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**Article** *in* African Journal of Ecology · March 2023

DOI: 10.1111/aje.13145



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Received: 14 November 2022 | Revised: 26 February 2023 | Accepted: 27 February 2023

DOI: 10.1111/aje.13145

African Journal of Ecology WILEY

RESEARCH ARTICLE

# Does variation in plant diversity and abundance influence browsing intensity in black rhinos?

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**Funding information**
The Africa Centre for Research, Agricultural Advancement, Teaching Excellence and Sustainability (CREATES-FNS), Grant/Award Number: BG.129/649/04/69; Rufford Foundation, Grant/Award Number: 38518-1

## Abstract

Variations in forage availability, selection and preferences can lead to intense foraging competition and depletion of food consequently lowering diet quality and population performance of black rhino species. This study investigated seasonal variations in rhino diet, foraging, preference and browsing intensity and how this is influenced by plant diversity and availability in Mkomazi National Park (MKONAPA). Fifty-eight square grids were randomly selected in each season, and plots were laid for vegetation assessment during wet and dry seasons in the sanctuary. Browsed species by rhinos were compared with rhino feeding data from fourteen rhino range areas within Africa. More than 85% of species edible in MKONAPA were similar to those in rhino range areas. *Acalypha ornata*, *Grewia similis* and *Commiphora africana* were highly utilised specie in both seasons. Diversity and abundance of consumed browses decreased towards the dry season while browsing intensity increased with forage preference in both seasons and was prominent when browse availability was low in dry seasons. Our study established seasonal variation in dietary composition, browsing intensity and preferences for black rhinos. We suggest establishing nutritional composition of preferred forages, assessing density of competitor browsers, translocating excess rhinos or expanding the sanctuary to meet the recommended ecological carrying capacity.

KEYWORDS
black rhino forage, browse utilisation, browsing intensity, *Diceros bicornis*, forage availability, forage preference, mkomazi rhino sanctuary

## Résumé

Les variations dans la disponibilité, la sélection et les préférences en matière de fourrage peuvent entraîner une concurrence intense et l'épuisement de la nourriture, réduisant ainsi la qualité du régime alimentaire et les performances de la population de rhinocéros noirs. Cette étude a porté sur les variations saisonnières du régime alimentaire, de la recherche de nourriture, des préférences et de l'intensité du broutage des rhinocéros, et sur la manière dont ces variations sont influencées par la diversité et la disponibilité des plantes dans le Parc National de Mkomazi (MKONAPA). Cinquante-huit grilles carrées ont été sélectionnées au hasard pour chaque saison, et des parcelles ont été mises en place pour l'évaluation de la végétation pendant les saisons humides et sèches dans le sanctuaire. Les espèces broutées par les rhinocéros ont été comparées aux données sur l'alimentation des rhinocéros provenant de quatorze zones de l'aire

  

de répartition du rhinocéros en Afrique. Plus de 85 % des espèces comestibles dans le MKONAPA étaient similaires à celles des aires de répartition du rhinocéros. *Acalypha ornata*, *Grewia similis* et *Commiphora africana* ont été les espèces les plus utilisées au cours des deux saisons. La diversité et l'abondance des herbes consommées ont diminué vers la saison sèche, tandis que l'intensité du broutage a augmenté avec la préférence pour les fourrages au cours des deux saisons, et était plus importante lorsque la disponibilité des herbes était faible au cours des saisons sèches. Notre étude a établi la variation saisonnière de la composition du régime alimentaire, de l'intensité du broutage et des préférences chez les rhinocéros noirs. Nous suggérons d'établir la composition nutritionnelle des fourrages préférés, d'évaluer la densité des herbivores concurrents, de transférer les rhinocéros en surnombre ou d'agrandir le sanctuaire pour atteindre la capacité écologique recommandée.

## 1 | INTRODUCTION

Black rhinos (*Diceros bicornis*) are classified as browsers based on their selection of concentrated dicotyledonous plant types (small trees, shrubs and forbs) across several temporal and spatial scales (Ahrestani & Sankaran, 2016; Cerling et al., 2003; Duthé et al., 2020). Black rhino feeding intensity varies with age, size, sex and season, and they tend to select habitats according to forage abundance and availability (Metzger et al., 2007; Van Beest et al., 2010). In heterogeneous landscapes, rhinos tend to select habitat patches with high diversity and consume specific plants that maximise nutrient and energy intake (Owen-Smith et al., 2010); however, other factors, such as home ranges (Mitchell & Powell, 2012), distance to surface water and disturbances (Duthé et al., 2020), influence space use. In most savannah areas, black rhino concentrates on low woody plants and herbs (Owen-Smith, 1992; Parker et al., 2009), and they feed on significant amounts of leaves, twigs and branches of forage located between 0.5 m and 2.0 m above ground (Mukinya, 1977). Grasses have been reported to be an insignificant component of the diet for black rhinoceros (Mabinya et al., 2002; Owen-Smith, 1992; Parker et al., 2009).

The feeding selection pattern of black rhinos is mainly determined by habitat, availability and abundance of food (Mukinya, 1977). Black rhinos exhibit better healthy and reproductive performance in habitats that provide sufficient quality and quantity of food plants (Lashley et al., 2015; Okita-Ouma, Pettifor, et al., 2021; Okita-Ouma, van Langevelde, et al., 2021). Inadequate forage availability and quality may affect nutritional and body condition status of herbivores such as black rhinos which leads to nutritional stress (Hrabar & Du Toit, 2005; Okita-Ouma, Pettifor, et al., 2021; Okita-Ouma, van Langevelde, et al., 2021). Also, persistent high density of herbivores may result in a low-quality diet for both grazers (Owen-Smith, 2008) and browsers (Okita-Ouma, Pettifor, et al., 2021; Okita-Ouma, van Langevelde, et al., 2021). Mega-browsers (i.e. a browsing animal exceeding 1000 kg in body mass), particularly the hindgut fermenters such as the black rhinoceros, are not affected much by low nutritional quality forage when they are in free ranging environment because they can process plants of low nutritional quality and high concentrations of secondary compounds (Goddard, 1968, 1970; Hall-Martin et al., 1982; Mukinya, 1977; Okita-Ouma, Pettifor, et al., 2021; Okita-Ouma, van Langevelde, et al., 2021). However, its tolerance for low-quality browse can have significant impact on its habitat, body condition and reproductive performance in enclosed areas such as sanctuaries at high densities (Okita-Ouma, Pettifor, et al., 2021; Okita-Ouma, van Langevelde, et al., 2021).

The black rhinoceros are now critically endangered in all of its range areas (Emslie, 2020). Before 1960, over ten thousand black rhinos were freely roaming in protected areas of Tanzania but by early 1980s, poaching had pushed the species towards 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 poaching (MNRT, 2018). This impelled the government of Tanzania to join recent conservation efforts for African rhinos by establishing rhino sanctuaries and intensive protection zones to improve protection and restore the remained population of this species (MNRT, 2018). Mkomazi Rhino Sanctuary (MRS), located within MKONAPA, is part of the Tanzania government, global effort to achieve rapid recovery of the national rhino herd while minimising the loss of remaining genetic diversity (MNRT, 2018). While this strategy has been successful in halting the rapid decline in rhino numbers due to poaching, rising in rhino populations within sanctuaries has been impeded by high population densities and diet-related challenges that contribute to poor breeding performance in black rhinos (Buk & Knight, 2010; Hutchins & Kreger, 2006); MRS is one of the sanctuaries that has been affected.

Studies of black rhino dietary assessment have largely been carried out by indirect observation method (Goza et al., 2019; Hall-Martin et al., 1982; Kotze & Zacharias, 1993; Muya & Oguge, 2000), direct observation or backtracking of the browsing path of mega-herbivores (Anderson et al., 2020; Emslie & Adcock, 1994; Ganqa et al., 2005; Goddard, 1968; Mukinya, 1977; Muya & Oguge, 2000) and faecal analysis technique (Anderson et al., 2020; Hall-Martin et al., 1982; Van Lieverloo et al., 2009) or both. Here we used indirect method

to identifying forage species eaten by rhinos as an indirect indicator of its diet and compared results with literature data on rhino feeding from fourteen rhino range areas in Africa savannah to ascertain forage species consumed by rhinos in wet and dry seasons in MRS.

Furthermore, based on the general perception that black rhinos are browsers and make extensive use of browsable species when they are readily available, we use literature and data from MKONAPA to validate the hypothesis that, forage browsing by black rhinos is influenced by resources availability which varies in space and time. In supporting this hypothesis, we focus on the following: (i) Identifying forage species browsed and preferred by black rhinos and how it varies between seasons; (ii) Comparing forage browsing in MRS with the browsed forage in other rhino range areas within Africa; (iii) Examining the composition and diversity of the forage browsed by black rhinos in different seasons; and (iv) Assessing forage browsing intensity by black rhino and how it varies between seasons.

## 2 | MATERIALS AND METHODS

### 2.1 | Study area

The 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 (Figure 1). MKONAPA was established in 2008 following the upgrade of the former Mkomazi-Umba game

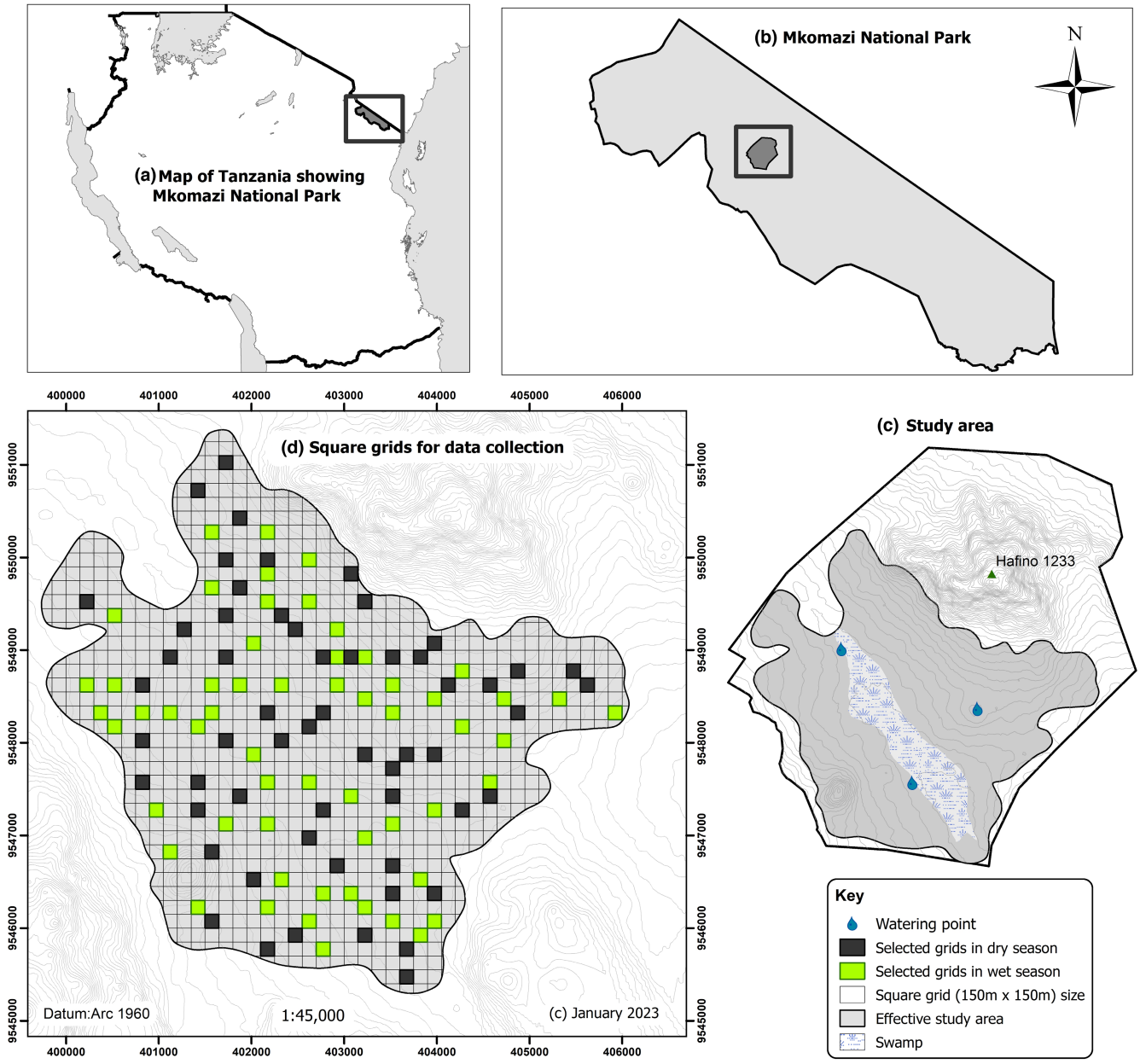


FIGURE 1 Map of Tanzania (top left inset) (a), showing the location of the study area. MRS location in MKONAPA (top right inset) (b), the effective study area (bottom left inset (c), and the enlarged area (bottom right insect) (d) shows the sampled grids during both wet and dry seasons in MRS.

reserve with an area of approximately 3245 km$^2$. 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). The sanctuary lies in a semi-arid 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 rain from March to May (Mseja et al., 2020). The average annual rainfall in 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 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. The percentage density to maximum stocking density estimates (Ecological Carrying Capacity) is 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).

## 2.2 | Methods

### 2.2.1 | Establishment of sampling areas

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 done by Knight and Morkel (1994). The sampling area was determined using secondary spatial data from MRS monitoring system showing locations of individuals or groups of rhinos feeding within the sanctuary from 2014 to 2021. First, we selected spatial 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. We analysed the selected dataset by using ArcMap software version 10.5 (Deboer, 2015). Then, we used the default settings of the Kernel density tool in ArcMap (Deboer, 2015) to create heatmap layers that show areas potentially used by rhinos during dry and wet seasons (sampling area) which covers 38 km$^2$. After establishing the sampling area in ArcMap software, a reconnaissance survey was conducted to familiarise with the terrain and dominant vegetation types. We used the information collected from the reconnaissance survey and GPS coordinate points from the map to establish sampling grids for field data collection.

### 2.2.2 | Sampling design

The entire rhino use area of 38 km$^2$ in both seasons was divided into square grids of 150 m × 150 m. Our study employed a simple random sampling design. We randomly selected 58 square grids in dry season through randomisation process in the ArcMap 10.5 software and repeated the same exercise for another 58 square grids during the wet season. A total of 116 square grids equivalent to 15% of the total grids were used for field data collection. In each selected square grid, a sampling plot of 50 m × 50 m in size was established in the top-right corner of the square grid, and within each sampling plot, a block of 20 m × 20 m and a quadrat of 1 m × 1 m was established in the same position for tree, shrub, and herb assessment respectively.

### 2.2.3 | Data collection and processing

We collected dry season data for 2 months from October to November, 2021 and wet season data for 2 months from April to May, 2022. A Global Positioning System (GPS) receiver was used to locate each sampling plot on the survey grids (Mikulyuk et al., 2010). We used field observation method (Goddard, 1970; Goza et al., 2019; Kotze & Zacharias, 1993; Muya & Oguge, 2000) to study total plant species available and those foraged by black rhinos in MRS. We further used indirect observation technique to identify and collect data on plant species browsed by rhinos (Hall-Martin et al., 1982; Oloo et al., 1994) due to presence of thick vegetation cover in some areas limiting direct observation of browsing rhinos. Freshly browsed trees, shrubs and herbs with a maximum canopy and branches height of 2 m were identified and recorded based on the browse characteristics of scissor-like oblique clips on the cut surface of shoots and twigs by black rhinos as described by Kotze and Zacharias (1993). Also, we identified rhino bite by the characteristic "pruning" of vegetation, where the twig is cut off by the proximal molars leaving a distinctive diagonal cut (Joubert, 1971). These characteristics made it possible to distinguish plants browsed by black rhinos and other herbivores in the sanctuary. We further assessed the browsing intensity on forage browsed by rhinos using the method described by Tchamba (1995) who categorised the browsing level on a scale index from one to five: (1) stand for not browsed, (2) – a quarter of the plant browsed (low browsed), (3) – half of the plant browsed (medium browsed), (4) – three-quarters of the plant browsed (highly browsed), and (5) – all plant browsed (heavily browsed) (Tchamba, 1995).

Plants were identified on-site by the botanist to the species level and registered in three life forms (trees, shrubs, and herbs). For each sampling plot, data of total plant species (woody and herbs), forage species available for the rhino diet, consumed forage species and browsing intensity were collected. Data obtained were used to calculate the abundance, composition and diversity of the plant species available and browsed by black rhinos in both wet and dry seasons. The GPS coordinates marked during the main field survey were used to generate the map of the selected square grids where the actual plant information was collected (Figure 1). Grasses were not recorded since it was not possible to distinguish between grasses eaten by rhinos and other herbivores by using the field observation method.

We used literature data from studies of black rhino forage consumption and preference conducted in fourteen rhino range areas within Africa savannah ecosystem to develop a list of the top five most consumed and preferred forage species by black rhinos in each area for wet and dry seasons (Appendix S1–S2).

### 2.2.4 | Data analysis

We determined the forage preference index (FPI) of all browsed species following (Petrides, 1975).

$$\text{Pref. Index} = \frac{\text{Relative Utilisation (RU)}}{\text{Relative Abundance (RA)}}$$

where RU is the percentage of the browsed species in the diet, while RA is the percentage of plant 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).

We calculated the diversity of total plant species, available browse and consumed browse species using the Shannon–Wiener diversity index. The diversity and forage preference indices were pooled together through R-software tool version 3.6.2, and we used an independent sample t-test to test the mean differences between seasons for normally distributed data. For non-parametric data, we used the Mann–Whitney U test. A simple linear regression analysis was used to test the relationships between forage browsed and forage available as well as a relationship between forage preference and browsing intensity using count data.

## 3 | RESULTS

### 3.1 | Plant species browsed by black rhinos in MRS

A total of 48 and 36 plant families with 151 and 85 plant species, respectively, were recorded as total plants observed in MRS in wet and dry seasons respectively. Out of this, 76% (108 species) and 78% (67 species) of the families were potentially available browses for rhino diet. About 67% (84 species) and 78% (67 species) of the families were browsed by rhinos as food in wet and dry seasons, respectively. The most consumed forage by rhinos in both seasons across different life forms, in order of importance, were *Acalypha ornata*, *Grewia similis* and *Commiphora africana*. There was no significant difference in abundance of the population of plant species in families available for the rhino diet ($t = 0.505$, $p = 0.616$) and families consumed ($t = 0.423$, $p = 0.674$) by rhinos between the two seasons. We further identified fifteen (15) principal browse species that contributed 80% and 86% of the total diet in wet (Table 1) and dry (Table 2) seasons, respectively. Principal browse species are those that constituted more than 1% ($n > 100$) of the total available diet for rhinos in all vegetation types in terms of numbers. See Appendix S2 for other forage species consumed by rhinos in dry and wet seasons in MRS. Forage browsing by rhinos was not varied between the two seasons ($t = 0.407$, $p = 0.684$) but correlated significantly with forage availability in wet ($r = 0.93$, $p < 0.001$) and dry ($r = 0.90$, $p < 0.001$) seasons.

**TABLE 1** The top 15 principal browse species consumed by black rhinos during the wet seasons in MRS.

| 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 tomentosa* | 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** | | |

*Note*: The list has been arranged by descending RU values. Bold values indicate statistical significance.
Abbreviations: FPI, Forage Preference Index; MBII, Mean Browsing Intensity Index; RA, Relative Abundance; RU, Relative Utilisation.

TABLE 2 The top 15 principal browse species consumed by black rhinos during the dry seasons in MRS.

| 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 tomentosa* | 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** | | |

*Note*: The list has been arranged by descending RU values. Bold values indicate statistical significance.
Abbreviations: FPI, Forage Preference Index; MBII, Mean Browsing Intensity Index; RA, Relative Abundance; RU, Relative Utilisation.

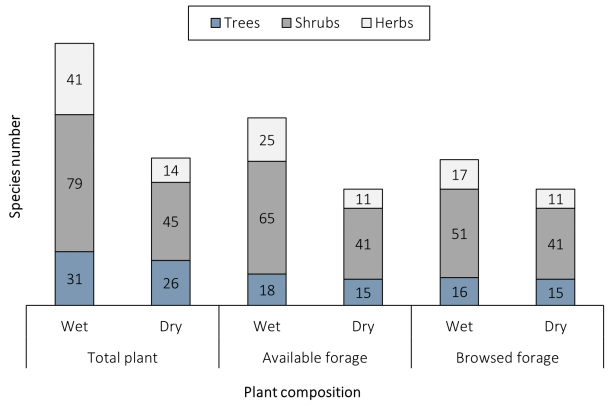


FIGURE 2 Seasonal variation in plant species composition in MRS.

## 3.2 | Composition of plant species browsed by black rhinos in MRS

The composition of available and consumed black rhino diet varied in each life form and was inconsistent between seasons, with high abundance of shrubs for both seasons (Figure 2; Figure 3). No variation was observed in species richness for the consumed diet in trees ($t = 0.149$, $p = 0.88$) but there was a significant variation in richness between shrubs ($w = 703$, $p < 0.001$) and herbs ($w = 355$, $p < 0.001$) across wet and dry seasons.

## 3.3 | Diversity of plant species browsed by black rhinos in MRS

The Shannon diversity index (H) mean value of the total plant was significantly higher ($t = 8.56$, $p < 0.001$) in wet season (3.62) than in dry season (3.01). The diversity index (H) mean value of the available forage species was significantly higher ($t = 8.31$, $p < 0.001$) in wet season (3.38) than dry season (2.77). Also, the diversity index (H) mean value of the consumed diet was significantly higher ($t = 4.58$, $p < 0.001$) in wet season (2.97) than dry season (2.31). Additionally, the diversity varied in each plant life form, with shrubs showing high index in both seasons (Table 3).

## 3.4 | Plant species preferences by black rhinos

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 few diet species between the two seasons (Table 1; Table 2). The FPI varied from highly preferred species with 1.64 to less preferred species with 0.25 in both seasons (Table 1; Table 2). Out of the 15 principal browsed species in each season, eight were mostly preferred (FPI >1) in wet season and 13 in 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 wet and dry seasons, respectively.

## 3.5 | Browsing intensity across foraged plant species by black rhino

Browsing intensity on the black rhino diet was significantly higher ($w = 482$, $p < 0.001$) in dry season than in wet season (Figure 4). 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

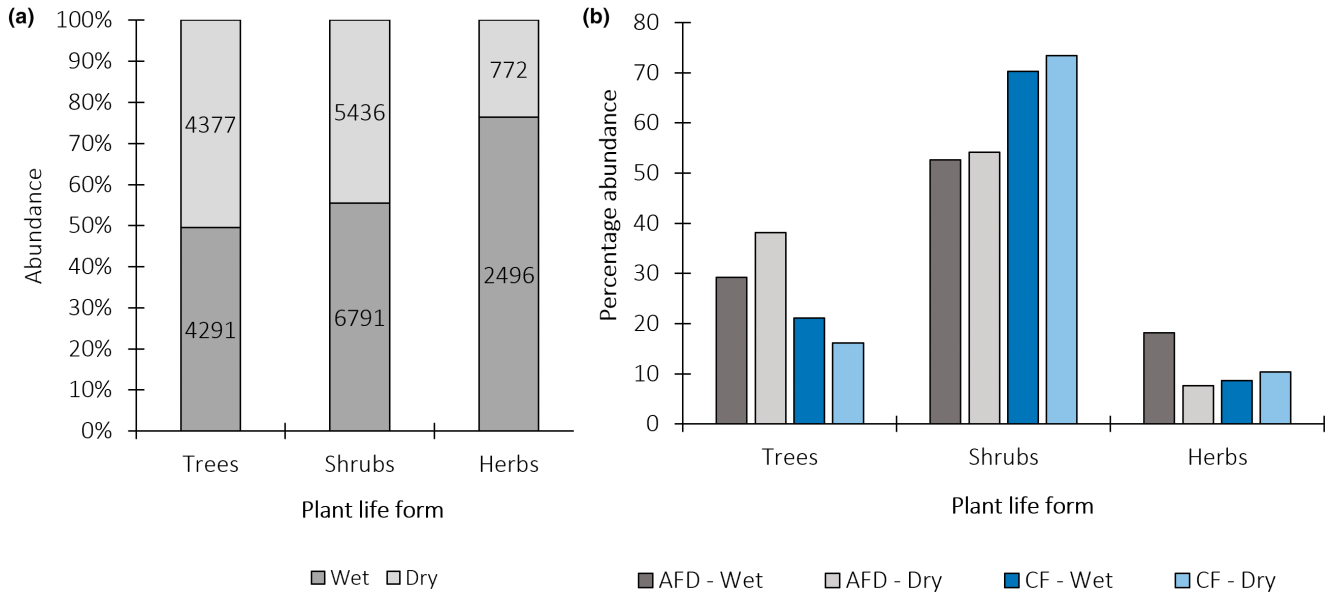


FIGURE 3 Variability in composition and abundance of plant life form in MRS. (a) Abundance of total plant species in each life form and (b) distribution of life form in available forage for diet (AFD) and consumed forage (CF) by black rhinos in wet and dry seasons.

TABLE 3 Mean values (±SD) for diversity indices of plant life form during wet and dry seasons in MRS.

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

[a]Diversity of available diet.
[b]Diversity of consumed diet.
**Statistically significant ($p < 0.001$).

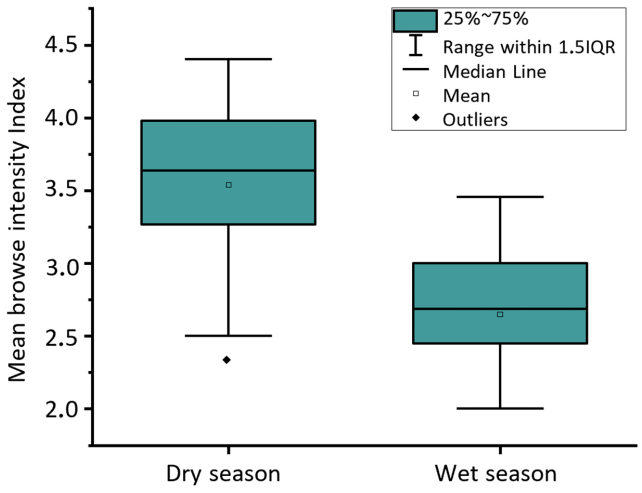


FIGURE 4 Comparison of mean browsing intensity index of browses foraged by black rhinos in MRS.

species foraged by black rhinos ranged between 2 and 3 (low to medium browsed) during wet season and between 4 and 5 (high to heavily browsed) during the dry season.

## 4 | DISCUSSION

In this study, we used field surveys and published records of browses consumption by black rhinos to identify forage consumption, preferences and the effect of plant diversity on the availability of a black rhino diet at Mkomazi National Park. Our reasoning is based on the assumption that forage browsing by black rhinos is influenced by resource availability which varies seasonally and in different locations. To our knowledge, the comparison of browses edible by rhinos obtained from different methodologies in different rhino range areas within Africa represents substantial information to accredit the methodology that was used to establish foraging species for black

rhinos in MRS. Additionally, this is the first study to investigate the availability, utilisation, and preference of forage for a black rhino diet at MKONAPA. Plant diversity, abundance and browsing intensity by rhinos were high in dry season than wet season. Also, forage species consumed by rhinos in MRS are 85% similar to those edibles in rhino range areas within Africa.

### 4.1 | Plant species browsed by black rhinos in rhino range areas within Africa Savannah

Black rhinoceros consume several plant species that varied seasonally in different locations as shown in records of published literature data on black rhino forage consumption across fourteen rhino range areas within Africa (Appendix S1–S2). The selected rhino range areas are representative of various habitats and several forage species consumed by black rhinos in Africa savannah. Analysis of forage edible in fourteen rhino range areas shows that species belongs to genera *Barleria*, *Commiphora*, *Euclea*, *Maerua*, *Solanum*, and *Ziziphus* are mostly consumed during wet seasons while *Balanites*, *Caesalpinia* and *Euphorbia* are mostly consumed during the dry seasons. Also, species of Acacia, *Grewia*, *Azima*, *Dichrostachys*, *Indigofera* and *Plumbago* genera are consumed throughout the year irrespective of seasonality (Buk & Knight, 2010; Ganqa et al., 2005; Goddard, 1970; Goza et al., 2019; Gyöngyi & Elmeros, 2017; Kotze & Zacharias, 1993; Makaure & Makaka, 2013; Muya & Oguge, 2000; Oloo et al., 1994). Similarly, black rhinos in MRS consume forages belonging to the same genera in both seasons. According to Muya and Oguge (2000), consumption of forage species differs in quantities in each season based on availability and nutrient demand by rhinos. Likewise, black rhinos in fourteen rhino range areas consumed *A. brevispica*, *A. drepanolobium*, (Fabaceae), *G. robusta*, *G. forbesii*, *G. bicolor* (Malvaceae), *Euphorbia tirucalli and Acalypha fruticosa* (Euphorbiaceae) which contain adequate nutritional contents (Dierenfeld et al., 1995; Ghebremeskel et al., 1991; Muya & Oguge, 2000).

### 4.2 | Families and plant species browsed by black rhinos in MRS

Black rhinos in MRS consume variable forage species available in the habitat in wet and dry seasons mainly from *Euphorbiaceae*, *Malvaceae*, *Burseraceae*, *Acanthaceae and Capparidaceae* families. Our results are in line with previous studies in eastern and southern Africa describing the black rhino food plants (Anderson et al., 2020; Buk & Knight, 2010; Ganqa et al., 2005; Goddard, 1968; Mukinya, 1977; Oloo et al., 1994). Black rhinos tend to highly utilise browses which are widely available in their habitat (Ganqa et al., 2005; Kotze & Zacharias, 1993; Mukinya, 1977; Muya & Oguge, 2000). We observed a similar trend in MRS, where three forage species, namely *Acalypha ornata*, *Grewia similis* and *Commiphora africana*, were highly available and highly browsed in order of importance by black rhinos, contributing to 58.18% and 45.62% of the diet in the dry and wet seasons, respectively. Species of *Acalypha fruticosa*, *Grewia tomentosa*, *Barleria submollis*, *Maerua edulis* and Acacia *Melifera* were also consumed throughout the year, while other species showed seasonal availability and consumption, for example *Commelina africana* and *Acacia bussei* in wet season also, *Barleria submollis* and *Blepharispermum zanzibarica* in 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 the highly consumed species to sustain rhino food availability.

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, 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) (Buk & Knight, 2010; Goddard, 1968, 1970; Mukinya, 1973, 1977; Van Lieverloo et al., 2009; Williams, 1985). Our findings concur with earlier studies showing presence of varied forage species composition which confirm the suitability of MRS in terms of providing varying amounts of forage for the diet of the black rhino population.

### 4.3 | Comparison of edible species by rhinos in MRS with other rhino range areas within Africa

More than 85% of forage species edible in large quantity 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 were consumed by black rhinos in MRS in wet and dry seasons are correspondingly consumed in fourteen rhino range areas (Anderson et al., 2020; Buk & Knight, 2010; Gyöngyi & Elmeros, 2017; Makaure & Makaka, 2013; Mukinya, 1977; Muya & Oguge, 2000; Oloo et al., 1994). Species that belong to *Acacia*, *Acalypha*, *Grewia* and *Barleria* genera found in rhino range areas are similarly consumed in MRS, for example, *Acalypha ornata*, *Barleria submollis*, *Grewia tomentosa* and *Acacia melifera*. Contrary to MRS which shows less consumption of *Acacia* species by black rhinos, several studies have reported high utilisation in both seasons. Species that are not observed in the list of five most edible forage in fourteen rhino range areas but are consumed in MRS in wet season (*Maytenus mossambicensis* and *Canthium glaucum)*, and dry seasons (*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 high nutritional value (Muya & Oguge, 2000), it is likely that rhinos are selecting these species in MRS to meet their dietary requirements

### 4.4 | Diversity of the browsed plant species by black rhinos

The wet season is more diverse than the dry season. This implies that forage in wet season constitutes a higher composition of plant species than in dry season. Our findings are concomitant with the findings in previous studies from southern and eastern Africa, where the overall diversity of plant species utilised by black rhinos was found to be greater during the wet season than dry season in a range of habitats (Goddard, 1968, 1970; Mukinya, 1977; Oloo et al., 1994). Also, a low diversity in consumed diet when compared with available diet in both seasons suggests that not all available forage species for diet are consumed by rhinos, but they tend to select few species based on preference and the ability to convey maximum nutrient benefits (Van Lieverloo et al., 2009). The diversity of browsed trees is almost 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 dry season indicates that rhinos select green leaves and twigs from different forage species when shrubs shed off leaves and many herbs dry out.

### 4.5 | Preferences of plant species by black rhinos

High preference of plant species by rhinos is due to high nutritional value which positively impacts rhino health stability (Dierenfeld et al., 1995; Muya & Oguge, 2000). Our results show a shift in forage preference during the dry season to avoiding leafless plants and increased preference for dry-tolerant plants and highly nutritious 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 our study is similar to other studies conducted in rhino range areas within Africa (Ganqa et al., 2005; Goddard, 1968, 1970; Goza et al., 2019; Kotze & Zacharias, 1993; Mukinya, 1977; Muya & Oguge, 2000; Van Lieverloo et al., 2009), but contrary to our study, *Acacia* and *Commiphora* species are less preferred except *Acacia drepanolobium* which is preferred in wet season. From our results, *Acacia* and *Commiphora* are highly available but less consumed by rhinos because most of them are medium to big trees of height above 2 m, hence not accessible by rhinos for diet and are likely less preferred by rhinos. Therefore, these findings suggest that a key habitat factor important in black rhinoceros conservation includes diverse plant species which are at a height below 2 m (Kotze & Zacharias, 1993; Muya & Oguge, 2000).

The browsing intensity on the most preferred forages is extremely high during dry periods of the year to the extent that might cause loss of some favourite species for rhinos in MRS. Apart from less availability, high population density observed is among the causes of deteriorating habitat quality (Okita-Ouma, Pettifor, et al., 2021; Okita-Ouma, van Langevelde, et al., 2021). This may accelerate browsing intensity on remaining preferred forage species and causes depletion of forage resources in MRS which consequently lowers rhino healthy and breeding performance. Through field observation in MRS, preferred species such as *Acalypha fruticosa*, *Balanites aegyptiaca*, *Hymenodictyon parvifolium*, *Grewia similis*, *Barleria submollis* and *Maerua edulis* 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.

## 5 | CONCLUSION

Understanding browser's diet selection and preference is essential for evaluating the suitability of different habitat and vegetation types and their ability to support the population of critically endangered species. Since diet is essential for survival and influences physiological processes that trigger population changes, our study established the black rhino diet composition, utilisation and preferences in wet and dry seasons. Forages consumed by black rhinos were highly abundant and diverse in wet season than dry season, and rhinos showed high preference for shrubs vegetation over others in both seasons. Evidence-based research from our study elucidated similarity in forage species browsed by black rhinos when compared with studies from other rhino range areas within Africa savannah. Our findings indicated that browsing intensity increased with forage preference in both seasons and was prominent when browse availability was low in dry seasons. This leads to intense foraging competition among rhinos and other browsers in the sanctuary and caused depletion of food resources consequently lowering the body condition status of rhinos and population performance.

Therefore, we recommend establishing a monitoring program of preferred browse species that are highly browsed by rhinos during the dry season and establishing their nutritional composition would further inform authorities about the forage quality status in relation to rhino body conditions in a high population density environment like MRS. Additionally, we further recommend further studies for assessing browse production, soil quality and density of other competitors (herbivores) in the sanctuary. Results obtained from the assessments will further guide managers to make decisive measures in improving the management of the sanctuary and promote rhino healthy and reproduction performance in an intensively managed space that does not have natural dynamics. Additionally, we recommend the use of faecal analyses over indirect observation techniques used in our study to further understanding the diet of black rhinos in MRS and within Tanzania and Africa at large.

Furthermore, since the management goals of the sanctuary are to increase numbers of rhinos and to restock safe areas within their former ranges in Tanzania, then population densities within the sanctuary should be monitored and managed through translocation of excess rhinos or expand the sanctuary area to improve forage availability, accessibility and lower population density to recommended ecological carrying capacity. This may also allow regeneration of overgrazed forages and improve rhino body condition and productivity hence sustaining population persistence in MKONAPA.

## AUTHOR CONTRIBUTIONS

Research conception: ESS; FM; LKM, Data collection and geospatial work: ESS, Statistical design, and data analysis: ESS, EHM; LKM, Manuscript preparation and proof reading: ESS; LKM; FM; EHM, the final manuscript has been read and approved by all the authors.

## ACKNOWLEDGEMENTS

The authors would like to thank the Mkomazi National Park Management for allowing access and facilitating the fieldwork. The Africa Centre for Research, Agricultural Advancement, Teaching Excellence and Sustainability (CREATES-FNS) under World Bank and The Rufford foundation for funding this study. The authors acknowledged the cooperation of the rhino sanctuary staff who provided valuable field assistance and logistics.

## CONFLICT OF INTEREST STATEMENT

We authors declared no potential conflicts of interest for the research, authorship, and/or publication of this article.

## DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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**How to cite this article:** 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*, *00*, 1–11. https://doi.org/10.1111/aje.13145