DETERMINANTS OF WET SEASON LANDSCAPE AND FORAGE SELECTIVITY BY CATTLE ON FARM KIAMSAB WEST 364, CENTRAL NAMIBIA

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ABSTRACT

Forage shortages are increasing in frequency and severity, affecting livestock farmers in Namibia. Cattle grazing preferences are well documented in various ecosystems but remain unknown in patchy, arid environments. This study investigated the determinants of forage and landscape selectivity by cattle during the wet season at Farm Kiamsab West, Central Namibia. Transects were demarcated on crests (n = 12, 72 plots) and slopes (n = 13, 78 plots) based on where cattle had been observed grazing, grazing signs, and accessibility. In each plot, species were identified to species level, grazing status was recorded, cover was visually estimated, and above-ground biomass was collected. Forage selectivity was determined with Jacob's Selectivity Index (JSI). Percentage slope, elevation, species richness, species diversity (H'), cover, and biomass were explanatory variables in the Canonical Correspondence Analysis (CCA) to identify landscape selection determinants. The Chi-Square Test of Association revealed that cattle exhibit selective foraging behaviour ($\chi^2 = 17.416$, df = 2, $p = 0.001$). The JSI demonstrated that cattle selected grasses such as *Eragrostis nindensis*, *Anthephora pubescens* and forbs *Cleome suffruticosa*, and *Tribulus terrestris*. Forage selectivity is linked with plants' nutritional value, palatability, and availability in the landscape. The CCA showed that explanatory variables explained 36.7% of the observed variation in landscape-type selection. The overall test of all canonical axes ($F = 1.4$, $p = 0.002$) was significant, with elevation ($F = 1.9$, $p = 0.004$), species richness ($F = 1.6$, $p = 0.014$), and slope ($F = 1.6$, $p = 0.02$) significantly influencing landscape-type selection. These determinants influence forage accessibility, availability and determine the balance of costs and benefits for selecting a landscape type, guiding cattle to forage where benefits outweigh effort. These findings inform targeted rangeland management strategies to promote preferred species, emphasizing

the importance of prioritizing richness, elevation and slope in managing mountainous rangelands.

Keywords: Foraging behaviour, species richness, elevation, percentage slope, crests, slopes

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ABREVIATIONS AND ACRONYMS

CCA – Canonical Correspondence Analysis

DCA – Detrended Correspondence Analysis

DEM – Digital Elevation Model

GDP – Gross Domestic Product

HCA – Hierarchical Cluster Analysis

JSI – Jacob's Selectivity Index

NBRI –National Botanical Research Institute

OFT – Optimal Foraging Theory

SRTM DEM – Shuttle Radar Topography Mission Digital Elevation Model

USGS – United States Geological Survey

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DEDICATION

This Thesis is dedicated to my beloved Mother, Sibongile Moyo, a beacon of strength; and to my dear sisters, Nhlanhla and Nobukhosi, whose kindness and unwavering belief in me has been my guiding light. May the blessings of the Lord surround and enrich your lives. With all my love and gratitude.

DECLARATION

I, Sijabuliso Dube, hereby declare that this study is my own work and is a true reflection of my research, and that this work, or any part thereof has not been submitted for a degree at any other institution.

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CHAPTER 1

1.1 Introduction

Rangeland management is of paramount importance in Namibia, given the susceptibility of its vast rangeland to degradation. Strong empirical evidence underscores the significant negative impacts of rangeland degradation on the livelihoods of agricultural producers in Namibia (Hamunyela, 2019; Pringle, 2021). With almost 70% of the population depending directly or indirectly on natural rangeland resources for their food security and economic well-being (Ministry of Agriculture, Water and Forestry, 2012), the consequences of rangeland degradation on livelihoods can be broad and complicated. Livestock farming, a cornerstone of Namibia's agricultural sector, which depends on rangelands, significantly supports livelihoods and the national economy, contributing more than 2% to the country’s GDP (High Economic Intelligence, 2024). Accounting for almost two-thirds of agricultural produce (Deutsche Gesellschaft für Internationale Zusammenarbeit, 2022), livestock play a pivotal role in converting the lignified grass of Namibia’s considerable arid farmland into valuable protein and income, making it the cornerstone of Namibia's agricultural sector (Nott *et al*., 2019). Livestock farming is the only viable option for Namibia’s considerable arid farmland (Nott *et al*., 2019) as some areas cannot support crop production due to arid climatic conditions.

Rangelands in Namibia are a cheaper source of nutrition for livestock. Cattle and other ruminant animals possess specialised microbes in their digestive system and serve as energy brokers between plant biomass cellulose and energy and protein essential for human consumption (Derner *et al*., 2017). Unlike cattle in intensive systems, which are confined to feedlots and fed according to the predetermined rations set by the farmer or the rancher, free-ranging animals select their diets from the diverse array of forage plant communities they exploit. Foraging behaviour helps animals to gain vital nutrients and energy essential to sustain survival, development, and reproduction (Breed & Moore, 2022). However, grazing lands from which free-ranging herbivores obtain their diets can be very complex systems and animals must make a series of decisions to forage optimally. Cattle, just like other grazing ungulates, often move within and between plant communities, selecting forage plants and grazing locations to obtain a balanced diet (Fynn & Provenza, 2024). This is because food resources are not aggregated in a single location but are patchily distributed in space and time (Fynn & Provenza, 2024).

Rangelands are intricate systems characterized by dynamic patterns and processes that vary in space and time (McNew *et al*., 2023). These ecosystems support a wide range of plant and animal communities, and are shaped by factors such as topography, climate, weather, and disturbance regimes (Hovick *et al*., 2023). Variability in rangelands frequently results in differences in the availability and quality of forage resources across different areas in the landscape (Raynor *et al*., 2021; Zimmer *et al*., 2021). This implies that some patches may have abundant and nutritious forages while some have sparse low-quality vegetation all depending on factors governing heterogeneity. Furthermore, the production of fodder in dry and semi-arid rangelands is seasonal, with the greater part of it growing in the short-wet season (Abdelsalam, 2021). Grasses grow ideally for comparatively short periods of time before withering out in arid and semi-arid regions due to irregular and poor rainfall patterns (Nketsang *et al*., 2025). Consequently, the short growing season of grasses leads to greater availability of feed during the wet season and early dry seasons and limited availability during the greater part of the dry season (Abdelsalam, 2021). The availability of fodder for grazing animals becomes scarce due to the seasonality of fodder production, which necessitates rangeland managers and livestock farmers to close this gap by outsourcing fodder from other areas (Abdelsalam, 2021; Tulu *et al*., 2023).

Cattle being known for their selective grazing behaviour, exhibit a hierarchy of instinctive responses and behaviours in their environment (Grings, 2020), and they switch between plants, plant parts, grazing patches, and different landscapes to diversify their diet during foraging to meet their nutritional needs (Filho & Gregorini, 2022). This means that cattle will utilise food resources in some patches more intensively than in others. Therefore, a better understanding of the determinants driving patch and forage selectivity in heterogeneous environments is required, especially in Namibia where cattle production plays a critical role in the economy (Ministry of Agriculture, Water and Forestry, 2012). The knowledge can help enhance grazing distribution at spatial scales and improve animal performance and rangeland productivity by working with the environment, not against it.

Namibia's vast lands are increasingly vulnerable to climate change and variability (Mendelsohn *et al*., 2022; Shikangalah, 2020), with drought and diminishing precipitation, having considerable implications on vegetation dynamics and ecosystems (Liu & Zhou, 2021). Diminishing rainfall patterns and drought are known to affect the species composition, abundance, cover, diversity, and biomass of rangelands (Smit *et al*., 2024). Rainfall is essential for the growth and development of pastures and other forage crops; more rainfall means more and better-quality forages, which is the foundation of livestock production (Hasan *et al*., 2024). Diminishing rainfall patterns have broad implications on the grazing ecology of cattle, the impacts are far worse for livestock reared in mountainous grazing lands, as such animals are faced with accessibility challenges. In certain regions, mountain pastures often serve as buffers, offering supplementary and cost-effective forage sources in years when vegetation becomes limited due to overgrazing, land degradation or extreme climatic events such as droughts (Abdalla *et al*., 2018; Mayer *et al*., 2022). In contrast, on some farms such as Farm Kiamsab West, mountain pastures are not forage banks for difficult times; instead, they provide forage throughout the year, with animals being moved to different camps on the farm. This is necessitated by the inherently low grass productivity due to the semi-arid nature of the area. To date, there are knowledge gaps regarding patch and forage selectivity on mountainous rangelands. This study investigated the determinants of wet season patch and forage selectivity by cattle on Farm Kiamsab West.

Allen *et al*. (2011) defined forage selection as the removal of specific forages or components of forages rather than other forages or plant parts. Patch and forage selectivity can be constrained by environmental and herbaceous plant community structure (Andrew, 2021; Gwatirisa *et al*., 2022; Kaufmann *et al*., 2013; Utsumi *et al*., 2009). Andrew, (2021) suggested that plant community properties such as plant biomass, species richness, and diversity influence the forage quality and quantity, potentially guiding the foraging choices of large herbivores.

Previous studies on landscape and forage selectivity have predominantly focused on qualitative and structural factors, often using experimental methods to assess choices based on nutrient content (Ganskopp & Bohnert, 2009; Pauler *et al*., 2020). Some have focused on herbivores other than cattle (Levi *et al*., 2022; Zhang *et al*., 2022) or employed mechanistic models to analyse intake and selectivity (Galyean & Gunter†, 2016), and frequently concentrated on specific focal species (Utsumi *et al*., 2009). There is limited knowledge on cattle foraging behaviour in sub-Saharan Africa, despite the significant impact on cattle and the management of rangelands. Hence, this study aims to investigate the determinants of forage and patch selection in a complex environment, considering the intricate relationship between landscape type and plant communities, to provide insights into grazing behaviour and resource utilization patterns in semi-arid landscapes. The research seeks to contribute to the enhancement of animal production and the sustainable management of rangeland ecosystems.

1.2 Statement of the problem

Namibia's rangelands are currently experiencing declining productivity as evidenced by increasing levels of bare ground, reduced basal cover, and extensive bush encroachment, largely due to climate change (Nott *et al*., 2019). These conditions threaten the profitability and sustainability of livestock farming. Declining rangeland productivity due to warming and drying trends will necessitate adaptive strategies such as destocking and supplemental feeding.

At Farm Kiamsab West, mountains and rolling hills terrain (Mendelsohn *et al*., 2022) likely influence cattle grazing behaviour, there is a potential of overgrazing particularly on accessible areas and underutilization of other areas (Rivero *et al*., 2021). Overgrazing has negative implications on the soil, forage quality, and livestock production (Ehlert, 2025. In cattle, this often manifests as reduced body condition scores, low calves' birth weights, and decreased reproductive performance and overall livestock farming profitability (Ehlert, 2025). Additionally, selective grazing accelerates the loss of palatable forage species, intensifying rangeland degradation, increasing production costs, and ultimately threatening livelihoods and food security (Nott *et al*., 2019). Understanding the determinants of forage and patch selectivity of cattle is crucial for implementing sustainable rangeland management strategies that mitigate degradation and support the long-term viability of livestock production.

1.3 Objectives and hypotheses

The main objective of this study was to investigate the determinants of wet season landscape and forage selectivity by cattle on Farm Kiamsab West, Central Namibia. The specific objectives were therefore to:

a) To determine wet season forage selection by cattle on Farm Kiamsab West, irrespective of landscape type. It was hypothesized that:

   Cattle, will clearly exhibit selectivity towards specific plants species during the wet season at Farm Kiamsab West.

b) To compare the plant species richness, diversity, and composition between two landscape types (crests and slopes) at Farm Kiamsab West. It was hypothesized that:

   Plant species richness, and diversity would be significantly higher on crests than on slopes, and the two landscape types will support distinct plant species at Farm Kiamsab West.

c) To compare the above-ground biomass and cover between crests and slopes at Farm Kiamsab West. It was hypothesized that:

   Crests will have significantly higher above-ground biomass and cover than slopes at Farm Kiamsab West.

d) To determine the influence of above-ground biomass, species richness, diversity, cover, slope and elevation on cattle landscape-type selection at Farm Kiamsab West. It was hypothesized that:

   The landscape type selection would be significantly influenced by above-ground biomass, species richness, diversity, cover, slope and elevation at Farm Kiamsab West.

1.4 Significance of the study

The results of the study are relevant to both rangeland scientists and livestock farmers. For rangeland scientists, the findings offer a foundation of designing strategies to mitigate the potential negative effects of cattle grazing on the ecosystem (Guo *et al*., 2009). By understanding cattle forage selection, scientists can better manage grazing pressure and develop measures to prevent overgrazing of preferred plant species and specific landscape types. For the livestock farmers, the insights gained can inform sustainable rangeland management strategies that optimize forage use, leading to healthier livestock, sustained productivity of the rangeland, and improved profitability. Practical recommendations such as promoting the growth of the highly selected species, implementing rotational grazing, and determining when to rotate animals between paddocks can be integrated into the management practices of the farm. Moreover, farmers can use this knowledge to decide which livestock breeds are better to keep that are suited for navigating terrains, ultimately leading to more efficient land utilization and enhanced long term rangeland productivity.

Moreover, the study adds to the relatively limited knowledge on wet season grazing dynamics. It also contributes to the understanding the complex interactions between plant community structure, topographical gradients and foraging behaviour of cattle, particularly in semi-arid rangelands found in the central Namibia. The insights are of great importance as they could help land and livestock managers to understand, explain, manipulate livestock distribution on the farm thereby minimizing over utilization of some plant species and specific landscape type.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview and implications of patch and forage selectivity.

Grazing management plays a crucial role in the sustainability of livestock production systems, particularly in semi-arid regions where seasonal changes in forage availability significantly impacts herd nutrition and productivity. With the rains becoming more frequent during the wet season, herbaceous plants begin to grow in abundance and are more readily consumed by cattle due to their increased availability (da Cunha *et al*., 2022). This increased abundance and plant diversity provide herbivorous animals, with a wider range of dietary choices. Consequently, these animals' exhibit distinct grazing behaviours, including landscape and forage selectivity, influenced by the variety of available plants. Cattle may selectively graze on a certain landscape over another, as well as select specific forage types within that landscape based on different interlinked factors (Anthony & Germino, 2022; Grings, 2020; Rivero *et al*., 2021). Understanding cattle grazing behaviour is essential for implementing effective grazing management strategies and maintaining the health of both livestock and the surrounding ecosystems.

Although the determinants of landscape and forage selectivity by cattle have been the subject of extensive research in various ecosystems around the world, knowledge gaps still exist in Namibia, where forages are patchily distributed. In the past, attention has been paid to the diet selection of cattle during the hot-dry season in semi-arid areas in Namibia (Katjiua & Ward, 2006), but the determinants of landscape and forage selection during the wet season remain obscure. Gaining more insights into grazing ecology is of paramount importance, given that grazing practices have implications for animal performance and the environment they are in. By grazing selectively, cattle can optimize their nutritional intake and balance their diet by consuming a diverse range of plants. This could potentially improve their overall well-being and reduce the risk of nutritional deficiencies (Distel *et al*., 2020; Lagrange *et al*., 2020; Provenza, 2023). Improper management of grazing activities could potentially result in overgrazing particularly in most preferred patches, leading to soil erosion, compaction, degradation of the land, and an increase in invasive plant establishment and bush proliferation (DiTomaso *et al.,* 2018; Ehlert *et al.*, 2025; Guo & Chen, 2024; Wen, 2023). Cumulatively, overgrazing can contribute to desertification, ultimately reducing the productivity of the land and causing long-term ecological damage (Bolo *et al*., 2019).

This literature review aims to provide valuable insights and explore the factors influencing wet season patch and forage selectivity by cattle, and the theories associated with grazing behaviour. It will draw from relevant studies conducted in similar ecosystems in different parts of the world, thereby highlighting the importance of this research for the management of livestock and rangeland resources in semi-arid regions such as central Namibia.

2.2 Forage selectivity by cattle

In herbivores, dietary balance achieved through the consumption of forage species with complementary nutrient profiles is critical for maintaining digestive efficiency and metabolic health. Different plants have different nutrient profiles; hence, selectivity allows animals to balance their diets more efficiently, and this is crucial for digestive efficiency and metabolic health (Leiber *et al*., 2020). The nutrient composition of plants shifts with their growing stages, as a result, animals must continuously adjust their foraging behaviour continuously (Westoby as cited in Leiber *et al*., 2020, p. 35). Forage selectivity in cattle is a dynamic process influenced by a multitude of interrelated factors, with grazing values of the plants, for example, playing a very significant role in influencing forage selection. For instance, a study conducted by Treydte *et al*. (2013) in South Africa observed that all grazers, domestic or wild, have a strong selection bias towards green, palatable grasses of high nutrient content. However, herbivores must not only balance their nutrients such as carbohydrates and proteins, but they have to navigate the challenge of avoiding and selectively ingesting potential toxins in certain circumstances, such as when small amounts are necessary for managing diseases or regulating metabolic functions (Frost & Mosley, 2024; Leiber *et al*., 2020). Hence, grazing animals aim to maximize nutrient and energy intake while minimizing the consumption of harmful chemicals, which drives them to selectively feed on specific forage species and plant parts.

Research has shown that cattle and other ruminants are highly adept at discriminating against available forage types and often select the ones that offer the highest nutrient benefits (Frost & Mosley, 2024; Garcia *et al.,* 2020). This nutritional wisdom stems from a combination of factors such as individual preferences, learned behaviours, physiological feedback mechanisms and sensory cues, which are largely regulated by the biophysical environment (Frost & Mosley, 2024; Garcia *et al.,* 2020; Smith *et al*., 2021). These interactions enable ruminants to assess the consequences of food ingestion in subtle but significant ways, thereby influencing their food selection (Frost & Mosley, 2024). Cattle just like other animals have pre- and post-ingestive feedback signals which may include but are not limited to taste, smell, and texture of forages, and other physiological responses such as satiety and digestibility as well as toxin detection (Distel *et al*., 2020; Frost & Mosley, 2024; Hirata & Kusatake, 2021). These signals develop over time through social learning and personal experience and may constrain the intake of some forages (Frost & Mosley, 2024). Additionally, spatial memory also plays key role in forage selection, allowing animals to recall and prioritize areas based on past forage availability and quality (Frost & Mosley, 2024; Garcia *et al.,* 2020). This cognitive ability is particularly relevant in mountainous and hilly terrain, as these factors influence forage distribution and accessibility.

According to the Optimal Foraging Theory (OFT) (Pyke, 2010; Pyke & Starr, 2020), animals adopt foraging strategies that maximize energy gain while minimizing effort. In mountainous landscapes, other areas may require more energy to access, consequentially influencing grazing decisions. Thus, animals may need to adjust their foraging behaviour in response to the changes in environmental conditions, an adaptive behaviour which allows them to optimize nutrient intake and energy efficiency when getting a feed resource or selecting a feeding patch in dynamic landscapes (Ginane *et al*., 2015; Grings, 2020; Rivero *et al.,* 2021). Research has consistently revealed that cattle, when faced with a diverse sward with both high- and low-quality forage species, selectively graze on more nutritious plants resulting in differential utilization of the available vegetation (Cuchillo-Hilario *et al*., 2018; Fraser *et al*., 2022). This behaviour supports the concept of optimal foraging, where animals aim to maximize nutrient intake by minimizing energy expenditure. Hence, it can be inferred that cattle adjust their grazing patterns based on available forage species, further highlighting the crucial role of forage quality in influencing forage selection.

Previous research has predominantly focused on how livestock forage selectivity is influenced by nutritional composition of plants and quality factors such as crude protein, minerals, carbohydrates, and fibre (Babayemi & Adebayo, 2020; Hirata *et al*., 2008; Manning *et al*., 2017; Tsutsumi *et al*., 2015, Pauler *et al*., 2020). However, this study examines whether cattle graze discriminately during the wet season, a period of abundance. Thereby providing insights into the wet season foraging patterns, which could help rangeland scientists and farmers to optimize grazing management practices by highlighting the species that cattle prefer when there is no scarcity.

From the extensive literature, researchers consistently outline that cattle exhibit forage selectivity, that is, they prefer certain species over others (Cuchillo-Hilario *et al*., 2018; Pauler *et al*., 2020; Simataa & Mapaure, 2024; Simelane *et al*., 2021; Utsumi *et al*., 2009). It has also been noted that during the wet season, grasses dominate cattle diets across the globe. For instance, in semi-natural grasslands, Cooke *et al*., (2024) outlined that in Southern Africa, cattle graze predominantly on herbaceous plants during the wet season, benefitting from abundance and quality of the forage. However, during the dry season, cattle increasingly rely on browse species and supplemental feed to meet their dietary needs (Cooke *et* al., 2024). von Müller *et al*. (2017) reported that grasses made up a substantial portion of the cattle diet during both the wet and dry seasons. Similarly, Mphinyane *et al*. (2015), in a study conducted in Botswana, stated that cattle primarily consume grasses during the wet season but browse through the dry season and forbs are selected by cattle to a lesser extent. In this study, Mphinyane *et al*. (2015) observed that cattle diet constituted 75% grass, 23% browse, and 2% forbs. These findings also coincide with the findings of Meisser *et al*. (2014) in the Swiss Alps, who reported that beef cows comprised 14% of graminoids, 10% of forbs, and 1% of legumes. In the Kafue floodplains of southern Zambia, Gondwe *et al*. (2023) evaluated the nutritive value of naturally growing pastures and identified grass species such as *Vetiveria nigritana* and *Polygonum salicifolium* to have higher crude protein content levels. Hence, research suggests that grasses are a primary component of cattle's diet during the wet season. In Namibia, grasses such as *Anthephora pubescens*, *Schmidtia pappophoroides*, *Eragrostis trichophora*, *Eragrostis nindensis* have been outlined as important forage species in cattle's diet in the central, northern, eastern, and north-eastern parts of Namibia (Rothauge, 2007; Simataa & Mapaure, 2024). However, little is known about the forage selectivity of cattle in the more arid southwest parts of central Namibia. This knowledge is important and could help the farmer to manipulate the rangeland to contain more preferred forage species.

2.2 Species richness, species diversity and species composition differences across the landscape

Understanding the vegetation attributes of rangelands is critical to their management (Acar & Osmam, 2022). Appreciating how species richness, species diversity, and species composition vary across landscapes is essential for managing the rangeland and optimizing land use, particularly in semi-arid rangelands. Topography has been shown to profoundly influence abiotic conditions which, in turn, shape the structure, function and dynamics of ecological communities (Jucker *et al*., 2018; Liang *et al*., 2024; Zheng *et al*., 2022). Differences in factors such as soil moisture and depth, wind, temperature, and exposure to sunlight, caused by different elevation gradients and slope might create microclimatic zonation and these variations are closely related to alterations in vegetation structure and composition (Matyukira *et al*., 2024; Singh, 2018).

Several studies outlined that topography plays a significant role in shaping species richness, species and composition. For example, in a study conducted in the Harego Mountain Forest, in Ethiopia, Worku *et al*. (2023) found out that species abundance and diversity indices were significantly higher in upper elevations, and environmental variables at different elevations play a role in shaping these patterns. Furthermore, slope steepness has been reported to significantly impact vegetation, especially at high altitudes (Liang *et al*., 2024). The slope steepness can affect hydrological conditions, particularly precipitation runoff, by determining the speed and direction of water flow on the surface (Liang *et al*., 2024). The steeper the slope, the faster the water flow and less infiltration, leading to lower moisture content in some hillside areas (Liang *et al*., 2024). Hence, these conditions can create drier conditions which support drought-tolerant species, thereby limiting overall species diversity and richness. On the other hand, gentler slopes promote better water retention and infiltration (Matyukira *et al*., 2024). Matyukira *et al*. (2024), in a study conducted in South Africa, observed a clear pattern in landscape dynamics, where flat and level areas had higher Topographic Wetness Index values compared to sloping and steep terrain. This suggests that flatter areas like crests with minimal slope gradients might be better at retaining moisture, which may result in higher species diversity and richness.

Contemporary studies revealed that elevation on mountainous regions create a mosaic of ecological zones, each supporting distinct plant communities adapted to specific environmental conditions. Studies across East Africa have explored how elevation influences species richness and community structure. Findings by Gebrehiwot *et al*. (2019) revealed a bimodal pattern, with herbaceous species richness low at medium elevations, but higher at both higher and lower elevations. In southern Ethiopia's semi-arid grasslands, Bora *et al*. (2020) reported that herbaceous species richness peaks at lower elevations, where warmer temperatures and greater resource availability support more diverse communities, while higher elevations host fewer, but more specialized species adapted to harsher conditions. This may suggest that some plants may favour stable conditions while others are adapted to slopes due to their tolerance to limited moisture and shallow soils. This differential adaptation along the topographic gradient can result in notable variations in species composition across the landscape.

The diet selected by cattle is strongly influenced by the availability of preferred feed resources, and their distribution within the landscape (Fraser *et al*., 2022). Despite the implications of variations in plant community patterns on the availability of preferred forage species and, consequently, cattle grazing patterns, much of the existing research has primarily focused on the impacts of cattle grazing on species richness, diversity, and composition in rangeland systems (Gebremedhn *et al*., 2023; Zhang *et al*., 2023). Moreover, there is a notable lack of studies directly comparing these factors between crests and slopes in mountain rangelands. This study aims to address this gap by investigating how species richness, diversity, and composition differ between the grazing landscapes such a crests and slopes at Farm Kiamsab West.

2.3 Above-ground biomass and cover across topographical gradients

The spatial and temporal condition of standing biomass is a crucial factor in managing grazing activities on rangelands (Rhodes *et al*., 2022). By assessing the amount and distribution of plants, farmers and land managers can make informed decisions on grazing practices to maintain ecosystem health and ensure sustainable forage availability for livestock (Rhodes *et al*., 2022). The timing and execution of management practices are often complicated by the dynamic nature of plant biomass, which fluctuates due to weather conditions, seasonal changes, grazing pressure and human activities (Rhodes *et al*., 2022). By comparing standing biomass and cover between grazing landscapes such as crests and slopes, land managers can incorporate these findings into decision-making tools for practices such as targeted grazing, rotational grazing, establishing proper carrying capacity and resting periods of rangelands. A single rangeland can exhibit varying levels of biomass and cover across different sites. This dynamic nature and variability complicate planning and present challenges for real-time decision making (Rhodes *et al*., 2022). Therefore, the comparison of biomass and cover between crests and slopes, will contribute to the development of adaptive strategies for managing these landscapes more effectively.

Studies have shown that soil and water availability play a crucial role in regulating plant productivity and community composition on rangelands (Nyenda *et al*., 2023; Polley *et al*., 2017). Polley *et al*. (2017) reports that in different ecosystems and within the same ecosystem, there is a positive link between precipitation and plant productivity. This implies that productivity generally improves due to increased water availability in the soil. A 6-year study conducted in the semi-arid steppe of Inner Mongolia, China; Wei *et al*. (2019) found out that topography and precipitation patterns notably influence soil water content and above-ground biomass in grasslands. The study revealed a significant negative relationship between soil water content and altitude, with higher biomass observed in the bottom or lower areas during the drier year (Wei *et al*., 2019). Conversely, in wetter years, above-ground biomass differed across landscape positions (top area, slope area, and bottom area) (Wei *et al*., 2019). Other studies on topography have reported significant vegetation differences in slope positions (Nyenda *et al*., 2023; Sanaei *et al*., 2019; Yao *et al*., 2022; Zhang *et al*., 2022). Therefore, these studies suggest that topographical variation plays a critical role in shaping vegetation dynamics, and it is likely that the distribution of above-ground biomass and cover will differ significantly between crests and slopes.

2.4 Factors influencing patch selectivity by cattle in heterogeneous landscapes.

2.4.1 Effects of species diversity and species richness

Cattle, as selective grazers, make landscape-type selection based on several factors, with species diversity and richness playing a critical role in the selection process. A higher number of species may increase the range of options available to cattle to forage on, thereby enhancing the likelihood of cattle selecting nutrient-dense and more palatable plants. This diversity allows for a balance of high-quality and low-quality forages, supporting more sustainable grazing patterns as animals can shift their selection in response to changing plant availability (Fraser *et al*., 2022). Albores-Moreno *et al*. (2020), Andrew, (2021), Fraser *et al*. 2022) and Utsumi *et al*. (2009) highlight the importance of species diversity in shaping cattle grazing behaviour. Utsumi *et al*. (2009) suggested that higher species diversity results in more discerning grazing behaviour, as cattle exhibit selectivity towards preferred species. This selectivity may contribute to a more balanced grazing pattern, promoting sustainability within plant communities. Xu *et al*. (2024) in a study investigating the foraging selectivity of co-grazing sheep and cattle in a meadow steppe, revealed that cattle foraging selectivity remains stable with increased plant diversity. However, cattle were observed to adjust their intake preferences albeit to a lesser extent compared to sheep (Xu *et al*., 2024). This suggests that species diversity can influence cattle foraging selectivity, where some species will be favoured over others. Similarly, Cuchillo-Hilario *et al*. (2018) confirm the influence of species diversity on cattle patch selection in mountainous rangelands, by revealing that cattle adjust their patch selection based on the diversity of the sward, particularly favouring specific species over others. In another study, it was found that greater plant diversity significantly enhanced sheep intake across different time intervals, with this positive effect becoming more pronounced as foraging progressed, indicating that higher species diversity directly contributes to greater food intake by offering a wider range of forage options (Feng *et al*., 2016). This suggests that highly diverse plant communities not only provide immediate benefits in terms of food availability but also maintain or heighten their appeal over time. Together, these studies illustrate how species diversity directly influences the selective grazing of cattle and the landscape selection dynamics.

Similarly, species richness plays a crucial role in influencing cattle foraging behaviour and grazing patch selection (Andrew, 2021). Landscapes with higher species richness may contain a higher concentration of the preferred forage species, making these areas more appealing to cattle. In species-rich areas, at finer spatial scales, landscape selection by cattle can be viewed as a trade-off between food quality and quantity. Cattle tend to graze patches where multiple palatable species coexist, enabling them to optimize their intake by maximizing both the nutritional value and the amount of forage available (Andrew, 2021). Feng *et al*. (2016) demonstrated that increasing plant species richness significantly modified the dynamics of food intake in sheep. Their findings suggest that species richness not only improves forage availability but also affects how animals interact with and utilize available resources in the landscape. Similar patterns have been reported by Li *et al*. (2021) who examined how dietary species richness affects herbivore performance. High dietary species richness positively influences generalist herbivores by enabling nutrient complementation and toxin dilution through dietary mixing (Li *et al*., 2021). This reinforces that grazing species rich landscapes allows animals to balance their nutrient intake, grazing efficiency and mitigate the effects of plant toxins, leading to better animal performance.

The OFT provides useful lens that helps understand how animals, including cattle make foraging decisions to maximize energy intake while minimizing effort (Breed, 2017; Pyke, 2019). According to the OFT, animals are expected to select foraging landscapes that offer highest nutritional returns at a lowest energetic cost (Pyke, 2019). In grazing systems, this may translate to a preference for areas with abundant, high quality and diverse forages. Increased species richness enhances foraging efficiency by providing a wider range of foraging options, which may lead to more selective and sustained grazing behaviour.

2.4.2 Influence of above-ground biomass and cover

Cattle are ruminants with a remarkable ability to convert low-quality, fibrous plant material into valuable products such as milk, meat, and skins (McAllister *et al*., 2020). The rumen microbial flora is responsible for producing enzymes that digest plant fibres and cellulose. During the wet season, favourable conditions promote rigorous plant growth, resulting in high biomass. Above-ground biomass plays a critical role in determining whether sufficient feed is available for grazing livestock, and it determines the carrying capacity of an area in a rangeland (Manning *et al.*, 2017; Fenetahun *et al.*, 2020). Higher above-ground biomass may typically indicate greater forage availability if the plant species present are palatable. Namibian rangelands are endowed with heterogeneous plant biomass, which fluctuates across different areas and seasons and is largely dependent on rainfall (Mendelsohn *et al*., 2022; Meshesha *et al*., 2019). Rainfall determines the quantity of forage biomass available for consumption by cattle and other herbivores (Meshesha *et al*., 2019).

A frequently debated topic in herbivore energy acquisition is the selection for forage quality and forage quantity. Overall body size is a key factor that influences the feeding behaviour and dietary needs of large herbivores (Fraser *et al*., 2022). Larger animals need a greater total quantity of nutrients per day but have less time to forage for each unit of nutrient compared to smaller animals with lower overall requirements (Fraser *et al*., 2022). As a result, large herbivores tend to focus more on maintaining the quantity of feed rather than prioritizing its quality (Fraser *et al*., 2022). Consequently, larger animals have been reported to be generally less selective compared to smaller ones (Cuchillo-Hilario *et al*., 2018; Fraser *et al*., 2022; Schieltz & Rubenstein, 2016). In this context, above-ground biomass and cover become key determinants of landscape type selection. Since large animals like cattle focus on consuming large quantities of forage, high biomass areas offer more available plant material, enabling them to meet their nutritional demands more efficiently. This may explain why landscapes with greater above-ground biomass and cover may be preferred in cattle grazing patterns, as they provide the quantity of feed necessary to sustain them. According to research, there is a negative relationship between herbage yield and both bite size and intake (Alvarez-Hess *et al*., 2021). When herbage yield is low, animals may be constrained by limited availability, requiring them to spend more time searching for suitable forages or graze over a larger area to meet their intake needs (Alvarez-Hess *et al*., 2021; Utsumi *et al*., 2009).

Studies highlight that cattle balance forage quality and quantity when selecting grazing landscapes. For example, a study conducted in Kilombero Valley in Tanzania, cattle were observed to graze on patches with moderate biomass and species richness at small spatial scales, indicating their strategy of patch selection aims to balance food quality and quantity (Andrew, 2021). Gwatirisa *et al*. (2022), also noted that Mashona cattle in the Makoholi rangelands in Zimbabwe followed vlei portions with higher biomass in both winter and summer. At a larger scale, Andrew, (2021) reported that cattle prefer patches with a higher abundance of palatable plant species and higher biomass. These studies suggest that patches with abundant biomass are preferred as they offer more feed resources with less effort, allowing cattle to maximize nutrient intake and achieve satiety more efficiently. In contrast, in low biomass areas, cattle may be forced to move frequently to locate better grazing landscapes. Hence, it is essential to investigate above-ground biomass and cover as determinants of landscape type selection, especially in the wet season when there is ample vegetation. Understanding how biomass and cover influence grazing patterns will shed some light on the importance of forage availability. With this information, rangeland management strategies can be optimized by determining which areas are most favoured by cattle due to their abundant plant material.

2.4.3 Influence of environmental factors on landscape-type selection

Herbivore foraging choices have been extensively studied, often focusing on the immediate foraging decisions rather than the intricate ways in which environmental factors influence plant availability and foraging behaviour. Among critical environmental factors, elevation and slope have been widely recognized as significant determinants of grazing patch selection. The influence of elevation, and slope on the selection of the landscape type is multifaceted. These topographic factors can influence the availability of forage plants (Ang'ila *et al*., 2023; Jia *et al*., 2023; Schoenbaum *et al*., 2017), the ease of movement and overall accessibility (Jia *et al.,* 2023; Raynor *et al*., 2021; Rivero *et al*., 2021). These factors all shape plant-herbivore interactions, and contribute to where animals will choose to graze, rest, and move (Ang'ila *et al*., 2023; Raynor *et al*., 2021).

Mosaics of microclimates with varying conditions of temperature, moisture, and soil fertility are often formed along topographic gradients, and they have a major influence on the growth and distribution of plants (Bora *et al*., 2020; Dani *et al*., 2023; Jucker *et al*., 2018; Singh, 2018). Research conducted in various regions highlights the significant impact of these factors on vegetation. For instance, the slope degree affects water drainage, soil depth, and nutrient distribution, resulting in variations in plant species composition and productivity (Chen *et al*., 2023; Jucker *et al*., 2018; Moeslund *et al*., 2013). Steeper slopes often have shallow soils and reduced plant growth (Zhang *et al*., 2022), compared to gentle slopes or flat areas. Research has shown that cattle tend to opt for more accessible, gentle, and productive areas where grazing is less energetically costly, and tend to avoid steep slopes (Mkabile, 2019). However, herbivores have been reported to adapt to changes in vegetation by adjusting their feeding site selection (Falú *et al*., 2014; Grings, 2020). This adaptive grazing pattern might suggest that animals may still graze on slopes in some landscapes, particularly in resource-scarce environments, if the forage quality available outweighs the difficulties presented by the terrain.

Elevation is the most studied physiographic factor influencing plant communities and forage availability. Different elevation gradients are associated with varying microclimatic conditions such as precipitation, temperature, soil moisture, solar radiation, and light availability, dictating the types of plants present in an area (Bora *et al*., 2023; Dani *et al*., 2023; He *et al*., 2023). Studies have demonstrated that cattle, when compared with other herbivores such as sheep, tend to select lower elevation sites (Raynor *et al*., 2020; Rivero *et al*., 2021), probably as a means of conserving energy by avoiding hills. However, this preference may shift seasonally, depending on the changes in vegetation and availability of feed resources at different altitudes (Mkabile, 2019).

The interaction between elevation and slope often creates distinct grazing patches in many rangeland systems, with cattle exhibiting preferences for more accessible areas that strike a balance between the ease of movement and forage quality. However, in areas such as Farm Kiamsab West, where the grazing landscape is characterized by mountains and steep slopes, little is known about how physiographic factors such as slope and elevation influence the selection of the grazing landscape. Gaining insights into these factors is essential for effectively managing grazing pressure and ensuring the sustainability of rangeland ecosystems.

CHAPTER 3

MATERIALS AND METHODS

3.1 Study area

3.1.1 Location and extent

The study was conducted at Farm Kiamsab West located at 22°59’55.49” S and 16°17’33.27” E in the Khomas Region, central Namibia. The farm is 100 km southwest of Windhoek, along the C26 gravel road (Fig. 1). The farm is 5000 ha in extent and is divided into 9 camps, excluding the home camp where the residence of the farm is. Sampling was done in 3 camps, namely: Bopos, Kudupos and Ammams. This is where cattle were free-ranging during the time of data collection.

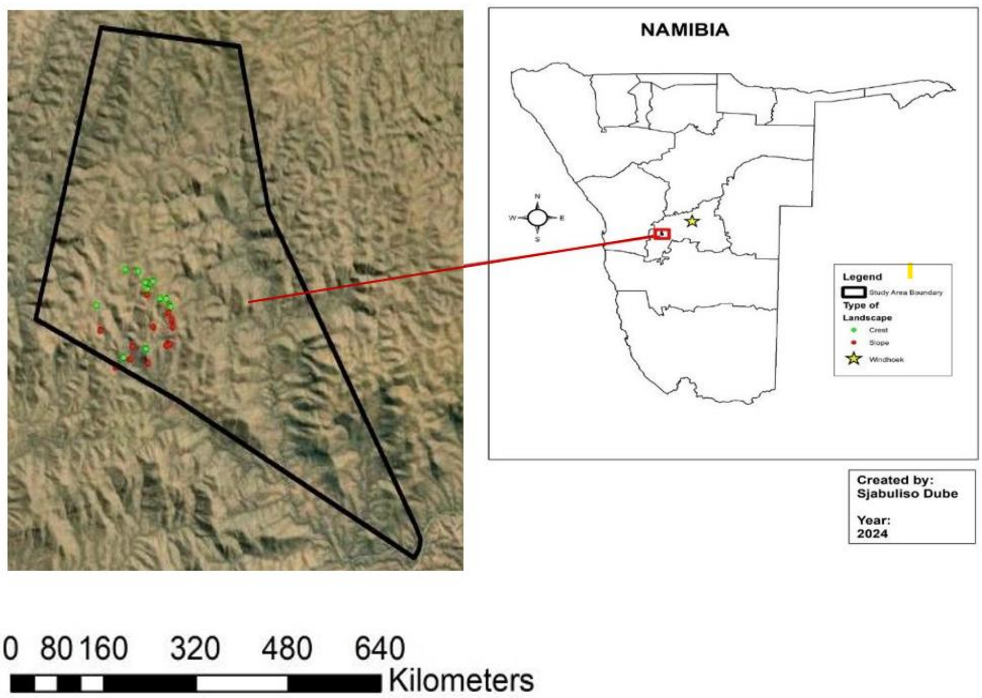

Figure 1: Map of Namibia highlighting the location of Farm Kiamsab West. The map

shows the boundary of the farm and delineates the marked plots, categorized into crests and slopes.

3.1.2 Physical features, geology, and soils

Farm Kiamsab West is in the Khomas Hochland Plateau, a significant ridge of elevated terrain characterizing the centre of Namibia (Goudie & Viles, 2015). The altitude ranges between 1700m and 2000m above sea level (Goudie & Viles, 2015; Mendelsohn *et al*., 2022). Predominantly characterized by rolling hills, the plateau boasts with diverse landscapes with a great variety of exposed rock formations such as valleys, escarpments, and mountains. The primary ephemeral river that transverses the area is the Kuiseb River.

Mendelsohn *et al*. (2022) classified the rock type as part of the Khomas Group made of schists, with soils exhibiting relatively low fertility, characterized by coarse-textured lithic leptosols that are very shallow and thin. According to Mendelsohn *et al*. (2022) the soils often contain gravel since they were formed by erosion, especially in the undulating areas and soil depth is limited due to the presence of hard impermeable hard rock within 30 cm of the surface. Consequently, the water-holding capacity of the soil is poor and the vegetation in the area is susceptible to drought (Mendelsohn *et al*., 2022).

3.1.3 Climate

The Farm Kiamsab West falls within the Khomas Hochland, which is climatically a transition zone between the hot Namib Desert and the slightly cooler hot steppe in the inland (Strohbach, 2021). The rainfall is infrequent and very unpredictable, and the average annual rainfall ranges between 200mm – 250mm (Mendelsohn *et al*., 2022). This makes planning for farmers very difficult, especially those who depend on rain-fed pastures. Areas surrounding Windhoek, typically receive 1 mm or more of rainfall on approximately 40-45 days a year, with the coefficient of variation (which reflects the reliability of rain around the area) ranging from 40% to 50% (Mendelsohn *et al.*, 2022). This implies that good harvests on pastures will only be produced with less certainty. Furthermore, the rainy season commences notably in January and continue through February and March with peak rainfall occurring in February and March. Another source of moisture is fog, the study site experiences approximately 1-5 days of fog per year (Mendelsohn *et al.*, 2022).

According to Mrs. Cathleen Deeli (Farm owner, personal communication, March 2024), no permanent water source is available on the farm, but water is mostly pumped from the Kuiseb River, and the animals sometimes drink from the two small dams that are on the farm, depending on the availability of water.

The mean annual temperature of the study site is 20°C (Mendelsohn *et al.*, 2022). The average maximum temperature during the hottest months of December and January is 30°C. The average minimum temperature during the coldest month of July ranges from 4°C to 6°C (Mendelsohn *et al.*, 2022). The occurrence of frost in the area is very low; the average number of frost days per year is generally low, ranging from 5 to 10, with frost occurring mostly in the valleys (Mendelsohn *et al.*, 2022). The differences in average temperature between the coldest and the hottest months are 10.1°C.

East winds are the most significant throughout the year (Goudie & Viles, 2015) and are likely to be 35 % calm (Mendelsohn *et al.*, 2022). The other significant winds are from the north, north-east and usually bring saturated air from those directions, thereby influencing rain (Mendelsohn *et al.*, 2022).

Humidity is low in the least humid months of September, October, and November ranging between 10% and 20%, but rising to approximately 55% during the most humid month of March (Mendelsohn *et al*., 2022). This increase in relative humidity is attributed to the influx of moisture from the Intertropical Convergence Zone (Mendelsohn *et al*., 2022).

Evaporation rates peak just before the onset of the rainy season due to heightened solar radiation, higher temperatures, and low humidity (Mendelsohn *et al*., 2022). The average annual evaporation rate for areas around Windhoek is 2240 mm/year, resulting in a water deficit ranging from 1900 mm to 2100 mm/year (Mendelsohn *et al*., 2022).

3.1.4 Flora

The study area falls within Namibia's largest biome, the Tree-and-shrub savanna, and is classified under the Acacia Tree and shrub Savanna sub-biome (Mendelsohn *et al*., 2022). The Acacia Tree and shrub Savanna sub-biome is characterized by large, open stretches of grassland dotted with different tree species of Acacia (Mendelsohn *et al*., 2022). The vegetation in the Highland shrubland is predominantly shrubby with low trees. Plant growth is limited by shallow soils, rocky terrain, as well as the summer rainfall, which averages between 200-250 mm annually (Mendelsohn *et al*., 2022). Grazing pressure from both livestock and wildlife further impacts plant growth in this region (Mendelsohn *et al*., 2022).

Vegetation structure is predominantly sparse grassland and shrubland with low biomass (Mendelsohn *et al*., 2022). The grass species commonly found on the farm include *Aristida adscensionis*, *Eragrostis nindensis*, *Anthephora pubescens*, *Enneapogon cenchroides*, and *Stipagrostis uniplumis*. Common forbs include *Tribulus terrestris, Pegolettia senegalensis, Hibiscus elliottiae* and *Amaranthus dinteri.* Scattered trees such as *Vachellia erioloba*, *Senegalia mellifera*, *Senegalia erubescens* and *Dichrostachys cinerea* can be observed, with certain patches dominated by *Senegalia mellifera, Senegalia erubescens* and *Dichrostachys cinerea,* especially on the watercourses in the south-western border of the farm. In the low-lying areas, the vegetation is more closed, particularly along ephemeral rivers, and on the mountains it is open.

3.1.5 Fauna

The study area is largely used for agriculture and tourism. The farm practices extensive livestock and wildlife production where animals graze on the natural pastures and are provided with lick supplements for trace elements, especially cattle. According to Mrs. Cathleen Deeli (personal communication, March 2024), the farm supports a herd of 108 Simmentaler and Bonsmara cattle alongside 275 Damara and Dorper sheep. Moreover, there are several horses on the farm, and wildlife such as zebras, oryxes, springboks and warthogs are frequently spotted on the farm. Populations of zebras and oryxes have been noted to increase after the rains.

3.2 Ethical considerations

The study was carried out with the kind permission from the farm owner Mrs Cathleen Deeli and the ethical approval and research permission was sought and obtained from the University of Namibia's Ethics Committee (Ethical Clearance Reference Number: SOS-0196) (Appendix 1) and the Centre for Research Services (Appendix 2). All procedures complied with the institutional guidelines for research involving domestic animals and it followed best practices for animal welfare that are usually followed in field-based behavioural studies. The non-invasive direct observations employed in this study posed minimal risks to the animals and did not interfere with their daily routines. The direct observations were conducted at a safer distance to ensure minimal disturbance or stress during foraging.

3.3 Study design

A stratified, purposive design with randomised systematic sampling was done as follows. The farm was stratified into two landscape types, namely crests and slopes. Crests are convex slopes, typically found in the upper parts of a mountain, while slopes are the angle of a surface relative to the horizontal plane (Wilson, 1997). On each landscape type, selection of the sampling site was based on where the cattle were seen foraging and on visual evidence of grazing, presence of dung and urine, and accessibility (i.e., it was selected purposively). Cattle were often sighted grazing in rugged terrain, steep slopes and mountain tops.

3.3.1 Layout of transects and plots

To establish the beginning of a line transect, a randomized sampling approach was used, where a marker was thrown randomly, and the point where it landed was designated as the starting point. At each selected site, one 50m line transect was laid out in a south-north direction or other convenient direction, depending on the local terrain. In total, 25 transects were established, 12 on crest landscapes and 13 on slope landscapes. Along each transect, six 1m x 1m plots were laid systematically at 10m intervals, starting from 0m, in an alternating left-right pattern (Fig. 2). This resulted in 72 plots on the crests and 78 plots on the slopes. Coordinates of each transect were recorded where the line transect started to allow monitoring studies to be done at the same place in the future (Appendix 3).

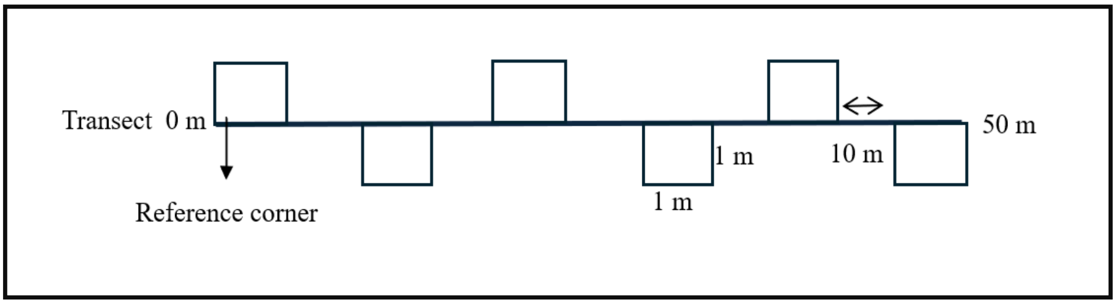

Figure 2: The systematic plot design used for the recording of plant species, in the 1 m x 1 m plots, also shows the reference corner where coordinates of each transect were recorded and the place where above-ground biomass was clipped (not drawn to scale).

During data collection, cattle were in Bopos which is the largest camp and Kudupos, in the morning and late afternoon, they moved to the water point located at Kudupos and dispersed across the camps during the day. Cattle were observed at a distance (20 – 60 meters) using binoculars, throughout the day, grazing locations were recorded using a GPS and subsequently visited. Hence, this study adopted the feeding site examination approach, where cattle grazing locations were observed and later visited to record species grazed as applied in ungulate dietary studies (Sathishkumar *et al.*, 2019). Data was collected throughout the day.

3.4 Field data collection

3.4.1 Measurement of plant attributes

In the 1m x 1m plots, grasses, forbs, sub-shrubs, ferns and sedges were identified to species level. In this study, sub-shrubs refer to low–growing plants, with woody or semi-woody bases that do not meet the morphological criteria of true forbs. Cover was visually estimated following a modified Braun-Blanquet scale (0, >0-25%, >25-50%, >50-75%, and >75% and above) as described by Kent, (2012). However, there were no bare plots during data collection. Hence, the least cover category is >0-25%. Species were also ranked from 1 to 3 according to their dominance with 1 denoting the most dominant species and 2 and 3 denoting the second and third most dominant species, respectively based on description by Anderson & Ingram, (1993). Only the top three species were ranked. All plants not identified in the field were collected and pressed for identification later using the field guides. Those that were unidentified were taken to the National Botanical Research Institute (NBRI) in Windhoek for identification. A complete list of all species recorded in the study area is found in Appendix 4.

3.4.2 Determination of grazing status

The status of grazing was assessed on each plant by checking stems and leaves to see whether they were grazed or not. Obvious bite marks and grazing signs were checked for on all the plants species in all six 1m x 1m plots along each transect. The presence of grazing signs, such as crushed tissue and fresh clippings, meant that a plant was grazed as described by (Sathishkumar *et al*., 2019) (Fig. 3).

Grazing status	Grass	Forb
Grazed		
Not grazed		

Figure 3: Pictorial depiction of how grazing status was determined based on the obvious signs of grazing. The top row shows plants classified as grazed, while the bottom row shows the plants classified as not grazed.

3.4.3 Measurement of above-ground biomass

Biomass was clipped in the first 1m x 1m plot of each transect using clippers. Only one plot out of six was clipped due to ethical and practical considerations. During the study period, forage quantity was very low and clipping more plots would have significantly reduced available plant material for livestock. Hence, only one plot was clipped to avoid competition with grazing animals. The first plot was selected consistently across all transects to maintain uniformity in the sampling procedure. While this approach was minimally invasive, it may have limited the representativeness of biomass estimates across each transect. It was intended to provide a relative indicator of above-ground productivity instead of an exhaustive measurement of total standing biomass per landscape. All above-ground biomass in the plot was cut 1cm above the ground and put in a paper bag. The samples were oven-dried at 100°C for 24 hours and weighed using an Adam CBW balance to obtain the dry mass as described by (Kent, 2012).

3.4.4 Measurement of slope, and elevation

To obtain the Digital Elevation Model (DEM), the United States Geological Survey (USGS) Earth Explorer website (https://earthexplorer.usgs.gov) was visited and used. Farm Kiamsab West, which is the area of interest, was identified using its coordinates and delineated with a polygon. The Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) data set was selected and downloaded. Also, the shapefiles corresponding to Farm Kiamsab West were downloaded from the farms' dataset available on the Digital Namibia website (https://digitalnamibia.nsa.org.na) under the Farm Registration Divisions.

The downloaded Digital Elevation Model (DEM) of 30 m resolution was loaded the DEM into QGIS 3.36, and the Farm Kiamsab West shapefiles were also imported into the software as well as the farm coordinates which were in CSV format. Both the SRTM DEM and the farm coordinates were re-projected from WGS84 to Universal Transverse Mercator (UTM) zone 33S. Slope values, were calculated using the built-in spatial analysis tool, while elevation values were obtained using the "Identify Features" tool. In short, point data were overlaid on the DEM to visualize the sampling units' elevations as well as the general elevation of the study site (Figure 4). Raster values were then added to the points using nearest neighbour interpolation. The extracted data were saved in a table formatted as a CSV file. This CSV file was subsequently imported into Microsoft Excel for preliminary data exploration.

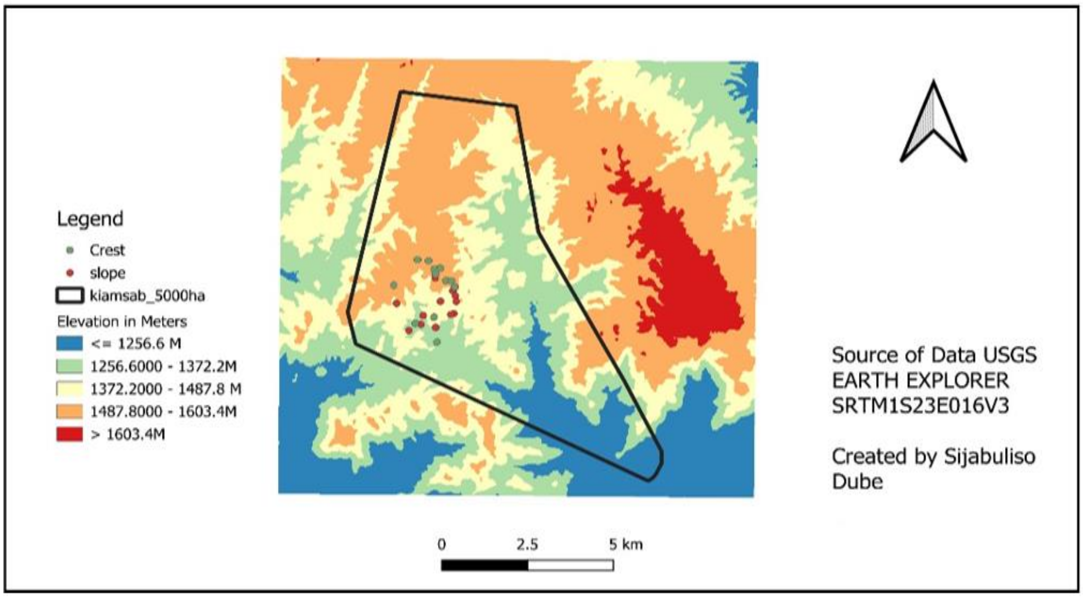

Figure 4: Visualization of the sampling sites' elevation and the general elevation of the study site. The Digital Elevation Model (DEM) was overlaid with point data

representing farm coordinates to extract elevation values and calculate slope using QGIS 3.36.

3.5 Data manipulation and analysis

3.5.1 Forage selectivity by cattle and frequency of occurrence

The Chi-Square Test of Association was used to test if cattle exhibit forage selectivity or they forage randomly (irrespective of landscape type). The Chi-square Test of Association is used to determine whether two categorical variables are statistically independent (McDonald, 2014). It uses the data to calculate a test statistic that measures how far the observed data are from the null expectation (McDonald, 2014).

Additionally, forage selectivity was assessed for forb, sub-shrub and grass species by comparing the proportion of plants grazed by cattle to the proportion of plant species in the environment using the Jacob's Selectivity Index (D) (JSI) (Jacobs, 1974). The index was calculated for grasses, forbs and sub-shrubs separately as:

$$D=\frac{(r-p)}{(r+p-2rp)}$$

Where r represents the proportion of a specific plant that is grazed, p represents the proportion of the plants in the environment. Jacobs' Index ranges from -1 to +1, with D = 0 indicating zero selectivity, denoting that the species is grazed in direct proportion to its availability in the environment, D < 0 indicating a avoidance or negative selection, denoting that the plant species is grazed less than its availability in the environment and D > 0 indicates a positive selection; implying that the resource is used more than its availability in the environment.

The Chi-square test of association was also used to determine if cattle preferred a certain life form over others (irrespective of landscape type).

3.5.2 Species richness, diversity, and composition

Plymouth Routine In Multivariate Ecological Research (PRIMER 5) software was used to compute the plant species diversity for all the plots using the Shannon-Wiener diversity index (H').

$$H' = -\sum_{i=1}^{s} (p_i)(\ln p_i)$$

Where p*i* is the proportion of individuals found in the i^{th} species, *ln* is the natural logarithm and s is the total number of species. Species richness (S) was also calculated by just counting the number of species in each plot.

The Mann-Whitney *U*-test was used in Statistical Package for the Social Sciences, Version 29.0.2.0 (20) to test for significant differences in diversity indices (H') between crests and slopes. The Mann Whitney *U*-test also known as the Wilcoxon rank sum W test is a non-parametric test used to compare the differences between two independent groups when the sample distributions fail to meet the requirements of its parametric counterpart, the independent *t*-test (Dytham, 2011). It is used when the measurements do not reach the level of interval or ratio scaling, instead, it is used with ordinal data. Its power lies in fact that it utilizes most of the quantitative information inherent in the data.

Species richness data were tested for normality using the Shapiro Wilk test and data were not normally distributed, hence the Mann-Whitney *U*-test was also used to compare species richness between crests and slopes.

The Hierarchical Cluster Analysis (HCA), using the Group Average Cluster Statistic was executed on a plot-by-species matrix comprising 48 species and 25 transects in PRIMER 5 to test if species composition differed between crests and slopes. Species presence/absence (binary) data were used. The HCA methods group observations by similarity, are used to look for patterns and order which may provide insights into the data (Dytham, 2011; Kent, 2012). The results can be portrayed as a dendrogram (tree/linkage) diagram showing different levels of similarity. The process of fusion of the clusters is based on the minimum average distance between individuals and groups (Kent, 2012).

Twenty-five transects (crests n = 12 and slopes n = 13) were used as sampling units for comparing species composition between the two landscape types, rather than the 150 individual plots (crests n = 72 and slopes n = 78). This was done to get a clearer picture on species composition patterns on broader scales. Considering that one of the objectives was to determine the influence of environmental variables on landscape type selection, and that some of the environmental variables were only related to the first plot (e.g. above-ground biomass which was cut on the first plot only due to ethical considerations; percentage slope and elevation which were only linked to the first plot of every transect), species composition data had to be integrated to transect level. This approach makes a provision for a comprehensive understanding of the patterns between species composition and environmental variables in both the Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA).

3.5.3 Plant species dominance

The Chi-Square Test of Association was used to determine if there was an association between landscape type and life form. Species dominance based on rankings was calculated as follows:

$\text{Species}_j \text{ score} = 70.2_r \sum w_i + 21.1_r \sum w_i + 8.7_r \sum w_i$

Where $\sum w_i$ is the sum of the quadrat scores for the quadrats where species j obtained rank r. The species scores were obtained by summing the quadrat scores to give a total score and the contribution of each species to the total biomass was calculated by dividing the species scores by the total number for all species in each patch and then multiplying the result by 100 to express it as a percentage (Anderson & Ingram, 1993).

3.5.4 Cover and above-ground biomass

The Chi-Square Test of Association was used to compare the numbers of plots falling in each cover category between crests and slopes.

The measurement unit for biomass used in this study was grams per square metre (g/m^2), which is a standard unit for small-scale, plot-level measurements for oven-dried biomass (Bonham, 2013; Kent, 2012). No conversion to kilograms per hectare (kg DM/ha) was performed, as the date reflect plot-level measurements. To compare above-ground biomass between the crests and slopes, the dry mass data were tested for normality using the Shapiro-Wilk test and were found to deviate from normal distribution. As biomass was clipped from a single 1m * 1m plot per transect, The Mann-Whitney *U* test was then used to test for differences between the two landscape types.

3.5.5 Determinants of landscape type selection

Detrended Correspondence Analysis is an unconstrained ordination technique or indirect gradient analysis that can be used on species data to reveal the variation in species composition across sites. In this study it was run in CANOCO 5 to reveal relationships amongst the various plant associations and see how the landscape types (crests and slopes), and species composition cluster towards each other. Species binary data were used in this analysis. One of the main features of DCA is detrending which is adjusting the axes to avoid giving misleading results and interpretation which is often common with other ordination methods such as Correspondence Analysis (Šmilauer, & Lepš, 2014).

To determine the influence of above-ground biomass, species richness, species diversity, cover, slope and elevation on landscape type selection a direct gradient analysis technique was used in CANOCO 5, namely Canonical Correspondence Analysis. CCA is a constrained or a direct ordination method which aims to find the variability in species composition data that can be explained by the measured explanatory variables (Kent, 2012). The resulting ordination diagram does not only express patterns in variation in floristic composition but also demonstrates the principal relationship between the species and each of the environmental variable (Kent, 2012).

The same species data set used for the HCA and DCA was used in the CCA, with the addition of environmental variables. For the environmental variables, median cover, mean species richness, mean species diversity, and the relative grazing index were calculated for each transect. The values were then incorporated into the species data matrix together with above-ground biomass and elevation, percentage slope derived from the coordinates using the QGIS 3.36 software. The Monte Carlo permutation test was used for the forward selection of explanatory variables to identify the most important explanatory variables that significantly influenced landscape-type selection. In CCA, a Monte Carlo permutation test is used to assess the significance of the environmental variables in explaining the variation in the ordination axis scores (Kent, 2012).

CHAPTER 4

RESULTS

4.1 Wet season forage selection by cattle

4.1.1 Overall trends

The Chi-square Test of Association revealed a significant association between plant species and grazing status ($\chi^2 = 17.416$, df = 2, p = 0.001), indicating that cattle at Farm Kiamsab West exhibit clear selectivity for specific plants during the wet season. A total of 48 different plants species was recorded in the field where 17 (35.4%) were grazed. These included 14 grasses species, of which 9 (64.29%) were grazed, 31 forbs and sub-shrubs of which 8 (25.8%) were grazed, and 3 non-grazed species of other lifeforms (1 fern and 2 sedge species). For forbs and sub-shrubs, *Tribulus terrestris* formed the largest proportional occurrence (27%), followed by *Pegolettia senegalensis* (17%). Of the two dominant forbs, cattle moderately selected *Tribulus terrestris* (D = 0.52) and *Pegolettia senegalensis* was strongly avoided (D = -0.81) (Table 1). Most of the grazed forb and sub-shrub species (87.5%) were selected as they were chosen at a higher proportion than their occurrence in the rangeland (Table 1). Of the 14 grasses encountered in the grazing landscapes, *Eragrostis nindensis* and *Aristida adscensionis* had the largest proportional occurrence each (28%). *Eragrostis nindensis* was highly selected (D = 0.44) and *Aristida adscensionis* was moderately avoided (D = -0.54) (Fig. 5). Overall, cattle exhibited selectivity for seventeen plant species, 53% of which were grasses.

4.1.2 Cattle selectivity for forbs and sub-shrubs

Cattle exhibited selectivity for certain forbs and sub-shrubs, and showed strong selectivity for *Cleome suffruticosa* as indicated by a value of D = 0.61 (Table 1). Cattle also exhibited moderate selectivity for *Tribulus terrestris* (D = 0.52), *Monechma divaricatum* (D = 0.51), *Otoptera burchellii* (D = 0.40), and low selectivity for *Talinum caffrum* (D = 0.32), *Tribulus zeyheri* (D = 0.31) and *Indofera auricoma* (D = 0.24). Twenty-three forbs and sub-shrubs were completely avoided regardless of their proportion in the environment as evidenced by their negative JSI value of -1.

Table 1: Jacobs' Selectivity Index (D) of various forb and sub-shrub species at Farm Kiamsab West. The index shows the cattle selectivity or avoidance of different forbs and sub-shrubs, with a value close to 1 indicating stronger selectivity and -1 indicating complete avoidance.

Species	**Grazed**	**Not grazed**	**Total**	**R**	**p**	**D**
Acrotome fleckii	0	3	3	0.00	0.02	-1.00
Amaranthus dinteri	0	8	8	0.00	0.04	-1.00
Aptosimum arenarium	0	3	3	0.00	0.02	-1.00
Belpharis obmitrata	0	2	2	0.00	0.01	-1.00
Cleome monophyla	0	1	1	0.00	0.01	-1.00
Cleome suffruticosa	6	0	6	0.12	0.03	0.61
Dactyliandra welwitschia	0	1	1	0.00	0.01	-1.00
Emilia marlothiana	0	1	1	0.00	0.01	-1.00
Euphorbia inaequilatera	0	4	4	0.00	0.02	-1.00
Forsskaolea viridis	0	2	2	0.00	0.01	-1.00
Helichrysum tomentosulum	0	1	1	0.00	0.01	-1.00
Heliotropium ciliatum	0	4	4	0.00	0.02	-1.00
Hibiscus calyphyllus	0	2	2	0.00	0.01	-1.00
Hibiscus dinteri	0	1	1	0.00	0.01	-1.00
Hibiscus elliottiae	0	8	8	0.00	0.04	-1.00
Hirpicium gazanoides	0	5	5	0.00	0.03	-1.00
Indigofera auricoma	3	4	7	0.06	0.04	0.24
Indigofera viciodes	0	2	2	0.00	0.01	-1.00
Monechma divaricatum	6	2	8	0.12	0.04	0.51
Monsonia senegalensis	0	6	6	0.00	0.03	-1.00
Nelsia quadrangular	0	5	5	0.00	0.03	-1.00
Otoptera burchellii	3	2	5	0.06	0.03	0.40
Phyllanthus pentandrus	0	2	2	0.00	0.01	-1.00
Portulaca oleracea	0	1	1	0.00	0.01	-1.00
Ruellia diversifolia	0	2	2	0.00	0.01	-1.00
Senecio consanguineous	0	7	7	0.00	0.04	-1.00
Pegolettia senegalensis	1	32	33	0.02	0.17	-0.82
Talinum caffrum	3	3	6	0.06	0.03	0.32

Tephrosia dregeana	0	2	2	0.00	0.01	-1.00
Tribulus terrestris	28	25	53	0.54	0.27	0.52
Tribulus zeyheri	2	2	4	0.04	0.02	0.31

4.1.3 Cattle selectivity for grasses

Cattle at Farm Kiamsab West exhibited selectivity for specific grass species during the wet season. *Eragrostis nindensis* (D = 0.44), *Anthephora pubescens* (D = 0.27), *Sporobolus africanus* (D = 0.10) and *Stipagrostis uniplumis* (D = 0.09) were the selected grass species (in decreasing order of importance) (Fig.5). *Aristida meridionalis*, *Cenchrus ciliaris*, *Fingerhuthia africana*, *Melinis repens*, and *Tragus berteronianus* were completely avoided and had a JSI value of -1. Grasses *Aristida adscensionis* (D = -0.54), *Eragrostis porosa* (D = -0.54), and *Enneapogon desvauxii* (D = -0.50) were moderately avoided and *Enneapogon cenchroides* (D = -0.18) and *Eragrostis trichophora* (D = -0.11) were mildly avoided. Cattle consumed these grass species less frequently than expected. All ferns and sedges had an index of -1 indicating complete avoidance by cattle (Table 2).

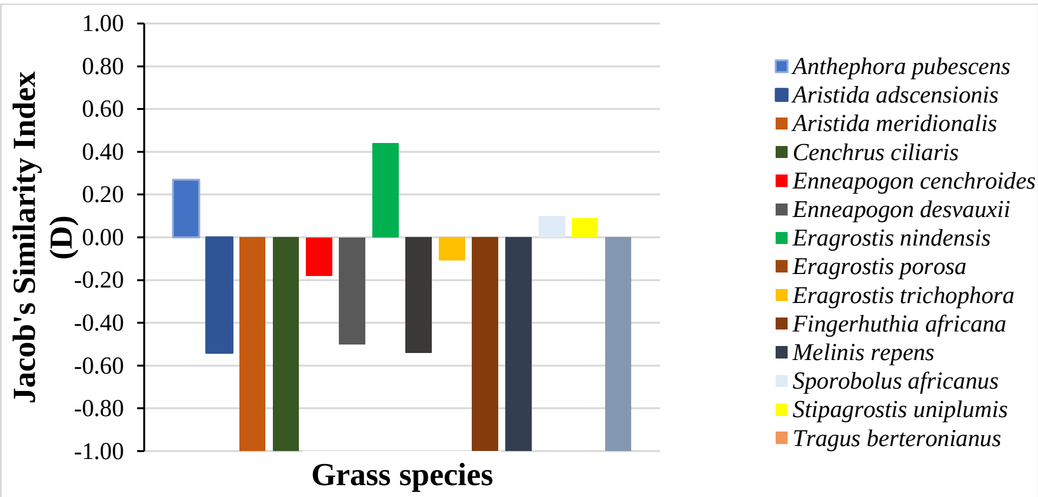

Figure 5: Jacobs' Selectivity Index for various grass species at Farm Kiamsab West.

4.1.4 Selectivity for lifeforms

The Chi-Square Test of Association revealed a significant association between selectivity and life form ($\chi^2 = 11.943$, df = 1, $p < 0.001$). Cattle at Farm Kiamsab West exhibited a preference for grasses. Although 26.76% of forbs and sub-shrubs were grazed, a higher proportion of grasses, 41.11% were grazed and none of the ferns and sedges were grazed (Fig. 6). This indicates that cattle showed a clear preference for grasses over forbs and sub-shrubs, and ferns and sedges.

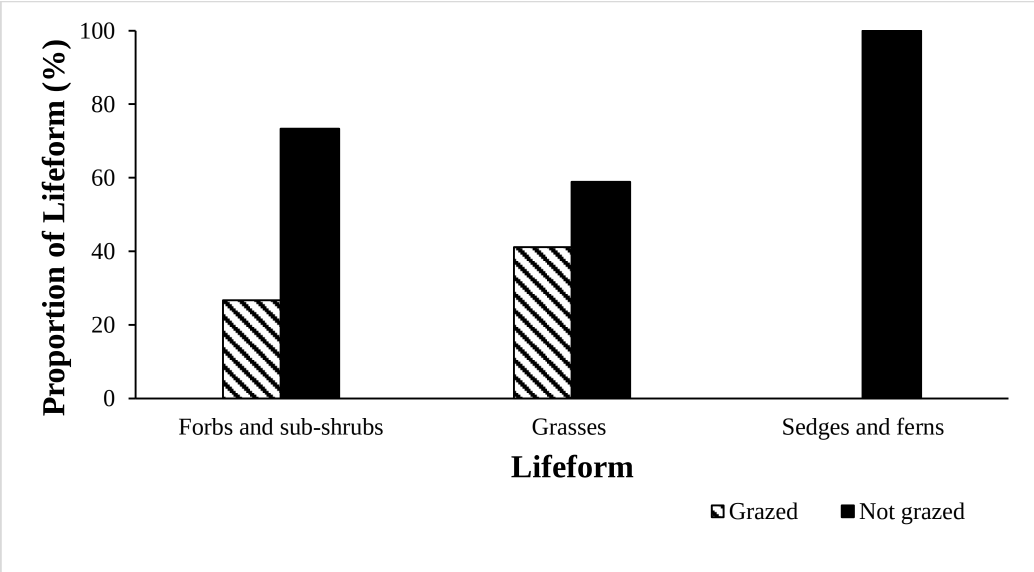

Figure 6: Proportion (%) of grazed and ungrazed lifeforms (Grasses, forbs and sub-shrubs, and sedges and ferns) observed at Farm Kiamsab West during the wet season. The figure illustrates cattle grazing selectivity across different lifeforms, showing a clear preference for grasses, which were grazed more frequently compared to forbs and sub-shrubs, and ferns and sedges.

4.2 Comparison of Species richness, diversity, and composition between landscape types

4.2.1 Species richness

Species richness differed significantly between crests and slopes (Mann-Whitney U = 2018.500, z = -3.030, p = 0.002). Species richness on crests (mean rank = 86.47) was significantly higher than on slopes (mean rank = 65.38). The median species richness was approximately 4 for both crests and slopes (Fig.7). Generally, the IQR was wider for the crests ranging from 3 to 6 and narrower for slopes ranging from 3 to 5. The larger range of species richness (1 - 9) indicates that crests support a variable number of species compared to slopes (1 to 7).

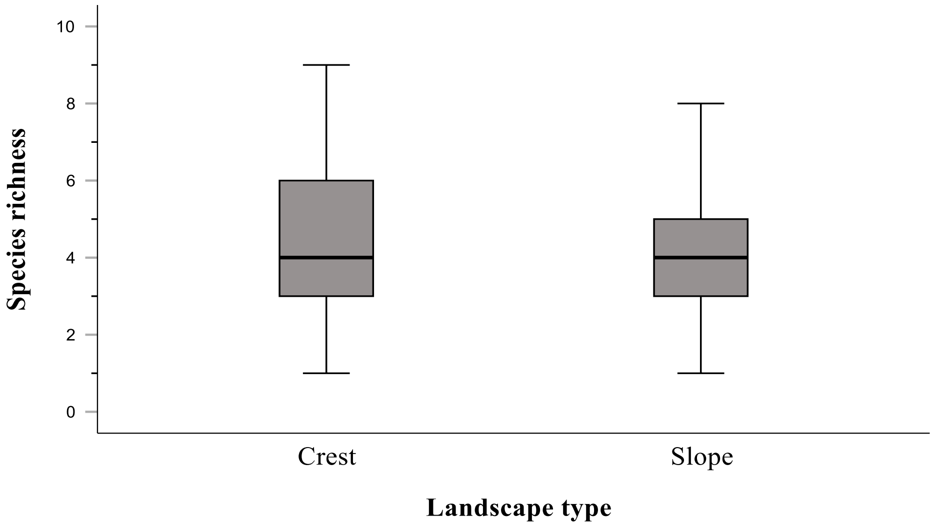

Figure 7: A Comparison of species richness between the crests which are at the mountain tops and the slopes which are inclined areas of the mountain extending between the base and the summit at Farm Kiamsab West.

4.2.2 Species diversity

There was a significant difference in plant species diversity between crests and slopes (Mann-Whitney $U = 2018.5$, $z = 3.030$, $p = 0.002$). The median species diversity was approximately 1.39 for both crests and slopes (Fig. 8). Generally, the IQR is slightly higher for the crests ranging from 1.25 to 1.75, while for the slopes range from 1.2 to 1.6. For the crests species diversity ranged from 0.65 to 2.2. The species diversity for slopes ranged from 0.75 to 2.1.

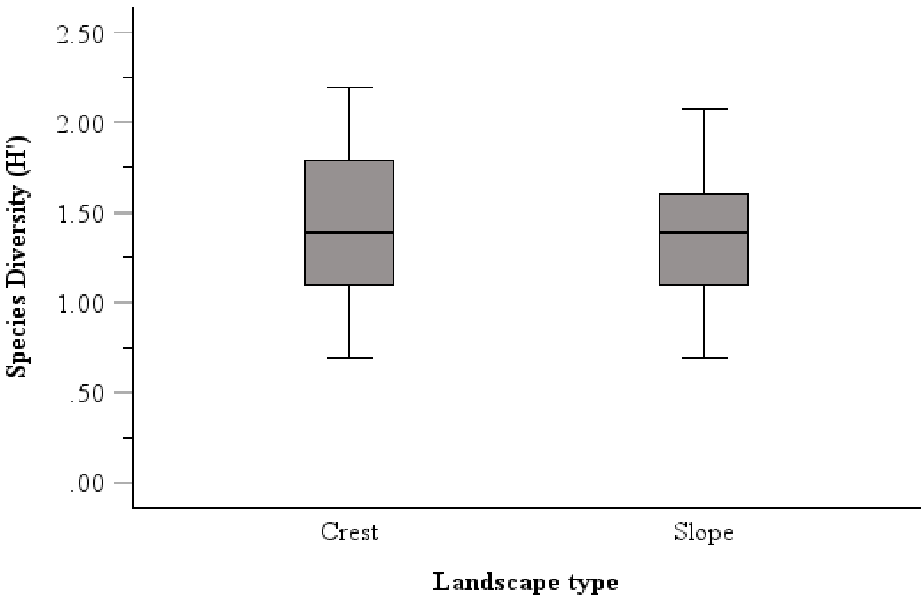

Figure 8: A Comparison of species diversity (Shannon Weiner Diversity indices H') between the crests and slopes at Farm Kiamsab West.

4.2.3 Species composition

The HCA separated the plots into 4 main clusters based on variations in plant species composition (Fig. 9). Cluster 1 is separated from Cluster 2 at 38%, whilst Cluster 2 separates from Cluster 3 and Cluster 4 at 45%. Additionally, Clusters 3 and 4 are 45% similar. Cluster 3 is the largest in the dendrogram, comprising of three sub-clusters. These findings outline an overall significant difference between the crests and slopes as indicated by the presence of distinct clusters specific to each landscape type. However, commonalities also exist to some extent, as shown by the presence of clusters with assorted plots from both landscape types. This implies that the two landscape types, despite having distinct communities, they also experience similar ecological conditions that may give rise to overlaps in species composition.

Cluster 1 was formed by four plots exclusively from the slopes and had *Aristida adscensionis, Enneapogon cenchroides*, and *Eragrostis nindensis* as the common grass species. These plots also had forbs such as *Senecio consanguineus* and *Tribulus terrestris* in common.

Cluster 2 stands out as the most distinct cluster, made up of only one plot from the slopes, forming a very small cluster in the landscape. Although the cluster is characterized by a mixture of grasses and forbs, and it contains unique species that are not found in any other plots. The grasses that include *Cenchrus ciliaris* and *Fingerhuthia africana* are found exclusively in this plot. This cluster also hosts rare species that occur in lower frequency in other plots; for example, the forbs *Phyllanthus pentadrus*, and *Cleome suffruticosa* and the fern *Cheilanthes marlothii* which are also present in plots in other clusters.

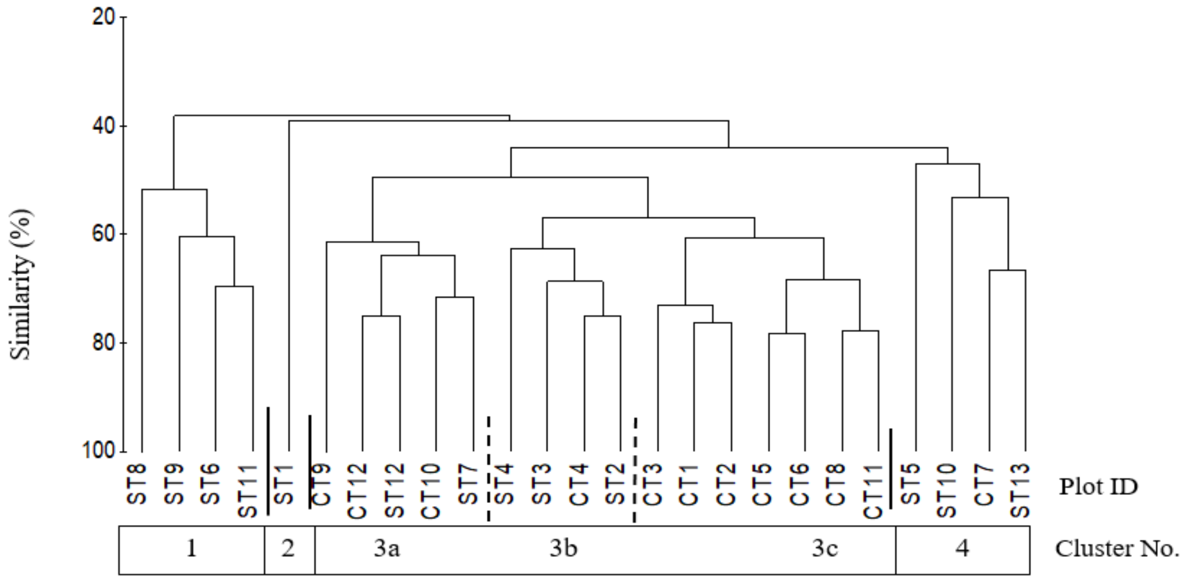

Figure 9: Hierarchical Cluster Analysis (HCA) dendrogram showing a classification of plant species into 4 main clusters based on species presence/absence data.

Cluster 3 is the largest, comprising a mixture of plots from both landscape types, though the majority (68.75%) are from the crests. The cluster is further divided into three sub-clusters based on the common species, with cluster 3a and 3b having mixed plots and 3c consisting of crest plots only. Generally, these sub-clusters emerge at 50% similarity. The cluster is largely associated with common species that occur on both slopes and crests. The plots in the sub-clusters are related to three distinct elevation categories, which are found in the low-elevation, mid-elevation and higher-elevation.

Cluster 3a consists of plots from both landscapes, three from the crests and two from the slopes. This floristic community shared *Aristida adscensionis, Eragrostis nindensis* and *Stipagrostis uniplumis*. *Eragrostis trichophora* only appeared in three plots, namely in CT9, CT10 and ST7. The species composition in this sub-cluster is balanced, with an equal representation of grasses and forbs. This sub-cluster includes plots situated at relatively low elevation, ranging from 1316.67 m to 1439.92 m above sea level.

Cluster 3b is the smallest of all the sub-clusters and consists of four slope plots and one plot from the crests. All the plots in this sub-cluster shared grasses such as *Eragrostis nindensis* and *Aristida adscensionis* and 75% of them also had *Stipagrostis uniplumis* in common. Two forb species were found to be common in this sub-cluster, namely *Pegolettia senegalensis* and *Tribulus terrestris.* Generally, this sub-cluster differs from the previous clusters by differences in forb species. The elevation for the plots in this sub-cluster ranges from 1426.30 m to 1501.97 m above sea level, a transitional zone between the lower and higher elevations.

Cluster 3c is the largest sub-cluster, distinctively composed of solely crest plots. Unlike the previous sub-clusters, which exhibited a mix of both crest and slope plots, this sub-cluster is associated with 7 plots exclusively from the crests. This sub-cluster is characterized by a more diverse species composition, including both grasses and a large variety of forbs, some of which are less common in other plots. Despite all the plots being from the same landscape, the similarity ranges from 60% to 80%, reflecting a moderate to high degree of variability in species composition within the crest landscape and suggesting specialization of certain species to this landscape. Almost all the plots had *Aristida adscensionis*, *Enneapogon desvauxii*, and *Eragrostis nindensis*, along with common forbs such as *Tribulus terrestris* and *Pegolettia senegalensis*. The species exclusive to these plots include the grass *Tragus berteronianus*, and forbs *Aptosimum arenarium,* and *Ruellia diversifolia*. This sub-cluster represents the highest elevation plots, ranging from 1496.85 m to 1538.19 m above sea level.

Cluster 4 consisted of three plots from the slopes and one from the crests. This cluster is separated from cluster 3 at 45%. The common species in this cluster include species such as *Tribulus terrestris* and *Hibiscus elliottiae,* which appeared in 75% of the plots, and grass species such as *Sporobolus africanus*, *Stipagrostis uniplumis* and *Enneapogon cenchroides* which appeared in 3 plots.

4.3 Comparison of species dominance between landscape types

4.3.1 Life form dominance

The Chi-square test of association revealed no significant association between landscape type and life form ($\chi^2 = 0.680$, df = 1, p = 0.409). Grasses were the dominant life form across both crests and slopes (Fig. 10). In crests, there were 65 (90.3%) instances where plots were dominated by grasses compared to 67 (85.9%) in slopes. Forbs and sub-shrubs were less dominant, with 7 (9.3%) occurrences in the crests and 11 (14.1%) in slopes.

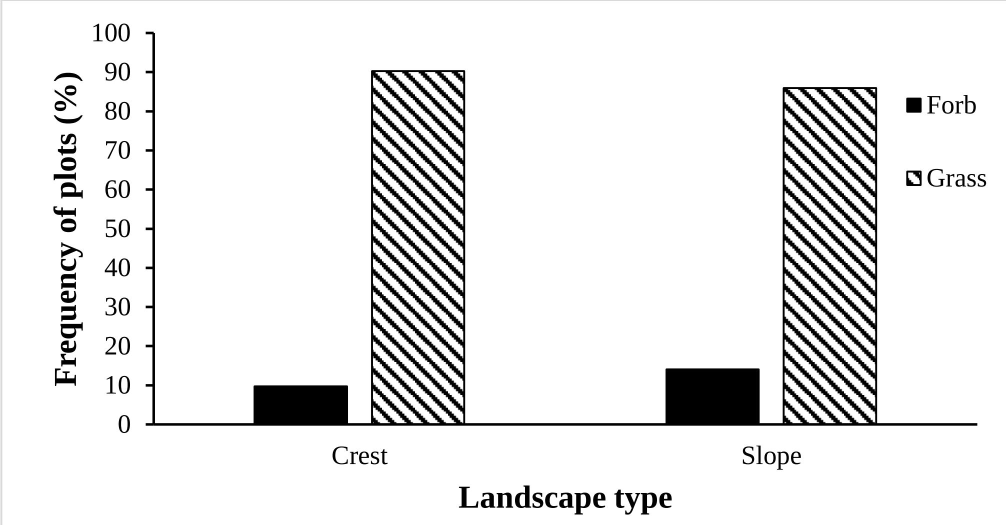

Figure 10: Comparison of dominant life form frequencies across crest and slope plots at Farm Kiamsab West.

4.3.2 Species dominance

The results indicate notable differences in species dominance between the crests and slopes. *Eragrostis nindensis* was the most dominant grass species on the crests, contributing 36.2% to the total biomass, followed by *Stipagrostis uniplumis* (27.8%) and *Aristida adscensionis* (18%) (Table 2). *Eragrostis nindensis* remained the most dominant species on the slopes with a contribution of 37.3%, followed by *Aristida adscensionis* (21%) and *Enneapogon cenchroides* (13.2%).

Table 2: A comparison of grass species dominance between crests and slopes based on species scores and percentage contributions at Farm Kiamsab West. Species scores represent the relative dominance based on visual estimates of plot biomass and the ranked importance of species within those plots. The percentage contributions indicate each species proportional share of the total biomass within the crest and slope plots.

Species	**Species score: Crest**	**Contribution (%)**	**Species score: Slope**	**Contribution (%)**
Anthephora pubescens	1185.0	6.8	1603.9	8.9
Aristida adscensionis	3122.3	18.0	3789.7	21.0

Aristida meridionalis	0.0	0.0	140.4	0.8
Cenchrus ciliaris	0.0	0.0	42.2	0.2
Enneapogon cenchroides	1098.2	6.3	2378.7	13.2
Enneapogon desvauxii	1178.3	6.8	59.6	0.3
Eragrostis nindensis	6282.4	36.2	6734.3	37.3
Eragrostis porosa	98.1	0.6	34.8	0.2
Eragrostis trichophora	17.4	0.1	0.0	0.0
Melinis repens	0.0	0.0	284.4	1.6
Sporobolus africanus	17.4	0.1	414.3	2.3
Stipagrostis uniplumis	4298.3	24.8	2059.4	11.4
Tragus berteronianus	43.5	0.3	0.0	0.0
Sedges and ferns				
Cyperus sp	0.0	0.0	140.4	0.8
Cheilanthes marlothii	0.0	0.0	280.8	1.6
Kyllinga alba	0.0	0.0	115.5	0.6

Tribulus terrestris (44%) was the most dominant forb on crests, followed by *Pegolettia senegalensis* (19.2%) and *Indigofera auricoma* (6.4%) (Table 3). On slopes, *Tribulus terrestris* (20.6%) continued to dominate the landscape, followed by *Amaranthus dinteri* (9.2%) and *Monechma divaricatum* (9.1%).

Table 3: A comparison of forb and sub-shrub species dominance between crests and slopes at Farm Kiamsab West. Species scores reflect the relative dominance based on visual biomass estimates and ranked contributions within plots. Percentage contributions represent each species proportional share of the total score across all plots in each landscape.

Species	**Species score: Crest**	**Contribution (%)**	**Species score: Slope**	**Contribution (%)**
Acrotome fleckii	0.0	0.0	344.1	3.0
Amaranthus dinteri	0.0	0.0	1039.2	9.2
Aptosimum arenarium	273.9	2.2	0.0	0.0
Belpharis obmitrata	280.8	2.3	0.0	0.0
Cleome monophyla	0.0	0.0	140.4	1.2
Cleome suffruticosa	252.8	2.1	702.0	6.2
Dactyliandra welwitschia	0.0	0.0	42.2	0.4
Emilia marlothiana	0.0	0.0	140.4	1.2
Euphorbia inaequilatera	340.4	2.8	0.0	0.0
Forsskaolea viridis	0.0	0.0	351.0	3.1

Helichrysum tomentosulum	0.0	0.0	210.6	1.9
Heliotropium ciliatum	0.0	0.0	410.6	3.6
Hibiscus calyphyllus	0.0	0.0	68.3	0.6
Hibiscus dinteri	0.0	0.0	26.1	0.2
Hibiscus elliottiae	203.6	1.7	126.6	1.1
Hirpicium gazanoides	438.6	3.6	210.6	1.9
Indigofera auricoma	786.4	6.4	42.2	0.4
Indigofera viciodes	63.3	0.5	210.6	1.9
Monechma divaricatum	210.6	1.7	1025.0	9.1
Monsonia senegalensis	132.9	1.1	140.4	1.2
Nelsia quadrangular	0.0	0.0	480.8	4.3
Otoptera burchellii	649.2	5.3	210.6	1.9
Pegolettia senegalensis	2361.1	19.2	288.1	2.5
Phyllanthus pentandrus	0.0	0.0	280.8	2.5
Portulaca oleracea	0.0	0.0	210.6	1.9
Ruellia diversifolia	491.4	4.0	0.0	0.0
Senecio consanguineus	0.0	0.0	840.5	7.4
Talinum caffrum	252.8	2.1	603.8	5.3
Tephrosia dregeana	0.0	0.0	421.2	3.7
Tribulus terrestris	5399.3	44.0	2338.1	20.6
Tribulus zeyheri	140.4	1.1	421.2	3.7

4.4 Comparison of cover and above-ground biomass between landscape types

4.4.1 Cover

The Chi-square test of association revealed no significant difference in cover between crests and slopes ($\chi 2 = 3.821$, df = 3, p = 0.281). Generally, the largest proportion of the plots (66%) had <25% cover, plots with 25-50% cover constituted 30.67%. Plots with >75% cover were few, with 0.67%, and those with 50-75% cover constituted the remaining 2.67%. In general, the farm had low cover (<25%) as demonstrated by the proportion of plots having less than 25% cover in both landscape types (Fig. 11).

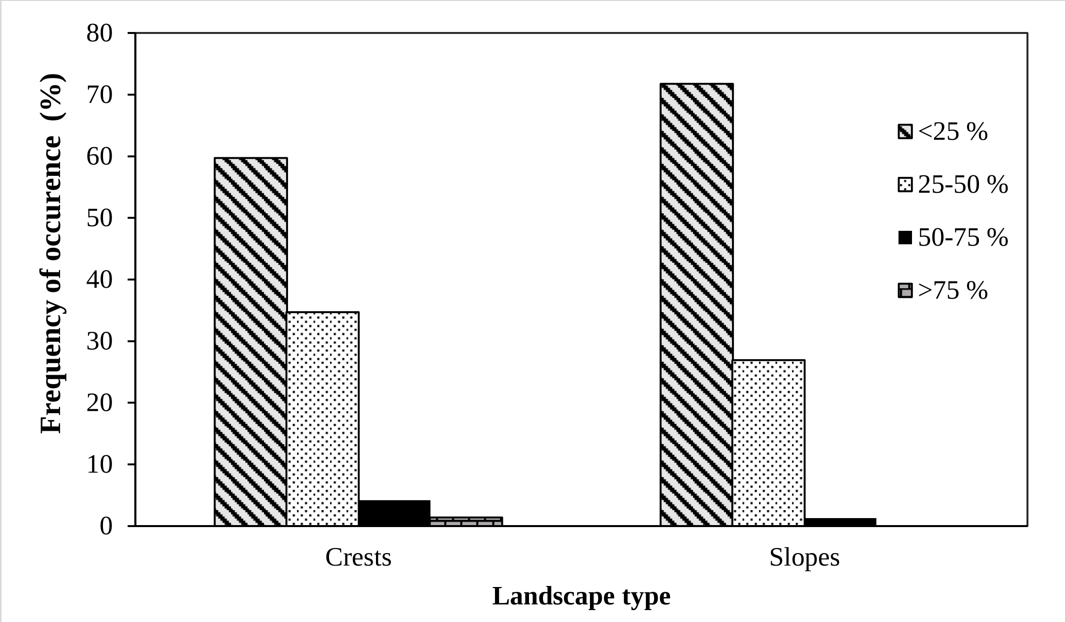

Figure 11: A comparison of cover categories between the crests and slopes at Farm Kiamsab West.

4.4.2 Above-ground biomass

The Mann-Whitney U Test revealed no significant difference in above-ground biomass between crests and slopes ($U = 47.500$, $Z = -1.659$, $p = 0.097$). Crests exhibited greater biomass variability compared to slopes (Fig. 12). For crests, the median biomass was 41.6g/m^2 and biomass ranged from 3 g/m^2 to 118 g/m^2, while for slopes it was much lower, with a median of 13.1 g/m^2 and a range of 3 g/m^2 to 58 g/m^2. However, a notable outlier was observed in the slope landscape, with a biomass measurement of 62 g. Although it cannot classified as an extreme outlier statistically, it is visually and numerically distinct from the general biomass distribution across the slope plots.

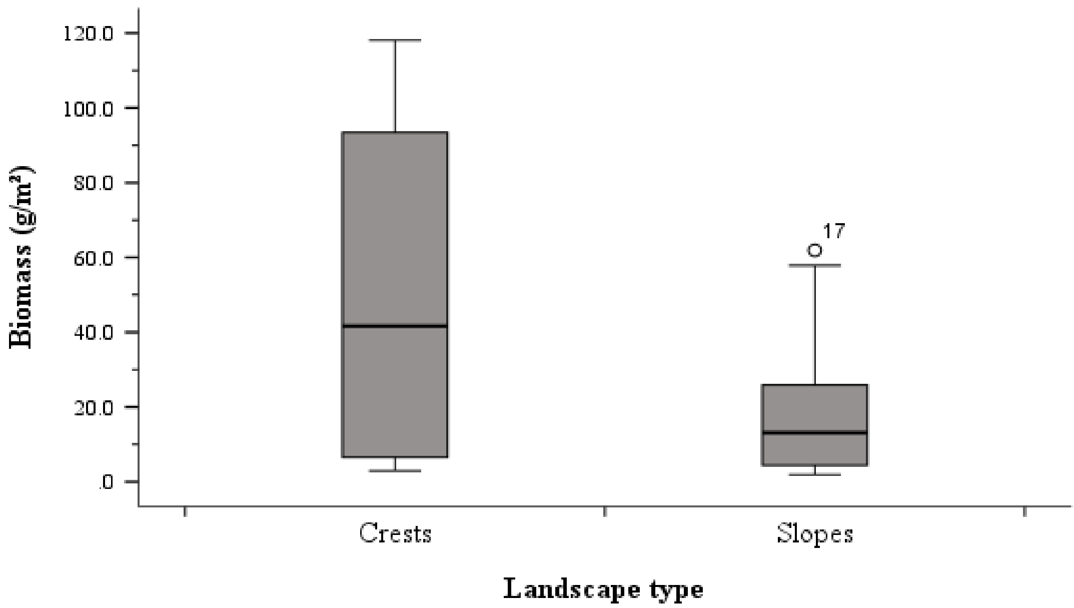

Figure 12: Comparison of above-ground biomass between crests and slopes at Farm Kiamsab West.

4.5 Determinants of landscape type selection by cattle

The DCA separated the plots into 2 main groups based on presence/absence data (Fig. 13). Group 1 consists of mixed plots, the majority are from the crests, and a few plots from the slopes. This group is largely associated with lower values of the hypothesised gradient shaping species composition in DCA axis 1. On the other hand, group 2 still on DCA axis 1 is correlated with slightly higher values of the gradient shaping species composition and the group consists of slope plots only. The analysis revealed that cumulatively, the first four axes explained 27.78% of the total variation in species composition. DCA axis 1 explained a significant part of the variation (13.05%) and DCA axis 2, 3 and 4 accounted for 7.1%, 4.88 and 2.75% respectively. Additionally, gradient length was generally average as shown by the moderate gradient length of 2.47 along DCA axis 1, and 2.14, 2.21 and 1.64 on DCA axis 2, 3 and 4 respectively (Table 4). The hypothesised gradient that is influencing species composition in DCA axis 1 is percentage slope. Whilst in the other three axes it could be other unidentified determinants of species composition. The findings point out the intricacy of the species-environment relationships in this landscape.

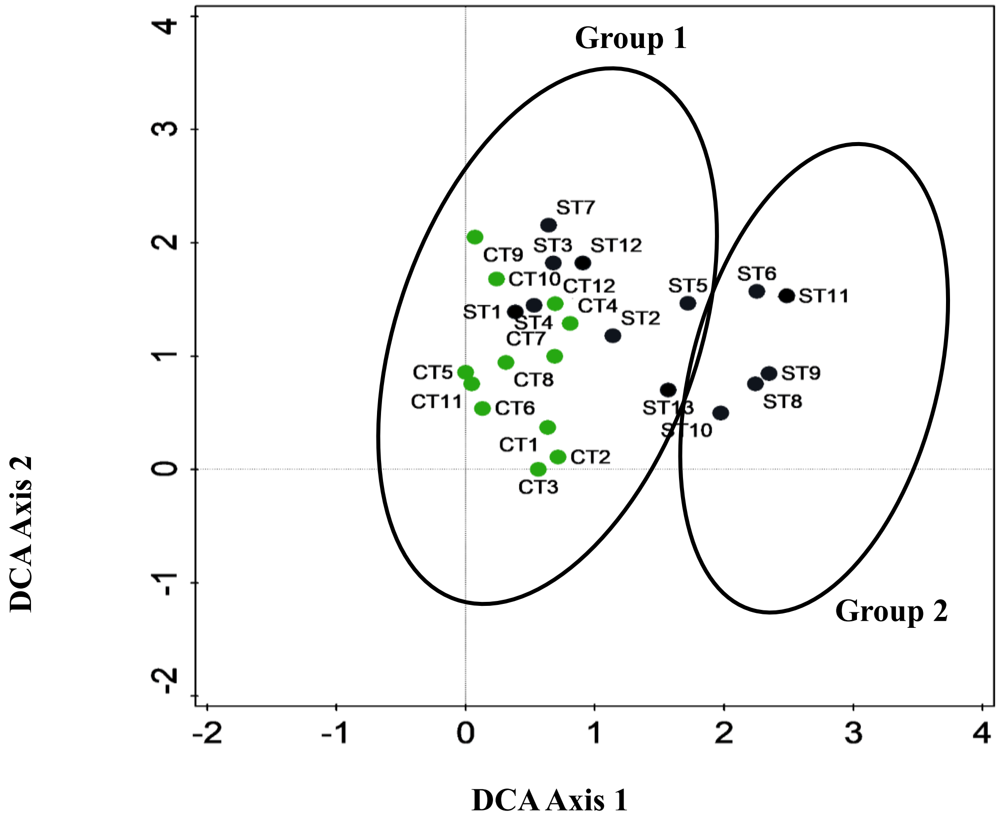

Figure 13: Detrended Correspondence Analysis (DCA) ordination diagram based on plant species presence/absence data illustrating the separation of plots into two groups along DCA Axis 1. The green dots represent the crest plots, and the black ones represent the slope plots crests in the landscape.

Table 4: Summary of DCA results, showing eigenvalues, cumulative explained variation, and gradient lengths across the first four axes.

Statistic	**Axis 1**	**Axis 2**	**Axis 3**	**Axis 4**
Eigenvalues	0.4395	0.2388	0.1643	0.0927
Explained variation (cumulative)	13.05	20.15	25.03	27.78
Gradient length	2.47	2.14	2.21	1.64

The explanatory variables used in the CCA explained 36.7% of the observed variation in landscape-type selection. The adjusted explained variation is 10.7% and the total inertia is 3.37. Additively, the first four axes explained 26.68% of the total variation in landscape-type selection. Individually, CCA axis 1 explained 9.72%, axis 2, 3 and 4 accounted for 6.35%, 5.41% and 5.2% of the observed variation in landscape type selection. The CCA revealed that generally the measured environmental variables have a meaningful influence on the landscape type selection by cattle as indicated by the significant overall test of all canonical axes ($F = 1.4$, $p = 0.002$). The forward selection of explanatory variables revealed that elevation ($F = 1.9$, $p = 0.004$), species richness ($F = 1.6$, $p = 0.014$), and percentage slope ($F = 1.6$, $p = 0.02$) had significant influence in landscape-type selection, thus resulting in the significant positive relationship with relative grazing index (representing selectivity for grazing sites) ($F = 1.5$, $p = 0.04$). The remaining explanatory variables such as species diversity ($F = 1.2$, $p = 0.158$), cover ($F = 1.0$, p 0.496) and above-ground biomass ($F = 0.9$, $p = 0.644$) were found to be insignificant in explaining landscape type selection.

The explainable variation in landscape type selection was positively correlated with species richness, species diversity, cover, above-ground biomass, elevation and relative grazing index on CCA axis 1 and negatively associated with slope (Fig 14). It was quite the opposite along CCA axis 2, the explainable variation in landscape-type selection was positively correlated with percentage slope and negatively correlated with species richness, species diversity, cover, above-ground biomass, elevation and relative grazing index (Fig. 14). Ranked by significance, the measured explanatory variables namely, elevation, species richness, percentage slope, relative grazing index, species diversity, cover and above-ground biomass account 7.5%, 6.1%, 6.2%, 5.5%, 4.5%, 3.7% and 3.3% respectively, to the observed variation (Table 5). This suggests that other factors not measured in this study are responsible for 63.3% in explaining landscape type selection.

Along CCA axis 1, the direction and influence of explanatory variables indicate that group 1 is strongly influenced by above-ground biomass, cover and elevation (Fig. 14). This group is strongly correlated with higher above-ground biomass, greater cover, higher elevation and lower percentage slope. Conversely, group 2, was associated with steeper slopes, lower elevation, low above-ground biomass, cover, and moderate species richness and diversity. The largest group in the CCA, which is group 1, which is mainly associated with elevation as shown by the presence of many crest plots correspond to cluster 3 of the HCA (Fig. 9) and group 1 of the DCA (Fig. 13). Group 2 of the CCA, which is largely influenced by percentage slope and is exclusively associated with slope plots corresponds with cluster 1, 2 and 4 of the HCA (Fig. 9) and group 2 of the DCA (Fig.13). Thus, cattle showed more selection of sites with higher species richness, gentler/flatter slopes and higher elevations.

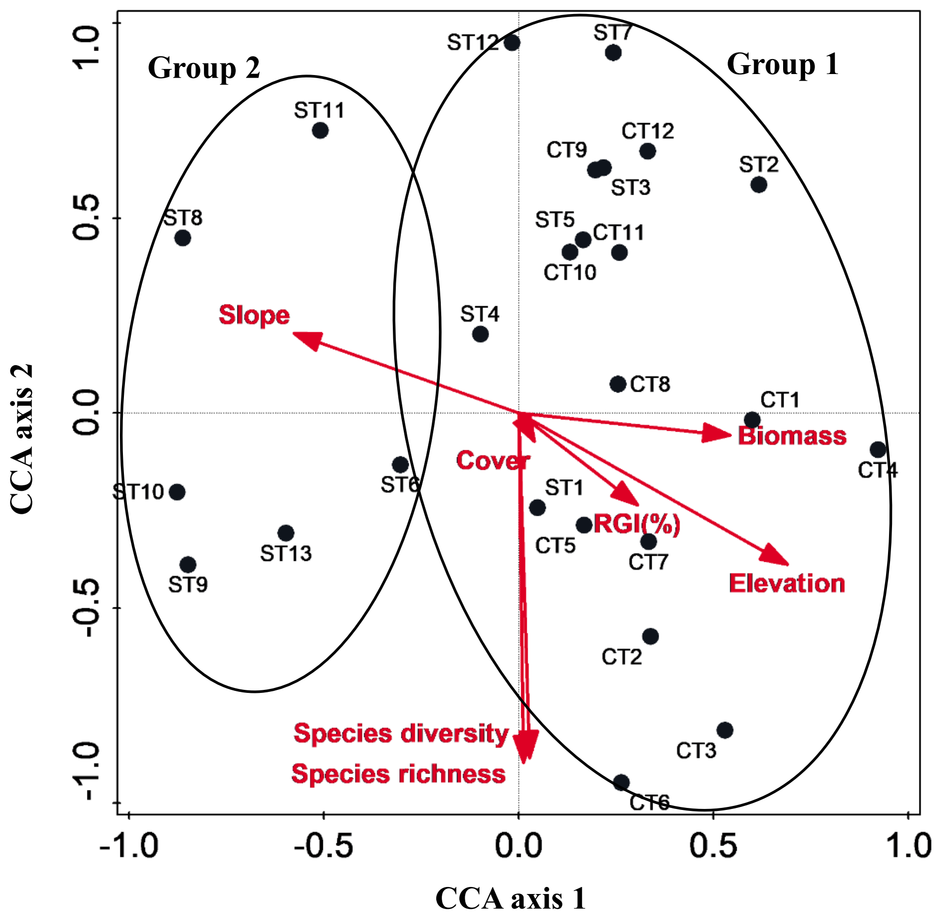

Figure 14: Canonical Correspondence Analysis (CCA) ordination diagram illustrating the influence of the measured environmental variables on landscape type selection at Farm Kiamsab West, Central Namibia.

Table 5: Summary results of the forward selection of explanatory variables, showing the order of selection, the percentage contribution, the corresponding F-values, and the p-values for each variable derived from a Monte Carlo permutation test.

Name	Explains %	Contribution %	pseudo-F	P	P(adj)
Elevation (m)	7.5	20.3	1.9	0.004	0.028
Species richness	6.1	16.7	1.6	0.014	0.098
% Slope	6.2	16.8	1.6	0.02	0.14
Relative Grazing Index (%)	5.5	15.0	1.5	0.04	0.28
Species diversity	4.5	12.2	1.2	0.158	1.
Cover	3.7	10.0	1.0	0.496	1.
Above-ground biomass (g/m²)	3.3	9.0	0.9	0.644	1.

CHAPTER 5

DISCUSSION

5.1 Forage selectivity by cattle

The main objective of this study was to investigate the determinants of wet season landscape and forage selectivity by cattle on Farm Kiamsab West. It was hypothesized that cattle, will clearly exhibit selectivity towards specific plant species during the wet season at Farm Kiamsab West. The results of this study support the hypothesis that cattle exhibit clear selective foraging behaviour. Cattle did not graze randomly, but rather showed a clear selectivity for specific forage species, as shown by the significant association between species and grazing status, and supported by the Jacob's Selectivity Index values.

Selection of various plant species by herbivores has been reported to be positively correlated with nutritional values, palatability and availability in the environment (Derebe & Girma, 2020; Simataa & Mapaure, 2024; Treydte *et al*., 2013). Cattle showed strong selectivity for specific grasses such as *Eragrostis nindensis* and *Anthephora pubescens*. These two grasses are perceived as valuable forage grasses because of their high nutritional content and palatability (Müller, 2007). These qualities may render them highly desirable to cattle. The moderate selectivity for grasses *Sporobolus africanus* and *Stipagrostis uniplumis* suggests that while the grasses were grazed more than would be expected by chance, their desirability is not particularly strong. *Sporobolus africanus* has poor to moderate grazing value due to its strong and tough coarse texture, as well as low leaf yield (Van Oudtshoorn, 2012). *Stipagrostis uniplumis* has a moderate grazing value, and it has been reported to be relatively well grazed in dry areas where it is dominant (Müller, 2007). In Namibia, *Stipagrostis uniplumis* is recognised to be a significant contributor to pasture production and a crucial source of fodder, which is normally grazed last as the season progresses (Müller, 2007). This likely explains the moderate selectivity noted in this study, it is not first choice particularly during the wet season when more nutritious alternatives are available.

Cleome suffruticosa and *Indigofera auricoma* were selectively grazed, potentially, due to protein rich-profiles and tender textures. *Indigofera auricoma* belongs to the *Indigofera* genus, which include leguminous plant species well known for high protein content due to their Nitrogen-fixing abilities. This affirms that cattle select high-value forage species as reported by other researchers (Simelane *et al*., 2021). The general preference for grasses over other life forms such as forbs, sub-shrubs, ferns and sedges, may reflect their high biomass production and greater energy contribution, especially during the wet season (Michaud *et al*., 2015). Most of the selected grasses form noticeable tussocks and provide cattle with a more concentrated abundant source of forage. By choosing grasses with larger tussocks, cattle may consume more quantity (biomass) per bite, which may help them to meet their nutritional requirements faster with less foraging effort thereby supporting the OFT which posits that animals choose foraging resources that allow them to optimise their energy and nutrient intake while minimising efforts (Pyke, 2019).

The avoidance of certain species such as *Aristida adscensionis, Aristida meridionalis*, *Cenchrus ciliaris*, *Fingerhutia africana, Melinis repens*, and *Tragus berteronianus* could be attributed to limited value as pasture grass due to low leaf yield, overall hardness and low palatability (Dannhauser & Jordan, 2015; Müller, 2007). Some *Aristida* species are often characterised by tough, wiry and high silica content, which makes them less palatable and difficult for cattle to digest; they are reported to be only palatable during the young vegetative stage before the seed ripens, the spiny seeds can penetrate and pierce animal skins (Müller, 2007). Correspondingly, grasses like *Melinis repens* and *Tragus berteronianus*, which are pioneer species, have low leaf yield hence low grazing values (Müller, 2007). Hence, avoidance of certain species could be attributed to low nutritive value or physical deterrents and the presence of toxic compounds. Grazing animals consume plant species that cause the least disruption to their digestive system and best meet their seasonal nutritional needs, and as a result, they become picky and tend to avoid harmful plants (Frost & Mosley, 2024). In this current study, the presence of deterrent compounds likely played a role in the avoidance of certain plant species. *Euphorbia* species, particularly *Euphorbia inaequilatera* were completely avoided (D = -1), potentially because species in the *Euphorbia* genus contain a toxic milky latex that can be irritating to the skin (Burke, 2005). Similarly, *Senecio consanguineus* was completely avoided. Some plants in the *Senecio* genus are poisonous due to the presence of pyrrolizidine alkaloids, which can cause liver damage if consumed in significant quantities and can cause fatal animal and human poisoning (Botha & Penrith, 2008; Burke, 2005; Mannheimer *et al*., 2008; Panziera *et al*., 2018). Additionally, the moderately selected *Tribulus terrestris,* is reported to be poisonous under specific conditions (Mannheimer *et al*., 2008; Mannheimer, 2012). Probably the animals may have learnt through post-ingestive feedback that some plants can be poisonous, thus reducing the intake. In some cases, rare species may have been led to the avoidance due to the plants' low frequency of occurrence in the landscape, limiting cattle exposure and opportunity to form preferences.

These findings are consistent with previous research studies conducted by Cuchillo-Hilario *et al*. (2018), Pauler *et al*. (2020), Simataa and Mapaure, (2024), Simelane *et* *al*. (2021) and Utsumi *et al*. (2009) in different ecosystems across the globe, where researchers demonstrated that cattle exhibit forage selection by preferring some species over others. However, this study focused on the wet season selectivity on patchy, semi-arid, and heterogeneous environments, and this provides insights into the wet season forage selection and gives accurate representation of forage selection during a time when vegetation growth is at its peak. These findings have important implications for the sustainable management of rangelands, biodiversity conservation, as well as for optimising livestock nutrition (Gwatirisa *et al*., 2022). Selective grazing, if not carefully monitored, especially in patchy heterogeneous environments, may have significant negative implications on the ecosystem. It can lead to depletion of preferred species and proliferation of less palatable plants, potentially leading to shifts in plant community structure and degradation of the rangeland over time, and an ultimate decline in livestock production (Onatibia *et al*., 2020; Rothauge, 2007). Understanding forage selectivity allows farmers and rangeland managers to implement targeted management strategies that could enhance rangeland productivity and animal performance while supporting biodiversity conservation. The rangeland can be manipulated to contain more of the preferred forage species than the less preferred and unpreferred forage, if the forage species preferred by animals are known (Faftine *et al*., 2021; Rothauge, 2007; Slayi & Jaja, 2024).

Data collection procedure involved determining the grazing status of all plant species within the plots. Overall, 48 plant species were observed, however, it is acknowledged that this may underestimate the full extent of the plant species encountered in the field, thus, forage selectivity, as some plants may have been completely uprooted and not encountered due to the relatively loose soils with high moisture content during the wet season. Additionally, for this study, only one herd was observed, this limits the generalizability of the findings, to fit a particular class of animals. Lastly, animal age and other herd dynamics, which could have influenced the outcomes, were not assessed. Hence, to further build on these findings, future research should consider incorporating pre- and post-grazing surveys as these might provide in-depth forage utilization insights. Additionally, grouping animals according to their different classes, as well as considering herd dynamics such as age would be beneficial in inferring forage selectivity variations within the herd, and this would provide valuable insights into grazing behaviour.

5.2 Comparisons of species richness, diversity and composition between landscape types

The second objective of this study was to compare species richness, diversity and composition between the two landscape types (crests and slopes). The results revealed that species richness, diversity and composition differed significantly between the two landscape types. These findings support the hypothesis that there is a clear difference in species richness, and diversity; the crests had higher species richness and diversity compared to the slopes.

These findings align with Ramos *et al*. (2020), who found that species richness and diversity reach their peak near mountain tops, in similar mountainous areas of the Brazilian Caatinga. The findings are also consistent with Zeng *et al*. (2014), in similar environments, who found out that species diversity and evenness were low in mid-slopes, and emphasised that slopes were hotter and drier, hence only a limited number of species could adapt to the prevailing thirsty conditions found in the slopes. While the current study did not specifically focus on elevation bands, the results are contrary to Dani *et al*. (2023) who using meta-analyses and case studies in mountainous regions from both temperate and tropical environments including locations such as the Andes, Himalayas, and Rocky Mountains, and He *et al*. (2023) in the Ningxia Helan Mountain, National Nature Reserve in China, reported that species richness follows a unimodal shape, with the peak in mid altitudes. Dani *et al*. (2023) and He *et al*. (2023) suggested that plants at upper and lower elevation gradients face harsher environmental conditions such as low temperature, high frequency of fog, shorter growing seasons and rainfall extremes, which may result in a reduction in species diversity. The results in this current study suggest that in certain contexts, crest may provide favourable microhabitats, possibly due to reduced competition, adequate sunlight or favourable soil conditions which support greater plant diversity. Thus, the divergence from the broader trend observed worldwide could be due to localised environmental conditions unique to the study area, meaning that topographical effects on species richness, diversity and composition along with dominance, may differ depending on specific landscape context, warranting further investigation.

Topography has been reported to decrease species similarity between locations by increasing species isolation and increasing environmental variability (Aggemyr *et al*., 2018; Stein *et al*., 2014; Wani *et al*., 2023). It creates unique conditions in each location (soil depth, moisture, temperature and other factors) which favour different species in each landscape type. The shallow lithic leptosols are known for poor soil fertility, low organic matter, poor water holding capacity as well as impermeable hard rock characterising the study area (Mendelsohn *et al*., 2022) combined with frequent water runoff and soil erosion typical in slopes (Cha & Kim, 2011; Mu *et al*., 2015; Zeng *et al*., 2014), may interfere with some plants' ability to establish roots, absorb nutrients and cope with less stable conditions. Consequently, restricting the diversity of plants growing on the slopes, allowing only the species adapted to low-nutrient and water-limited conditions to persist. Hence, the challenging environmental conditions on slopes often result in more heterogeneous microhabitats that support a diverse range of plants that are specifically adapted to harsh conditions (He *et al*., 2023; Singh, 2018). The restriction of *Acrotome fleckii*, *Emilia marlothiana*, *Forsskaolea viridis*, *Helichrysum tomentosulum*, and T*ephrosia dregeana*, to slopes, suggest that some plants are adapted to the harsher conditions of mountainous terrains (Burke, 2004, 2005; Mannheimer *et al*., 2008).

Although both landscape types were dominated by grasses, the difference in species composition and dominance patterns paint some level of differentiation where some species found on higher elevation have evolved to occupy a niche different from those on slopes and lower elevations vice versa. The presence of certain species exclusively on crests and on slopes, for example *Stipagrostis uniplumis* on crests and *Enneapogon cenchroides* on slopes, indicate habitat filtering or niche specialisation where environmental conditions select for species best suited to each landscape type. These findings support the notion that different species occur on different slope types and certain species specialise in different parts of the mountain landscapes (Dannhauser & Jordan, 2015; Lasway *et al*., 2023). The significant clustering in the HCA, supports the idea that species composition is shaped by unique environmental conditions of each landscape type. Elevation influences a variety of environmental conditions such as temperature, soil moisture, nutrient availability and together these factors impact species distribution (Cheng *et al*., 2023; Dani *et al*., 2023). These conditions may result in microhabitats which favour the establishment of certain plant species.

The dominance of *Eragrostis nindensis* across both landscapes, however, shows that some species are generalists capable of thriving under a wide range of conditions. This is an indication that *Eragrostis nindensis* is adaptable to the terrain of both landscapes, thriving very well in the shallow soils and withstanding grazing pressure. Burke, (2004) highlights that some species are broadly adaptable and widespread across Namibia. Furthermore, the observed overlap as reflected in the HCA and the DCA, suggest moderate environmental gradients rather than stark ecological divides. This overlap indicated that while topography influences species composition, it does not create entirely distinct floristic zones. It shows that some species are sufficiently plastic or tolerant to occur on both landscape types especially those with widespread amplitudes such as *Stipagrostis uniplumis* and *Tribulus terrestris*. Species such as *Eragrostis nindensis*, *Stipagrostis uniplumis* and *Tribulus terrestris* grow in a variety of habitats (Burke, 2004), hence, they occur in both the landscapes. *Tribulus terrestris* has broad adaptability, in form of seed dispersal, rapid growth, and tolerance to difference soil conditions and that gives the forb competitive advantage in diverse conditions including disturbed areas (Burke, 2004; CABI, 2022).

These findings imply that species distributions in the landscape are governed by a combination of environmental factors such as soil conditions, moisture retention and species-specific traits such as root depth, reproductive strategy and drought tolerance. The difference in species richness, diversity and composition between crests and slopes have practical implications on rangeland management. Areas with higher species richness and diversity such as crests may serve as biodiversity reservoirs and must be managed to maintain ecological integrity. Slopes, on the other hand, since they have lower species richness and diversity may be vulnerable to overgrazing under intense grazing pressure and as a result may require conservation strategies that prevent soil erosion and the loss of currently present plant species.

Despite the significant results, it should be noted that the current study only compared species richness, diversity and composition between the two landscape types.

Aggregating data by landscape type might conceal meaningful patterns within each landscape type. Equally important, this study did not assess the environmental factors such as temperature, moisture, and soil properties, which potentially influence species composition.

5.3 Comparisons of above-ground biomass and cover between landscape types

The third objective of this study was to compare above-ground biomass and cover between crests and slopes at Farm Kiamsab West. The results revealed no significant differences in above-ground biomass and cover between the crests and slopes, hence, the hypothesis that crests will have significantly higher biomass and cover than slopes at Farm Kiamsab West was refuted. Overall, the farm was characterised by low cover as indicated by the high proportion of plots (66%) in the >25% cover category and the vegetation was generally sparse. These results suggest that both landscape types experience environmental constraints that limit plant productivity.

Climatic conditions explain the similarity in above-ground biomass and cover across the study site. It is generally known that high precipitation leads to high above-ground plant productivity (Polley *et al*., 2017). Precipitation being the major driver of above-ground productivity, low rainfall typical of this semi-arid rangeland likely imposes overriding limitations on plant growth (Mendelsohn *et al*., 2022), regardless of topographical variation. Precipitation, temperature and elevation have been shown to impact the above-ground biomass (Yan *et al*., 2015; Yao *et al*., 2022). Both landscape types generally experience similar rainfall patterns, soil type and nutrient availability since they are in the same vicinity; hence, there are no marked differences in above-ground biomass and cover between the two landscapes. These results align with previous studies conducted by Wei *et al*. (2019) in a semi-arid steppe in Inner

Mongolia, China, who found that during the wetter year above-ground biomass did not differ significantly between three landscape positions namely top area, slope area and bottom area. The results are however, are inconsistent with previous studies on topography that reported significant differences in biomass and cover in different slope positions (Nippert *et al*., 2011; Sanaei *et al*., 2019; Yao *et al*., 2022; Zhang *et al*., 2022).

In grass-dominated landscapes, high levels of grazing have been reported to reduce grass biomass (Smit & Coetsee, 2019). During the study, the camps were subject to grazing from both livestock and wildlife. This continuous grazing might have contributed to the similarities in above-ground biomass and cover between crests and slopes. Despite the insignificant differences in above-ground biomass between crests and slopes, it should be noted that crests had a wider range suggesting a more heterogeneous distribution of biomass compared to a narrower range of biomass observed in the slopes. Since, grazing does not reduce grass biomass homogenously or evenly across the landscape (Archer *et al*., 2017), landscapes might have experienced differently.

The lack of significant differences in biomass and cover between the crests and slopes at Farm Kiamsab West, has serious implications for both livestock production and rangeland management. The uniform biomass and cover in both crests and slopes couples with the fact that the vegetation is sparse suggest that limited forage availability which may constrain the carrying capacity of the farm. This highlights the need for careful planning for establishing stocking rates and grazing management to avoid the degradation of the rangeland. Adaptive strategies such as rotational grazing, resting of overgrazed camps or deferred grazing may help improve forage recovery and maintain the range in a healthy state. Collectively, these findings underline the vulnerability of this rangeland and the need for adopting sustainable management strategies that align with these ecological conditions.

Despite the insightful results, it is important to acknowledge that a small sample size used in this study may have limited the statistical power to unmask the significant differences in above-ground biomass and cover between the two landscape types. As Bonham (2013) notes, small areas described by plots may yield biased estimates of biomass due to inherent spatial variability of vegetation. In this study, biomass was clipped in a single 1 m * 1 m plot per transect. While less invasive, this method may not have captured the full heterogeneity present within each landscape. This limited spatial representation could have contributed to the absence of statistically significant differences, particularly in areas where local variation was high.

This is supported by the observation of a notably high biomass value, recorded at ST5 (62g) in the slopes. While most plots in the slopes recorded relatively low biomass, plot ST5 was distinct both numerically and visually. The notable outlier in the slopes may be attributed to site-specific ecological conditions. ST5 occurred in the highest elevation (1508.7 m above sea level) among all slope transects, and at moderate percentage slope of 15.8%. Higher elevation sites may experience better microclimatic conditions which favour plant productivity (Nippert *et al*., 2011; Sanaei *et al*., 2019). Compared to other transects in the slopes landscape, which in general occurred in lower elevations and recorded lower biomass, the conditions at ST5 may have been favourable for plant growth. With a single plot used to represent each transect, localised differences in biomass may also have influenced comparisons between crests and slopes. This suggests that fine-scale topographic variation, particularly elevation and slope, can influence above-ground biomass patterns even within the same landscape type. The presence of such variability underscores the importance of increasing plot replication in future research to better account for spatial heterogeneity.

5.4 The determinants of landscape type selection by cattle

The fourth objective of this study was to determine the influence of above-ground biomass, species richness, diversity, cover, slope and elevation on landscape type selection by cattle at Farm Kiamsab West. It was hypothesised that the landscape type selection would be significantly influenced by above-ground biomass, species richness, diversity, cover, slope and elevation. The CCA revealed that all the measured environmental variables were significant in explaining landscape type selection, they explained 36.7% of the observed variation in landscape type selection. Therefore, the findings support the hypothesis that landscape type selection would be significantly influenced by above-ground biomass, species richness, diversity, cover, slope and elevation at Farm Kiamsab West. Only elevation, species richness and slope emerged as key determinants. Above-ground biomass, species diversity and cover did not significantly influence the landscape type selection along the gradient.

These findings are consistent with the prior studies by Andrew, (2021) in the Kilombero Valley Floodplain, and Xu *et al*. (2024) in a semi-arid meadow steppe in western Jilin Province, northeast China, who demonstrated that species richness is an important factor determining grazing patch selection for large herbivores. Switching between alternative forage species is one strategy employed by cattle to diversify their diet during foraging to meet their nutritional demands (Lagrange *et al*., 2020; Nota *et al*., 2024; Utsumi *et al*., 2009). Species richness allows cattle to broaden their diet breadth and selectively graze those plants they prefer most, allowing them to meet different metabolic and nutritional needs (Andrew, 2021; Thompson *et al*., 2021). The richer and more diverse the forage, the wider the choices for grazers. Such dietary flexibility may encourage animals to increase their intake (Thompson *et al*., 2021), potentially resulting in higher protein and energy gains. Species-rich landscapes also allow cattle to optimise their nutrient balance and forage efficiently by minimising movements and effort spent searching for food (Andrew, 2021). Additionally, plant diversity provides complimentary benefits to cattle such as mitigating and neutralising harmful effects of toxic compounds found in certain plants (Distel *et al*., 2020; Fynn *et al*., 2019; Wang *et al*., 2010).

Elevation and percentage slope were also significant determinants of landscape type selection which is consistent with the findings of Andrew, (2021) who observed a progressive change in grazing intensity with elevation, where livestock preferred higher elevations over low-lying areas because of presence of desirable nutrient- and energy-rich plant species in higher elevation sites. These research findings are also in line with Raynor *et al*. (2021) and Rivero *et al*. (2021) who affirm that large herbivore grazing distribution is strongly influenced by landscape features such as slopes and distance to water. Generally, cattle tend to avoid high elevation and steeper slopes (Mkabile, 2019). In this study, cattle indeed tended not to select steeper slopes but grazed on higher elevations due to the existence of higher species richness at those sites. Topography influences ease of movement and access to forage resources (Bailey *et al*., 2015; Kaufmann *et al*., 2013; Mkabile, 2019; Raynor *et al*., 2021; Rivero *et al*., 2021). Since cattle and other herbivores aim to forage optimally, by balancing the energy costs with the net gains of foraging in a particular area, slope and elevation are key to landscape type selection. In the current study, crests were found at high elevations and were associated with higher species richness and diversity.

These results suggest that the measured variables such as slope, elevation, species richness, diversity, above-ground biomass and cover exert moderate influence (36.7%) on cattle foraging behaviour. A large proportion of the unexplained variation implies that other biophysical or behavioural factors not included in the model of the current study such as distance to the water point, shade, mineral licks and social herd dynamics also play a role in shaping landscape use. This underscores the value of incorporating a wider set both ecological indicators and behavioural observations when designing grazing strategies. An adaptive management approach that accounts for both measured environmental gradients and the factors not considered in this study but specific to this rangeland system, is therefore, essential to ensure sustainable grazing and to avoid overutilization of preferred landscapes.

Plant community properties and physiographic factors are key determinants of cattle distribution by several studies (Andrew, 2021; Homburger *et al*., 2015; Mkabile, 2019). Often a times, studies have focused on assessing single sites, and general influence of topography on forage and landscape selectivity. This study, however, stratified the grazing landscape into crests and slopes within a single site, providing a more detailed evaluation of the determinants at finer scales. The method allows for a better understanding of specific determinants that influence landscape type selection, thereby providing insights for targeted rangeland management. Though it should be acknowledged that focusing on the stratified landscape types, may limit the findings generalizability, especially to other rangelands with different environmental conditions. Secondly, solely focusing on crests and slopes may overlook other important landscape features (e.g., terrain ruggedness) that are part of the grazing landscape. Hence, it would be beneficial to include these landscapes in future studies to further build on the findings of this study.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

This study provides comprehensive insights into cattle forage selectivity and the factors influencing landscape type selection at Farm Kiamsab West. The findings demonstrate that cattle exhibit clear forage selectivity, preferring *Eragrostis nindensis*, *Anthephora pubescens*, and *Cleome suffruticosa* over other species. Cattle also have a marked preference for grasses over forbs, sub-shrubs, ferns and sedges. This selectivity is potentially driven by the nutritional profiles and the abundance of different plant species, which provide essential nutrients for bulk feeders such as cattle. Moreover, the study revealed that species richness, diversity and composition differ significantly between crests and slopes, with crests being more species rich and diverse compared to slopes. The study also identified elevation, slope and species as key determinants of landscape type selection, highlighting the influence of both plant community structure and physiographic factors in influencing cattle grazing patterns in semi-arid rangelands.

The results highlight the importance of maintaining species richness to support both livestock production and ecosystem health. Effective rangeland management should therefore, prioritize the enhancement of species richness, while taking into consideration topographic factors such as elevation and slope when crafting grazing strategies. Although the differences in above-ground biomass and cover between the crests and slopes were insignificant, targeted management strategies that ensure degradation or overgrazing of these landscape types is avoided at all cost, could be beneficial.

In conclusion, the findings of this study contribute new knowledge to the understanding of cattle foraging behaviour in patchy semi-arid rangelands characterized by mountains and rolling hill terrain. In particular, it outlines how topographic features together with plant community properties interact to shape cattle foraging behaviour. The findings provide insights for the development of targeted management practices that balance the needs of livestock production with the sustainability of rangeland ecosystem. Future research should consider exploring these dynamics across different seasons and also incorporate other environmental variables to refine these findings to enhance the long-term viability of semi-arid rangeland systems.

6.2 Recommendations

While this study provides insights into wet season foraging behaviour of cattle, several areas warrant further investigation. Future studies could explore landscape and forage selectivity of cattle during different seasons. Understanding whether the patterns and these determinants observed in the wet season persist during the dry season, could offer a more comprehensive understanding of cattle foraging behaviour throughout the year. Moreover, bearing in mind that this is only a once-off study, the full array of landscape type and forage selection behaviours exhibited by cattle over different seasons and conditions may not have been comprehensively captured. Conducting a similar study over an extended period, could yield detailed insights into cattle selectivity and will facilitate a deeper understanding of how grazing patterns of cattle change over time. Land managers and the farmer could implement the following recommendations:

a. This study revealed that cattle exhibited clear forage selectivity for specific plant species. Farmers and land managers should prioritize the protection and propagation of *Eragrostis nindensis* and *Anthephora pubescens* to enhance pasture resilience. This could be achieved through reseeding, or rotational resting of grazed patches, and implementation of deferred grazing to enable these species to recover, set seed and regenerate. Regular monitoring to be conducted to assess the abundance of these species and to ensure they are not over utilized.
b. Grazing practices should take into consideration the differences in species richness, diversity and composition between crests and slopes. Targeted rangeland management strategies which optimize sustainable use of these landscapes should be adopted; this will minimize overutilization of resources in the crests and underutilization in the slope plots. Targeted management strategies such rotational grazing plans that alternate between the two landscape types paired with temporary fences, strategic placement of artificial water points, mineral licks, to help manage cattle movement, reduce concentrated pressure on crests and promote sustainable use of the range.
c. Taking note that this study revealed species richness as one of the key determinants of landscape type selection, it is crucial to promote species richness in both landscape types but more so in slopes to help distribute grazing pressure more evenly across the landscape. Management interventions may include reseeding with mixed seed blends suited for local topography.

Future research could also consider comparing species richness, diversity and composition in different elevation bands between the two landscape types.

d. Since this study only focused on one herd, observing the grazing patterns of separate herds or different classes of cattle could provide a deeper understanding on grazing behaviour of cattle. The use of GPS collars and behavioural tracking could provide deeper insights into how different classes utilize forage resources and the landscape.
e. Although the study found no statistically significant differences in biomass and cover between the crests and slopes, the sparse vegetation observed across the landscape indicates that the rangeland is vulnerable to degradation. There is need for regular monitoring, in order to adjust management accordingly in both landscape types. Erosion control measures such as contour bunds or grass strips could minimize potential soil erosion particularly on slopes and the farmer can reseed with drought tolerant and fast establishing native species.

REFERENCES

Abdalla, M., Hastings, A., Chadwick, D., Jones, D., Evans, C., Jones, M., Rees, B., & Smith, P. (2018). Critical review of the impacts of grazing intensity on soil organic carbon storage and other soil quality indicators in extensively managed grasslands. *Agriculture Ecosystems & Environment*, *253*, 62–81. https://doi.org/10.1016/j.agee.2017.10.023

Abdelsalam, M. I. (2021). Effects of Overgrazing on Rangeland Resources in Semi-arid Areas and Rangeland and Management: A review Article. *Agrica*, *10*(2), 144–151. https://doi.org/10.5958/2394-448x.2021.00022.5

Acar, Ramazan & Osman, Ibrahim. (2022). Some Classical Methods of Vegetation Attributes Measurements in Rangelands. Selcuk Journal of Agricultural and Food Sciences. 10.15316/SJAFS.2022.084.

Aggemyr, E., Auffret, A., Jädergård, L., & Cousins, S. (2018). Species richness and composition differ in response to landscape and biogeography. *Landscape Ecology*, *33*. https://doi.org/10.1007/s10980-018-0742-9

Albores-Moreno, S., Alayón-Gamboa, J.A., Morón-Ríos, A.Ortiz-Colin, P., Ventura-Cordero, J., Pech, P. G. G., Mendoza-Arroyo, G. E., Ku-Vera, J. C., Jimenez-Ferrer, G & Pineiro-Vazquez, A. T. (2020). Influence of the composition and diversity of tree fodder grazed on the selection and voluntary intake by cattle in a tropical forest. *Agroforest Syst* **94**, 1651–1664. https://doi.org/10.1007/s10457-020-00483-9

Allen, V. G., Batello, C., Berretta, E. J., Hodgson, J., Kothmann, M., Li, X., McIvor, J., Milne, J., Morris, C., Peeters, A., Sanderson, M. (2011). An international terminology for grazing lands and grazing animals. *Grass and Forage Science*, *66*(1), 2–28. https://doi.org/https://doi.org/10.1111/j.1365-2494.2010.00780.x

Alvarez-Hess, M. L., Douglas, M. M., Wright, N., Norbu, K., Giri, W. J., Wales, J. L., Jacobs, M. J., & Auldist, M. (2021). Effects of herbage mass and herbage allowance on bite mass of grazing dairy cows. *Animal Feed Science and Technology, 278*, 115011. https://doi.org/10.1016/j.anifeedsci.2021.115011

Anderson, J. M., & Ingram, J. S. I. (1993). Tropical Soil Biology and Fertility: A Handbook of Methods. *The Journal of Ecology*, *78*(2), 547. https://doi.org/10.2307/2261129

Andrew, S. M. (2021). Effects of Plant Species Diversity and Biomass on Grazing Patch Selection by Semi Free-Ranging Cattle. *Tanzania Journal of Science*, *47*(1), 282–295. https://doi.org/10.4314/tjs.v47i1.24

Ang'ila, R. O., Kimuyu, D. M., Wambugu, G. M., Kenfack, D., Musili, P. M., & Kartzinel, T. R. (2023). Fine-scale variation in soil and topography influences herbaceous vegetation and the distribution of large mammalian herbivores. *African Journal of Ecology*, *61*(3), 706–716. https://doi.org/https://doi.org/10.1111/aje.13166

Anthony, C. R., & Germino, M. J. (2022). Predictive models of selective cattle use of large, burned landscapes in semi-arid sagebrush-steppe. *Rangeland Ecology & Management*, *85*, 1-8.

Archer, S., Andersen, E., Predick, K., Schwinning, S., Steidl, R., & Woods, S. (2017). *Woody Plant Encroachment: Causes and Consequences*. https://doi.org/10.1007/978-3-319-46709-2_2

Babayemi, O., & Adebayo, A. (2020). Assessment of nutritive value of selectively grazed forbs by cattle in communal grazing land of Ido Local Government Area, Oyo state, Nigeria. *Nigerian Journal of Animal Production*, *47*. https://doi.org/10.51791/njap.v47i5.1264

Bailey, D., Stephenson, M., & Pittarello, M. (2015). Effect of terrain heterogeneity on feeding site selection and livestock movement patterns. *Animal Production Science*, *55*, 298. https://doi.org/10.1071/AN14462

Bolo PO; Sommer R; Kihara J; Kinyua M; Nyawira S; Notenbaert A. (2019) Rangeland degradation: Causes, consequences, monitoring techniques and remedies. Working Paper. CIAT Publication No. 478. International Center for Tropical Agriculture (CIAT). Nairobi, Kenya. 23 p. Available at: https://hdl.handle.net/10568/102393

Bonham, C. D. (2013). Measurements for terrestrial Vegetation (2nd Ed.). Wiley-Blackwell https://doi.org/10.1002/9781118534540

Bora, Z., Xu, X., Angassa, A., Wang, Y., & Zhao, Y. (2020). Do Herbaceous Species Functional Groups Have a Uniform Pattern along an Elevation Gradient? The Case of a Semi-Arid Savanna Grasslands in Southern Ethiopia. *International Journal of Environmental Research and Public Health*, *17*(8), 2817. https://doi.org/10.3390/ijerph17082817

Breed, M. D. (2017). 1976 Marginal Value Theorem. In *Conceptual Breakthroughs in Ethology and Animal Behaviour* (pp. 153–155). https://doi.org/10.1016/B978-0-12-809265-1.00048-4

Breed, M. D., & Moore, J. (2022). Foraging. In *Animal Behaviour* (pp. 309–341). Elsevier. https://doi.org/10.1016/B978-0-12-819558-1.00009-9

Burke, A. (2005). Wild flowers of the Northern Namib (1st ed). Namibia Scientific Society. 99916-40-53-3

Burke, A. (2004). Wild Flowers of the Central Namib. Namibia Scientific Society. 99916-40-46-0 https://books.google.com.na/books?id=0CNFAQAAIAAJ

CABI. (2022). *Tribulus terrestris (puncture vine)*. CABI Compendium. https://doi.org/https://doi.org/10.1079/cabicompendium.54447

Cha, K., & Kim, T.-H. (2011). Evaluation of slope stability with topography and slope stability analysis method. *KSCE Journal of Civil Engineering*, *15*, 251–256. https://doi.org/10.1007/s12205-011-0930-5

Chen, K., Pan, Y., Li, Y., Cheng, J., Lin, H., Zhuo, W., He, Y., Fang, Y., & Jiang, Y. (2023). Slope position-mediated soil environmental filtering drives plant community assembly processes in hilly shrublands of Guilin, China. Frontiers in Plant Science, 13, 1074191. https://doi.org/10.3389/fpls.2022.1074191

Cheng, Z., Aakala, T., & Larjavaara, M. (2023). Elevation, aspect, and slope influence woody vegetation structure and composition but not species richness in a human-influenced landscape in northwestern Yunnan, China. *Frontiers in Forests and Global Change*, *6*. https://www.frontiersin.org/journals/forests-and-global-change/articles/10.3389/ffgc.2023.1187724

Cooke, A.S., Machekano, H., Gwiriri, L.C., Tinsley, J. H. I., Silva, G. M., Nyamukondiwa, C., Safalaoh, A., Morgan, E. R. & Lee, M. R. (2025). The nutritional feed gap: Seasonal variations in ruminant nutrition and knowledge gaps in relation to food security in Southern Africa. *Food Sec.* **17**, 73–100. https://doi.org/10.1007/s12571-024-01509-1

Cuchillo-Hilario, M., Wrage-Mönnig, N., & Isselstein, J. (2018). Forage selectivity by cattle and sheep co-grazing swards differing in plant species diversity. *Grass and Forage Science*, *73*, 320–329. https://doi.org/10.1111/gfs.12339

da Cunha, S. S., Ramos, M. B., de Almeida, H. A., Maciel, M. G. R., de Souza, S. M., Pedrosa, K. M., & de Faria Lopes, S. (2022). Vegetation cover and seasonality as indicators for selection of forage resources by local agro-pastoralists in the Brazilian semi-arid region. *Scientific Reports*, *12*(1), 15174. https://doi.org/10.1038/s41598-022-18282-w

Dani, R. S., Divakar, P. K., & Baniya, C. B. (2023). Diversity and composition of plants species along elevational gradient: research trends. *Biodiversity and Conservation*, *32*(8), 2961–2980. https://doi.org/10.1007/s10531-023-02638-3

Dannhauser, C. S., & Jordaan, G. D. (2015). Practical veld and pasture management for farmers: management, animal production, optimization. Kejafa Knowledge Works.

Derebe, Y., & Girma, Z. (2020). Diet composition and preferences of Bohor reedbuck (*Redunca redunca*) in the compound of Alage College, Central Rift Valley of Ethiopia. *Ecology and Evolution, 10*, 13370–13381. https://doi.org/10.1002/ece3.6939

Derner, J. D., Hunt, L., Filho, K. E., Ritten, J., Capper, J., & Han, G. (2017). Livestock production systems. In *Agricultural Systems* (Vol. 54, Issue 2, pp. 269–270). https://doi.org/10.1016/s0308-521x(97)89831-9

Distel, R. A., Arroquy, J. I., Lagrange, S., & Villalba, J. J. (2020). Designing Diverse Agricultural Pastures for Improving Ruminant Production Systems. *Frontiers in Sustainable Food Systems*, *4*. https://www.frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2020.596869

DiTomaso, J. M., Monaco, T. A., & James, J. J. (2017). *Invasive plant species and novel rangeland systems. Briske DD (ed) Rangeland systems: processes, management and challenges*. Springer, New York, NY, USA.

Dytham, C. (2011). *Choosing and Using Statistics: A Biologist's Guide*. Wiley. https://books.google.com.na/books?id=ZvulFAhLIHYC

Ehlert, K., Menendez, H., Bachler, J., & Dagel, A. (2025). The lasting effects of overgrazing on rangeland ecosystems. South Dakota State University Extension. https://extension.sdstate.edu/lasting-effects-overgrazing-rangeland-ecosystems

Faftine, O.; Alage, A.; and Muir, J. P., "Characterization of Forage Selected by Cattle on Communal Range in Manhiça, Mozambique" (2021). *IGC Proceedings (1989-2023)*. https://uknowledge.uky.edu/igc/19/25/1

Falú, D. E. M., Brizuela, M. Á., Cid, M. S., Cibils, A. F., Cendoya, M. G., & Bendersky, D. (2014). Daily feeding site selection of cattle and sheep co-grazing a heterogeneous subtropical grassland. *Livestock Science*, *161*, 147–157. https://doi.org/https://doi.org/10.1016/j.livsci.2013.11.010

Fenetahun, Y., Xu, X. W., & Wang, Y. D. (2020). Forage composition, biomass and carrying capacity dynamics in yabello rangeland, southern ethiopia using different grazing sites. *Applied Ecology and Environmental Research*, *18*(5), 7233–7253. https://doi.org/10.15666/aeer/1805_72337253

Feng, C., Ding, S., Zhang, T., Li, Z., Wang, D., Wang, L., Liu, C., Sun, J., & Peng, F. (2016). High plant diversity stimulates foraging motivation in grazing herbivores. *Basic and Applied Ecology*, *17*(1), 43–51. https://doi.org/https://doi.org/10.1016/j.baae.2015.09.004

Filho, L. C. P. M., & Gregorini, P. (2022). Editorial: Grazing behaviour and welfare of ruminants. *Frontiers in Veterinary Science, 9*, 890289. https://doi.org/10.3389/fvets.2022.890289

Fraser, M. D., Vallin, H. E., & Roberts, B. P. (2022). Animal board invited review: Grassland-based livestock farming and biodiversity. *Animal*, *16*(12), 100671. https://doi.org/https://doi.org/10.1016/j.animal.2022.100671

Frost, R., & Mosley, J. (2024). *Diet Selection of Grazing Animals*. Rangelands Gateway. https://rangelandsgateway.org/topics/uses-range-pastureland/diet-selection-grazing-animals

Fynn RWS and Provenza FD (2023) Functional adaptive resources for large herbivores in African savannas: an ecological-gradient based framework. *Front. Conserv. Sci.* 4:1133329. doi: 10.3389/fcosc.2023.1133329

Galyean, M. L., & Gunter†, S. A. (2016). Predicting forage intake in extensive grazing systems1. *Journal of Animal Science*, *94*(suppl_6), 26–43. https://doi.org/10.2527/jas.2016-0523

Ganskopp, D. C., & Bohnert, D. W. (2009). Landscape nutritional patterns and cattle distribution in rangeland pastures. *Applied Animal Behaviour Science*, *116*(2), 110–119. https://doi.org/https://doi.org/10.1016/j.applanim.2008.10.006

García, C. A. M., Maxwell, T. M. R., Hickford, J., & Gregorini, P. (2020). On the search for grazing personalities: From individual to collective behaviours. *Frontiers in Veterinary Science, 7*, 74. https://doi.org/10.3389/fvets.2020.00074

Gebrehiwot, K., Woldu, Z., Gelaw, M., Desalegn, T., & Teferi, E. (2019). Elevational changes in vascular plants richness, diversity, and distribution pattern in Abune Yosef mountain range, Northern Ethiopia. *Plant Diversity, 41*(4), 220-228. https://doi.org/10.1016/j.pld.2019.06.005

Gebremedhn, H. H., Ndiaye, O., Mensah, S., Fassinou, C., Taugourdeau, S., Tagesson, T., & Salgado, P. (2023). Grazing effects on vegetation dynamics in the savannah ecosystems of the Sahel. *Ecological Processes*, *12*(1), 54. https://doi.org/10.1186/s13717-023-00468-3

Ginane, C., Bonnet, M., Baumont, R., & Revell, D. (2015). Feeding behaviour in ruminants: A consequence of interactions between a reward system and the regulation of metabolic homeostasis. *Animal Production Science*, *55*, 247–260. https://doi.org/10.1071/AN14481

German Federal Ministry for Economic Cooperation and Development (BMZ), (2022) *Business scouts for development.* Sector Brief Namibia: Agriculture. Deutsche für Internationale Zusammenarbeit (GIZ) GmbH

Gondwe, Smart & Chibinga, Oswin & Kanyinji, Francisco. (2024). Nutritive value of selected naturally growing dry season pastures in flood plains of Kafue river in Southern Zambia. University of Zambia Journal of Agricultural and Biomedical Sciences. 7. 11-17. 10.53974/unza.jabs.7.1.1084.

Goudie, A., & Viles, H. A. (2015). *Landscapes and Landforms of Namibia*. https://doi.org/10.1007/978-94-017-8020-9

Grings, E. E. (2020). *Cattle Grazing Behaviour and Diet Selection: Implications for Management Cattle Grazing Behaviour and Diet Selection: Implications for Management Key Points*.

Guo, Y., Poulton, G., Corke, P., Bishop-Hurley, G. J., Wark, T., & Swain, D. L. (2009). Using accelerometer, high sample rate GPS and magnetometer data to develop a cattle movement and behaviour model. *Ecological Modelling*, *220*(17), 2068–2075. https://doi.org/https://doi.org/10.1016/j.ecolmodel.2009.04.047

Guo, Yanjun & Chen, Yuanyuan. (2024). A review of the impact of grazing on grassland ecosystems: Research progress and prospects. Advances in Resources Research. 4. 455-473. 10.50908/arr.4.3_455.

Gwatirisa, C., Mudereri, B. T., Chitata, T., Mukanga, C., Ngwenya, M. M., Muzvondiwa, J. V., Mugandani, R., & Sungirai, M. (2022). Microhabitat and patch selection detection from GPS tracking collars of semi-free ranging Mashona cattle within a semi-arid environment. *Livestock Science*, *261*. https://doi.org/10.1016/j.livsci.2022.104963

Hamunyela, N. (2019). *An investigation into the causes and impacts of land degradation, and possible management strategies and mitigation measures in the Oshana region, Northern Namibia*. https://scholar.sun.ac.za

Hasan, Faysal Mehedi & Lomax, Sabrina & Thomson, Peter & Islam, Md & Chlingaryan, Anna & Clark, Cameron. (2024). The impact of rainfall on beef cattle growth across diverse climate zones. animal. 101336. 10.1016/j.animal.2024.101336.

He, X., Arif, M., Zheng, J., Ni, X., Yuan, Z., Zhu, Q., Wang, J., Ding, D., & Li, C. (2023). Plant diversity patterns along an elevation gradient: the relative impact of environmental and spatial variation on plant diversity and assembly in arid and semi-arid regions. *Frontiers in Environmental Science*, *11*.

Higher Economic Intelligence (2024). *Agriculture, Forestry, and Fishing Sector, Q2 2024, Namibia.* https://hei.com.na/wp-content/uploads/2024/09/Agriculture-Forestry-and-Fishing-Sector-Q2-2024-Namibia.pdf

Hirata, M. & Kusatake, N. (2021). Relative importance of senses in forage discrimination by cattle depends on the sensory contrast between the discrimination targets: a preliminary study. *Anim Cogn* **24**, 99–106 https://doi.org/10.1007/s10071-020-01422-y

Hirata, M., Sakou, A., Terayama, Y., Furuya, M., & Nanba, T. (2008). Selection of feeding areas by cattle in a spatially heterogeneous environment: selection between two tropical grasses. *Journal of Ethology*, *26*(3), 327–338.

Homburger, H., Lüscher, A., Scherer-Lorenzen, M., & Schneider, M. (2015). Patterns of livestock activity on heterogeneous subalpine pastures reveal distinct responses to spatial autocorrelation, environment and management. *Movement Ecology*, *3*, 35.

Hovick, T. J., Duchardt, C. J., & Duquette, C. A. (2023). Rangeland biodiversity. In *Rangeland Wildlife Ecology and Conservation* (pp. 209-249). Cham: Springer International Publishing.

Jacobs, J. (1974). Quantitative measurement of food selection. *Oecologia*, *14*(4), 413–417. https://doi.org/10.1007/BF00384581

Jia, X., Huang, T., Chen, M., Han, N., Liu, Y., Chen, S., & Zhang, X. (2023). Distribution of Grazing Paths and Their Influence on Mountain Vegetation in the Traditional Grazing Area of the Tien-Shan Mountains. *Remote Sensing*, *15*(12), 3163. https://doi.org/10.3390/rs15123163

Jucker, T., Bongalov, B., Burslem, D. F. R. P., Nilus, R., Dalponte, M., Lewis, S. L., Phillips, O. L., Qie, L., & Coomes, D. A. (2018). Topography shapes the structure, composition and function of tropical forest landscapes. *Ecology Letters*, *21*(7), 989–1000.

Katjiua, M. L. J., & Ward, D. (2006). Cattle diet selection during the hot-dry season in a semi-arid region of Namibia. *African Journal of Range and Forage Science*, *23*(1), 59–67. https://doi.org/10.2989/10220110609485887

Kaufmann, J., Bork, E. W., Blenis, P. V, & Alexander, M. J. (2013). Cattle habitat selection and associated habitat characteristics under free-range grazing within heterogeneous Montane rangelands of Alberta. *Applied Animal Behaviour Science*, *146*(1), 1–10. https://doi.org/https://doi.org/10.1016/j.applanim.2013.03.014

Kent, M. (2012). *Vegetation Description and Data Analysis - a Practical Approach - Martin Kent - 2nd ed. 2012, Wiley-Blackwell*.

Lagrange, S., Beauchemin, K. A., MacAdam, J., & Villalba, J. J. (2020). Grazing diverse combinations of tanniferous and non-tanniferous legumes: Implications for beef cattle performance and environmental impact. *Science of The Total Environment, 746*, 140788. https://doi.org/10.1016/j.scitotenv.2020.140788

Lagrange, S., Beauchemin, K. A., MacAdam, J., & Villalba, J. J. (2020). Grazing diverse combinations of tanniferous and non-tanniferous legumes: Implications for beef cattle performance and environmental impact. *Science of The Total Environment, 746*, 140788. https://doi.org/10.1016/j.scitotenv.2020.140788

Lasway, J. V., Njovu, H. K., Eustace, A., Mathisen, K. M., Skarpe, C., & Peters, M. K. (2023). Species richness, vegetation structure, and floristic composition of woody plants along the elevation gradient of Mt. Meru, Tanzania. *Biotropica*, 55, 828–838. https://doi.org/10.1111/btp.13232

Leiber, F., Walkenhorst, M., & Holinger, M. (2020). The relevance of feed diversity and choice in nutrition of ruminant livestock. *Landbauforschung Volkenrode*, *70*, 35–38. https://doi.org/10.3220/LBF1592393539000

Levi, M., Lee, D. E., Bond, M. L., & Treydte, A. C. (2022). Forage selection by Masai giraffes (Giraffa camelopardalis tippelskirchi) at multiple spatial scales. *Journal of Mammalogy*, *103*(3), 737–744. https://doi.org/10.1093/jmammal/gyac007

Li, G., Shi, C., Song, Y., Chu, H., & Zhang, Z. (2021). The role transition of dietary species richness in modulating the gut microbial assembly and postweaning performance of a generalist herbivore. *mSystems, 6*(4), e00979-21. https://doi.org/10.1128/mSystems.00979-21

Liang, T., Tian, F., Linqing, Z., Jin, H., Tagesson, T., Rumpf, S., He, T., Liang, S., & Fensholt, R. (2024). Global assessment of vegetation patterns along topographic gradients. *International Journal of Digital Earth*, *17*, 2404232. https://doi.org/10.1080/17538947.2024.2404232

Liu, X., & Zhou, J. (2021). Assessment of the continuous extreme drought events in namibia during the last decade. *Water (Switzerland)*, *13*(20). https://doi.org/10.3390/w13202942

Mannheimer, C., Maggs-Kölling, G., Rügheimer, S., & Kolberg, H. (2008). *Wildflowers of the southern Namib.* 978-99916-0-878-5. Macmillan

Mannheimer, C. (2012). *Wildflowers of the Central Highlands of Namibia*. Windhoek, Macmillan Education Namibia.https://books.google.com.na/books?id=Tiw8nQEACAAJ

Manning, J. K., Cronin, G. M., González, L. A., Merchant, A. M., & Ingram, L. J. (2017). *The Nutritive Value Of Forage And Weed Species Grazed By Beef Cattle In Australia And The Effect On Livestock Selectivity*. https://api.semanticscholar.org/CorpusID:135272275

Matyukira, C., Mhangara, P., & Gidey, E. (2024). Modelling topographic influences on vegetation vigour in the Cradle Nature Reserve, Gauteng province, South Africa. *Geocarto International*, *39*, 2395313. https://doi.org/10.1080/10106049.2024.2395313

Mayer, A., Egger, C., Loyau, A., Plutzar, C., Schmeller, D. S., & Gaube, V. (2022). Mountain pastures increase the resilience of livestock farming to extreme events in the Ariège department, France. *Agronomy for Sustainable Development*, *42*(3), 49.

McAllister, T. A., Stanford, K., Chaves, A. V., Evans, P. R., Eustaquio de Souza Figueiredo, E., & Ribeiro, G. (2020). Nutrition, feeding and management of beef cattle in intensive and extensive production systems. In *Animal Agriculture: Sustainability, Challenges and Innovations* (pp. 75–98). Elsevier. https://doi.org/10.1016/B978-0-12-817052-6.00005-7

McDonald, J. H. (2014). *Handbook of Biological Statistics* (3rd ed). Sparky House Publishing. Baltimore, Maryland.

McNew, L. B., Dahlgren, D. K., & Beck, J. L. (2023). *Rangeland wildlife ecology and conservation* (p. 1023). Springer Nature.

Mendelsohn, J., Jarvis, A., Robertson, T., & Mendelsohn, M. (2022). *Atlas of Namibia-Its land, water and life*, Namibia Nature Foundation, Windhoek

Meshesha, D. T., Moahmmed, M., & Yosuf, D. (2019). Estimating carrying capacity and stocking rates of rangelands in Harshin District, Eastern Somali Region, 9Ethiopia. *Ecology and Evolution*, *9*(23), 13309–13319.

Michaud, A., Plantureux, S., Pottier, E., & Baumont, R. (2015). Links between functional composition, biomass production and forage quality in permanent grasslands over a broad gradient of conditions. *The Journal of Agricultural Science*, *153*(5), 891–906.

Ministry of Agriculture Water and Forestry. (2012). *National Rangeland Management Policy & Strategy Restoring Namibia's Rangelands June 2012 NationalRestoring Namibia' s Rangelands. June.*

Mkabile, Q. (2019). *Mapping and predicting potential distribution patterns of free-range livestock in the rural communal rangelands of Mgwalana, Eastern Cape, South Africa*.

Moeslund, J. E., Arge, L., Bøcher, P. K., Dalgaard, T., & Svenning, J.-C. (2013). Topography as a driver of local terrestrial vascular plant diversity patterns. *Nordic Journal of Botany*, *31*(2), 129–144. https://doi.org/https://doi.org/10.1111/j.1756-1051.2013.00082.x

Mu, W., Yu, F., Li, C., Yuebo, X., Tian, J., Liu, J., & Zhao, N. (2015). Effects of Rainfall Intensity and Slope Gradient on Runoff and Soil Moisture Content on Different Growing Stages of Spring Maize. *Water (Switzerland)*, *7*, 2990–3008.

Müller, M. A. N., & van Eck, J. (2007). *Grasses of Namibia*. Ministry of Agriculture, Water, and Forestry. https://books.google.com.na/books?id=jOHaAAAAMAAJ

Namibia Statistics Agency. (2024) *Digital Namibia: Namibia statistics for development*. Retrieved 28/07/2024, from https://digitalnamibia.nsa.org.na

Nippert, J. B., Ocheltree, T. W., Skibbe, A. M., Kangas, L. C., Ham, J. M., Arnold, K. B. S., & Brunsell, N. A. (2011). Linking plant growth responses across topographic gradients in tallgrass prairie. *Source: Oecologia*, *166*(4), 1131–1142.

Nketsang, T. S., Kassa, S. M., Kgosimore, M., & Tsidu, G. M. (2025). Understanding the Impacts of Rainfall Variability on Natural Forage–Livestock Dynamics in Arid and Semi-Arid Environments. *Applied Sciences*, *15*(7), 3918. https://doi.org/10.3390/app15073918

Nota, G., Svensk, M., Barberis, D., Frund, D., Pagani, G., Pittarello, M., Probo, M., Enri, S. R., Lonati, M. & Lombardi G. (2024) Foraging behaviour of Highland cattle in silvopastoral systems in the Alps. *Agroforest Syst* **98**, 491–505. https://doi.org/10.1007/s10457-023-00926-z

Nott, C., Boys, J., & Nzehengwa, J. (2019). *Reviving Namibia's Livestock Industry: Regenerative Livestock Production Trends, Key Profit Drivers, Case Studies and Recommendations* (2019 Edition).

Nyenda, T., Musungwa, T., Piyo, T., Kowe, P., Muvengwi, J., & Witkowski, E. (2023). Edaphic and topographic gradients have differential influence on woody species assemblages on ultramafic and non-ultramafic soils in an African Savanna. *Plant Soil* **493**, 249–266. https://doi.org/10.1007/s11104-023-06228-8

Oñatibia, G. R., Golluscio, R. A., Texeira, M., & Paruelo, J. M. (2020). Controls of forage selective defoliation by sheep in arid rangelands. *Ecosphere, 11*(11), e03285. https://doi.org/10.1002/ecs2.3285

Panziera, W., Pavarini, S. P., Sonne, L., Barros, C. S. L., & Driemeier, D. (2018). Poisoning of cattle by Senecio spp. in Brazil: a review. *Pesquisa Veterinária Brasileira*, *38*(08), 1459–1470.

Pauler, C. M., Isselstein, J., Suter, M., Berard, J., Braunbeck, T., & Schneider, M. K. (2020). Choosy grazers: Influence of plant traits on forage selection by three cattle breeds. *Functional Ecology*, *34*(5), 980–992. https://doi.org/https://doi.org/10.1111/1365-2435.13542

Polley, H. W., Bailey, D. W., Nowak, R. S., & Stafford-Smith, M. (2017). Ecological Consequences of Climate Change on Rangelands. In D. D. Briske (Ed.), *Rangeland Systems: Processes, Management and Challenges* (pp. 229–260). Springer International Publishing. https://doi.org/10.1007/978-3-319-46709-2_7

Pringle, H. (2021). A Preliminary Degradation Pathology of Rangeland Declines Near Opuwo in the Kunene, Namibia: The Tragedy of Disrupting Traditional Commons Management. *Sustainability in Environment*, *6*(1), p142. https://doi.org/10.22158/se.v6n1p142

Provenza, F. (2023). Nourishing Earth, Nourishing Ourselves. Part 1: Linking Plant Diversity With the Health of Livestock and Humans. *Journal of the American Holistic Veterinary Medical Association*, *71*, 10–17. https://doi.org/10.56641/HSZV1020

Pyke, G. (2010). Optimal Foraging Theory: Introduction. In *Encyclopedia of Animal Behaviour* (pp. 601–603). https://doi.org/10.1016/B978-0-08-045337-8.00210-2

Pyke, G. H. (2019). Optimal foraging theory: An introduction. In Chloe, J.C. (Eds) Encyclopedia of Animal Behaviour, (2nd ed.). vol. 2, pp. 111-117. Elsevier, Academic Press

Pyke, G. H., & Starr, C. K. (2020). Optimal Foraging Theory. In C. K. Starr (Ed.), *Encyclopedia of Social Insects* (pp. 1–9). Springer International Publishing.

Ramos, M. B., Diniz, F. C., de Almeida, H. A., de Almeida, G. R., Pinto, A. S., Meave, J. A., & Lopes, S. de F. (2020). The role of edaphic factors on plant species richness and diversity along altitudinal gradients in the Brazilian semi-arid region. *Journal of Tropical Ecology*, *36*(5), 199–212. https://doi.org/DOI: 10.1017/S0266467420000115

Raynor, E. J., Gersie, S. P., Stephenson, M. B., Clark, P. E., Spiegal, S. A., Boughton, R. K., Bailey, D. W., Cibils, A., Smith, B. W., Derner, J. D., Estell, R. E., Nielson, R. M., & Augustine, D. J. (2021). Cattle grazing distribution patterns related to topography across diverse rangeland ecosystems of North America. *Rangeland Ecology & Management, 75*, 91-103. https://doi.org/10.1016/j.rama.2020.12.002

Rhodes, E. C., Tolleson, D. R., & Angerer, J. P. (2022). Modeling Herbaceous Biomass for Grazing and Fire Risk Management. *Land*, *11*(10). https://doi.org/10.3390/land11101769

Rivero, M. J., Grau-Campanario, P., Mullan, S., Held, S. D. E., Stokes, J. E., Lee, M. R. F., & Cardenas, L. M. (2021). Factors affecting site use preference of grazing cattle studied from 2000 to 2020 through GPS tracking: A review. In *Sensors* (Vol. 21, Issue 8). MDPI AG. https://doi.org/10.3390/s21082696

Rothauge, A. (2007). *Some principles of sustainable rangeland management in Namibia*.

Slayi, M., & Jaja, I. F. (2024). Integrating Mixed Livestock Systems to Optimize Forage Utilization and Modify Woody Species Composition in Semi-Arid Communal Rangelands. *Land*, *13*(11), 1945. https://doi.org/10.3390/land13111945

Sanaei, A., Li, M., & Ali, A. (2019). Topography, grazing, and soil textures control over rangelands' vegetation quantity and quality. *Science of The Total Environment*, *697*, 134153. https://doi.org/https://doi.org/10.1016/j.scitotenv.2019.134153

Sathishkumar, S., Arandhara, S., & Baskaran, N. (2019). *Determinants of Diet Selection by Blackbuck at Point Calimere WLS, Southern India: A Regression with Empirical Variable Selection (REVS) Approach*. https://doi.org/10.13140/RG.2.2.27460.17289

Schieltz, J. M., & Rubenstein, D. I. (2016). Evidence based review: positive versus negative effects of livestock grazing on wildlife. What do we really know? *Environmental Research Letters*, *11*(11), 113003. https://doi.org/10.1088/1748-9326/11/11/113003

Schoenbaum, I., Kigel, J., Ungar, E. D., Dolev, A., & Henkin, Z. (2017). Spatial and temporal activity of cattle grazing in Mediterranean oak woodland. *Applied Animal Behaviour Science*, *187*, 45–53. https://doi.org/https://doi.org/10.1016/j.applanim.2016.11.015

Shikangalah, R. N. (2020). *Dendrochronology in Namibia: A Review*. *24*, 556136. https://doi.org/10.19080/IJESNR.2020.23.556136

Simataa, C. B., & Mapaure, I. (2024). Comparison of diurnal and seasonal patterns of feeding behaviour of cows and calves at Neudamm Farm in Namibia. *African Journal of Food, Agriculture, Nutrition and Development*, *24*(1), 25288–25305.

Simelane, P., Shapiro, J., Mahlaba, T., Mccleery, R., Macfadyen, D. N., & Monadjem, A. (2021). *The Foraging Ecology of Nguni and Brahman Cattle under Different Management Systems in High-Altitude Grasslands of South Africa*.

Singh, S. (2018). Understanding the role of slope aspect in shaping the vegetation attributes and soil properties in Montane ecosystems. *Tropical Ecology*, *59*, 417–430.

Šmilauer, P., & Lepš, J. (2014). *Multivariate Analysis of Ecological Data using Canoco 5* (Second Edition). Cambridge University Press. http://regent.prf.jcu.cz/maed2/.

Smit, M., Malan, P., Smit, N., & Deacon, F. (2024). Response of herbaceous vegetation in the southern Kalahari following a prolonged drought. *Journal of Arid Environments, 222*, 105157. https://doi.org/10.1016/j.jaridenv.2024.105157Smit, I., & Coetsee, C. (2019). *Interactions Between Fire and Herbivory: Current Understanding and Management Implications* (pp. 301–319).

Strohbach, B. (2021). Vegetation survey of the Khomas Hochland in central-western Namibia: syntaxonomical descriptions. *Bothalia, African Biodiversity & Conservation*, *51*. https://doi.org/10.38201/btha.abc.v51.i2.4

Thompson, L., Maciel, I., Rodrigues, P., Cassida, K., & Rowntree, J. (2021). Impact of Forage Diversity on Forage Productivity, Nutritive Value, Beef Cattle Performance and Enteric Methane Emissions. *Journal of Animal Science*, *99*.

Treydte, A. C., Baumgartner, S., Heitkönig, I. M. A., Grant, C. C., & Getz, W. M. (2013). Herbaceous Forage and Selection Patterns by Ungulates across Varying Herbivore Assemblages in a South African Savanna. *PLoS ONE*, *8*(12), e82831.

Tsutsumi, M., Takahashi, Y., Emoto, S., Ito, N., Otani, I., & Matsumoto, K. (2015). Component-based quantification and prediction of diet selection by cattle grazing on multi-species communities. *Grassland Science*, *62*. https://doi.org/10.1111/grs.12109

Tulu, D., Gadissa, S., Hundessa, F., & Kebede, E. (2023). Contribution of Climate-Smart Forage and Fodder Production for Sustainable Livestock Production and Environment: Lessons and Challenges from Ethiopia. *Advances in Agriculture*, *2023*, 8067776.

United States Geological Survey. (2024) *EarthExplorer*. U.S. Department of the interior. Retrieved 27/07/2024, from https://earthexplorer.usgs.gov

Utsumi, S. A., Cangiano, C. A., Galli, J. R., McEachern, M. B., Demment, M. W., & Laca, E. A. (2009). Resource heterogeneity and foraging behaviour of cattle across spatial scales. *BMC Ecology*, *9*. https://doi.org/10.1186/1472-6785-9-9

Van Oudtshoorn, F. (2012). *Guide to Grasses of Southern Africa*. Briza Publications. https://books.google.com.na/books?id=C4YopwAACAAJ

von Müller, A., Renison, D., & Cingolani, A. (2017). Cattle landscape selectivity is influenced by ecological and management factors in a heterogeneous mountain rangeland. *The Rangeland Journal*, *39*. https://doi.org/10.1071/RJ15114

Wang, L., Wang, D., He, Z., Liu, G., & Hodgkinson, K. C. (2010). Mechanisms linking plant species richness to foraging of a large herbivore. *Journal of Applied Ecology*, *47*(4), 868–875. https://doi.org/10.1111/j.1365-2664.2010.01837.x

Wani ZA, Negi VS, Bhat JA, Satish KV, Kumar A, Khan S, Dhyani R, Siddiqui S, Al-Qthanin RN and Pant S (2023) Elevation, aspect, and habitat heterogeneity determine plant diversity and compositional patterns in the Kashmir

Himalaya. *Front. For. Glob. Change* 6:1019277. doi: 10.3389/ffgc.2023.1019277

Wei, P., Pan, X., Xu, L., Hu, Q., Zhang, X., Guo, Y., Shao, C., Wang, C., Li, Q., & yin, Z. (2019). The effects of topography on above-ground biomass and soil moisture at local scale in dryland grassland ecosystem, China. *Ecological Indicators*, *105*, 107–115

Wen, Z. (2023), Impacts of grazing activities on grassland ecosystems, Geographical Research Bulletin, 2023, Volume 2, Pages 234-237, Released on J-STAGE Online ISSN 2758-1446, https://doi.org/10.50908/grb.2.0_234.

Wilson, L. (1997). Slopes. In *Geomorphology* (pp. 1002–1020). Springer Berlin Heidelberg. https://doi.org/10.1007/3-540-31060-6_336

Worku, B., Belachew, G. M., Melese, M., Tesfaye, (2023), Influence of Elevation and Anthropogenic Disturbance on Woody Species Composition, Diversity, and Stand Structure in Harego Mountain Forest, Northeastern Ethiopia, *International Journal of Forestry Research*, 8842408, 17 pages, 2023. https://doi.org/10.1155/2023/8842408

Xu, M., Zhang, Y., Zhou, Y., Wang, S., Xiao, Y., Feng, X., & Wang, L. (2024). Foraging selectivity of co-grazing cattle and sheep varies differently with plant diversity. *Journal of Environmental Management*, *370*, 122593.

Yan, F., Wu, B., & Wang, Y. (2015). Estimating spatiotemporal patterns of above-ground biomass using Landsat TM and MODIS images in the Mu Us Sandy Land, China. *Agricultural and Forest Meteorology*, *200*, 119–128.

Yao, Z., Xin, Y., Yang, L., Zhao, L., & Ali, A. (2022). Precipitation and temperature regulate species diversity, plant coverage and above-ground biomass through opposing mechanisms in large-scale grasslands. *Frontiers in Plant Science*, *13*.

Zeng, X. H., Zhang, W. J., Song, Y.-G., & Shen, H. T. (2014). Slope aspect and slope position have effects on plant diversity and spatial distribution in the hilly region of Mount Taihang, North China. *Journal of Food, Agriculture and Environment*, *12*, 391–397.

Zhang, H., Liu, N., Yang, G. W., Badgery, W. B., Guo, Y. P., & Zhang, Y. J. (2022). Diet selection of sheep shifted from quality to quantity characteristics of forages as sward availability decreased. *Animal*, *16*(6), 100546.

Zhang, X., Zhou, C., & Lu, J. (2022). Influence of topography, soil properties and plant community on the biomass of Abies georgei var. smithii seedlings in Southeast Tibet. *Journal of Mountain Science*, *19*(9), 2664–2677.

Zhang, Y., Jin, B., Zhang, X., Wei, H., Chang, Q., Huang, F., Liu, W., Lv, Y., Xu, Q., Sun, G., & Cheng, H. (2023). Grazing alters the relationships between species diversity and biomass during community succession in a semi-arid grassland. *Science of The Total Environment*, *887*, 164155.

Zheng, J., Arif, M., He, X., Ding, D., Zhang, S., Ni, X., & Li, C. (2022). Plant community assembly is jointly shaped by environmental and dispersal filtering along elevation gradients in a semi-arid area, China. *Frontiers in Plant Science*, *13*.

Zimmer, S. N., Schupp, E. W., Boettinger, J. L., Reeves, M. C., Thacker, E. T. (2021). Considering spatiotemporal forage availability in rangeland inventory and monitoring. *Rangeland Ecology & Management.* 79. 53-63.

10.1016/j.rama.2021.07.008

APPENDICES

Appendix 1: Ethical Clearance Certificate

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ETHICAL CLEARANCE CERTIFICATE

Ethical Clearance Reference Number: SOS-0196 **Date: 31 JANUARY 2024**

This Ethical Clearance Certificate is issued by the University of Namibia Ethics Committee (REC) in accordance with the University of Namibia's Research Ethics Policy and Guidelines. Ethical approval is given in respect of undertakings contained in the Research Project outlined below. This Certificate is issued on the recommendations of the ethical evaluation done by the ethics committee.

Title of Project:	DETERMINANTS OF WET SEASON PATCH AND FORAGE SELECTIVITY BY CATTLE OF FARM KIAMSAB WEST, CENTRAL NAMIBIA
Student:	SIJABULISO DUBE
Student Number:	222084011
Supervisor(s):	Prof. ISAAC MAPAURE

Centre for Research Services

Take note of the following:

1. Any significant changes in the conditions or undertakings outlined in the approved Proposal must be communicated to the ethics committee. An application to make amendments may be necessary.
2. Any breaches of ethical undertakings or practices that have an impact on ethical conduct of the research must be reported to the ethics committee.
3. The Principal Researcher must report issues of ethical compliance to the ethics committee (through the Chairperson) at the end of the Project or as may be requested by the ethics committee.
4. The ethics committee retains the right to:

i) Withdraw or amend this Ethical Clearance if any unethical practices (as outlined in the Research Ethics Policy) have been detected or suspected,

ii) Request for an ethical compliance report at any point during the course of the research.

The ethics committee wishes you the best in your research.

Dr. Zivayi Chiguvare (Chairperson Ethics Committee)

Prof. Davis Mumbengegwi (Head, Multidisciplinary Research)

Appendix 2: Research Permission Letter

CENTRE FOR RESEARCH SERVICES
Office of the Pro-Vice Chancellor: Research, Innovation & Development
University of Namibia, Private Bag 13301, Windhoek, Namibia
340 Mandume Ndemufayo Avenue, Pioneers Park, Office F223 - Fblock, Second Floor
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UNAM
UNIVERSITY OF NAMIBIA

RESEARCH PERMISSION LETTER

Date: 29/10/2024

Student Name: SIJABULISO DUBE

Student Number: 222084011

Programme: Master of Science: Biodiversity Management and Research

Approved Research Title: DETERMINANTS OF WET SEASON PATCH AND FORAGE SELECTIVITY BY CATTLE OF FARM KIAMSAB WEST, CENTRAL NAMIBIA

TO WHOM IT MAY CONCERN:

I hereby confirm that the above-mentioned student is registered at the University of Namibia for the programme indicated. The proposed study met all the requirements as stipulated in the University guidelines and has been approved by the relevant committees.

The proposal adheres to ethical principles as per attached Ethical Clearance Certificate. Permission is hereby granted to carry out the research as described in the approved proposal.

Best Regards

Dr. AEE Shikongo
Head: Postgraduate Research Support Services
Tel: +264 61 206 3129
E-mail: aeshikongo@unam.na

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Appendix 3: The GPS coordinates of all transects

Camp	Patch	Transect	Waypoint	Degrees South	Degrees East
Bopos	Slopes	1	80	-22.9778	16.28622
Bopos	Slopes	2	81	-22.9792	16.28696
Bopos	Slopes	3	82	-22.9807	16.28721
Bopos	Slopes	4	83	-22.9807	16.28274
Bopos	Slopes	5	90	-22.9743	16.28116
Bopos	Slopes	6	92	-22.9814	16.27023
Kudupos	Slopes	7	94	-22.9889	16.27381
Kudupos	Slopes	8	96	-22.9847	16.27784
Kudupos	Slopes	9	98	-22.9841	16.28654
Bopos	Slopes	10	99	-22.988	16.28143
Bopos	Slopes	11	102	-22.9844	16.28572
Bopos	Slopes	12	103	-22.9851	16.28091
Bopos	Slopes	13	105	-22.9871	16.27723
Bopos	Crests	1	75	-22.9715	16.28259
Bopos	Crests	2	76	-22.975	16.28423
Bopos	Crests	3	77	-22.975	16.28581
Bopos	Crests	4	78	-22.9767	16.28674
Bopos	Crests	5	84	-22.9695	16.27921
Bopos	Crests	6	85	-22.9719	16.28084
Bopos	Crests	7	89	-22.9732	16.2813
Bopos	Crests	8	91	-22.9764	16.26941
Bopos	Crests	9	95	-22.9869	16.27563
Kudupos	Crests	10	97	-22.992	16.28183
Kudupos	Crests	11	100	-22.9692	16.2761
Bopos	Crests	12	104	-22.9851	16.28092

Appendix 4: The list of grass species, forbs and sub-shrubs, sedges and ferns recorded in the study area during the study

Grass species	**Crests**	**Slopes**
Anthephora pubescens Nees	✓	✓
Melinis repens (Willd.) Zizka subsp. *Repens*	✓	
Sporobolus africanus (Poir.) Robyns & Tournay	✓	✓
Stipagrostis uniplumis (Licht.) De Winter	✓	✓
Tragus berteronianus Schult.	✓	
Aristida adscensionis L.	✓	✓
Aristida meridionalis Henrard		✓
Cenchrus ciliaris L.		✓
Eragrostis trichophora Coss. & Durieu	✓	✓
Eragrostis porosa Nees	✓	✓
Eragrostis nindensis Ficalho & Hiern	✓	✓
Enneapogon desvauxii P.Beauv	✓	✓
Enneapogon cenchroides (Licht. ex Roem. & Schult.) C.E.Hubb.	✓	✓
Fingerhutia africana L. Bolus.		✓
Fern and sedges		
Kyllinga alba Nees		✓
Cyperus sp Carl Linnaues		✓
Cheilanthes marlothii (Hieron.) Schelpe		✓

Forbs and sub-shrubs	**Crests**	**Slopes**
Acrotome fleckii (Gürke) Launert		✓
Amaranthus dinteri Schinz		✓
Aptosimum arenarium Engl.	✓	
Blepharis obmitrata C.B.Clarke	✓	
Cleome monophyla L.		✓
Cleome suffruticosa Schinz	✓	✓
Dactyliandra welwitschii Hook.f.		✓
Emilia marlothiana (O.Hoffm.) C.Jeffrey		✓
Euphorbia inaequilatera Sond.	✓	
Helichrysum tomentosulum (Klatt) Merxm.		✓
Heliotropium ciliatum Kaplan		✓
Hibiscus dinteri Hochr.		✓
Hibiscus calyphyllus Cav.		✓
Hibiscus elliottiae Harv.	✓	✓
Hirpicium gazanoides (Harv.) Roessler	✓	✓
Indigofera auricoma E.Mey.	✓	✓
Indigofera viciodes Jaub. & Spach	✓	✓
Monechma divaricatum (Nees) C.B.Clarke	✓	✓
*Monsonia senegalensis*Guill. & Perr.	✓	✓
Nelsia quadrangular (Engl.) Schinz		✓
Otoptera burchellii DC.	✓	✓
Phyllanthus pentandrus Schumach. & Thonn.		✓

Portulaca oleracea L.		✓
Ruellia diversifolia S.Moore	✓	
Senecio consanguineus DC.		✓
Pegolettia senegalensis (Pers.) Oliv. & Hiern	✓	✓
Forsskaolea viridis Ehrenb. ex Webb		✓
Talinum caffrum (Thunb.) Eckl. & Zeyh.	✓	✓
Tephrosia degreana E.Mey.		✓
Tribulus terrestris L.	✓	✓
Tribulus zeyheri Sond.	✓	✓