Understanding the two-way interactions between aardvark (*Orycteropus afer*) burrowing and the surrounding landscape characteristics at Rietvlei Nature Reserve, South Africa

By

Morena John Mapuru

Submitted in fulfilment of the requirements for the degree

Master of Science in Geography

In the faculty of Natural and Agricultural Sciences

University of Pretoria

Pretoria

24 September 2021

Supervisor: Dr. Natalie Haussmann

Co-Supervisor: Dr. Christel Hansen

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Declaration

I, Morena John Mapuru declare that the thesis/dissertation which I hereby submit for the degree Master of Science in Geography at University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Signature:

Date: 24 September 2021

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Abstract

Burrowing mammals, i.e., mammals that dig in the ground for shelter creation, food, and nesting, play an important role in the ecosystem, since their burrows support plant and animal assemblages that differ from that of the surrounding environment. Previous research suggests that environmental parameters, such as soil texture and vegetation, influence the distribution of burrows in the landscape. However, burrowing mammals are not only influenced by soil texture but also influence the soil texture. The current study investigated the two-ways interactions between aardvark (*Orycteropus afer*) burrowing and the characteristics of the surrounding landscape at Rietvlei Nature Reserve, South Africa. First, soil type, geology, rockiness, vegetation, distance to water lines, and distance to roads were explored as potential determinants, both of burrow presence (using Fisher exact tests), as well as burrow density (using Generalized Linear Models (GLZs)) in quadrats. Second, spatial clustering of aardvark burrows was explored using *Average Nearest Neighbour Analysis, Multi-distance Spatial Cluster Analysis, and Optimized Hot-Spot analysis* in ArcGIS Pro. Finally, mean, sorting, skewness, and kurtosis were calculated to compare soil texture between burrow mounds and control samples. Controls were taken 2 meters away from burrow mounds and represent areas not recently burrowed by aardvark. The study found no association between burrow presence in a quadrat and any of the environmental determinants investigated. In addition, none of the potential determinants was a significant predictor of burrow density within quadrats. Cluster analysis results from three quadrats with highest number of burrows (Q2, 3 and 28) show the dispersion of burrows in two (Q3 and 28) of the three quadrats used, whereas the third (Q2) quadrat shows clustering at distances less than 28 m and dispersion at distances greater than 43 m. The study further found that aardvark burrowing affects the size and distribution of soil particles but not sorting. The mean, kurtosis, and skewness of soil samples from burrow and controls differ significantly ($P>0.05$). While sorting of soil samples from burrows and controls did not differ significantly ($P<0.05$). From the results of GLZs, it is possible that other factors, instead of the environmental parameters explored here, are driving aardvark distributions. These may include more nuanced differences in plant cover and grass height between quadrats. Quadrats are, for example, rotated when it comes to managed veld burning. This affects grass cover, which in turn may affect aardvark burrowing. It is thus recommended that this be investigated

Keywords: aardvark, burrow distribution, burrowing mammals, cluster analysis, diggings, Orycteropus afer

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Acknowledgement

I would like to thank, "*God of Mount Zion*", for granting me the strength and resources to undertake this research study.

Thank you very much to my supervisors, Dr. Natalie Haussmann and Dr. Christel Hansen, without whose support, guidance, and patience, I would not have been able to complete this dissertation.

Thanks to Mr. Martin Ntsoane (Rietvlei Nature Reserve) and Lauren Pijper for their support during data collection.

I would like to pass my sincere gratitude to South African National Research Foundation (NRF) for the financial support in the form of Scarce Skills MSc bursary, as well as a Y-rated grant for field logistics (Grant number 120404).

Thanks to my family for their love, encouragement, and support throughout the duration of the study.

"*I Dedicate this masters to Mapuru family. Re leboha lehodimo (we thank the heavens)*"

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Table of Contents

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

List of Figures

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

List of Tables

Equations

Chapter 1: Introduction

1.1 Background and study rationale

Burrowing mammals are mammal species that dig in the ground for, among others, shelter creation, food, and nesting (Foster et al., 2019). The burrows and mounds of burrowing mammals play an important ecological role in the ecosystem by providing habitats that support plant and animal assemblages that differ from that of the surrounding environment (Kurek et al., 2014; Wesche et al., 2007). Kurek et al., (2014), found that burrows of European badgers (*Meles meles*) and foxes (*Vulpes vulpes*) supported high number of alien, pioneer and short lived species than unburrowed sites. American Vizcachas (*Lagostomus maximus*) facilitate burrowing owls by construction of burrows that they use as nest sites (Machicote et al., 2004). Grazing by small burrowing mammals enhances nutrient uptake by plants, resulting in increased foraging quality which attracts megaherbivours such as cattle (Davidson et al., 2021). Burrows can also shelter other species during periods of extreme weather (Anzah & Butler, 2017; Laundre, 1993; Mielke, 1977). For example, according to Pike and Mitchell, (2013) burrow-dwelling tortoises (*Gopherus polyphemus*) from Florida (United State) depend on burrows created by other species for thermoregulation during extreme temperature conditions.

Many burrowing mammal species are also referred to as ecosystem engineers, as they change the structural composition of the physical environment through their digging behaviour (Jones et al., 2016). Ecosystem engineering burrowers ameliorate soil properties, change soil chemistry and soil water infiltration rates (Mielke, 1977). It is important to understand the mechanisms through which these species change the environment. For conservation purposes, it is also important to understand the biotic and abiotic drivers within the landscape that determine where burrowing mammal species create their burrows. There are many burrowing species across the globe. However, for this study, only one species of burrowing mammal, the aardvark (*Orycteropus afer)* was investigated. The aardvark was chosen as a study species because of its ability to create large burrows that were easily identified during data collection.

Spatial distribution of species burrows across the landscape are determined by the spatial patterns of the biotic and abiotic components of the environment (Wiegand et al., 1997). These environmental elements presumably also play a pivotal role in the distribution and occurrence of the aardvark burrows in the South African landscape. In addition to being influenced by their surrounding landscape, aardvark also influences the ecology of their surroundings (Haussmann et al., 2018; Taylor & Skinner, 2004).

However, the understanding of how aardvark and the biotic and abiotic environment influence one another through their interaction lacks scientific documentation in South Africa. This research gap triggered the motivation to conduct this study. In the effort to fill the identified research gap, the current study investigated the two-way interactions between the aardvark and its surrounding landscape at Rietvlei Nature Reserve, Gauteng, South Africa. This study used a combination of fieldwork, laboratory work, geospatial methods, and statistical analyses to identify potential environmental (biotic and abiotic) drivers of burrow locations, numbers, and presence/absence, as well as the impacts of aardvark excavating trends on the Rietvlei Nature Reserve landscape soil texture.

1.2 Aims and objectives

This research investigated the two-way interactions between aardvark (*Orycteropus afer)* burrowing and the surrounding landscape characteristics at Rietvlei Nature Reserve (South Africa). To achieve this, four objectives were set below, namely:

- Objective 1: To identify potential determinants (vegetation, soil, rockiness, geology, distance to roads, and water bodies) of aardvark burrow presence/absence.
- Objective 2: To identify potential determinants of aardvark burrow densities in quadrats.
- Objective 3: To explore spatial clustering of burrows in three high-burrow quadrats.
- Objective 4: To quantify the impact of aardvark burrowing on soil physical properties, specifically soil texture.

1.3 Dissertation outline

This research consists of six chapters, namely:

- <u>Chapter 1: Introduction</u> provides a short introduction on the interaction between burrowing mammal (aardvark) and their surrounding environments. It further conceptualizes the aim and objectives of the study, as well as the outline of this dissertation.
- <u>Chapter 2: Literature Review</u> focuses on a review of previous studies on the ecological impacts of burrowing mammals and environmental determinants influencing their burrow location. It also provides an overview of studies on South African burrowing mammals, a thorough description of the study species, as well as a conceptual framework stipulating the direction that was taken by the study.

- Chapter 3: Materials and Methods provides a detailed description of the study area where research was conducted, and a thorough discussion of the methods that were used for the execution of this research.
- Chapter 4: Results on the spatial distribution of aardvark burrows and environmental determinants influencing burrow presence/absence and density. Findings on the impacts of the aardvark on soil texture are also presented in this section.
- Chapter 5: Discussion reviews the results presented in Chapter 4 with the reference to broader literature presented in Chapter 2.
- Chapter 6: Conclusion provides concluding remarks and future recommendations for Prospective research.

Chapter 2: Literature review

2.1 Ecological impacts of burrowing mammals

Globally, the digging and foraging behaviour of burrowing mammals yields a variety of environmental impacts. Burrowing mammals are often referred to as ecosystem engineers (Jones et al., 2016;Whittington-Jones, 2006), because of their ability to modify their physical environment (Eldridge & Whitford, 2009), disturb soil structure (Kurek et al., 2014), improving resource availability (Yu et al., 2017), and changing the living conditions for other species (Whitford & Kay, 1999).

Although burrow excavation may have negative impacts on plant cover in some cases (Wiegand, Dean, & Milton, 1997), burrows have also been associated with enhanced species biomass, richness, and diversity (Kurek et al., 2014; Wesche et al., 2007; Wiegand et al., 1997). According to Noble et al. (2007), soil mixing, and urine and faecal deposition around the mounds of Australian burrowing bettong (*Bettongia lesueur*) increase organic and inorganic nutrients, which allow better growth of plants. Furthermore, burrows of burrowing mammals can play an ecological role by facilitating seed trapping (Boeken et al., 1995), accumulating litter (James et al., 2009), and water (Laundre, 1993; Shachak et al., 1991), thus increasing resource availability.

Burrowing mammals can further aid in maintaining the physical landscape of grassland environments. Species such as the South American vizcachas (*Lagostomus maximus*), burrowing bettongs in Australia, and prairie dogs (*Cynomys ludovicianus*) in North America may prevent shrub invasion through their foraging and burrowing behaviour (Machicote et al., 2004; Noble et al., 2007; Weltzin et al., 1997). Noble et al., (2007) showed that shrub-land expansion in semi-arid regions of North America and Australia has been attributed to a decrease in populations of prairie dogs and bettongs respectively.

Furthermore, burrowing mammals may accelerate soil erosion by removing vegetation, which anchors the soil in the ground, when digging, thus increasing the rate of run-off (Harvey et al., 2019). This has the potential to remove the fertile topsoil that is suitable for agriculture (Abba et al., 2015; Moore et al., 1999). In arid and semi-arid environments the removal of plants by burrowing mammals can perpetuate the expansion of the desert environment (Fleming et al., 2014). Furthermore, the discrete geomorphological disturbances of burrows on rangelands inflict injuries on livestock when they walk over them while grazing (Marsh, 1998). This is one of the other reasons they are unwanted in the farms by agricultural management.

However, burrowing mammals also contribute positively to their environment and farming communities. Burrowing insectivores and omnivores, such as South African veld rat (*Aethomys ineptus*) and southern multi-mammate mouse (*Praomys natalensis*) in Zimbabwe, Mozambique and South Africa, play an important positive ecological role when feeding on insects that damage crops, and plants that serve as a food source for many herbivorous burrowing mammals (Curtis & Perrin, 1979), and by so doing they allow for crops in agricultural spaces to grow better, thus increasing production rates.

All these impacts show that burrowing mammals change the ecology of the environment. However, understanding of the nature and magnitude of these impacts still leaves a huge research gap in the field of ecology. By filling this gap, a better decision-making in terms of managing the existence of these species in the environment would be realised.

2.2 Burrowing mammals in Africa/South Africa

There are various types of burrowing mammal species in South Africa, which differ in terms of diet, active time frames (nocturnal vs. diurnal), rate of excavation, and size of their burrows (Foster et al., 2019; Haussmann, 2017). Most burrowing mammals in South Africa play a pivotal role by contributing to natural disturbances and amelioration of physical environments in many ecological systems (Bragg, 2003; Whittington-Jones et al., 2011).

Many studies on South African burrowing mammals are focused on their ecosystem engineering behaviour and the role they play in the environment. For example, Haussmann et al., (2018) investigated the ecosystem engineering behaviour of aardvark (*Orycteropus afer*) by comparing the soil and vegetation between burrow entrances, mounds, and control sites. The study found that the soil in burrow entrances was less compact, cooler, and drier than on the mounds and controls studied, while vegetation cover was higher on older burrows. The results of this study showed no difference in soil fertility across all sites studied (burrow entrances, mounds, and controls). On the other hand, Bragg, (2003) found that Cape porcupines (*Hystrix africaeaustralis*) influence the physical landscape through both biotic (foraging on geophytes) and abiotic (soil turnover) mechanisms. Cape porcupines also play a vital role by preventing the establishment of forests in grassland environments when it feeds on bark belowground (Bragg, 2003), this maintains rangelands for grazing. The burrows of burrowing mammals such as aardvark further provide refuge for other species during periods of extreme climatic conditions and nesting (Oduro & Boateng, 2009). These burrows provide microclimate sites with moderate temperatures and high moisture contents that are needed by both flora and fauna to survive (Oduro &

Boateng, 2009). Whittington-Jones et al, (2011) showed that 21 mammal species, two bird species, three reptile species, and one amphibian species in arid and semi-arid parts of South Africa utilized burrows of aardvark for refuge. This shows that the aardvark influences the environment positively for the survival of other species.

In contrast, Fowler, (2004) showed the effects of burrowing activity by rodents and how they impact archaeological sites in Ndondondwane, South Africa. This study found that rodents displace large volumes of soil and expose it to erosion agents, thereby negatively influencing archaeological studies.

Some of these burrowing mammal species are highly disliked within agricultural sectors in South Africa, these include but are not limited to, Highveld gerbil (*Gerbilliscus brantsi*), black-backed jackal (*Canis mesomela*), common warthog (*Phacochoerus africanu*), and the Cape ground squirrel (*Xerus inauris*) (Foster et al., 2019). This happens because these species tend to feed on crops and livestock in the farms, thus limiting agricultural productivity. A bit more research on the sustainable management of these species on the environment would help in ensuring a better relationship and co-existence of these mammals and human beings in one space with less to no conflicts.

2.3 Potential determinants of burrow distributions

Many biotic and abiotic environmental parameters within the ecosystem influence the location of burrows of burrowing mammal species, thereby, influencing their occurrence and distribution across the landscape (Oduro & Boateng, 2009; Taylor & Skinner, 2004). These determinants include among others, soil type (Van Aarde et al., 1992a), topography, geology, slope, infrastructure, vegetation, water bodies (Li et al., 2018), and rainfall patterns (Romañach et al., 2005).

Dentzien-Dias and Figueiredo, (2015) stated that tuco-tuco (*Ctenomps sp*) prefers to inhabit sandy soils in South America while Bobak marmot (*Rodentia sciuridae*) of eastern Europe and Central Asia prefer mostly arable cropland, dark kastanozems as well as southern chernozem soil types and grassland environments. Cape porcupines of South Africa burrow where geophytes (their food source) occur and they prefer to burrow in mesic environments (Bragg, 2003). Davis and Kalisz (1992), studied the burrow system of the prairie vole (*Microtus ochrogaster*) in central Kentucky, USA. The results of this study showed that this species creates burrows on lush and dark green vegetation where the soil is not hard to excavate. In comparison, southern hairy-nosed wombat (*Lasiorhinus lotifrons*) from Australia, burrow in both hard and soft soil (Shimmin et al., 2002). Jackson (2000), examined the adaptation ability of southern African whistling rats (*Paratomys brantsii and P.littledalei*) to live in an open arid environment. This study showed that, although both rodents are endemic to arid regions, *P. littledalei* burrows are restricted to areas with good plant cover, while many *P. brantsii* are situated in open locations with very limited plant cover.

This illustrates that burrowing species in the ecosystem have different preferences in terms of where to locate their burrows, and this plays a pivotal role in their distribution and occurrence in the environment. Understanding habitat preferences of these species will not only aid conservationist to know how to manage them, but also land managers and agricultural sector to better understand their behavioural patterns. More studies focusing on the latter are particularly needed, and highly recommended for future research.

2.4 Ecology of the study species (aardvark (*Orycteropus afer*))

The aardvark is a medium-sized (approximately 50-80 kg) mammal species restricted to sub-Saharan Africa (Melton, 1976; Taylor &Skinner, 2004). They reside in a diverse range of habitats, including all varieties of savanna, open woodland, scrub, grassland, and rainforests of the Congo Basin (Taylor & Skinner, 2004). The biotic and abiotic components of the terrestrial environment play a pivotal role in the distribution of burrows and burrow locations of these species in the ecosystem. Studies suggest that they favour areas with sandy soils and that they generally tend to avoid true forests and very arid areas (Van Aarde et al., 1992; Taylor & Skinner, 2004). They may also be absent in rocky and mountainous regions because the soil is too shallow and hard to excavate or where their food source is scarce (Taylor & Skinner, 2003).

The aardvark is a nocturnal species, although during the colder winter season it forages in the afternoon. It feeds on termites and ants, with ants being favoured during dry seasons and termites in the wet season (Melton, 1976; Taylor & Skinner, 2004). Melton, (1976) mentioned that they also feed on scarab beetle larvae and have been recorded eating the fruit of wild cucumber, possibly to increase moisture intake. This species also hardly interacts with other individuals of the same species, except during the mating season, which in southern Africa occurs early in summer (Taylor & Skinner, 2003, 2004). They are adapted to dig and push back the soil with their hind feet and tail (Melton, 1976), usually excavating three types of burrows. These are (1) shallow foraging burrows for food searching, (2) large temporary shelters, and (3) more complex burrows for permanent residence (Melton, 1976; Oduro & Boateng, 2009).

Only large temporary shelters and more complex burrows were considered for sampling in the current study. The aardvark burrows are used by many animals for refuge (Melton, 1976), since these ameliorate temperatures and moisture content to the outside environment (see Whittington-Jones et al., 2011).

2.5 Cluster analysis as a tool to study burrow distributions

One of the tools that can be used to study the spatial distribution of objects is cluster analysis (Fisher et al., 2007). Cluster analysis is a name for a variety of mathematical methods/tools used to study clustering and dispersion of entities. It is used to find out a similar set of any particular phenomenon and group them into a cluster. The majority of studies on spatial clustering use Ripley's K-function statistics(De-la-Cruz et al., 2019; Filius et al., 2020; Jiang et al., 2017), to determine whether and at what scales there is clustering. For example, Fisher *et al.*, (2007) assessed the ability of Ripley's K-function analysis to determine changes in burrowing owl nest clustering. The results show that the tool is effective in detecting owl nest clustering and their changes. Similarly, Wilschut *et al.*, (2015) investigated the spatial distribution patterns of burrows of great gerbils in Kazakhstan using the same method and the study found significant clustering of occupied burrows.

Cluster analysis tools can analyse the spatial patterns of incident point data (Mitchell, 2005). They summarize spatial dependence (feature clustering or dispersion) over a range of distances (Eder, 2017; Mitchell, 2005; Santos et al., 2018) by illustrating how the spatial clustering or dispersion of feature centroids changes when neighbourhood size changes (Bailey & Gatrell, 1995). Some of these tools (e.g., multi-distance spatial cluster analysis, based on Ripley's K-Function) compute the average number of neighbouring features associated with each feature; neighbouring are those closer than the distance being evaluated (Wilschut et al., 2015). As the evaluation distance increases, each feature will typically have more neighbours (Fisher et al., 2007; Jiang et al., 2017). If the average number of neighbours for a particular evaluation distance (expected distance) is higher/larger than the average concentration of features (i.e., in the observed distance) throughout the study area, the distribution is considered clustered at the distance (Daszykowski & Walczak, 2009; Mitchell, 2005), and the opposite happens when the evaluation distance is smaller than the average concentration of features. The Ripley's K-Function is often presented with the formula below (Mitchell, 2005):

Equation 1: Formula for computing Ripley's K-Function, Where d is the distance, n is equal to the total number of features, A represents the total area of the features and k (I,j) is weight. If there is no edge correction, then the weight will be equal to one when the distance between i and j is less than d, and will equate to zero otherwise.

$$L(d) = \sqrt{\frac{A \sum_{i=1}^{n} \sum_{j=1, j\neq i}^{n} k_{i,j}}{\pi n(n-1)}}$$

On the other hand, some tools perform cluster analysis by measuring the average distance between each feature centroid and its nearest neighbours' centroids (e.g. average nearest neighbour algorithm) (Allstadt et al., 2007; De-la-Cruz et al., 2019). If the average distance measured is less than the average for a hypothetical random distribution, the distribution of the features being analysed is considered clustered (Jiang et al., 2017; Mitchell, 2005), and if the average distance is greater than a hypothetical random distribution, features are considered dispersed. The average nearest neighbour has been successfully used to study spatial patterns of burrowing owl (*Speotyto cunicularia*) nests within black-tailed prairie dog (*Cynomys ludovicianus*) in the USA (Desmond et al., 1995). The results showed that burrowing owl burrows/nests were random and dispersed in distribution. This method is represented with the formula below (Mitchell, 2005):

Equation 2: The Average Nearest Neighbour (ANN) algorithm, where D_O is the observed mean distance between each feature and its nearest neighbour and D_E is the expected mean distance for the features given in a random pattern.

$$ANN = \frac{D_O}{D_E}$$

According to Daszykowski and Walczak, (2009), density-based clustering and Hot-Spot analysis identifies significant distinctive groups/clusters in the data, based on the idea that a cluster in data space is a contiguous region of high point density, separated from other such clusters by contiguous of low point density. The data points in the separating regions of low point density are typically considered noise/outliers (Daszykowski & Walczak, 2009). This method of cluster analysis has also been successfully used in studying spatial patterns of ecological parameters and security patterns to improve the structure and functioning of the ecosystem (Allstadt et al., 2007; Altermatt & Holyoak, 2012; Lion & Baalen, 2008).

Identifying clusters of burrows in high-burrow quadrats offers insight into burrow distribution in the landscape. Clustering of burrows could indicate preference of that area to burrowing mammals than other areas.

2.6 Soil texture analyses

Soil texture refers to the proportion of sand, silt, and clay-sized particles that makes up the mineral fraction of the soil (Martín et al., 2018). A soil texture triangle, such as the one below (Figure 1), depicts soil texture as determined by the proportion of sand, silt, and clay (Martín et al., 2018).

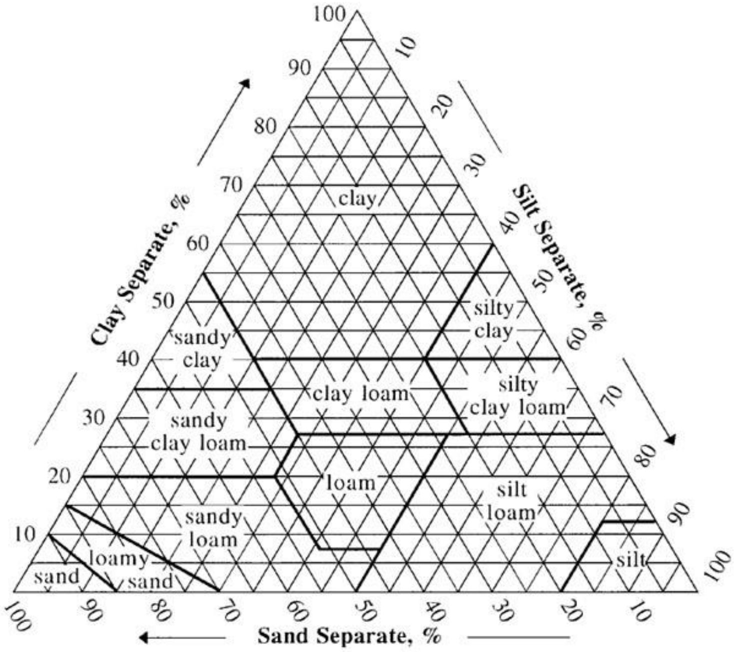

Figure 1: Soil textural as determined by the proportion of Sand, Silt and Clay (adapted from: Martín et al., 2018).

The texture of soil samples is typically shown in a cumulative frequency curve, which shows phi (Φ) size values corresponding with percentile intervals required to calculate indices. Figure 2below is an example of a cumulative frequency distribution of the phi scale vs. cumulative weighted percentage.

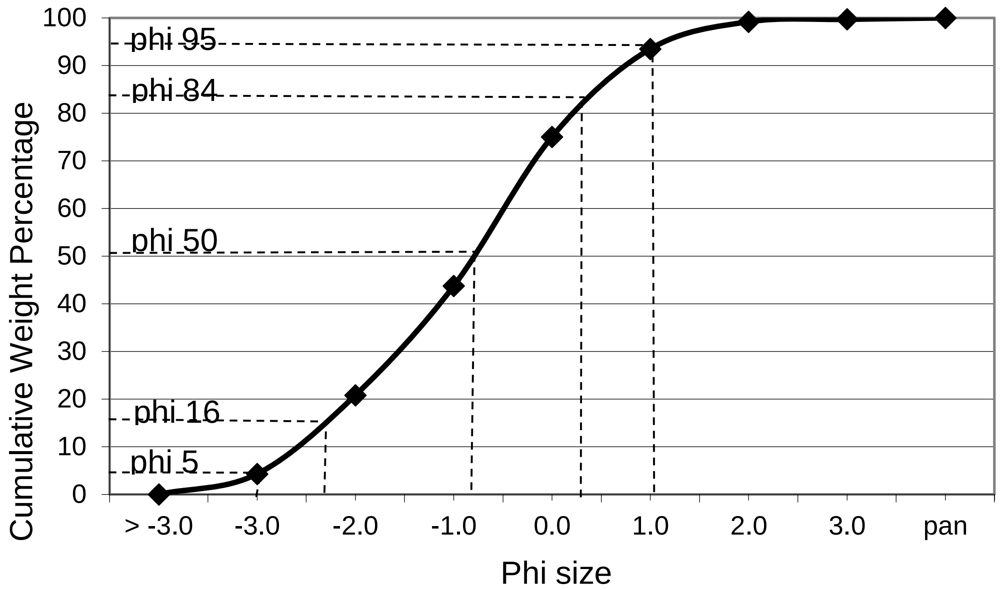

Figure 2: Example of a cumulative frequency distribution of soil particle sizes by weight. This specific example is for identifying phi size values corresponding with percentile intervals required to calculate indices (adapted from: Yoshida et al., 2014).

Many indices can be calculated to compare soil texture between soil samples. Often-used indices are the mean, sorting (standard deviation), skewness, and kurtosis (Folk & Ward, 1957). The calculations of each of these indices are typically constructed using the formulas given in Table 1 (Folk & Ward, 1957)

Table 1: Formulas used to calculate the grain size indices (Folk and Ward, 1957).Φ16 refers to the phi size of the sample at which 16% of the particles are larger and is normally read off a cumulative frequency distribution, such as the one in Figure 2.

Index	Formula
Phi (Φ) mean	$M_2 = \frac{\phi16+\phi50+\phi84}{3}$
Phi (Φ) sorting	$\sigma_\phi = \frac{\phi84-\phi16}{4} + \frac{\phi95-\phi5}{6.6}$
Phi (Φ) skewness	$Sk_1 = \frac{\phi16+\phi84+2\phi50}{2(\phi84-\phi16)} + \frac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$
Phi (Φ) kurtosis	$K_G = \frac{\phi95-\phi5}{2.44(\phi75-\phi25)}$

The mean is a measure of the average grain size of the sample. Soil grain particle sizes are often defined according to the particle diameter (Whiting &Wilson ., 2011). **Table 2** below shows various soil names and their related particle diameter.

Table 2: Soil names and their related particle diameter.

Names	Particle diameter (mm)	Particle diameter (µm)
Very coarse sand	2.0 to 1.0	2000 to 1000
Coarse sand	1.0 to 0.5	1000 to 500
Medium sand	0.5 to 0.25	500 to 250
Fine sand	0.25 to 0.10	250 to 100
Very fine sand	0.10 to 0.05	100 to 50
Silt	0.05 to 0.002	50 to 2
Clay	0.002 to below	2 to below

Sorting measures the variation of grain particle sizes of samples. According to Folk and Ward (1957), particles with lower sorting values are highly sorted, while particles with high sorting values are poorly sorted (see Table 3).

Table 3: Descriptive terms and ranges for sorting values (adapted from: Maher et al., 1991).

Description	Sorting values
Very well sorted	< 0.35
Well sorted	0.35 – 0.50
Moderately well sorted	0.50 – 0.70
Moderately sorted	0.70 – 1.00
Poorly sorted	1.00 – 2.00
Very poorly sorted	2.00 – 4.00
Extremely poorly sorted	> 4.00

Skewness measures the degree to which a histogram of the particle sizes approaches symmetry. Samples may have the same average grain sizes and sorting but may be quite different in the degree of symmetry. Symmetrical histograms have a skewness equal to zero. However finer particle sizes are said to be positively skewed, while those with a larger proportion of coarse particles are negatively skewed (see Table 4) (Folk & Ward, 1957).

Table 4: Descriptive terms and ranges for skewness values (adapted from: Maher et al., 1991).

Description	Skewness values
Highly negatively skewed	< -1.62
Negatively skewed	-1.0 – -1.62
Moderately negatively skewed	-0.3 – -1.0
Finely negatively skewed	-0.3 – -0.1
Symmetrical	-0.1 – 0.1
Finely positively skewed	0.1 – 0.3
Positively skewed	0.3 –1.0
Very positively skewed	1.0 – 1.62
Highly positively skewed	> 1.62

Kurtosis measures the peakedness of a curve (Table 5), where the phi values represent the same percentages as those for sorting. If the curve of the sample is better sorted in the central part than in the tails, the curve is said to be excessively peaked (leptokurtic), and if the sample curve is better sorted in the tails than in the central portion, the curve is flat peaked (platykurtic) (Folk & Ward, 1957).

Table 5: Descriptive terms and ranges for Kurtosis values (adapted from: Maher et al., 1991).

Description	Kurtosis values
Very platykurtic	< 0.67
Platykurtic	0.67-0.90
Mesokurtic	0.90-1.11
Leptokurtic	1.11-1.50
Very leptokurtic	1.50-3.00
Extremely leptokurtic	> 3.00

2.7 Conceptual framework of research

As shown with the arrows on the diagram (Figure 3 below), two-way interactions were studied looking at abiotic landscape features and aardvark burrowing. Thus, the abiotic features determining burrow clustering, and determinants of burrow location and numbers were identified, and conversely, implications of aardvark burrowing activity on soil texture were analysed. The interaction between aardvark and biotic features was studied by looking at how vegetation influences the distribution of burrow systems. Although aardvark also influences the biotic components of the environment, this does not form part of this study.

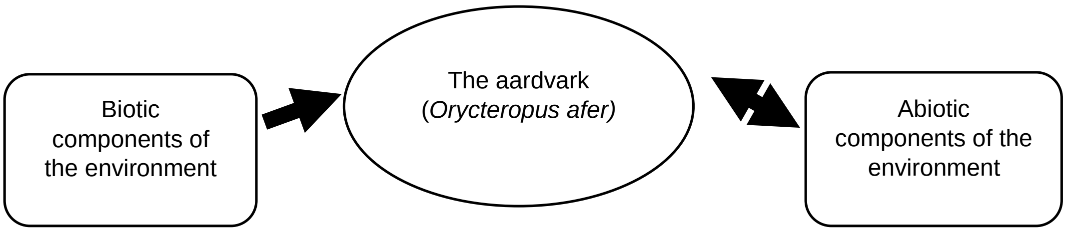

Figure 3: On one-way (aardvark and biotic) and two-way (aardvark and abiotic) interactions that were studied, the arrows represent the direction of influence that was investigated. Although aardvark also influences the biotic components of the environment, such interactions were not studied in this research and the arrow has thus not been added.

Chapter 3: Methods

3.1 Study area

Rietvlei Nature Reserve (RNR) is situated in the southern portion of the City of Tshwane Metropolitan Municipality (CTMM) in the Gauteng Province of South Africa (Figure 4). The reserve is approximately 3800 ha in size (Marais, 2004), and the geology is characterized by dolomite (sedimentary rock made from dolomite mineral) to the east, andesitic lava (derived from basalt and rhyolite) in the central part, and shale (made from compaction process of clay and silt) in the west, with the soil type a mixture of avalon (very deep, well-drained soil from shale and sandstone), rensburg (sticky and swelling clay with dull colours), hutton (very deep, poorly drained soil formed from alluvium), mispah (very shallow, loamy sand textured) and dundee (very deep, somewhat poorly drained soil formed in loamy alluvium) (Republic of South Africa, 1973). The reserve is characterized as a grassland biome (Mucina & Rutherford, 2006), with a relatively flat topographical landscape, interspersed with water bodies (dams and streams), buildings, and roads. A distinction is made in the reserve between grassland and low-lying grassland, with grassland being, on average, richer and shorter grass assemblages than low-lying grassland. The area receives summer rainfall, with an annual mean of approximately 720 mm (Marais, 2004), with the mean average temperatures ranging from a minimum of 4 °C in winter to a maximum of 27 °C in summer (Marais, 2004). Approximately 80 mammal species are known to occur in the reserve, with aardvark (*Orycteropus afer*) the largest of the burrowing mammals (Marais, 2004). Visitors use the reserve for leisure activities such as braais (barbeque), holidaying, and viewing wildlife that occur in the reserve.

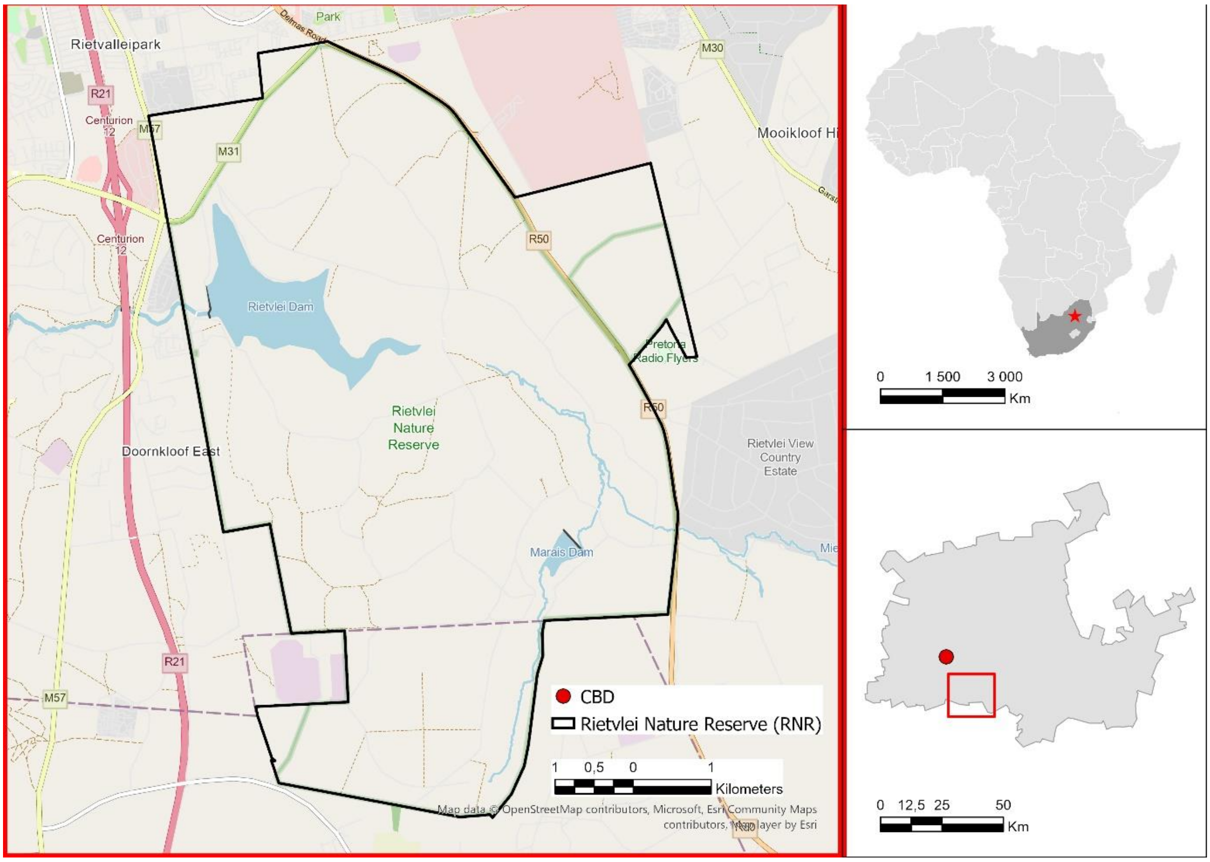

Figure 4: Rietvlei Nature Reserve and its location in the City of Tshwane Metropolitan Municipality (CTMM) and South Africa.

3.2 Field data collection

3.2.1 Previous burrow survey

This study used secondary data on burrow location collected in April 2015 by a team of University of Pretoria researchers (see Haussmann et al., 2018). A stratified random sampling approach was used, whereby a team of eight to 14 people was deployed to systematically search for burrows in randomly chosen one ha quadrats within each of the reserve's management blocks (the strata). This approach was used to search for burrows within approximately 1% (with a total of 45 one ha quadrats) of the reserve (Figure 5).

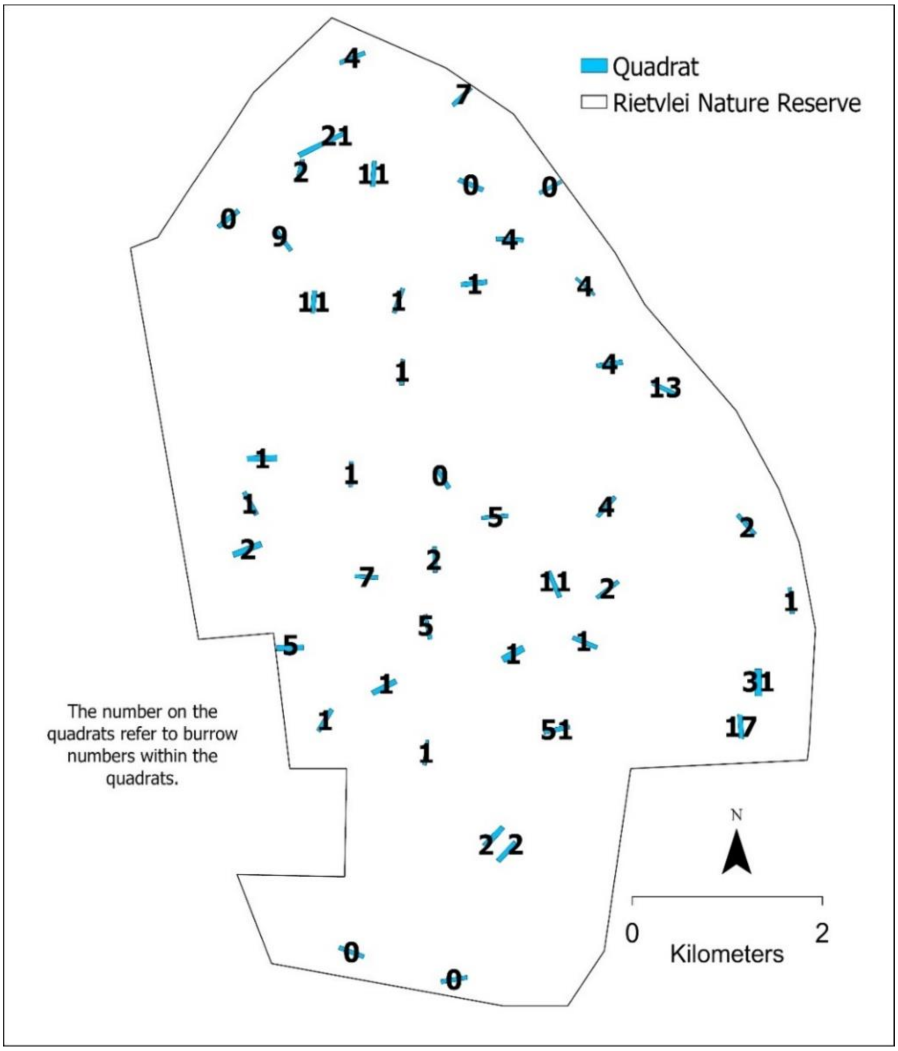

Figure 5: 45 one-ha quadrats used in 2015 to sample for aardvark burrow locations. The number on the quadrats refers to burrow numbers within the quadrat.

To avoid recording feeding scrapes and any other forms of depressions as burrows, only tunnel-like structures with roof on top were recorded. The excavations that were large enough to shelter an aardvark were then considered as its burrows. Using this method, GPS coordinates of 250 burrows were recorded within the reserve. Quadrats were located only on grassland vegetation, due to the inaccessibility of the reed environment, which then resulted in no burrow recording on the dundee (soil type), since it forms the substrate of reeds at Rietvlei Nature Reserve.

Out of the 250 burrows, 60 were randomly selected in 2015 for the ecological sampling of (mostly) vegetation characteristics surrounding the burrows. Also, soil physical properties (moisture, compaction, and temperature) surrounding burrows were determined to a limited extent in 2015, but soil texture was not (see Haussmann et al., 2018).

3.2.2 Collection of soil texture data (Appendix B)

The major limitation of this study was not to find the original 60 burrows that were sampled in 2015 to take samples for soil texture comparisons. This was due to burrow deterioration over time, these burrows could not be located in 2020 and 2021. Thus, burrows were then selected and sampled opportunistically, wherever they were encountered in the reserve in 2020 and 2021 for soil texture analyses. A total of 50 soil samples (500-900 grams, with a maximum depth of 3 cm (Olson & Al-Kaisi, 2015)) were taken at burrow mounds (the excavated heap of soil deposited during digging), and another 50 from controls, 2 m away from the burrow (in the direction perpendicular to mounds) (see Haussmann et al., 2018).

3.3 Soil texture laboratory analyses and data processing

For soil texture analysis, the collected samples were gently disaggregated using a mortar and pestle in the laboratory, then oven-dried for 24 hours at 60 °C (Folk & Ward, 1957). The samples were weighed before being shaken through a mechanical sieve-stack (8000 µm, 4000 µm, 2000 µm, 1000 µm, 500 µm, 250 µm, 125 µm, and 63 µm). The shaking on a sieve stack took 15 minutes for each sample and mass sediments retained were weighed and recorded after being sieved (Folk & Ward, 1957). The calculated percentage of dry sediment mass (per sieve class) was used to calculate the cumulative percentages of the samples. For each soil sample, a cumulative frequency distribution (in phi values) was plotted and percentile intervals (5%, 16%, 25%, 50%, 75%, 84%, and 95%) required to calculate Folk and Ward indices were identified (Folk & Ward, 1957). Lastly, mean grain size, sorting, skewness, and kurtosis were calculated per sample, following the grain size indices of Folk & Ward (1957).

3.4 GIS data sets and analyses

3.4.1 Data collection, sources, and preparation

Geospatial analyses were conducted using ArcGIS Pro 2.6. This product integrates with the Living Atlas from ArcGIS Online that provides high-resolution satellite imagery, making it easier to digitize at a large scale (Kneissl et al., 2011). The study comprised the use of both primary and secondary data. All data were stored in Hartebeesthoek 1994 LO27 as the chosen Coordinate Reference System (CRS). This CRS is suitable since Hartebeestoek 1994 is the local geodetic datum for South Africa and Rietvlei Nature Reserve is located within the 2-degree band of 27 E (27 degrees Latitude; east of GMT). Table 6 below provides an overview of the geospatial layers used for the execution of this project. The chosen geospatial layers were based on environmental determinants shown to be important for burrow location, as identified from the literature (refer to 2.3 Potential determinants of burrow pg. 15). Variables used were burrowed locations, soil type, rockiness, geology, vegetation, proximity to infrastructure (road network), and proximity to water bodies. Parameters such as topography, slope and rainfall were not included in this analysis, because the spatial scale of the RNR is very small, therefore it is unlikely that they are different across the landscape. Initial datasets were created predominantly through digitizing based on secondary datasets (maps of geology, hydrology, vegetation, soil, rockiness, and roads) obtained from RNR. Maps of the reserve were scanned and georeferenced in ArcGIS Pro 2.6. Once georeferenced, the various information layers were digitized to polygons (vector data) for geology, vegetation, water bodies, rockiness, and soil; or polylines (vector data) for hydrological lines (water bodies), and roads. To ensure that the digitizing process resulted in few errors, a consistent CRS was used (see discussion above), and features were mapped at a constant scale (1:3 500).

Table 6: Required data layers, their sources, and description.

Geospatial layer	Source	Description
Burrow locations	Haussmann et al. (2018)	The aardvark burrow locations collected in 2015 by University of Pretoria researchers.
Geology	CTMM (Rietvlei Nature Reserve)	Geology was categorized into 8 categories, namely tillite, sandstone, shale, quartzite, dolomite, diabase (dolerite), andesitic lava, and chert.
Soil type	CTMM (Rietvlei Nature Reserve)	The soil type in the reserve was categorized into five categories, namely rensburg, mispah, dundee, avalon, and hutton.

Geospatial layer	Source	Description
Rockiness	CTMM (Rietvlei Nature Reserve)	Two rockiness categories: <40% rock cover and >40% rock cover, retrieved from the soil map.
Vegetation	CTMM (Rietvlei Nature Reserve)	The vegetation types in the reserve were categorized into three categories namely, low-lying grassland, grassland, and reeds (*Arundinella nepalensis*).
Road network (infrastructure)	CTMM (Rietvlei Nature Reserve)	The road dataset was used to determine the distance of burrows to roads.
Water lines (water bodies)	CTMM (Rietvlei Nature Reserve)	Water lines (hydrology network) were used to determine the distance of burrows to these.

3.4.2 Data storage and management

All layers were stored in a centralized and accessible database. Because the project makes use of ArcGIS Pro, this database consists of a file geodatabase (*.gdb). Minimum metadata adhering to Esri standards was captured. This type of metadata management style conforms to ISO 19139 *Geographical information-metadata-XML* schema implementation (see Appendix A).

3.4.3 Location identification and proximity calculations

The *Identity* tool was used to determine, per quadrat, the type of vegetation, soil, rockiness cover, and geology on which quadrats occurred. Euclidean distance calculations were used to calculate distances to water bodies/lines, and roads closest to burrows, and these distances were averaged per quadrat.

3.4.4 Cluster analysis

In the conduction of this analysis, four cluster analysis techniques in ArcGIS Pro were used. These techniques are 1) *Average Nearest Neighbour,* 2) *Density-Based Clustering,* 3) *Multi-distance Spatial Cluster Analysis (Ripley's K-Function), and 4) Optimized Hot-Spot analysis*. *Average Nearest Neighbour* used Euclidean as the distance method. *Density-Based Clustering* was run using the observed mean distance from *Average Nearest Neighbour* and defined distance as a clustering method. *Multi-distance Spatial Cluster Analysis* was executed using 5 (average distance between burrows) as a distance band, working under the narrative of expected vs. observed distance .i.e., cluster of points results when expected distance is greater than observed distance, while the dispersion of points results from expected distance being less than observed distance. Furthermore, *Optimized Hot-Spot analysis* is run to statistically identify the significant clusters of cold and hot spots. The *optimized Hot-Spot analysis* was based on only three quadrats with higher number of burrows. Upon running all these tools, an evaluation procedure was conducted for validation of the outcomes. Figure 6 below depicts the procedure used in the conduction of this analysis.

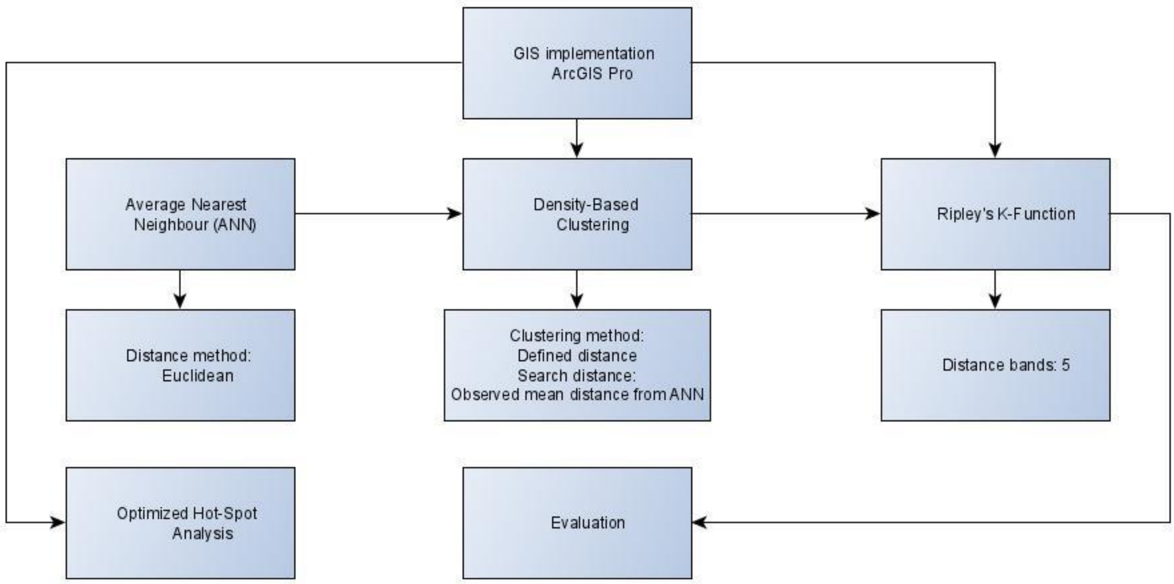

Figure 6: Cluster analysis methodology process.

3.5 Statistical analyses in R

3.5.1. Assessing potential determinants of burrow presence/absence within quadrats

The Chi-Square test and Fisher exact test are used to assess the association between two categorical variables that are independent and not related (Kim, 2017). The chi-squared test applies an approximation assuming the sample is large, while the Fisher exact test runs an exact procedure especially for small-sized samples (i.e., expected numbers less than 5) (Kim, 2017). In this study, Fisher exact tests were used to determine whether associations exist between aardvark burrow presence/absence in a quadrat and the following categorical variables 1) vegetation type, 2) soil types, 3) soil rockiness, and 4) geology. Because most quadrats contained burrows, expected absences were mostly less than five in 20 % of the table and Fisher exact tests, as opposed to chi-squared tests, were therefore used. The analysis of the test was implemented using the MASS package in R statistical software (R Team Core, 2016).

3.5.2 Assessing potential determinants of burrow numbers in quadrats

To determine whether vegetation, soil types, rockiness, geology, and distance to roads and water bodies have any significant contribution towards aardvark burrow numbers, Generalized Linear Models (GLZ) were performed. GLZs are mathematical extensions of linear models, they are more flexible and better suited for analysing ecological relationships (Bolker, 2008). This is because they are integrated with parameters that can analyse datasets from Poisson, normal, binomial, and negative binomial probability distributions (Bolker, 2008). To understand the type of data and regression model suited to execute these analysis, tests such as over-dispersion (Dormann, 2016) and zero-inflation (Desmarais & Harden, 2013) are run. Over-dispersion describes the observation that variation is higher than it would be expected (Perumean-Chaney et al., 2013). An over-dispersed dataset is better suited for negative binomial regression (Perumean-Chaney et al., 2013). In contrast, data that are not over-dispersed, are oftentimes well suited for Poisson regression (Bolker, 2008). Over-dispersion is often mentioned together with zero-inflation. Zero-inflation accounts for data with excess zeros. Should the data have excess zeros, a zero-inflated regression is recommended to run the analysis (Figure 7) (Bolker, 2008).

Using the performance package in R software, over-dispersion and zero-inflation were tested for data of this study through the use of check over-dispersion and check zero inflation functions respectively (Bolker, 2008). The results showed that the dataset for burrow numbers was over-dispersed, but not zero-inflated. Due to this, negative binomial regression (R package (MASS)) was adopted to analyse data. Figure 7 below depicts the procedure taken in choosing a suitable Generalized Linear Model (GLZ) to run for the burrow number dataset. Ultimately, GLMs were used in conjunction with Fisher exact tests. This is because the GLMs tested for the contributions of potential determinants towards aardvark burrow density, whereas the Fisher exact tests tested for the association between burrow presence/absence of burrows and environmental variables.

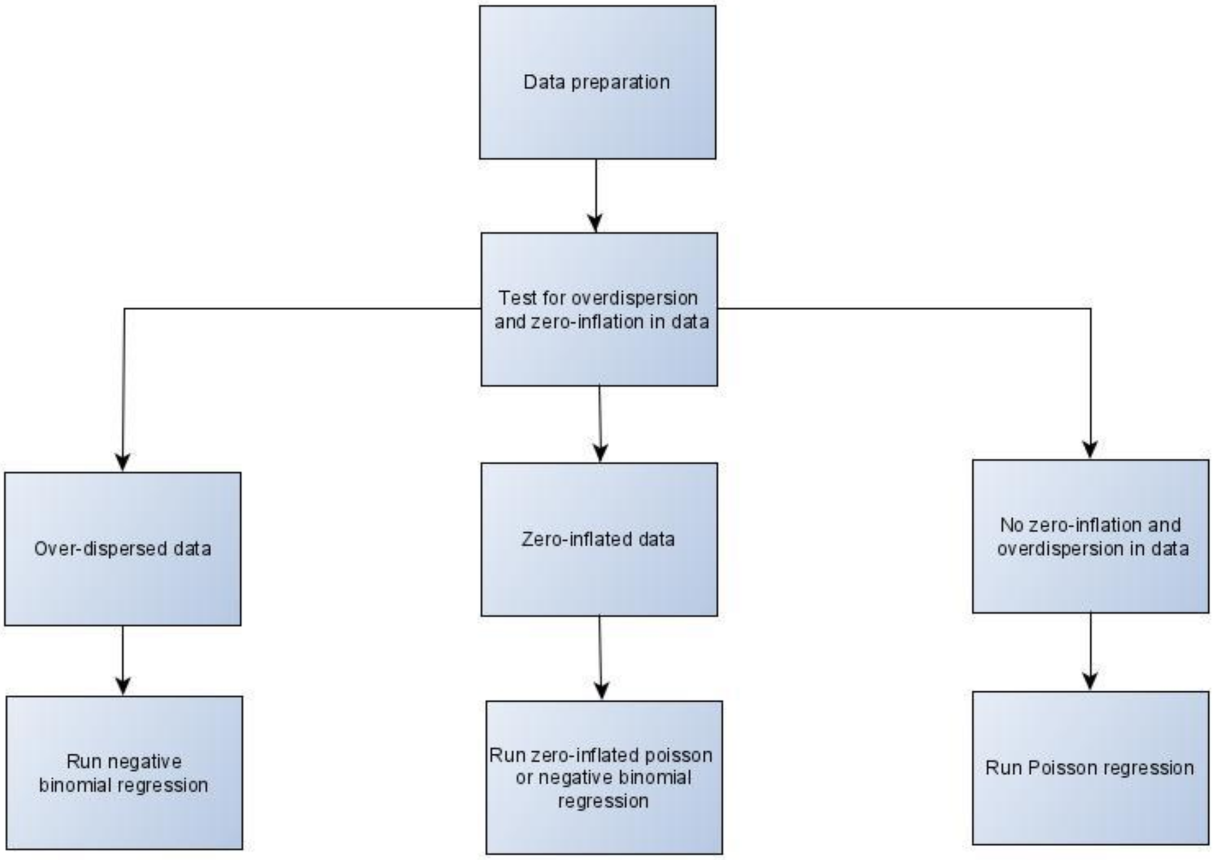

Figure 7: The procedure to conduct a Generalized Linear Model (GLZ) and Generalised Linear Model (GLM).

3.5.3 Grain size statistics analyses

Residuals for grain size indices were checked for normality using the Shapiro-test (library (ggpubr)) and Q-Q plot in R studio software. Following this, paired t-tests were used to compare mean, kurtosis and skewness of grain sizes between burrow mounds and controls. A Wilcoxon signed-rank test was used to compare sorting data, which were not normally distributed. Soil texture statistical analyses were all done using R software (R Team Core, 2016).

3.5.4 Ethical clearance

Ethical clearance for this research project was obtained from the ethics committee of the Faculty of Natural and Agricultural Sciences at the University of Pretoria before commencing the research process. Permit to collect data from 2020 to 2021 was requested and granted by the Rietvlei Nature Reserve management. Only soil samples from burrows and controls were collected from this study site, no interactions took place between a researcher and aardvark species, therefore, no data was collected from this species as per stated in the ethical clearance application

Chapter 4: Results

4.1 Exploring the spatial distribution of aardvark burrows

Burrows in Rietvlei Nature Reserve were found on all searched vegetation types, soil types, rockiness levels, and geologies (Figure 8, **Figure 9** and **Figure 10**). Burrow distance to water bodies range from 158 to 1 897 meters, with the mean distance being 823 meters. Burrow distance to infrastructure (roads) ranged from 26 to 680 meters with the mean distance being 171 meters. Burrow numbers per one-ha quadrat ranged from zero to 51. The quadrats with blue boundaries on the three maps below are of high burrow densities and were used for cluster analyses.

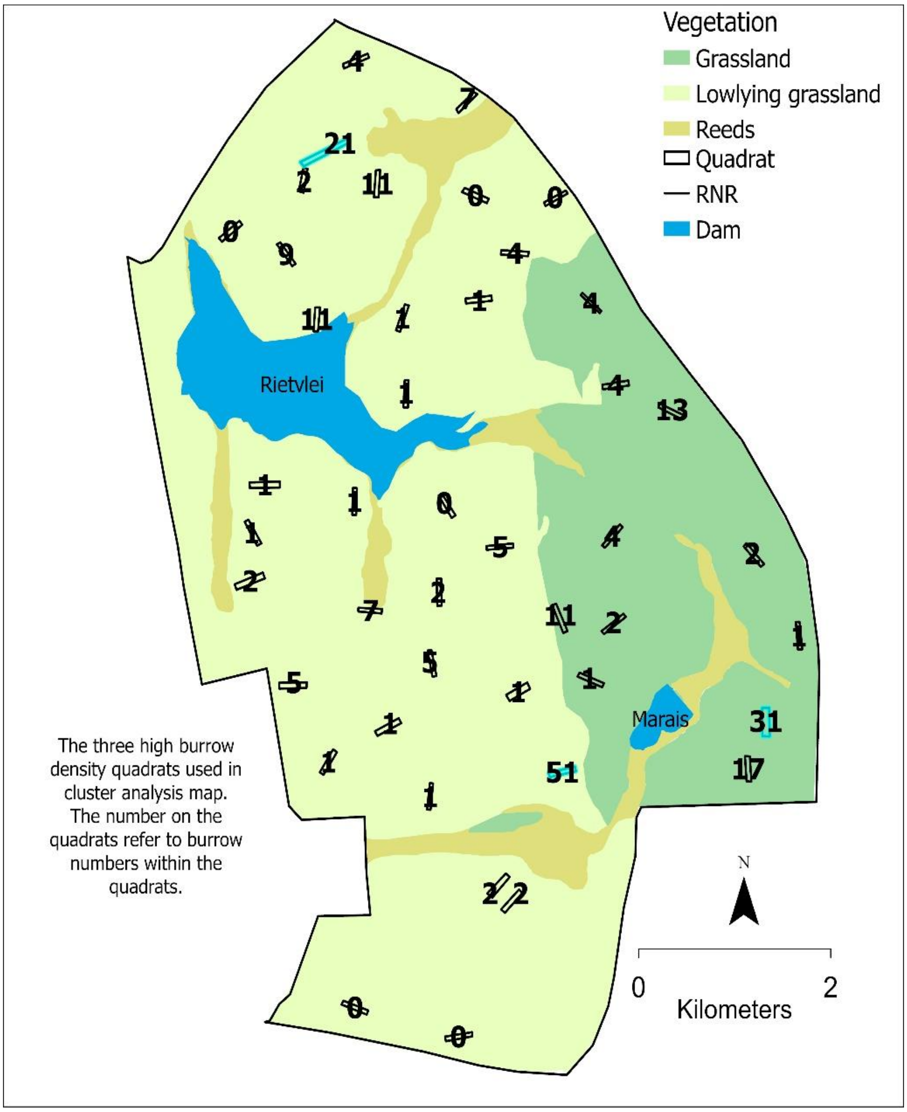

Figure 8: Vegetation features map

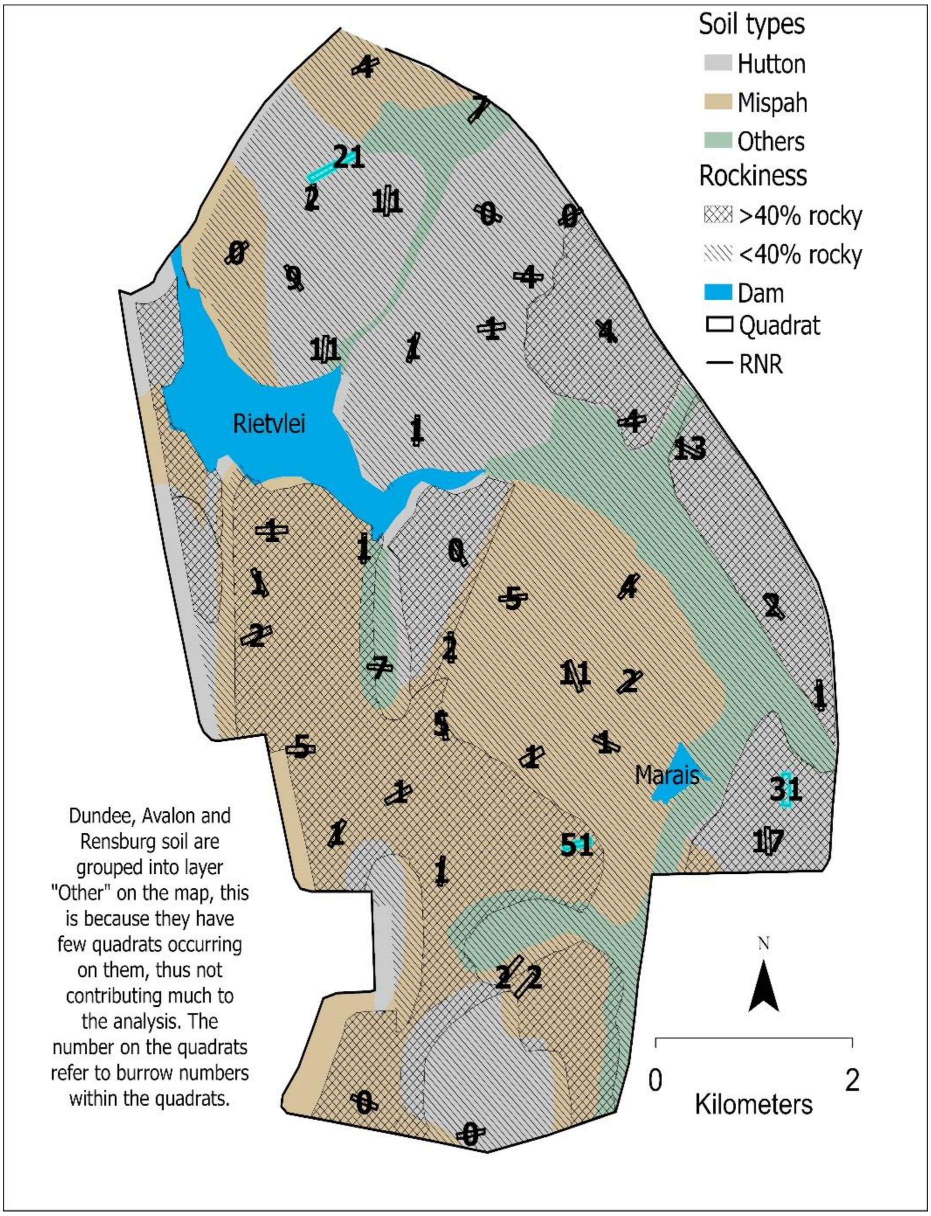

Figure 9: Soil features and rockiness map.

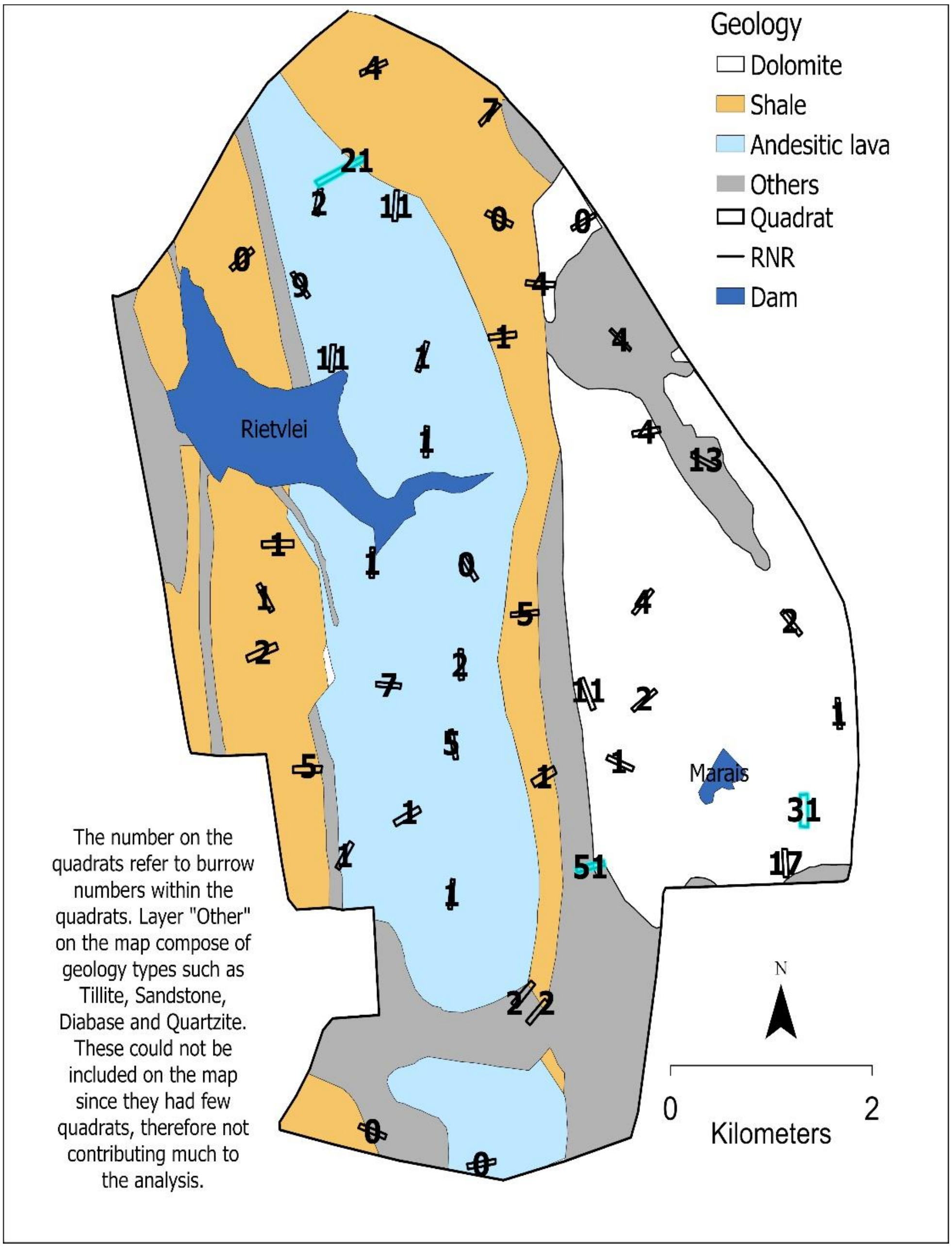

Figure 10: Geology feature map

4.1.1 Potential determinants of aardvark burrow presence/absence

The Fisher exact test results show that there is no association (P>0.05) between burrow presence/absence in quadrats and the potential environmental determinates (see Table 6).

Table 7: Fisher exact test results of an association between burrow presence/absence and vegetation, soil types, rockiness, geology, distance to roads, and distance to water bodies.

Environmental Parameter		Burrow Presence		p-value
		Yes	No	
Vegetation	Low-lying grassland	27	7	0.08
	Grassland	11	0	
Soil type	Hutton	16	4	0.06
	Mispah	20	3	
Rockiness	<40% rock	15	3	1.00
	>40% rock	23	4	
Geology	Shale	10	2	
	Dolomite	9	1	0.84
	Andesitic lava	14	3	

4.1.3 Exploring spatial clustering of burrows in high burrow quadrats

Spatial clustering was studied in the three quadrats with the highest numbers of burrows recorded (Quadrats 2 (green), 3 (red) and 28 (yellow), see Table 8 and **Figure 11**). Overall cluster analysis was conducted using 5 m as an average expected distance. Using the *Average Nearest Neighbour Analysis* for Quadrat 2, no spatial pattern was observed (burrows were randomly distributed), while in Quadrat 3 and 28 significant dispersion was apparent. On the other hand, Ripley's K function (*Multi-distance spatial clustering*) shows that for quadrat 2 clustering occurred at distances up to 28 m between burrows, while dispersion occurred at distances from 43 m between burrows. Ripley's K function further show that the overall pattern for Quadrats 3 and 28 was dispersion, with observed mean distances to neighbours being 10.7 and 13.2 m respectively (Table 8 and Table 9). At distances exceeding 21 m, burrows followed a dispersed pattern for Quadrat 3; for Quadrat 28 this distance was 40 m. Neither of these quadrats displayed clustering of burrows (Table 8 and Table 9). *Optimized Hot-*

Spot analysis on the type of burrow (complex burrows, simple burrows) further shows that no significant (P<0.05) hot or cold spots were present in any of the quadrats.

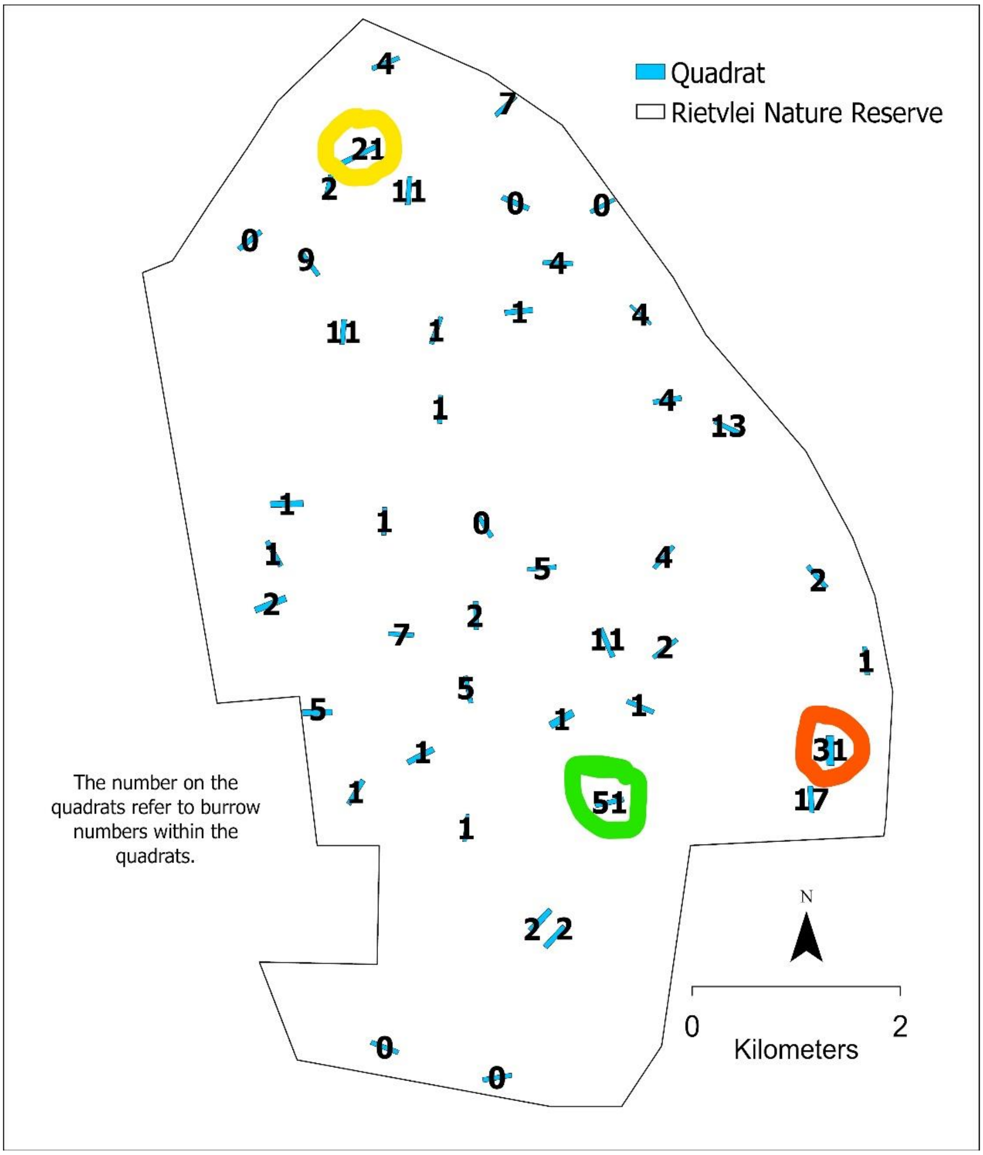

Figure 11: 45 one-ha quadrats used in 2015 to sample for aardvark burrow locations. The number on the quadrats refers to burrow numbers within the quadrat. The three green (Q2), yellow (Q28) and red (Q3) circles on the map highlights the higher burrow density quadrats used for cluster analysis.

Table 8: Clustering analyses for Quadrat 2, 3, and 28.

Quadrat	Number of burrows	Average Nearest Neighbour (NN)	Observed Mean Distance (m)	Multi-distance Spatial Clustering
2	51	1.0; random, P = 0.72	7.1	Significant clustering up to 28 m, most pronounced clustering at 7 m; significant dispersion from 43 m, most pronounced dispersion at 213 m
3	31	1.2; significant dispersion, P= 0.04	10.7	No clustering; significant dispersion from 21 m, most pronounced dispersion at 321 m
28	21	1.5; significant dispersion, P ~ 0.0	13.2	No clustering; significant dispersion from 40 m, most pronounced dispersion at 396 m

Table 9: Multi-distance Spatial Cluster Analysis for Q2, Q3, and Q28. Only significant results are shown. The most pronounced clustering for Q2 occurs at 21.3 m; the pronounced dispersion at 213 m. For Q3 and Q28 the most pronounced dispersion is evident for 321m and 396 m, respectively.

Distance in Meters (Expected)	Distance Band	Pattern
	Q2	
0-28.4	Expected < observed	Clustered
43-85	expected > observed	Dispersed
121-156	expected > observed	Dispersed
191-213	expected > observed	Dispersed
	Q3	
21-321	expected > observed	Dispersed
	Q28	
40-396	expected > observed	Dispersed

4.1.2 Potential determinants of burrow density

Only 21% (determined by performance function, Dsquared) of the variation in burrow density was explained by the predictor variables. Furthermore, none of the potential determinants were significant predictors of aardvark burrow density (Table 10) and the best model included none of the predictor variables. The GLM used to run this analysis reads as follows, "Model <- glm.nb ('number of burrows'~.-transect, data = dataset)".

Table 10: Results from Generalized Linear Model on the effects of potential determinants towards aardvark burrow numbers.

Predictor variable	Chi^2	df	p-value
Vegetation	0.049	1	0.82
Soil type	4.933	3	0.18
Rockiness	0.008	1	0.93
Geology	1.399	2	0.50
Distance to roads	1.229	1	0.27
Distance to waterlines	0.141	1	0.71

4.2 Soil particle size between burrows and controls

The mean phi particle size on the burrows and controls ranged from silt to very coarse sand. Sorting values from burrow mounds ranged from poorly sorted to very poorly sorted, while those of controls ranged from moderately sorted to very poorly sorted. Kurtosis ranged from very platykurtic to very leptokurtic on mounds, whereas controls ranged from very platykurtic to leptokurtic. Burrow mounds skewness ranged from moderately negatively skewed to highly positively skewed, while on controls the skewness ranged between moderately negatively skewed and very positively skewed.

These results suggest that the mean, kurtosis, and skewness of the soil samples from burrow and controls differ significantly ($p<0.05$), with the mean, kurtosis, and skewness of the burrow being smaller than that of the control (Table 11 and Figure 12). On the other hand, sorting did not differ significantly between control and mounds ($p>0.05$) (Table 11 and Figure 12).

Table 11: Paired t-test results comparing four particle size indices between burrow mounds and 2 meters nearby control.

Indices	t	v	P-value
Mean	3.92		0.00
Sorting		536.5	0.45

Indices	t	v	P-value
Kurtosis	1.64		0.01
Skewness	3.73		0.00

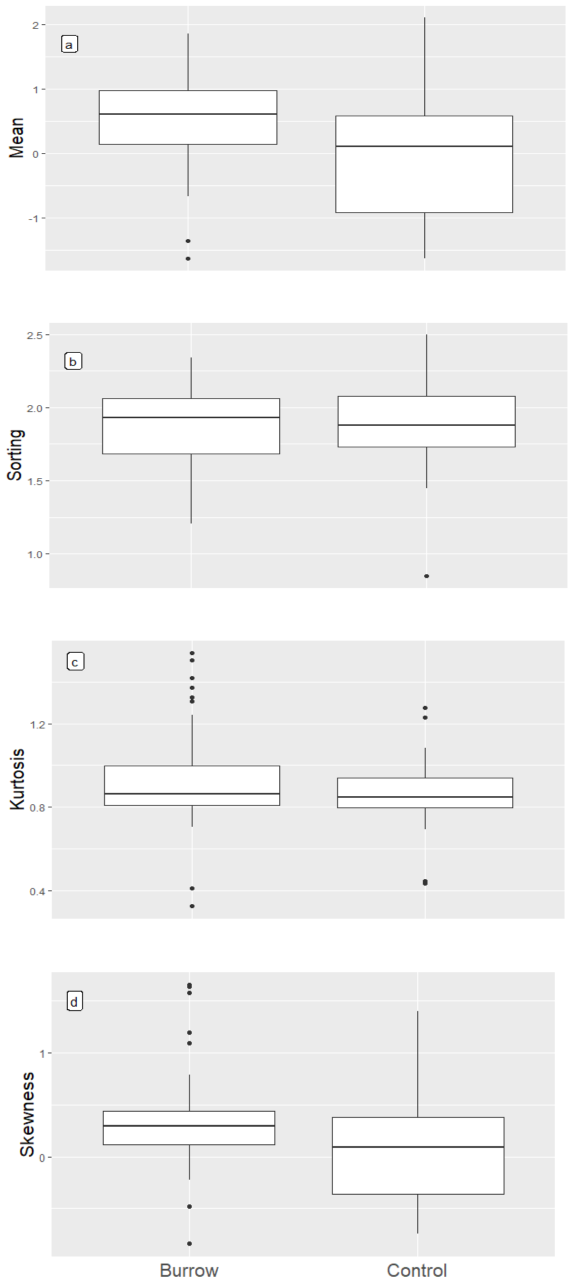

Figure 12: Comparison of the four-particle size indices between burrows and controls: a.) mean, b.) sorting, c.) kurtosis, d.) skewness. Horizontal lines represent median (central line through boxplot), interquartile range (box plot edges) and vertical lines represent the range. Individual points represent outliers.

Chapter 5: Discussion

5.1 Potential determinants of aardvark burrow densities and presence/absence in quadrats

Previous studies have identified environmental variables that influence the burrowing trends of species (Oduro & Boateng, 2009; Romañach et al., 2005; Taylor & Skinner, 2004; Van Aarde et al., 1992a), thereby impacting their occurrence and distribution in the landscape. For instance, aardvark tends to avoid rocky environments when burrowing, because of the difficulty to excavate (Taylor & Skinner, 2003). Aardvark are also documented to be absent in mountainous regions, presumably due to the high rock content (Van Aarde et al., 1992). The current study indicates that at Rietvlei Nature Reserve, aardvark burrows occur on both rocky (>40% rocky content) and less rocky (<40% rocky content) soil types. This could be due to the reserve not being mountainous, therefore not rocky enough to limit aardvark burrowing. This study further suggests that, although aardvark have previously been shown to have preferences in terms of where to place their burrows, soil types, geology and rockiness levels in this reserve are not significant predictors of their burrow densities.

At the broad, southern African spatial scale, aardvark occurs on most vegetation types, but are absent in true forests (Skinner & Smithers, 1990). This is because they are nocturnal species (Taylor & Skinner, 2003), mostly active at night, and they, therefore, prefer an open environment with higher visibility to minimise being prone to predators.. At the smaller spatial scale of Rietvlei Nature Reserve, the current study found no difference in burrow presence/absence or densities between the two types of grassland vegetation (grassland and low-lying grassland). This is perhaps not surprising, as both are relatively open vegetation types, that do not limit visibility, providing suitable habitat for the aardvark (Taylor & Skinner, 2004).

Although aardvark may be absent in very arid environments (Van Aarde et al., 1992; Taylor & Skinner, 2004), perhaps, because dry environments are generally hard to dig, they also tend to avoid digging in areas with high groundwater levels (Knöthig, 2005). In terms of the distance of aardvark burrows to hydrology lines (water bodies), a positive relationship, in which high burrow density quadrats would be further away from water lines, was, therefore, expected. However, the 2015 sampling effort was limited to the two grassland vegetation types and was not conducted on the reed vegetation, due to its inaccessibility. Therefore, the edge of the quadrats from water lines was already a larger distance away, i.e., all quadrats were over 100 meters from water lines. This could be the reason that distance to water lines is not a significant predictor of aardvark burrow densities.

The results of this study further showed that distance to roads also did not affect aardvark burrowing, with quadrats closer to roads having similar aardvark densities to quadrats further from roads. Because of the disturbance that roads may have on many animals (Hill et al., 2021; Shannon et al., 2014), the expectation was to find fewer aardvark burrows in quadrats closer to roads, compared to those located further away. Contrary to this expectation, however, the aardvark appears comfortable with constructing burrows close to roads, with burrows observed as close as a few meters from the road's edge (see Figure 13). This suggests a certain extent of habituation of aardvark to human infrastructure at Rietvlei Nature Reserve.

It is evident from the results of this study that the investigated environmental parameters do not influence the overall aardvark burrow distribution at the study site. While, parameters such grass height and cover were not investigated, it is possible that they influence burrow distribution of this species (Davidson et al., 2021; Hoogland, 1995). Burrowing mammals such as aardvark would always want to construct their burrows in a landscape not infested by predators/open enough (short grasses) to detect them from distance (Taylor & Skinner, 2003). It is therefore recommended that this assumption be investigated for future research. The current study did not look into these because it was restricted by the sampling that happened in 2015, where the relationship between aardvark burrowing and vegetation was investigated to certain extent.

Figure 13: Aardvark burrows found closer to the road.

5.2 Spatial clustering of burrows in the three high-burrow quadrats

Burrowing mammals' excavations do not exist forever in the landscape – they tend to deteriorate with time (Goodman et al., 2018; Holmes et al., 2016). Porcupine diggings in the Northern Cape, South Africa, for example, have a lifespan of between approximately one to three years (Bragg et al., 2005). Due to the dynamic nature of burrowing species, as old burrows fill up, new burrows are created in new locations. A similar trend was observed in this study area, whereby the 250 aardvark burrows recorded in 2015 had deteriorated to such an extent, that they could not be located again in 2020. An example of an abandoned burrow, as observed in 2021, can be seen in Figure 14.

Figure 14: Deteriorated and over-grown burrow at Rietvlei Nature Reserve.

From a burrow perspective, the Rietvlei landscape is, therefore, quite dynamic and the distribution of aardvark burrows in 2015 was not fixed but had changed by 2020. Nevertheless, there is no reason to suspect that the 2015 distribution is not representative of aardvark burrowing in general and would, therefore, reflect patterns in burrow behaviour. Without any evidence of contrary, aardvark burrows from 2015 still represents aardvark burrow distributions in the landscape. In general, the results suggest that patterns in aardvark burrow distribution are not consistent across all spatial scales and within all quadrats. Whereas burrows, in general, appear to be dispersed across the Rietvlei landscape, at smaller spatial scales, burrows sometimes seem to cluster. Similarly, burrows of rodents, such as the Siberian marmot *(Marmota sibirica*) also demonstrate inconsistent occurrence across the landscapes, that is, spatially clustered and isolated at times (Townsend, 2006).

Aardvark are solitary species that do not live in groups (Taylor & Skinner, 2003, 2004). This explains the general dispersed nature of their burrows throughout the landscape (based on the high-density burrow quadrats investigated). Two potential explanations for burrow clusters at smaller spatial scales are given. First, given that the aardvark constructs a new burrow every few days (Melton, 1976), and also constructs complex burrows with multiple entrances (personal observation); clustered burrows could be created by a single aardvark. It is, however, also possible that burrow clusters observed at smaller spatial scales were constructed by multiple burrowers, but that they differed in construction age and were, therefore, either not occupied at the same time, or were being used by other species (Whittington-Jones et al., 2011).

The 2015 aardvark burrow survey did not include the entirety of Rietvlei Nature Reserve. Instead, 1% of the reserve was surveyed for burrows, totalling 45 1-ha plots throughout the reserve. Thus, clustering for the whole reserve could not be assessed. Instead, clustering was assessed per quadrat, using the three historically most densely populated quadrats (2, 3, and 28). However, within the 45 quadrats, burrow numbers varied greatly, with some quadrats having no burrows, and others over 50 burrows. This suggests that, at the larger spatial scale of the whole reserve, clusters, i.e., areas of localised higher burrow numbers, potentially do occur. However, reasons for some quadrats containing such high burrow densities, while others contain no burrows at all, are still unknown. Given that burrows often occur some distance from their foraging areas (Knöthig, 2005) and Rietvlei is a small nature reserve, with termite mounds regularly seen interspersed throughout the landscape (personal observation), it seems unlikely that termite distributions are driving burrow locations. As much as this variable could not be tested/investigated in this study due to time limitations, future research on the influence of termite mounds on aardvark burrowing is highly recommended. Rietvlei is relatively flat from a topographical perspective and none of the burrows were recorded on steep slopes, small-scale topography could play a role in determining burrow locations. Such reasons, however, remain speculative and, in general, aardvark at Rietvlei appear to be largely unrestricted in terms of burrowing locations.

5.3 Impacts of aardvark burrowing on soil texture

Many studies on the impacts of burrowing on soil properties have focused on soil compaction and moisture (Alkon, 1999; Boeken et al., 1998; Louw et al., 2019; Shachak et al., 1991; Wang et al., 2018). For example, Louw et al., (2019) found that the impacts of an aardvark on soil moisture vary between sites of different characteristics. The study suggests that digging trends of these species' changes compaction of the soil, with burrow mounds being less compact than control sites. Several other studies have also shown soil texture to influence burrow locations (Anthony, 1980; Arieli, 1979; Rhodes & Richmond, 1985; Stokes & Boersma, 1991), with burrowers such as Wyoming ground squirrels (*Spermophilus elegans*) in Colorado (United State (US)) and Kangaroo rat (*Dipodomys ordii*) in North America, mostly preferring to locate their burrows where soil contains a higher amount of silt and clay content (John and Timothy, 1993). Anthony, (1980) also found that Pine voles (*Microtus pinetown*) in US require soil with more than 35% gravel, less than 65% fines, 25-48% sand, and more than 20% clay. However, burrowing mammals are not only influenced by soil texture but possibly also influence the soil texture, through turning over the soil layers during their digging, a process known as bioturbation (Wijnhoven et al., 2006).

The texture of burrow mounds depends on the texture of the material from which it was constructed (Platt et al., 2016). For example, by bringing soil from deeper soil horizons to the surface, burrowing species may be moving less weathered (coarser) soil particles to the surface (Ross, 1968; Johnson et al., 2005). Species such as Prairie dogs (*genus Cynomys*) and Pocket gophers (*Thomomys bottae minor* and *T. talpoides*) in California and Colorado, bring stones to the surface as they dig (Grinnell, 2020; Thorp, 1949). However, other studies found the opposite, for example, finer particles were deposited in mounds from burrows of East African Mole rats (*Cryptomys hottentotus hottentotus* and *Georychus capensis*) and Central America Pocket gophers (*T. bottae*) (Branson et al., 1965; Hagenah & Bennett, 2013; Donald et al., 1987; Mielke, 1977). Similar results were also observed in the current study, whereby soils on aardvark mounds are finer (i.e., possess larger mean phi sizes), have a greater positive skew (tail of fines), and are more peaked (better sorted in the central part than in the tails) than those of undisturbed control sites.

Variation in grain particle sizes (sorting) did not differ significantly between burrow mounds and controls. There is a suspicion that, perhaps the reason for this could be that, parent materials/sub-soil profiles from which burrow mounds were constructed are similar to that of control sites in terms of sorting (Platt et al., 2016). This is possible because the controls were only 2 meters from the mounds. Another possible reason for these results could be due to the high degree of soil mixing during the excavation process (Litaor et al., 1996). This may have led to sorting becoming similar between mounds and controls. Similar to the current study results, the sorting of banner-tailed kangaroo rat (*Dipodomys spectabilis*) mounds was found to be similar to that of controls (Moorhead et al., 1988).

In addition to affecting soil particle size, burrowing also affects the distribution of particle sizes (skewness and kurtosis), thereby creating microsites that are different in terms of overall particle size characteristics. Such microsite creation has consequences in terms of niche creation for plant species. Studies suggest that soil on burrow mounds allows for better growth of plants (Kurek et al., 2014; Wesche et al., 2007; Wiegand et al., 1997), ascribed to greater porosity and permeability which foster plants growth and higher infiltration rate (Mielke, 1977). The ameliorated conditions of burrow mounds allow for the establishment of species that would otherwise not be able to occur on the undisturbed landscape, by increasing species richness and composition (Kurek et al., 2014; Wesche et al., 2007)

Chapter 6: Conclusion and Recommendations

Conclusion:

The aardvark is a well-adapted digger, occurring in almost all habitat types in southern Africa (Skinner & Smithers, 1990), and this research supports this. At Rietvlei Nature Reserve, aardvark burrows were dispersed throughout the landscape, with burrowing seemingly unrestricted by the environmental parameters studied. The study found no association between burrow presence in a quadrat and any of the environmental determinants investigated. Moreover, none of these potential determinants were a significant predictors of burrow densities within the quadrats. The cluster analysis results showed that patterns of aardvark burrow distribution are not consistent across all spatial scales. At broader spatial scales burrows appeared dispersed, while at smaller spatial scales appeared clustered. The study further found that the digging trends of the aardvark affect the size and distribution of soil particles, but not sorting.

Recommendations:

- Among potential environmental drivers that were not investigated here, a more nuanced difference in plant cover and grass height (Davidson et al., 2021; Hoogland, 1995) between quadrats may be playing a role in aardvark burrowing. It is, thus, recommended that investigations be conducted on these parameters as well. Because quadrats are, for example, rotated when it comes to managed veld burning, this affects grass cover, which in turn may affect aardvark burrowing (Maponga et al., 2018; Nieman et al., 2021).
- 2015 burrow survey covered only 1% of the reserve from which 45 1-ha quadrats were sampled, and the current study was only limited to these. It is possible that an increase in sampling effort could potentially influence the results differently. Therefore, it is recommended that further investigations be conducted using the current study objectives, but applying a different sampling method i.e. sampling the whole reserve vs current sampling.

References

Abba, A. M., Zufiaurre, E., Codesido, M., & Bilenca, D. N. (2015). Burrowing activity by armadillos in agroecosystems of central Argentina: Biogeography, land use, and rainfall effects. *Agriculture, Ecosystems and Environment*, 200, 54–61.

Alkon, P. U. (1999). Microhabitat to landscape impacts: Crested porcupine digs in the Negev Desert highlands. *Journal of Arid Environments*, 41, 183–202.

Allstadt, A., Caraco, T., & Korniss, G. (2007). Ecological invasion: Spatial clustering and the critical radius. *Evolutionary Ecology Research*, 9, 375–394.

Altermatt, F., & Holyoak, M. (2012). Spatial clustering of habitat structure effects patterns of community composition and diversity. *Ecology*, 93, 1125–1133.

Anthony, R. G., & Fisher, A. R. (1980). The Effect of soil texture on distribution of Pine Voles in Pennsylvania Orchards. *American Midland Naturalist,* 104, 39–46.

Anzah, F., & Butler, D. R. (2017). Revisiting an early classic on gopher bioturbation and geomorphology: Joseph G. (1923) The burrowing rodents of California as agents in soil formation. *Journal of Mammalogy*, 4, 137–149.

Arieli, R. (1979). The atmospheric environment of the fossorial mole rat (*Spalax ehrenbergi*): Effects of season, soil texture, rain, temperature and activity. *Comparative Biochemistry and Physiology*, 63, 569–575.

Bailey, T. C., & Gatrell, A. C. (1995). *Interactive spatial data analysis*. Longman Scientific & Technical Essex.

Boeken, B., Lipchin, C., Gutterman, Y., & Van Rooyen, N. (1998). Annual plant community responses to density of small-scale soil disturbances in the Negev Desert of Israel. *Oecologia*, 114, 106–117.

Boeken, B., Shachak, M., Gutterman, Y., & Brand, S. (1995). Patchiness and disturbance: Plant community responses to porcupine diggings in the central Negev. *Ecography*, 18, 410–421.

Bolker, B. M. (2008). *Ecological Models and Data in R*. Princeton University Press.

Bragg, C. (2003). Cape porcupine density, burrow distribution and space use in a geophyte-diverse semi-arid environment. *Dissertation - University of Cape Town*, *February*, 1–124.

Bragg, C. J., Donaldson, J. D., & Ryan, P. G. (2005). Density of cape porcupines in a semi-arid environment and their impact on soil turnover and related ecosystem processes. *Journal of Arid Environments*, 61, 261–275.

Branson, A. F. A., Miller, R. F., & Mcqueen, I. S. (1965). Plant communities and soil moisture relationships near denver. *Wiley on behalf of the Ecological Society of America Stable,* 46, 311–319.

Curtis, B. A., & Perrin, M. R. (1979). Food preferences of the vlei rat (*Otomys Irroratus*) and the four-striped mouse (*Rhabdomys pumilio*). *South African Journal of Zoology*, 14, 224–229.

Daszykowski, M., & Walczak, B. (2009). Density-based clustering methods. *Comprehensive Chemometrics*, 2, 635–654.

Davidson, A.D., Detling, J.K. & Brown, J.H. (2012). Ecological roles and conservation challenges of social, burrowing, herbivorous mammals in the world's grasslands. *Frontiers in Ecology and the Environment*, 10, 477-486.

Davis, W. H., & Kalisz, P. J. (1992). Burrow systems of the prairie vole (*Microtus ochrogaster*) in central Kentucky. *Journal of Mammalogy*, 73, 582–585.

De-la-Cruz, I. M., Castro-Campillo, A., Zavala-Hurtado, A., Salame-Méndez, A., & Ramírez-Pulido, J. (2019). Differentiation pattern in the use of space by males and females of two species of small mammals (*Peromyscus difficilis and P. melanotis*) in a temperate forest. *Therya*, 10, 3–10.

Dentzien-Dias, P. C., & Figueiredo, A. E. Q. (2015). Burrow architecture and burrowing dynamics of Ctenomys in foredunes and paleoenvironmental implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 439, 166–175.

Desmarais, B. A., & Harden, J. J. (2013). Testing for zero inflation in count models: Bias correction for the Vuong test. *Stata Journal*, 13, 810–835.

Desmond, M. J., Savidge, J. A., & Seibert, T. F. (1995). Spatial patterns of burrowing owl (*Speotyto cunicularia*) nests within black-tailed prairie dog (*Cynomys ludovicianus*) towns. *Canadian Journal of Zoology*, 73, 1375–1379.

Dormann, C. F. (2016, 07 December). *Overdispersion, and how to deal with it in R and JAGS*.

Eder, M. (2017). Visualization in stylometry: Cluster analysis using networks. *Digital Scholarship in the Humanities*, 32, 50–64.

Eldridge, D. J., & Whitford, W. G. (2009). Badger (*Taxidea taxus*) disturbances increase soil heterogeneity in a degraded shrub-steppe ecosystem. *Journal of Arid Environments*, 73, 66–73.

Filius, J., van der Hoek, Y., Jarrín-V, P., & van Hooft, P. (2020). Wildlife roadkill patterns in a fragmented landscape of the Western Amazon. *Ecology and Evolution*, 10, 6623–6635.

Fisher, J. B., Trulio, L. A., Biging, G. S., & Chromczak, D. (2007). An analysis of spatial clustering and implications for wildlife management: A burrowing owl example. *Environmental Management*, 39, 403–411.

Fleming, P.A., Anderson, H., Prendergast, A.S., Bretz, M.R., Valentine, L.E., & Hardy, G.E.S. (2014). Is the loss of Australian digging mammals contributing to a deterioration in ecosystem function? *Mammal Review*, 44, 94-108.

Folk, R.L., & Ward, W.C. (1957). Brazos River bar [Texas]; a study in the significance of grain size parameters. *Journal of sedimentary research*, 27, 3-26.

Foster, I. B., McIntyre, T., & Haussmann, N. S. (2019). Understanding the relationship between farmers and burrowing mammals on South African farms: Are burrowers friends or foes? *Agriculture and Human Values*, 36, 719–731.

Fowler, C., 2004. *The archaeology of personhood: An anthropological approach*. Routledge, London.

Goodman, S. J., Smith, J. A., Gorman, T. A., & Haas, C. A. (2018). Longevity of gopher tortoise burrows in sandy soils. *Southeastern Naturalist*, 17, 531–540.

Grinnell, J. (2020). *The burrowing rodents of California as agents in soil formation*. University of California Press, Berkeley.

Hagenah, N., & Bennett, N. C. (2013). Mole rats act as ecosystem engineers within a biodiversity hotspot, the Cape Fynbos. *Journal of Zoology*, 289, 19–26.

Harvey, G. L., Henshaw, A. J., Brasington, J., & England, J. (2019). Burrowing invasive species: An unquantified erosion risk at the aquatic-terrestrial interface. *Reviews of Geophysics*, 57,1018–1036.

Haussmann, N. S. (2017). Soil movement by burrowing mammals: A review comparing excavation size and rate to body mass of excavators. *Progress in Physical Geography*, 41, 29–45

Haussmann, N. S., Louw, M. A., Lewis, S., Nicol, K. J. H., van der Merwe, S., & le Roux, P. C. (2018). Ecosystem engineering through aardvark (*Orycteropus afer*) burrowing: Mechanisms and effects. *Ecological Engineering*, 118, 66–72.

Hill, J. E., DeVault, T. L., & Belant, J. L. (2021). A review of ecological factors promoting road use by mammals. *Mammal Review*, 51, 214–227.

Holmes, A.L., Green, G.A., Morgan, R.L. & Livezey, K.B. (2003). Burrowing Owl nest success and burrow longevity in north central Oregon. *Western North American Naturalist*, 63, 244-250.

Hoogland, J.L. (1995). *The black-tailed prairie dog: social life of a burrowing mammal*. University of Chicago Press.

Iggy-Litaor, M., Mancinelli, R., & Halfpenny, J. C. (1996). The influence of pocket gophers on the status of nutrients in Alpine soils. *Geoderma*, 70, 37–48.

Thorp, J. (1949). Effects of certain animals that live in soils. *American Association for the Advancement of Science,* 68, 180–191.

Jackson, T. P. (2000). Adaptation to living in an open arid environment: Lessons from the burrow structure of the two southern African whistling rats*, Parotomys brantsii and P. Littledalei*. *Journal of Arid Environments*, 46, 345–355.

James, A. I., Eldridge, D. J., & Hill, B. M. (2009). Foraging animals create fertile patches in an Australian desert shrubland. *Ecography*, 32, 723–732.

Jiang, L., Wang, X., Li, L., Shi, Z., & Yang, X. (2017). Spatial association of shrubs and their interrelation to burrowing site preference of subterranean rodents on dune slope in the Otindag Sandy Land, China. *Sustainability*, 9, 1729.

Johnson, D. L., Domier, J. E. J., & Johnson, D. N. (2005). Reflections on the nature of soil and its biomantle. *Annals of the Association of American Geographers*, 95, 11–31.

Johnson, D. L., Watson-Stegner, D., Johnson, D. N., & Schaetzl, R. J. (1987). Proisotropic and proanisotropic processes of pedoturbation. *Soil Science*, 143, 278–292.

Jones, C.G., Lawton, J.H., & Shachak, M. (1994). Organisms as ecosystem engineers. *Oikos*, 69, 130-147.

Kim, H. Y. (2017). Statistical notes for clinical researchers: Chi-squared test and Fisher's exact test. *Restorative Dentistry & Endodontics*, 42, 152.

Kneissl, T., Van Gasselt, S., & Neukum, G. (2011). Map-projection-independent crater size-frequency determination in GIS environments - New software tool for ArcGIS. *Planetary and Space Science*, 59, 1243–1254.

Knothig, J. (2005). 'Biology of the Aardvark (*Orycteropus afer*)'. Masters dissertation, Ruprecht-Karls-Universitat.

Kurek, P., Kapusta, P., & Holeksa, J. (2014). Burrowing by badgers (*Meles meles*) and foxes (*Vulpes vulpes*) changes soil conditions and vegetation in a European temperate forest. *Ecological Research*, 29, 1–11.

Laundre, J. W. (1993). Effects of small mammal burrows on water infiltration in a cool desert environment. *Oecologia*, 94, 43–48.

Li, S., Cui, B., Xie, T., Bai, J., Wang, Q., & Shi, W. (2018). What drives the distribution of crab burrows in different habitats of intertidal salt marshes, Yellow River Delta, China. *Ecological Indicators*, 92, 99–106.

Lion, S., & Baalen, M. Van. (2008). Self-structuring in spatial evolutionary ecology. *Ecology Letters*, 11, 277–295.

Louw, M. A., Haussmann, N. S., & le Roux, P. C. (2019). Testing for consistency in the impacts of a burrowing ecosystem engineer on soil and vegetation characteristics across biomes. *Scientific Reports*, 9, 1–12.

Machicote, M., Branch, L. C., & Villarreal, D. (2004). Burrowing owls and burrowing mammals: Are ecosystem engineers interchangeable as facilitators? *Oikos*, 106, 527-535.

Maponga, R., Ahmed, F., & Mushore, T. D. (2018). Remote sensing-based assessment of veld fire trends in multiple interwoven land tenure systems in Zimbabwe. *Geocarto International*, 33, 612–626.

Marais, R. (2004). 'A plant ecological study of the rietvlei nature reserve , Gauteng province'. Unpublished masters dissertation. University of the Free Ftate.

Marsh, R. E. (1998). Historical review of ground squirrel crop damage in California. *International Biodeterioration and Biodegradation*, 42, 93–99.

Martín, M. Á., Pachepsky, Y. A., García-Gutiérrez, C., & Reyes, M. (2018). On soil textural classifications and soil-texture-based estimations. *Solid Earth*, 9, 159–165.

Melton, D. A. (1976). The biology of aardvark *(Tubulidentata-Orycteropodidae)*. *Mammal Review*, 6, 75–88.

Mielke, H. W. (1977). Mound building by pocket gophers (*Geomyidae*): Their impact on soils and vegetation in North America. *Journal of Biogeography*, 4, 171.

Mines, S. D. of, & Africa, G. S. of S. (1973). 1 : 50 000 Geological Series: Republic of South Africa. Legend for sheets 2527 DA Wolhuterskop, 2527 DB Brits, 2527 DC Hekpoort, 2527 DO Broederstroom, 2528 CA Pretoria, 2528 CB Silverton, 2528 CC Lyttelton, 2528 CD Rietvleidam. 2527DA/2528CD. Government Printer, South Africa.

Mitchell, A. (2005). *The ESRI Guide to GIS Analysis. Redlands*. CA, Esri Press.

Moore, N., Whiterow, A., Kelly, P., Garthwaite, D., Bishop, J., Langton, S., & Cheeseman, C. (1999). Survey of badger (*Meles meles*) damage to agriculture in England and Wales. *Journal of Applied Ecology*, 36, 974–988.

Moorhead, D.L., Fisher, F.M. and Whitford, W.G. (1988). Cover of spring annuals on nitrogen-rich kangaroo rat mounds in a Chihuahuan Desert grassland. *American Midland Naturalist*, 120,443-447.

Nieman, W. A., Van Wilgen, B. W., & Leslie1, A. J. (2021). A review of fire management practices in African savanna-protected areas. *Koedoe*, 63, 1–13.

Noble, J. C., Müller, W. J., Detling, J. K., & Pfitzner, G. H. (2007). Landscape ecology of the burrowing bettong: Warren distribution and patch dynamics in semiarid eastern Australia. *Austral Ecology*, 32, 326–337.

Oduro, W., & Boateng, O. C. (2009). Habitat ecology of aardvarks (*Orycteropus afer*) in Bui National Park, Ghana. *Afrotherian Conservation*, 53, 100-115.

Olson, K. R., & Al-Kaisi, M. M. (2015). The importance of soil sampling depth for accurate account of soil organic carbon sequestration, storage, retention and loss. *Catena*, 125, 33–37.

Perumean-Chaney, S. E., Morgan, C., McDowall, D., & Aban, I. (2013). Zero-inflated and overdispersed: What's one to do? *Journal of Statistical Computation and Simulation*, 83, 1671–1683.

Pike, D. A., & Mitchell, J. C. (2013). Burrow-dwelling ecosystem engineers provide thermal refugia throughout the landscape. *Animal Conservation*, 16, 694–703.

Platt, B. F., Kolb, D. J., Kunhardt, C. G., Milo, S. P., & New, L. G. (2016). Burrowing through the literature: The impact of soil-disturbing vertebrates on physical and chemical properties of soil. *Soil Science*, 181, 175–191.

R Team Core. (2016). *R: A language and environment for statistical computing*. *R Foundation for Statistical Computing*.

Rhodes, D. H., & Richmond, M. E. (1985). Influence of soil texture, moisture and temperature on nest-site selection and burrowing by the pine vole (*Microtus pinetorum*). *American Midland Naturalist*, 113, 102–108.

Romañach, S. S., Reichman, O. J., & Seabloom, E. W. (2005). Seasonal influences on burrowing activity of a subterranean rodent (*Thomomys bottae*). *Journal of Zoology*, 266, 319–325.

Ross, B.A., Tester, J.R. & Breckenridge, W.J. (1968). Ecology of Mima-type mounds in northwestern Minnesota. *Ecology*, 49, 172-177.

Rutherford, M. C., Mucina, L., & Powrie, L. W. (2012). The South African National Vegetation Database: History, development, applications, problems and future. *South African Journal of Science*, 108, 01–08.

Santos, A., Aguirre, J., Rodríguez-Tovar, F. J., & Mayoral, E. (2018). Multi-storm events recorded on Panopea burrows (Pliocene, Spain): The importance of sequestered information inside burrows. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 507, 155–167.

Shachak, M., Brand, S., & Gutterman, Y. (1991). Porcupine disturbances and vegetation pattern along a resource gradient in a desert. *Oecologia*, 88, 141–147.

Shannon, G., Angeloni, L. M., Wittemyer, G., Fristrup, K. M., & Crooks, K. R. (2014). Road traffic noise modifies behaviour of a keystone species. *Animal Behaviour*, 94, 135–141.

Shimmin, G. A., Skinner, J., & Baudinette, R. V. (2002). The warren architecture and environment of the southern hairy-nosed wombat (*Lasiorhinus latifrons*). *Journal of Zoology*, 258, 469–477.

Stokes, D. L., & Boersma, P. D. (1991). Effects of substrate on the distribution of magellanic penguin (*Spheniscus magellanicus*) burrows. *The Auk*, 108, 923–933.

Taylor, W. A., & Skinner, J. D. (2003). Activity patterns, home ranges and burrow use of aardvarks (*Orycteropus afer*) in the Karoo. *Journal of Zoology*, 261, 291–297.

Taylor, W. A., & Skinner, J. D. (2004). Adaptations of the aardvark for survival in the Karoo: A review. *Transactions of the Royal Society of South Africa*, 59, 105–108.

Townsend, S. E. (2006). Burrow cluster as a sampling unit: An approach to estimate marmot activity in the eastern steppe of Mongolia. *Mongolian Journal of Biological Sciences*, 4, 31–36.

Van Aarde, R. J., Willis, C. K., Skinner, J. D., & Haupt, M. A. (1992a). Range utilization by the aardvark, (*Orycteropus afer*) (Pallas, 1766) in the Karoo, South Africa. *Journal of Arid Environments*, 22, 387–394.

Wang, Q., Yu, C., Pang, X. P., Jin, S. H., Zhang, J., & Guo, Z. G. (2018). The disturbance and disturbance intensity of small and semi-fossorial herbivores alter the belowground bud density of graminoids in alpine meadows. *Ecological Engineering*, 113, 35–42.

Weltzin, J. F., Archer, S., & Heitschmidt, R. K. (1997). Small-mammal regulation of vegetation structure in a temperate savanna. *Ecology*, 78, 751–763.

Wesche, K., Nadrowski, K., & Retzer, V. (2007). Habitat engineering under dry conditions: The impact of pikas (*Ochotona pallasi*) on vegetation and site conditions in southern Mongolian steppes. *Journal of Vegetation Science*, 18, 665–674.

Whitford, W. G., & Kay, F. R. (1999). Biopedturbation by mammals in deserts: A review. *Journal of Arid Environments*, 41, 203–230.

Whittington-Jones, G. M., Bernard, R. T. F., & Parker, D. M. (2011). Aardvark burrows: A potential resource for animals in arid and semi-arid environments. *African Zoology*, 46, 362–370.

Whittington-Jones, G. M. (2006). The role of aardvarks (*Orycteropus afer*) as ecosystem engineers in arid and semi-arid landscapes of South Africa. *Dissertation - Rhodes University*, *December*, 1–181.

Wiegand, T., Dean, W. R. J., & Milton, S. J. (1997). Simulated plant population responses to small-scale disturbances in semi-arid shrublands. *Journal of Vegetation Science*, 8, 163–176.

Wijnhoven, S., Thonon, I., Velde, G. Van Der, Leuven, R., Zorn, M., Eijsackers, H., & Smits, T. (2006). The impact of bioturbation by small mammals on heavy metal redistribution in an embanked floodplain of the river Rhine. *Water, Air, and Soil Pollution*, 177, 183–210.

Wilschut, L. I., Laudisoit, A., Hughes, N. K., Addink, E. A., de Jong, S. M., Heesterbeek, H. A. P., Reijniers, J., Eagle, S., Dubyanskiy, V. M., & Begon, M. (2015). Spatial distribution patterns of plague hosts: Point pattern analysis of the burrows of great gerbils in Kazakhstan. *Journal of Biogeography*, 42, 1281–1292.

Yoshida, H., Yamamoto, T., Mori, Y., Masuda, H., Okazaki, K., & Sugasawa, H. (2014). Particle size measurement of reference particle candidates and uncertainty region of count and mass based cumulative distribution. *Advanced Powder Technology*, 25, 1748–1753.

Yu, C., Pang, X. P., Wang, Q., Jin, S. H., Shu, C. C., & Guo, Z. G. (2017). Soil nutrient changes induced by the presence and intensity of plateau pika (*Ochotona curzoniae*) disturbances in the Qinghai-Tibet Plateau, China. *Ecological Engineering*, 106, 1–9.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Appendix A

RNR

Type File Geodatabase Feature Class

Tags Rietvlei Nature Reserve site.

Summary

This is the study area for my Masters research project. In this study is used to construct a study site map.

Description

At this site a lot of wild and endanger species are conserved and some other species opportunistically use and reside by this site because its abundant resource availability. Rietvlei Nature Reserve is located at Gauteng province, Pretoria in particular. People use it for various reasons, ranging from braais, vacations, sailing, animal watching etc. Its a grassland biome with three dominant vegetation type, which includes grassland, low-lying grassland and reeds.

Credits

This data is user friendly in all ArcGIS pro platform and it is also easier to read.

Use limitations

It is designed for this research use only. However, available on request. Also it cannot be used in any other analytical software's except Esri products.

Extent

West 28.260692 East 28.325437

North -25.846845 South -25.936325

Scale Range

Maximum (zoomed in) 1:5,000

Minimum (zoomed out) 1:150,000,000

Topics and Keywords ▶

Content type ⇔ Downloadable Data

Citation ▶

Title RNR

Presentation formats ⇔ digital map

Resource Details ▶

Dataset languages ⇔ English (SOUTH AFRICA)

Spatial representation type ⇔ vector

Processing environment ⇔ Microsoft Windows 10 Version 10.0 (Build 18362) ; Esri ArcGIS 12.3.0.15769

Credits

This data is user friendly in all ArcGIS pro platform and it is also easier to read.

ArcGIS item properties

Name ⇔ RNR

Location ⇔ file://\\LAPTOP-GJRQK032\Users\Mapuru Morena\Documents\ArcGIS\Projects\Lerato\Lerato.gdb

Access protocol ⇔ Local Area Network

Extents ▶

Extent

Geographic extent

Bounding rectangle

Extent type

Extent used for searching

West longitude ⇔ 28.260692

East longitude ⇔ 28.325437

North latitude ⇔ -25.846845

South latitude ⇔ -25.936325

Extent contains the resource ⇔ Yes

Extent in the item's coordinate system

westBL ⇔ 28.260692

eastBL ⇔ 28.325437

southBL ⇔ -25.936325

northBL ⇔ -25.846845

exTypeCode ⇔ Yes

Resource Constraints ▶

Constraints

Limitations of use

It is designed for this research use only. However, available on request. Also it cannot be used in any other analytical software's except Esri products.

Spatial Reference ▶

ArcGIS coordinate system

Type ⇔ Geographic

Geographic coordinate reference ⇔ GCS_WGS_1984

Coordinate reference details ⇔

GeographicCoordinateSystem

WKID 4326

XOrigin -400

YOrigin -400

XYScale 999999999.99999988

ZOrigin -100000

ZScale 10000

MOrigin -100000

MScale 10000

XYTolerance 8.98315284119521e-09

ZTolerance 0.001

MTolerance 0.001

HighPrecision true

LeftLongitude -180

LatestWKID 4326

WKT
GEOGCS["GCS_WGS_1984",DATUM["D_WGS_1984",SPHEROID["WGS_1984",6378137.0,298.257223563]],PRIMEM["Greenwich",0.0],UNIT["Degree",0.0174532925199433],AUTHORITY["EPSG",4326]]

Reference system identifier

Value ⇔ 4326

Codespace ⇔ EPSG

Version ⇔ 6.14(3.0.1)

Spatial Data Properties ▶

Vector ▶

Level of topology for this dataset ⇔ geometry only

Geometric objects

Feature class name RNR

Object type ⇔ composite

Object count ⇔ 250

ArcGIS Feature Class Properties ▶

Feature class name RNR

Feature type ⇔ Simple

Geometry type ⇔ Polygon

Has topology ⇔ FALSE

Feature count ⇔ 250

Spatial index ⇔ TRUE

Linear referencing ⇔ FALSE

Geoprocessing history ▶

Process

Process name

Date 2020-09-18 16:00:02

Tool location c:\users\mapuru morena\appdata\local\programs\arcgis\pro\Resources\ArcToolbox\Toolboxes\Data Management Tools.tbx\CreateFeatureclass

Command issued

```
CreateFeatureclass "C:\Users\Mapuru
Morena\Documents\ArcGIS\Projects\Lerato\Lerato.gdb" RNR Polygon #
No Yes
"GEOGCS['GCS_WGS_1984',DATUM['D_WGS_1984',SPHEROID['WGS_1984',63781
37.0,298.257223563]],PRIMEM['Greenwich',0.0],UNIT['Degree',0.017453
2925199433]];-400 -400 1000000000;-100000 10000;-100000
10000;8.98315284119521E-09;0.001;0.001;IsHighPrecision" # # # # #
```

Include in lineage when exporting metadata No

Distribution ▶

Distribution format

Name ⇔ File Geodatabase Feature Class

Fields ▶

Details for object RNR ▶

Type ⇔ Feature Class

Row count ⇔ 250

Field OBJECTID ▶

Alias ⇔ OBJECTID

Data type ⇔ OID

Width ⇔ 4

Precision ⇔ 0

Scale ⇔ 0

Field description ⇔

Internal feature number.

Description source ⇔

Esri

Description of values ⇔

Sequential unique whole numbers that are automatically generated.

Field Shape ▶

Alias ⇔ Shape

Data type ⇔ Geometry

Width ⇔ 0

Precision ⇔ 0

Scale ⇔ 0

Field description ⇔

Feature geometry.

Description source ⇔

Esri

Description of values ⇔

Coordinates defining the features.

Field Shape_Length ▶

Alias ⇔ Shape_Length

Data type ⇔ Double

Width ⇔ 8

Precision ⇔ 0

Scale ⇔ 0

Field description ⇔

Length of feature in internal units.

Description source ⇔

Esri

Description of values ⇔

Positive real numbers that are automatically generated.

Field Shape_Area ▶

Alias ⇔ Shape_Area

Data type ⇔ Double

Width ⇔ 8

Precision ⇔ 0

Scale ⇔ 0

Field description ⇔

Area of feature in internal units squared.

Description source ⇔

Esri

Description of values ⇔

Positive real numbers that are automatically generated.

Metadata Details ▶

Metadata language ⇔ English (SOUTH AFRICA)

Scope of the data described by the metadata ⇔ dataset

Scope name ⇔ dataset

Last update ⇔ 2021-08-17

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

ArcGIS metadata properties

Metadata format ArcGIS 1.0

Created in ArcGIS for the item 2020-09-18 16:00:02

Last modified in ArcGIS for the item 2021-08-17 18:19:39

Automatic updates

Have been performed Yes

Last update 2020-11-11 00:18:56

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Appendix B

Sample	mean	sorting	kurtosis	skewness
Burrow	1.44	1.83	0.96	0.68
Burrow	0.82	2.24	0.75	0.29
Burrow	1.43	2.23	0.90	0.52
Burrow	0.85	1.48	1.21	0.62
Burrow	0.20	1.83	0.82	0.08
Burrow	1.85	1.22	1.50	1.65
Burrow	1.80	1.21	1.42	1.63
Burrow	1.82	1.48	1.17	1.19
Burrow	1.67	1.53	1.24	1.09
Burrow	1.73	1.25	1.31	1.58
Burrow	1.33	1.61	1.33	0.79
Burrow	1.00	2.11	0.86	0.38
Burrow	1.27	1.73	1.54	0.67
Burrow	0.65	1.56	1.05	0.35
Burrow	1.23	1.66	1.37	0.66
Burrow	0.53	1.92	0.83	0.30
Burrow	0.03	1.96	0.82	0.07
Burrow	-0.50	1.42	0.41	0.43
Burrow	0.20	2.01	0.85	0.15
Burrow	0.10	1.90	0.85	0.05
Burrow	-0.13	1.87	0.86	-0.02
Burrow	0.27	1.83	0.88	0.17
Burrow	0.10	1.90	0.72	0.20
Burrow	0.33	1.79	0.73	0.22
Burrow	0.37	1.97	0.81	0.23
Burrow	-0.30	1.48	0.33	0.40
Burrow	1.07	1.81	0.93	0.56
Burrow	0.35	1.93	1.04	0.20
Burrow	0.77	2.06	0.81	0.35
Burrow	0.60	2.23	0.85	0.21
Burrow	0.87	2.14	0.81	0.34
Burrow	0.90	2.02	0.97	0.39
Burrow	0.60	2.14	0.86	0.25
Burrow	0.90	2.08	0.82	0.36
Burrow	0.77	2.08	0.81	0.30
Burrow	1.00	2.02	0.87	0.44
Burrow	0.17	1.67	0.82	0.13
Burrow	0.13	1.98	1.03	0.14
Burrow	0.70	1.90	0.93	0.31

Burrow	0.43	1.93	0.85	0.11
Burrow	-0.07	2.13	0.77	-0.04
Burrow	-0.13	2.01	0.81	-0.06
Burrow	-0.60	2.34	0.70	-0.19
Burrow	0.63	2.04	0.87	0.24
Burrow	0.17	2.02	1.01	0.09
Burrow	0.13	2.20	0.88	0.04
Burrow	-1.37	2.10	0.80	-0.48
Burrow	-0.67	2.06	0.75	-0.23
Burrow	0.87	1.98	0.95	0.36
Burrow	-1.63	1.63	0.94	-0.84
Control	1.80	1.61	1.23	0.91
Control	1.37	1.65	1.08	1.05
Control	1.39	1.67	1.07	0.80
Control	0.93	2.06	0.93	0.40
Control	0.27	1.80	0.43	0.51
Control	2.10	1.50	1.05	1.39
Control	1.55	1.49	1.08	1.03
Control	1.83	1.45	1.06	1.26
Control	1.55	1.60	0.89	0.90
Control	1.95	1.71	0.94	1.06
Control	0.10	2.08	0.82	0.08
Control	0.13	0.85	1.28	0.70
Control	0.40	2.06	0.89	0.19
Control	0.10	1.74	0.45	0.53
Control	0.10	2.05	0.92	0.07
Control	0.07	2.00	0.83	0.09
Control	0.63	1.84	0.83	0.33
Control	0.13	1.91	0.85	0.14
Control	0.40	2.01	0.75	0.22
Control	0.20	1.71	0.87	0.22
Control	-0.37	1.76	0.90	-0.12
Control	0.03	1.88	0.88	0.10
Control	0.60	1.86	0.81	0.28
Control	-0.03	1.76	0.83	0.04
Control	0.27	1.83	0.79	0.26
Control	0.87	2.08	0.89	0.33
Control	-1.30	2.10	0.97	-0.43
Control	-0.63	2.24	0.90	-0.17
Control	0.40	2.22	0.83	0.20
Control	0.20	2.34	0.80	0.13
Control	0.10	2.50	0.76	0.05
Control	0.53	2.21	0.80	0.24

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Control	0.80	2.00	0.83	0.39
Control	-1.07	2.18	0.78	-0.32
Control	-1.43	1.71	0.94	-0.64
Control	-0.97	1.77	0.76	-0.45
Control	-0.90	1.74	0.97	-0.37
Control	-0.93	1.73	0.94	-0.38
Control	-1.40	2.10	0.74	-0.46
Control	-0.83	2.08	0.78	-0.26
Control	-1.43	1.60	0.72	-0.74
Control	-1.53	1.77	0.96	-0.68
Control	-1.13	1.83	0.95	-0.48
Control	-0.10	2.00	0.83	-0.06
Control	-1.23	2.08	0.89	-0.41
Control	-1.18	2.16	0.69	-0.40
Control	-0.43	1.97	0.83	-0.14
Control	-1.63	1.88	0.80	-0.68
Control	-1.60	1.99	0.79	-0.59
Control	0.17	2.24	0.84	0.03