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Dlamini, Sifiso

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University of the Witwatersrand, Johannesburg

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The Impacts of Ungulate Foraging on Small Mammal Diversity in a Protected Site and Livestock Grazing Site

by

Sifiso Dlamini

(1255065)

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Supervisor: Dr Kim Madikiza

Co-supervisor: Prof. Emmanuel Do Linh San (University of Fort Hare)

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Abstract

Vegetation cover and food availability are important determinants of how favourable an area is for the settlement of animals, especially small mammals such as rodents, which rely heavily on vegetation for protection against predators and access to food. This study investigated the impact that ungulate foraging activities (both domesticated and wild) have on small mammal diversity in two Short *Euphorbia* Thicket habitats within the Albany Thicket Biome: a natural site in the Great Fish River Nature Reserve and an adjacent livestock grazing site belonging to Kwandwe Private Game Reserve. Trapping was carried out over 7-day/7-night trapping sessions during the wet and dry seasons at each site, with grids of 10 × 10 traps with a 10 m spacing. Over a total of 5,600 trap nights/days, 272 unique individuals of six small mammal species (4 rodents, 1 shrew, and 1 sengi) were captured. Habitat (i.e., the 1 ha area studied on each site) and microhabitat differences were assessed for the two study sites using plant cover at different heights, the number of bushes, the presence of *Euphorbia bothae*, as well as the amount of bare ground and rocky surfaces around each trap station. Between the habitats, vegetation in all the height categories differed significantly during each season, while the number of bushes did not differ. The microhabitats also showed seasonal variation, with the dry season having less vegetation cover than the wet season. Although greater vegetation cover was recorded during the wet season, small mammal abundance was low, as were species richness and diversity. It was the dry season that had the higher small mammal abundance for both sites, with the protected site having four times the abundance (across all species) of the livestock grazing site. Small mammal diversity was, however, highest at the livestock grazing site, where the species were evenly represented, whereas the protected site had unevenly represented species with a lower diversity. It is concluded that both domesticated and wild ungulate foraging activities, as well as seasonal changes in climatic conditions, alter vegetation cover. This determines whether a habitat is conducive for small mammals, thereby driving their richness, abundance, and ultimately diversity within a habitat.

Keywords: abundance, browsing, grazing, diversity, livestock, live-trapping, seasonality, small mammals, species richness, ungulates, vegetation cover

Introduction

The economic, ecological, and social necessities catered for and sustained by land require that it be treated and regarded as an invaluable resource. The invaluable nature of land can be attributed to its potential to afford diverse living organisms the platform to contribute efficiently to ecosystem and environmental processes, e.g., nutrient flow and soil formation (Grant and French, 1980; Chapin *et al.*, 1997). The efficiency of ecosystem and environmental processes enables the symbiotic relationships that exist between constituents of ecosystems to thrive and thus creating favourable conditions for conservation of biodiversity. For instance, plants have relationships with herbivores such as granivores and frugivores which ensure that upon providing nourishment for these animals, seed dispersal can take place to afford plants the opportunity to colonize new areas (Hollander and Vander Wall, 2004; Sato, 2022). Through these interactions, the nutritional sustenance required by animals for reproduction and survival is provided while making it possible for plants to thrive in habitats where their viable seeds manage to set root (Hollander and Vander Wall, 2004; Sato, 2022).

Biodiversity can be defined as the variability among living organisms within a single ecosystem or habitat including the number of different organisms, species, and their relative frequency in that ecosystem (Gaston and Spicer, 2004; Maclaurin and Sterenly, 2008). Variability among living organisms has been influenced mostly by land-use due to the increased expanse of land demarcated for agricultural practices (Donald *et al.*, 2001; Oliver and Morecroft, 2014). This increase has brought about the inevitable spatial overlap of agriculture land with conservation areas resulting in natural habitat loss (Ricketts and Imhoff, 2003; Wessels *et al.*, 2003). Forests and grasslands are among the natural habitats that have been affected by changes in land use, as they have been converted either to croplands, homogenous forests for logging, or other uses such as feedlots (Pereira *et al.*, 2012; Nagendra *et al.*, 2013). As an example, in the Mpumalanga Province (South Africa), the introduction of forest plantations greatly disturbed the grassland habitats and reduced the variety of grassland bird species in that area (Allan *et al.*, 1997). Similarly, in the KwaZulu Natal Province, an overexploitation of *Ocotea bullata* (stinkwood) for building and woodwork material, and *Alepidea amatymbica* (Ikhathazo) for its medicinal use, led to a drastic change in the vegetative makeup of the forests (Nontshongwana, 1999).

These above-mentioned changes disturb habitat structures and render them inhospitable to some of the native arboreal, terrestrial, and avian inhabitants which rely on tree and plant

cover for nesting, feeding, and protection. They also alter natural interactions between members of an ecosystem and, as a consequence, disturb the flow of energy and nutrients within the ecosystem (Cardinale *et al.*, 2006; Hansen *et al.*, 2012). Among the numerous consequences of these changes in land use is biodiversity loss through the decrease in species abundance and richness, mainly due to the removal of tree and vegetation cover (Hoffman and Zeller, 2005). For example, the introduction of forest plantations to the grasslands of the KwaZulu Natal Mistbelt threatened the existence of blue swallows (*Hirundo atrocaerulea)*, as well as plants such as milkweed (*Asclepias woodie*) and red-hot poker (*Kniphofia leucocephala)* in that area (Armstrong *et al*., 1996; Scott-Shaw, 1999).

Vegetation cover is an important determinant of how favourable an area is for the settlement of animals, especially small mammals (Peles and Barrett, 1996; Joubert and Ryan, 1999; O'Farrell *et al.*, 2008). Small mammals such as rodents, for instance, rely heavily on vegetation cover; hence, their presence and abundance in an area is greatly influenced by it (Longland and Price, 1991; Peles and Barrett, 1996; Whitting-Jones *et al.*, 2008). Rodent species such as the four-striped grass mouse (*Rhabdomys pumilio*), South African pouched mouse (*Saccostomus campestris*) and Natal multimammate mouse (*Mastomys coucha*) are known to prefer areas with high vegetation cover of heights greater than or equal to 10 cm as these afford them protection from predators (Longland and Price, 1991; Eccard *et al.*, 2000; Whitting-Jones *et al.*, 2008).

Bushclumps or bushes (i.e., clumps of woody, herbaceous and grass species) are a type of vegetation structure preferred by rodents, as they not only function as refuges from predators but also serve as microhabitat for gathering resources such as food, while housing workable soil that rodents can burrow into (August, 1983; Whitting-Jones *et al.*, 2008). A microhabitat is a small-scale area preferred by a community of organisms due to its physical characteristics that create a conducive environment to live in (Morris, 1987; Corrêa *et al*., 2018). An example of such characteristics is canopy cover, provided by the taller and leafy components of bushclumps, which plays a pivotal role in regulating light, levels of air humidity, and soil humidity within the microhabitat (Bogoni *et al*., 2013). The regulation of light and temperature penetrating a microhabitat ensures that the immediate environment has a less variable temperature than the macrohabitat temperature, thus providing ideal nesting sites and thermoregulatory conditions (Kaufman *et al.*, 1983; Mehrabi *et al.*, 2014; Scheffers *et al.*, 2014). For example, Green *et al*. (1984) found that the white-footed mouse (*Peromyscus leucopus*) mostly preferred habitats with dense canopy covers, large shrubs, and grasses. The

habitat preferences of this species were linked to the variation in the penetration of light in different vegetation cover which resulted in varying soil temperatures (Kaufman *et al*., 1983).

The vegetation cover that regulates soil temperature within microhabitats usually consists of perennial plants, annual plants, or both. Perennial plants cater to a folivorous diet, while annual plants produce more seeds than perennials and hence cater to a granivorous diet in small mammals (Dean, 1995; Joubert and Ryan, 1999). However, some of these plants also meet the nutritional needs of larger animals (e.g., livestock) that heavily rely on plant matter. Livestock plays a significant role in driving vegetation cover, as the degree to which grasses, herbaceous and woody species are consumed determines the amount of aboveground biomass present and its diversity (Lechmere-Oertel *et al*., 2005). The variety of plants forming bushes tend to be palatable and preferred by livestock, thereby subjecting them to overconsumption (Milton *et al*., 1994; Evans *et al*., 1997). For example, Hester *et al*. (2006) observed that sweet thorn (*Vachellia karroo*) bushes that grow amongst bitter aloe (*Aloe ferox*) were highly browsed by livestock in comparison to bitter aloe. As a consequence, *A. ferox* grew taller and was much more abundant than *V. karroo* in that area (Milton, 1994; Evans *et al.*, 1997; Lechmere-Oertel *et al*., 2005).

Seasonal changes can also bring about changes in vegetation cover by promoting or impeding plant productivity (Lima *et al.*, 2006; Siddique *et al*., 2016). Rainy periods, for example, tend to influence plant growth that favours food production and an increase in the expanse covered by vegetation (Lima *et al.*, 2006). On the other hand, hot and dry periods reduce water availability which lowers the efficiency of photosynthesis resulting in plant productivity declining and as such depriving plant growth (Ahmad, 2016). These seasonal changes may thus impose harsh demands on small mammals' physiological functions, therefore reducing their activity and consequently limiting their sightings (Getz, 1961; Stokes *et al*., 2001; Hume *et al.*, 2020). These weather conditions may affect the occurrence and abundance of rodents, therefore causing fluctuations in their population sizes within an area (Butet *et al.*, 2006; Lima *et al.*, 2006; Solonen and Ahola, 2010).

Pooled together, a decrease in vegetation cover and plant diversity, coupled with unfavourable weather conditions wane the beneficial conditions of a habitat for small mammals, thus leading to the reduction in the presence, richness and ultimately diversity of rodent species occurring in that area (Monadjem and Perrin, 1998; Hoffman and Zeller, 2005; Solonen and Ahola, 2010). Reduction in small mammal species' presence and diversity may lead to a

decline in the efficacy of their functional roles in their ecosystems, for example in a) the movement of organic matter from unfavourable to favourable locations for decomposition, b) the regulation of aboveground arthropod biomass, and c) influencing the species that make up plant cover in forests through the consumption of seeds (Ryszkowski, 1975; Grant and French, 1980). The ecosystems would also be deprived of the role played by burrowing rodents in improving water storage in semi-desert grasslands and in affecting soil chemistry through the upward movement of soil containing nutrients and minerals to the surface (Ryszkowski, 1975; Grant and French, 1980).

Motivation/rationale for the study

The type of habitat that animals prefer is selected based on various factors that directly contribute to the animals' fitness and survival (Morrison *et al*., 2006). Understanding how changes in natural habitats affect small mammal diversity is important, as this contributes to their survival and the thriving of other species that rely on their ecological roles (Grant and French, 1980; O'Farrell *et al*., 2008). It also sheds light on the influence that microhabitat conditions have on small mammal occurrence and the impact that disturbances of landscape structures have on habitat loss and biodiversity loss (Hoffman and Zeller, 2005).

Knowledge of the impacts that changes to natural habitats have on vegetation and small mammals (their presence and diversity) can be used to determine how productive a habitat is and how conducive it is for faunal and floral populations to establish in that habitat (Jackson and Fahrig, 2013). The focus on the vegetation also informs on the nature of the plant species in the habitats and their capacity to dominate in the absence of viable competition, which may lead to decreased diversity (Luske *et al*., 2009).

Through the present study, small mammal species that are vulnerable to natural habitat disturbances can be identified, and then measures to curb the impacts of habitat disturbances can be taken. The importance of promoting the conservation of small mammals outside conservation areas is also stressed, so that the roles played by small mammals are not halted in those habitats. The study also draws attention to the need for monitoring the presence and dominance of plant species that occupy a larger portion of an area than others and recommends research into their impact on habitat productivity, so that if they bear any negative traits, their growth and establishment elsewhere can be prevented.

Aim of the study

The overall aim of the study was to determine the impacts of ungulate foraging on small mammal diversity in two Short *Euphorbia* Thicket habitats within the Albany Thicket Biome: a natural site in the Great Fish River Nature Reserve and an adjacent livestock grazing site belonging to Kwandwe Private Game Reserve.

Objectives

1. To quantify potential habitat differences between the protected site and the livestock grazing site.
2. To determine whether there are differences in small mammal richness, abundance, and diversity between the two study sites.
3. To determine whether microhabitats differ seasonally in the two study sites and whether this has an impact on small mammal biodiversity.

Hypotheses

1. The foraging preferences of ungulates within the protected and livestock grazing sites, respectively, will alter vegetation cover, resulting in habitat differences between the sites.
2. Spatial differences in vegetation cover, microhabitat structures and food availability (both between and within study sites) are likely to lead to differences in small mammal richness, abundance, and diversity because they affect predation risk, potential ecological niches that can be exploited, as well as individual/population growth.
3. Microhabitat structures are partly affected by seasonal changes in weather conditions, and therefore plant growth and productivity. This temporal change in vegetation cover and food availability has the potential to impact small mammal abundance and community composition.

Predictions

1. Selective grazing and browsing by domesticated ungulates promote a vegetation cover that is dominated by a single plant species in the livestock grazing site, whilst generalist foraging by wild ungulates promotes a more heterogeneous vegetation cover in the protected site.

2. In the protected site, the higher availability of food and the greater and more diverse vegetation cover results in higher small mammal richness, abundance, and diversity than in the livestock grazing site with its less diverse vegetation cover, which limits food availability and the type of niches available.
3. Plant growth and productivity peak in the wet season, therefore increasing vegetation cover and food availability within the microhabitats. This promotes microhabitat use by a variety of small mammals in the protected site more than in the livestock grazing site during the wet season than in the dry season.

Literature Review

South Africa has a land expanse that is covered by biomes such as the Savanna, Succulent Karoo, and Albany Thicket (Rutherford *et al*., 2006). The Albany Thicket, Savanna, Grassland, and Nama-Karoo biomes make up the vegetation in the Eastern Cape province (Hoare *et al*., 2006; Rutherford *et al*., 2006). The biomes present in the Eastern Cape are made up of vegetation units such as the Groot Thicket, Gamtoos Thicket, Sundays' Noorsveld, Great Fish Noorsveld, and Great Fish Thicket (Hoare *et al*., 2006). These vegetation units are defined by different vegetation types of which Karroid Shrubland, Spekboom Noorseveld, and Fish Thicket are examples that are found in the Great Fish River Nature Reserve (GFRNR) (Hoare *et al*., 2006; Gaylard *et al*., 2021). Succulents such as *Euphorbia gorgonias*, *Euphorbia bothae*, and *Aloe africana*; trees such as *Scutia myrtina* and *Combretum caffrum*; grasses such as *Aristida diffusa* and *A. congesta*; and shrubs such as *Pentzia globosa* and *Euclea undulata* are some of the plants that comprise the vegetation types found within GFRNR (Hoare *et al*., 2006; Gaylard *et al*., 2021).

GFRNR is part of the network of nature reserves that make up 4.1% of South Africa's landmass. Within its landmass and vegetation are housed various small mammal species, some of which are rodents (order Rodentia), shrews (order Eulypotyphla) and sengis (order Macroscelidea). Some of the rodent species found in the GFRNR are woodland dormouse (*Graphiurus murinus*), Southern African vlei rat (*Otomys irroratus*), Namaqua rock mouse (*Micaelamys namaquensis*), southern multimammate mouse (*Mastomys coucha*), four-striped grass mouse (*Rhabdomys pumilio*), and pygmy mouse (*Mus minutoides*); shrews such as the reddish-grey musk shrew (*Crocidura cyanea*); and sengis such as western rock sengi (*Elephantulus rupestris*) (Arnolds, 2010; Madikiza, 2010; Lagesse and Thondhlana, 2016; Madikiza *et al.*, 2019).

The ecology of the small mammals captured in this study

Namaqua rock mouse (*Micaelamys namaquensis*)

The Namaqua rock mouse is a terrestrial species that notably occurs in savanna and fynbos habitats (Kenser *et al*., 2013; Kingdon, 2015). It makes use of areas where rocky ground is dominant because of its preference for rock crevices as shelter (De Graff, 1997; Kesner *et al.*, 2013; Kingdon, 2015). In its habitats, the Namaqua rock mouse's activity tends to be slightly higher just before dawn and after dusk because of its nocturnal nature (Kenser *et al*., 2013;

Kingdon, 2015). During its active period, it forages primarily on grass, foliage and seeds, with insects also part of the diet, especially in summer (Kesner *et al*., 2013; Kingdon, 2015). The summer period together with spring are used for breeding by this small mammal species (De Graff, 1997; Skinner and Chimimba, 2005; Kesner *et al*., 2013).

Southern multimammate mouse (*Mastomys coucha*)

The multimammate mouse is a terrestrial species that occurs in grasslands, woodland savanna, and is also found in human dwellings (Skinner and Chimimba, 2005; Leirs, 2013). This species is also common in sites that have experienced habitat disturbances such as fires and clearcutting, where they pioneer the colonization of the sites (De Graff, 1997; Leirs, 2013). It is a nocturnal species with an opportunistic omnivorous diet that consists of seeds, foliage, grass, and insects (Leirs, 2013; Kingdon, 2015). Breeding is aseasonal but there is a peak during the wet season, followed by a decline once the dry season commences (Skinner and Chimimba, 2005; Leirs, 2013).

Four-striped grass mouse (*Rhabdomys pumilio*)

Four-striped mice are primarily a terrestrial species but can also be scansorial (Happold, 2013). They can be found in habitats such as dry riverbeds, grasslands, and near agricultural land (De Graff, 1997; Skinner and Chimimba, 2005; Happold, 2013). This species is known to succeed *M. coucha* in colonizing areas that are recovering from habitat disturbances (Skinner and Chimimba, 2005; Happold, 2013). They have a diurnal and crepuscular activity pattern and possess an omnivorous diet that varies seasonally according to the availability of seeds, insects, and plant matter such as leaves and stems (Happold, 2013; Kingdon, 2015). This species breeds during spring and summer, especially after rainfall (De Graff, 1997; Happold, 2013).

Pygmy mouse (*Mus minutoides*)

Pygmy mice are a terrestrial species that occurs in several habitats such as Afromontane and riparian forests, cultivated fields, and grasslands (Monadjem, 2013; Kingdon, 2015). Their diet is omnivorous, consisting of grass seeds, foliage, and insects (De Graff, 1997; Monadjem, 2013; Kingdon, 2015). They breed throughout the year but breeding peaks during the wet season (Monadjem, 2013).

Reddish-grey musk shrew (*Crocidura cyanea*)

Reddish-grey musk shrews occur in habitats such as dense shrubs and grasslands where their activity is nocturnal (Dippenaar, 1997; Baxter and Dippenaar, 2013). They are a terrestrial species that feed on insects only (Baxter and Dippenaar, 2013; Kingdon, 2015). Their breeding is opportunistic, but mostly takes place in the wet season (Baxter and Dippenaar, 2013).

Western rock sengi (*Elephantulus rupestris*)

Western rock sengi occur in arid and semi-arid areas where they makes use of boulder piles and rocky outcrops as shelter (Perrin, 2013; Kingdon, 2015). It is terrestrial species with a crepuscular activity pattern and its diet consists strictly of insects (Perrin, 1997, 2013; Skinner and Chimimba, 2005). Breeding among western rock sengis occurs during the warm and wet months of spring and summer (Skinner and Chimimba, 2005; Kingdon, 2015).

Materials and Methods

Study area

The study took place next to Fort Brown, Eastern Cape province, South Africa **(Figure 1)**. The two study sites were selected to represent Short *Euphorbia* Thicket vegetation, but with different browsing/grazing regimes. One of the study sites was a protected site (Great Fish River Nature Reserve) **(Figures 1 & 2)** and the second study site was a livestock grazing site belonging to Kwandwe Private Game Reserve **(Figures 1 & 3)**. The two study sites are adjacent to each other and are separated by an electrical fence.

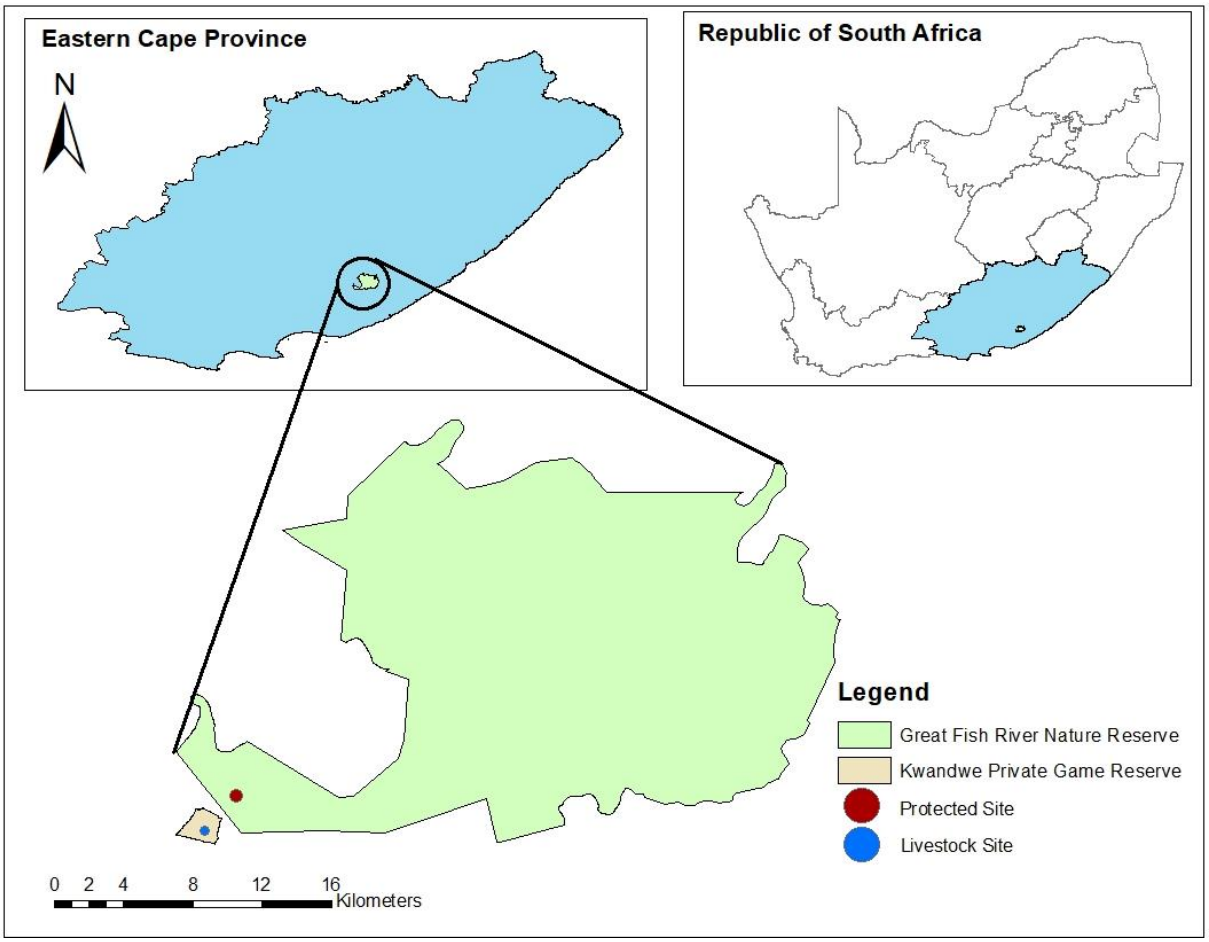


Figure 1. Map showing the location of the Great Fish River Nature Reserve and the Kwandwe Private Game Reserve annexure site used by local communities for livestock grazing. The two selected sampling sites (characterised by Short *Euphorbia* Thicket vegetation) are denoted with a red dot (Protected Site) and a blue dot (Livestock Site), respectively.

a) Study site 1 (Protected Site): The Great Fish River Nature Reserve (GFRNR)

The first study site was located in the Great Fish River Nature Reserve (GFRNR), which is 83 km from Grahamstown (33˚ 03′ 59″ S, 26˚49′ 17″ E). The reserve spans over 46 000 ha and is home to ungulate browsers such as the black rhinoceros (*Diceros bicornis minor*), greater kudu (*Tragelaphus strepsiceros*), common eland (*Taurotragus oryx*) (partly browser and partly grazer), and grazers such as Cape buffalo (*Syncerus caffer*), red hartebeest (*Alcelaphus buselaphus caama*), and warthog (*Phacochoerus africanus*). It also home to small mammals that prey on rodents, shrews, and sengis such as the small-spotted genet (*Genetta genetta*), Cape genet (*Genetta tigrina*), small grey mongoose (*Galerella pulverulenta*), yellow mongoose (*Cynictis penicillata*) and black-backed jackal (*Canis mesomelas*) (Do Linh San *et al.*, 2009; Mbatyoti, 2010, 2012).

GFRNR experiences an average annual rainfall of 480 mm and the temperature can reach a maximum of 40°C during summer and be as low as 0°C during winter (Gaylard *et al.*, 2021). The area is also covered by vegetation types such as the Medium *Portulacaria* Thicket dominated by *Portulacaria afra* (spekboom) shrubs; Short *Euphorbia* Thicket, which is characterised by the presence of *Euphorbia bothae*; and Bushclump Karroid Thicket which is characterized by a layer of karroid herbaceous layer and bushclumps of *Rhus* spp. (sumac) and *Scutia myrtina* (cat thorn) (Arnolds, 2010; Do Linh San *et al.*, 2009).

Within the GFRNR, we located one reference study site at 33°07′15″ S, 26°38′57″ E **(Figure 2)**. The study site was *ca* 61 ha area that had previously been primarily vegetated by *E. bothae*, but black rhinoceroses heavily browsed it to extinction in the area and opened room for grasses, bushclump karroid thicket, and karoo shrubs to expand their growth and establish their dominance in the area (Luske *et al*., 2009).

b) Study site 2 (Livestock Site): Kwandwe Private Game Reserve (Kwandwe)

The second study site was located at 33°08′38″ S, 26°38′57″ E, 2.6 km from the GFRNR southwestern entry point (Kamadolo Gate) with an area of 296 ha belonging to Kwandwe Private Game Reserve (**Figure 3**). This area is fenced and mainly used for cattle grazing and goat browsing by the local community. It is predominantly vegetated by *Euphorbia bothae* and grasses such as *Digitaria eriatha* (pangola grass) and *Cynodon dactylon* (couch grass).



Figure 2. A view of the vegetation within the Protected Site in the Great Fish River Nature Reserve.



Figure 3. A view of the vegetation within the Livestock Site in Kwandwe Private Game Reserve.

Data collection

Trapping of small mammals

To assess the use and selection of microhabitats by small mammals, trapping was conducted during both the wet (January–February 2022) and dry seasons (May–June 2022) over 7 days and 7 nights each. I deployed 100 Sherman live traps (H. B. Sherman Traps, Tallahassee, Florida, USA; breadth × height × length: 8 × 9 × 23 cm) in both study sites, with trap checking taking place twice a day, in the morning (07:00–11:00) and afternoon (14:00–17:00). A grid of 100 stations (10 rows × 10 lines) was established, with each station having one trap positioned on the ground at a distance of *ca* 10 m from neighbouring traps. The slight distance variation between traps was due to availability of cover for the protection of the traps from direct sunlight and from being trampled on by foraging large mammals. The traps were baited with a mixture of rolled oats and sunflower oil and bait was complemented or replaced when and where needed.

Handling of trapped small mammals

Caught rodents were removed from the traps, inserted into a pre-weighed Ziploc plastic bag, and weighed to the nearest gram using a 60 g or 100 g spring balance (Pesola, Baar, Switzerland). Each newly captured rodent was sexed by examining the genitals and checking for the presence of mammae (nipples) on the belly. Species identification was made based on body mass, head–body length, tail length, and various *ad hoc* external features (general appearance, fur coloration, size of ears and presence/absence of hair inside ear lobes, number and position of mammae) (Skinner & Chimimba, 2005; Stuart & Stuart, 2015). Captured individuals were marked by shaving off some hair on their backs in various patterns, using a pair of clinical scissors, to ensure that recaptured rodents can be easily identified. Both newly marked and retrapped animals were released at the corresponding trapping station. All procedures were carried out following the approval of the Animal Research Ethics Committee at the University of the Witwatersrand (Clearance Certificate 2021/04/08/B).

To determine potential differences between microhabitats, several predictor variables (**Table 1**) were evaluated inside 100 quadrats (10 m × 10 m) at each study site and during both the wet and dry seasons. A 5 m tape measure was used to mark out the 10 m × 10 m quadrats with the centre point being the position of the trap. The vegetation cover in each quadrat was visually estimated based on four height categories (≤ 10 cm, 11–50 cm, 51–150 cm, and >

150 cm) which were used to classify the vegetation. The degree to which the vegetation in each of the height categories occupied the quadrat was quantified using five simple categories (0 = 0%, 1 = 1–25%, 2 = 26–50%, 3 = 51–75%, 4 = 76–100%). These five categories lessened the shortcoming in accuracy when working out the percentage cover of each height category. In addition, rocky surfaces or rocks together with bare soil were quantified to determine the degree to which they dominate ground cover within the microhabitat, as some rodent species prefer areas with such surfaces (Skinner and Chimimba, 2005). Lastly, the percentage cover of euphorbs was estimated and the number of bushes inside each quadrat counted (**Table 1**).

Table 1. Microhabitat variables (predictors) that were measured for each trap within a 10 m × 10 m quadrat centred on the trap.

Microhabitat variables	Type of variable	Description
Vegetation ≤ 10 cm	Ordinal	Percentage of quadrat area covered with vegetation ≤ 10 cm in height (mostly grass).
Vegetation 11–50 cm	Ordinal	Percentage of quadrat area covered with vegetation 11–50 cm in height (mostly grass and karroid shrublets).
Vegetation 51–150 cm	Ordinal	Percentage of quadrat area covered with vegetation 51–150 cm in height (mostly shrubs and bushes).
Vegetation > 150 cm	Ordinal	Percentage of quadrat area covered with vegetation > 150 cm in height (mostly bushclumps and trees).
% Rock	Ordinal	Percentage of quadrat area covered with rocks and/or a rocky surface.
Bare Ground	Ordinal	Percentage of quadrat area devoid of vegetation and made of soil, sand or gravel.
% Euphorbs	Ordinal	Percentage of quadrat area covered with *Euphorbia bothae* plants.
No. of bushes	Count	Number of bushes (dense plant or groups of plants that were visually deemed to be suitable for small mammals to hide from predators and nest).

Data analysis

Data was collected and recorded on Excel spreadsheets with basic analysis performed using Microsoft Excel version 2210 (Microsoft Office 365). IBM SPSS Statistics 26 was used to run statistical tests on the microhabitat data and a Shapiro–Wilk test was run to assess the normality of the data. A related-samples Wilcoxon Signed Rank Test was performed for pairs of data in each site for both seasons, comparing each of the microhabitat characteristics separately. Similarly, a Mann–Whitney *U* test was performed to compare the microhabitat

characteristics between the two sites in each season. The comparison of microhabitat characteristics between sites and within sites was done using medians and interquartile ranges. A Holm's Sequential Bonferroni Procedure (HSBP) was used to correct any errors that may have occurred during the multiple hypotheses testing procedure (Holm, 1979).

The success of the trapping sessions was calculated using the following formulas (Simonetti, 1986):

Method 1: $\text{Trapping Success} = \frac{\text{Total number of individuals captured}}{\text{Trapping effort} \times \text{Number of sessions} \times \text{Number of trap nights}} \times 100$

Where trapping effort is the number of traps used for capturing the rodents and the number of sessions being the number of times that the traps are checked in a day.

Method 2: $\text{Trapping success} = A \times \frac{100}{TU - \frac{IS}{2}}$

Where A is the number of small mammals caught, TU = P × I × N: P is the number of trapping intervals, I is the length of the trapping sessions, and N is the number of traps being used. IS represents the number of traps that closed due to being triggered by a captured animal or other factor.

Method 3: $\text{Trapping success} = A \times \frac{100}{TU - NA}$

Where NA is the number of traps that are unavailable for small mammals due to false triggers (by non-target species or due to hyper-sensitivity), absence of bait, or trap malfunctioning.

The occurrence of individuals was counted for each species, site, and season and then plotted on histograms. Population density was calculated for each site for both seasons together with the population sizes. The Shannon Diversity (SDI) (H'; range: 0–3), Evenness of representation (J'; range 0–1), Simpson's Diversity (SiDI) (D; range: 0–1), and Margalef (D_{mg}; range: 0–1) indices were calculated for each site and each season to give a measure of diversity (Krebs, 1989). Pianka's index of overlap (PIO) (α; range: 0–1) was also calculated for each site to compare the seasons and between the two sites for each season (Krebs, 1989). A Generalized Linear Model (GzLM) was run in SPSS 29 to determine which of the 8 microhabitat features are key factors determining small mammal abundance through their influence on capture success (i.e., a trap successfully trapping any individual of any species at least one time during the 7-day/7-night trapping session), the number of captures, and the number of unique individuals in each site per season. A binomial distribution with a logit link

function was used for the assessment of the relationship between capture success and the microhabitat features. To assess the relationships between the number of captures or the number of unique individuals and microhabitat features, a negative binomial distribution with a log link function was chosen. The Fisher method was chosen for parameter estimations when generating the models of the relationships between the explanatory variables and the response variables.

Results

Trapping success

Based on a total of 700 trap days and 700 trap nights at each site and during each season (total = 5,600 traps checked), trapping success was higher in GFRNR (Protected Site) than in Kwandwe (Livestock Site) in both seasons (**Table 2**). The difference in the outcomes of the three methods was small for both sites and seasons. Method 2 had higher trapping success values, followed by method 3 and method 1 with the lowest values. All the methods were consistent in showing that there was greater trapping success in the conservation area than in the grazing site. The higher trapping success in the conservation area was met with low mortality rates of 7.14% in the wet season and 1.10% in the dry season. When considering the low capture success in the grazing site, the mortality rate of 24.44% during the dry season (mostly cold related) was very high compared with the 5.56% mortality rate in the wet season.

Table 2. The overall trapping success of small mammals over the wet (January–February) and the dry (May–June) seasons in the protected site (GFRNR) and the livestock grazing site (Kwandwe) obtained using three methods. Values correspond to the number of small mammals caught per 100 traps (either set or actually available for capture, depending on the method) per checking session.

Site & Season	Method 1	Method 2	Method 3
GFRNR (Wet)	2.00	2.02	2.01
Kwandwe (Wet)	1.21	1.23	1.22
GFRNR (Dry)	13.00	13.31	13.11
Kwandwe (Dry)	2.79	2.85	2.81

Diversity and variation in the small mammal communities

The dry season had the highest SDI and SiDI on both sites, while the lowest SDI and SiDI were recorded at Kwandwe during the wet season (**Table 3**). The high SDI and SiDI values at GFRNR and Kwandwe indicate a high species diversity during the dry season whereas the lower values during the wet season depict low species diversity. The Margalef index was low (ranging from 0.33–0.39) for all sites and seasons with the lowest being at GFRNR during the dry season, showing a very low species richness. Species evenness was highest in Kwandwe during the dry season where abundance had small variations among the four species and the least being at the same site during the wet season (see **Table 4**). Evenness was also low at GFRNR during the dry season where *M. coucha* and *R. pumilio* were dominant among the five species that were captured. From the species that were captured during the dry and wet

seasons on both sites, PIO was calculated and found to be high which showed small changes to the small mammal communities during the two sampling periods.

Table 3. Differences in species diversity indices for each site and season together with Pianka's index of overlap.

Sites & Seasons	Shannon Diversity Index	Evenness of Representation	Simpson's Diversity Index	Margalef Index	Pianka's Index α
GFRNR (Wet)	0.71	0.45	0.44	0.33	0.89
GFRNR (Dry)	0.92	0.39	0.56	0.31	
Kwandwe (Wet)	0.58	0.36	0.32	0.39	0.73
Kwandwe (Dry)	1.29	0.64	0.72	0.38	

Vegetation differences between study sites

The vegetation in the two study sites, when comparing the sites using the four height categories, was found to have significant differences in the presence of vegetation from all the heights in the dry season ($p < 0.05$, significant even after an HSBP). The wet season, however, showed no significant difference in the vegetation cover greater than 150 cm between the sites ($p = 0.053$) but differed significantly in the vegetation cover from the other 3 categories ($p < 0.05$). *E. bothae*, which was part of the vegetation being assessed, was not tested for any statistical difference because it was absent in GFRNR but was dominant in Kwandwe. There were no significant seasonal differences in the number of bushes between the sites ($p > 0.05$).

The degree to which vegetation of the different heights covered each microhabitat was around 2 = 50% as shown by the common median of 2 (**Figures 4 & 5**) in both sites and seasons. **Figures 4 and 5** also show that the number of bushes in the microhabitats over the two seasons was on average 5 in both sites. Interquartile ranges (IQR) for the vegetation categories further show how the level of cover by vegetation in each height on both sites and seasons was mostly at 50% and the least cover being 25% in each microhabitat (**Figures 6 & 7**). The IQR for the number of bushes shows each microhabitat had at least 2 bushes within it in both sites over the two seasons.

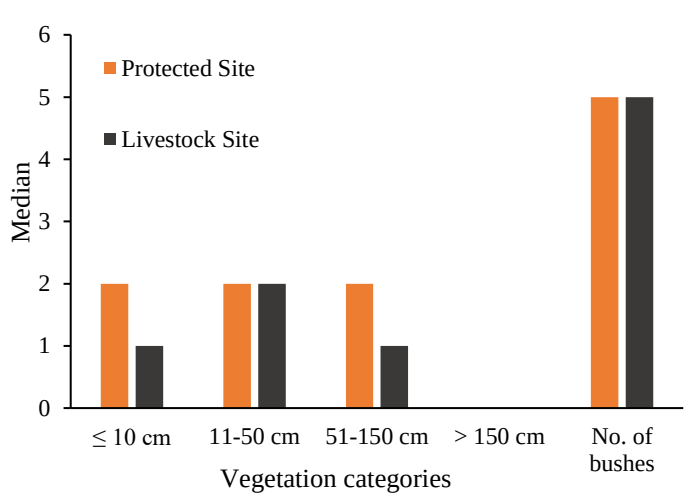


Figure 4. Distribution of the vegetation cover data from the microhabitats in the wet season at both study sites.

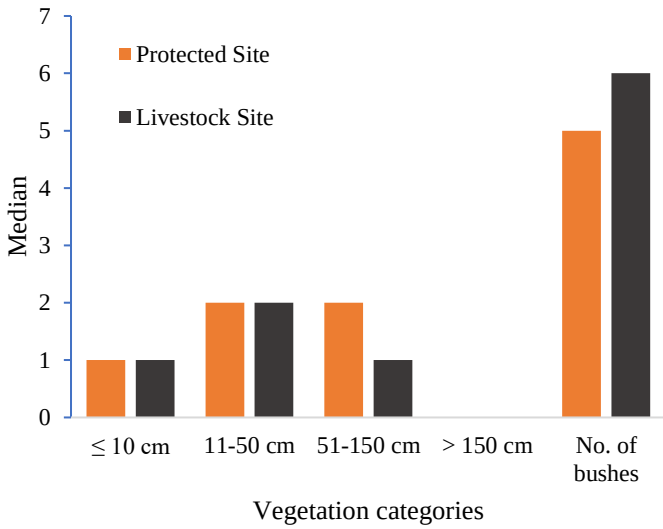


Figure 5. Distribution of the vegetation cover data from the microhabitats in the dry season at both study sites.

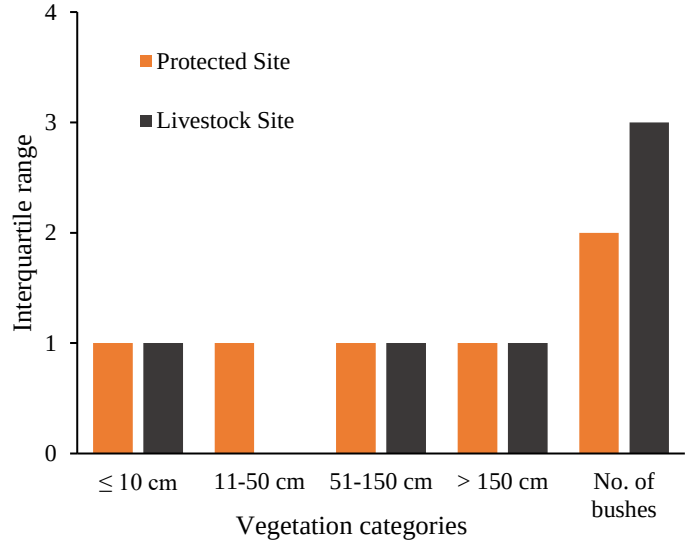


Figure 6. Interquartile range for the vegetation cover in the microhabitats during the wet season.

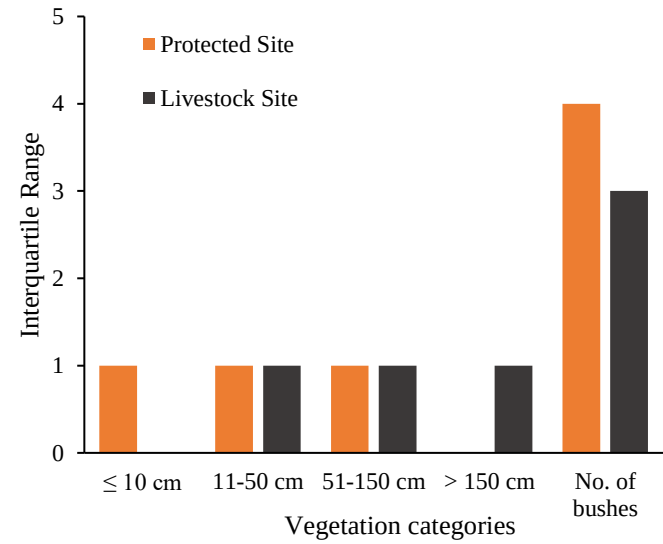


Figure 7. Interquartile range for the vegetation cover in the microhabitats during the dry season.

Vegetation differences within study sites

A Wilcoxon signed rank test was performed for the vegetation cover in GFRNR for both seasons. The statistical test revealed that there were significant changes in the vegetation cover at all the height categories and in the number of bushes ($p < 0.05$). The HSBP further confirmed that the observed differences were substantial. According to the medians and IQR values of the vegetation cover in **Figures 8 and 9**, these differences were not large. The median value for vegetation cover of ≤ 10 cm in height shows that there was a slight decline in the vegetation cover of that height in the dry season, but the IQR shows that the decline was small as the values are the same in both seasons.

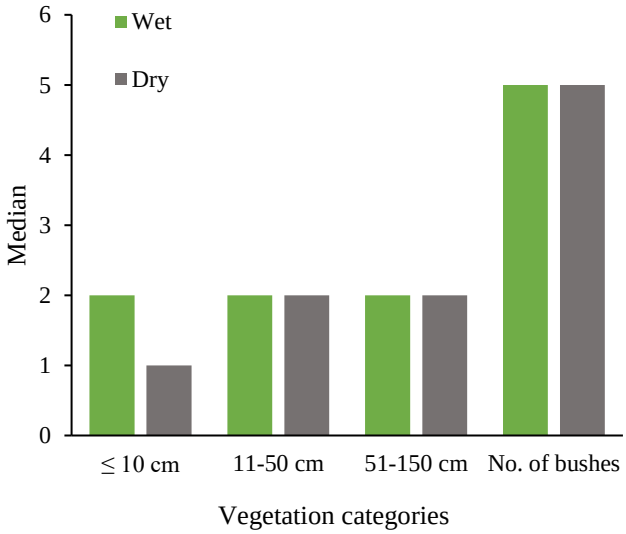


Figure 8. Median values showing variation in vegetation cover in the assessed height levels at GFRNR over the two seasons.

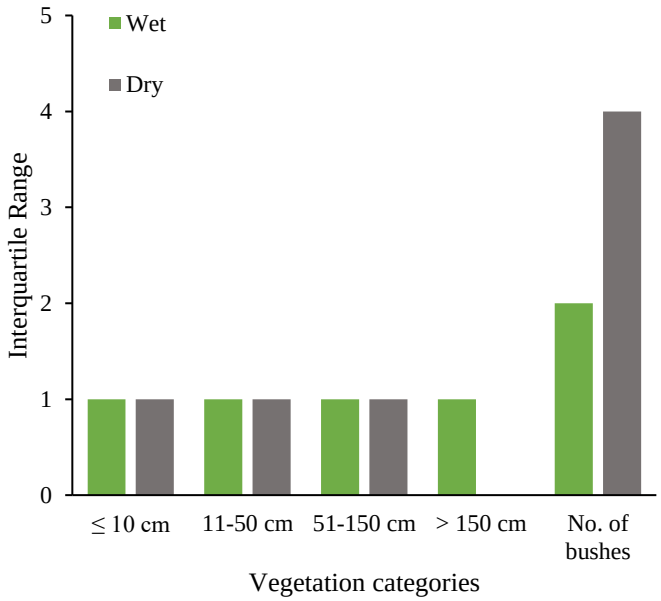


Figure 9. Interquartile range values showing seasonal changes in vegetation cover at each height level at GFRNR.

The Wilcoxon signed rank test also showed that there were significant changes in vegetation cover of the heights ≤ 10 cm and 10–50 cm in Kwandwe ($p < 0.05$). The changes were however not considerably large as seen in **Figures 10 and 11** where the medians and IQRs of the vegetation cover of these heights remained the same in both seasons. There was also a significant change in the number of bushes, with the dry season having slightly more bushes than the wet season. The difference was also not by a large margin as **Figures 10 and 11** show that the median of bushes differed by only 1 while the IQR values were the same for both seasons. Vegetation cover of heights 51–150 cm and > 150 cm had no significant differences between the seasons and **Figures 10 and 11** show that the medians and IQR values were the same.

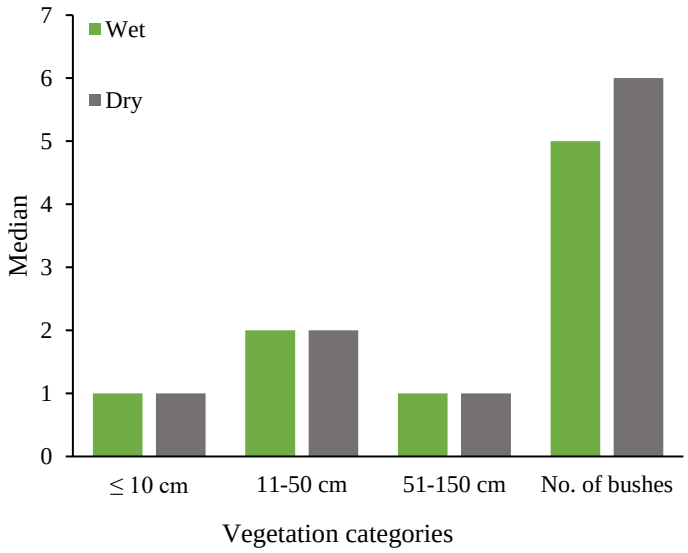


Figure 10. Median values showing variation in vegetation cover in the assessed height levels at Kwandwe over the two seasons.

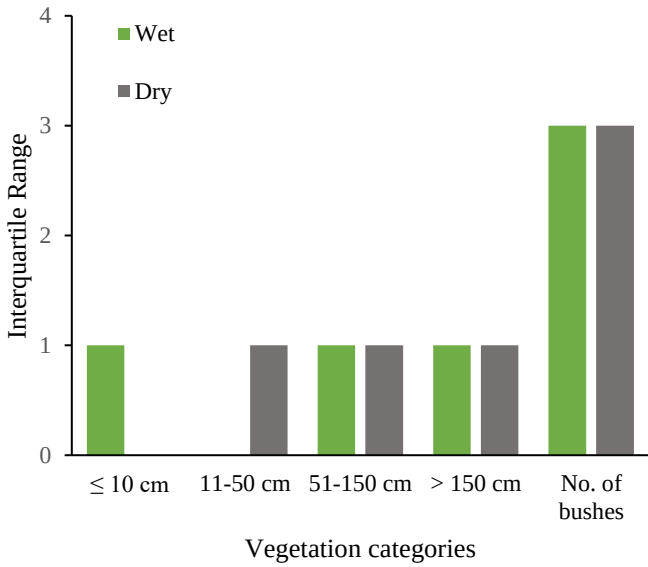


Figure 11. Interquartile range values showing seasonal changes in vegetation cover at each height level at Kwandwe.

Comparison of microhabitat structures between sites

Microhabitat structures between the two study sites were assessed for differences using a Mann–Whitney U test. In the wet season, the statistical test revealed that three of the microhabitat characteristics differed significantly between the sites and an Holm's Sequential Bonferroni Procedure (HSBP) substantiated these findings. These were a) vegetation ≤ 10 cm in height ($z = -3.89$, $p = 0.0001$), b) vegetation 11–50 cm in height ($z = -3.06$, $p = 0.002$), and c) vegetation 51–150 cm in height ($z = -3.91$, $p < 0.001$). The median values of vegetation ≤ 10 cm and 51–150 cm in height show us that GFRNR had more microhabitats in which 50% of the space was covered by plants of these heights than Kwandwe (**Figure 12**). The IQR values of these significantly differing features, however, indicate further that the differences revealed were small considering that a large portion of the microhabitats on both study sites had them covering 1 = 25% of the space (**Figure 13**).

There were no significant differences found in the other assessed microhabitat features between the sites: a) vegetation > 150 cm ($z = -1.93$, $p = 0.053$), b) bare ground ($z = -0.356$, $p = 0.722$), and c) the number of bushes ($z = -0.934$, $p = 0.350$). *E. bothae* was also assessed and found to not be an ideal factor for comparison between the sites as it was only present in Kwandwe while rocky cover had a statistically significant difference showed by the Mann–Whitney U test ($z = -2.02$, $p = 0.044$), but the HSBP correction showed that the difference was not significant.

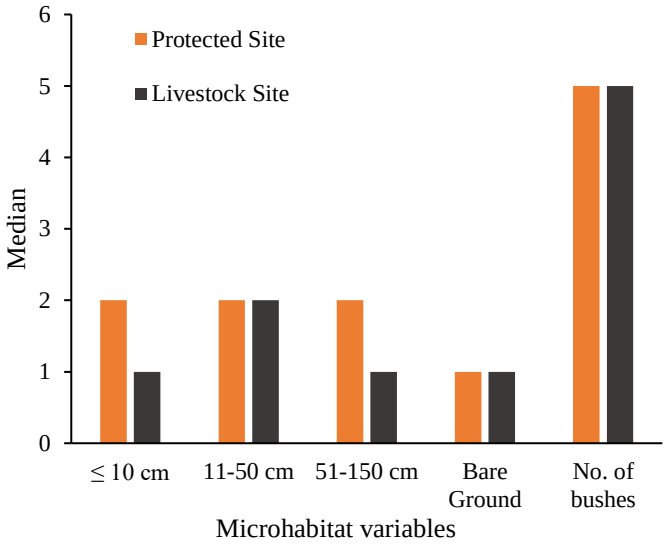


Figure 12. Median vegetation cover, bare ground cover and number of bushes at the trap stations (10 m × 10 m quadrats) at both study sites during the wet season.

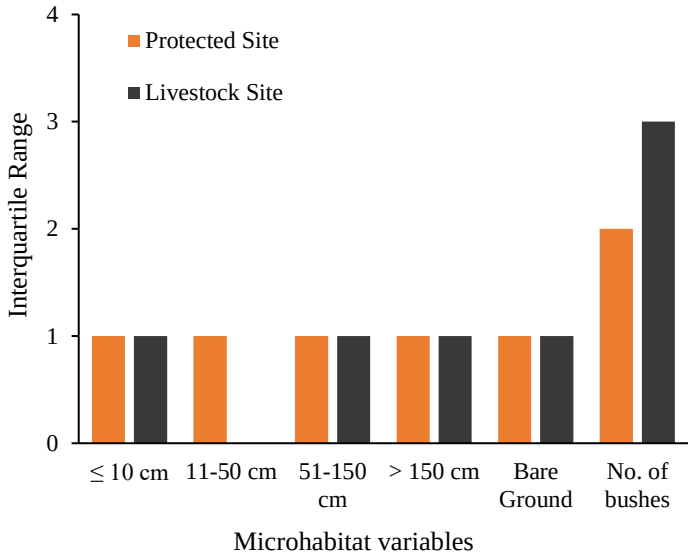


Figure 13. Interquartile range values showing similar variation in vegetation cover, bare ground and number of bushes at both study sites during the wet season.

In the dry season, the vegetation of heights > 150 cm (z = -2.84, p = 0.005), 51–150 cm (z = -2.90, p = 0.004), 11–50 cm (z = -5.324, p < 0.001), and ≤ 10 cm (z = -2.824, p = 0.005) were found to differ significantly between the sites. The HBSP supported these significant findings reported by the Mann–Whitney U test. **Figure 14** shows that the margin of difference was very small as the median values of space covered by the vegetation in their respective heights were mostly 1 to 2 (25 to 50%) of each microhabitat on both study sites. **Figure 14** also shows that the significant difference in the vegetation of height 51–150 cm was due to a slightly higher number of microhabitats in GFRNR having 50% of their space occupied by plants of that height range than there were in Kwandwe. **Figure 15** then shows that the number of microhabitats in GFRNR having plants 51–150 cm tall covering 50% of the space was not considerably large when compared to Kwandwe as the IQR of 1 for both sites indicates that the vegetation mostly occupied 25% of the microhabitat space.

The significant difference observed in the vegetation category > 150 cm was due to Kwandwe having slightly more microhabitats whose spaces were covered by plants of that height in the dry season than there were in GFRNR (**Figure 15**; IQR of Kwandwe = 1, IQR of GFRNR = 0). The medians of this vegetation height category were zero (not shown on the figures) for both sites to indicate that the difference that separated them was small. Bare ground (z = -1.413, p = 0.158) and the number of bushes (z = -0.189, p = 0.850) did not differ between the sites during the dry season. Although the median bare ground exposed was larger in GFRNR than in Kwandwe (**Figure 14**), the difference was not significant as the similar IQR values for

both sites in **Figure 15** indicate that the pool of microhabitats had the amount of bare ground exposed being 1 = 25% of the space.

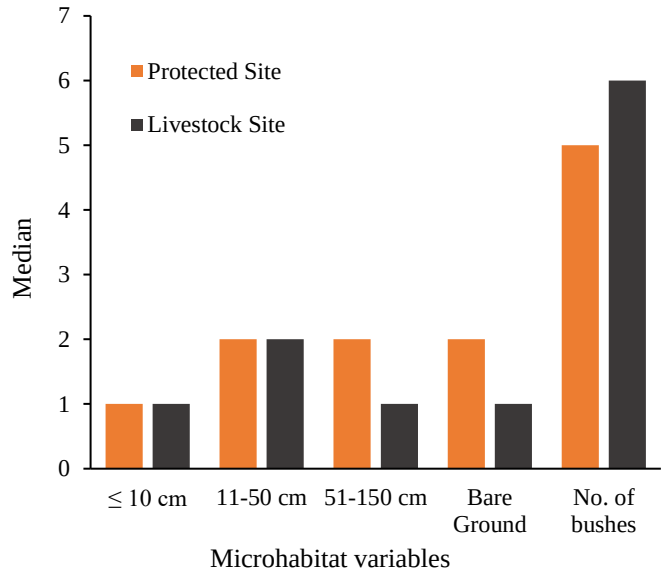


Figure 14. Median vegetation cover, bare ground cover and number of bushes at the trap stations (10 m × 10 m quadrats) at both study sites during the dry season.

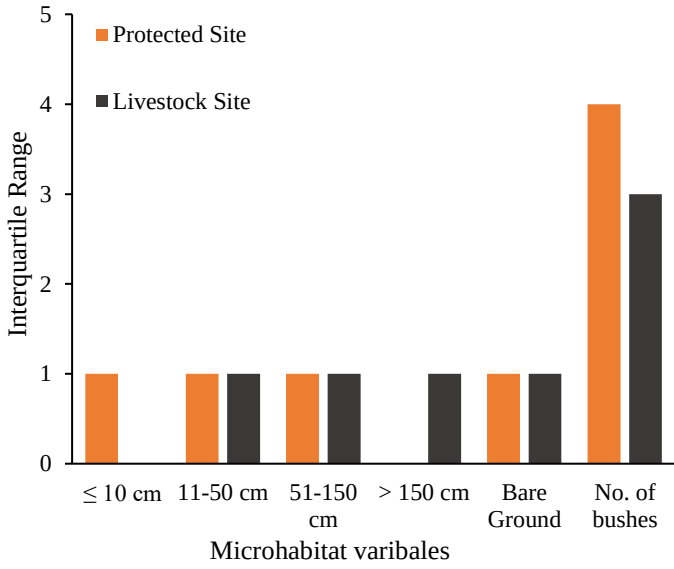


Figure 15. Interquartile range values showing similar variation in vegetation cover, bare ground and number of bushes at both study sites during the dry season.

Small mammal abundance and population density

The two trapping sessions had a total of 272 individuals from 6 small mammal species (**Table 4**). GFRNR had the most captures across both seasons, recording 210 individuals at the site, where 28 were in the wet season and 182 in the dry season. Kwandwe, on the other hand, had fewer captures when compared to GFRNR, as a total of only 62 individuals were captured across both seasons. The most common species in GFRNR were *Rhabdomys pumilio* and *Mastomys coucha*. In the wet season, *R. pumilio* made up 71.43% of the total captures, whilst 25% were *M. coucha* individuals. They also made up the bulk of the captures in the dry season, with 45.60% being *R. pumilio* and 48.89% being *M. coucha*. *Mus minutoides* were also found at both sites during both seasons, but in far lesser abundance than *R. pumilio* and *M. coucha*. *M. minutoides* had a higher number of individuals captured in the dry season at Kwandwe than at GFRNR. *M. namaquensis* was mostly caught at Kwandwe during both seasons, with no individuals captured in GFRNR in the wet season and only one during the dry season. Two other species, *Crocidura cyanea* and *Elephantulus rupestris*, were captured in GFRNR and Kwandwe, respectively, and only one individual from each across the entire trapping period.

Population density was calculated seasonally for each site and took into account the *ca* 61 ha of the GFRNR area and the 296 ha of Kwandwe (**Table 4**). There were more small mammals found per hectare in GFRNR during the dry season than there were in the wet season. Kwandwe also had more small mammal individuals per hectare in the dry than in the wet season. Overall, the population density in GFRNR during the dry season was almost 7 times more than that in the wet season, 20 times more than that of Kwandwe during the dry season, and virtually 50 times more than that of the wet season.

Table 4. The abundance of each small mammal species captured over the wet (January–February) and dry (May–June) seasons and the population densities in Kwandwe and GFRNR. *M. n. = Mastomys natalensis, R. p. = Rhabdomys pumilio, M. c. = Mastomys coucha, C. c. = Crocidura cyanea, E. r. = Elephantulus rupestris*.

Site (Season)	***M. n.***	***R. p.***	***M. c.***	***M. m.***	***C. c.***	***E. r.***	**Pop. density (ind./ha)**
GFRNR (Wet)	-	20	7	1	-	-	0.46
Kwandwe (Wet)	14	2	-	-	-	1	0.06
GFRNR (Dry)	1	83	88	9	1	-	2.99
Kwandwe (Dry)	15	4	11	15	-	-	0.15

In the wet season, the GzLM model revealed minimal influence of the microhabitat features on small mammal captures in the GFRNR (**Table 5)**. Vegetation of heights 51–150 cm had a stronger influence on captures than all the other five variables (p = 0.405), whilst vegetation of height > 150 cm had the weakest influence on captures (p = 0.932). The model, as a whole, showed that these microhabitat features had an insignificant effect on capturing small mammal within the microhabitats (Akaike Information Criterion (AIC) = 130.26; Omnibus test: Likelihood Ratio Chi-Square (LRC-S) = 31.67, df = 27, p = 0.244).

Table 5. Effects of the microhabitat features on small mammal captures during the wet season in the GFRNR (GzLM, Type III test). Microhabitat features present here are those that had a Wald test result greater than zero.

Microhabitat variables	**Wald Chi-Square**	**df**	***p***
≤ 10 cm	0.967	3	0.809
11–50 cm	0.597	3	0.897
51–150 cm	4.004	4	0.405
> 150 cm	0.441	3	0.932
Bare Ground	0.473	2	0.789
No. of bushes	8.913	12	0.710

During the dry season, the change in vegetation cover of height ≤ 10 cm had the strongest influence on the small mammal captures (p = 0.003), whilst the number of bushes within the microhabitats had the least influence (p = 0.991) in the GFRNR (**Table 6**). Bare ground had the second strongest influence on small mammal capture (p = 0.078), while the other microhabitat features had lesser influence on the capture success. The constituent microhabitat features in the GFRNR during the dry season had a collectively significant influence on capture success (AIC = 76.563; Omnibus test: LRC-S = 158.703, df = 28, p < 0.0001).

Table 6. Effects of the microhabitat features on small mammal captures during the dry season in the GFRNR (GzLM, Type III test). Microhabitat features present here are those that had a Wald test result greater than zero.

Microhabitat variables	Wald Chi-Square	df	*p*
≤ 10 cm	13.643	3	0.003
11–50 cm	5.299	3	0.151
51–150 cm	7.403	4	0.116
> 150 cm	0.593	3	0.898
Bare Ground	3.104	1	0.078
% Euphorbs	< 0.00001	1	1.000
No. of bushes	4.524	14	0.991

In Kwandwe, during the the wet season the percentage of *Euphorbia* plants had the strongest influence on the capture success (p = 0.106), followed by the presence of vegetation of height > 150 cm (p = 0.290) (**Table 7**). Bare ground (p = 0.340) also had a relatively minor effect on small mammal capture success when compared to the other microhabitat features such as vegetation cover of heights 11–50 cm and 51–150 cm (p = 0.536 and p = 0.810, respectively). The combined effect of the microhabitat features in Kwandwe during the wet season had a significant effect on capture success (AIC = 108.095; Omnibus test: LRC-S = 36.783, df = 22, p = 0.025).

Table 7. Effects of the microhabitat features on small mammal captures during the wet season in Kwandwe (GzLM, Type III test).

Microhabitat variables	Wald Chi-Square	df	*p*
≤ 10 cm	0.054	2	0.973
11–50 cm	2.178	3	0.536
51–150 cm	0.964	3	0.810
> 150 cm	2.475	2	0.290
% Rocks	0.017	1	0.897
Bare Ground	4.490	1	0.340
% Euphorbs	4.492	2	0.106
No. of bushes	2.392	8	0.967

During the dry season in Kwandwe, the microhabitat features had minimal influence on small mammal capture success (**Table 8**). None of the constituent microhabitat features had a significant effect on the capture success ($p > 0.5$). Their combined influence on capture success was also insignificant (AIC = 158.560; Omnibus test: LRC-S = 10.399, df = 22, $p = 0.982$).

Table 8. The influence of microhabitat features on small mammal capture success in Kwandwe during the dry season (GzLM, Type III test).

Microhabitat variables	Wald Chi-Square	df	*p*
≤ 10 cm	0.415	2	0.813
11–50 cm	0.338	3	0.953
51–150 cm	1.934	3	0.586
> 150 cm	0.808	2	0.668
% Rocks	0.280	1	0.596
Bare Ground	0.022	1	0.881
% Euphorbs	0.191	2	0.909
No. of bushes	0.793	8	0.999

Small mammal occurrence

Over the two trapping seasons, the number of times individuals from each species were captured over the 7-day/7-night trapping period was totalled and represented as occurrence (**Figures 16–19**). The occurrence representation depicts the level of activity in each area for each season. Most individuals occurred once or twice across all species that were captured. *M. namaquensis* occurred the most in Kwandwe in both seasons, while *R. pumilio* was the most

active in GFRNR during the wet season and *M. coucha* during the dry season. *R. pumilio* was the most common across both seasons and sites, followed by *M. coucha*, which occurred during the wet season at GFRNR and on both sites during the dry season.

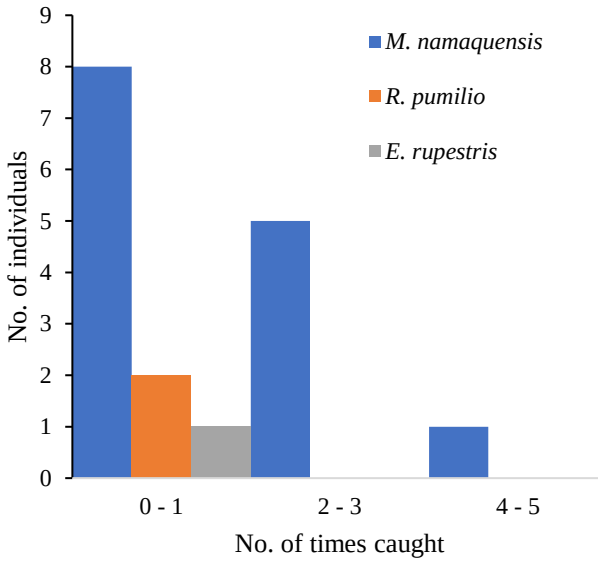


Figure 16. The occurrence of individuals from the 3 species that were captured over the 7-day/7-night trapping period at Kwandwe over the wet season.

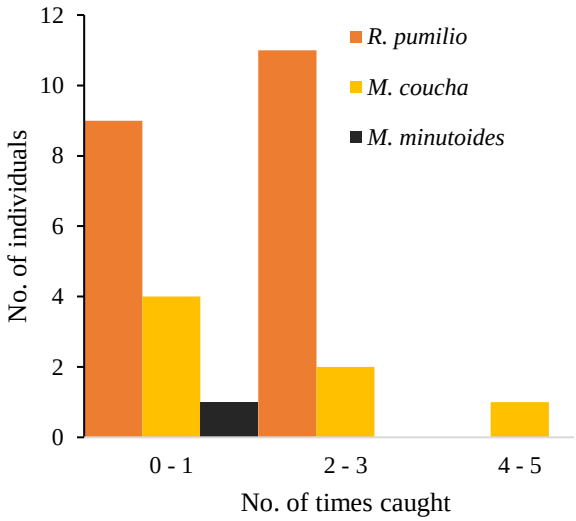


Figure 17. The occurrence of individuals from the 3 species that were captured over the 7-day/7-night trapping period at GFRNR during the wet season.

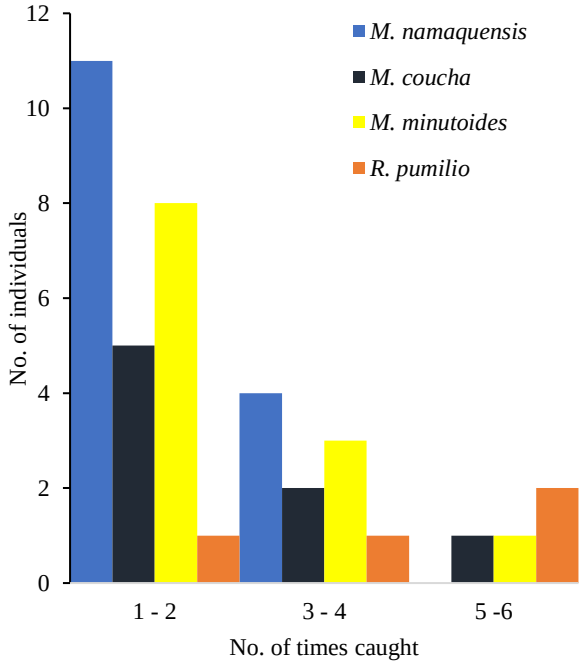


Figure 18. The occurrence of individuals from the 4 species that were captured over the 7-day/7-night trapping period at Kwandwe during the dry season.

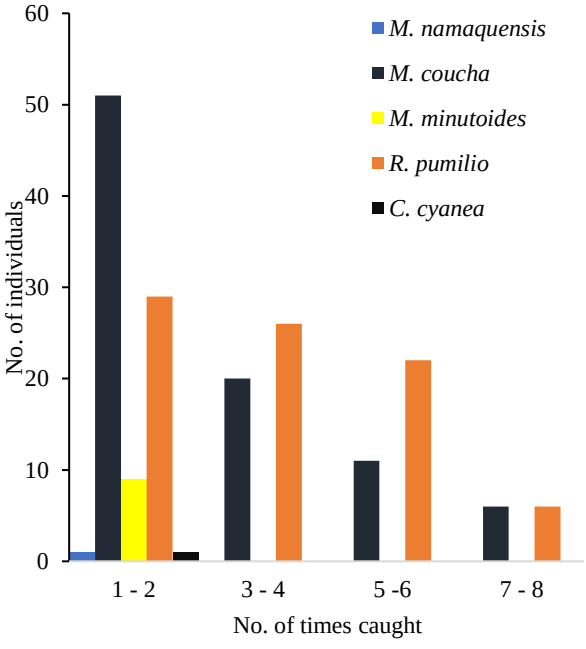


Figure 19. The occurrence of individuals from the 5 species that were captured over the 7-day/7-night trapping period at GFRNR over the dry season.

The number of captures during the wet season in the GFRNR was influenced greatly by vegetation cover of heights 51–150 cm (p = 0.003) (**Table 9**). The expanse of bare ground (p = 0.027) together with the number of bushes (p = 0.035) and vegetation of heights 11–50 cm (p = 0.046) also had considerable effects on the number of captures. The collective effect of the microhabitat features was significant, although the model was not the best representation of the important determining factors for the number of small mammal captures (AIC = 216.698; Omnibus test: LRC-S = 45.267, df = 28, p = 0.021).

Table 9. The degree to which the microhabitat features influenced the number of small mammal captures recorded during the wet season in the GFRNR (GzLM, Type III test).

Microhabitat variables	Wald Chi-Square	df	*p*
≤ 10 cm	3.947	3	0.267
11–50 cm	6.174	2	0.046
51–150 cm	11.575	2	0.003
> 150 cm	3.683	2	0.159
Bare Ground	4.904	1	0.027
% Euphorbs	0.299	1	0.585
No. of bushes	13.579	6	0.035

During the dry season in the GFRNR, the absence of *Euphorbia* had a greater effect on the number of captures than all the other microhabitat features (p = 0.157) (**Table 10**). The expanse of bare ground was the second-best determining factor in the model although it did not have a considerable effect on the number of captures (p = 0.469). The model showed that the collective effect of the microhabitat features was small and insignificant (AIC = 612.400; Omnibus test: LRC-S = 23.871, df = 29, p = 0.735).

Table 10. Measures of the effect that each of the microhabitat features in the GFRNR had on the number of captures during the dry season in the GFRNR (GzLM, Type III test).

Microhabitat variables	Wald Chi-Square	df	*p*
≤ 10 cm	1.492	3	0.684
11–50 cm	1.701	3	0.637
51–150 cm	1.556	4	0.817
> 150 cm	0.314	2	0.855
Bare Ground	0.524	1	0.469
% Euphorbs	1.999	1	0.157
No. of bushes	10.134	13	0.683

The expanse of bare ground within the microhabitats was a significant determining factor in the number of small mammals captured during the wet season in Kwandwe (p = 0.004) (**Table 11)**. Vegetation cover of height ≤ 10 cm (p = 0.439) and the percentage cover of euphorbs (p = 0.369) had smaller measures of influence on the number of captures than that of bare ground within the microhabitats, whereas the other features had a very small influence on the number of captures, especially when compared to that of bare ground. The model generated for the effects of all the microhabitat features on the number of small mammal captures showed a significant combined influence (AIC = 148.848; Omnibus test: LRC-S = 65.973, df = 22, p < 0.001).

Table 11. Measures of the effect that each of the microhabitat features in Kwandwe had on the number of captures during the wet season. Obtained through the GzLM, Type III test.

Microhabitat variables	Wald Chi-Square	df	*p*
≤ 10 cm	0.599	1	0.439
11–50 cm	1.170	2	0.557
51–150 cm	0.594	2	0.743
> 150 cm	0.462	2	0.794
% Rocks	0.013	1	0.911
Bare Ground	8.122	1	0.004
% Euphorbs	0.807	1	0.369
No. of bushes	4.261	5	0.513

In the dry season, Kwandwe did not have any features that influenced the number of small mammal captures that strongly (**Table 11**). The amount of bare ground within the microhabitats, however, had a stronger effect on the number of captures than all the other features of the microhabitats (p = 0.10). Second to bare ground in having a strong effect was vegetation cover of height 51–150 cm (p = 0.239), while the other features had very small effects. The model representing the interaction of the eight microhabitat features with the number of small mammal captures showed no combined significant effect of the predictor variables (AIC = 296.995; Omnibus test: LRC-S = 17.620, df = 22, p = 0.728).

Table 11. Measures of the effect that each of the microhabitat features in Kwandwe had on the number of captures during the dry season. Obtained through the GzLM, Type III test.

Microhabitat variables	Wald Chi-Square	df	*p*
≤ 10 cm	1.456	2	0.483
11–50 cm	0.392	3	0.942
51–150 cm	2.865	2	0.239
> 150 cm	0.468	2	0.791
% Rocks	0.694	1	0.405
Bare Ground	2.698	1	0.100
% Euphorbs	1.463	2	0.481
No. of bushes	3.358	6	0.739

In the GFRNR, vegetation of height 51–150 cm had a greater measure of influence on the number of unique individuals than all the other features that contributed to the model in the wet season ($p = 0.003$) (**Table 12**). The number of bushes within the microhabitats also had a significant effect on the number of unique individuals captured ($p = 0.039$). Vegetation cover of height 11–50 cm ($p = 0.075$) and bare ground ($p = 0.076$) had virtually similar effects on the number of unique individuals during the wet season, while the vegetation cover > 150 cm had a smaller measure of influence ($p = 0.191$). The absence of euphorbs ($p = 0.717$) was not a significant determining factor of the number of unique individual captures in the microhabitats during the wet season. The collective effect of the model had a significant effect on the number of unique individuals captured during the wet season (AIC = 207.773; Omnibus test: LRC-S = 44.265, df = 27, $p = 0.019$).

Table 12. The degree to which the microhabitat features influenced the number of unique individuals recorded during the wet season in the GFRNR (GzLM, Type III test).

Microhabitat variables	Wald Chi-Square	df	*p*
≤ 10 cm	2.117	3	0.555
11–50 cm	5.155	2	0.075
51–150 cm	11.514	2	0.003
> 150 cm	3.331	2	0.191
Bare Ground	3.216	1	0.076
% Euphorbs	0.132	1	0.717
No. of bushes	13.264	6	0.039

In the dry season, there were no microhabitat features that had a significant effect on the number of unique individuals captured in the GFRNR (**Table 13**). The absence of euphorbs, however, had a greater effect on the number of unique individuals captured during the dry season than all the other microhabitat features that contributed to the model (0.215). The second-best measure of influence on the number of unique individuals was by the amount of bare ground exposed in the microhabitats (p = 0.390). All the other features had very small measures of influence on the number of unique individuals captured during the dry season, with the least being that of vegetation cover of height 51–150 cm (p = 0.971). The full model was statistically non-significant (AIC = 587.521; Omnibus test: LRC-S = 21.334, df = 29, p = 0.847).

Table 13: The degree to which the microhabitat features influenced the number of unique individuals recorded during the dry season in the GFRNR (GzLM, Type III test).

Microhabitat variables	Wald Chi-Square	df	*p*
≤ 10 cm	2.010	3	0.570
11–50 cm	2.183	3	0.535
51–150 cm	0.521	4	0.971
> 150 cm	0.518	2	0.772
Bare Ground	0.740	1	0.390
Euphorbs	1.540	1	0.215
Number of bushes	8.650	13	0.799

The number of unique individuals in Kwandwe, during the wet season, was influenced mostly by the amount of bare ground within the microhabitats (p = 0.005). Bare ground was the only microhabitat feature that had a significant effect when compared to the other features (**Table 14**). The percentage cover of *Euphorbia* plants (p = 0.338) had a small measure of influence together with vegetation cover of height ≤ 10 cm (p = 0.469), whereas the other microhabitat features had virtually negligible effects on the number of unique individuals captured within the microhabitats in Kwandwe. Their combined effect on the number of unique individuals captured was significant, even though the full model was not the best model (AIC = 148.528; Omnibus test: LRC-S = 49.613, df = 22, p = 0.001).

Table 14. The degree to which the microhabitat features influenced the number of unique individuals recorded during the wet season in Kwandwe (GzLM, Type III test).

Microhabitat variables	Wald Chi-Square	df	*p*
≤ 10 cm	0.524	1	0.469
11–50 cm	0.317	2	0.854
51–150 cm	0.587	2	0.746
> 150 cm	0.414	2	0.813
%Rock	0.045	1	0.832
Bare Ground	8.038	1	0.005
Euphorbs	0.918	1	0.338
Number of bushes	3.773	5	0.583

During the dry season, none of the microhabitat features had a significant effect on the number of unique individuals captured in Kwandwe (**Table 15**). The percentage of bare ground cover within the sampled quadrats was again the feature with the strongest effect (p = 0.187). Vegetation cover of 51–150 cm had the second strongest effect on the number of unique individuals captured (p = 0.291), while the other microhabitat features had very small effects when compared to the two highest. The least measure of influence on the number of unique individuals was by vegetation cover of height 11–50 cm (p = 0.852). The collective effect of the microhabitat features on the number of unique individuals was not statistically significant (AIC = 271.315; Omnibus test: LRC-S = 15.989, df = 22, p = 0.816).

Table 15. The degree to which the microhabitat features influenced the number of unique individuals recorded during the dry season in Kwandwe (GzLM, Type III test).

Microhabitat variables	Wald Chi-Square	df	*p*
≤ 10 cm	1.139	2	0.566
11–50 cm	0.791	3	0.852
51–150 cm	2.471	2	0.291
> 150 cm	0.724	2	0.696
%Rock	0.533	1	0.465
Bare Ground	1.740	1	0.187
Euphorbs	1.633	2	0.442
Number of bushes	3.372	6	0.761

Table 16 summarizes the main results of the GzLM analyses. Bare ground was the only microhabitat feature that had a significant effect on capture success, the number of captures, and the number of unique individuals, and it made substantial contributions to the models that

showed a strong influence on the three response variables. Of the 12 models, bare ground contributed significantly to six of them, and of those six models, three were made up exclusively of bare ground. The amount of exposed ground was a strong determining factor for the number of captures during the wet (p = 0.001) and dry seasons (p = 0.048), and the number of unique individuals during the dry season in Kwandwe (0.133).

The absence of *Euphorbia* in the GFRNR had some influence on the number of captures and the number of unique individuals during the dry season, and it was the sole microhabitat feature in the model that somehow suggested a tendency to affect the number of captures (p = 0.138) and unique individuals (p = 0.153). The very large AIC values of these models indicate that they were not ideal representations of the relationship between the microhabitat features and the number of captures and unique individuals.

Table 16. Top Generalized Linear Models for microhabitat features that had significant effects on capture success, the number of captures, and the number of unique individuals in the GFRNR and Kwandwe during the wet (W) and dry (D) seasons. [a] = capture; [b] = number of captures; [c] = number of unique individuals

Model	Likelihood Ratio Chi-Square	df	AIC	*p*	Site (Season)
51–150 cm [a]	2.753	4	116.921	0.600	GFRNR (W)
≤ 10 cm + Bare Ground [a]	9.472	4	59.087	0.050	GFRNR (D)
Bare Ground + % Euphorbs[a]	17.744	3	87.633	< 0.001	Kwandwe (W)
51–150 cm [a]	2.522	3	134.757	0.471	Kwandwe (D)
No. of bushes [b]	21.141	12	203.981	0.048	GRFNR (W)
Euphorbs [b]	2.195	1	571.145	0.138	GRFNR (D)
Bare Ground [b]	12.108	1	106.342	0.001	Kwandwe (W)
Bare Ground [b]	3.907	1	270.246	0.048	Kwandwe (D)
No of bushes [c]	20.544	12	195.079	0.057	GFRNR (W)
% Euphorbs [c]	2.046	1	543.854	0.153	GFRNR (D)
≤ 10 cm + Bare Ground + % Euphorbs [c]	33.543	5	122.999	< 0.001	Kwandwe (W)
Bare Ground [c]	2.259	1	242.689	0.133	Kwandwe (D)

Discussion

Habitat differences

Observable differences in the habitats of the two study sites were notable, Kwandwe being vegetated by mostly *Euphorbia bothae*, while GFRNR was covered by an assorted layer of grasses, herbaceous plants, and shrubs. The presence of grasses and herbaceous plants was not restricted to GFRNR, as Kwandwe had them also. Herbaceous plants and some grasses made up the plant cover ≤ 10 cm high which, during the wet season, covered much more ground than it did during the dry season in both habitats. The decrease in the space covered by plants ≤ 10 cm high may have been due to plant crown damage by foraging or being trodden on while other plants may have dried up and died in the dry season due to the nature of their lifecycles because they may have been seasonal herbaceous plants and grasses (Chaves *et al*., 2002; Magandana *et al*., 2009; Lebopa, 2010). GFRNR maintained a larger presence of plants ≤ 10 cm high from the wet to dry season than Kwandwe, probably because they were the understory of nurse plants which protected them from foliage damaging condition (Cornelissen *et al*., 2003). Some of these plants may have had their reproductive parts senesce in the course of the season (Cornelissen *et al*., 2003).

The difference revealed in the cover by plants 11–50 cm high in both sites was by a small margin and this was likely due to the resilience of the plants when seasons changed. Some of the woody plants made up the vegetation in the 11–50 cm category and may have been subject to foraging due to maintaining their foliage. Kwandwe, however, had slightly fewer of these plants covering the area than GFRNR because of the frequent presence of browsing goats in the area. It is also likely that GFRNR had more cover by the plants 11–50 cm high because of being part of a larger and open area where animals could forage, whereas Kwandwe is enclosed and subject to having concentrated foraging (Eccard and Liesenjohann, 2008). Browsing activity by goats in Kwandwe was also a possible cause for the lesser presence of vegetation which was 51–150 cm high when compared to GFRNR in both seasons (Bergström, 1992). Our grazing site showed no seasonal difference in this category of vegetation cover possibly because the plants within the height of 51–150 cm were subject to continuous browsing both in the wet and dry seasons. On the other hand, the conservation area may have had foraging animals make use of plants in this height category but to a lesser extent than what the grazing site experienced because of the availability of other areas to forage in as they tracked the expanse of the reserve (Eccard and Liesenjohann, 2008).

Some of the plants making up the vegetation in the 51–150 cm category were tall grasses which, in the wet season, grew well especially in the conservation area, but the dry season had these grasses dried up with some making up litter at the base of other plants. There were also woody plants that made up both the 51–150 cm and > 150 cm categories whose area of coverage declined from the wet season to the dry season due to herbivory in the conservation area. The grazing site showed no significant variation in the vegetation cover of height > 150 cm because of being sporadic and made up of trees and some tall-growing *Euphorbia* species which we expected not to change seasonally. On the other hand, the conservation area had plants such as cat thorn and *Rhus* spp. which made up the vegetation cover of height > 150 cm whose cover was relatively continuous throughout the site and did not vary much likely due to being resilient, but the tall grasses had dried and fallen.

The resilience of these plants contributed to the maintenance of bushes and their numbers during the two seasons in both sites. We had not expected to have more bushes in the dry season than there were in the wet season in the two sites, but this was likely due to the plants making up the bushes being in their growing period when we first sampled the sites, therefore, contributing to clusters of vegetation which were not bushes at the time. The grasses, herbaceous plants, and woody plants that made up the bushes that had not been recognized as such during the wet season were possibly at their shoot stage when sampling took place. They may have been shielded within the light clusters of vegetation allowing them to grow without being foraged on, trodden on, or exposed to harsh sunlight and wind that would have disturbed their growth. The absence of a significant difference in the number of bushes between the study sites in both seasons may have been a consequence of the wet season promoting plant growth and productivity in both sites and the emergence of other plants within the light clusters of vegetation in the dry season, therefore, forming bushes (Juan de Dios *et al*., 2009). The bushes that formed from the emergence of plants within the light clusters of vegetation may have made up for any bushes that had their constituent plants either lost due to drying up or reaching the end of their lifecycle.

The removal of vegetation cover, especially the plants ≤ 10 cm high, by foraging or drying up due to water scarcity resulted in bare ground exposure which was greater in the dry season than the wet season in both study sites. In the conservation area, there were instances during the dry season when warthogs decimated plants ≤ 10 cm and 11–50 cm high when digging the ground for roots and tubers within our study area. Most of these plants may have not recovered because of being uprooted and displaced resulting in an increased expanse of bare

ground. The exposed ground may have been subjected to compaction by animals, wind, and hot temperatures which lower humidity and make the soil less favourable for plant growth (Ni *et al*., 2019). These conditions may have been the reason for the seasonal differences in bare ground recorded within each site. The differences observed in all the habitat features between the study sites show that they differed as predicted, even though the differences were not major.

Small mammal species and abundance

The expectation was to have more small mammals captured during the wet season than in the dry season because of the greater availability of food and denser vegetation cover that are made possible by the rains (Taylor and Green, 1976). Trapping success was highest in the dry season with captures being ten times more than they were in the wet season, similar to studies by Abramsky and Rosenzweig (1983) and Fuller and Perrin (2001), where small mammal abundance and diversity were highest during the dry season and lowest in the wet season. The number of species was higher in the dry season for both the livestock and protected sites, each having four and five species, respectively. During the wet season, only three species were captured per study site with *Rhabdomys pumilio* being the only common one on both sites. The success of the dry season may have been brought about by the coinciding of our sampling period with the breeding season of *Mastomys coucha* and *Mus minutoides* (see Table 17, page 40) (Leirs *et al*., 1990; Christensen, 1993; Skinner and Chimimba, 2005). This may justify the large number of small mammals found on both sites during the dry season than in the wet season, as they may have been moving about looking for mates. On the other hand, the lesser number of small mammals captured during the wet season may have been due to the young adults or juveniles being too small to trap at the time. The greater availability of food and vegetation cover, which restricted their movements to small home ranges, may have also brought about the lesser number of small mammals captured during the wet season.

Small mammal captures in the livestock site during the wet and dry seasons were dominated by *Micaelamys namaquensis*, making up more than 50% of the total number of unique individuals captured in the site. The higher abundance of *M. namaquensis* than all the other species in the livestock site, where cattle and goats were frequent, was similar to an observation by Starik *et al*. (2020) where this species was abundant in their livestock rangeland site where cattle grazing was very frequent. In a conservation and residential site that is primarily vegetated by herbaceous and semi-open thickets, Ramahlo *et al*. (2022)

found that *M. namaquensis* was twice as abundant during the wet season than in the dry season. This was opposite to what we observed in our protected site where *M. namaquensis* was completely absent in the wet season and only a single capture was recorded in the dry season.

Its dominance in the livestock site where vegetation cover was lesser may be attributed to its adaptability to open areas (Skinner and Chimimba, 2005). It could also be due to the Namaqua rock mouse being adapted to xeric areas that are characterized by succulent plants such as the *E. bothae* vegetating the livestock site (De Graff, 1997). The livestock site also had *R. pumilio* occurring in both seasons but to a far lesser extent than it did in the protected site, most likely due to *R. pumilio* preferring grasslands with other plants as vegetation cover to serve as food and protection from predators (De Graaff, 1997; Krug, 2002). In the protected site, the presence of tall grass and the variety of plants could have been the influencing factor for the *R. pumilio* abundance to be 10 times more than that of the livestock site in the same season. The dry season being outside the breeding period of *R. pumilio*, the abundance can be attributed to the juveniles and young adults that had been born during the wet season and also to the generally high occurrence of this species in areas inhabited by other rodent species (Happold, 2013). The high abundance of *R. pumilio* during the dry season in the protected site was coupled with an abundance of *Mastomys coucha* which in the previous season had occurred in very small numbers.

Mastomys coucha inhabits grasslands and is especially good at pioneering the occupation of land that had undergone disturbance (Meester *et al*., 1979; De Graaff, 1997; Skinner and Chimimba, 2005). This could perhaps justify their presence making up almost half the individuals captured in the protected site, which is an area that has recovered and became vegetated by a variety of plants and grasses after being severely browsed by black rhinos, leading to the extinction of *E. bothae* from that site (Juske *et al*., 2009). The number of captures during the wet season was very low when compared to the dry season captures, which was 12 times higher. Ramahlo *et al*. (2022) reported similar observations in their nature conservancy site where the dry season captures were 7 times more than those in the wet season. *Mastomys coucha* abundance during the dry season could be attributed to increased home ranges during the breeding season (Christensen, 1996; Leirs, 2013), whereas the wet season had a small number of individuals because grass cover was highest during that season, making the habitat unsuitable for them (Monadjem and Perrin, 2003). The livestock site's habitat had less grass cover during the dry season which could explain *M. coucha* making up

almost a third of the individuals captured. This occurrence of *M. coucha* in high numbers in the livestock site coincided with that of *Mus minutoides*.

Table 17. The ecological characteristics of the small mammals captured over the two trapping sessions in the Protected Site (GFRNR) and the Livestock Site (Kwandwe) (De Graaf, 1997; Skinner and Chimimba, 2005; Kenser *et al.,* 2013; Perrin, 1997, 2013; Kingdon, 2015).

Species	Study site	Activity pattern	Diet	Reproductive season	Specialist/Generalist
Crocidura cyanea (Reddish-grey musk shrew)	Protected Site	Nocturnal	Insectivore	Summer	Generalist
Elephantulus rupestris (Western rock sengi)	Livestock Site	Diurnal	Insectivore	Spring and summer	Specialist
Mastomys coucha (Southern multimammate mouse)	Protected Site and Livestock Site	Nocturnal	Omnivore	Whole year	Generalist
Micaelamys namaquensis (Namaqua rock mouse)	Protected Site and Livestock Site	Nocturnal	Omnivore	Spring and summer	Generalist
Mus minutoides (Pygmy mouse)	Protected Site and Livestock Site	Nocturnal	Omnivore	Whole year	Generalist
Rhabdomys pumilio (Four-striped grass mouse)	Protected Site and Livestock Site	Crepuscular and diurnal	Omnivore	Summer and spring	Generalist

Mus minutoides was found to abound when *M. coucha* abounds and this is thought to be an adaptive mechanism by *M. minutoides* where it uses the high numbers of *M. coucha* as a defence against predation (De Graaff, 1997; Avery *et al.*, 2003). They inhabit habitats such as grasslands, rocky areas, and plantations (De Graaff, 1997; Skinner and Chimimba, 2005; Monadjem, 2013). This species made up a third of the captures in the livestock site during the dry season after not occurring during the wet season and this may be due to its preference for shorter grass cover as observed by Jooste and Palmer (1982). The abundance of *M. coucha* in the protected site, however, was not met with as great an abundance of *M. minutoides* as the one in the livestock site, possibly due to individuals entering traps without triggering them or their numbers were affected by larger territorial small mammals that occurred in large numbers such as *R. pumilio* (Monadjem, 1999). There were isolated captures of *Elephantulus rupestris* during the wet season in the livestock site and *Crocidura cyanea* in the protected site during the dry season.

The capture of *E. rupestris* in the livestock site was perhaps due to the species' preference for rocky habitats and the livestock site had rocky patches, while the protected site where no capture was recorded did not have any rocky areas (Skinner and Chimimba, 2005). Monadjem and Perrin (2003) recorded a large number of captures of *E. rupestris*, during the winter period (which is our dry season), but in this study, it never occurred, probably due to their naturally low abundance at both sites. It is also possible that the bait was not effective in luring individuals of *E. rupestris* because of their insectivorous diet. *Crocidura cyanea*, on the other hand, is a trap-shy species that occurs in habitats such as grasslands and bushvelds, where it makes use of leaf litter and ground-level vegetation (Jooste and Palmer, 1982; Monadjem, 1997; Baxter and Dippenaar, 2013).

Small mammal richness and diversity

The number of species found in each site did not vary greatly between the sites in both seasons. In the protected site, of the three species that occurred during the wet season, two were unique to the site, as was the case with those that occurred in the livestock site. Species richness in the livestock site was low in the wet season, coupled with low diversity, which is what we expected given that the site has one dominant plant (*E. bothae*), while other plants occur less frequently, which does not favour small mammals (Monadjem and Perrin, 1998; Hoffman and Zeller, 2005). The dry season had one more species than in the wet season but still maintained the low species richness, but diversity was higher in the dry season compared

to the wet season as each species was fairly represented. The fair representation of each species could be a consequence of a possible breeding period during the trapping session or foraging for mature seeds was taking place frequently during the dry season (Taylor and Green, 1976; Leirs *et al*., 1990).

Species occurring during the dry season in the protected area were two more than those that occurred in the wet season, implying that it was favourable for small mammal occurrence. Species richness was low in the wet season, similar to the livestock site, and was also accompanied by low diversity. The dry season, however, had a higher species richness although there was no corresponding increase in diversity as *R. pumilio* and *M. coucha* were overly represented with their numbers being exponentially larger than those of *M. namaquensis, C. cyanea,* and *M. minutoides*. The low diversity in this site was most likely due to it being in a recovery stage as the high numbers of *M. coucha* and *R. pumilio* are indicative of a transition (Meester *et al*., 1979; De Graaff, 1997). *Mastomys coucha* being adept at colonizing disturbed habitats, are then followed by a large number of *R. pumilio*, which then succeed them in colonizing the habitat (Meester *et al*., 1979; De Graaff, 1997).

Microhabitats and their use by small mammals

Seasonal changes in vegetation cover brought variation in microhabitat structures within each study site. The wet season, with favourable conditions for plant growth, had vegetation cover available for both habitation and food supply (August, 1983; Whitting-Jones *et al.*, 2008), and was predicted to have more small mammals using microhabitats during this season than in the dry season. We hypothesized that the temporal change in vegetation cover and food availability would influence small mammal abundance, hence having them make use of the microhabitats. The prediction, however, was not supported by the findings of this study as the wet season had lower abundance and diversity of small mammals utilizing microhabitats than the dry season even though the vegetation cover and food availability were lesser. These findings differed from those by Muck and Zeller (2006), where they found a high small mammal abundance during the wet season when vegetation cover was higher than in the dry season.

Worth noting in the dry season was the effect that the area covered by bare ground within microhabitats had on small mammals in both sites. In the GFRNR, the decrease in vegetation cover of $\leq$ 10 cm together with an increase in bare ground did not have a negative effect on the occurrence and abundance, which was not expected considering that *M. coucha* and *R.*

pumilio, the most abundant, prefer areas with minimal open areas (Eccard *et al*., 2000; Skinner and Chimimba, 2005; Happold, 2013; Leirs *et al*., 2013). This was also unexpected because the perception of predation risk is the same for small mammals, whether nocturnal or diurnal, so when vegetation cover was reduced and bare ground increased, the increased predation risk could have discouraged their occurrence and abundance, but instead encouraged them (Loggins *et al*., 2019). The observed encouragement of microhabitat use could have been due to the changes being too minimal to deter the small mammals. During the wet season in the livestock site, bare ground was an important determining factor of small mammal occurrence and may have been a deterrent to small mammal occurrence when coupled with euphorbs since the occurrence and abundance were lowest during that trapping season.

It could also be that foraging in the wet season did not need small mammals to move around because of the abundance of food, but in the dry season the foraging intensity increased due to the lesser availability of food within short distances (Mitchell and Powell, 2012). This could possibly account for the traps that had two rodents trapped inside at the same time. The protected site microhabitats were preferred for use by small mammals far more than those in the livestock site which may have been a result of the microhabitats having more usable plants. This observation was in contrast to Muck and Zeller (2006) where small mammals preferred microhabitats in the site where domesticated ungulates foraged, whilst the wild ungulate foraged site was less preferred, and this was evidenced by the fewer species recorded in the wild ungulate foraged site than in the domesticated ungulate foraged site. The absence of *E. bothae* in the protected site proved to have a positive effect on the occurrence and abundance of small mammals, which could explain the poor capture success and abundance of small mammals in the livestock site where *E. bothae* was dominant. The lack of foliage and seeds in *E. bothae*, together with its nature of growing in closely knit clumps, could make it unusable for food and habitation by small mammals.

Conclusion

The vegetation that makes up the cover in the habitats was different, firstly in terms of its type and secondly the height. In the livestock site, *E. bothae* dominated space which meant grasses, herbs, and shrubs took up the remaining space which was not much, whilst the protected site did not have a single dominating plant. When grazing and browsing, cattle and goats were most likely channelled towards the same areas in the livestock site because of the

great expanse covered by *E. bothae*. As a result, small mammals may have had limited space for habitation and feeding because of the favourable microhabitat makeup being disturbed by the choice of plants the cattle and goats made use of. The protected site had a variety of vegetation cover which brought the habitat differences observed between the two sites. These differences in vegetation meant wild ungulates, when either grazing or browsing, were not restricted in their movement or area of foraging, as such, when plants and grass were consumed, it was not concentrated therefore not promoting frequent disturbance of small mammals and their ideal microhabitats in the area.

The availability of constant vegetation cover at different heights was ideal for ensuring that protection from predators is maintained while still having plant resources for food. It also ensured that microhabitats are kept usable by small mammals even in the dry season when plant productivity had declined. Microhabitats being kept useful may be the reason for the high small mammal abundance, even though the species richness was not very different between the two sites in both seasons. The occurrence of three of the same species on both sites could imply that their abundance in the livestock site was hindered by the repeated use of grassy areas for grazing by cattle and bushes for browsing by goats. Small mammal diversity in the protected area could improve over time, as new plants colonize the area that was once vegetated by *E. bothae*.

It is evident that vegetation of height $\leq$ 10 cm, the number of bushes, and the area of bare ground are important factors that drive in the occurrence and abundance of small mammals. Euphorbs seem to be an important deterrent to small mammals, possibly due to their lack of useful foliage and seeds, but the substantive reason for this could still be looked into.

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