmowed (CMO) blocks where differences were observed, considerably large densities of buffalo (*Syncerus caffer)*, Plains zebra (*Equus quagga*), Grant's gazelle (*Nanger granti*), elephant (*Loxodonta africana*), Lelwel hartebeest (*Alcelaphus buselaphus lelwel*), Beisa oryx (*Oryx beisa*), impala (*Aepyceros melampus*), eland (*Taurotragus oryx*), and Grevy's zebra (*Equus grevyi*), were observed (Figure 4.11). Other species that were observed in small densities included Somali ostrich (*Struthio molybdophanes*), African hare (*Lepus microtis*), and Common duiker (*Sylvicapra grimmia*).

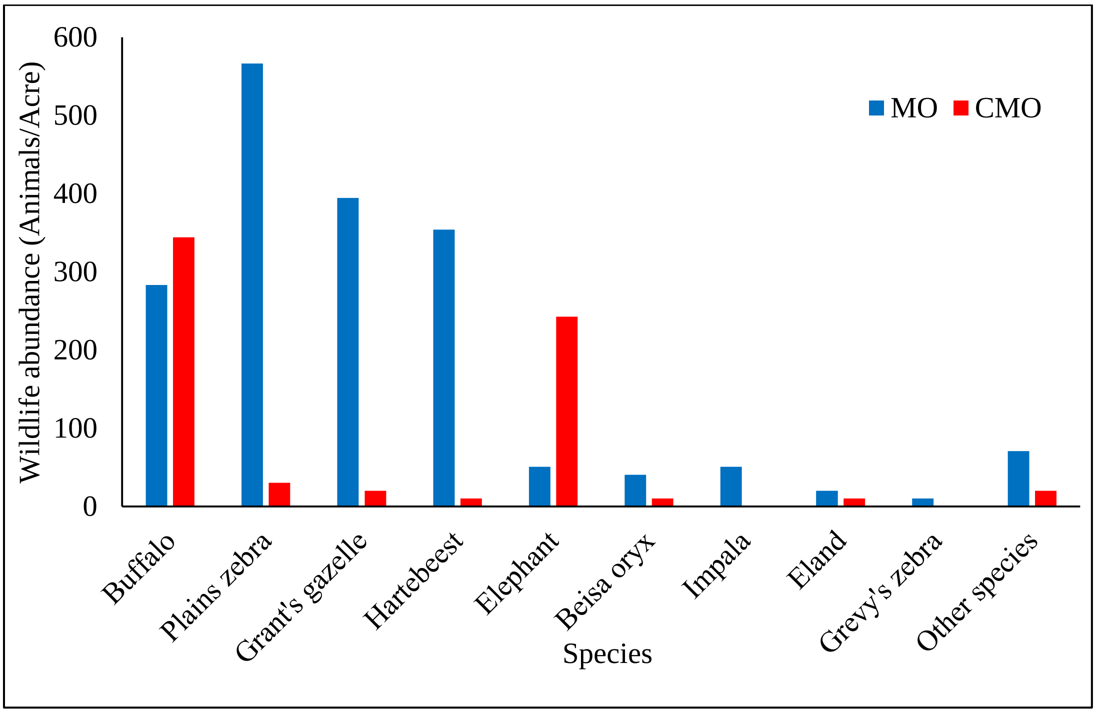

Figure 4.11: Wildlife Abundance in Mowed (MO) and Control (CMO) Blocks

Rangeland management practices are vital for rangeland health and productivity promoting plant species diversity and wildlife abundance (Erfanzadeh, 2014; Bailey et al., 2019).

Mowing as a rangeland management practice recorded a significantly higher wildlife abundance and a noticeable magnitude of change, consistent with the findings of Mose et al. (2013). Mowing of grasslands and carrying away reduced basal gaps and above-ground biomass. This allowed fresh nutritious vegetation to regenerate, attracting large wildlife densities. Also, areas with low above-ground biomass form convenient feeding and resting sites for wild ungulates because they offer good visibility for the avoidance of predators (Hopcraft et al., 2012; Mose et al., 2013). Plains zebra (*Equus quagga*) was among the most dominant species in the Conservancy and formed a prey base for the predators and may have benefited from the blocks that had reduced above-ground biomass. It was observed that elephants and buffalo were influenced by the quantity of forage rather than quality, which was consistent with Mose et al. (2013) findings.

Different studies have diverse outcomes on the response of wildlife to prescribed grazing with some studies recording increased wildlife abundance (Metera et al., 2010; Teague et al., 2011; Odadi et al., 2017) and others recording reduced wildlife abundance (Kimuyu et al., 2017; Filazzola et al., 2020). This study did not support any of these conclusions as no significant change in wildlife abundance was observed. Even after noting a marked increase in vegetation potassium levels, no change was observed in above-ground biomass, basal gaps, diversity, and soil chemical elements levels. Since the physical characteristics remained unchanged, nothing could attract wild ungulates to the prescribed grazing sites. Increased nutrients in vegetation without an increase in soil nutrients in this study may raise a question as to whether the effects were already neutralised, or whether other factors not investigated by this study were at play (Sargent, 2016).

Unprescribed grazing also did not influence wildlife abundance. In the other metrics investigated in this study, the unprescribed grazing reduced above-ground biomass and vegetation phosphorous levels and increased basal gaps, but no change was observed in vegetation nitrogen and potassium levels, diversity, and other soil chemical elements levels. Even with the substantial grazing happening in unprescribed grazing sites, wild ungulates still occupied these sites in equal measure compared to control blocks. The presence of humans and livestock in these unprescribed grazing sites made them safe for wild ungulates because they harbour minimal or no predators (Thaker et al., 2011). Also, the use of acaricides on livestock by herders tends to decrease tick densities in these mixed-use areas, forming favourable resting sites for wildlife (Keesing et al., 2013). This underscores the coexistence between livestock and wildlife as seen in communal and private lands in northern Kenya (Western et al., 2009).

4.7 Limitations of the Study and Opportunities for Future Research

The study sites were all located on vertisols soil sites, which constitute a significant portion of the Lewa Wildlife Conservancy's rangeland. As such, the patterns observed may differ when these treatments are carried out on soils with lower clay content and differing mineralogy. The study was also restricted to blocks subjected to the three management practices in June 2020, with prescribed grazing and mowing both being carried out for discrete periods of time, while unprescribed grazing was continuous throughout the study period. The irregularity of unprescribed grazing by livestock prevents this treatment from being recommended unreservedly, despite its potential positive effectiveness. Furthermore, the study period witnessed a notable decrease in precipitation compared to historical averages, potentially confounding the relative magnitudes of the different treatment effects. Finally, the study scope was restricted to sites within relatively flat terrains for uniformity, limiting the potential for results to be generalized across sites with varying topography. Future research should look to incorporate diverse soil types and topography and provide comprehensive documentation of unprescribed grazing practices to facilitate clear establishment of causal relationships with biophysical conditions.

CHAPTER FIVE

SUMMARY, CONCLUSION, AND RECOMMENDATION

5.1 Summary

This study explored the influence of rangeland management practices on levels of select soil chemical elements, vegetation metrics, and wildlife abundance in Lewa Wildlife Conservancy for increased rangeland productivity and wildlife abundance.

The study used a random systematic sampling approach, with ArcGIS 10.8.1 used to select study blocks at random, and the Land-Potential Knowledge System (LandPKS) used to select appropriate matching controls for each treatment plot. The study was limited to the vertisols soil sites, and to blocks where the management practices were undertaken in June 2020, apart from unprescribed grazing which was continuous. Further to this, the study only focused on select soil chemical elements (TN, P, K, pH, and EC), select vegetation chemical elements (N, P, and K), biomass, basal gaps, diversity, and wildlife abundance.

Soil samples were scooped with a clay auger using the zigzag method at a depth of 10 cm, 30 cm, and 50 cm and mixed to get a composite sample for laboratory chemical analysis. A 25 m line transect was established where the length of any gap between rooted vegetation was measured and the cumulative length of each sampling plot determined for comparisons between each treatment and its controls. For vegetation diversity, a modified line-point intercept was used where at every five metres of a 25 m transect, a 50 cm × 50 cm quadrat was placed and species within the quadrat were counted and identified with the aid of the PlantNet application. The vegetation inside the quadrats was then clipped and air-dried until they attained a constant weight, and the final weight was recorded to estimate biomass. The five sets of vegetation clipped per site were mixed to get a composite sample and taken to the laboratory for chemical analysis. A 4 m × 100 m line transect was established inside the sampling plots to count wildlife dung piles within the transect to estimate wildlife densities per acre of land. This was repeated twice, with dung piles smashed after each count to prevent recounting.

The mowing of grasslands and carrying away (MO) sites exhibited notable characteristics, including significantly lower above-ground biomass, reduced basal gaps, and significantly higher levels of vegetation phosphorus and wildlife abundance. However, there was no observed change in diversity and soil nutrient levels. Prescribed grazing (PG) sites, on the other hand, showed higher vegetation potassium levels, with no significant alterations in soil chemical elements, above-ground biomass, basal gaps, diversity, or wildlife abundance. Unprescribed grazing (UG) sites recorded significantly lower vegetation phosphorus levels and above-ground biomass, along with significantly higher basal gaps. However, no significant change was detected in diversity, wildlife abundance, and soil chemical elements. Despite the absence of observable changes in soil potassium levels, the magnitude of reduction was more pronounced in UG compared to PG, while no significant change was observed in MO.

5.2 Conclusion

In conclusion, this comprehensive study illustrates the complex relationship between rangeland management practices and their effects on soil chemical elements, vegetation metrics, and wildlife abundance in rangelands. While soil chemical properties remained largely unaffected by these practices, the slight reduction in soil Phosphorus levels in unprescribed grazing sites suggests a potential link between livestock intensity and soil nutrient changes. Vegetation metrics, on the other hand, displayed significant variations, with unprescribed grazing increasing basal gaps and potentially making these areas susceptible to soil degradation and erosion.

Prescribed grazing and mowing of grassland and carrying away had notable effects on vegetation nutrient levels. Importantly, the study found that wildlife abundance was primarily influenced by mowing of grassland and carrying away practices, likely due to reduced basal gaps and above-ground biomass which allowed fresh nutritious vegetation growth and increased visibility for feeding, resting, and avoidance of predators.

The findings underscore the importance of tailored rangeland management approaches, as demonstrated by the positive outcomes observed in Lewa Wildlife Conservancy, where mowing of grassland and carrying away practices contributed to enhanced rangeland health and increased wildlife abundance.

5.3 Recommendation

This study was undertaken 18 months after the implementation of rangeland management practices, except for unprescribed grazing that was continuous. The study, therefore, recommends the isolation of unprescribed grazing from livestock after some time, and time series data be collected in all treatments to understand changes in metrics at time intervals and the time in which effects are neutralised.

The study recommends the use of mowing of grasslands and carrying away since it positively influenced most of the metrics under investigation. However, the practice to be deployed can be chosen based on the metrics the rangeland practitioners would like to influence.

The study was limited to black cotton soil since this is where the rangeland management practices were undertaken, and this soil type represents at least 85% of the Conservancy. Therefore, the study also recommends similar studies be undertaken in other areas where similar rangeland management practices are applied in different soil types.

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APPENDICES

Appendix I: Species List Per Study Blocks

Unprescribed grazing		Control for unprescribed grazing	
Species name	**Family**	**Species name**	**Family**
Cenchrus stramineus	Poaceae	*Cenchrus stramineus*	Poaceae
Cenchrus mezianus	Poaceae	*Cenchrus mezianus*	Poaceae
Cynadon dactylon	Poaceae	*Solunum incunum*	Solanaceae
Eragrostis superba	Poaceae	*Erigeron bonariensis*	Asteraceae
Corchorus trilocularis	Malvaceae	*Setaria pumila*	Poaceae
Solunum incunum	Solanaceae	*Aerva lanata*	Amaranthaceae
Erigeron bonariensis	Asteraceae	*Verbena officinalis*	Verbenaceae
Indigofera volkensii	Papilionaceae	*Solunum lanzae*	Solanaceae
Cynodon nlemfuensis	Poaceae	*Justicia diclipteroides*	Acanthaceae
Conyza aegyptiaca	Asteraceae		
Cyperus rotundus	Cyperaceae		
Prescribed grazing		**Control for prescribed grazing**	
Species name	**Family**	**Species name**	**Family**
Cenchrus stramineus	Poaceae	*Cenchrus stramineus*	Poaceae
Cenchrus mezianus	Poaceae	*Cenchrus mezianus*	Poaceae
Heteropogon contortus	Poaceae	*Heteropogon contortus*	Poaceae
Hibiscus aponeurus	Malvaceae	*Hyparrhenia hirta*	Poaceae
Verbena officinalis	Verbenaceae	*Rhynchosia minima*	Fabaceae
Abutilon mauritianum	Malvaceae	*Helichrysum glumaceum*	Asteraceae
Helichrysum glumaceum	Asteraceae	*Ipomoea obscura*	Convolvulaceae
Medicago minima	Fabaceae	*Balanite grabra*	Balanitaceae
Mowing of grasslands and carrying away		**Control for mowing of grasslands and carrying away**	
Species name	**Family**	**Species name**	**Family**
Cenchrus stramineus	Poaceae	*Cenchrus stramineus*	Poaceae
Cenchrus mezianus	Poaceae	*Cenchrus mezianus*	Poaceae
Themeda triandra	Poaceae	*Themeda triandra*	Poaceae
Aristida kenyensis	Poaceae	*Aristida kenyensis*	Poaceae
Eragrostis superba	Poaceae	*Microchloa kunthii*	Poaceae
Microchloa kunthii	Poaceae	*Hibiscus aponeurus*	Malvaceae
Cenchrus ciliaris	Poaceae	*Helichrysum glumaceum*	Asteraceae
Helichrysum glumaceum	Asteraceae	*Tripteris vaillantii*	Asteraceae
Digitaria abyssinica	Poaceae	*Cenchrus ciliaris*	Poaceae
		Digitaria abyssinica	Poaceae
		Indigofera volkensii	Papilionaceae

Appendix II: Diversity Datasheet

DIVERSITY											
Date:			**Treatment ID:**			**Transect ID:**		**Area Name:**			
Gps X:			**Gps Y:**			**Habitat:**		**Comments:**			
Vegetation/Grass Species											
Transect Distance (Metres)	***Pennisetum stramenium***	***Pennisetum meziunum***	***Themeda triandra***	***Cynadon dactylon***							
5											
10											
15											
20											
25											

Appendix III: Biomass and Vegetation Sample Identity Datasheet

BIOMASS AND VEGETATION SAMPLE IDENTITY		
Date:		
Treatment ID:		
Transect ID:		
Gps X:	**Gps Y:**	
Area Name:		
Habitat:		
Comments:		
Transect Distance (Metres)	**Sample ID**	
5		
10		
15		
20		
25		

Appendix IV: Basal Gaps Datasheet

BASAL GAPS			
S/N	**Date:**		
	Treatment ID:		
	Transect ID:		
	Gps X:		**Gps Y:**
	Area Name:		
	Habitat:		
	Comments:		
	Length (cm)		**Difference (cm)**
	From	**To**	
1			
2			
3			
4			
5			
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Appendix V: Dung Count Datasheet

DUNG COUNT		
Date:		
Treatment ID:		
Transect ID:		
Gps X:	**Gps Y:**	
Area Name:		
Habitat:		
Comments:		
Species	**Tally**	**Total**
Plains zebra		
Grevy's zebra		
Grant's gazelle		
Hartebeest		
Elephant		
Beisa oryx		
Impala		
Eland		
Buffalo		
Giraffe		
Warthog		
Duiker		
Reedbuck		
Ostrich		
Others (Specify)		