THE EFFECT OF HABITAT TYPE ON RODENT, SHREW AND SENGI SPECIES ABUNDANCE, RICHNESS, DIVERSITY AND COMPOSITION AT FARM KARACHAS, OUTJO, NAMIBIA

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ABSTRACT

Natural habitats have been fragmented by many human activities including farming, hence affecting vegetation structure. Despite being very dry, Namibia has many farms in which game, livestock and crop farming are practiced. Yet such activities affect populations of many other organisms including small mammals such as rodents, shrews and sengis. The present study investigated the effect of habitat type on rodent, shrew and sengi species abundance, richness, diversity and composition in selected open grassland habitat and woody habitats at Karachas Farm, Outjo, Namibia. Sampling at each habitat type was replicated twice. Woody plant species abundance, composition, height and percentage grass cover were determined and compared between the open grassland and woody habitats. A capture-mark-recapture (CMR) technique was employed to obtain data on rodents, shrews and sengis. Each habitat type was sampled over five consecutive nights using Sherman live traps. The result of *t*-, chi-square and Mann-Whitney tests, respectively, showed a statistically significant difference in the mean abundance of woody plants, plant height, and plant species richness between the open grassland and woody habitats. A Mann-Whitney test showed no statistically significant difference in the percentage grass cover between the open grassland and woody habitats. A Hierarchical Cluster Analysis (HCA) based on a Bray Curtis Similarity Index showed a low (31%) level of similarity in woody plants species composition between the open grassland and woody habitats. A total of 800 trap-nights yielded 145 individuals comprising 6 rodent red veld rat (*Aethomys chrysophilus*), namaqua rock mouse (*Micaelamys namaquensis*), bushveld gerbil (*Gebilliscus leucogaster*), maltimammate mouse (*Mastomys natalensis*), tree mouse (*Thallomys paedulcus*), pouched mouse (*Saccostomus campestris*), sengi (*Elephantulus intufi*) and shrew (*Crocidura hirta*) species. *t*- tests and a Mann- Whitney test, respectively, showed no statistically significant variation in rodent, shrew and sengi species abundance, richness, and diversity between the open and woody habitats. An HCA based on a Bray Curtis Similarity Index showed a high (63 %) level of similarity in rodent, shrew and sengi species composition between the open grassland and woody habitats. The present study therefore showed insufficient evidence to support the hypotheses that habitat type has an effect on rodent, shrew and sengi species abundance, richness, diversity and composition. Further studies should focus on researching the range of factors that drive rodent, shrew and sengi diversity in different habitat types of the farm. The study also recommend the use of more than one trap type when surveying rodent, shrew and sengi communities.

Keywords: rodents, shrews, sengis, abundance, richness, diversity, composition, open grassland, woody plants/habitat, plant height, grass cover, Outjo, Namibia

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LIST OF ABBREVIATIONS AND/ OR ACRONYMYS

~	About
(α)	Alpha
CMR	Capture-Mark-Recapture
°C	Degrees Celsius
df	Degree of freedom
=	Equal to
E	East
i.e.	For example
GPS	Geographic Position System
g	Grams
>	Greater than
HCA	Hierarchical Cluster Analysis
<	Less than
Mastomys spp	*Mastomys* species
m	Metres
PAST	Paleontological Statistics
%	Percentage

±	Plus minus
p	Probability
n	Sample size
H’	Shannon Diversity Index
sp.	Single species
S	South
SE	Standard Error
SPSS	Statistical Software Package for Social Science
Subsp	Subspecies
e.g.,	Such as
-	To
Spp.	Two or more species

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DEDICATIONS

This thesis is dedicated to my mother, Mrs. Ndinomukulili Kapala, whose love, support and encouragement have enriched my soul to pursue and complete this research.

DECLARATIONS

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

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Name of Student Signature Date

CHAPTER 1: INTRODUCTION

1.1 Background of the study

African terrestrial ecosystems are important wildlife habitats offering multiple resources and services including food, fuel, and shelter needed by species for survival (Lacher *et al*., 2019). Complex and dynamic interactions between climate, soils, and disturbances (e.g., fire and herbivory) determines the structure and productivity of habitats (Sebata, 2017). In Namibia terrestrial ecosystems occupy about 64% of the land area (Sweet & Burke, 2000), of which the largest portion is utilized for both commercial and subsistence livestock farming with natural vegetation for grazing (Mendelsohn *et al*., 2002). Farms provide various habitats including, native woodland, freshwater habitats, and species-rich grassland needed for animal survival and reproduction (Malmstrom, 2012; Sheridan *et al*., 2017).

Small mammals (mammal species that weigh less than 5 kg as adults; Hoffmann *et al*., 2010; Merritt, 2010) are one of the most common vertebrates that utilise in a terrestrial ecosystems (Łopucki & Mróz, 2016) and they are considered to be good indicator of ecosystem functionality and health, mainly in African savannas (Avenant, 2011). Merritt (2010) reported that 90% of ~5,416 recognized species of living mammals are “small”. There is a considerable range of small mammal species that include species such as mice, voles, shrews, gerbils, flying squirrel, and chipmunks (Hoffmann *et al*., 2010; Merritt, 2010). Rodents are the most varied group of small mammals with numerous habitat associations, and they account for ~44% of mammalian species (Wolff, 2007). Shrew made up ~312 species (Bantihun & Bekele, 2015), whereas sengis (elephant shrews) are restricted to Africa, with the exception of western Africa and the vast Sahara region (Rathbun, 2009). Rodents and shrews exploit a range of habitats globally (Datiko & Bekele, 2014). Thus, even minor changes in the habitat may affect the abundance, diversity, and composition of some rodent species (Malcom & Ray, 2000; Flores-Peredoand & Vázquez-Domínguez, 2016).

Numerous activities imposed in ecosystems by humans (e.g., clearing land for agricultural purposes) and wildlife (e.g., heavy grazing) result in changes in rodent and shrew species composition and diversity (Hoffmann & Zeller, 2005). Farms are no exception as activities such as grazing by herbivores, trampling by large wildlife (Ministry of Environment and Tourism, 2013), burning, and biological processes such as woody encroachment (Luza *et al*., 2016), usually damage habitat integrity and persistence of species thus influencing vegetation structure and cover needed by rodents to survive (Magige, 2016). Intensive grazing by large mammals degrades the land and makes it inhabitable for rodents because of loss of cover and food resources (Liu *et al*., 2008; Bantihun & Bekele, 2015). For instance, continuous and selective grazing by megaherbivores may lead to consistently reduced vegetation cover, known to be unfavourable for small mammals (Hauptfleisch & Avenant, 2015). The absence of most common rodent species such as the multimammate mouse (*Mastomys natalensis*) and unstriped grass rats (*Arvicanthis* species) in some habitats of the Komto protected forest in Western Ethiopia in sub-Saharan Africa may be attributed to a prolonged habitat disturbance and the application of rodenticides (Erena, Yosef & Bekele, 2011).

The reduction or loss of vegetation cover adversely affects rodent and shrew species abundance, diversity and composition because they are highly exposed to predation

(Hoffmann & Zeller, 2005). The abundance of animals largely depends on the seasonal availability of food resources and water (Datiko & Bekele, 2014). For example, during the wet season, rodent and shrew species abundance and richness were shown to be highest and lowest during the dry season, respectively (Rautenbach, Dickerson & Schoeman, 2014). Furthermore, Datiko & Bekele (2014) reported that the disturbance of vegetation structure and cover affects the micro-climate and necessary ground cover needed by rodents and shrews, and sengis against their predators.

Although there are several studies on small mammals (e.g., Muck & Zeller, 2006; Katakweba *et al*., 2012; Hauptfleisch, Vinte & Blaum, 2017; Kapia, 2018) in Namibia very few studies have focussed on the diversity of small mammals with habitat types on farms with reference to their associated habitat types. Hence, small mammal habitat preference on farm in the country are poorly known. The present study was therefore aimed at gaining insight into the effects of habitat type on rodent and shrew species abundance, richness, diversity and composition at Farm Karachas, Outjo, Namibia as a model study. The findings of the present study will allow insights into how changes in farm ecosystems may affect the rodent, shrew and sengi ecology.

1.2 Problem statement

Numerous studies on small mammals have been conducted in Namibia, however not many studies have focused on the ecological variation of habitat types available for rodents, shrews and sengis on farms in the country. Rodents and shrews are important contributors to biodiversity of ecosystems (Hoffman & Zeller, 2005; Bertolino, Girardello & Amori, 2014), as prey animals, dispersers of seeds and soil engineers (Avenant, 2011) thus forming an integral part of farms. The maintenance of these functions and services are critically less effective due to the reduced abundance and species richness of small mammals in the land used by wildlife (Hauptfleisch, Vinte & Blaum, 2017).

Changes of habitat structure and diversity are often associated with changes in small mammal community structure and species richness (Hoffman & Zeller, 2005). Rodents and shrews are more likely to be negatively affected by habitat overuse by either domestic or wildlife such as large mammals (Mulungu *et al*., 2008) and disturbance due to fire occurring on farms as a result of destruction to food resources and habitat cover.

Agricultural practices often neglect general biodiversity and wildlife while concentrating on livestock and crop production despite their devastating impacts on the environment (Michael, Ringo & Ratnayeke, 2016) which influences vegetation structure and cover biologically and ecologically needed by small mammals (Magige, 2016). Hence, the present study assessed the effects of habitat types on rodent, shrew and sengi species abundance, richness, diversity and composition at Farm Karachas, Outjo, Namibia.

1.3 Research objectives

1.3.1 General objective

The overall objective of the present study was to assess the effect of habitat type on rodent, shrew and sengi species abundance, richness, diversity and composition at Farm Karachas, Outjo, Namibia.

1.3 2 Specific objectives

The specific objectives of the study were to determine and compare rodent, shrew and sengi:

a) Species abundance in an open grassland and woody habitats at Farm Karachas in Outjo;

b) Species richness in an open grassland and woody habitats at Farm Karachas in Outjo;

c) Species diversity in an open grassland and woody habitats at Farm Karachas in Outjo; and

d) Species composition in an open grassland and woody habitats at Farm Karachas in Outjo.

1.4 Research hypotheses

The following null hypotheses (H_0) were tested in the present study:

a) Open grassland and woody habitats do not influence rodent, shrew and sengi species abundance at Farm Karachas in Outjo;

b) Open grassland and woody habitats do not influence rodent, shrew and sengi species richness at Farm Karachas in Outjo;

c) Open grassland and woody habitats do not influence rodent, shrew and sengi species diversity at Farm Karachas in Outjo; and

d) Open grassland and woody habitats do not influence rodent, shrew sand pecies composition at Farm Karachas in Outjo.

1.5 Significance of the study

Given the habitat change due to human activities such as farming, the present study provides data on the influence of habitat types on rodent, shrew and sengi species abundance, richness, diversity and composition at Farm Karachas, Outjo Namibia. Some rodent and shrew species are considered to be good indicators of ecosystem disturbance where they become dominant such as the multimammate mouse (*Mastomys coucha*) (Avenant, 2011). Some are considered to be good pioneer species (e.g., multimammate mice (*Mastomys spp*) and brush-tailed Hairy-footed Gerbil (*Gerbilliscus vallinus*)) and flourish after disturbances caused by drought, fire, overgrazing and cultivation (Ferreira & Van Aarde, 2000; Caro, 2001; Hoffmann & Zeller, 2005). On the other hand, some small mammals (e.g., *M. coucha*) are considered to be indicators of good quality habitats when they are less abundant (Avenant, 2003).

Understanding species abundance and richness in a habitat may be an important indicator of habitat quality, therefore useful for monitoring habitat degradation (Kiwia, 2006). The level of rodent, shrew and sengi species abundance show their habitat type preference. The result of the present study may therefore assist in identifying rodent, shrew and sengi species habitat preference in the study area, which may be critical to understand and identify indicators of disturbance (e.g., fire and heavy grazing) and therefore allow the development of methods to protect habitats overlooked for conservation on farms. Furthermore, management decisions (e.g., rotational grazing, as opposed to continuous grazing) made to benefit rodents, shrews and sengis may also benefit other species (Avenant & Cavallini, 2007; Avenant, 2011).

The present study investigates difference in rodent, shrew and sengi species abundance, richness, diversity and composition in two contrasting habitats on the farm that included open grassland and woody habitat. This may assist in gaining insights into the reasons for the differences in species abundance, richness, diversity and composition. The result of the present study may therefore contribute to the body of knowledge and also provide a baseline for potential future studies on the ecological effect of habitat types on rodents and shrew diversity in the study and other areas in Namibia and beyond. Although rodents and shrews form an important component of biodiversity in ecosystems (Mulungu *et al*., 2008), little is known on the effect of habitat types on small mammal diversity in Namibia.

1.6 Limitations of the study

Due to limited time, the study did not allow for a full assessment of the habitat characteristics (this study only characterized habitats based on woody plant structures and grass cover). Other factors that might have influenced habitat types may include soil types, presence of herbivores, seasons, fire disturbance and as a result influencing the rodents, shrews and sengis found within the farm. The present study only used Sherman live traps to capture rodents and shrews. Trap type has been reported for its limitations when assessing small mammal populations (Santos-Filho *et al*., 2015). The use of different trap types increases the probability of capturing rare or shy species (Astúa *et al*., 2006). Other traps may also need to be considered in future studies such as pitfalls traps that commonly trap rare, trap-shy species (Caceres, Nápoli & Hannibal, 2011). Trap position (Astúa *et al*., 2006) and behavioral attributes such as foraging activity pattern have also been highlighted to adversely affect small mammal trapping (Santos-Filho *et al*., 2015). During the present study, *Thallomys paedulcus* was habitat-specific, only present in the woody habitat. It forages most of the time on trees (Nel, 2013), thus making it difficult to trap since traps were set on the ground. The commonly used rolled oats mixed with peanut butter as bait, used for this study may not be appropriate for shrews because they are insectivorous hence shrews may be under-represented. Lastly, there was no voucher specimen collection of rodent, shrew and sengi, hence identification was limited.

CHAPTER 2: LITERATURE REVIEW

2.1 The biology of rodents, shrews and sengis

Small mammals, such as rodents and shrews are well-adapted to the environment and have a wide distribution (Liu *et al*., 2008). Their life histories are characterized by fluctuating populations, high reproductive rates and short life expectancy (Rautenbach, Dickerson & Schoeman, 2014). Despite similarities in body size and attributes scaling to body size, they exhibit significant differences in other properties such as life history traits (Gliwicz & Taylor, 2002).

Rodents belong to the order Rodentia, the most diverse group of living mammals with numerous habitat associations, and include over 40 % of all mammalian fauna globally (Wilson & Reeder, 2005; 2011; Rautenbach, 2013; Flores-Peredo & Vázquez-Domínguez, 2016). The order includes ~2000 extant species and has members found on all continents except Antarctica (Kay & Hoekstra, 2008; Samuels & Van Valkenburgh, 2008; Verde Arregoitia, Fisher & Schweizer, 2017).

Rodents are conspicuous inhabitants of terrestrial ecosystems including human-modified habitats such as agricultural and urban areas (Jayaraj *et al*., 2012) due to their morphological and behavioural adaptations to a wide range of environmental conditions (Viera & Paise, 2011; Sponchiado, Melo & Cáceres, 2012; Luza *et al*., 2016; Luza *et al*., 2018). They have a wide range of ecological specialization, and they have arboreal, fossorial (burrowing), semiaquatic, jumping and gliding forms (Samuels & Van Valkenburgh, 2008; Verde Arregoitia, Fisher & Schweizer, 2017). Compared with other mammalian orders, rodents exhibit a wide array of body sizes (Verde Arregoitia, Fisher

& Schweizer, 2017) ranging from < 10 g to >500 kg (Samuels & Van Valkenburgh, 2008) and all have gnawing teeth with space behind them, the diastema (Tobin, Michael & Fall, 2004). Most rodents are herbivorous, feeding entirely on plant material such as seeds, stems, leaves, flowers and roots, some are omnivorous and a few are predators (Hoffmann & Zeller, 2005), exhibiting choices and preferences in their diets, but often selecting the most abundant, palatable food available (Tobin, Michael & Fall, 2004). Rodents have advanced cognitive abilities, they can quickly learn to avoid poisoned baits, which makes them difficult pests to eliminate (Krojerová-Prokešová *et al*., 2016). They are prolific breeders with a short lifespan (Auffray, Renaud & Claude, 2009), and their population can grow rapidly to utilize available habitats and food resources because of high reproductive capacity (Tobin, Michael & Fall, 2004).

There are about ~429 species of insectivorous species worldwide of which ~312 are shrews (Bantihun & Bekele, 2015). Shrews are widely globally and they occur in all terrestrial habitats, from montane, boreal regions to arid areas (Churchfield, 1990). Shrews belong to the order Eulipotyphla, suborder. Although shrews predominantly feed on insects, they also feed on small birds, grasshoppers, butterfly and moth larvae, wasps, crickets, spiders, mice, small snakes, while some shrew species are herbivorous (Stuart & Stuart, 2007). Shrews use burrows constructed by other small mammals (Rzebik-Kowalska & Lungu, 2009). They are generally small with nocturnal habits (Merritt *et al*., 2005) and have a long snout, poor sight, but with a good sense of smell and hearing (Churchfield, 1990). They therefore rely on their senses of smell and hearing to locate prey and avoid predators such as snakes and owls (Siemers *et al*., 2009), that are particularly significant consumers of shrews (Tores *et al*., 2005).

Sengis also called "elephant-shrews" belong to the order Macroscelidea, Family Macroscelididae and their evolutionary history confined to Africa (Carlen *et al*., 2017). In the past, it was recognized that all living sengis were mostly insectivorous, which supported their inclusion in the order Insectivora (Rathbun, 2009), currently, elephant shrews have been recognized as a distinct order (Smit, 2008). Sengis occupy the extremes of terrestrial habitats, which typically provide adequate cover from predators with either vegetation or overhanging ledges (Rathbun, 2009). Depending on the habitat and species, sengis shelter in rock crevices, bases of bushes in thickets and less commonly in shallow burrows abandoned by rodents, whereas some sengis may excavate their burrows in soft substrates (Ribble & Perrin, 2005). They use their long nose as a probe to search for prey (such as invertebrates, fruits and seeds) and their long tongue to flick food items into their small, under-slung mouths (Rathbun, 2009). Although studies have shown that these species are partially nocturnal, sengis are primarily diurnal with a good deal of activity at sunrise and sunset (Skinner & Chimimba, 2005).

2.2 Significance of rodents, shrews and sengis in ecosystems

Despite their diverse range, rodents and shrews have complex effects on the structure, composition and functional diversity of their environment through various ecological interactions such as pollination (Johnson *et al*., 2011), seed dispersal and seed removal, consumption of seedlings, seeds, fruits and arthropods (Flores-Peredo *et al*., 2011), nutrient cycling (Delcros, Taylor & Schoeman, 2015), bioturbation, and as vectors of human diseases (Medan *et al*., 2011). Rodents are important herbivores that aerate the soil and improve plant regeneration from buried seeds or exposed soils as a seed bed through their burrowing activities (Tobin, Michael & Fall, 2004). The burrow-digging species such as pouched mice (*Saccostomus spp*) excavate their own burrows (Jacques, McBee & Elmore, 2015), thus contributing to soil mixing, improved soil aeration, and improved plant germination (Witmer, Moulton & Swartz, 2012). Rodents, shrews and sengis are also primary prey for many mammals, birds, and reptiles, therefore sustaining population of these species (Tobin, Michael & Fall, 2004; Hauptfleisch, Vinte & Blaum, 2017).

Furthermore, rodents and shrews act as useful indicators of ecological integrity and can be used to predict environmental change (Avenant & Cavallini, 2007; Mortellitietal, 2010; 2011; Delcros, Taylor & Schoeman, 2015) by responding to habitat disturbance (Leis *et al*., 2008, Mortellitietal, 2010; 2011). This is due to their rapid turnover rate, high biotic potential, ability to invade reclaimed land and their sensitivity to environmental disturbance (Garshong *et al*., 2013). Moreover, most species reproduce rapidly and consequently showing good response to successional changes in vegetation (Avenant, Watson & Schulze, 2008). For example, the dominance of specialist species such as *M. coucha* (Avenant, 2000) in a habitat may be an indication of a disturbed habitat (Avenant, 2003), while it is low involvement in the habitat may be an indication of a healthy and a relatively stable ecosystem (Avenant, 2011).

2.3 Habitat type in terrestrial ecosystems

Habitat type is broadly defined as a set of physiognomically distinct categories of vegetation communities (Hutto, 1985). Habitat type has also been defined as the suite of resources (food, shelter) and environmental conditions (abiotic and biotic) that determine the presence, survival and reproduction of a population (Caughley & Sinclair, 1994; Sinclair, Fryxell & Caughley, 2005). Habitats depends on both abiotic characteristics of the environment such as the underlying geology and climatic patterns, and biotic characteristics such as the presence of particular species to determine their distribution (Peña-Claros *et al*., 2012). Animals select different structural habitats (i.e., local resources or conditions) in a way that is intended to increase their performance at small spatial and temporal scales (Gaillard *et al*., 2010). The increase in spatial and temporal scales result in individual behavioural decisions to only select resources that enhance survival and reproductive performance at the individual and population levels (Gaillard *et al*., 2010).

The major activities such as land conversion for road use, timber harvesting practices, incorrect grazing practices and misuse of fire, lead to the loss of a once continuous habitat, resulting in distinct habitats such as open grassland and woody habitats on farms (Deák *et al*., 2020). Such habitats may differ in terms of their vegetation, soil type, soil condition, nutrients and other factors (Rodrigues *et al*., 2018).

2.3.1 Open grassland habitat

Grasslands are defined as an ecosystem with a significant grass cover combined with varying degrees of woody vegetation, including relatively open savannas and woodlands and some deserts and shrub grasslands that include a significant cover of grasses interspersed with succulent plants and/or shrubs (Blair, Nippert & Briggs, 2014). Open grasslands are characterized as land that is dominated by grasses rather than large shrubs or trees (Carpenter, 1940). On farms, open grassland habitat is the result of inappropriate fire management (Joubert, Rothauge & Smit, 2008), harvesting of trees for charcoal production, intense herbivory, or their combination (Barger, 2011). Foster *et al*. (2014) demonstrated that decreasing biodiversity by reducing woody species in ecosystems creates open grasslands.

2.3.1 Woody habitat

Woody habitat in woodland savanna' refers to the more mesic savanna where tree stands occur in open formations, with some shrubs in a ground layer dominated by grasses (Levin, 2013). Woody plants are key components to ecosystems as they create favourable microenvironments (e.g., through deposition of leaf litter and shading) and habitats that can support diversity (Sebata, 2017). They offer browsing landscape for ungulates and are also a major source of fuelwood (Sebata, 2017). Additionally, an increase in woody vegetation is associated with intensive grazing by cattle, and where woody plants have evolved with herbivory, herbivores play a key role in regulating plant cover needed by other organisms (Holdo, Holt & Fryxell, 2013). Increased woody vegetation may be attributed to overgrazing (Riginos & Young, 2007) which leads to increased dispersal of woody seeds, reduce fire frequency and intensity due to lowered grass-fuel loads and increase water availability for deep-rooted woody plants (Sebata, 2017), facilitating an increase in germination rates and woody cover.

2.4 The influence of habitat type on rodent, shrew and sengi ecology

Various habitat characteristics such as foliage height, vegetation cover, soil structure and type are important factors in rodent ecology (Rhodes & Richmond, 1983) as they influence ground cover, food and other resources needed for survival and reproduction (Malmstrom, 2012). In a study on the diversity, relative abundance and habitat association of rodents in forest patches and adjacent farmland in Aquatimo, East Gojjam, Ethiopia, small mammal species such as the woodland thicket rat (*Grammomys dolichurus),* black rat (*Rattus rattus*), lovat's climbing mouse (*Dendromus lovati*), and smoky white-toothed shrew (*Crocidura fumosa*) indicated restricted distribution suggesting that their distribution was influenced by habitat types (Dubale & Ejigu, 2015). It has however, been reported that habitat association and distribution of rodents may be determined by the extent of ground cover, habitat structure and availability of food resources (Dubale & Ejigu, 2015).

The quantity of ground cover is critical to the density and diversity of small mammals (Hoffmann & Zeller, 2005). The diversity of small mammals can be influenced by the presence of limited resources, the abundance of forage and its nutritional attributes, and availability of shelter (Hebblewhite, Merrill & McDermid, 2008; Krojerová-Prokešovà *et al*., 2016). The diversity of rodents and shrew assemblages may also vary both seasonally and annually in different vegetation types (Rautenbach, Dickerson & Schoeman, 2014) as a result of a change in the quality and quantity of resources such as food and shelter (Chekol, Bekele & Balakrishnan, 2012; Dubale & Ejigu, 2015). A study by Datiko and Bekele (2014) reported that the natal multimammate mouse (*Mastomys natalensis*), striped grass mouse (*Lemniscomys striatus*) and spiny mouse (*Acomys cahirinus*) were found in all habitat types in Chebera Churchura National Park, in Ethiopia with varied abundance, suggesting their ecological adaptability.

Furthermore, the distribution of rodent and shrew species have been reported to be influenced by habitat complexity in relation to food availability and vegetation cover (Datiko & Bekele, 2014), and that there is an association between species composition and the available food resources (Makundi *et al*., 2005). The difference in abundance of habitats may be attributed to the presence of several microhabitats such as habitat covers and diverse resources in wooded grassland (Datiko & Bekele, 2014). This is evident in a study where more individuals were sampled from bushland habitats than in other habitats, likely as a result of the habitat's composition of plants such as redwing (*Pterolobium* *stellatum),* woolly caper-bush (*Capparis tomentosa*) and stinging nettle *(Urtica simensis*) (Bantihun & Bekele, 2015). These plants are thorny, and hence prevent the movement of humans and livestock, thereby resulting in more shelter for small mammals (Bantihun & Bekele, 2015). Variation in nature and density of vegetation may also contributed to more individual rodents and shrews being sampled from disturbed forest habitats than in other habitats (Mulungu *et al*., 2008).

Generally, farmlands harbor high population numbers of rodent pests than to natural forests (Datiko, Bekele & Belay, 2007) partially due to the availability of nutritious food in farmlands being highly preferred during the fruiting and before harvesting periods, thus providing enough cover and nutritious food (Dubale & Ejigu, 2015). In their study, Dubale & Ejigu, (2015) found that bushy habitat type was inhabited by more species than grassland and the forest habitats, because bushy habitats are known to provide enough food and cover than grassland and forest habitats. Additionally, bushy vegetation provides safe sites for germination and growth of herbaceous plants, therefore increasing the diversity of the potential food resources for small mammals (Kerley *et al*., 2004).

The distribution of rodents and shrews is not only influenced by vegetation cover, edaphic factors may also influence small mammal populations (Hardy, 1945). Soil components such as soil texture, moisture, aeration, soil chemical contents, soil fertility, and soil types directly and indirectly affect the distribution and abundance of animals (Erena, Yosef & Bekele, 2011). In fossorial mammals, soils directly affect their distribution by providing shelter and indirectly by influencing the distribution of vegetation (Hardy, 1945). For example, loam soil is mostly preferred by *M. natalensis* because the burrowing that provides good aeration and drainage is relatively easy to undertake (Massaweet *et al*., 2008). Therefore, soil type is very important as burrows may be needed to create a safe site for the reproduction and survival of young and food hoarding sites (Erena, Yosef & Bekele, 2011).

2.5 The effect of land use on rodent, shrew and sengi ecology

African savannas accommodate a high diversity of larger herbivore species of different body sizes (Hagenah, Prins & Olff, 2009) resulting in competition for grass and woody vegetation (Loggins *et al*., 2019). In Namibia, livestock and wildlife farming plays a major role in agriculture (Mendelsohn *et al*., 2002). Various studies including but not limited to Namibia (Muck & Zeller, 2006; Erckie, 2007; Hagenah, Prins & Olff, 2009; Ellis & Cushman, 2018) have investigated at the impacts of larger herbivore on rodent species abundance and community composition. It has been reported that rodents and larger herbivores in ecosystems compete for food resources (such as seeds, stems and leaves), and were larger herbivores where absent, habitat quality for rodents was higher (Hagenah, Prins & Olff, 2009).

Overuse of habitats by either domestic or wild species of larger mammals adversely impacted food and cover required by rodents and shrews (Mulungu *et al*., 2008). The effect of livestock grazing on rodents and shrews varies depending on the level of grazing, habitat type and species involved (Rickel, 2004). Furthermore moderate grazing may result in a positive effect for some species while overgrazing decreases the population of most species (Rickel, 2004). In a study on evidence-based review on the positive and negative effects of livestock grazing on wildlife, overall small mammal abundance declined with grazing, while individual species responses varied significantly, such that species richness either declined or remained the same but rarely increased with grazing

(Schieltz & Rubenstein, 2016). This may be a result of the interaction between the behaviour and habitat requirements of individual small mammals and the effect that grazing has on the modification of the vegetation (Schieltz & Rubenstein, 2016).

Different body size classes of herbivores have positive and negative effects on rodents diversity, intense grazing by larger herbivores (such as by buffalo, zebra) improves the vegetation structure for smaller herbivores as it results in the development of patchy vegetation with short grazing lawn (Hagenah, Prins & Olff, 2009). However, medium sized herbivores such as impala, decreases the number of high-quality plant species available for smaller herbivores species, thus negatively influencing rodents through competition for food (Hagenah, Prins & Olff, 2009).

Vegetation modification by larger herbivores such as by grazing and trampling, limits the habitats available and reduces the vegetation cover needed by rodents (Goheen *et al*., 2004). A decrease in vegetation cover leads to higher exposure of rodents to their predators and thus, increases their predation risk (Siemers *et al*., 2009). Rodents and shrews serve as prey for many different species of reptiles, birds and mammals, thus they avoid areas where the risk of predation is high (Krijger *et al*., 2017). To avoid high predation risks, rodents and shrews use indirect cues such as vegetation cover, weather conditions, light intensity and direct cues such as sound, odor, urine or other excrements from potential predators to assist in assessing predation risk during foraging (Krijger *et al*., 2017). Many smaller vertebrates preferentially forage under vegetative cover, where it is more difficult to be detected by predators, avoiding areas with sparse cover or greater distances between refuges (Baker & Brown, 2014; Banasiak & Shrader, 2016). On the other hand, other species prefer foraging in areas with better visibility in order to easily detect (Heithaus, 2009).

CHAPTER 3: MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location and extent

The study was conducted on Farm Karachas on the Outjo-Otavi gravel road located in Outjo District, Kunene Region, Namibia (20.1128°S and 16.1610°E; Figure 1) in July 2020. The study site is located within the tree and shrub savanna biome of Namibia (Figure 1) (Mendelsohn *et al.*, 2002).

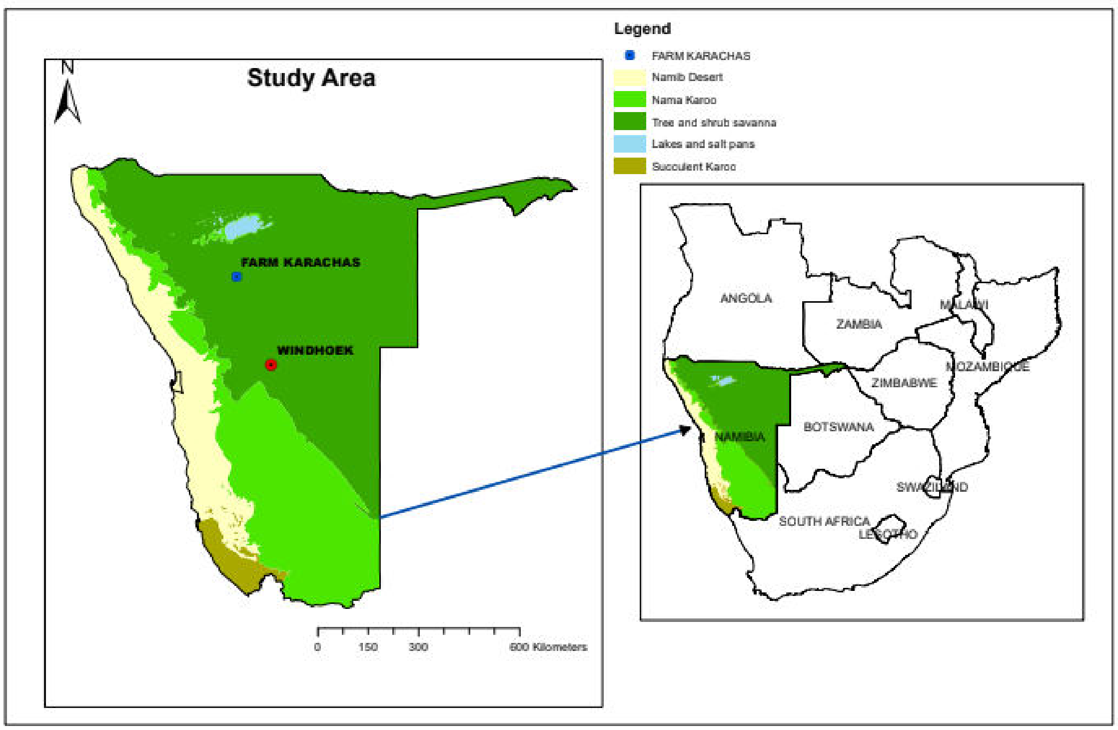

Figure 1: A biome map of Namibia (with an insert map of Southern Africa) showing its biomes and the study area (Farm Karachas, Outjo District, Kunene) (Adopted from: Map of Namibian biomes, Atlas of Namibia: http://www.unikoeln.de/sfb389/e/e1/download/atlas_namibia/pics/living_resources/biomes.jpg

3.1.2 Climate

Rainfall and temperature are the two main environmental factors that influence mammals both directly and indirectly (Skinner & Chimimba, 2005). Namibia is predominantly an arid to semi-arid country due to its geographic location (Goudie & Viles, 2014). Outjo town, just as the rest of Namibia, falls within the Subtropical High-Pressure Zone, which is known for its massive dry air (Mendelsohn *et al*., 2002). Outjo town, located 30 km west of the study site, has a distinct seasonal variation in temperature (Mendelsohn *et al*., 2002). During winter, temperatures can get to below 0^{o} C, although winters are often mild, with the coldest month being July (Mendelsohn *et al*., 2002). Average minimum temperatures range from 0° C during winter to 15.5° C in summer. The area receives a minimum of 350 mm and a maximum of 400 mm of precipitation per year. Heavier rainfall is most common between January and March with little to no rainfall in September (Mendelsohn *et al*., 2002).

3.1.3 Fauna

Farm Karachas is home to numerous wildlife and domestic mammals. Livestock farming is one of the main agricultural activities on the farm. During the data collection period large mammal wildlife observed on the farm included: - jackal (*Canis mesomelas*), kudu (*Tragelaphus strepsiceros*), springbok (*Antidorcas marsupialis*), steenbok (*Raphicerus campestris*), leopard (*Panthera pardus*) and common warthog (*Phacochoerus africanus*), and domestic mammals that included cattle, goat, sheep, horses, and donkeys.

The small mammals previously reported to occur in the tree and shrub savannah include: large-eared mouse (*Malacothrix typica*), pouched mouse (*Saccostomus campestris*), bushveld gerbil (*Gebilliscus leucogaster*), hairly-footed gerbil (*Gerbilliscus paeba.*), red veld rat (*Aethomys chrysophilus*), Namaqua rock mouse (*Micaelamys namaquensis*), tree mouse (*Thallomys paedulcus*), multimammate mouse (*Mastomys natalensis*), stripped mouse (*Rhabdomys pumilio*), bushveld sengi (*Elephantulus intufi*), lesser red musk shrew (*Crocidura hirta*) and dent's houses bat (*Phinolophus denti*) (Stuart & Stuart, 2007).

Reptiles, such as lizards, were also sighted on the farm during the sampling period. A variety of birds such as the laughing dove (*Spilopelia senegalensis*), helmeted guinea fowl (*Numida meleagris*), and common quail (*Coturnix coturnix*) were also observed during the sampling period. As were many insects such as common flies, grasshoppers, butterflies, spiders, and ants.

3.1.4 Flora

The Tree and Shrub Savanna biome (Figure 1) supports > 500 t plants species (Mendelsohn *et al*., 2002). The vegetation of this biome include species such as false umbrella thorn (*Vachellia reficiens*), candle thorn (*Vachellia hebeclada subsp. Hebeclada),* black thorn *(Senegalia mellifera xtbsp. Detinens),* blue thorn *(Senegalia erubescens)*, blade Thorn (*Senegalia cinerea*), and in some areas, umbrella thorn (*Vachellia tortilis subsp. Heteracantha*) (Mendelsohn *et al*., 2002). The dominant woody plants species include False-umbrella thorn *(Vachellia reficiens*), sickle bush (*Dichrostachys cinerea*), purple-pod Terminalia (*Terminalia prunoides*), mopane (*Colophospermum mopane*), red bushwillow (*Combretum apiculatum*) and *Comiphora species* (Mendelsohn *et al*., 2002). The dominant vegetation of the study areas, *D. cinerea* shrub, the velvet raisin *Grewia flava*, and the sand-paper raisin *Grewia flavences*. Tree distribution during the sampling period was variable, but mostly included shepherd tree (*Boscia albitrunca*), blade thorn (*S. cenerea*)*,* and black thorn (*S. mellifera*). Grass cover in the Tree and Shrub Savanna biome ranged from sparse to clumped (Stuart & Stuart, 2007).

3.1.5 Geology and soil

The geology of Outjo is characterized and dominated by limestone and schists (Mendelsohn *et al*., 2002). The soils are of moderate to high fertility, and the dominant soil type is cambic soil characterized by changes in color, structure and consistency with a coarse texture (Mendelsohn *et al*., 2002).

3.2 Data collection

3.2.1 Selection of the study sites

The specific sampling sites at Farm Karachas were randomly selected but included replicates in contrasting habitats. The GPS coordinate points of selected contrasting habitat were as follow: Site 1, Open grassland (20.57713˚S, 016.78233˚E); woody habitat (20.05148˚S, 016.43509˚E) and Site 2 open grassland (20.04673˚S, 014.716˚E); woody habitat (20.04689˚S, 016.43316˚E). Open grassland habitat on a fallow field and a woody habitat with grass under-growth were selected as contrasting habitats and was supported by a vegetation survey to ensure these two habitats were different in terms of vegetation structure. The two contrasting sampling habitat on each sites were 600 meters apart to avoid sampling rodents and shrews from an adjacent trapping site (Fauteux *et al*., 2018). The areas that were considered open grassland (Figure 2) were characterized by a relatively high grass cover and other graminoid vegetation in an open land with little or no tree and shrub cover (Sanderson, Wedin & Tracy, 2009; Blair, Nippert & Briggs, 2014). In contrast, the woody habitat (Figure 3) was dominated by woody plants with areas dominated by trees and shrubs (Sebata, 2017). A Global Position System (GPS) was used to mark the location of each sampling habitat.

Figure 2: A typical sampled open grassland habitat at Farm Karachas in Outjo. Photo by S. Kapala (2020).

Figure 3: A typical sampled woody habitat at Farm Karachas in Outjo. Photo by S. Kapala (2020).

3.2.2 Vegetation structure parameters

In the present study, it was critical to establish that the two sampling habitats were contrasting in terms of vegetation structure. Hence, in each habitat ,10 plots of 10 m × 10 m (Figure 4) spaced 10 m apart were demarcated using a standard measuring tape and were sampled for woody plant species composition, richness, abundance, and height. Within each 10 m × 10 m plot, a 1 m × 1 m plot was demarcated (Figure 4) to assess the percentage grass covers. In total, 40 plots (20 open grassland, 20 woody habitat) were sampled over the entire study area.

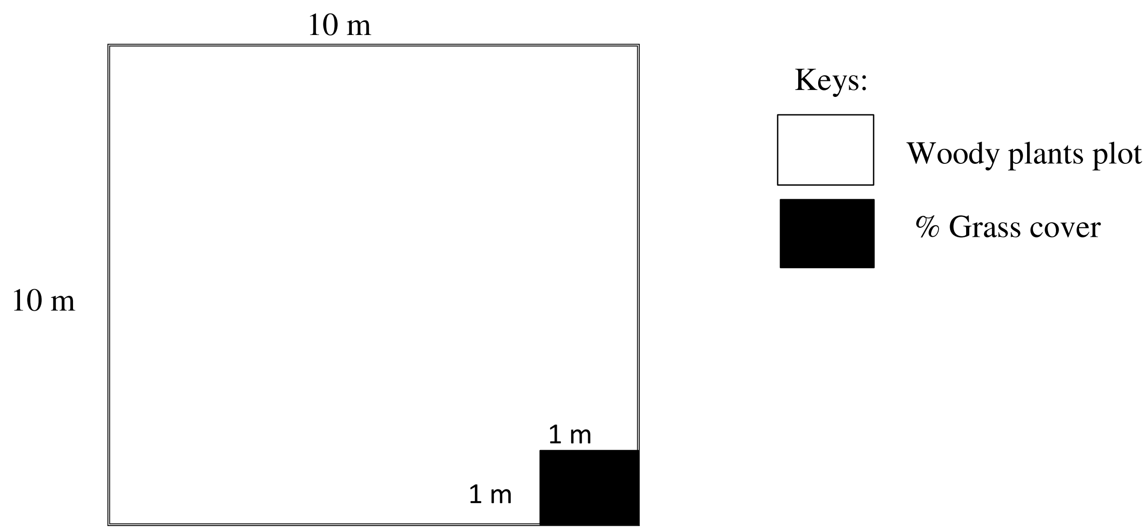

Figure 4: A systematic diagram of the plots used to sample vegetation parameters in the open grassland and woody habitat at Farm Karachas, Outjo, Namibia

Within each plot, individual woody plants were counted and identified to the species level using Le Roux and Müller's Field Guide to the Trees and Shrubs of Namibia by Le Roux *et al*. (2009). The total number of woody plants sampled at each habitat site was determined. All the trees and shrubs were counted and each was measured and categorized into height classes. The height of each woody plant in each plot was estimated by placing the range pole against the plant and was allocated into a predetermined class that include: < 1 m, 1 – 1.5 m, 1.5 – 2 m, 2 – 2.5 m, 2.5 – 3 m, and > 3 m depending on its estimated height. Total grass cover was visually estimated as a percentage of the ground cover within 1 m × 1 m plot (Figure 4) using the modified Blaun-Blanquet cover scale that includes: 0-25%, 25-50%, 50-75% and 75-100% (Werger, 1974).

3.2.3 Rodent, shrew and sengi sampling

Before sampling, the present study received approval from the University of Namibia, Centre of Research and Publication and the Research Ethics Committee. Research Permission Letter was issued by Dr. Seith. J. Eiseb, the Director: Postgraduate Studies, University of Namibia (Appendix 1). Data collection permission on Farm Karachas was granted by Mr. F. Puriza, the owner. Sampling the study area was performed according to the ethics policy and research ethics guidelines. The present study used a quantitative research design to collect data on rodents, shrews and sengis species abundance, richness, diversity and composition in the open grassland and woody habitat sites. Sampling was undertaken on two transects, spaced 20 m apart using a standard measuring tape. Each transect consisted of 40 Sherman-live traps spaced at 10 m intervals using metal droppers as flagging for identifying the positions of the traps, forming a distance of 400 m per transect and giving a total of 80 traps per site. Traps were marked with unique numbers for each transect and site (i.e., Open grassland O1, O2, O3… O80 and woody habitat W1, W2, W3….W80) using pen-tel markers to match the flagging droppers to ensure animals were released at the point of capture facilitating re-bait and preventing the loss of traps (Hoffmann *et al*., 2010).

A capture-mark-recapture (CMR) sampling method (Hoffmann & Zeller, 2005) was employed to collect data on rodent and shrew species abundance and diversity. CMR studies have shown that the majority of small mammals during the trapping sessions are recaptured from the 4th day of consecutive trapping (Tasker & Dickman, 2001). In each habitat, trapping was conducted consecutively for 5 nights (Hauptfleisch, Vinte & Blaum, 2017). Traps were baited with rolled mixture of oats and peanut butter (Mfune, Kangombe

& Eiseb, 2013; Kapia, 2018) (Figure 5A) in the late afternoon before sunset around 17h00 and inspected for the presence of small mammals the next morning at sun rise around 07h00. Sikes and Gannon (2011) reported that live traps for nocturnal species is set before dusk and checked at dawn. Trapping regimes were designed to target nocturnal small mammal species (Lim & Pacheco, 2016). Diurnal trapping is not recommended to prevent small mammal mortalities because Sherman traps get very hot (Thibault *et al*., 2019).

Figure 5: A) Balls of bait including a mixture of peanut butter and oats and B) A typical sampled small mammal in a zip-lock bag. Photo by Kapala (2020).

During the inspection of traps, surgical gloves and protective masks were worn at all times because the small mammals host a variety of ecto-parasites and endo-parasites (Hoveka, 2015), thus gloves and mask provided a barrier against infectious excreta and body fluids during handling (Thibault *et al*., 2019). Captured rodents, shrews and sengis were transferred from traps into standard zip-lock plastic bags (Figure 5B) to allow safe data processing of the trapped animal. The Zip-lock bags were cut open at the corners to ensure air ventilation.

The following data were recorded for each individual trapped rodent, shrew and sengi: species (as identified using the Field Guide to Mammals of Southern Africa by Stuart and Stuart (2007), and Smither's Mammals of Southern Africa: A Field Guide by Smithers (2012)), date, trap number and sex. Body mass was recorded to the nearest grams using the compact scale (HT Series Compact Scales A&D Australasia Pty. Ltd, Thebarton, Australia) while the reproductive status was noted as either breeding or non-breeding. (Hoffmann *et al*., 2010). Characteristics of breeding individuals include descended testes in males and open vagina, lactating or pregnant (identified by palpation technique) in females (Hoffmann *et al*., 2010). Non-breeding characteristics included abdominal testes in males and closed vagina in females. Standard body measurements such as head and body length (measured from the tip of the nose to the end of the chordate bone; Hoffmann *et al*., 2010), tail length, ear length, and hind foot length was measured with a standard ruler. These standard body measurements facilitated the morphological identification of species. Small mammals that were trapped for the first time were toe clipped (small part of the end of the nail) using a nail cutter and assigned a reference number and released, at the point of initial capture. Unique single and or combinations of multiple digits, (computer generated random combination of numbers) are removed from the hands and/ or feet when the animal is first captured, to allow recognition of each individuals (Blair, 1941, Gannon *et al*., 2007). Toe clipping small part of the end of the nail is considered ethical as it provide minimal invasive in terms of pain and discomfort to the animal (Wever *et al*., 2017). The method is also known to improve survival during handling of a sensitive species than other methods such as ear notching (Petit *et al*., 2012). Traps without animals were closed immediately after checking to prevent the capturing of diurnal, non-targeted taxa (Sikes & Gannon, 2011).

3.3 Data analysis

3.3.1 Vegetation structure parameters

For all ecological analyses, data was firstly compared between the two open grassland habitats and the two woody habitats to justify the need for pooling or separately analyzing the factors contributing to variations in preferred habitat type. The percentage proportion for each height class was then determined by dividing the total number of woody plant species in each height class with the total number of all woody plants sampled in the habitat, and then multiplied with hundred. To estimate the percentage grass cover, the grass cover was divided into 4 percentage cover categories that included: 0-25%, 25-50%, 50-75% and 75-100%. The percentage grass cover for each plot was determined for all habitats. Plots with similar percentage grass cover were counted per habitat. The midpoint for each grass category was determined, multiplied with the frequency of the category and divide by the sum of the number of plots per habitat to yield the mean percentage grass cover.

3.3.2 Rodent, shrew and sengi species abundance and richness

Species abundance and richness in both open grassland and woody habitat were determined. Species abundance was determine determined by the total number of individuals per rodent, shrew and sengi species per habitat, whereas species richness was determined by the number of different species of rodent, shrew and sengi species per habitat (Hauptfleisch, Vinte & Blaum, 2017).

3.3.3 Statistical analysis

Descriptive statistics were used to summarize the recorded woody vegetation data. Woody structures (height class, species abundance, richness, and composition) were used as test variable while habitats were used as grouping variable (open grassland and woody habitat). All data were first tested for normality using the Shapiro-Wilk test (Shapiro and Wilk, 1965). Parametric tests were used when data were normally distributed ($P > 0.05$) and non-parametric test were used when data were not normally distributed ($P < 0.05$). Independent sample two-tailed t-test were used to analyze woody species abundance of the sampled plots. Woody plants species richness and the percentage grass cover data were not normally distributed ($P < 0.05$) thus a Mann-Whitney U test was used to analyze species richness of woody species and percentage grass cover. Mann-Whitney U test is a non-parametric test that does not require assumption of a normal distribution (Corder & Foreman, 2014). The height structures were compared among the habitats using a Chi-square goodness-of-fit test (χ^2). Chi-Square goodness-of-fit test is based on the difference between the observed and the expected values for each category, thus it is used to estimate how much the observed values of a particular given sample are significantly different from the expected values of the distribution (Miller & Siegmund, 1982). An independent *t*-test was used to estimate the mean difference in rodent, shrew and sengi species abundance between open grassland and woody habitat. A t-test is aimed at comparing characteristics representing groups, and the mean values become representative when the population has a normal distribution (Kim & Park, 2019). A Mann Whitney-U test was used to compare whether there was any statistically significant difference in the mean rodent, shrew and sengi species richness between open grassland and woody habitat at Farm Karachas. All the above statistical analyses were based on algorithms in the Statistical Package of Social

Science (SPSS) software programme IBM version 26, with the level of significance set at (α) = 0.05.

Species diversity was calculated using the Shannon-Wiener index of diversity (Shannon & Weaver, 1946) to compare the rodent, shrew and sengi species diversity in the open and woody habitat using the formula below which considers both species richness and evenness:-

$$H' = \sum_{i=1}^{s} P_i \ln P_i$$

Where H' is the species diversity index, s is the number of species, and P_i is the proportion of individuals of each species belonging to the i^{th} species of the total number of individuals. A Mann-Whitney U test was used to determine whether there were any statistically significant differences in the mean rodent, shrew and sengi species diversity between the open grassland and woody habitat on Farm Karachas. A Mann-Whitney U test can also be used to test for the difference in means (Campbell & Swinscow, 2009).

A Hierarchical Cluster Analysis (HCA) was used to assess % similarity difference in the species composition of woody plant species and rodent, shrew and sengi species composition between the open grassland and woody habitat in the study area. HCA grouping objects based on the similarity of their attributes (Leal *et al*., 2016). The HCA based on Bray-Curtis Index to determine similarities between the habitats. The Bray-Curtis Index is recommended for analyses of species composition data (McKillup, 2011) and classifies measures as percent similarity (Yoshioka, 2008). The results of an HCA are presented as a dendrogram to illustrate the relationships between all the samples based on a defined measure of similarity, where the objects are joined together in a hierarchical fashion from the closest (most similar) to the furthest (i.e., the most dissimilar) (Aljumily, 2016). The HCA was performed using algorithms in Paleontological Statistics (PAST), Version 4.03 (Hammer *et al*., 2001).

CHAPTER 4: RESULTS

4.1 Vegetation structure

There was no statistically significant difference in the species abundance of woody plants between sites 1 and 2 in both open grassland and woody habitats: t_{18} = -1.197; n = 20; P = 0. 247; and woody habitats: t_{18} = -0.384; n =20; P = 0.705). Similarly, there was no significant difference in the height of woody plant classes between sites 1 and 2 in both habitats (open grassland habitats: χ^2_3 = 5.498; n = 20; P = 0.139; and woody habitats: χ^2_3 = 59.862; n = 20; P = 0.100). Mann-Whitney U-test revealed that species richness of woody plants between site 1 and site 2 of both habitats did not differ significantly (open grassland habitats: U_1 = 39.5; n = 20; P = 0.380; and woody habitats: U_1 = 46.5; n = 20; P = 0.779). Similarly, grass cover between sites 1 and 2 in both habitats did not differ significantly (open grassland habitats: U_1 = 49.5; n = 20; P = 0. 968; and woody habitats: U_1 = 12.5; n = 20; P = 0.100). Since there was no significant difference in the species abundance and richness, height, and percentage grass cover between the two open grassland and the two woody habitat, these data were pooled (open grassland site 1 and open grassland site 2 and woody habitat site 1 with woody habitat site 2) to represent two single data sets: open grassland and woody habitat as presented below:

4.1.1 Woody plants species abundance

A total of 539 woody plant species were recorded in 40 sampled plots. Out of of 539, 113 woody plants were from the open grassland habitat and 426 from the woody habitat. The woody habitat had a statistically significantly higher mean abundance (21.30 ± 2.035) of woody plants than the open grassland habitat (mean 5.65 ± 0.545; $t_{38} = -7.424$; $n = 40$; $P = 0.000$) (Figure 6). The most abundant woody plant species in the open grassland were *Boscia albitrunca* and *Dichrostachys cinerea*. *Senegalia cenerea*, *Catophractes alexandrii*, *Dichrostachys cinerea, Grewia flava, Grewia flavences* were most abundant in the woody habitat.

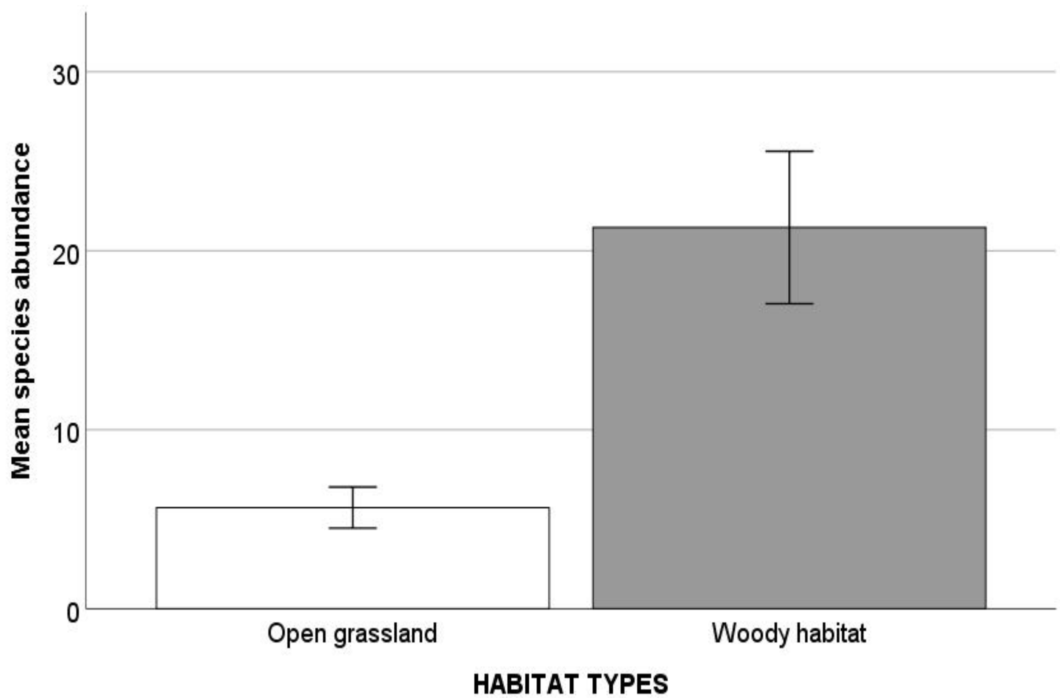

Figure 6: The mean (±SE) woody species abundance in the open grassland and woody habitat at Farm Karachas, Outjo

4.1.2 Height structure

Chi-square analysis showed a statistically significant difference in the tree height classes of woody plants in the open grassland and woody habitats (χ^2_5 = 101.1; n = 539; P = 0.000). The height of woody plants varied amongst the different classes, being most frequent in the > 3 m height and < 1 m height classes (Figure 7). According to Figure 7, 77% of woody plants observed in the open grassland habitat were in the height class < 1 m. No woody plants were in the height classes 2- 2.5 m and 2.5 – 3 m in the open grassland habitat. In the woody habitat, 30% of the woody plants were in the height classes < 1m and > 3m making 60% of plants recorded in this study site. The lowest proportion (1%) of woody species was in the height class 2.5 – 3 m.

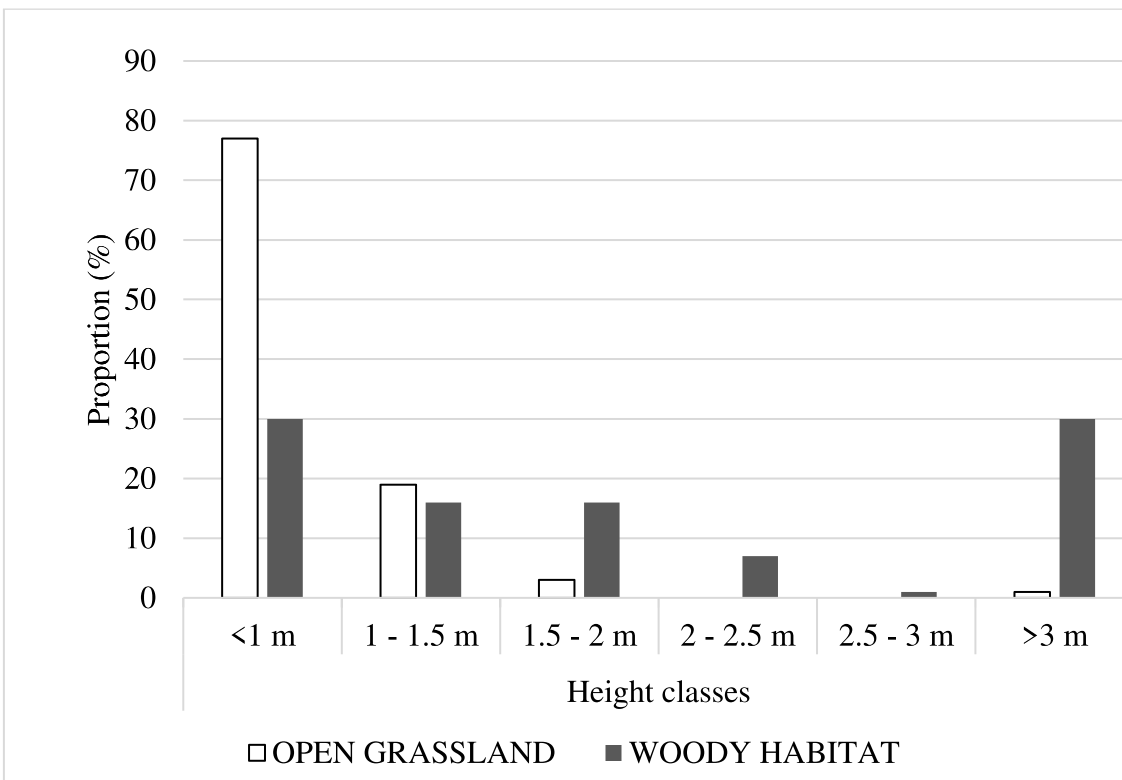

Figure 7: Tree height (m) classes in the open grassland and woody habitat at Farm Karachas, Outjo

4.1.3 Woody plant species richness

Woody plant species richness was statistically significantly higher ($U_1 = 12.5$; $n = 40$, $P = 0.00$) in the woody habitat (range 4-7 species) than in the open grassland habitat (range 1-4 species) (Figure 8).

Figure 8: A box and whisker plot of the median species richness of woody plant species in the open grassland habitat and woody habitat at farm Karachas, Outjo. The horizontal line (thick) inside the box represents the median. The top part of each box represents the 75th percentile (upper quartile) while the lower part is the 25th percentile (lower quartile). The end of each line above and below the open box indicates the largest and lowest values, respectively, that are not outliers. Extreme values are outside the box.

4.1.4 Woody plant species composition

An HCA based on the Bray-Curtis Similarity Index using binary (present-absent) data categorized the species composition of woody plant species in both the open grassland and woody habitat into two clusters (Figure 9). A dendrogram (Figure 9) showed a low (0.31 or 31%) similarity in the woody plant species composition between the open grassland and woody habitat, indicating that species composition of woody plants varied significantly between the open grassland and woody habitat.

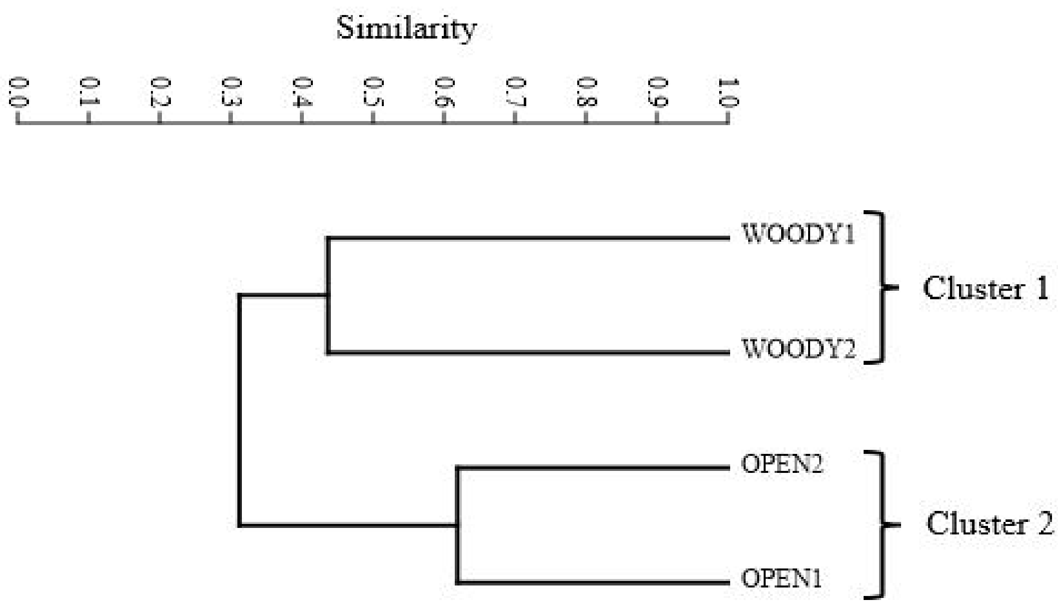

Figure 9: A Hierarchical Cluster Analysis (HCA) dendrogram illustrating the classification of habitat types into two clusters based on the variation of woody plant species composition in the open grassland and woody habitat types at sites 1 and 2 at Farm Karachas, Outjo. OPEN1 = open grassland habitat, site 1; OPEN2 = open grassland habitat, site 2; WOODY1 = woody habitat, site 1; and WOODY2 = woody habitat, site 2.

The dendrogram (Figure 9) also showed that the open grassland habitat sites 1 and 2 were 0.62 (or 62%) similar, whereas woody habitat sites 1 and 2 were 0.43 (or 43%) similar.

Cluster one represent the open grassland habitat sites 1 and 2 that were dominant by the woody plant species *Dichrostachys cinerea*, *Grewia flavences* and *Boscia albitrunca*. The least recorded woody species included *Senegalia hereroensis*, *Catophractes alexandri*, *Croton gratissimus* and *Grewia favences*. *Terminalia prunioides*, *Combretum apiculatum* and *Albizia anthelmintica* were absent from this cluster. Cluster 2 consist of woody plant species found in the woody habitat sites 1 and 2. The most dominant woody species in this cluster were *Senegalia ceneria, S. mellifera, Dichrostachys cinerea, Grewia flava* and *G. flavences*. The least observed woody plant species were *Terminalia pruinoides, Compretum apiculatum, Boscia albitrunca, Albizia anthelmintica* and *Senegalia hereroensis.*

4.1.5 Grass cover

A Mann Whitney U test showed no statistically significant difference in mean percentage (%) grass cover (U_1 = 195; n = 40; P = 0.899) between the open grassland and woody habitats. The mean % grass cover in open grassland and woody habitats ranged from 12.5% to 87.5% and 12.5% to 87.5%, respectively, (Figure 10).

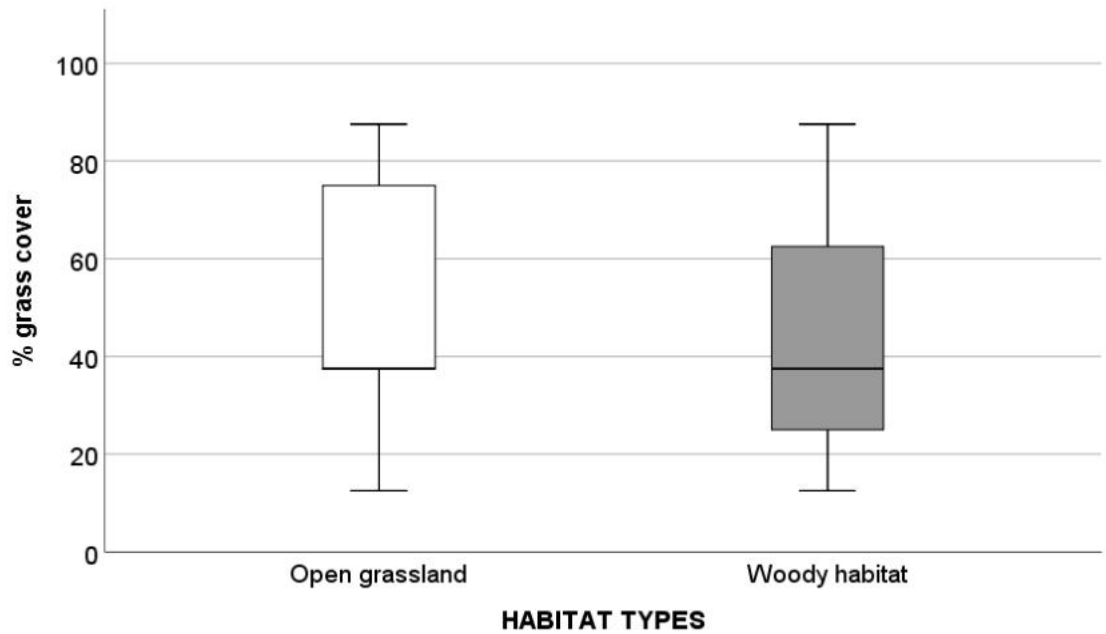

Figure 10: The mean percentage (%) grass cover in the open grassland and woody habitats at Farm Karachas, Outjo. The horizontal line (thick) inside the box is the median. The top part of each box represents the 75th percentile (upper quartile) while the lower part is the 25th percentile (lower quartile). The end of each line above and below the open box indicates the largest and lowest values, respectively, that are not outliers.

4.2 Rodent, shrew and sengi species community structure and composition

4.2.1 Rodent, shrew and sengi species abundance

Out of 800 traps set during the sampling period, 145 rodent, shrew and sengi species were trapped during the sampling period with 60 in open grassland and 85 in the woody habitats, respectively. In the open grassland habitat, rodents accounted for 60% and shrews for 40% of the total catch, respectively, while in the woody habitat they accounted for 75% and 25%, respectively (Table 1). An independent *t*-test showed no statistically significant difference in rodent, shrew and sengi species abundance (t_{18} = -1.157; n = 20; P = 0.263) between the open grassland and woody habitats.

Table 1: Rodent, shrew and sengi species abundance recorded during the study period in the open grassland and woody habitats at Farm Karachas, Outjo. *n* = number of individuals sampled; % = relative abundance.

Small mammals		Habitat			
		Open grassland		Woody Habitat	
		n	%	*n*	%
Family and species	**Common name**				
Muridae					
Aethomys chrysophilus	Red veld rat	6	10	18	21
Micaelamys namaquensis	Namaqua rock mouse	4	7	4	5
Gerbilliscus leucogaster	Bushveld gerbil	6	10	33	39
Mastomys natalensis	Natal multimammate mouse	3	5	2	2
Thallomys paedulcus	Acacia rat	0	0	2	2
Nesomyidae					
Saccostomus campestris	Pouched mouse	17	28	5	6
Soricidae					
Crocidura hirta	Lesser red musk shrew	5	8	3	4
Macroscelididae					
Elephantulus intufi	Bushveld sengi	19	32	18	21
Sum of captures		60		85	
Species richness		7		8	

In the open grassland habitat, *S*. *campestris* dominated the catches (*n* = 17) followed by *A*. *chrysophilus* and *G*. *leucogaster* (*n* = 6). The least captured rodent species was *M*. *natalensis* (*n* = 3). *Sengi* (*Elephantulus intufi*) species recorded (*n* = 19) than shrew species (*Crocidura* spp.) (*n* = 5). In the woody habitat, G. *leucogaster* dominated (*n* = 33) the rodent species sampled, followed by *A*. *chrysophilus* (*n* = 18). The least captured rodent species were *M*. *natalensis* and *T*. *paedulcus* spp. (*n* = 2). Sengis (*E*. *intufi*) recorded (*n* = 18) and shrew species (*Crocidura* spp.; *n* = 3) (Table 1).

4.2.2 Rodent, shrew and sengi species richness

A *t*-test showed no statistically significant difference in rodent, shrew and sengi species richness (t_{18} = 0.00; *n* = 20; *P* = 1.000) between open grassland (mean 4.2 ± 0.416; standard error (SE)) and woody habitats (mean 4.2 ± 0.611 standard error (SE)) (Figure 11). Seven species were recorded in the open grassland habitat (5 rodent and one shrew and sengi species) compared to 8 species in the woody habitat (6 rodent and one shrew and sengi species each).

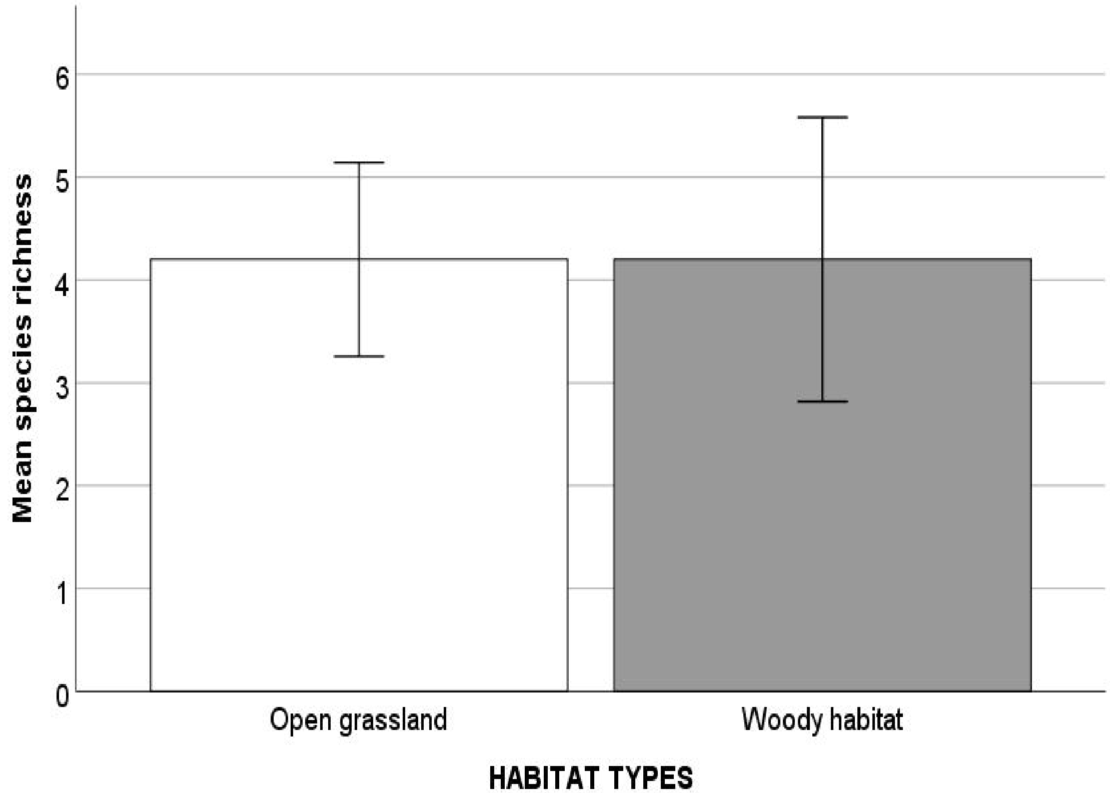

Figure 11: The mean (± Standard Error (SE)) rodent, shrew and sengi species richness in the open grassland and woody habitats at Farm Karachas, Outjo.

4.2.3 Rodent, shrew and sengi species diversity

A Mann–Whitney U test showed no statistically significant difference (U_1 = 32.50; n = 20, P = 0.184) in rodent, shrew and sengi species diversity recorded in the open grassland (ranged from 0-1.61) and woody habitat (ranged from 0-1.46) (Figure 12). The highest mean species diversity (H' = 1.61) was recorded in the open grassland habitat.

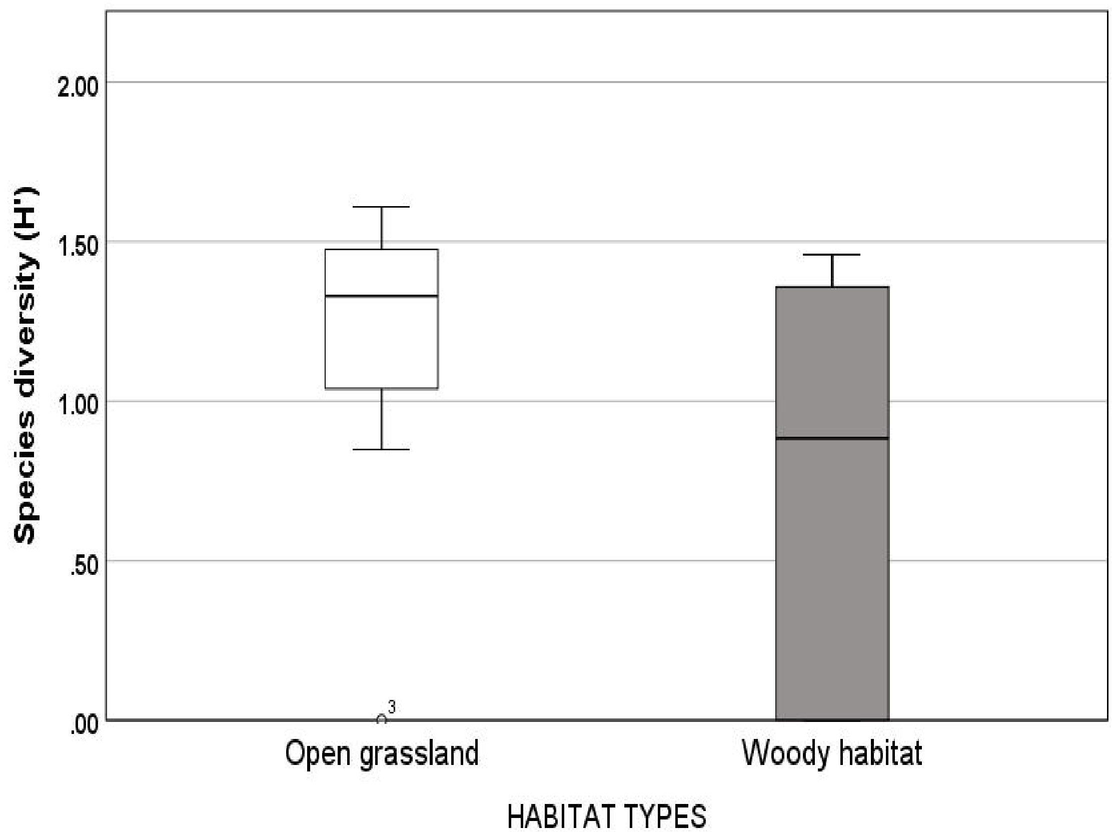

Figure 12: A box and whisker plot comparing the median of rodent, shrew and sengi species diversity (*H*') between the open grassland and woody habitats at Farm Karachas, Outjo.

The horizontal line (thick) in the box is the median. The top part of each box represents the 75th percentile (upper quartile) while the lower part is the 25th percentile (lower quartile). The end of each line above and below the open box indicates the largest and lowest values, respectively, that are not outliers. Extreme values are outside the box.

4.2.4 Rodent, shrew and sengi species composition

A dendrogram from an HCA based on a Bray-Curtis Similarity Index using binary (present-absent) data separated rodent, shrew and sengi species composition into three clusters (Figure 15). It indicated a high similarity in rodent, shrew and sengi species composition between the habitats. Cluster 1 and 2 were 63% similar with clusters 3, indicating that rodent, shrew and sengi species composition was not dissimilar between the open grassland and woody habitats (Figure 13).

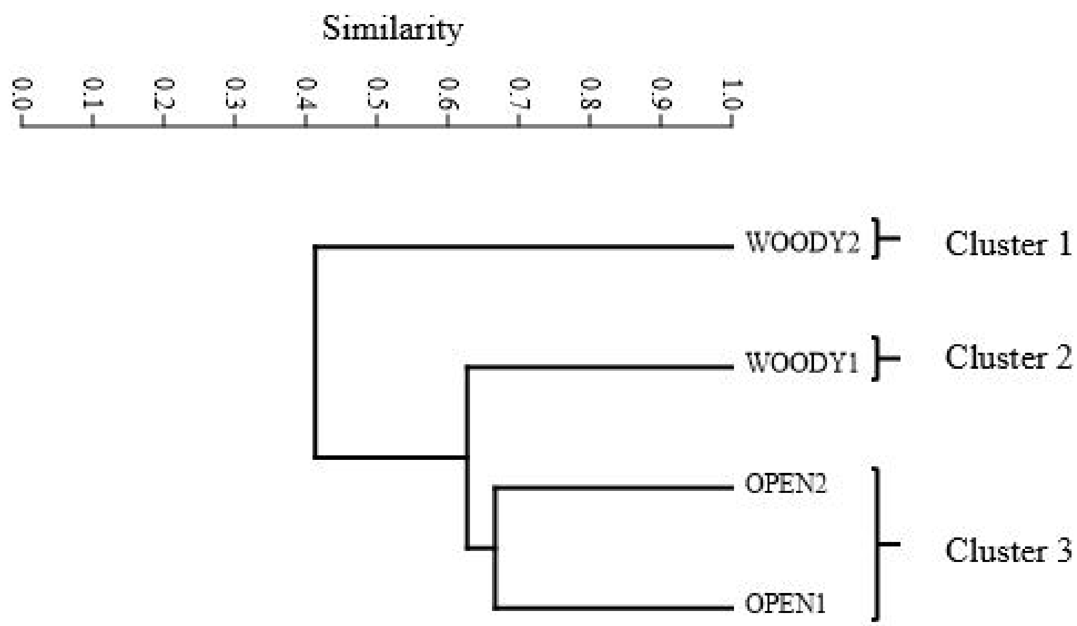

Figure 13: A dendrogram of a hierarchical cluster analysis (HCA) based on Bray-Curtis similarity matrix using binary data showing rodent, shrew and sengi species composition between open grassland and woody habitat (site 1 and 2) at Farm Karachas. OPEN1 = open grassland, site 1; OPEN2 = open grassland, site 2; WOODY1 = woody habitat, site 1; and WOODY2 = woody habitat, site 2.

Cluster 1 of the HCA dedrogram consisted of all rodents, shrew and sengi species that were trapped during sampling period (*A. chrysophilus, M. namaquensis, G. leucogaster, M. natalensis, S. campestris, T. paedulcus, C. hirta,* and *E. intufi*) in the woody habitat, site 2. The rodent species, *A. chrysophilus* and *G. leucogaster* and the sengi species, *E. intufi* occurred in high numbers, indicating that this species had a preference for the woody habitat. *Thallomys paedulcus* species was only observed in this cluster. Cluster 2 represents three rodents *(A. chrysophilus, G. leucogaster, S. campestris*) and a sengi (*E. intufi*) species from the woody habitat, site 1. The dominant rodent species was *A. chrysophilus*, while *E. intufi* was the dominant sengi species. Cluster 3 comprises rodents, shrews and sengi species recorded in the open grassland, sites 1 and 2. The dominant rodent species in the open grassland were *S. campestris* and *A. chrysophilus*, more sengis (*E. intufi*) were also recorded in the habitat. Other small mammal species belonging to this cluster included the rodent species *M. namaquensis, M. natalensi,* and *G. leucogaster* and the shrew species *C. hirta*. *Thallomys paedulcus* was absent from this cluster.

CHAPTER 5: DISCUSSION

5.1 Comparison of vegetation characteristics in the open grassland and woody habitats.

In order to investigate the effect of habitat type on rodent and shrew species abundance, richness, diversity, and composition in contrasting habitats in the present study, it was critical to ascertain that the two selected habitats differed significantly in vegetation attributes. Analysis of vegetation structure showed that the open grassland and woody habitats that were selected for this study differed significantly in species abundance, tree heights structure, and species richness of woody plants, except for the percentage of grass cover. Furthermore, HCA revealed a low level of similarity (31%) in species composition of woody plants between the open grassland and woody habitats. These vegetation analysis clearly indicate that the two selected habitats were different enough from each other**.**

5.2 Small mammal community structure and composition

5.2.1 Rodent, shrew and sengi species abundance

The result of this study showed no statistically significant difference in rodent, shrew and sengi species abundance between the open grassland and woody habitats. The lack of a statistically significant difference in the mean percentage grass cover between open grassland and woody habitat may explain the similarity in rodent, shrew and sengi species abundance in the open grassland and woody habitats. Both habitats had sufficient grass cover to support these small mammals, therefore the null hypothesis that there will be no difference in rodent, shrew and sengi species abundance in the open grassland and woody habitats is supported.

Generally, vegetation cover is primarily an important component of habitats that greatly affects small mammal species diversity and compositions (Monadjem, 1999; Gumbi *et al.,* 2018). This is because vegetation cover especially grass and herbaceous plant covers provide not only food but also reduces the probability of small mammals being detected and predated on by the aerial and ground predator (Symes *et al*., 2013). Additionally, the safety for small mammals appears to correlate with some measure of vegetation such as shrub cover or grass height (Loggins *et al*., 2019). For example, Tattersall *et al*. (2001) demonstrated that tall grasses provide cover and protection from predators for small mammals, whereas short grasses and open patches provide little protection and tend to be avoided by small mammals. Similarly, in the grasslands of KwaZulu-Natal, Province, South Africa. Banasiak and Shrader (2016) showed that small mammals improved their foraging effort in places with high vegetation cover, likely because such sites were perceived to be safe, thus suggesting that vegetation cover influences small mammal movements and use of microhabitats. However, the present study did not find any link between the recorded vegetation parameters and rodent species abundance, richness, diversity, and composition, despite significantly different habitat types.

The present study showed that rodents were most abundant while shrews were the least abundant in both habitats. Similar results have been reported in agricultural areas in the Mbeya region, Tanzania where rodents and shrews formed 96.6% and 3.4%, respectively, of the total rodent and shrew species abundance trapped (Michael, Ringo & Ratnayeke, 2016). Furthermore, Simelane *et al*. (2018) recorded a greater number of rodents than shrews in the foothills of the Drakensberg Mountains. Moreover, in a study by Bantihun and Bekele (2015) on diversity and habitat association of small mammals in the Aridtsy forest, Awi Zone, Ethiopia, the total capture included eight species of small mammals of which only 1.1% were shrews. The low number of shrews and sengis trapped in studies of small mammals is attributable to the trapping method used, especially the Sherman trap (Nicolas *et al*., 2006; Hurst *et al*., 2014; Simelane *et al*., 2018). Besides, the commonly used rolled oats mixed with peanut butter as bait, it is not most appropriate for shrews because they are insectivorous hence shrews that are trapped are the ones that may have just stumbled into the Sherman live traps (Kok, Parker & Barker, 2013). In contrast, Armand *et al*. (2013) demonstrated that baits or lure commonly used to trap small mammals do not only attract them but also serve as food for sustenance for trapped individuals. For example, peanut butter and oats mixtures baits provide an extra smell that probably acts to provide extra food, depending on the seasonal availability of other food resources (Kok, Parker & Barker, 2013). For instance, bait attracts insects such as bees, beetles, butterflies, crickets, grasshoppers, and moths that are being preyed on by insectivorous shrew and sengi species.

Compared to open grassland habitat, the total abundance of rodents, shrews and sengis was higher in the woody habitat. This may be a reflection of high plant species diversity, abundance, and grass cover which provided suitable habitat for rodents, shrews and sengis in the woody habitat compared to open grassland through an abundance of food, shelter, and safer movement of small mammals. Silva, Hartling and Opps (2005) also found that mammalian diversity is likely to be lower in open habitats, where cover providing food and shelter is reduced, as well as increasing predation risk. It is also possible that the canopy cover of woody plants compensate for aerial predation and provides a suitable microclimate for small mammals (Melo *et al*., 2013). Furthermore, foraging behavior influenced species abundance of rodents, shrews and sengis, for instance, in a dry environment, such as that of the present study (Mendelsohn *et al*., 2003), captures could reduce in the open grassland during the dry seasons as also observed by Mulungu *et al*. (2011) in Tanzania and Swaziland. Generally, species are expected to adapt their behavior to avoid predation, and successfully search for food, mates, shelter, and a suite of environmental conditions for their survival (Yadok, Pech & Chapman, 2019), thus affecting their distribution.

The dominance of individual rodents also varied, *G. leucogaster* and *A. chrysophilus* were the most trapped rodents in the woody habitat whereas, in the open grassland habitat, *S. campestris* was the frequently trapped rodent species. Although *G. leucogaster* utilizes a wide variety of habitats including grasslands, savannas, woodlands, and cultivated areas (Smithers, 2011) and displays a wide range of environmental tolerance (Campbell, Lewis & Williams, 2011), the presence of a large number of *G. leucogaster* in the woody habitat may be that it is a generalist while the other rodent species have specific microhabitat requirements that can be found embedded within a microhabitat (Matthews *et al*., 2005). Hence, the high abundance in the woody habitat may reflect the use of the microhabitats irrespective of their wide range of habitat tolerance.

Saccostomus campestris is known to have a wide habitat tolerance and can be found in open, dense vegetation and rocky areas (Stuart & Stuart, 2007). It is a granivorous species (Hurst *et al*., 2014), hence its higher abundance in the open grassland habitat than in the woody habitat because open grassland provides more seeds. *Aethomys chrysophilus* is omnivorous therefore had higher abundance in the woody habitat because it typically relyies more on plants than animal food resources (Linzey & Chimimba, 2008).

Across all habitats*, M*. *namaquensis* showed equal preference for the open grassland and woody habitats. It occurs widely throughout the Southern Africa sub-region (Mills, 1997) irrespective of habitat type (Fagir *et al*., 2014). Equal preferences, may be an indication of habitat tolerance. *Mastomys natalensis* was the least recorded rodent species in both open grassland and woody habitats. In contrast, several studies (Magige, 2016; Michael, Ringo & Ratnayeke, 2016; Kapia, 2018; Simelane *et al*., 2018) reported *M. natalensis* as the most abundant and successful rodent sampled in study their areas, which is more likely to be an indication that the species is common in agricultural areas (Magige, 2016). *Mastomys natalensis* was expected to be abundant (Stuart & Stuart, 2007) because it is omnivorous and a generalist species (Mamba *et al*., 2019). However, few were captured and recorded during this study. *Thallomys paedulcus* was also a least sampled rodent species and was also absent in the open grassland habitat. It is an arboreal species (Karantanis *et al*., 2017) that prefers areas dominated by Acacias (Stuart & Stuart, 2007; Karantanis *et al*., 2017), and is also known to have a low density throughout its distributional range (Skinner & Chimimba, 2005).

Sengis (*Elephantulus intufi)* accounted for 31% and 21%, compared to shrews (*Crocidura hirta)* 8% and 4% respectively, in the open grassland and woody habitat. *Elephantulus intufi* is known to be less influenced by land use compared to many other small mammals (Child *et al*., 2017) has a broad habitat tolerance (Smit, 2011). On the other hand, *C*. *hirta* was the least sampled shrew species on the farm in both the open grassland and woody habitats. This species is predominantly found in association with moist habitats, although it is also found in very dry areas (Stuart & Stuart, 2007) that are seasonally independent of water (Smithers, 2012). The moist environments are linked with a high abundance of invertebrates which serves as prey for the shrew species (Simelane *et al*., 2018). The low levels of moisture may therefore explain the low numbers of *C. hirta* in the habitats. The use of Sherman live traps may have contributed to the low abundance of *C. hirta* in both habitats. Bantihul & Bekele (2015) reported that the use of Sherman live traps led to the capture of a low number of shrews. This is in contrast to the high trap success of shrews in a study in Ethiopia when pitfall traps were used compared to Sherman live traps (Nicolas & Colyn, 2006). They argued that many shrews are lightweight hence rarely trigger the door trapping mechanism of the Sherman live traps.

5.2.2 Rodent, shrew and sengi species richness

The species richness of rodents, shrews and sengis in the present study was expressed as the number of species that were trapped per habitat during the trapping period and as the mean number of species per trap-night from each habitat. It was expected that species richness would be higher in the woody habitat than in the open grassland habitat. However, the present study showed that there was no significant difference in the mean rodent, shrew and sengi species richness between the open grassland and woody habitats, thus accepting the null hypothesis which state that open grassland and woody habitats do not influence rodent, shrew and sengi species richness at Farm Karachas in Outjo. It has been shown that changes in grass biomass influence species occurrence and species richness, hence increased grass cover would increase small mammal species richness (Loggins *et al*., 2019). Hence, the lack of a significant difference in rodent and shrew the mean percentage grass cover between the open grassland and woody habitats in the present study may have contributed to lack of a significant difference in rodent, shrew and sengi species richness. Grass cover contributes to the provision of both food and protection from predation, especially from aerial predators. Moreover, Saeed (2010) reported that, low variation in species richness among habitats may suggest that small mammal selection of habitat may not be influenced by individual perception and response to environmental conditions.

Furthermore, a study in the Nama Karoo, South Africa by Hoffmann and Zeller (2005) reported that intensive and uncontrolled grazing by animals had a clear negative impact on species richness, diversity, and settlement or survival of small mammals due to the loss of ground vegetation cover which leads to a reduction in food supply (plants, arthropods) and available dew for small mammals. The present study site was not intensively grazed (personal observations), therefore open grassland and woody habitat exhibited the same species richness (Figure 13).

5.2.3 Rodent, shrew and sengi species diversity

The present study showed that there was no significant difference in the mean rodent, shrew and sengi species diversity sampled in the open grassland and woody habitats, therefore accepting the null hypothesis which predicted that open grassland and woody habitat do not influence rodent and shrew species diversity at Farm Karachas. Many rodent, shrew and sengi species were caught both in the open grassland and woody habitat, suggesting these small mammals were responding to other vegetation parameters such as woody plant canopy cover, species composition of grasses that were not considered, or a completely different set of variables such as competition for food (Symes *et al*., 2013). Both habitats were situated on the same farm which is likely to provide similar environmental conditions needed by the species to obtain food resources, select a mate, and successfully reproduce. The open grassland habitat had a mean species diversity ranging from 0 to 1.61, whereas the woody habitat ranged from 0 to 1.46. This may be attributed to an association of the trapped species with grassland microhabitats and that some small mammals prefer habitats dominated by graminoids (Michał & Rafał, 2014). Rosenzweig (1995) reported that the better the variety of resources in a habitat, the better the species diversity of organisms that inhabit them and this may correspond to the number of niches available within that particular habitat. Rodents, shrews and sengis may therefore, have found open grassland sufficient in providing food.

Rautenbach *et al*. (2013) reported that rodent and shrew species diversity assemblages vary both seasonally and annually in different vegetation types due to differences in the vegetation structure and cover among seasons. Data on rodent, shrew and sengi species diversity in the open grassland and woody habitats were collected in the same year and season, providing these small mammals with similar niche opportunities to exploit such as quantity and quality of crucial resources (e.g., shelter and food) (Mulungu *et al*., 2008). Moreover, this may be affected by the breeding and reproductive season, thus resulting in no significant difference in the rodent, shrew and sengi species diversity between the two habitats. The same trend was observed by Simelane *et al*. (2018) who reported that species diversity did not vary significantly across six habitats, but varied between the dry and wet seasons. In contrast, a study by Imasiku (2011) in selected grassland and mixed shrub and vegetation in Etosha National Park, Namibia showed no statistically significant difference in small mammal species diversity between study sites and seasons.

5.2.4 Rodent, shrew and sengi species composition

Most of the rodents and shrew, and sengi sampled during the present study have been documented by previous studies undertaken elsewhere in Namibia (e.g., Hoffmann & Zeller, 2005; Imasiku, 2011; Karuaera, 2011; Mfune, Kangombe & Eiseb, 2013; Hauptfleisch, 2014; Hauptfleisch, Vinte & Blaum, 2017; Kapia, 2018). The two habitats in the present study shared the same rodent species that included (*A. chrysophilus, M. namaquensis, G. leucogaster, M. natalensis, S. campestris*), shrew species (*C. hirta*) and sengi species (*E. intufi*). Only *T. paedulcus* was caught exclusively in the woody habitat.

A dendrogram from an HCA based Bray – Curtis Index Similarity using present/absent binary data showed a high similarity (63%) in rodent, shrew and sengi species composition between the open grassland and woody habitats, indicating that heterogeneity was relatively low. The heterogeneity hypothesis suggests that the more spatially diverse the community is, the greater the species richness, which also accounts for species composition (Waide, 1999). The observed high similarity in the present stud may also suggest minimal species migrations between the open grassland and woody habitats. This may also indicate that the farm is in good health and species are dependent on the farm. The present study therefore, accepts the null hypothesis of no difference in rodent, shrew and sengi species composition in the open grassland and woody habitats.

There was little variation (63% similarity) in rodent, shrew and sengi species composition between the open grassland and woody habitats, indicating that some species, such as *T. paedulcus* that was absent in the open grassland habitat were not common among the habitats. This may suggest a more even distribution of rodents, shrews and sengi and resemblances in habitat qualities. On the other hand, variations in small mammal composition may also be influenced by factors such as food, niche separation, and microhabitats (Saeed, 2010).

The result of the present study suggests that seven species, i.e., *A. chrysophilus, M. namaquensis, G. leucogaster, M. natalensis, S. campestris, C. hirta* and *E. intufi* have a wide range of habitat preference among the species captured, as they were observed in both the open grassland and woody habitats. The spatial distance of 600 m between the habitats did not have a significant impact on the rodent, shrew and shrew species composition because no species captured in the open grassland was recaptured in the woody habitat and vice versa. Both habitats were sampled on the same month, year, and season and were therefore exposed to similar environmental conditions such as exposure to sunlight, temperature, and moonlight. Stromgren (2008) reported that temperature may have an effect on the activity of small mammals, especially on the timing of the activity.

The dominant rodent species in the woody habitat was *G. leucogaster* followed by *A. chrysophilus*. Both species are widely distributed and are omnivorous (Stuart & Stuart, 2007). The diet of *G. leucogaster* typically comprises of more arthropods than plants materials, seeds (Skinner & Smithers, 1990). Hoffmann and Zeller (2005) reported that *G. leucogaster* depends much on adequate vegetation cover and not necessarily on food availability as it was found to depend on other resources availability such as availability of water. It can therefore be inferred that the dominance of *G. leucogaster* is a result of vegetation cover in the woody habitat. Despite its wide distribution, some studies have found *G. leucogaster* to be sensitive to change in vegetation cover (Muck & Zeller, 2006).

Vesey-Fitzgerald (1966) reported that the diet of *A. chrysophilus* mainly consists of hard dry fruit of trees and shrubs such as *Grewia spp* and *Combretum spp* which they collect on the ground and store in their shelter to be eaten at any season. In the present study, *G. flava* and *G. flavences* were amongst the most abundant woody plant species in the woody habitat, therefore contributing to the higher dominance of *A. chrysophilus* in the woody habitat.

The pouched mouse *Saccostomus campestris* dominated the open grassland habitat. It is a granivore, primarily eating seeds, grains, and nuts and prefers open patches with tall vegetation for cover rather than heavily grazed vegetation (Hagenah, Prins & Olff, 2009). In the present study, grasses in the open grassland habitat were more than 1 m high (personal observation), therefore contributing to its higher capture. However, in a study by Fitzherbert *et al*. (2007) on habitat preferences of small mammals in the Katavi ecosystem in western Tanzania, *S. campestris* abundance was found to significantly correlate with measures of leaf and tree cover.

Sengi species (*Elephantulus intufi*) dominated both the open grassland and woody habitats while shrew species (*C. hirta*) was the least captured in both. Stuart and Stuart (2007) reported that *E. intufi* rely more on bush or grass cover that have pathways between shelters. It feeds on insects and other invertebrates, with a marked preference for ants and termites (Stuart & Stuart, 2007). Its dominance may be an indication of a high abundance of food resources. *Crocidura hirta* is mostly associated with moist habitats with good ground vegetation cover (Stuart & Stuart, 2007), hence, is sensitive to dry and lowly covered vegetation areas. Loggins *et al*. (2019) reported that *C. hirta* populations decline with an increase in woody cover, therefore contributing to its low capture in the woody habitat in the present study.

The distribution of organisms is affected by environmental characteristics they are exposed to (Malmstrom, 2012). For example, soil and/or climate may influence small mammal species composition (Rautenbach *et al*., 2013), perhaps why some species such as *T. paedulcus* was found in the woody habitat rather than in the open habitat. The arboreal Acacia rat (*T. paedulcus*) depends on Acacia tree species, for food and nesting (Stuart & Stuart, 2007). Acacia thorns provide optimal protection against predators during foraging (Delany, 1972). It lives under the ragged bark of *Acacia* tree trunks and branches and nests as high as 4 m from the ground (Hutchins, 2014). *Thallomys paedulcus* species can serve as an ecological indicator by identifying areas with *Acacia* species. *Senegalia* spp (previously known as *Acacia* spp) were one of the most abundant woody plant species in the woody habitat. The woody habitat accounted for 30% of the woody plants that were in the height classes < 1 m and > 3 m. The sampling technique that was used to trap small mammals in the study site may have been ineffective in capturing arboreal species such as *T. paedulcus* (Rautenbach, 2013) therefore explaining their exclusive presence in the open grassland.

Mastomys natalensis and *M. namaquensis* were less dominant in both habitats the open grassland and woody habitat. Jackson and Van Aarde *et al*. (2003) reported that *M. natalensis* generally occurs in areas receiving more than 600 mm per annum. The present study area however receives a minimum of 350 mm and a maximum of 400 mm of precipitation per year (Mendelsohn *et al*., 2002). *Mastomys natalensis* is omnivorous and a generalist (Mamba *et al*., 2019), but has a poor colonizing ability and prefers randomly unstable habitats (Willan & Meester, 1989), hence contributing to its low capture. On the other hand, species within the genus Mastomys are considered to be indicator species that increases following a disturbance (Erena, Yosef & Bekele, 2011). It is also possible that this may also be attributed to inter-specific competition, where one species dominates another that is also important in shaping small mammal community structure (Cao *et al*., 2016). The low dominance of *M. natalensis* in the present study may therefore indicate that the farm is of good quality.

It is noteworthy in the present study that *M*. *namaquensis* was the least dominant species in both the open grassland and woody habitats. Fagir *et al*. (2014) and Van Maltilz *et al*. (2006) reported that *M*. *namaquensis* is one of the dominant small mammals irrespective of the habitat type. The low dominance of *M. namaquensis* in the present study may be due to its preference for rocky outcrops or hillsides (Fagir *et al*., 2014) which was not typical landscape for the study area in the present study (personal observation).

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The present study has shown that there was no significant difference in rodent, shrew and sengi species abundance on the open grassland and woody habitats. This may be due to the percentage of grass cover similar in both habitats. Hence, there was sufficient evidence to accept the null hypothesis that rodent, shrew and sengi species abundance will not be significantly different in the woody habitat than open grassland habitat. *Gerbilliscus leucogaster* and *A. chrysophilus* were found to be the dominant rodent species in the woody habitat, while *S. campestris* was dominant in the open grassland habitat. *Elephantulus intufi* was found to be the dominant sengi species in both habitats with *C. hirta* being the least trapped shrew species in both habitats.

The results of the present study suggest that rodent, shrew and sengi species richness and diversity were not influenced by the open grassland habitat and woody habitat. This may indicate that the two habitats did not have a sufficient difference in key vegetation factors that would have led to or be associated with a difference in rodent, shrew and sengi species richness and diversity. Hence, there was sufficient evidence to accept the null hypotheses that rodent, shrew and sengi species richness and diversity will not be significantly different in the woody habitat than open grassland habitat.

The common rodent, shrew and sengi species found in the open grassland and woody habitats were *A. chrysophilus, M. namaquensis, G. leucogaster, M. natalensis, S. campestris, C. hirta, and E. intufi. Thallomys paedulcus* was absent in the open grassland habitat. The rodent, shrew and sengi species composition did not differ among the habitats probably as a result of similarity in ground cover and food resources which are major determinants of species compositions of small mammals. There was a high level of similarity (63%) in rodent, shrew and sengi species compositions. Hence, there was sufficient evidence to accept the null hypothesis that rodent, shrew and sengi species composition will not be significantly different in the woody than open grassland habitat.

6.2 Recommendations:

While the data collection period of the present study was of short duration, the limited data available highlighted the critical need for further studies on the effect of habitat type on rodent and shrew species abundance, richness, diversity, and composition of the community structure, therefore further studies must be conducted to improve the reliability of the result in the present study. Similar rodent and shrew species diversity in the open grassland and woody habitats remain unclear and therefore, it is critical to conduct a similar study over a longer period of time where no ecological disturbance has occurred, to assess if these findings will be supported by other studies. The is also a critical need for a comparative study of rodents and shrews species abundance, richness, diversity and composition to be undertaken in the two habitats over different seasons to evaluate whether there is seasonal variation. Seasonality represents a major factor that determines how individuals use vegetation type as it influences the dynamics of their food, cover, and reproductive period. In addition, there is a critical need to evaluate edaphic (soil properties) and grazing intensity on the farm in order to assess the response of rodents and shrews to different habitat types.

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APPENDICES

Appendix 1: Research permission letter

CENTRE FOR POSTGRADUATE STUDIES

University of Namibia, Private Bag 13301, Windhoek, Namibia
340 Mandume Ndemufayo Avenue, Pioneers Park
☎ +264 61 206 3275/4662; Fax +264 61 206 3290; URL: http//www.unam.edu.na

UNAM
UNIVERSITY OF NAMIBIA

10 July 2020

RESEARCH PERMISSION LETTER

Student Name: **Salmi Kapala**
Student number: **201201786**
Programme: **MSc Biodiversity Management Program**

Approved research title: Effects of habitat type on species abundance, species diversity and species composition of rodents and shrews in Neudamm farm and Outjo farm

TO WHOM IT MAY CONCERN

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

Permission is hereby granted to carry out the research as described in the approved proposal.

Best Regards,

Dr. Seth J. Eiseb
Acting Director
Centre for Postgraduate Studies
Tel: +264 61 2063414
E-mail: directorpgs@unam.na