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Seasonal variation in forage availability and nutritional composition of the black rhino (diceros bicornis michaeli) diet in Mkomazi National Park, Tanzania

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SEASONAL VARIATION IN FORAGE AVAILABILITY AND NUTRITIONAL COMPOSITION OF THE BLACK RHINO (*Diceros bicornis michaeli*) DIET IN MKOMAZI NATIONAL PARK, TANZANIA

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A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science in Biodiversity and Ecosystem Management of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

A study was conducted on rhino forage availability and diet to gather vital information for the sustainable conservation of critically endangered black rhino populations. Specifically, the study was set to establish the quantity and quality of natural forages browsed by rhinos in Mkomazi National Park (MKONAPA) as affected by seasonality. This study was prompted by the observed decline in body condition during dry periods, highlighting the need for a better understanding of forage quantity and quality in the area. The current study aimed to investigate seasonal variations in the black rhino diet at MKONAPA by comparing foraging, browsing intensity, forage preference and nutritional composition of the most preferred forage between wet and dry seasons. A simple-random sampling technique was deployed to select 58 square grids in the wet and dry seasons (replication), and plots were laid for vegetation assessment and plant sample collection in the Mkomazi rhino sanctuary (MRS). Browses foraged by rhinos were compared with rhino feeding data from fourteen rhino-range areas within Africa savannah. Results showed that more than 85% of species edible in MKONAPA were similar to those in rhino range areas. The diversity of consumed browses was higher (t = 4.58, $p<0.001$) in wet season than in dry season. Forage browsing intensity by rhinos correlated positively with forage preference and was significantly high (w= 482, $p<0.001$) in dry season when browse availability was low. Forage nutrient composition was within the average level reported in browses consumed by free-ranging rhinos within Africa savannah, but the crude fat ($3.07 \pm 1.04\%$) and crude protein ($9.33 \pm 1.45\%$) were marginally low in dry season, while zinc was low in both seasons. This study established seasonal variation in dietary composition, browsing intensity and nutritional composition. This study suggests establishing a monitoring program of preferred and highly nutritional forages for rhino diet during the dry season, assessing the density of competitor browsers, supplementing rhinos with lucerne diet during prolonged dry seasons and mineral (zinc) licks to improve rhino body condition status and health in the sanctuary.

DECLARATION

I, Emanuel Stephen Sisya do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this dissertation is my original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

_____   _____

Emanuel Stephen Sisya   Date

The declaration is confirmed by:

_____   _____

Dr. Francis Moyo   Date

_____   _____

Prof. Linus K. Munishi   Date

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Senate of the Nelson Mandela African Institution of Science and Technology the dissertation entitled "*Seasonal Variation in Forage Availability and Nutritional Composition of the Black Rhino (Diceros Bicornis Michaeli) Diet in Mkomazi National Park, Tanzania*" in partial fulfillment of the requirements for the award of the Degree of Master of Science in Biodiversity and Ecosystem Management of the Nelson Mandela African Institution of Science and Technology.

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LIST OF ABBREVIATIONS AND SYMBOLS

AfRSG	African Rhino Specialist Group
AOAC	Official Methods of Analysis of the Association of Official Analytical Chemists
CITES	Convection on International Trade in Endangered Species of Wild Fauna and Flora
CP	Crude Protein
CR	Critically Endangered
DM	Dry matter
DNA	Deoxyribonucleic Acid
FPI	Forage Preference Index
GIS	Geographical Information System
GPS	Global Positioning System
IPZ	Intensive Protection Zone
IUCN	Red List of Threatened Species
MBII	Mean Browsing Intensity Index
MKONAPA	Mkomazi National Park
MNRT	Ministry of Natural Resources and Tourism
MRS	Mkomazi Rhino Sanctuary
NM-AIST	Nelson Mandela Africa Institute of Sciences and Technology
RA	Relative Abundance
RU	Relative Utilization
SD	Standard Deviation

CHAPTER ONE

INTRODUCTION

1.1   Background of the Problem

The eastern black rhinoceros (*Diceros bicornis michaeli*) is a charismatic and megaherbivore keystone species that contributes significantly to ecosystem functions, improving tourism's income and forex and supporting biological diversity in its range areas (Emslie & Brooks, 1999; Okello & Grasty, 2009; Ariya *et al.,* 2017). However, poaching (Emslie & Brooks, 1999), unpredictable climatic conditions and anthropogenic habitat loss (Ferreiraid *et al.,* 2019) are threatening black rhino population growth and persistence, particularly the remaining small populations that occur in patchy in their original habitats. The east black rhinoceros is listed as critically endangered in the International Union for Conservation of Nature (IUCN) Red List of Threatened Species in all range areas (Emslie, 2020).

Before 1960, over ten thousand black rhinos were freely roaming in protected areas of Tanzania, but by the early 1980s, poaching had pushed the species toward the brink of extinction and reduced the population to less than 100 individuals in the wild by 1992 (MNRT, 2018). In Mkomazi National Park (MKONAPA), the free-ranging eastern black rhinoceros (*Diceros bicornis michaeli*), which is the focus of this study, decreased sharply from the recorded 200 individuals in 1970 to zero (total local extinction) in 1985 due to mainly poaching and habitat degradation (MNRT, 2018). The decline in the population of free-roaming black rhinoceros in Africa over the last 30 years has prompted states and conservation organizations to prioritize the species over other large wild animal species for conservation (MNRT, 2018). To improve species protection and biological management, states and conservation organizations have implemented new in situ approaches known as sanctuaries and intensive protection zones (IPZs) (Emslie & Brooks, 1999; Emslie, 2020). Sanctuaries are relatively small, enclosed, and highly protected areas (Knight & Morkel, 1994), and as such, they can provide adequate protection to endangered species from humans and predators and increase the genetic viability of metapopulations through biological management (Brett, 1998; Emslie & Brooks, 1999).

In Tanzania, rhino management in sanctuaries was introduced in 1997 by establishing breeding programs and improving the security of the species through law enforcement (MNRT, 2018). This was important to achieve rapid recovery of the national herd while minimizing the loss of remaining genetic diversity. The management of rhinos and their habitats in sanctuaries has the potential to improve rhino breeding performance, reduce mortality rates, and expand the rhino

food resource base (MNRT, 2018). However, rhino sanctuaries face several challenges, including high population density, interspecific and intraspecific competition, diseases and lack of adequate diet, all of which contribute to poor body condition and breeding performance in rhinos (Hutchins & Kreger, 2006; Buk & Knight, 2010).

Despite the widely accepted goal of a minimum annual population growth rate of 5% among managers of black rhino populations in Tanzania and Africa (Emslie & Brooks, 1999; Buk & Knight, 2010), rhino population growth in the Mkomazi-Tsavo ecosystem is severely hampered by high population density and dietary-related challenges (Buk & Knight, 2010). This study therefore addresses dietary deficiency challenges by assessing seasonal variation in forage availability, browsing, preference and nutritional composition of the black rhino diet in an intensively managed space that does not have natural dynamics, i.e., the Mkomazi Rhino Sanctuary (MRS).

1.2   Statement of the Problem

Black rhinos, as a browser species, have two aspects in regard to foraging: they rely on the availability of diet species, but when everything is available, they prefer to select small trees, shrubs and herbs of dicotyledonous plants in various habitats (Duthé *et al.,* 2020). The selection is normally based on availability, which varies in space and time in rhino range areas (Duthé *et al.,* 2020). Given that Mkomazi is one of the range areas where black rhinos have been reintroduced and bred since 1977, there is an increase in population, which may likely have impacted the availability and preference of forage species. These changes in the rhino population are likely to cause feed resource competition that affects nutrient availability in the MRS, especially during the dry season, which may indirectly impact the body condition status and fitness of individual rhinos in the sanctuary.

1.3   Rationale of the Study

Despite the descriptions of foraging and nutrition value of the black rhino diet in various rhino range areas, no such descriptions exist for Mkomazi Rhino Sanctuary. Therefore, this study was set to determine the quantity and quality of available diet for black rhinos in the sanctuary and its variation between seasons. A detailed understanding of black rhino dietary composition, quality and seasonal variation will facilitate MRS and other rhino sanctuaries in Tanzania and beyond to develop a monitoring and management program for increasing the availability of quality forage species consumed by black rhinos to enhance the sustainability of critically endangered species in their natural habitat.

1.4   Research Objectives

1.4.1   Main Objective

To assess seasonal variations in forage availability, browsing, preference, and nutritional composition of the black rhino diet at Mkomazi Rhino Sanctuary (MRS) in Tanzania.

1.4.2   Specific Objectives

(i)   To assess the abundance, composition, and diversity of the plant species available for diet and those browsed by black rhinos in wet and dry seasons at Mkomazi Rhino Sanctuary.

(ii)   To identify browsed plant species most preferred by black rhinos in dry and wet seasons at Mkomazi Rhino Sanctuary.

(iii)   To determine the similarities and differences in plant species browsed by rhinos in Mkomazi Rhino Sanctuary and in other rhino range areas within Africa savanna?

(iv)   To determine the nutrient composition of browse species most preferred by black rhinos in Mkomazi Rhino Sanctuary and its variation between seasons.

1.5   Research Questions

(v)   What is the abundance, composition, and diversity of the plant species available for black rhino diet and those consumed by black rhinos in the dry and wet seasons at Mkomazi Rhino Sanctuary?

(vi)   Which browse plant species are most preferred by black rhinos in dry and wet seasons at Mkomazi Rhino Sanctuary?

(vii)   What are the similarities and differences in plant species browsed by rhinos in MRS and in other rhino range areas within Africa savanna?

(viii) What is the effect of seasons on the nutrient composition of browse species most preferred by black rhinos at Mkomazi Rhino Sanctuary??

1.6   Significance of the Study

This study provides baseline information on habitat potential to sustain black rhino populations in natural settings. The study presents useful information to help wildlife managers identify natural habitats with appropriate vegetation types and compositions for the reintroduction and breeding of

black rhinos within Tanzania and beyond. It also contributes to the Tanzanian government's long-term conservation and management goals for the black rhino population (MNRT, 2018).

1.7   Delineation of the Study

This present study focuses on dietary deficiency challenges by assessing seasonal variation in forage availability, browsing, preference and nutritional composition of the black rhino diet in an intensively managed space that does not have natural dynamics, i.e., the Mkomazi Rhino Sanctuary (MRS). Furthermore, it extended into assessing assess the abundance, composition, and diversity of the plant species available for diet and those browsed by black rhinos in wet and dry seasons at MRS. Also aimed at identifying browsed plant species most preferred by black rhinos in dry and wet seasons as well as determining the nutrient composition of browse species most preferred by black rhinos in MRS and its variation between seasons.

This study used indirect observation techniques to identify plant species browsed by rhinos in wet and dry seasons at MRS; future studies should focus on faecal analysis to ascertain the list of forage species consumed by black rhinos. This study considered loss of rhino body condition to be caused by inadequate food resources in the sanctuary; future research should consider studying this condition by exploring more parameters that cause rhinos to lose body condition status, such as stress, diseases, lactation, territorial defense, and others. Also, the methodology used in this study considered random selection of sampling plots in different grids during wet and dry seasons due to homogeneity in the plant community in MRS; future studies should consider selecting the same sampling grids in wet and dry seasons to minimize sampling biases, especially when conducting plant nutritional studies, which are more likely to be affected by soil type, terrain, moisture availability and other factors that limit nutrient uptake from the soil. Additionally, future studies should address the magnitude of factors affecting the availability of forage species in the habitat, such as presence of unpalatable invasive species, presence of anti-nutritional factors such as tannins, phenols and alkaloids in the available rhino diet in a confined environment like MRS, where animals are not allowed to move outside to find an additional diet. Moreover, this study considered only a few nutritional parameters essential to rhino health; therefore, future research should focus on an array of nutritional parameters contributing to enhance rhino health and breeding performance, such as metabolizable energy.

CHAPTER TWO

LITERATURE REVIEW

2.1 Existing Rhino Species in the World

Rhinoceros has five living species worldwide (Conrad, 2012; Cheung *et al.,* 2018); three species, namely, Sumatran (*Dicerorhinus sumatrensis*), Javan (*Rhinoceros sondaicus*) and Indian (*Rhinoceros unicornis*) rhinos, occur in Asia, while two species, namely, black (*Diceros bicornis*) and white (*Ceratotherium simum*) rhinos, occur in Africa (Emslie & Brooks, 1999; Emslie, 2020). The white and black African rhino species have several recognized subspecies. The black rhinos have four subspecies, but only three exist, namely, the eastern black rhinos (*Diceros bicornis michaeli*), southwestern (*Diceros bicornis bicornis)* and south-central (*Diceros bicornis minor*). A fourth subspecies, *Diceros bicornis longipes,* which ranges through the savanna zones of central-west Africa, is currently considered extinct in its last known habitats (Emslie & Brooks, 1999). White rhinos exist in two subspecies, the Southern white rhinoceros (*Ceratotherium simum simum*) and Northern white rhinoceros (*Ceratotherium simum cottoni*) (Conrad, 2012). Southern white rhinoceros is the most abundant subspecies of rhino in the world, and South Africa is the stronghold for this subspecies, accounting for more than 93.0% of the total population (Emslie, 2020). Northern white rhinos occur at such a low number that they teeter on the edge of extinction (Emslie & Brooks, 1999). Tanzania has only black rhinos with subspecies, the eastern (*D. b. michaeli*) and the south-central (*D. b. minor*). Moreover, there are major differences between the habitat and climates in the core areas of the rhino subspecies' distributions, and it is likely that each subspecies has specific genetic or behavioral adaptations to its environment (Emslie & Brooks, 1999; Emslie, 2020).

2.2 Black Rhino Classification and Range Distribution in African Savannah

Black rhinoceros belongs to the phylum *Chordata*, class *Mammalia*, order *Perissodactyla* and family *Rhinocerotidae* (Emslie, 2020). The three remaining recognized subspecies of black rhino (hereafter black rhino) occupy different areas of Africa. The eastern black rhinoceros, the focus of this study, had a historical distribution from southern Sudan, Uganda, Ethiopia, and Somalia through Kenya into north-central Tanzania. Today, its range is limited to Kenya and Tanzania (Emslie & Brooks, 1999). The current stronghold is found in Kenya, and the smaller but growing population is found in northern Tanzania in MKONAPA, Serengeti National park, Ngorongoro Conservation Area Authority, Ikorongo-Grumeti, and Maswa Game reserves. The south-central rhino is believed to have occurred from southern Tanzania through Zambia, Zimbabwe, and Mozambique to large parts of South Africa. Today, its stronghold is South Africa and, to a lesser

extent, Zimbabwe, with smaller numbers remaining in Southern Tanzania at Nyerere National Park and Selous Game Reserve (Emslie & Brooks, 1999; MNRT, 2018). The southwestern rhino was originally distributed in north western Namibia, southern Angola, western Botswana, and southwestern South Africa. A significant population has remained in the desert and arid savanna areas of Namibia, while a small population has been observed in Angola and South Africa (Emslie & Brooks, 1999).

2.3   Habitat and Ecology

Black rhino occurs in a wide variety of habitats from desert areas to savanna and wetter wooded areas. The highest densities of rhinos are found in savannahs on nutrient-rich soils and in succulent Valley Bushveld areas. Black rhinos are browsers and favor small acacia and other palatable woody species, such as Grewia and Euphorbiaceae, as well as palatable herbs and succulent plants (Emslie, 2020). Apart from plant species composition and size structure, black rhino habitat carrying capacity is related to several factors, including rainfall, soil nutrient status, fire histories, levels of grass interference and extent of densities of other large browsers that bring resource competition in the habitat. To increase metapopulation growth rates and prevent potential habitat damage, black rhinos should be managed at densities below their long-term ecological carrying capacity for their sustainable growth (Mukinya, 1977; Hall-Martin *et al.,* 1982; Kotze & Zacharias, 1993; Emslie & Brooks, 1999; Emslie, 2020). Furthermore, to avoid the problem of overstocking, rhinos from well-established populations that are approaching 75% of the established ecological carrying capacity should be translocated to suitable areas within their historical range to establish a new metapopulation (Emslie & Brooks, 1999).

2.4   Current Conservation Status within Red List of Threatened Species

Black rhinoceros has been mentioned as a critically endangered (CR) species under criteria A2abd+4abd in the IUCN Red List of Threatened Species (Emslie, 2020). The IUCN Red List Categories and Criteria are intended to be an easily and widely understood system for classifying species at high risk of global extinction. Additionally, black rhinoceros was listed in Appendix 1 of CITES (the Convection on International Trade in Endangered Species of Wild Fauna and Flora) in 1977. Appendix 1 of CITES lists species that are the most endangered among CITES-listed animals and plants. These are species threatened with extinction, and CITES prohibits international trade in specimens of these species except when the purpose of the import is not commercial, for instance, for scientific research. In these exceptional cases, trade may take place provided it is authorized by the granting of both an import permit and an export permit (or re-export certificate).

2.5   Biology, Reproduction, and Social Behavior

Black rhinos are essentially solitary and are known to be aggressive. Breeding takes place throughout the year, although peaks in breeding activity occur at varying times in different range countries. Reproductive maturity is reached at four to six years in females and seven to nine years in males. The gestation period is between 15 and 17 months, with an average interval of two and a half to three and a half years between calves under the most favorable conditions. Characteristic courtship behaviors are displayed by both sexes; females usually spray urine, scape dung, and cock the tail, while males spray, make flehmen respond to transfer pheromones to the vomeronasal on the roof on mouth, and follow estrus females for long distances.

2.6   Economic, Ecological and Tourism Potential

Black rhinos in eastern and southern Africa are important and valuable animals for tourist viewing activities (Ariya *et al.,* 2017; MNRT, 2018; Muntifering *et al.,* 2021). Black rhinos, being one of the 'big five' game species, can provide as much viewing satisfaction to visitors and constitute the core of the tourism industry in Eastern Africa (Ariya *et al.,* 2017; MNRT, 2018). Black rhinos further capture world attention apart from generating significant revenue from wildlife-based tourism (Ariya *et al.,* 2017; Muntifering *et al.,* 2021). For example, Lake Nakuru National Park revenue has increased tremendously since 1987 when rhinos were introduced from Solio ranch (Ariya *et al.,* 2017). Furthermore, black rhinos, similar to other charismatic megaherbivores, require large areas to support viable populations. They therefore not only act as flagship species but also act as umbrella species for the ecosystems they inhabit because their conservation requirements, by default, encompass those of other smaller species (Okello & Grasty, 2009). By successfully conserving rhinos within an area, other species in the area also benefit, thus contributing towards the wider National biodiversity goals (MNRT, 2018). It is therefore important to invest adequately in the conservation of black rhinos and cherish these magnificent animals for posterity.

2.7   Conservation Challenges of Black Rhino

Black rhinos in Africa and globally face a variety of threats, the main being poaching (Emslie & Brooks, 1999). Black rhinos are illegally killed for their horns to supply illegal trade in consumer countries in the Middle and Far East (Emslie & Brooks, 1999; MNRT, 2018; Emslie, 2020). Most of the poached rhinoceros horn ends up in Yemen for ornamental use to be made into dagger handles (Emslie & Brooks, 1999; Amin *et al.,* 2006) and in China for medicinal use (Emslie, 2020). Some populations of the eastern black rhinoceros in enclosed areas, especially sanctuaries, appear

to face several challenges, including intraspecific and interspecific competition from other browsers, diseases, lack of adequate diet, and overstocking, all of which contribute to clear signs of density-dependent reductions in reproductive performance in black rhinos (Emslie & Brooks, 1999; Amin *et al.,* 2006; Buk & Knight, 2010).

Furthermore, competition from other browsers, such as African elephants (*Loxodonta africana*) and Kudus (*Tragelaphus strepsiceros*), appears to negatively affect rhinoceros habitat carrying capacity (Emslie & Brooks, 1999; Amin *et al.,* 2006). Environmental factors such as drought have been reported to affect lactating mothers and newly born calves due to reduction in availability of nutritious food (Hillman-Smith & Groves, 1994; Amin *et al.,* 2006). Malnutrition makes rhinos more vulnerable to parasites and diseases. Predation from spotted hyenas (*Crocuta crocuta*), leopards (*Panthera pardus*) and lions (*Panthera leo*) is also a challenge to rhino survival in both wild and semiwild environments because they typically target sick, juvenile and young rhinos, although the presence of other prey in ample numbers, such as wildebeests, buffalo, warthogs, impala and other small antelopes, may have reduced their vulnerability (Mills *et al.,* 2006). Hyena and leopard predation have been reported in Ngorongoro, Serengeti, and MKONAPA (Amin *et al.,* 2006; Mills *et al.,* 2006).

2.8   Conservation Strategies for Black Rhinos

One of the major conservation measures taken has been to include the Eastern black rhinoceros on CITES Appendix 1 (Critically Endangered) since 1977 (Emslie & Brooks, 1999), enhanced law enforcement through effective field surveillance (Amin *et al.,* 2006), and keeping the remaining rhinos in fenced sanctuaries, conservancies, rhino conservation areas and Intensive Protection Zones (IPZ) where law enforcement effort can be concentrated at effective levels (Emslie & Brooks, 1999). Additionally, all international trading in Black Rhinos and the items produced from the species have been banned. Furthermore, communities have been integrated into rhino conservation to enhance conservation efforts and minimize poaching threats in rhino range areas in Botswana, Kenya, Namibia, Nepal Tanzania and South Africa (Emslie & Brooks, 1999; Young *et al.,* 2007; Esmond & Martin, 2010; Sebele, 2010; Ariya *et al.,* 2017; Muntifering *et al.,* 2020). Moreover, several initiatives and international organizations that foster rhino conservation have been established and have collaborated with rhino range states in combatting rhino poaching. These include the Species Survival Commission of IUCN and the African Rhino Specialist Group (AfRSG), both works towards promoting the recovery of the African rhino population to a viable level and their long-term conservation (Emslie & Brooks, 1999). In the 1990s, a number of

consumer states introduced domestic anti-trade measures and legislation to combat illegal trade to complement CITES international trade restrictions (Emslie, 2020).

In addition to international efforts, the National Conservation and Management Plan for Black rhinos for the period of five years (2018-23) was developed in Tanzania and implemented (MNRT, 2018). The plan focuses on the management and conservation of eastern black rhinoceros strictly in protected areas in intensive protection zones and sanctuaries. The plan further emphasizes improved biological management, monitoring and rhino health status for rapid metapopulation growth aimed at attaining at least a 5% per annum growth rate to achieve at least 205 black rhinos by 2023 (MNRT, 2018). Additionally, protection of rhino populations and their habitats to reduce illegal killing of rhinos to less than 1% per annum through effective law enforcement measures has been the key priority of the plan (MNRT, 2018). Significant efforts to reduce rhino poaching through effective protection and law enforcement coupled with a strong base of investigation and intelligence networks have been implemented. Currently, rhino poaching has been reduced to less than one percent in Tanzania, and the national population estimates between 2020 and 2021 have shown an annual increase of over 4%.

2.9 Foraging Behavior of Black Rhinos

Rhinos are usually solitary and live in a home range with abundant food and water (Mukinya, 1977; Tatman *et al.,* 2000). They are less active during the day and become active in the mornings and evenings when they regularly feed and drink (Mukinya, 1977). Black rhinos are browsers with comparatively narrow mouths and prehensile lips, enabling them to feed on woody vegetation (Oloo *et al.,* 1994) and occasionally graze on grass (Mabinya *et al.,* 2002). Because of their conspicuous mouthparts, they are often referred to as hook-lipped rhinos (Emslie & Brooks, 1999). Black rhino feeding is noticeably distinct, as it clips off vegetation to leave a scissor-like cut stump (Kotze & Zacharias, 1993; Oloo *et al.,* 1994).

2.10 Rhino Body Condition Score

A standardized body condition scoring system for black rhinoceros was established to minimize assessor bias and provide a standardized, reliable and repeatable body condition scoring system for black rhinos (Reuter & Adcock, 1998). According to Reuter and Adcock (1998), the amount of subcutaneous fat in the body of black rhino and the degree of muscling are evaluated by body condition scoring. This reflects variations in body weight and provides an estimation of the rhino fitness level and nutritional status. In black rhinos, loss of body condition is often an indication of a lack of adequate diet due to drought conditions on the environment, disease and frost. The body regions observed

when assessing black rhino body condition include the neck, shoulder (scapular), ribs (costal region), spine (vertebral region), rump (gluteal region), abdomen and tail base (caudal region). The description of the appearance of each of the assessment sites and score at different body conditions in black rhinos is shown in Table 1 (Reuter & Adcock, 1998).

Apart from this inexpensive and rapid/visual body condition score, there are also quantitative methods for assessing the body condition of animals, which include body measurements of weight and lengths over time. Other methods are biochemical analysis, e.g., serum metabolites or hormone levels (Trivedi *et al.,* 2021), and ultrasonography. The limitations of modern methods, such as biochemical analysis methods, are that they are time consuming and expensive, and ultrasonography is not effective at imaging body parts that have gas in them or are hidden by bone. In conclusion, the standardized body condition scoring system for black rhinos is of vital importance in enabling wildlife managers to optimize the speed of assessing the animal health status as well as detecting several problems facing the animal for effective monitoring (Reuter & Adcock, 1998).

Table 1: **Standard body condition scoring system for black rhinos describing the appearance of each of the assessment sites at different body conditions in black rhino**

CONDITION Assessment site	Numerical scale	5	4	3	2	1
	Descriptive scale	Excellent (heavy)	Good (ideal)	Fair (average)	Poor (thin)	Very poor (emaciated)
A Neck	General appearance	thick, well-muscled, rounded	well-muscled, rounded	Rounded	flat, narrow neck; nuchal ligament visible	narrow, angular (bony) neck; nuchal ligament prominent
	Prescapular groove			slightly visible	obvious	deep groove, very obvious
B Shoulder	General appearance	well-muscled, rounded	rounded	Flat	flat, slightly angular (bony)	angular, bony
C Ribs	Scapula	covered,	covered,	spine visible	obvious	very obvious
		well covered (skin folds)	covered (skin folds)	Visible	obvious	very obvious
D Spine	General appearance	rounded	slightly angular	back groove back visible	groove deep obvious	back groove
	Spinous processes	covered	slightly visible	Visible	prominent	very prominent
E Rump	General appearance	well rounded	flattened	slightly concave	concave obvious depression	
	Bony protuberances	covered	slightly visible	visible	prominent	very prominent
F Abdomen	General appearance	distended, taught	filled	slightly tucked in	tucked in	tucked in
	Flank-fold	none	sometimes slightly visible	slightly visible	visible	obvious
G Tail base		rounded (bulging)	rounded	narrow	slightly bony	very thin and bony

Reuter and Adcock (1998)

2.11 Plant Species Foraged by Black Rhino and their Preference

Black rhinos are browsers and prefer feeding on forages located between 0.5 m and 1.20 m above ground. Forage species above 2 m in height have been unavailable to black rhinos unless they bring down tall plant branches to less than 2 m levels (Mukinya, 1977). In addition, depending on the plant's hardiness, black rhinos eat shrubs, herbs, forbs, succulents, and significant amounts of leaves, twigs, and branches of dicotyledon plants depending on seasons (Adcock, 2017). According to Mukinya (1977), black rhinos prefer to eat various nutritious trees (*Commiphora africana and Balanites aegyptiaca*), shrubs (*Acacia drepanolobium, Acacia brevispica, Grewia similis and Maerua edulis*), and herbs (*Croton dichogamus, Indigofera schimperi,* and *Solanum incanum*) of dicotyledon plant species. Other species consumed by rhinos are shrubs (*Acacia sieberiana, Abutilon grandiflorum and Ziziphus abyssinica*) and herbs (*Achyranthes aspera, Hibiscus* species and *Indigofera volkensii*) (Anderson *et al.,* 2020). Diet selection by black rhinos is influenced by forage availability and forage quality; therefore, black rhinos broaden their dietary requirement options to ensure nutrient availability and lower the intake of plants that secrete harmful chemicals for defense (Muya & Oguge, 2000; Buk & Knight, 2010).

2.12 Seasonal Variation in Forage Availability in Black Rhino Habitat

Seasonal variations, which result in lower precipitation levels during the dry season, contribute to fluctuations in forage availability (Winkel, 2004). In a variety of habitats, the overall diversity of food plants used by black rhinos is greater during the wet season than in the dry season (Hall-Martin *et al.,* 1982; Mukinya, 1977). Dry seasons are a critical time for large herbivores because both the quantity and nutritional composition of available food decrease dramatically; rhinos usually adapt their foraging strategies by broadening their diet selection to include less nutritious vegetation components to compensate for the reduced forage and nutritional value (Ferreiraid *et al.,* 2019). Black rhinos consume varieties of preferred plant species, and their diet proportions vary depending on habitat and season (Mukinya, 1977; Oloo *et al.,* 1994). The most consumed families during dry seasons are Euphorbiaceae and Capparaceae because of their succulent nature, while during the wet seasons, Fabaceae, Malvaceae, Solanaceae, and Zygophyllaceae are mostly consumed (Oloo *et al.,* 1994; Mukinya, 1977; Ganqa *et al.,* 2005; Buk & Knight, 2010; Anderson *et al.,* 2020).

2.13 Nutritional Composition of the Diet Consumed by Black Rhinos

Good quality forages should provide primary nutrients for all herbivores, with concentrate feeds used to balance energy, protein, minerals, or vitamins needed. Nutritional stress, which is the

disparity between what is consumed and what nutrients are required for animal physiological activities, is suspected to be a primary cause of biochemical and pathological disorders, stillbirths, and death in various captive animals (Ghebremeskel *et al.,* 1991; Valley *et al.,* 2015). Black rhinos are hind gut fermenters and prefer plant species with high plant fibre content ranging between 17-51% dry matter (DM) and avoid plant species with high volatile chemical compound content, such as phenol, alkaloid, and ether extract (Muya & Oguge, 2000; Buk & Knight, 2010; Valley *et al.,* 2015; Anderson *et al.,* 2018). Muya and Oguge (2000) also suggested that suitable areas for establishing black rhino sanctuaries should have diverse forages with low phenol and alkaloid contents. Additionally, the nutrient composition of plant species in habitats is affected by soil type, terrain, moisture availability and other factors that limit nutrient uptake from the soil (Valley *et al.,* 2015). Most browse consumed by black rhinos in Africa savannah is composed of crude protein (4-18% DM), lipids (1.2-7.1% DM), nitrogen-free extract (33.6-63.9% DM), and ash (3-12% DM) (Ghebremeskel *et al.,* 1991; Valley *et al.,* 2015). An average crude protein level of 8.5% has been reported for browse species sampled during the dry season, whereas an average of 6.2% DM has been reported for browse sampled at the end of the rainy season (Ghebremeskel *et al.,* 1991; Valley *et al.,* 2015). Carbohydrates are required to provide the body of an animal with fuel and energy that is required for daily activities and optimum function of the brain, heart, nervous, digestive and immune system, while carbohydrate deficiency causes depletion of body tissue (Aletan & Kwazo, 2019). Dietary energy is available from the fermentation of structural CHO, including hemicellulose and un lignified cellulose, throughout the cecum and colon, which comprise 73% of gut capacity. The digestive energy required for mature horses and black rhinos is 2.45 - 2.90 Mcal/kg, while for pregnant and lactating females, it is 2.25 - 2.60 Mcal/kg, although its availability in forages consumed by rhinos varies due to the limited availability of food resources at certain times of the year (Aletan & Kwazo, 2019).

Furthermore, macro-elements such as calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), sodium (Na) and trace elements such as copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se) and zinc (Zn) have been identified as necessary for rhino health in varying proportions depending on physiological requirements (Clauss *et al.*, 2007). The average rhino browse mineral concentrations reported for macro-elements include Ca, 0.7 - 4.9%; P, 0.04 - 0.26%; Mg, 0.3 – 0.5%; K, 0.2 – 0.6% and a Ca:P ratio of 2:1 (Valley *et al.,* 2015; Ghebremeskel *et al.,* 1991). The reported concentrations of microelement nutrition include Cu (4-8 Mg/g), Fe (25-125 Mg/g), Mn (5-20 Mg/g), and Zn (30-50 Mg/g) (Ghebremeskel *et al.,* 1991; Maskall & Thornton, 1991; Valley *et al.,* 2015). These minerals are always limited resources for captive megaherbivores such as black rhinos, so their status in the utilized forage plants must be

established to plan for their active supplementation if they are found to be insufficient in the sanctuary (Clauss *et al.,* 2007).

2.14 Factors Affecting the Availability and Distribution of Foraged Plant Species in an Area

Droughts, fire, diseases, invasion of unpalatable plants, and competition from other browsers have all been reported as factors causing rhino forage to decline in their natural setting (Gyöngyi & Elmeros, 2017). Adcock (2017) argues that high animal density, intra-competition within browsing species and inter-competition and impacts of other browsing game species can cause serious damage to the vegetation, contribute to depletion of food resources for rhinos and affect the agreed black rhino carrying capacity of 0.45 rhinos per square kilometer within sanctuaries in East Africa (Okita-Ouma *et al.,* 2021). Habitat factors such as presence of steep slopes from 45 degrees and above are not accessible to black rhinos and may cause injuries (Ganqa *et al.,* 2005). Additionally, the absence of paths to access areas with browse vegetation has been reported to affect the availability of woody browse by black rhinos in the Western Itala Game Reserve (Ganqa *et al.,* 2005). The presence of antinutritional factors such as tannins (Clauss, 2003) and high levels of phenols (from 7.65 mg/g and above) and alkaloids (5.29 mg/g and above) decreases the availability of forage species since rhinos tend to avoid plant species with high contents of such compounds in the habitat (Muya & Oguge, 2000). Furthermore, black rhinos are affected by the temporal spread of an exotic invasive species that has colonized the habitat in terms of structural and species composition and suppressed the growth of natural vegetation. Additionally, the height of available forage is also among the factors affecting the availability of forage species by rhinos since rhino forage plant species occur at heights below 2 m (Kotze & Zacharias, 1993; Muya & Oguge, 2000). Therefore, most woody plants above 2 m are not accessible to rhinos and hence cannot provide a diet other than shade to rhinos. Fire is a powerful management tool that improves foraging opportunities for many African savannah herbivores, but frequent fires have been reported to have negative effects on the abundance of plant species preferred by rhinos in the habitat (Anderson *et al.,* 2020). Henceforth, frequent fire should be avoided in rhino range areas for proper management of this critically endangered species.

2.15 Forage Assessment Methodology

The diet of black rhinos has been studied using traditional to modern methods as technology has emerged. Previous studies have largely employed direct observation (backtracking) and indirect observation techniques (Oloo *et al.,* 1994; Mukinya, 1977; Muya & Oguge, 2000; Ganqa *et al.,* 2005), while modern studies have deployed DNA analysis of fecal matter (Kartzinel *et al.,* 2015;

Anderson *et al.,* 2020). The reported shortcoming in the backtracking method is a failure to identify grass consumption and underestimation of herbs, whereas for fecal analysis, some species might not be identified to the species level (Lieverloo *et al.,* 2009). Parker and Bernard (2006) suggested that fecal analysis, backtracking and indirect observations are proper methods to assess the diet of megaherbivores that are most selective, such as black rhinos and giraffes. Although fecal analysis integrates information over time and is a more conservative and potentially accurate method for diet assessment studies, it is concluded that if traditional methods are to be used, they should be integrated with other techniques at a broad scale to ascertain the results obtained from such studies.

2.16   Management of Rhinos by using a Geographical Information System (GIS)

A geographic information system (GIS) is a basic mapping tool that offers powerful analytical and predictive capabilities to help wildlife managers make decisions on wildlife conservation (Venkatachalam, 2006). It has been used to improve rhino protection and monitoring for management purposes by generating a large amount of data by using instruments including drones, satellite imagery, trapping cameras and others (Tatman *et al.,* 2000; Venkatachalam, 2006). Furthermore, GIS makes it simple to generate prediction models of rhino distribution and density within a conservation area, establishment of black rhino activity pattern, home range and habitat usage, which in turn can be useful for security and monitoring purposes (Rookmaaker, 2004).

CHAPTER THREE

MATERIALS AND METHODS

3.1   Description of the Study Area

This study was conducted at MRS located in the central region of MKONAPA between latitudes 4°02' – 4°07' south and longitudes 38°05' – 38°11' north (Fig. 1). The MKONAPA was established in 2008 following the upgrade of the former Mkomazi-Umba game reserve with an area of approximately 3245 km^2. The MKONAPA is home to a variety of species with conservation concerns according to the IUCN red list and CITES Appendices. The park harbors endangered species, black rhinos (*Diceros bicornis*) and wild dogs (*Lycaon pictus*), and rare species, Gerenuk (*Litocranius walleri*), Oryx (*Oryx beisa*), and Cheetah (*Acinonyx jubatus*), due to its diverse habitat mosaic. The park is home to over 450 bird species, including migratory birds, making the park one of the best places for bird watching in Tanzania. The MRS was established in 1997 purposely for breeding black rhinos and later restocking areas that previously had black rhinos within Tanzania. The sanctuary covers an area of 45 km^2 (1.4% of the MKONAPA). Out of 45 km^2, only 38 km^2 is effectively used by rhinos inside the sanctuary. The remaining 7 km^2 is occupied by Hafino hill, which is not accessible to rhinos. The sanctuary lies in a semiarid climatic condition in the southern portion of the Somali Maasai Regional Centre of Endemism (Mseja *et al.,* 2020). The area receives a binomial rainfall pattern with short rains from late November to January and long rains from March to May (Mseja *et al.,* 2020). The average annual rainfall in the MRS is between 300 and 900 mm, while the average minimum and maximum temperatures range from 9.4 to 17.5°C and 29 to 37.8°C, respectively (Mseja *et al.,* 2020). The sanctuary is an ideal habitat for black rhinos and contains a diversity of woody and herbaceous browse for the rhino diet. The current average population density is 0.55 rhinos per km^2 which is slightly higher when compared with other rhino range areas in Africa savannah (Okita-Ouma *et al.,* 2021). The percentage density to maximum stocking density estimate (ecological carrying capacity) was 116.7%. Apart from the population of black rhinos, the sanctuary is also home to a variety of other herbivores, such as giraffes (*Giraffa camelopardalis*), impalas (*Aepyceros melampus*), common elands (*Taurotragus oryx*), warthogs (*Phacochoerus africanus*), and small antelopes (MNRT, 2018).
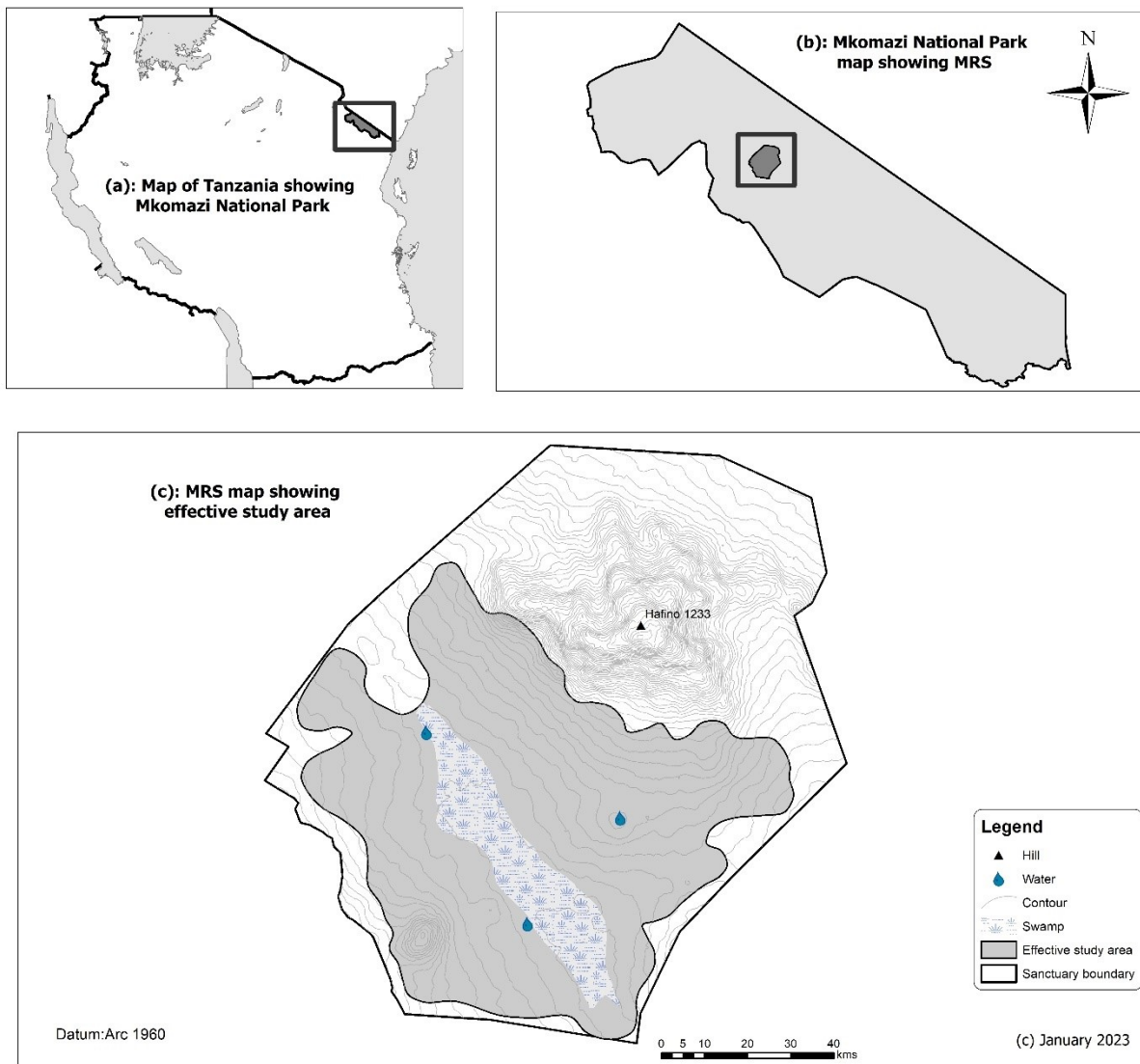
Figure 1:   **Map of Tanzania (top left inset) (a), showing the location of the study area: Mkomazi Rhino Sanctuary location in MKONAPA (top right inset) (b) and the effective study area location (bottom inset (c)**

3.2   Study Design and Sampling Strategy

This section describes the procedural establishment of the sampling area, sampling design and strategy for the study.

3.2.1   Establishment of Sampling Area

The MRS covers a representative vegetation structure of the park and is the most favourable site that offers good habitat for rhinos in the park following the assessment performed by Knight and Morkel (1994). The sampling area was determined using spatial data (global positioning system coordinates) obtained from MRS black rhino monitoring system showing locations of individuals or groups of rhinos feeding within the sanctuary for the period of eight years (2014 – 21). The spatial data were analyzed using ArcMap software version 10.5 (ESRI, 2017). First, the data sets

were characterized to obtain data for the dry season in October and November when rhinos experience poor body condition and for the wet seasons in April and May when rhinos are healthy. Then, the default settings of the kernel density tool in ArcMap (Deboer, 2015) were used to create heatmap layers that show areas potentially used by black rhinos during dry and wet seasons (sampling area), which covers 38 km^2 (Fig. 1c). After establishing the sampling area in ArcMap software, a field reconnaissance survey was conducted to familiarize the terrain and dominant vegetation types of the study area. The information collected from the reconnaissance survey and GPS coordinate points from the map was used to establish sampling points/grids for field data collection.

3.2.2 Sampling Design

The entire rhino use area (38 km^2) was divided into square grids of 150 m x 150 m. A simple random sampling design was used in this study. A total of 58 square grids out of 780 square grids were randomly selected in the dry season through a randomization process in hawths analysis tools for ArcGIS 10.5 software, and the same exercise was repeated during the wet season whereby another 58 square grids were randomly selected for field data collection. A total of 116 square grids, which is equivalent to 15% of the rhino use area, were used in this study (Fig. 2). In each selected square grid, three sampling plots of 50 x 50 m, 20 x 20 m and 1x1 m were nested and laid diagonally on the top right corner across the square grid for tree, shrub, and forb identification, respectively, during the dry and wet seasons.
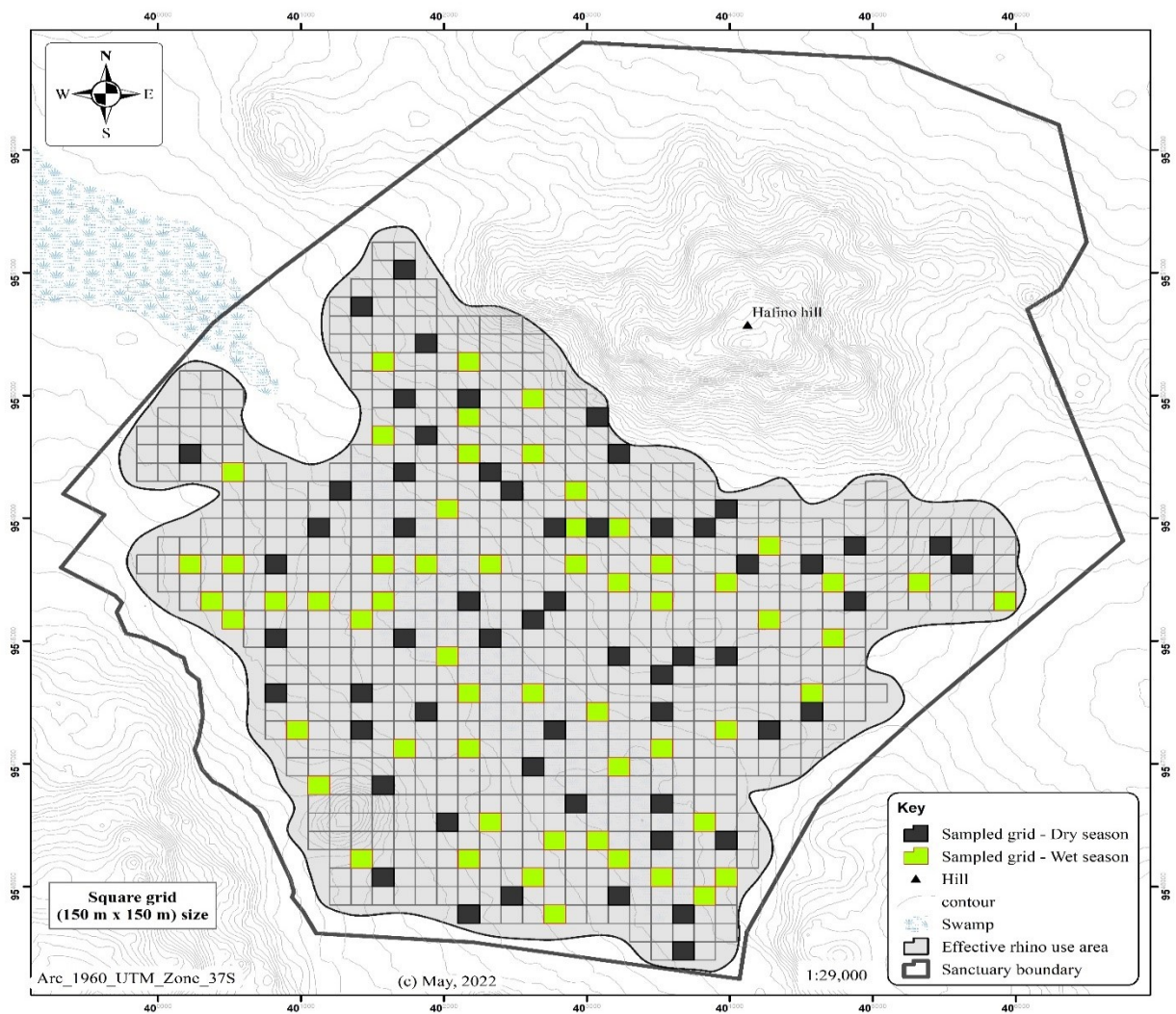
Figure 2: A map showing sampled grids during both wet and dry seasons in Mkomazi Rhino Sanctuary

3.3 Data Collection

The study used a combination of approaches to collect data required to respond to each specific objective. Ecological surveys through field observation and laboratory analysis were conducted to collect the types of required data. Data collection for the dry season was conducted from October to November 2021 and for the wet season from April to May 2022. A global positioning system (GPS) receiver was used to locate each sampling plot on the survey grids.

3.3.1 Assessment of the Abundance, Composition, and Diversity of Plant Species at Mkomazi Rhino Sanctuary

The field observation method was used to study the plant species foraged by black rhinos (Muya & Oguge, 2000; Goza *et al.,* 2019). In each sampling plot, the number of plant species (woody and herbs) observed, including those foraged by black rhinos, was recorded during the dry and wet seasons. All woody plants and herbs were identified on-site by the botanist to the species level and

were categorized into tree, shrub, and herb life forms. In this study, a tree is a woody, perennial plant that has one central stem from which branches grow to form a crown, and a shrub is a woody, perennial plant that has several stems usually produced from near the soil line of the plant. Additionally, herbs are non woody plants that have green and tender stems with few branches. The unidentified plants in the field were collected in the press and later identified at the National herbarium in Arusha. Data obtained were used to compute the diversity, composition, and abundance of the total plant species and available forage species for the black rhino diet observed in the habitat during wet and dry seasons.

3.3.2 Identification of Browsed Plant Species Preferred by Black Rhinos at Mkomazi Rhino Sanctuary

A preferred food plant was defined as a plant species that was consumed proportionately more frequently by rhinos than its abundance in the immediate environment (Petrides, 1975). The value of preference was used to determine and distinguish between preferred woody and herb species from those not preferred in relation to rhino browsing. The indirect field observation technique of observing browsed forages (Hall-Martin *et al.,* 1982; Oloo *et al.,* 1994) was used to collect data on plant species browsed by black rhinos. The indirect field observation method was deployed due to the presence of thick vegetation cover in some areas limiting direct observation of browsing rhinos (Oloo *et al.,* 1994). Freshly and old browsed trees, shrubs, and herbs were surveyed in selected sampling plots and identified based on the browse characteristics of scissor-like oblique clips on the cut surface of shoots and twigs by black rhinos (Kotze & Zacharias, 1993). Additionally, the rhino bite was identified by the characteristic "pruning" of vegetation, where the twig is cut off by the proximal molars, leaving a distinctive diagonal cut (Morgan *et al.,* 2009; Helary *et al.,* 2012) that was easily detectable and distinguish plants browsed by black rhinos and other herbivores. Browsed and non-browsed plant species with a maximum canopy and branch height of 2 m were counted and recorded in each sampling plot, and the data obtained were used to estimate forage utilization by black rhinos and the preference of forage species for black rhinos (Petrides, 1975). Data obtained were also used to calculate the abundance, composition, and diversity of the forage browsed by black rhinos. Grasses were not recorded in this study since it was not possible to distinguish between grasses foraged by rhinos and other herbivores by using an indirect field observation method.

3.3.3 Assessment of Browsing Intensity on Browsed Species by Black Rhinos at Mkomazi Rhino Sanctuary

The browsing intensity on foraged species by black rhinos was assessed in selected sampling plots based on a visual assessment of the total crown browsed using the method described by Tchamba (1995). The browsing level was categorized on a scale from 1 to 5: "1" stands for not browsed, "2" - a quarter of the woody plant browsed (low browsed), "3" - half of the woody plant browsed (medium browsed), "4" - three-quarters of the woody plant browsed (highly browsed), and "5" - all the woody plant browsed (heavily browsed) (Tchamba, 1995).

3.3.4 Identification of Plant Species Browsed By Black Rhinos within Africa Savannah

Available literature data from studies of black rhino forage consumption and preference conducted in fourteen rhino range areas within Africa savannah were used to develop a list of consumed and preferred families and forage species by black rhinos in each area for wet and dry seasons (Table 2) to affirm the list of browses consumed by rhinos in MRS. The selected studies were of different plant identification methodologies, such as direct observation of feeding rhinos, backtracking, field observation of foraged plant species and faecal analysis.

All plants eaten by black rhinos were assigned to respective families as per recent nomenclature and categorized by wet and dry seasons. Data were analyzed across fourteen rhino range locations where black rhinos exist and bred. Within each rhino site, including MRS, the summation of the frequency of eaten plant species was established at the family and species levels. Thereafter, the values of similar families in all range areas were compiled in wet and dry seasons separately, and the summation were ranked in ascending order and compared with the ranked list of consumed families in MRS. Furthermore, the summation list of browsed plant species by rhinos in each rhino range area was ranked, and the top five species were selected in the dry and wet seasons and compared with the most browsed plant species by rhinos during the wet and dry seasons in the MRS.

Table 2: Cited studies from 14 rhino range areas within Africa savannah with the list of plant species most consumed by black rhinos identified by different types of methodologies

Rhino range area	Habitat	Season	Methodology	Source
Nairobi NP, Kenya	Shrubland	W	Field plant observation	Muya and Oguge (2000)
Laikipia, Kenya	Shrubland	W/D	Backtracking	Oloo *et al.* (1994)
Ngorongoro and Olduvai Gorge, Tanzania	Savanna	W/D	Direct observation	Goddard (1968)
Tsavo NP, Kenya	Woodland	W/D	Direct observation	Goddard (1970)
Masai Mara Game Reserve	Woodland	W/D	Feeding track observation	Mukinya (1977)
Great Fish River Reserve, South Africa	Bush clump savanna	Wet	Backtracking and faecal analysis	Lieverloo *et al.* (2009)
Great Fish River Reserve, South Africa		S/W	Backtracking	Ganqa *et al.* (2005)
Gonarezhou, Zimbabwe	Savanna	Wet	Field plant observation	Goza *et al.* (2019)
Ado elephant NP, South Africa	Savanna	W/D	Feeding track observation	Hall-Martin *et al.* (1982)
Midlands Conservancy, Zimbabwe	Woodland	Dry	Backtracking	Makaure and Makaka (2013)
Itala Game Reserve, South Africa	Savanna	Dry	Field plant observation	Kotze and Zacharias (1993)
Augrabies Falls, Karoo and Vaalbos NP, South Africa	Bushland	Dry	Backtracking	Buk and Knight (2010)
Serengeti NP, Tanzania	Savanna	Wet	Back tracking and DNA metabarcoding	(Anderson *et al.* (2020)
Majete Wildlife Reserve, Malawi	Woodland	Wet	Backtracking	Gyöngyi and Elmeros (2017)

3.3.5 Determination of the Nutrient Composition of Browses Preferred by Black Rhinos at Mkomazi Rhino Sanctuary

Samples of the 17 preferred browses foraged by black rhinos identified in objective 2 were collected during the main survey in both wet and dry seasons. Nine (9) principal/preferred plant species were sampled from ten (10) randomly selected 50 m x 50 m sampling plots in the dry season, and the same procedure was repeated for the eight (8) principal/preferred species identified in the wet season.

(i)   Sample Collection

One hundred to 150 grams of fresh plant sample material (twigs/leaves) was clipped from a minimum of five mature plants per species with fresh browse signs by black rhinos (Ghebremeskel *et al.,* 1991). Leaves were found in all plant species sampled during the wet season, but in dry season seasons, leaves were found only in *Balanites aegyptiaca* plant species. The plant leaf and twig samples collected represented those parts of each plant species commonly consumed by black rhinos (Ghebremeskel *et al.,* 1991). Plant samples were packed in clean paper, allowed to dry in a cool environment as suggested by Aletan and Kwazo (2019) and transported to the NM-AIST laboratory for preparation.

(ii)   Sample Preparation

The collected plant species samples were separated into leaves and twigs, and a total of 26 samples constituting 17 twig samples and nine leaf samples were obtained. Samples were washed with deionized water and air dried under the shade (Kumar *et al.,* 2021). The dried samples of twigs and leaves were ground in a Willey mill machine into a fine powder and sifted through a sieve of 2.0 mm mesh to obtain a more homogeneous sample and stored in dry polythene bags at room temperature. The dried plant samples were analyzed separately using proximate analysis to measure the contents of ash, carbohydrate, crude fat, crude fibre, and crude protein (Ghebremeskel *et al.,* 1991; Kumar *et al.,* 2021). The analysis of ash, carbohydrate and crude fibre was performed at the NM-AIST laboratory, while the analysis of crude fat and crude protein was performed at the Arusha Technical College laboratory. The dried samples were further analyzed for macro and micro elemental nutrients by using atomic absorption spectrometry (AAS) after the digestion process (Grauso *et al.,* 2020; Kumar *et al.,* 2021) at the Tanzania Atomic Energy Commission laboratory in Arusha.

(iii)   Proximate Analysis

The proximate composition of ash, carbohydrate, crude fat, crude fibre, and crude protein of 26 plant samples was determined using the adopted method of analysis from the Association of Official Analytical Chemists (AOAC, 1990). All the proximate analysis procedures are shown hereunder, and values are reported in percentages as follows:

Determination of Moisture Content

The moisture content was determined using the weight difference method. A clean container was oven-dried at 105°C for 1 hour, cooled and then weighed (W1). Two grams (W2) of dry sample was placed in the container and oven-dried at 105°C. The sample was then weighed after cooling in a desiccator (W3):

$$\text{Moisture content (\%)} = \frac{W2 - W3 \times 100}{W2 - W1}$$

Determination of Ash

The ash content was determined using the weight difference method. A porcelain crucible was dried for one hour at 105°C before being cooled and weighed (W1). Two grams of plant sample was placed in the crucible and weighed again (W2). The crucible containing plant sample was ashed for an hour at 250°C, followed by five hours at 550°C in a muffle heating system. The sample was weighed again after cooling in a desiccator (W3):

$$\text{Ash (\%)} = \frac{W2 - W3 \times (100)}{W2 - W1}$$

Determination of Crude Fat

The crude fat content was determined using the weight difference method. The 5-gram powdered sample was added to 100 mL diethyl ether in a volumetric flask and shaken in an orbital shaker for 24 hours. The ether extract was collected in a beaker that had been previously weighed (W1). After being equilibrated with 100 mL diethyl ether and shaken for 24 hours, the filtrate was collected in the same beaker (W1). After being concentrated to dryness in a steam bath, the ether was dried in an oven at 40–60°C, and the beaker was reweighed (W2):

$$\text{Crude fat (\%)} = \frac{\text{Weight of flask with fat (W2) - weight of empty flask (W1)} \times (100)}{\text{Weight of the original sample}}$$

Determination of Crude Fibre

The crude fibre content was determined using the weight difference method. Two grams of a dried sample was processed for half an hour in 100 mL of 1.25% H_2SO_4 and filtered under pressure. The remainder of the residue was washed with hot water. This procedure was repeated with 100 mL of 1.25% NaOH solution on the residue. The remaining filtrate was dried and weighed at 100°C (C1). The filtrate was incinerated in a muffle furnace at 550°C for 5 hours before being reweighed (C2).

$$\text{Crude fibre (\%)} = \frac{C2 - C1 \times (100)}{\text{Weight of the original sample}}$$

Crude Protein Determination

The Kjeldahl method was used to determine crude protein contents in a sample (Kumar *et al.,* 2021). Approximately 0.5 grams of each plant species sample was weighed in duplicate and digested. Total nitrogen (N) and crude protein in the plant sample were calculated as follows:

$$\text{Percent N} = \frac{(14 \times 0.1) \times A \times 100}{W}$$

Whereby,   A = the titter of acid used in millilitres,

W = original weight of the digested sample and

N = total nitrogen.

   Crude protein (%) = Percent N x Factor (6.25)

Carbohydrate Determination

The carbohydrate content was determined by the difference method adopted from AOAC (1990).

Carbohydrate (%) = 100 – (% CP + % CFA + % CF + % Ash content + % MC)

Whereby,   CP = crude protein, CFA= crude fat,

CF = crude fibre, MC = moisture content and

AC = ash content.

(iv)   Elemental Nutrient Analysis

The elemental composition of 26 plant samples from 17 plant species was analysed by using the di-acid digestion method, with a ratio of 9 by 4 for the mixture of HNO_3 (nitric acid) and $HClO_4$ (perchloric acid). Triplicate samples of powdered plant material (1.0 gram) from each plant sample

were weighed and placed into different 100 mL volumetric flasks. The 10 mL of HNO_3 was added to this and left overnight for pre-digestion. The following day, 8 mL of $HClO_4$ was added, and the contents were gently swirled. The flask was placed on a hot plate at a low temperature (approximately 100°C). The flask was then heated to higher temperatures (approximately 260°C or higher) until the emission of red NO_2 fumes ceased. The content was further evaporated to a reduced volume of 3 or 5 mL. When the liquid became colorless, it indicated that the digestion process was completed. The mixture was allowed to cool before adding 20 mL of deionized water to the flasks. The volume was filled with deionized water, and the solution from each sample was filtered through filter paper. The mixture of this solution was used to determine macro elements: calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), sodium (Na), and microelements, copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn), by using an atomic absorption spectrometer machine (Perkin Elmer AA Analyst 700) (Kumar *et al.,* 2021).

3.4 Data Analysis

3.4.1 Plant Species Diversity

Species richness and diversity of total plant (woody and herbs) species observed in a study area, forage available for black rhino diet and forage species consumed by rhinos was computed using the Shannon–Wiener diversity index (H) as per Equation 1.

$$H = - \blacksquare \; pi$$

Whereby,

p is the proportion (n/N) of individuals of one particular species found (n) divided by the total number of individuals found (N), *ln* is the natural log, Σ is the sum of the calculations and s is the number of species.

3.4.2 Forage Preference Index

The forage preference index (FPI) of all browsed species was determined following Petrides (1975) as per Equation 2.

$$\text{Forage Preference Index (FPI)} = \frac{\text{Relative Utilization (RU)}}{\text{Relative abundance (RA)}}$$

Whereby,

RU is the percentage of the browsed species in the diet,

RA is the percentage of forage species available in the environment (Petrides, 1975).

The FPI value varies from 0 to infinity, whereby values greater or less than 1 indicate species that are preferred or avoided, respectively, and values of exactly 1.00 represent neither preferred nor neglected species but being eaten (Petrides, 1975).

3.4.3 Measure of Linear Relationship and Association between Variables

Correlation analysis was used to measure the strength of the linear relationships and association between forage browsed and forage available as well as a linear relationship between forage preference and browse intensity using count data.

3.4.4 Descriptive Analysis

Data collected for each parameter on nutrient composition were analyzed using descriptive statistics by R-statistical software version 4.3.1. The central tendency (mean ± standard deviation) was calculated for triplicate samples and reported.

Furthermore, data from the literature on plant species browsed by black rhinos in fourteen rhino range areas were analyzed and compared using a Microsoft Excel spreadsheet.

3.4.5 Statistical Analysis

The Shapiro–Wilk test for normality was performed on species diversity and richness data, forage preference index data, browsing intensity data, and nutrient composition data. For all data that passed the normality test, independent sample Student's t test was performed, whereas for non-normally distributed data, a Mann–Whitney U test was executed (Tererai *et al.,* 2013) to determine whether there were statistically significant variations in diversity, forage preference, browsing intensity and nutrient composition between dry and wet seasons. The statistical software used was R-software Version 4.3.1, and the level of significance was set at $\alpha=0.05$.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1   Results

4.1.1   Abundance and Composition of Plant Species Foraged By Black Rhinos in Mkomazi Rhino Sanctuary

A total of 151 and 85 plant species from 48 and 36 plant families were recorded in MRS during the wet and dry seasons, respectively. Of these, 76% (108 species) and 78% (67 species) of the families were potentially available plant species for the rhino diet in the wet and dry seasons, respectively. Approximately 67% (84 species) and 78% (67 species) of the families were browsed (consumed) by rhinos as food in the wet and dry seasons, respectively. The composition of total plant species, available forage and browsed/consumed forage in both seasons is shown in Fig. 3. There was significant variation in species richness for the total plants observed (w = 572, $p<0.001$) and available forage for the rhino diet (w = 631, $p<0.001$) but no variation in browsed/consumed forage by rhinos (t = 0.457, $p=0.648$) between the two seasons.
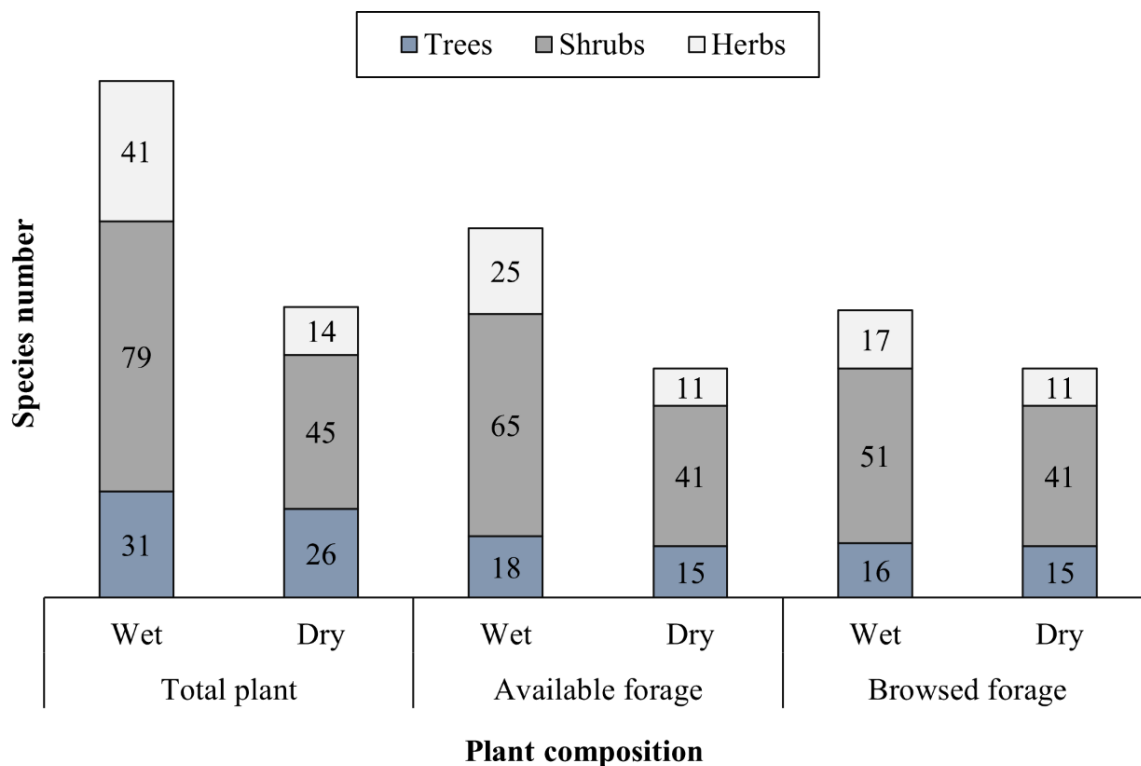
Figure 3:   **Seasonal variation in plant species composition in Mkomazi Rhino Sanctuary**

The abundance and composition of total plants observed, available forage for rhino diet, and consumed forage by rhinos in three plant life forms varied between seasons (Fig. 4). In

comparison, there was a significant difference in the abundance of available forage for diet in shrubs (w = 703, $p<0.001$) and herbs (w = 355, $p<0.001$), but there was no variation in the abundance of available forage for diet in trees (t = 0.149, $p = 0.882$) across the wet and dry seasons (Fig. 4). The available forage for diet (AFD) was observed to have a higher percentage in shrubs and herbs in the wet season than in the dry season (Fig. 5) Also, the consumed forage (CF) was observed to have a higher percentage in the wet season than in the dry season in all plant growth forms (Fig. 5).
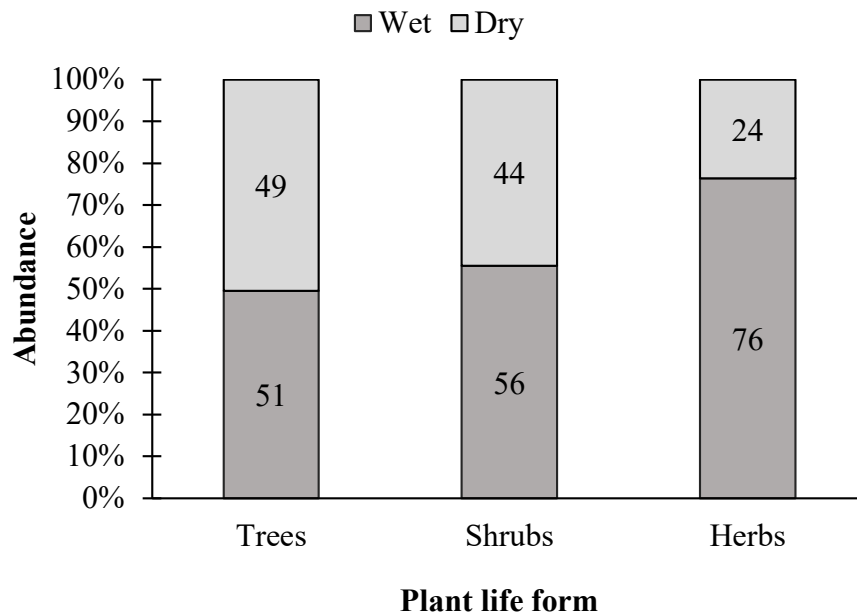
Figure 4: **Variability in abundance of plant life forms in the wet and dry seasons at Mkomazi Rhino Sanctuary**
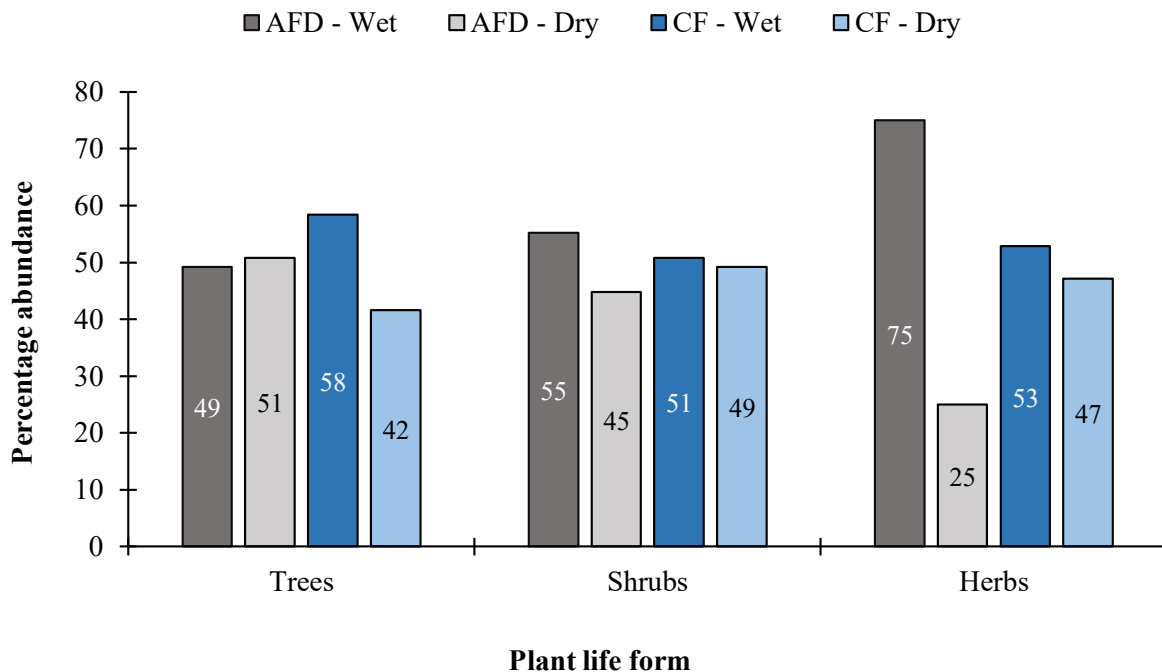
Figure 5: **Percentage contribution of plant life form in available forage for diet (AFD) and consumed forage (CF) by black rhinos across wet and dry seasons in Mkomazi Rhino Sanctuary**

4.1.2 Diversity of plant species foraged by black rhinos in Mkomazi Rhino Sanctuary

The Shannon diversity index (H) mean value of the total plant was significantly higher (t = 8.56, $p < 0.001$) in the wet (3.62) season than in the dry (3.01) season. The diversity index (H) mean values of the available forage for the rhino diet were significantly higher (t = 8.31, $p<0.001$) in the wet season (3.38) than in the dry season (2.77). Additionally, the diversity index (H) values of the consumed forage were significantly higher (t = 4.58, $p<0.001$) in the wet season (2.97) than in the dry season (2.31). Additionally, the diversity varied in each plant growth form, with shrubs showing a high index in both seasons (Table 3). There was a decline in diversity from the wet to dry season in shrubs and herbs except for trees.

Table 3: **Shannon diversity indices (mean ± SD) of plant growth forms in the wet and dry seasons in Mkomazi Rhino Sanctuary**

| Plant form | Index | Mean value ± SD | | t test | p value |
		Wet	Dry		
Trees	Diversity[†]	1.24 ± 0.35	1.12 ± 0.42	1.76	0.081
	Diversity[‡]	0.91± 0.49	1.00 ± 0.44	1.17	0.243
Shrubs	Diversity[†]	1.83 ± 0.38	1.31 ± 0.38	7.46	<0.001**
	Diversity[‡]	1.44 ± 0.43	1.10 ± 0.37	4.14	<0.001**
Herbs	Diversity[†]	1.32 ± 0.35	0.70 ± 0.37	9.48	<0.001**
	Diversity[‡]	0.55 ± 0.50	0.54 ± 0.38	0.131	0.896

[†]- Diversity of available forage, [‡]- Diversity of consumed forage and ** Statistically significant at (p < 0.001)

4.1.3 Plant families and species browsed by black rhinos in Mkomazi Rhino Sanctuary

Families with most species browsed by black rhinos in both seasons across different life growth forms in order of importance were *Euphorbiaceae*, *Burseraceae*, and *Malvaceae,* with varied abundances (Fig. 6). The study identified 15 principal browse species that contributed 80% and 86% of the total diet in the wet (Table 4) and dry (Table 5) seasons, respectively. Principal browse species were those that constituted more than 1% (n>100) of the total available diet for the rhinos in all vegetation types. Appendix 1 showed field pictures of forage species consumed by black rhinos in wet and dry season in MRS. Appendix 2 showed other plant species available for rhino diet and those consumed during the wet and dry seasons in MRS. Species of *Acalypha ornata, Grewia similis* and *Commiphora africana* showed a high utilization index in both seasons, while some species were browsed by rhinos in only one season (Table 4); for example, *Commelina*

africana was consumed in the wet season. Forage browsing by rhinos did not vary between the two seasons (t=0.407, *p*=0.684) but correlated significantly with forage availability in the wet (r=0.93, *p*<0.001) and dry (r=0.90, *p*<0.001) seasons.
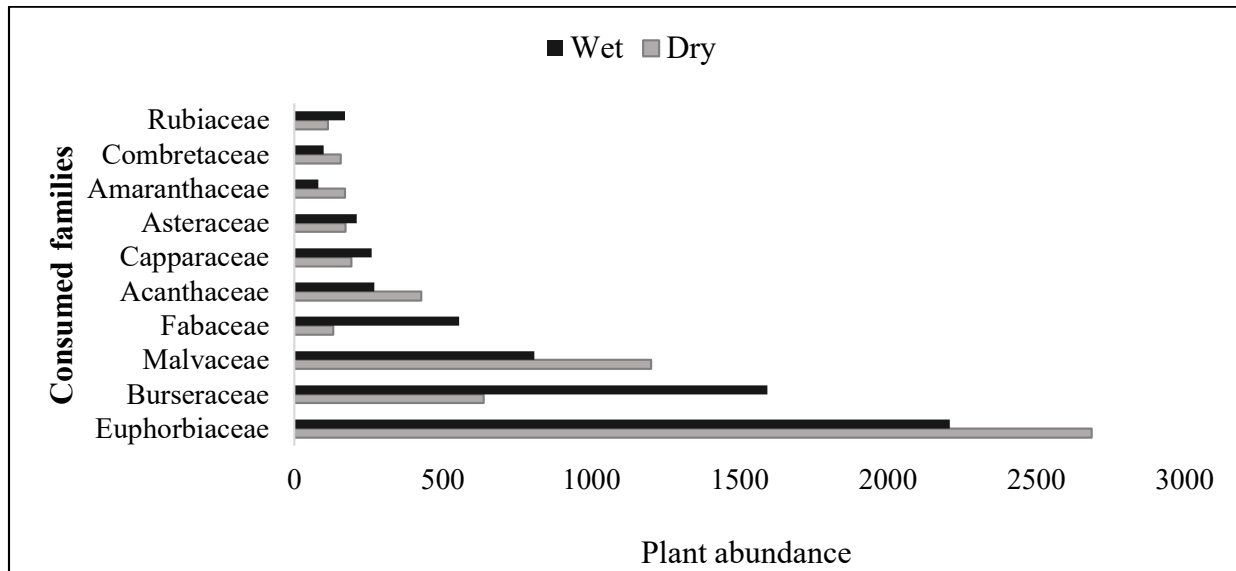
Figure 6:   **Comparison of families browsed by rhinos in the wet and dry seasons at Mkomazi Rhino Sanctuary**

Table 4:   **The top 15 principal browse species consumed by black rhinos during the wet seasons in Mkomazi Rhino Sanctuary: The list has been arranged by descending RU values**

Browsed species	Family	Plant form	RA	RU	FPI	MBII
Acalypha ornate	Euphorbiaceae	Shrub	14.25	21.95	1.54	2.7
Grewia similis	Malvaceae	Shrub	9.13	13.42	1.59	3.0
Commiphora africana	Burseraceae	Tree	14.09	10.25	0.73	2.6
Acalypha fruticosa	Euphorbiaceae	Shrub	6.14	9.79	1.47	2.8
Grewia villosa	Malvaceae	Shrub	3.87	5.67	1.46	2.8
Commelina africana	Commelinaceae	Herb	4.42	3.02	0.68	2.4
Acacia bussei	Fabaceae	Tree	4.43	2.73	0.62	2.7
Barleria submollis	Acanthaceae	Herb	2.87	2.19	0.76	2.6
Maytenus mossambicensis	Celastraceae	Shrub	1.32	2.16	1.64	3.1
Acacia melifera	Fabaceae	Tree	2.38	1.97	0.83	2.6
Grewia forbesii	Malvaceae	Shrub	1.35	1.83	1.35	2.7
Canthium glaucum	Rubiaceae	Shrub	1.04	1.50	1.44	2.6
Maerua edulis	Capparaceae	Shrub	1.94	1.37	0.70	2.5
Acacia tortilis	Fabaceae	Tree	2.22	1.28	0.58	2.5
Acacia drepanolobium	Fabaceae	Tree	0.83	1.22	1.47	2.4
Total			**70.28**	**80.35**		

Abbreviations: RA - relative abundance; RU - relative utilization; FPI - forage preference index and MBII - mean browsing intensity index.

Table 5: The top 15 principal browse species consumed by black rhinos during the dry seasons in Mkomazi Rhino Sanctuary: The list has been arranged by descending RU values

Browsed species	Family	Plant form	RA	RU	FPI	MBII
Acalypha ornata	Euphorbiaceae	Shrub	27.49	37.89	1.38	4.0
Grewia similis	Malvaceae	Shrub	8.67	12.75	1.47	3.9
Commiphora africana	Burseraceae	Tree	19.15	7.54	0.39	3.3
Grewia villosa	Malvaceae	Shrub	3.80	5.26	1.39	3.9
Barleria submollis	Acanthaceae	Herb	3.53	5.01	1.42	3.9
Acalypha fruticosa	Euphorbiaceae	Shrub	2.41	3.75	1.56	4.5
Blepharispermum zanzibarica	Asteraceae	Shrub	2.17	2.68	1.24	3.7
Combretum zeyheri	Combretaceae	Shrub	1.53	2.17	1.42	3.8
Hymenodictyon parvifolium	Rubiaceae	Tree	1.23	1.75	1.43	4.0
Balanites aegyptiaca	Zygophyllaceae	Tree	1.12	1.71	1.53	4.1
Maerua edulis	Capparaceae	Shrub	0.94	1.32	1.41	3.8
Maytenus mossambicensis	Celastraceae	Shrubs	0.82	1.10	1.35	3.7
Hibiscus micranthus	Malvaceae	Herbs	0.75	1.06	1.41	3.5
Achyranthes aspera	Amaranthaceae	Herbs	0.76	1.04	1.37	3.5
Acacia melifera	Fabaceae	Tree	2.34	0.57	0.25	3.1
Total			**76.71**	**85.60**		

Abbreviations: RA - relative abundance; RU - relative utilization; FPI - forage preference index and MBII - mean browsing intensity index

4.1.4 Comparison of edible families and species by black rhinos in Mkomazi Rhino Sanctuary and within rhino range areas in Africa savannah

The list of the top five most edible families by black rhinoceros in the wet and dry seasons was identified from records of published literature data on black rhino forage consumption across fourteen rhino range areas within Africa savannah (Table 6). *Euphorbiaceae Fabaceae* and *Malvaceae* were the three families browsed in fourteen rhino range areas and in MRS in both wet and dry seasons (Table 6). Black rhinoceros consumes various plant species that belong to different plant families in fourteen rhino range areas within African savannah. The list of the top five species most browsed by black rhinoceros in the wet and dry seasons was identified in each rhino range area (Table 7). The results showed that more than 85% of plant species edible in fourteen rhino range areas within Africa savannah in the wet and dry seasons are similar to those consumed and preferred by rhinos in the wet and dry seasons in MRS.

Table 6: **The comparison between the list of top five (5) edible families by black rhinos in wet and dry seasons in 14 rhino range areas within Africa and those browsed in Mkomazi Rhino Sanctuary**

WET SEASON				DRY SEASON			
Family edible in 14 rhino range areas	*Rank value	Family edible in MRS	**Rank value	Family edible in 14 rhino range areas	*Rank value	Family edible in MRS	**Rank value
Malvaceae	1	Euphorbiaceae	1	Euphorbiaceae	1	Euphorbiaceae	1
Euphorbiaceae	2	Malvaceae	2	Fabaceae	2	Malvaceae	2
Fabaceae	3	Burseraceae	3	Malvaceae	3	Burseraceae	3
Ebenaceae	4	Fabaceae	4	Capparidaceae	4	Fabaceae	4
Acanthaceae	5	Acanthaceae	5	Verbenaceae	5	Capparidaceae	5

*: Summation family ranking in all rhino range areas by season, **: family ranking based on browsing percentage within MRS

Note: Forage plant identification methods: †= Plant field observation; ‡ = Direct observation of feeding rhinos; § = backtracking

and ¶ = Faecal analysis

Table 7: The list of the top five species with the highest percentage contribution to the diet, as reported in fourteen studies conducted in rhino range areas within Africa savannah

Rhino range area	Most edible forage species		References
Nairobi NP, Kenya [†]	*Grewia similis, Hibiscus aponuerus Phyllanthus fischeri, Acacia brevispica, Acalypha fruticosa, Barleria grandicalyx*		Muya and Oguge (2000)
Laikipia, Kenya [‡]	*Acacia hockii, Acacia brevispica, Ferula communis, Tinnea aethiopica, Euclea divinorum*	*Acacia brevispica, Phyllanthus fischeri, Carissa edulis, Acacia hockii, Ecbolium revolutum*	Oloo *et al.* (1994)
Ngorongoro and Olduvai Gorge, Tanzania [‡]	*Trifolium masaiense, Justicia betonica, Indigofera basiflora, Acacia lahai, Lathyrus hygrophilus*	*Indigofera basiflora, Euphorbia tirucalli, Justicia betonica, Pluchea dioscoride, Indigofera errecta*	Goddard (1968)
Tsavo NP, Kenya [‡]	*Indigofera spinosa, Tephrosia villosa, Dirichletia glaucescens, Grewia sp., Hibiscus micranthus*	*Indigofera spinosa, Tephrosia villosa, Grewia sp., Caesalpinia trothae, Justicia fischeri*	Goddard (1970)
Masai Mara Game Reserve [‡]	*Solanum incanum, Acacia hockii, Dichrostachys cinerea, Maerua edulis, Grewia similis, Commiphora africana*	*Dichrostachys cinerea, Grewia similis, Acacia hockii, Croton dichogamus, Balanites aegyptiaca, Acacia drepanolobium*	Mukinya (1977)
Great Fish River Reserve, South Africa [§,]	*Grewia robusta, Plumbago auriculata, Azima tetracantha, Jatropha capensis, Coddia rudis*		Van Lieverloo *et al.* (2009)
Great Fish River Reserve, South Africa [§]	*Plumbago auriculata, Grewia robusta, Azima tetracantha, Jatropha capensis, Ehretia rigida*	*Euphorbia bothae, Grewia rubusta, Plumbago auriculata, Azima tetracantha, Acacia karroo*	Ganqa *et al.* (2005)
Gonarezhou, Zimbabwe [†]	*Acacia nigrescens, Dichrostachys cinerea, Diplorhynchus condlycarpon, Spirostachys africana, Flueggea virosa*		Goza *et al.* (2019)
Ado elephant NP, South Africa [†]	*Grewia robusta, Azima tetracantha, Walafrida geniculate, Felicia muricata, Galenia pubescens*	*Azima tetracantha, Schotia afra, Zygophyllum morgsana, Hermannia pallens, Justicia orchioides*	(Hall-Martin *et al.* (1982)
Midlands Conservancy, Zimbabwe [§]		*Acacia nilotica, Lantana camara, Rhus tenuinervis, Gardenia volkensii, Acacia karoo*	Makaure and Makaka (2013)
Itala Game Reserve, South Africa [†]		*Acacia nilotica, Dichrostachys cinerea, Acacia karoo, Ehretia rigida, Coddia rudis*	Kotze and Zacharias (1993)
Augrabies Falls, Karoo and Vaalbos NP, South Africa [§]		*Acacia mellifera, Euphorbia rectirama, Acacia karroo, Zygophyllum sp, Acacia mellifera, Grewia flava, Acacia tortilis*	Buk and Knight (2010)
Serengeti NP, Tanzania [§]	*Acacia sieberiana, Hibiscus sp., Achyranthes aspera, Indigofera volkensii, Acacia drepanolobium, Ziziphus abyssinica*		Anderson *et al.* (2020)
Majete Wildlife Reserve, Malaw*i* [§]	*Dichrostachys cinerea, Diplorhynchus condylocarpon, Grewia bicolor, Karomia tettensis, Acacia nilotica*		Gyöngyi and Elmeros (2017)

4.1.5 Plant species preferences by black rhinos in dry and wet seasons at Mkomazi Rhino Sanctuary

Black rhinos displayed no variation in forage preferences between seasons (w = 2349, *p* = 0.082); however, there was a slight shift in the preferences of rhinos in a few diet species between the two seasons (Table 4; Table 5). The FPI varied from highly preferred species (1.64) to less preferred species (0.25) in both seasons (Table 4; Table 5). Out of the 15 principal browsed species in each season, eight were mostly preferred (FPI>1) in the wet season and 13 in the dry season. The highest FPI was observed in shrub species of *Maytenus mossambicensis* (1.64) and *Acalypha fruticosa* (1.56), while the lowest was observed in trees of *Acacia tortilis* (0.58) and *Acacia melifera* (0.25) in the wet and dry seasons, respectively.

4.1.6 Browsing intensity across foraged plant species by black rhino in Mkomazi Rhino Sanctuary

Browsing intensity on the black rhino diet was significantly higher (w= 482, *p*<0.001) in the dry season than in the wet season (Fig. 7). The indices for browsing intensity showed strong and significant positive correlations with FPI in both dry (r=0.548, *p*<0.001) and wet (r=0.547, *p*<0.001) seasons. The browsing intensity index on species foraged by black rhinos ranged between index 2 and 3 (low to medium browsed) during the wet season (Table 4) and between index 4 and 5 (high to heavily browsed) during the dry season (Table 5). Species of *Acalypha fruticosa* and *Maytenus mossambicensis* were highly browsed and showed a high preference index in the dry and wet seasons, respectively.
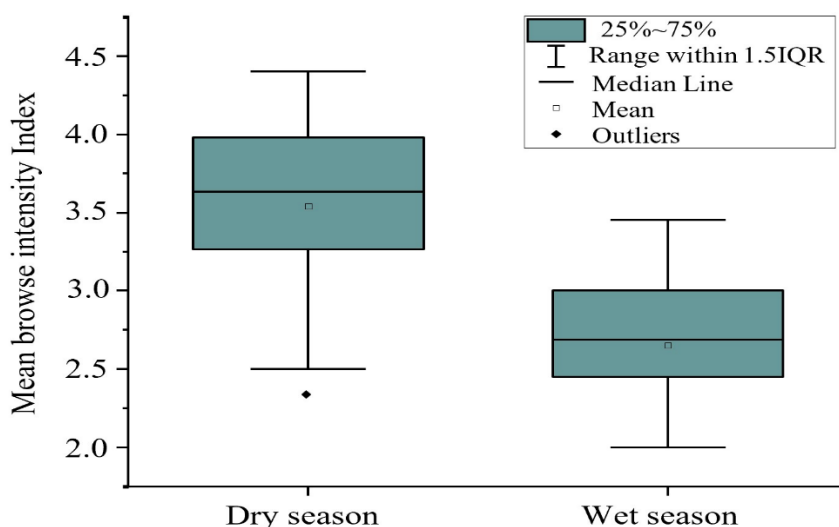
Figure 7: Comparison of the mean browsing intensity index of browses foraged by black rhinos in wet and dry seasons in Mkomazi Rhino Sanctuary

4.1.7 Proximate composition of browse species preferred by black rhinos at Mkomazi Rhino Sanctuary

The results from the proximate analysis showed that 26 plant samples collected in MRS in the wet and dry seasons contained a considerable concentration of essential nutrients that are vital to black rhino nutrition (The list of browses has been arranged by descending FPI values: Each value represents the mean of triplicate measurements [Table 8 and Table 9]). The nutrient composition of leaves (moisture, ash, and crude fibre) was significantly higher ($p<0.05$) than that of twigs of the same plants in the wet season except for crude fat, crude protein and carbohydrate (Table 8). Statistical analysis showed that the proximate composition of species browsed by rhinos in the wet season was significantly higher ($p<0.05$) than that in the dry season, except for carbohydrates and ash (Table 10 and Fig. 8).

Table 8: **Proximate composition of browses (leaves and twigs) consumed by black rhinos during the wet season at MRS. The list of browses has been arranged by descending FPI values. Each value represents the mean of triplicate measurements**

Preferred browse species	Plant part	Moisture %	Dry matter (%)				
			Ash	C. Fibre	C. Fat	CP	Carbohydrate
M. mossambicensis	L	11.90	15.10	10.60	7.28	16.65	38.47
	T	10.50	8.70	17.00	7.58	16.55	39.67
A. fruticosa	L	13.50	9.80	18.00	4.12	15.97	38.61
	T	12.40	4.20	27.00	3.56	15.53	37.31
A. ornata	L	14.30	9.00	22.00	5.14	15.10	34.46
	T	11.90	3.10	27.20	5.36	14.85	37.59
Grewia similis	L	15.30	10.20	18.30	4.62	15.74	35.84
	T	15.00	5.60	24.00	4.20	15.67	35.53
G. villosa	L	15.40	6.70	24.90	3.74	13.24	36.02
	T	12.50	3.30	26.50	5.58	15.17	36.95
A. melifera	L	13.90	8.20	20.90	3.48	15.02	38.50
	T	11.20	5.20	24.40	6.08	14.76	38.36
B. submollis	L	15.50	12.90	21.00	6.96	15.19	28.45
	T	13.50	3.20	27.00	3.64	15.70	36.96
C. africana	L	17.00	6.60	22.00	7.25	15.48	31.67
	T	13.30	3.30	26.00	6.46	14.98	35.96
L and T comparison		0.015**	<0.001*	<0.018**	0.991	0.805	0.158

L = leaf, T = twigs, C. Fibre = crude fibre, C. Fat = crude fat and CP = crude protein
Statistically significant at p: * = < 0.001 and ** = <0.05.

Table 9: Proximate composition of browses (leaves and twigs) consumed by black rhinos during the dry season at MRS.

Preferred browse species	Plant part	Moisture %	Dry matter (%)				
			Ash	C. Fibre	C. Fat	CP	Carbohydrate
A. fruticosa	T	8.20	6.80	24.10	1.96	10.80	48.14
B. aegyptiaca	T	8.20	8.15	23.00	4.28	9.86	46.51
	L	8.30	15.3	16.80	3.08	10.07	46.45
G. similis	T	8.00	7.30	33.00	2.96	10.35	38.39
H. parvifolium	T	8.20	8.15	23.00	4.28	9.86	46.51
B. submollis	T	5.00	11.9	37.00	3.08	9.27	33.75
C. zeyheri	T	8.00	5.60	39.20	1.24	5.50	40.46
G. villosa	T	7.80	10.90	37.50	3.10	9.08	31.62
A. ornata	T	8.50	6.80	38.24	3.10	9.21	34.15
C. africana	T	8.10	4.70	38.00	2.90	9.52	36.78

L = leaf, T = twigs,

Table 10: Comparison of the proximate composition of browses consumed by black rhinoceros in the dry and wet seasons at Mkomazi Rhino Sanctuary

Nutrient composition % (DM)	Dry		Wet		p values
	Mean ± SD	N	Mean ± SD	N	
Moisture	7.96 ± 1.14	16	13.57 ± 1.78	10	<0.001*
Ash	8.31 ± 3.35	16	7.19 ± 3.62	10	0.437
Crude Fibre	31.23 ± 8.12	16	22.29 ± 4.58	10	0.019**
Crude Fat	3.07 ± 1.04	16	5.33 ± 1.47	10	<0.001*
Crude Protein	9.33 ± 1.45	16	15.35 ± 0.79	10	<0.001*
Carbohydrate	39.99 ± 5.97	16	36.27 ± 2.85	10	0.220

Statistically significant at p: * = < 0.001 and ** = <0.05, N = number of plant samples and DM = dry matter
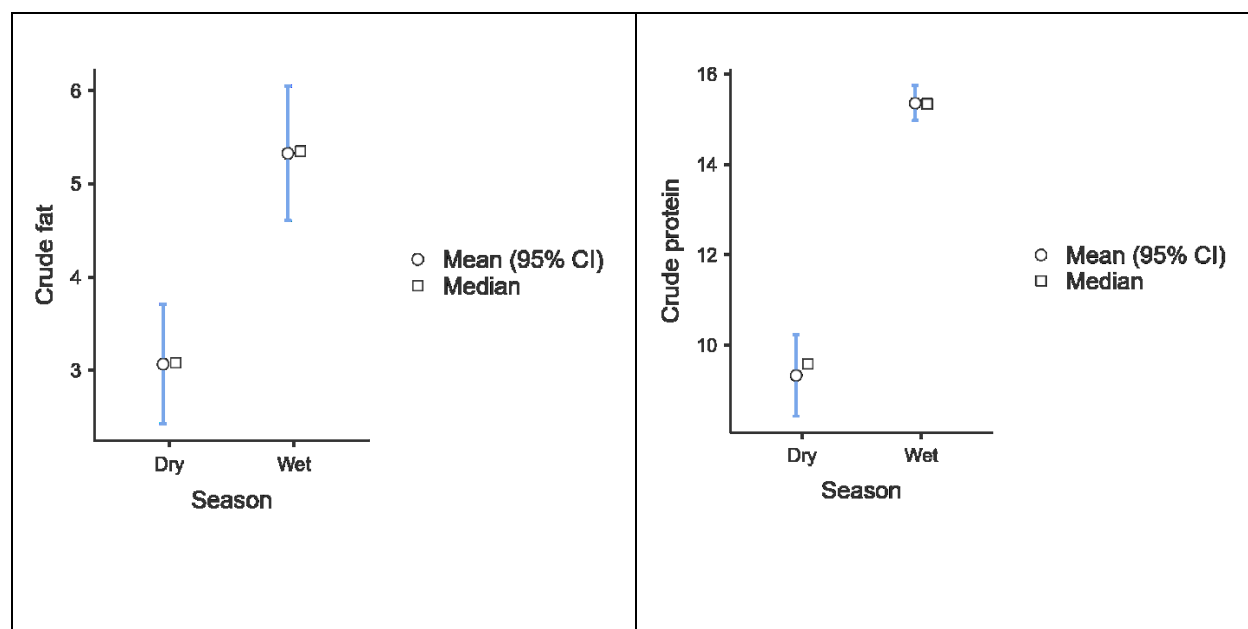
Figure 8: Descriptive plot showing the variation in crude fat and crude protein on forage browsed by black rhinos in the wet and dry seasons at Mkomazi Rhino Sanctuary

4.1.8 Elemental composition of browse species preferred by black rhinos in Mkomazi Rhino Sanctuary

The analysis of micro- and macro-elements in 26 plant samples collected in MRS in the wet season indicated the presence of considerable concentrations of macro and micro-elemental nutrients essential for black rhino health (Table 11 and Table 12). Leaves were significantly higher ($p<0.05$) in macro elements K and Na than twigs of the same plant species except for Ca, Mg, and P (Table 11). Also, trace element nutrients in leaves were similar ($p>0.05$) to those in twigs of the same plant species except for copper (Cu), which was significantly higher ($p<0.05$) in leaves (Table 11). Results showed no significant difference ($p>0.05$) in elemental nutrients of plant species browsed by rhinos in the wet and dry seasons (Table 13).

Table 11: Elemental composition of browses (leaves and twigs) consumed by black rhinos during the wet season at MRS: The list of browses has been arranged by descending FPI values: Each value represents the mean ± SD of triplicate measurements in dry matter

Preferred browse species	Plant part	Macro elements (% DM)					Trace elements (mg/kg DM)			
		Ca	Mg	K	P	Na	Cu	Fe	Mn	Zn
M. mossambicensis	L	3.94± 0.03	1.45± 0.01	4.35± 0.05	0.28± 0.01	0.68± 0.15	28.33 ± 0.71	51.97 ± 1.28	70.20 ± 5.06	23.20 ± 1.06
	T	3.80± 0.03	0.46± 0.02	0.81± 0.01	0.36± 0.01	0.16± 0.01	13.60 ± 0.78	51.14 ± 0.82	63.80 ± 2.32	44.70 ± 0.87
A. fruticosa	L	2.16± 0.02	0.29± 0.01	2.50± 0.03	0.23± 0.00	0.18± 0.04	8.73 ± 0.45	42.42 ± 0.14	43.40 ± 2.63	17.80 ± 0.87
	T	1.92± 0.03	0.23± 0.01	2.14± 0.03	0.18± 0.02	0.16± 0.06	10.07 ± 0.51	32.36 ± 0.32	36.17 ± 1.24	19.47 ± 0.95
A. ornata	L	2.40± 0.05	0.33± 0.02	1.76± 0.04	0.22± 0.01	0.21± 0.02	30.77 ± 0.86	39.97 ± 0.46	71.20 ± 0.96	19.87 ± 0.75
	T	2.33± 0.04	0.15± 0.01	1.03± 0.01	0.25± 0.01	0.11± 0.03	7.40 ± 0.85	38.06 ± 0.69	67.73 ± 3.25	24.07 ± 0.57
G. similis	L	2.03± 0.03	0.32± 0.01	1.67± 0.03	0.12± 0.01	0.19± 0.06	19.80 ± 0.70	61.86 ± 1.18	42.07 ± 4.45	16.73 ± 0.47
	T	2.03± 0.05	0.13± 0.00	0.97± 0.02	0.10± 0.01	0.12± 0.22	11.80 ± 0.53	37.45 ± 0.70	28.93 ± 2.41	24.50 ± 0.70
G. villosa	L	1.37± 0.03	0.16± 0.00	1.47± 0.03	0.14± 0.01	0.22± 0.06	12.07 ± 0.40	69.88 ± 1.85	43.57 ± 1.42	20.77 ± 0.91
	T	2.41± 0.04	0.14± 0.01	1.40± 0.02	0.21± 0.01	0.16± 0.10	9.667 ± 0.12	62.27±01.11	38.93 ± 3.59	18.50 ± 0.70
A. melifera	L	3.01± 0.05	0.32± 0.02	1.09± 0.02	0.12± 0.01	0.13± 0.04	15.00± 1.61	18.94± 0.02	36.47± 1.42	10.30± 0.56
	T	2.14± 0.03	0.18± 0.01	0.81± 0.01	0.21± 0.00	0.11± 0.03	5.67 ± 0.50	50.87 ± 0.63	19.67 ± 2.22	20.57 ± 0.50
B. submollis	L	3.29± 0.08	1.38± 0.02	2.62± 0.07	0.15± 0.01	0.72± 0.12	16.40 ± 1.56	56.17 ± 1.25	39.70 ± 2.27	38.40 ± 1.30
	T	2.76± 0.04	0.45± 0.01	1.10± 0.02	0.15± 0.01	0.16± 0.03	18.67 ± 1.36	57.13 ± 1.86	86.47 ± 4.20	42.23 ± 0.81
C. africana	L	0.86± 0.02	0.28± 0.01	2.13± 0.04	0.27± 0.01	0.19± 0.04	23.90 ± 0.90	44.13 ± 0.68	34.40 ± 2.25	38.20 ± 1.28
	T	2.33± 0.04	0.24± 0.01	2.07± 0.03	0.38± 0.01	0.18± 0.01	13.67 ± 0.45	60.80 ± 0.79	54.23 ± 0.38	26.97 ± 1.14
L and T comparison		**0.849**	**0.117**	**0.041****	**0.390**	**0.049****	**0.021****	**0.933**	**0.847**	**0.393**

L = leaf, T = twigs, **= Statistically significant at $p < 0.05$.

Table 12: **Elemental composition of browses (leaves and twigs) consumed by black rhinos during the dry season at Mkomazi Rhino Sanctuary. The list of browses has been arranged by descending FPI values. Each value represents the mean ± SD of triplicate measurements of dry matter**

Preferred browse species	Plant part	Macro elements (% DM)					Trace elements (mg/kg DM)			
		Ca	Mg	K	P	Na	Cu	Fe	Mn	Zn
A. fruticosa	T	1.74± 0.05	0.30± 0.01	1.41± 0.04	0.16± 0.00	0.14± 0.01	15.43 ± 0.32	41.63 ± 0.98	56.17 ± 2.27	22.93 ± 0.67
B. aegyptiaca	T	1.79± 0.02	0.15± 0.01	1.41± 0.02	0.10± 0.00	0.18± 0.09	12.50 ± 0.80	45.17 ± 0.35	32.57 ± 5.10	15.13 ± 0.55
	L	4.34± 0.06	0.63± 0.01	2.37± 0.02	0.14± 0.01	0.49± 0.03	24.63 ± 0.90	49.52 ± 1.07	55.43 ± 2.26	13.77 ± 0.15
G. similis	T	2.00± 0.05	0.15± 0.01	1.14± 0.03	0.14± 0.00	0.16± 0.02	10.53 ± 1.16	87.60 ± 2.57	54.07 ± 1.79	38.57 ± 0.55
H. parvifolium	T	1.95± 0.03	0.31± 0.01	2.01± 0.02	0.25± 0.01	0.11± 0.00	14.70 ± 0.52	57.35 ± 0.58	49.33 ± 3.88	33.03 ± 0.55
B. submollis	T	3.07± 0.06	0.43± 0.01	1.04± 0.02	0.20± 0.01	0.14± 0.04	18.50 ± 0.98	62.42 ± 1.09	96.70 ± 2.54	45.57 ± 1.93
C. zeyheri	T	2.72± 0.03	0.14± 0.00	0.58± 0.01	0.12± 0.00	0.11± 0.01	6.87 ± 0.83	63.20 ± 1.21	38.10 ± 1.31	29.97 ± 1.04
G. villosa	T	2.83± 0.04	0.14± 0.01	1.11± 0.02	0.17± 0.00	0.11± 0.02	18.50 ± 1.22	80.40 ± 1.83	57.60 ± 2.06	29.67 ± 1.05
A. ornata	T	3.74± 0.07	0.22± 0.01	0.10± 0.02	0.30± 0.01	0.10± 0.02	50.43 ± 1.58	39.40 ± 1.29	145.50±1.67	28.57 ± 1.30
C. africana	T	1.60± 0.05	0.26± 0.01	2.11± 0.03	0.33± 0.02	0.18± 0.04	18.78 ± 0.70	52.63 ± 1.50	44.32 ± 1.25	32.58 ± 0.75

L = leaf, T = twigs

Table 13: Comparison of composition in browses consumed by black rhinoceros in the dry and wet seasons at Mkomazi Rhino Sanctuary

Elemental nutrient	Dry	Wet	p value
	Mean ± SD		
Calcium (% DM)	2.38 ± 0.74		
Magnesium (% DM)	0.23 ± 0.10	0.898	0.228
Potassium (% DM)	1.31 ± 0.49	1.75 ± 0.91	0.197
Phosphorus (% DM)	0.20 ± 0.08	0.21 ± 0.08	0.681
Sodium (% DM)	0.14 ± 0.03	0.23 ± 0.19	0.154
Copper (mg/kg DM)	18.47 ± 12.64	15.35 ± 7.31	0.438
Iron (mg/kg DM)	58.85 ± 16.69	48.46 ± 13.23	0.100
Manganese (mg/kg DM)	52.71 ± 18.45	48.56 ± 18.32	0.593
Zinc (mg/kg DM)	30.67 ± 8.67	25.39 ± 10.06	0.200

Not statistically significant at $p < 0.05$, DM = Dry matter

4.2   Discussion

4.2.1   Families and Plant Species Browsed by Black Rhinos in Mkomazi Rhino Sanctuary

Black rhinos in MRS consume variable forage species available in the habitat in wet and dry seasons, mainly from the *Euphorbiaceae, Malvaceae, Burseraceae, Acanthaceae and Capparidaceae* families. Results in this study are in line with previous studies in eastern and southern Africa describing black rhino food plants (Oloo *et al.,* 1994; Ganqa *et al.,* 2005; Buk & Knight, 2010; Anderson *et al.,* 2020). Black rhinos tend to highly utilize browses that are widely available in their habitat (Kotze & Zacharias, 1993; Muya & Oguge, 2000; Ganqa *et al.,* 2005). A similar trend was observed in MRS, where three forage species namely: *Acalypha ornate, Grewia similis,* and *Commiphora africana,* were vastly available and highly browsed in order of importance by black rhinos, contributing 58.17% and 45.62% of the consumed diet in the dry and wet seasons, respectively.

Species of *Acalypha fruticosa, Grewia villosa*, *Barleria submollis, Maerua edulis* and *Acacia melifera* were also consumed throughout the year, while other species showed seasonal availability and consumption, such as *Commelina africana* and *Acacia bussei* in the wet season and *Barleria submollis* and *Blepharispermum zanzibarica* in the dry season. The dependence of black rhinos on a few browses strongly limits their food resources. It is therefore important to monitor the distribution and abundance of highly consumed species to sustain rhino food availability. Additionally, further research on either sexual or asexual propagation of native and useful species should be considered to improve the spread and coverage of the most preferred species.

4.2.2 Comparison of Edible Plant Species by Rhinos in Mkomazi Rhino Sanctuary and within Africa Savannah

The selected fourteen rhino range areas are representative of various habitats and several forage species consumed by black rhinos in Africa savannah. Results from the analysis of literature data show a similar trend in edible families by rhinos throughout the year in MRS and in fourteen rhino range areas but differ in quantities in each season based on availability. Family *Burseraceae* is not observed on the top list in fourteen rhino range areas, but it is vastly available, highly nutritious, and consumed by black rhinos in MRS and in other rhino range areas within Africa (Mukinya, 1973; Muya & Oguge, 2000).

More than 85% of forage species edible in large quantities in fourteen rhino range areas within African savannah in wet and dry seasons belong to the same genera and species consumed by rhinos in MRS despite being identified by different methodologies. Species of *Grewia similis, Acalypha fruticosa, Commiphora africana, Commelina africana, Maerua edulis, Achyranthes aspera, Hibiscus micranthus, Acacia drepanolobium* and *Acacia melifera* that are consumed by black rhinos in MRS in the wet and dry seasons are correspondingly consumed in fourteen rhino range areas (Mukinya, 1977; Oloo *et al.,* 1994; Muya & Oguge, 2000; Buk & Knight, 2010; Anderson *et al.,* 2020). Species that belong to *Acacia, Acalypha, Grewia a*nd *Barleria* genera found in 14 rhino range areas are similarly consumed in MRS; for example, *Acalypha ornata, Barleria submollis, Grewia villosa* and *Acacia melifera.* Contrary to MRS, which shows less consumption of *Acacia* species by black rhinos, several studies have reported high utilization in both seasons. Species that are not observed in the list of five most edible forages in fourteen rhino range areas but are consumed in MRS in the wet season (*Maytenus mossambicensis* and *Canthium glaucum)* and dry season (*Blepharispermum zanzibarica* and *Maytenus mossambicensis)* are highly preferred by rhinos and very nutritious (Dierenfeld *et al.,* 1995). Based on the evidence that preference for forage species by rhinos is due to their high nutritional value (Muya & Oguge, 2000), it is likely that rhinos are selecting these species in MRS to meet their dietary requirements.

4.2.3 Abundance and Composition of Plant Species Browsed by Black Rhinos at Mkomazi Rhino Sanctuary

The forage composition in the MRS falls within the findings of previous studies conducted within rhino range areas in sub-Saharan Africa. Ngorongoro reported 191 plant species from 49 families, including Laikipia (103 species from 37 families), Tsavo National Park (102 species from 32 families), Masai Mara (70 species), Great Fish River Reserve (80 species), and Luangwa Valley (220 species) (Goddard, 1968, 1970; Mukinya, 1973, 1977; Williams, 1985; Van Lieverloo *et al.,*

2009; Buk & Knight, 2010). The composition of browsed species from previous studies differed between sites due to browse availability, preference for black rhinos and seasonality. Findings in this study concur with earlier studies showing presence of varied forage species compositions in rhino habitats (Buk & Knight, 2010), which confirms the suitability of MRS in terms of providing varying amounts of forage for the diet of the black rhino population. Moreover, results show the highest percentage contribution of shrubs to the diet and dominance of shrubs over others in both seasons. According to earlier studies (Muya & Oguge, 2000), this is important to black rhino forage since most woody vegetation is consumed within the reach below the height of 2 m (Kotze & Zacharias, 1993). Therefore, it is important to consider both plant species and height of available forage for diet when assessing habitat suitable for breeding black rhinos.

4.2.4 Diversity of Plant Species Browsed by Black Rhinos at Mkomazi Rhino Sanctuary

Generally, the wet season is more diverse than the dry season in MRS, which implies that forage in the wet season constitutes a higher composition of plant species than in the dry season. These findings are consistent with the findings in previous studies from southern and eastern Africa, where the overall diversity of forage species browsed by black rhinos was found to be greater during the wet season than during the dry season in a range of habitats (Mukinya, 1977; Oloo *et al.,* 1994). Also, a low diversity in consumed dietary forage compared with available forage for diet in both seasons suggests that not all available forage for diet is consumed by rhinos, but they tend to select few species based on preference and the ability to convey maximum nutrient benefits (Mukinya, 1977; Anderson *et al.,* 2020; Lieverloo *et al.,* 2009). The diversity of browsed trees is similar in both seasons because rhinos likely consume small trees of similar plant species composition in both seasons; however, a significantly lower variation in diversity for shrubs and herbs in the dry season indicates that rhinos select green leaves and twigs from different forage species when shrubs shed off leaves and many herbs dry out.

4.2.5 Preferences of Plant Species by Black Rhinos

The preference for forage species by rhinos is likely due to their high nutritional value, which positively impacts rhino health stability (Dierenfeld *et al.,* 1995; Muya & Oguge, 2000) and availability. Findings from this study show a shift in forage preference during the dry season to avoid leafless plants and an increased preference for dry-tolerant plants and highly nutritious plants, such as *Balanites aegyptiaca* and *Acalypha fruticosa.* This suggests that black rhinos tend to shift their preferences based on forage quality and availability and integrate consumption of diet with availability to satisfy their nutritional requirements for their survival (Muya & Oguge, 2000). The preference for *Acalypha, Balanites, Barleria, Grewia* and *Hibiscus* observed in MRS is similar

to other studies conducted in rhino range areas within Africa savannah (Muya & Oguge, 2000; Ganqa *et al.,* 2005; Lieverloo *et al.,* 2009; Goza *et al.,* 2019). *Acacia* and *Commiphora* species are less preferred by rhinos despite being highly available in MRS because most of them are taller trees with heights above 2 m and hence are not broadly accessible by rhinos for diet. These findings therefore suggest that a key habitat factor important in black rhinoceros conservation includes diverse plant species that are at a height below 2 m (Kotze & Zacharias, 1993; Muya & Oguge, 2000).

Black rhinos in MRS have a restricted diet with a preference for a few key plant species and therefore tend to select leafy species and few wet twig species in the dry season. The browsing intensity by rhinos on the most preferred forages is extremely high during dry periods of the year to the extent that it might cause loss of some favourite species for rhinos diet in MRS. Apart from less availability, high population density observed is among the causes of deteriorating habitat quality (Okita-Ouma *et al.,* 2021). This may accelerate browsing intensity on remaining preferred forage species and cause depletion of forage resources in MRS, which consequently lowers rhino health and breeding performance. Through field observations in MRS, preferred species such as *Acalypha fruticosa, Balanites aegyptiaca, Hymenodictyon parvifolium, Grewia similis, Barleria submollis,* and *Maerua edulis,* which are highly nutritious, were highly browsed during the dry season. Therefore, these species should be monitored as critical species to provide dry season diet for black rhinos in MRS. Additionally, Ijdema, (2007) suggests that diet overlaps with other browsers could further reduce the capacity of the vegetation to sustain the browser population through the dry season. Therefore, despite the observation of relatively few kudus during field observation in MRS, the status of potential competitors of the black rhino diet in the sanctuary has to be established.

4.2.6 Nutrient Composition of Browse Species Preferred by Black Rhinos in Mkomazi Rhino Sanctuary

Rhinos select plant species based on a diverse array of physical characteristics and nutritional contents. Protein, fats, and carbohydrates are the essential nutrients reported in several studies to have a vital role in animal health (Dierenfeld *et al.,* 1999; 2006; Kumar *et al.,* 2021). Macro and trace essential elements have diverse functions in an animal body, including physiological, catalytic, structural, and regulatory functions (Kumar *et al.,* 2021). The results of nutrient composition observed in MRS are discussed in relation to the observed difference between the concentrations of nutrients in forage species consumed in MRS and the concentration of plant nutrients reported in browses consumed by free-ranging black rhinos in Africa savannah. Results show that the average range value of nutrients evaluated in forage species that are preferred by

black during wet and dry seasons in MRS are similar to the average level for crude protein, crude fat, crude fibre, carbohydrate, and ash reported in browses consumed by free-ranging black rhino within Africa savannah (Ghebremeskel *et al.,* 1991; Dierenfeld *et al.,* 1995) (Appendix 3). The mean crude protein reported in the wet season is within the marginal ranges recommended for adult rhinos and equine for maintenance and reproduction (7 –12% of DM) (Dierenfeld *et al.,* 2006), but dietary protein levels reported in the dry season are low and may decrease by 30% when unavailable protein found in the lignin fraction of browses was chemically subtracted from crude protein as described by Dierenfeld *et al.* (2000, 2006). Crude protein and crude fat values measured in this study provide a direct indicator for their availability during the wet season and deficiency during the dry season. Based on this observation, black rhinos in MRS are likely to consume low crude protein and crude fat forage during the dry seasons, which may likely accelerate poor body condition and low reproduction. Additionally, a minimum crude fat and high carbohydrate value on preferred food plants during the dry season was also reported in a study conducted by Hariyadi *et al.* (2015). A high value of structural carbohydrates observed in *A. fruticose, B. aegyptiaca and H. parvifolium* during the dry season is likely the major source of energy contributing to rhino health when subjected to nutritional stress under low crude protein and crude fat. Therefore, crude protein and crude fat diets should be considered when planning measures to improve rhino health, body condition status and reproductive performance, especially in dry seasons in MRS.

Results for elemental nutrients for the preferred browses documented in this study during wet and dry seasons are within the range values reported in other studies that detailed mineral composition for Ca, Mg, K, P, Na, Cu, Fe, Mn, and Zn (Appendix 4) for the black rhino browses (Brett *et al.,* 1991; Maskall & Thornton, 1991; Dierenfeld *et al.,* 1995; Duncan & Poppi, 2008; Dierenfeld *et al.,* 2011). Divergence is observed in Mg and K, which are in excess (Mg by 51% and K by 40%) in the wet season; Zn, which is marginally lower in both (wet by 45% and dry by 35%) seasons; and Cu, which is excessively higher in both (wet by 59% and dry by 74%) seasons. These findings seem consistent with those of plants consumed by black rhinoceros in the Zambezi Valley, which reported high dietary K and deficiency in Zn (Dierenfeld *et al.,* 1995). Zinc deficiency in the diet may lead to the development of skin and foot lesions in rhinos and domestic horses (Clauss & Hatt, 2006) and hence should be monitored in the sanctuary. Furthermore, Ca and P play a vital role in metabolic processes in the animal body and in MRS, and their levels are optimum in most preferred and highly nutritious forage species of *M. mossambicensis* in the wet season and *Balanites aegyptiaca* in the dry season.

According to Buk and Knight (2010), the serenity of browsing intensity on preferred browse depends on availability. A similar trend has been observed in MRS, where browsing intensity

increases with forage preference in both seasons but becomes prominent when browse availability is low during the dry seasons. The browsing intensity is low to pecies of *M. mossambicensis, A. fruticosa* and *A. ornata* consumed by rhinos in the wet season because rhinos have diverse array of nutritious species to select in the habitat that provide substantial quantities of essential nutrients. Moreover, browsing intensity by rhinos to species of *A. fruticosa, B. aegyptiaca* and *G. similis* is high during the dry season because forage species are less available in the habitat and rhinos has few options. The highly browsed forages fail to adequately provide sufficient nutrition that supports rhino health despite being highly nutritious. Furthermore, the deficiency of preferred browses (*A. fruticosa, B. aegyptiaca* and *G. similis*), which are highly nutritious during the dry season due to overutilization, is likely the cause of the poor body condition observed in black rhinos in MRS. Therefore, the evaluated nutritional composition of preferred food plants provides important information for the management of nutrient balance for black rhinos in the sanctuary.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1   Conclusion

In this study, forages consumed by black rhinos were highly abundant and diverse in wet season than dry season and was contributed by the availability of adequate diet for rhinos in wet season than dry seasons in MRS. The findings of this study reveal that the most preferred food plants are also highly nutritious in terms of nutritional composition and black rhinos have high preference for browses with high nutritional values during both seasons, but wet season was more nutritious than dry seasons. The similarity in forage species browsed by black rhinos in MRS and other rhino range areas within Africa savannah observed in this study qualifies MRS as the best breeding site and a safe home for black rhino in the park. The findings further indicated that browsing intensity increased with forage preference in both seasons and was prominent when browse availability was low in dry seasons. This led to intense foraging competition among rhinos and other browsers in the sanctuary and caused depletion of food resources to sustain the black rhino population during the dry season in the sanctuary. Furthermore, the low level of crude protein and crude fat observed in browses preferred by rhinos, high browsing intensity and limited quantity of forage observed during the dry season when compared with wet seasons are likely the major causes of the accelerated poor body condition status observed in rhinos at MRS. This study has further provided valuable information to wildlife managers in developing future management programs for the diet of black rhinos in intensively managed sanctuaries that does not have natural dynamics such as MRS in Tanzania and other sanctuaries in African savannah at large.

5.2   Recommendations

(i)   A management recommendation resulting from this study is to enhance habitat quality by establishing a monitoring program of the most preferred and highly nutritious forage species, such as *A. fruticosa and B. aegyptiaca* (high protein and energy); *G. similis* (high protein); and *B. aegyptiaca* and *H. parvifolium* (high fat and energy), during the dry season to sustain their availability. Additionally, further research on either sexual or asexual propagation of these native and useful species should be considered to improve their spread and coverage in MRS to support the population of critically endangered species in MRS.

(ii)   Mineral concentrations in forage consumed by black rhinos should be monitored. Additionally, mineral licks, especially zinc and others, should be provided to rhinos in the sanctuary, as it is possible that not all their mineral requirements are being met.

(iii)   Furthermore, an adaptation option to mitigate against the impacts of high browsing intensity by rhinos on preferred browses during prolonged drought periods is to supplement rhinos with a lucerne diet to improve their body condition status and health.

(iv)   Since forage depletion in MRS is contributed by the high number of rhinos in the sanctuary (current population density is 0.55 rhinos per square kilometer) compared to the established ecological carrying capacity of 0.45 rhinos per square kilometer, this study recommends further population management actions, including translocation of excess rhinos or expanding the sanctuary area to meet the recommended ecological carrying capacity. This will improve the availability of forage resources through regeneration of overbrowsed forages and expansion of forage coverage and productivity.

(v)   In the course of improving the management of the sanctuary and promoting rhino health and reproductive performance, this study recommends further studies for assessing browse production, soil quality and density of other competitor herbivores in the sanctuary.

(vi)   Furthermore, for future studies of the rhino diet, the use of faecal analyses over indirect observation techniques used in this study is highly recommended to further understand the diet of black rhinos in MRS and within Tanzania and Africa at large.

REFERENCES

Adcock, K. (2017). *Visual Assessment of Black Rhino Browse Availability, Version 3.2*. https://doi.org/10.13140/RG.2.2.27760.76803

Aletan, U. I., & Kwazo, H. A. (2019). *Analysis of the Proximate Composition, Anti-Nutrients, and Mineral Content of Maerua Crassifolia Leaves*. https://scholar.google.com

Amin, R., Thomas, K., Emslie, R. H., Foose, T. J., & Strien, N. V. (2006). An overview of the conservation status of and threats to rhinoceros species in the wild. *International Zoo Yearbook*, *40*(1), 96–117. https://doi.org/10.1111/j.1748-1090.2006.00096.x

Anderson, T. M., Ngoti, P. M., Nzunda, M. L., Griffith, D. M., Speed, J. D. M., Fossøy, F., Røskaft, E., & Graae, B. J. (2020). The burning question: Does fire affect habitat selection and forage preference of the black rhinoceros Diceros bicornis in East African savannahs? *Oryx*, *54*(2), 234–243. https://doi.org/10.1017/S0030605318000388

AOAC. (1990). *Association of Official Analytical Chemists.* https://scholar.google.com

Ariya, G., Sitati, N., & Wishitemi, B. (2017). Tourists' perceived value of wildlife tourism product at Lake Nakuru National Park, Kenya. *European Journal of Tourism, Hospitality and Recreation*, *8*(2), 147–156. https://doi.org/10.1515/ejthr-2017-0014

Brett, R. (1998). Mortality factors and breeding performance of translocated black rhinos in Kenya: 1984–1995. *Pachyderm, 26*, 1984–1995.

Buk, K. G., & Knight, M. H. (2010). Seasonal diet preferences of black rhinoceros in three arid South African National Parks. *African Journal of Ecology*, *48*(4), 1064–1075. https://doi.org/10.1111/j.1365-2028.2010.01213.x

Cheung, H., Mazerolle, L., Possingham, H. P., & Biggs, D. (2018). Medicinal Use and Legalized Trade of Rhinoceros Horn From the Perspective of Traditional Chinese Medicine Practitioners in Hong Kong. *Tropical Conservation Science*, *11*, 1940082918787428.

Clauss, M. (2003). *Tannins in the Nutrition of Wild Animals: A Review*. https://scholar.google.com

Clauss, M., Castell, J. C., Kienzle, E., Schramel, P., Dierenfeld, E. S., Flach, E. J., Behlert, O., Streich, W. J., Hummel, J., & Hatt, J. M. (2007). Mineral absorption in the black

rhinoceros (Diceros bicornis) as compared with the domestic horse. *Journal of Animal Physiology and Animal Nutrition*, 91(5-6), 193-204.

Clauss, M., & Hatt, J. M. (2006). The feeding of rhinoceros in captivity. *International Zoo Yearbook*, 40(1), 197-209.

Conrad, K. (2012). Trade Bans: A Perfect Storm for Poaching? *Tropical Conservation Science*, *5*(3), 245–254. https://doi.org/10.1177/194008291200500302

DeBoer, M. (2015). Understanding the heat map. *Cartographic Perspectives,* (80), 39-43.

Dierenfeld, E. S., Du Toit, R., & Braselton, W. E. (1995). Nutrient composition of selected browses consumed by black rhinoceros (*Diceros bicornis*) in the Zambezi Valley, Zimbabwe. *Journal of Zoo and Wildlife Medicine*, 1995, 220–230.

Dierenfeld, E. S., Kilbourn, A., Karesh, W., Bosi, E., Andau, M., & Alsisto, S. (2006). Intake, utilization, and composition of browses consumed by the Sumatran rhinoceros (*Dicerorhinus sumatrensis harissoni*) in captivity in Sabah, Malaysia. *Zoo Biology*, *25*(5), 417–431. https://doi.org/10.1002/zoo.20107

Dierenfeld, E. S., Wildman, R. E. C., & Romo, S. (2000). Feed intake, diet utilization, and composition of browses consumed by the Sumatran rhino (*Dicerorhinus sumatrensis*) in a North American zoo. *Zoo Biology*, *19*(3), 169–180. https://doi.org/10.1002/1098-2361(2000)19:3<169::AID-ZOO1>3.0.CO;2-D

Dierenfield, E., Toit, R., & Braselton, W. E. (2011). Nutrient Composition of Selected Browses Consumed by Black Rhinoceros (*Diceros bicornis*) in the Zambezi Valley, Zimbabwe. *Journal of Zoo and Wildlife Medicine*, *26*(2), 220–230.

Duncan, A. J., & Poppi, D. P. (2008). Nutritional Ecology of Grazing and Browsing Ruminants. In I. J. Gordon & H. H. T. Prins (Eds.), *The Ecology of Browsing and Grazing* (pp. 89–116). Springer. https://doi.org/10.1007/978-3-540-72422-3_4

Duthé, V., Glauser, G., Defossez, E., Rasmann, S., & Westhuizen, R. V. D. (2020). *Out of Scale Out of Place: Black Rhino Forage Preference across the Hierarchical Organization of the Savanna Ecosystem*. https://scholar.google.com

Emslie. (2020). *Diceros bicornis: Emslie, R. The IUCN Red List of Threatened Species 2020: e.T6557A152728945* [Data set]. International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.UK.2020-1.RLTS.T6557A152728945.en

Emslie, R., & Brooks, M. (1999). *African Rhino. Status Survey and Conservation Action Plan. IUCN/SSC African Rhino Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK. ix + 92 pp.* IUCN, Gland, Switzerland, and Cambridge, UK.

Martin, E., & Martin, C. (2010). Enhanced community support reduces rhino poaching in Nepal. *Pachyderm,* 48, 48-56.

Ferreira, S. M., le Roex, N., & Greaver, C. (2019). Species-specific drought impacts on black and white rhinoceroses. *PLoS One,* 14(1), e0209678.

Fowler, C. W. (1987). A review of density dependence in populations of large mammals. *Current Mammalogy*, 1987, 401–441.

Ganqa, N., Scogings, P., & Raats, J. (2005). Diet selection and forage quality factors affecting woody plant selection by black rhinoceros in the Great Fish River Reserve, South Africa. *South African Journal of Wildlife Research*, *35*, 77–83.

Ghebremeskel, K., Williams, G., Brett, R. A., Burek, R., & Harbige, L. S. (1991). Nutrient composition of plants most favoured by black rhinoceros (*Diceros bicornis*) in the wild. *Comparative Biochemistry and Physiology Part A: Physiology*, *98*(3–4), 529–534.

Goddard, J. (1968). Food preference of two black rhinoceros populations. *African Journal of Ecology*, *6*, 1–18. https://doi.org/10.1111/j.1365-2028.1968.tb00898.x

Goddard, J. (1970). Food preferences of black rhinoceros in the Tsavo National Park. *African Journal of Ecology*, *8*(1), 145–161.

Goza, D., Zisadza-Gandiwa, P., Mashapa, C., Muboko, N., & Gandiwa, E. (2019). Assessment of Browse Availability and Suitability for Black Rhino's Re-Introduction in Northern Gonarezhou National Park, Southeastern Zimbabwe. *Open Journal of Ecology*, *9*(09), 326.

Grauso, L., De Falco, B., Lanzotti, V., & Motti, R. (2020). Stinging nettle, Urtica dioica L.: Botanical, phytochemical and pharmacological overview. *Phytochemistry Reviews*, *19*(6), 1341–1377. https://doi.org/10.1007/s11101-020-09680-x

Gyöngyi, K., & Elmeros, M. (2017). Forage choice of the reintroduced black rhino and the availability of selected browse species at Majete Wildlife Reserve, Malawi. *Pachyderm*, *2017*(58), 40–50.

Hall-Martin, A. J., Erasmus, T., & Botha, B. P. (1982). Seasonal variation of diet and faeces composition of Black Rhinoceros *Diceros Bicornis* in the Addo Elephant National Park. *Koedoe*, *25*(1), 63–82. https://doi.org/10.4102/koedoe.v25i1.605

Hall-Martin, A. J., Erasmus, T., & Botha, B. P. (1982). Seasonal variation of diet and faeces composition of black rhinoceros Diceros bicornis in the Addo Elephant National Park. *Koedoe*, 25(1), 63-82.

Hariyadi, A. R. S., Sajuthi, D., Astuti, D. A., Alikodra, H. S., & Maheshwari, H. (2015). Analysis of nutritional quality and food digestibility in male Javan rhinoceros (*Rhinoceros sondaicus*) in Ujung Kulon National Park. *Pachyderm*, *57*, 86–96.

Helary, S. F., Shaw, J. A., Brown, D., Clauss, M., & Owen-Smith, N. (2012). Black rhinocerous (*Diceros Bicornis*) Natural diets: Comparing Iron Levels Across Seasons and Geographical Locations. *Journal of Zoo and Wildlife Medicine*, *43*(3s), S48–S54.

Hillman-Smith, A. K. K., & Groves, C. P. (1994). Diceros bicornis. *Mammalian Species*, *455*, 1–8. https://doi.org/10.2307/3504292

Hutchins, M., & Kreger, M. D. (2006). Rhinoceros behaviour: Implications for captive management and conservation. *International Zoo Yearbook,* 40(1), 150-173.

Ijdema, H. (2007). *Competition Between Black Rhinoceros (Diceros Bicornis) and Greater Kudu (Tragelaphus Strepsiceros) in the Great Fish River Reserve, South Africa*. https://scholar.google.com

Kartzinel, T. R., Chen, P. A., Coverdale, T. C., Erickson, D. L., Kress, W. J., Kuzmina, M. L., Rubenstein, D. I., Wang, W., & Pringle, R. M. (2015). DNA metabarcoding illuminates dietary niche partitioning by African large herbivores. *Proceedings of the National Academy of Sciences*, *112*(26), 8019–8024. https://doi.org/10.1073/pnas.1503283112

Knight, M. H., & Morkel, P. (1994). *Assessment of the Proposed Mkomazi Rhino Sanctuary, Mkomazi Game Reserve, Tanzania. Unpublished Report.* https://scholar.google.com

Kotze, D. C., & Zacharias, P. J. K. (1993). Utilization of woody browse and habitat by the black rhino (*Diceros bicornis*) in western Itala Game Reserve. *African Journal of Range & Forage Science*, *10*(1), 36–40. https://doi.org/10.1080/10220119.1993.9638319

Kumar, M., Puri, S., Pundir, A., Bangar, S. P., Changan, S., Choudhary, P., Parameswari, E., Alhariri, A., Samota, M. K., & Damale, R. D. (2021). Evaluation of nutritional, phytochemical, and mineral composition of selected medicinal plants for therapeutic uses from cold desert of Western Himalaya. *Plants*, *10*(7), 1429.

Van Lieverloo, R. J., Schuiling, B. F., De Boer, W. F., Lent, P. C., De Jong, C. B., Brown, D., & Prins, H. H. (2009). A comparison of faecal analysis with backtracking to determine the diet composition and species preference of the black rhinoceros (*Diceros bicornis minor*). *European Journal of Wildlife Research,* 55, 505-515.

Mabinya, L. V., Brand, J. M., Raats, J. G., & Trollope, W. S. W. (2002). Estimation of grazing by herbivores from analysis of dung. *African Journal of Range & Forage Science*, *19*(3), 175–176. https://doi.org/10.2989/10220110209485791

Makaure, J., & Makaka, C. (2013). Dry Season Browse Preference for the Black Rhinoceros (*Diceros bicornis)*: The Case of the Midlands Black Rhino Conservancy (MBRC), Zimbabwe. *Greener Journal of Biological Sciences*, *3*(1), 031–047.

Maskall, J., & Thornton, I. (1991). Trace element geochemistry of soils and plants in Kenyan conservation areas and implications for wildlife nutrition. *Environmental Geochemistry and Health*, *13*(2), 93–107. https://doi.org/10.1007/BF01734300

Mills, A., Morkel, P., Amiyo, A., Runyoro, V., Borner, M., & Thirgood, S. (2006). Managing small populations in practice: Black rhino Diceros bicornis michaeli in the Ngorongoro Crater, Tanzania. *Oryx*, *40*(3), 319-323.

MNRT. (2018). *Conservation and Management Plan for the Black Rhinoceros (Diceros Bicornis Michaeli & Diceros Bicornis Minor) In Tanzania, (2018-2023). The 4th Edition (Wildlife Division, Ministry of Natural Resources and Tourism, Tanzania).* https://scholar.google.com

Morgan, S., Mackey, R. L., & Slotow, R. (2009). A priori valuation of land use for the conservation of black rhinoceros (*Diceros bicornis)*. *Biological Conservation*, *142*(2), 384–393. https://doi.org/10.1016/j.biocon.2008.10.033

Mseja, G. A., Kisingo, A. W., Stephan, E., & Martin, E. H. (2020). Dry Season Wildlife Census in Mkomazi National Park, 2015. In J. O. Durrant, E. H. Martin, K. Melubo, R. R. Jensen, L. A. Hadfield, P. J. Hardin, & L. Weisler (Eds.), *Protected Areas in Northern Tanzania* (Vol. 22, pp. 133–143). Springer International Publishing. https://doi.org/10.1007/978-3-030-43302-4_10

Mukinya, J. G. (1973). Density, distribution, population structure and social organization of the black rhinoceros in Masai Mara Game Reserve. *African Journal of Ecology*, *11*(3–4), 385–400.

Mukinya, J. G. (1977). Feeding and drinking habits of the black rhinoceros in Masai Mara Game Reserve. *African Journal of Ecology*, *15*(2), 125–138. https://doi.org/10.1111/j.1365-2028.1977.tb00386.x

Muntifering, J. R., Clark, S., Linklater, W. L., Uri-Khob, S., Hebach, E., Cloete, J., Jacobs, S., & Knight, A. T. (2020). Lessons from a conservation and tourism cooperative: The Namibian black rhinoceros case. *Annals of Tourism Research*, *82*, 102918.

Muntifering, J. R., Linklater, W. L., Naidoo, R., Du Preez, P., Beytell, P., Jacobs, S., & Knight, A. T. (2021). Black rhinoceros avoidance of tourist infrastructure and activity: Planning and managing for coexistence. *Oryx*, 55(1), 150-159.

Muya, S. M., & Oguge, N. O. (2000). Effects of browse availability and quality on black rhino (*Diceros bicorni*s michaeli Groves 1967) diet in Nairobi National Park, Kenya. *African Journal of Ecology*, *38*(1), 62–71. https://doi.org/10.1046/j.1365-2028.2000.00213.x

Okello, M. M., & Grasty, K. (2009). The Role of Large Mammals and Protected Areas to Tourist Satisfaction in the Northern Circuit, Tanzania. *Tourism Analysis*, *14*(5), 691–697. https://doi.org/10.3727/108354209X12597959359419

Okita-Ouma, B., Pettifor, R., Clauss, M., & Prins, H. H. T. (2021). Effect of high population density of eastern black rhinoceros, a mega-browser, on the quality of its diet. *African Journal of Ecology*, *59*(4), 826–841. https://doi.org/10.1111/aje.12893

Okita-Ouma, B., van Langevelde, F., Heitkönig, I. M. A., Maina, P., van Wieren, S. E., & Prins, H. H. T. (2021). Relationships of reproductive performance indicators in black rhinoceros (*Diceros bicornis michaeli*) with plant available moisture, plant available nutrients and woody cover. *African Journal of Ecology*, *59*(1), 2–16. https://doi.org/10.1111/aje.12779

Oloo, T. W., Brett, R., & Young, T. P. (1994). Seasonal variation in the feeding ecology of black rhinoceros (*Diceros bicornis* L.) in Laikipia, Kenya. *African Journal of Ecology*, *32*(2), 142–157. https://doi.org/10.1111/j.1365-2028.1994.tb00565.x

Parker, D. M., & Bernard, R. T. F. (2006). A Comparison of Two Diet Analysis Techniques for a Browsing Megaherbivore. *Journal of Wildlife Management*, *70*(5), 1477–1480.

Petrides, G. A. (1975). Principal foods versus preferred foods and their relations to stocking rate and range condition. *Biological Conservation*, *7*(3), 161–169.

Reuter, H. O., & Adcock, K. (1998). Standardized body condition scoring system for black rhinoceros (diceros bicornis). *Pachyderm*, *26*, 116–121.

Rookmaaker, L. C. (2004). Historical distribution of the black rhinoceros (Diceros bicornis) in West Africa. *African Zoology*, *39*(1), 63–70.

Sebele, L. S. (2010). Community-based tourism ventures, benefits and challenges: Khama Rhino Sanctuary Trust, Central District, Botswana. *Tourism Management*, *31*(1), 136–146.

Tatman, S. C., Stevens-Wood, B., & Smith, V. B. T. (2000). Ranging behaviour and habitat usage in black rhinoceros, Diceros bicornis, in a Kenyan sanctuary. *African Journal of Ecology*, *38*(2), 163–172. https://doi.org/10.1046/j.1365-2028.2000.00235.x

Tchamba, M. N. (1995). The impact of elephant browsing on the vegetation in Waza National Park, Cameroon. *African Journal of Ecology*, *33*(3), 184–193.

Tererai, F., Gaertner, M., Jacobs, S. M., & Richardson, D. M. (2013). Eucalyptus invasions in riparian forests: Effects on native vegetation community diversity, stand structure and composition. *Forest Ecology and Management*, *297*, 84–93.

Trivedi, S., Burnham, C. M., Capobianco, C. M., Boshoff, C., Zheng, Y., Pettiglio, J. W., Ange-van Heugten, K., Bissell, H. D., & Minter, L. J. (2021). Analysis of Blood Biochemistry of Free Ranging and Human-Managed Southern White Rhinoceros (Ceratotherium simum simum) Using the i-STAT Alinity v®. *Veterinary Medicine International*, *2021*, 1–6. https://doi.org/10.1155/2021/2665956

Valley, Z., Dierenfeld, E. S., Toit, R., Braselton, W. E., Dierenfeld, E. S., Ph, D., Toit, R., & Braselton, W. E. (2015). *Nutrient Composition of Selected Browses Consumed by Black Rhinoceros (Diceros bicornis) in the Zambezi Valley, Zimbabwe*. *26*(2), 220–230.

Venkatachalam, P. (2006). GIS as a tool for development. *Durrell Institute of Conservation & Ecology (DICE)*, *28*, 95.

Williams, N. L. (1985). Black rhino in South Luangwa National Park: Their distribution and future protection. *Oryx*, *19*(1), 27–33. https://doi.org/10.1017/S0030605300019517

Winkel, F. (2004). *Diet choice of the black rhinoceros (Diceros bicornis) in the Double Drift Game Reserve, Eastern Cape Province, South Africa. Double Drift Game Reserve, Eastern Cape Province, South*. *October*. https://scholar.google.com

Young, J. K., Gerber, L. R., & D'Agrosa, C. (2007). Wildlife Population Increases in Serengeti National Park. *Science*, *315*(5820), 1790–1791.

APPENDICES

Appendix 1: **Pictures showing some of the preferred browse species consumed by rhinos in wet and dry seasons observed during field data collection in MRS**

Grewia similis: A shrub highly consumed by rhinos during both wet and dry seasons in MRS

Balanites aegyptiaca: A tree consumed by rhinos in both season and preferred most during the dry season due to succulent in nature.

Acacia nilotica: A tree with true signs of black rhino browsing. This plant is consumed and preferred by rhinos in both season in MRS.

Acacia drepanolobium: A shrub with true sign of black rhino cutting observed during the wet season in MRS.

Acalypha fruticosa: A shrub consumed and preffered by black rhinos in both seasons in MRS. This photo was taken during the dry season when when leaves shedoff, rhinos consumed twigs only.
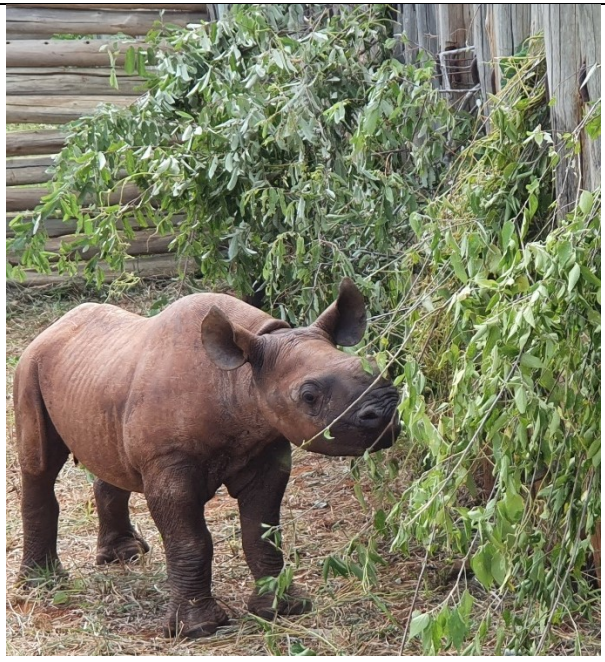
Acalypha ornata: A very nutirious and highly preferred browse consumed by an ophanage rhino calf inside the holding compound in MRS.

Hymenodictyon parvifolium: A semi succulent tree favoured by black rhinos during dry season due to its ability to retain water in dry periods

Maerua edulis: A shrub fovoured by black rhinos during the dry season. This plant is consumed by black rhinos during dry season in MRS

NB: *All photos were taken by Emanuel Sisya during field survey in November 2021 and May 2023.*

Appendix 2:   List of plant species available for diet and those consumed by black rhinos in wet and dry seasons in MRS observed during the field survey in 2020/2021

Family and Plant name	Life form	WET SEASON		DRY SEASON	
Barleria submollis	Herb	365	152	354	323
Barleria prionitis	Herb	352	84	89	74
Barleria sp	Herb	176	21		
Blepharis inopinata	Herb			28	25
Crabbea velutina	Herb	84	6		
Justicia flava	Herb	37	5		
Crabbea hirsuta	Herb	11	4		
Crabbea velutina	Herb			3	1
Blepharis maderaspatensis	Herb	10	2		
Neuracanthus africanus	Herb	4		8	4
Thunbergia guerkeana	Herb	1			
Justicia heterocarpa	Herb	1		2	1
Amaranthaceae	Herb				
Achyranthes aspera	Herb	268	46	76	67
Sericocomopsis hildebrandtii	Herb	97	24	49	39
Cyathula lanceolata	Herb	58	10	72	64
Anacardiaceae					
Lannea schweinfurthii	Shrub	49	45	36	33
Sclerocarya birrea	Shrub	28	14	32	16
Lannea humilis	Shrub	12	3	9	6
Apocynaceae					
Secamone parvifolia	Shrub	17	14		
Secamone attenuifolia	Shrub	3	2	2	1
Asparagaceae					
Asparagus africanus	Shrub	63	4	28	19
Asteraceae					
Blepharispermum zanzibarica	Shrub	56	56	218	173
Vernonia sp	Shrub	8			
Vernonia exsertiflora	Shrub	4	3	4	3
Blepharis inopinata	Shrub	1	1		
Burseraceae					
Commiphora africana	Tree	1794	712	1922	486
Commiphora abyssinica	Tree	122	78	175	108

Commiphora schimperi	Tree	80	21	118	16
Commiphora habessinica	Tree	17	12	32	28
Capparaceae					
Maerua edulis	Shrub	247	95	94	85
Maerua decumbens	Shrub	134	51	24	22
Capparis tomentosa	Shrub	73	55	39	35
Cadaba farinosa	Shrub	67	22	7	5
Boscia coriacea	Shrub	40	14		
Boscia angustifolia	Shrub	27	3	18	16
Maerua triphylla	Shrub	11	7	8	5
Cadaba trifoliata	Shrub	8	6	20	13
Cadaba kirkii	Shrub	6			
Boscia mossambirensis	Shrub	4	3	8	8
Boscia salicifolia	Shrub	4	1	4	2
Capparis fascicularis	Shrub	3	3		
Thylachium thomasii	Shrub	1	1	2	1
Celastraceae					
Maytenus mossambicensis	Shrub	168	150	82	71
Maytenus senegalensis	Shrub	9	8		
Combretaceae					
Combretum zeyheri	Shrub	81	38	154	140
Combretum aculeatum	Shrub	20	8		
Terminalia spinosa	Small tree	20	1	33	16
Terminalia brownii	Small tree	12			
Commelinaceae					
Commelina benghalensis	Herb	563	210		
Cucurbitaceae					
Zehneria sp	Herb	1			
Ebenaceae					
Euclea racemosa	Shrub	57	12		
Euclea natalensis	Shrub	5	1	3	1
Diospyros scabra	Shrub	2		14	8
Diospyros sp	Shrub	1			
Euphorbiaceae					
Acalypha ornata	Shrub	1814	1525	2759	2443

Acalypha fruticosa	Shrub	782	680	242	242
Euphorbia heterophylla	Shrub	8			
Croton dichogamus	Shrub	8	4	4	3
Fabaceae					
Acacia bussei	Tree	564	190	173	31
Acacia melifera	Tree	303	137	234	37
Acacia tortilis	Tree	283	89	449	2
Albizia anthelmintica	Tree	131	7	207	3
Acacia nilotica	Tree	108	14	130	25
Acacia drepanolobium	Tree	95	85		
Tephrosia villosa	Tree	88	6	8	7
Acacia brevispica	Tree	52	22	35	33
Tylosema esculentum	Small tree	52	52	5	5
Aeschynomene rubrofarinacea	Small tree	21	7	14	4
Glycine sp	Shrub	20	7		
Indigofera spicata	Shrub	7	5		
Xeroderris stuhlmannii	Tree	7			
Entada rheedii	Tree	7			
Indigofera hirsuta	Shrub	3	2	3	2
Lamiaceae					
Ocimum gratissimum	Herb	49	3	15	4
Clerodendrum eriophyllum	Herb	8	2		
Clerodendrum myricoides	Herb	2			
Loganiaceae					
Strychnos decussata	Tree	1	1		
Malvaceae					
Grewia similis	Shrub	1162	932	870	822
Grewia tomentosa	Shrub	493	394	381	339
Grewia kakothamnos	Shrub	292	108	151	16
Grewia forbesii	Shrub	172	127	7	7
Grewia platyclada	Shrub			13	9
Sida cordifolia	Shrub	128	71	18	17
Hibiscus micranthus	Herb	89	17	75	68
Sterculia africana	Small tree	58	44	72	44
Grewia sp	Shrub	37	22		

Grewia bicolor	Shrub	34	12	9	9
Abutilon mauritianum	Herb	26	10		
Tephrosia villosa	Herb	15			
Melhania velutina	Herb	14			
Hibiscus sp	Herb	6			
Sida ovata	Herb	2			
Grewia flavescens	Shrub	1			
Ochnaceae					
Ochna holstii	Shrub	5			
Ochna ovata	Shrub	2			
Olacaceae					
Jasminum fluminense	Shrub	8			
Ximenia caffra	Shrub	3		7	5
Rhamnaceae					
Ziziphus mucronata	Shrub	10	4		
Rubiaceae					
Canthium glaucum	Shrub	121	104		
Hymenodictyon parvifolium	Shrub	77	67	123	113
Rutaceae					
Vepris glomerata	Shrub	55	50	61	59
Vepris stolzii	Shrub	19	12	34	33
Vepris sp	Shrub	6	4		
Salvadoraceae					
Salvadora persica	Shrub	54	30	31	28
Sapindaceae					
Haplocoelum foliolosum	Shrub	7	3	7	4
Solanaceae					
Solanum incanum	Shrub	27	11	3	2
Verbenaceae					
Lippia kituiensis	Shrub			1	1
Vitaceae					
Cissus tridentata	Shrub	6			
Zygophyllaceae					
Balanites aegyptiaca	Tree	105	78	112	110

Appendix 3: **Comparison between the established average range value of the proximate composition of browses consumed by the black rhinos within rhino range areas in Africa savannah and those in MRS**

Nutrient composition	Average range values in MRS		Average range values in rhino range areas within Africa
	Wet (%)	Dry (%)	
Moisture	10.5 - 17.0	5.0 – 9.5	5.0 – 39%
Ash (DM)	3.1 – 15.1	4.7 – 15.3	3 – 16%
Crude Fibre (DM)	10.6 - 27.2	16.8 – 39.2	10.1 - 51.3%
Crude Fat (DM)	3.48 - 7.58	1.24 – 4.96	1.2 - 7.1%
Crude Protein (DM)	13.24 - 16.65	5.5 - 10.8	4.4 - 22%
Carbohydrate (DM)	28.45 - 39.67	31.62 - 48.14	24 – 60%

Ghebremeskel *et al.* (1991) and Dierenfeld *et al.* (1995)

Appendix 4: **Comparison between the established average range value of the elemental composition of browses consumed by the black rhinos within rhino range areas in Africa savannah and those in Mkomazi Rhino Sanctuary**

Elemental nutrient	Average range values in Mkomazi Rhino Sanctuary		Average range values in rhino range areas within Africa
	Wet	Dry	
Calcium (% DM)	0.86 - 3.94	1.59 - 4.34	0.7 - 4.9
Magnesium (% DM)	0.13 - 1.45	0.14 - 0.63	0.12 – 0.65
Potassium (% DM)	0.81 - 4.35	0.58 - 2.37	0.28 – 2.82
Phosphorus (% DM)	0.10 - 0.38	0.10 - 0.33	0.04 - 0.26
Sodium (% DM)	0.10 - 0.72	0.10 - 0.49	0.03 – 0.72
Copper (mg/kg DM)	5.67 - 30.77	6.87 – 50. 43	3 – 12
Iron (mg/kg DM)	18.94 - 69.88	39.40 – 87.60	25 - 125
Manganese (mg/kg DM)	19.67 - 84.47	32.57 – 96.70	5 - 120
Zinc (mg/kg DM)	10.30 0 44.70	13.77 – 45.57	30 - 50

Brett *et al.* (1991), Maskall and Thornton (1991), Dierenfeld *et al.* (1995), Duncan and Poppi (2008), and Dierenfield *et al.* (2011).

RESEARCH OUTPUTS

(i)   Publication

Sisya, E. S., Moyo, F., Martin, E. H., & Munishi, L. K. (2023). Does variation in plant diversity and abundance influence browsing intensity in black rhinos? *African Journal of Ecology*, 2023, 1-11.

(ii)   Poster Presentation