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Investigation of Seed and Seedling Predation and Natural History of Bushveld Savanna Rodents

Christopher Banotai
Western Kentucky University, christopher.banotai918@topper.wku.edu

INVESTIGATION OF SEED AND SEEDLING PREDATION AND NATURAL HISTORY OF BUSHVELD SAVANNA RODENTS

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Christopher M Banotai

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INVESTIGATION OF SEED AND SEEDLING PREDATION AND NATURAL HISTORY OF BUSHVELD SAVANNA RODENTS

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Mike Stokes, Advisor

Carl Dick

Scott Grubbs

Dean, Graduate Studies and Research 11/21/17
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I dedicate this thesis to my mother, Mary, who is the single most influential and inspirational person in my life. I could not have competed my degree or this thesis without her unending support

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INVESTIGATION OF SEED AND SEEDLING PREDATION AND NATURAL HISTORY OF BUSHVELD SAVANNA RODENTS

Christopher Banotai December 2017 65 Pages

Directed by: Michael Stokes, Carl Dick, and Scott Grubbs

Department of Biology Western Kentucky University

There is currently a decline in large, old trees within many ecosystems where they play important ecological and economic roles. One ecosystem suffering from this decline is the bushveld savanna of South Africa. One particularly important species in decline is the ecologically, economically, and culturally significant marula tree (*Sclerocarya birrea* subsp. *caffra*). This species' decline is characterized by a steep drop in recruitment of seedlings into the population. Rodents are known to influence plant communities across many ecosystems through herbivory of adult plants as well as predation of seeds and seedlings. This research provides a record of rodent species present in the bushveld savanna ecosystem of Balule Nature Reserve where a decline in marula recruitment is taking place. Further, it offers a summary of morphological statistics and natural history traits for these rodents. Morphological statistics can be used for species identification. Reproductive status of individuals can inform researchers about reproductive phenology and how it may be affected by environmental conditions. Finally, trapping for this study took place during an historic regional drought. Trapping success was used to develop a limited window into how reduced precipitation affects rodent abundances. Morphological traits measured coincide with those available in the literature. Reproductive activity for males and females of one species, Namaqua rock mouse (*Micaelamys namaquensis*), did not overlap completely, with females not being reproductively active while males were.

Individuals captured and identified as chestnut climbing mice (*Dendromus mystacalis*) had statistically significantly longer tails and hind feet, and were heavier than reported in reference works.

Introduction:

Rodent species are known to show spatial and temporal fluctuations in abundances and reproduction, which are often attributed to environmental conditions (Massawe et al., 2011). Rodent population abundances and densities can change based on fine-scale and coarse-scale influences (Massawe, 2011). Rodent reproduction has been found to be correlated with coarse-scale climatic factors such as seasonal rainfall regimes (Massawe et al., 2011). Rainfall facilitates primary production and availability of nutritious seeds, seedlings, and vegetative cover, which are all beneficial resources for rodent populations (Delany, 1972; Leirs, 1992, Massawe et al., 2011). Food availability directly affects rodents' rates of maturation and survival, which increase during the wet season (Massawe, 2011; Sluydts et al., 2007). These positive effects on rodent abundance and diversity occur after a species-specific lag period based on reproductive phenology and resource availability (Yarnell et al., 2007). This lag period is largely unstudied in South African rodents (Massawe et al., 2011). Examples of fine-scale influences on population variability include availability of cover and nesting places, predation pressure (Van Gulck et al., 1998; Vibe-Petersen et al., 2006), and intraspecific and interspecific competition (Leirs et al., 1992). I set out to capture rodents in the lowveld savanna ecosystem during an atypical, historic drought to investigate how environmental conditions may influence rodent abundance and reproductive phenology. ("South

Africa", 2015). Further, I wanted to compare morphological statistics of species that I could capture to those in reference works such as De Graaff (1981) and Skinner & Chimimba (2005).

Study organisms

Relatively little information is available on the natural history of the rodent species in this study. The Namaqua rock mouse (*Micaelamys namaquensis* [A. Smith, 1843]) is usually very abundant relative to the other rodent species in their range (Kok et al., 2012). They are known to be nocturnal generalist foragers with large spatial and seasonal variability within their diets. Leaves, seeds, and arthropods have been found in their feces (Abu Baker & Brown, 2012; Lancaster, 2009). Skinner and Chimimba (2005), as well as De Graaff (1981), suggest that seeds constitute a large portion of this species' diet. Namaqua rock mice usually occupy areas of rocky topography (Abu Baker & Brown, 2012; Skinner & Chimimba, 2005). Breeding September-May, Namaqua rock mice employ a polygynous reproductive strategy and live in family groups often larger than 10 individuals (Fleming & Nicolson, 2004; Lancaster, 2009). There is no sexual dimorphism (Lancaster, 2009). Two to seven pups are usually produced in each litter (De Graaff, 1981). Family groups share nests made from grass or grass-like material jammed into rock crevices or openings in trees (De Graaff, 1981). Walker (2015) estimated that this species reaches densities of 33–300 individuals/ha depending on the season. This species can live up to two years in the wild (Lancaster, 2009).

Red veld rats (*Aethomys chrysophilus* [de Winton, 1897]) are habitat generalists and display significant morphological variation throughout the species' distribution (Linzey & Chimimba, 2008). This species' diet is omnivorous, but they rely more heavily on plant matter such as fallen fruit than other foods, with substantial geographic and seasonal variation (De Graaff, 1981; Linzey & Chimimba, 2008). Red veld rats are known to raid seed crops (Skinner & Chimimba, 2005). This species is nocturnal (De Graaff, 1981). Although they usually occur at lower densities relative to some sympatric rodent species, areas with plentiful groundcover such as vegetation and rocks, have increased densities (Linzey & Chimimba, 2008). Breeding for this species is year-round, peaks in summer, and animals usually produce litters of between two and seven pups (De Graaff, 1981). Red veld rats build burrows with interconnecting runways, often converging on old termite mounds or bushes (De Graaff, 1981). Red veld rats host a broad diversity of ectoparasites and endoparasites (De Graaff, 1981). Because of this, they are believed to be a potential reservoir for zoonotic diseases (De Graaff, 1981).

Nine subspecies are recognized within Smith's bush squirrel (*Paraxerus cepapi* [A. Smith, 1836]), varying in fur color and body size throughout the species' geographic distribution (Skinner & Chimimba, 2005). Males are usually slightly heavier than females (Skinner & Chimimba, 2005). These squirrels are a savanna woodland species, relying on the presence of trees for suitable habitats (Skinner & Chimimba, 2005). These squirrels usually live in small groups consisting of a male, female, subadult offspring, and the most recent offspring (Skinner & Chimimba, 2005). Within this group, sharing a nest, grooming each other, marking each other with anal scent glands, foraging together, and chasing unfamiliar individuals from a feeding area are common behaviors (Skinner & Chimimba, 2005). Males defend the group's territory, but the entire group may also exhibit mobbing behavior upon detecting the presence of a predator (Skinner & Chimimba, 2005; De Graaff, 1981). Smith's bush squirrel is diurnal, often basking in the sun before descending from the trees to forage (Skinner & Chimimba, 2005). Crevices in trees are lined with leaves and grass to be used as nests (Skinner & Chimimba, 2005). Flowers, leaves, seeds, berries, fruits, and bark of an array of species (including *Acacia spp.*), and some insects make up this squirrel's diet (Skinner & Chimimba, 2005). De Graaff (1981) states that Smith's bush squirrels have been reported eating the seedlings of *Acacia* species. The species has also been reported to forage on undigested seeds, including those of marula, remaining in elephant dung within Kruger National Park (Pienaar, 1968). This was understood to be the extent of their impact on the recruitment of that tree species, but recent research has shown that they can penetrate and eat unprocessed marula seeds (Midgley et al., 2012). Like many squirrels, Smith's bush squirrel participates in scatter hoarding behaviors with seeds; this has been witnessed with marula seeds (Midgley et al., 2012; Skinner & Chimimba, 2005). This behavior may facilitate the dispersal of marula and any other plant species whose seeds are hoarded. Producing litters of one to three pups, repoduction takes place year-round and peaks in the warm and wet months of October-April (Skinner & Chimimba, 2005). Research is deficient concerning the parasites and pathogens hosted by this species (De Graaff, 1981).

The bushveld gerbil (*Tatera leucogaster* [Peters, 1852]) is widely distributed throughout southern Africa (Odhiambo et al., 2008). It generally occurs at low population densities (Odhiambo et al., 2008). Bushveld gerbils have an affinity for sandy soils where they develop well-maintained burrows at the bases of grass clumps (Skinner & Chimimba, 2005; Saetnan & Skarpe, 2006). Male-female pairs share burrows; however, complex warrens have been discovered that may be used communally to some extent (Skinner & Chimimba, 2005). Peak reproductive activity for this species (based upon captured, pregnant females) occurs February-June (Odhiambo et al., 2008). The bushveld gerbil is nocturnal (De Graaff, 1981). During the dry season, their diet is mostly made up of foliage, with the grass, seed (trees and bushes), and arthropod composition of their diet increasing during the wet season (Odhiambo et al., 2008; De Graaff, 1981). However, some feeding trials carried out in Botswana showed this species has preference for grass blades over seeds and shoots of other plant species (Saetnan & Skarpe, 2006). Bushveld gerbils frequently cover small stores of food (De Graaff, 1981). Population densities fluctuate with the seasons, low during the wet season and increasing during the dry season (Odhiambo et al., 2008). Timing of breeding varies by geographic location (Skinner & Chimimba, 2005). Litters of two to nine young are produced (Skinner & Chimimba, 2005; De Graaff, 1981).

Some individuals captured in this study were tentatively identified as chestnut climbing mice (*Dendromus mystacalis* [Heuglin, 1863]) based on similar morphological characteristics and statistics to those presented in De Graaff (1981) including the presence of what appeared to be semi-prehensile tails. Although more prominent in eastern and central Africa, this species' distribution does extend into South Africa within the regions of the extreme Eastern Cape, KwaZulu-Natal, Mpumalanga, Gauteng, and Limpopo provinces (De Graaff, 1981; Skinner & Chimimba, 2005). Chestnut climbing mice are known to be omnivivorous foragers, with a tendency toward granivory and insectivory (De Graaff, 1981; Skinner & Chimimba, 2005). Chestnut climbing mice are associated with trees and tall grass where they place their ball-shaped nests woven out of vegetation (De Graaff, 1981; Skinner & Chimimba, 2005). Another strategy employed by the species is to use unoccupied weaver or bishop bird nests (Skinner & Chimimba, 2005). These nests are used by the mice May-July for resting and raising young (Skinner & Chimimba, 2005). New nests are made the following season (Skinner & Chimimba, 2005). Some reports have been made of these mice utilizing underground burrows, though it is unclear if they excavate their own burrows or use those of other species (Skinner & Chimimba, 2005). De Graaff (1981) reports that they are known to be arboreal, descending to the ground at night, while Skinner & Chimimba (2005) state that chestnut climbing mice are terrestrial. These mice are known to produce three to eight pups (De Graaff, 1981). Notable anatomical features include an opposable thumb and semi-prehensile tail (De Graaff, 1981).

Several rodents captured in this study were identified as multimammate mice (*Mastomys natalensis* [Smith, 1834]). Females of this species possess 12 pairs of mammae in two continuous rows extending from the chest to the inguinal area (Skinner & Chimimba, 2005). Multimammate mice occur along the eastern coastal region, extending to the northeastern corner (Skinner & Chimimba, 2005). Multimammate mice occupy a wide range of habitats that experience over 40 cm of rainfall (De Graaff, 1981; Skinner & Chimimba, 2005). In areas receiving less than 40 cm of rainfall, they are often distributed along river valleys (De Graaff, 1981; Skinner & Chimimba, 2005). This species can be commensal with humans, taking up residence in human habitations (De Graaff, 1981; Skinner & Chimimba, 2005). Multimammate mice are known to be pioneer colonizers of disturbed and recovering ecosystems, but are often pushed out by specialists (Skinner & Chimimba, 2005). This species is nocturnal and terrestrial, excavating burrows in the soil or utilizing unoccupied burrows created by other species (Skinner & Chimimba, 2005). Home ranges for this species vary widely across individuals and this difference is not correlated with seasonality (Skinner & Chimimba, 2005). Main food sources for multimammate mice include the seeds of grasses and other plants, dried pods of *Acacia* spp., dried and pulpy exteriors of fruits, and a smaller proportion of insect matter from termites, grasshoppers, and coleoptera (Skinner & Chimimba, 2005). During population explosions or times of food scarcity, multimammate mice are known to be cannibalistic (Skinner & Chimimba, 2005). Breeding patterns do vary across the species' distribution (Skinner & Chimimba, 2005). Multimammate mice reproduce year-round, though rarely in winter, and most commonly with vegetation germination in the wet season (Skinner & Chimimba, 2005). Massawe et al. (2011) determined that in Tanzania, Namibia, and Swaziland, multimammate mouse breeding patterns were strongly correlated with rainfall, with 70% of their adult females in breeding condition during the wet season over a three-year period (2001-2009). Litter size is extremely variable and is associated with environmental conditions (Skinner & Chimimba, 2005). Consequently, this species is prone to population explosions in times of favorable environmental conditions and food availability (Skinner & Chimimba, 2005).

This research set out to investigate natural history traits of rodents native to the bushveld savanna ecosystem of South Africa. To date, much of the research focus in this region has been limited to larger and more "charismatic megafauna" such as elephants, rhinos, and lions. This leads to a void in the knowledge concerning a widespread group of organisms that often produce significant effects on plant communities in other ecosystems (Bricker et al., 2010; Edwards et al., 1999; Linzey & Washok, 2000; Midgley et al., 2012; Ostfeld et al., 1997). Morphological statistics provide important information that can be used for region-specific identification purposes as well as providing references for comparison across a species' distribution. Recording when a species is in breeding condition allows for the tracking of part of its life history phenology.

Methods

During the week of 13 March 2016, six trapping sites representing different microhabitats of Balule Nature Reserve (BNR) were selected. Sites were chosen under the guidance of reserve staff to maximize diversity of ground cover, canopy cover, proximity to surface water, presence of tree species of interest, and overall vegetation community composition. Plant diversity and density as well as ground and canopy cover were characterized by sampling at 1 m intervals along five transects placed across the trapping site. Transects were oriented facing away from the nearest road, and were spaced every 7 m apart across the site starting 2 m in from the left corner closest to the road. These transects were also where the traps were placed. Woody plants were identified to species when possible. Grasses were also identified to species; however, due to the grazing of ungulates and potentially the drought, some grasses were lacking the inflorescences necessary for identification. Identifications were based upon BNR staff knowledge and reference works such as Van Wyk & Van Wyk (2011) and Van Oudtshoorn, (1999).

Site 1 was selected because it possessed an open canopy, several adolescent knobthorn (*Acacia nigrescens*) trees, and high percentage of grass coverage. Site 2 was selected because it possessed a canopy with greater coverage and more living woody content than site 1 and because of the presence of several downed trees, rocks, and a large animal den site that may provide habitat for rodents. This site was dominated by red bush willows (*Combretum apiculatum* [Sond]), a prolific seed producer. Site 3 was selected due to its rocky topography, presence of downed trees that may provide habitat for rodents, and the presence of several knobthorns. Site 4 was selected due to the presence of two mature marula trees, one mature knobthorn, and the presence of large stones and several downed trees that may provide habitat for rodents. Site 5 was selected due to its proximity to the R40 (a main highway), the presence of three marula trees, very little canopy cover, and exceptionally high grass coverage (79%). Site 6 was selected due to an open canopy, high forb percentage (37%), and the presence of downed trees and termitaria that may provide shelter for rodents. Overall, site selection was focused on best representing the different microhabitats within the bushveld savanna ecosystem.

On 11 April, after the traps were baited at site 2, 21/25 traps at were crushed and damaged. Elephants were the suspected culprits and the reserve staff warned that elephants have a propensity to return to places where they find novel objects. Due to this, trapping at site 2 was halted and site 7 was selected. Trapping site coordinates are in Table 1.

Table 1) GPS Coordinates of the seven trapping sites utilized in this experiment.

Site	Coordinates
1: Open Site	S 24.21124, E 030.84408
2: Little Dam	S 24.19713, E 030.84114
3: River Site	S 24.18201, E 30.837565
4: Double Dam Slope	S 24.19127, E 030.82509
5: Roadside	S 24.21325, E 030.84747
6: Oxford Big Dam	S 24.18860, E 030.84235
7: Below double Dam	S 24.19078, E 030.82453

Trapping techniques were approved by the American Society of Mammalogists (Sikes & Gannon, 2011) and the WKU Institutional Animal Care and Use Committee. Trapping occurred between 22 March and 2 August. The types of traps employed were Sherman® LNG12 traps and Sherman® LNG traps, made by H. B. Sherman Traps Inc.®

(3731 Peddie Drive, Tallahassee, FL, USA), and Tomahawk® model 201 traps (6151 U.S. Hwy 51, Hazelhurst, WI, USA) (Fig. 1). Sherman traps are designed to target smaller rodents such as rats and mice, whereas the larger Tomahawk traps are designed to target larger species such as Smith's bush squirrel. Combining different trap types and sizes within an experimental design is understood to be the most effective technique for determining small mammal community composition (Manley et al., 2006).

Figure 1) Models of traps used in rodent trapping at BNR

Traps were arranged in a five by five grid at each site and placed approximately 7 m apart so that the length of one side of the grid was about 28 m, as was done in a similar study at the reserve (Walker, 2015). I placed traps at the nearest clump of vegetation or debris to shelter them from direct sunlight and trampling. Due to the drought conditions and scarcity of groundcover at some locations, the actual distance between traps varied by up to 3 m.

Two different baits were used during this research. From 23 March 2016 to 18 April 2016, traps were baited with a mixture of peanut butter and oats. On 19 March, a switch was made to baiting traps with sunflower seeds in an attempt to increase trapping success. This was maintained through August 2016. Traps were set in the late afternoon and checked early the following morning. Traps were opened and closed at these times to avoid confining the rodents during the heat of the day.

De Graaf (1981) was the diagnostic manual used for field identification of rodents as no individuals could be sacrificed for later expert identification. Manual restraint and grabbing the rodents by the nape of the neck were employed in handling captured rodents. This is considered the best way to handle them and is not considered to be painful (Sikes & Gannon, 2011; Manley et al., 2006). As requested by BNR staff, rodents were placed in large plastic sandwich bags and measurements were taken through the bags. Weight, total length, tail length, hind foot length, ear length, and sex were recorded for each captured individual. Measurements were made in millimeters using a standard metric ruler. Weights, in grams, were taken using a hanging Pesola scale (CH-8834 Schindellegi, SUI). For analysis of morphological measurements, individuals that were captured at the same trap and on the same site or had exceptionally similar measurements to another individual on the same grid were removed from analysis to avoid using duplicate data of the same individual.

All captured rodents were marked for identification purposes with a permanent marker or non-toxic dye. The identification marking was made with the intention of estimating population densities and recording of recaptures using the Schumacher and Eschmeyer variant of the Schnabel method (Krebs, 1999).

Weather data such as daily average temperature, humidity, and precipitation were collected to observe how the drought conditions may affect rodent abundance and density. These data were initially collected online from the Hoedspruit Airforce Base weather station, located ca. 18 km from BNR (www.wunderground.com/weather/za/hoedspruit-air-base).

Results

This study included 4282 trap nights. Considerable variability was present in the number of individuals captured at each trapping site (Fig. 2). There was no seasonal influence on rodent abundances (Fig. 3). Trapping techniques were successful in reducing the exposure of captured rodents to the elements, with only four fatalities taking place during this research project. All fatalities were of rodents captured in outbuildings, therefore were likely to be the consequence of capture myopathy and could not be attributed to exposure to severe conditions. Unfortunately, the marking methods were unreliable and not enough recaptured individuals could be identified for population abundance estimations.

Reproductively active Namaqua rock mouse and red veld rat individuals and the dates on which they were captured are displayed in Table 10. Namaqua rock mouse females were not reproductively active during a period that I was capturing males with descendent testes. Summary statistics for the weight, head and body length, tail length, hind foot length, and ear length for males and females are displayed in Tables 4-9. These largely overlap with De Graaff (1981). However, the values of mean weight, tail length and hind foot length of individuals otherwise identified as chestnut climbing mice were statistically significantly higher than described in De Graaff (1981). Habitat assessments for trapping grids are presented in Appendix 1.

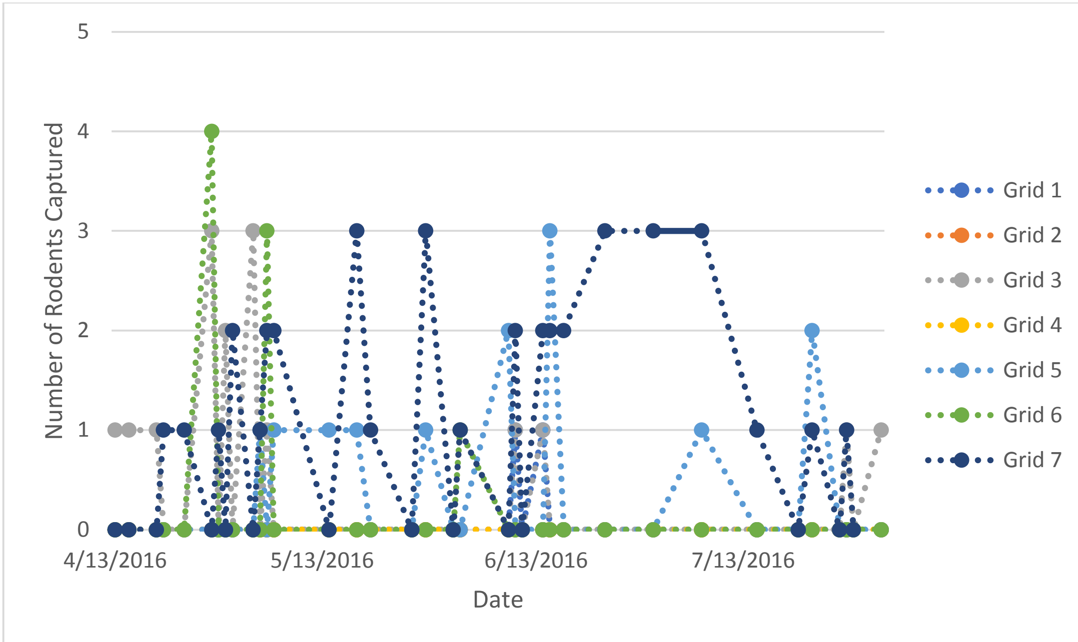
The mean temperature measured each month at the weather station at Hoedspruit Air Force Base from 1 January, 1986 through 31 December, 2015 as well as the mean annual precipitation and number of days with rain are listed below in Table 1. The mean temperatures and precipitation for January-December 2016 are displayed in Table 2. Precipitation during the wet season of 2016 was significantly lower than historic means, creating drought conditions, leading to reduced rodent abundances.

Table 2) Mean historical temperature (°C) and monthly rainfall (mm) measured at Hoedspruit, Airforce Base, Hoedspruit, South Africa for from 1 January, 1986 through 31 December, 2015 adapted from wunderground.com

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean temp. (°C)	24.1	23.7	23.4	20.6	18	16.5	16.6	18.2	21.7	22.9	23.8	24.5
Mean Rainfall (mm)	48	79	61	26	4	11	3	1	15	17	50	40

Table 3) Mean temperature (Celsius) and sum of rainfall (mm) measured at Hoedspruit, Airforce Base, Hoedspruit, South Africa in 2016 adapted from wunderground.com

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean temp. (°C)	24	25	24	24	18	17	16	18	20	21	22	23
Mean Rainfall (mm)	16	25	106	15	4	0.0	3	6	2	10	61	73



igure 2) Number of rodents captured at each trapping site over time.

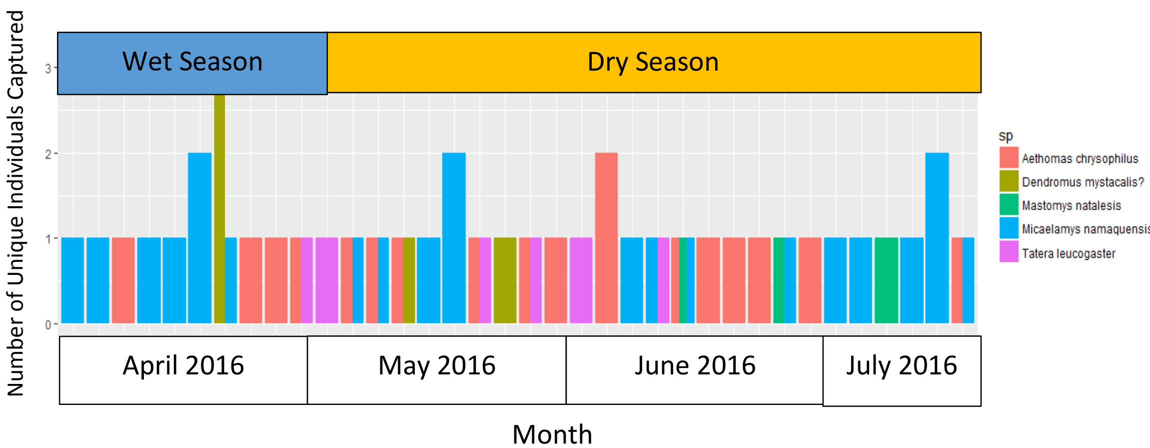


Figure 3) The number of unique individuals per species captured over time, with each bar representing a successful trapping event.

Table 4) Morphological statistics for 16 male and 9 female Namaqua rock mice (*Micaelamys namaquensis*)

Micaelamys namaquensis	Parameter	Mean Value (mm)	N	Range	Standard Deviation
Males	Head and body	104.8	16	75.0—130.0	15.4
	Tail	117.9	16	100.0—155.0	16.3
	Hind Foot	23.7	16	21.0—36.0	3.5
	Ear	15.2	16	11.0—20.0	2.1
	Weight (g)	41.9	16	30.5—73.0	11.7
Females	Head and body	82.5	9	13.5—130.0	33.0
	Tail	119.8	9	100.5—156.0	18.2
	Hind foot	23.4	9	19.5—28.0	2.3
	Ear	15.9	9	13.0—18.25	1.6
	Weight (g)	46.5	9	32.5—71.5	14.8

Table 5) Mean morphological statistics for 6 male and 12 female red veld rats (*Aethomys chrysophilus*)

Aethomys chrysophilus	Parameters	Value (mm)	N	Range (mm)	Standard Deviation
Males	Head and body	118.5	6	100.0—136.0	12.5
	Tail	137.7	6	121.5—157.0	16.4
	Hind Foot	27.0	6	26.0—29.0	1.0
	Ear	20.1	6	18.0—21.5	1.2
	Weight (g)	74.4	6	66.0—87.0	7.7
Females	Head and body	127.5	12	118.0—155.0	10.9
	Tail	136.3	12	110.0—163.0	18.9
	Hind Foot	24.4	12	21.0—26.0	1.9
	Ear	20.0	12	18.0-22.0	1.1
	Weight (g)	66.7	12	53.0—82.0	8.9

Table 6) Mean morphological statistics for 6 female bushveld gerbils (*Tatera leucogaster)*

Parameters	Value (mm)	N	Range (mm)	Standard Deviation
Head and body	107.8	6	74.0—126.0	18.4
Tail	143.6	6	91.5—158.5	25.7
Hind Foot	29.7	6	20.5—32.5	4.6
Ear	19.4	6	15.0—30.5	5.8
Weight (g)	72.2	6	67.5—79.5	5.3

Table 7) Mean morphological statistics for 8 male individuals tentatively identified as chestnut climbing mice (*Dendromus mystacalis*)

Parameters	Value (mm)	N	Range (mm)	Standard Deviation
Head and body	67.7	5	57.5—78.0	8.1
Tail	95.6	5	89.0—102.0	5.2
Hind Foot	21.4	5	19.0—22.5	1.5
Ear	14.2	5	12.0—16.0	1.8
Weight	13.1	5	10.5—18.2	3.2

Table 8) Morphological statistical values from De Graaff (1981) for male *D. mystacalis* and results of a t-test comparing them to individuals I captured and identified as *D. mystacalis*. Asterisks denote statistically significant differences.

Parameters	Value (mm)	N	Range (mm)	Standard Deviation	t-statistic	Two-tailed probability
Head and body	63	16	55—80	6.3	1.4	0.2
Tail	85	16	75—95	5.95	3.6	0.002*
Hind Foot	17	16	16—20	1.1	7.2	<0.001*
Ear	14	16	13—15	.77	.36	.72
Weight	7.4	8	8—14	22.7	4.2	.001*

Table 9) Mean morphological statistics for 2 male and 2 female individuals identified as multimammate mice (*Mastomys natalensis*)

Mastomys natalensis	Parameters	Value (mm)	N	Range (mm)	Standard Deviation
Males	Head and body	109.5	2	105.0—114.0	6.4
	Tail	103.0	2	95.0—11 .0	11.3
	Hind Foot	26.5	2	22.0—31 .0	6.0
	Ear	16.5	2	16.0—17 .0	0.7
	Weight (g)	40.75	2	36.5—45 .0	6.0
Females	Head and body	87.5	2	84.0—91.0	4.9
	Tail	88.5	2	86.0—91 .0	3.5
	Hind Foot	28.5	2	N/A	0.0
	Ear	18.5	2	17.0—20.0	2.1
	Weight (g)	28.25	2	26.0—30.5	3.2

Table 10) Reproductively active individuals and the dates on which they were captured

Species	Reproductive Status	Capture Date
Micaelamys namaquensis	Lactating	4/19/2016
Micaelamys namaquensis	Lactating	4/19/2016
Micaelamys namaquensis	Scrotal	4/26/2015
Micaelamys namaquensis	Scrotal	6/14/2016
Micaelamys namaquensis	Scrotal	6/15/2016
Aethomas chrysophilus	Scrotal	4/30/2016
Aethomas chrysophilus	Lactating	5/6/2016
Aethomas chrysophilus	Scrotal	6/17/2016
Aethomas chrysophilus	Lactating	7/15/2016

Discussion:

South Africa’s dry season is normally April—October and wet season is November-March. Instead, during 2016 this region of South Africa was suffering from the worst drought it had seen in 30 years, accruing miniscule amounts of precipitation (Tables 2 and 3) (“South Africa”, 2015). If the normal precipitation regime had occurred during trapping, more rodents may have been captured in March and early April compared to the rest of the trapping schedule. Rodent capture varied more by trapping site than by season. Previous studies on BNR, conducted in a mild drought and utilizing the same methods, captured seven species of rodents (Walker, 2015). In this study, only five species were captured. This reduction in species richness can be expected with reduced precipitation (Massawe et al., 2011). Smiths’ bush squirrel (*Paraxerus cepapi*), captured in 2014 and not captured in 2016, was visibly active and abundant throughout BNR during times of trapping. In fact, the greatest cause of mortality to seedlings in the BNR screenhouse was predation by Smith’s bush squirrels. The decreases in rodent abundance were likely due to the lack of a seasonal availability of food and vegetative cover during the wet season (Delany, 1972; Leirs, 1992, Massawe et al., 2011).

Morphological measurements for all captured species fit within the ranges of previously published data (De Graaff, 1981). The individuals captured in this study tentatively identified as chestnut climbing mice had statistically significantly longer tail and hind foot and were statistically significantly heavier than previously reported in De Graaff (1981) (Tables 7 and 8).

Namaqua rock mice are known to breed September-May (Fleming & Nicolson, 2004). One lactating female of this species was captured 19 April, 2016. Scrotal males were captured 14 and 15 June 2016. The female's condition fits the description of Namaqua rock mice breeding phenology; however, the males are in breeding condition later than expected. Beatley (1969) tracked winter annual parameters, post-reproductive rodent densities, and precipitation over five years in a Nevada desert, USA. He found that in years with lower precipitation, there was a reduction in the reproduction of rodents. He postulated that this reduction in rodent reproduction is due to reduced availability of winter annual vegetation—a food, vitamin, and dietary water source necessary for production of milk and offspring. Perhaps, a similar phenomenon is occurring in the lowveld of South Africa with Namaqua rock mice with drought conditions causing females not to be reproductively active, though more investigation is required. Red veld rats are known to breed year-round, peaking in summer (De Graaff, 1981). Lactating females of this species were captured 6 May and 15 July 2016. Scrotal males were captured 30 April and 17 June 2016. No scrotal or lactating chestnut climbing mice, bushveld gerbils, or multimammate mice were captured in this study.

I set out to investigate which rodents were present in the bushveld savanna ecosystem of BNR and their natural history characteristics. Results from this research generally support information presented by Skinner & Chimimba (2005) and De Graaff (1981). No species were captured outside of their known distributions. Though few individuals in reproductive status were captured, most who were in reproductive condition fit into published phenologies. Walker (2015) and Barber (2015) collectively captured 136 Namaqua rock mice, 32 Smith's bush squirrels, three single-stripe mice

(*Lemniscomys rosalia* [Thomas, 1904]), 12 pygmy mice (*Mus minutoides* [Smith, 1834]), 22 red veld rats, two pouched mice (*Sacostomys campestris* [Peters, 1846]), and six bushveld gerbils over 6370 trap nights from mid-June through mid-August 2014 at BNR. Not only do their results show higher rodent abundances for most of the species that were captured in 2016, they also display an increased species richness. Lower abundances of rodents relative to Walker (2015) and Barber (2015) coincided with drought conditions. This correlation is expected because rodent reproduction and overall abundance is known to decrease in years of reduced precipitation (Delany 1972; Leirs 1992, Massawe et al., 2011). It is unknown how drought conditions affect species turnover of bushveld savanna rodents in this region. There are at least 25 additional rodent species whose distributions overlap BNR (De Graaff, 1981; Skinner & Chimimba, 2005). Further investigation is needed to determine if they are present in BNR and if so, which trapping methods are effective in capturing them.

Chapter 2: Investigation of Seed and Seedling Predation by Selected Bushveld Savanna Rodent Species on Native Trees

Abstract:

The abundance of large, old trees has been declining across many ecosystems. These trees provide ecological and economic benefits to their local areas. One ecosystem suffering high mortality of adult trees, as well as a decline in recruitment, is the South African bushveld savanna which includes Kruger National Park and its associated parks and nature reserves. I set out to investigate feeding ecology of bushveld savanna rodents, including red veld rat (*Aethomys chrysophilus* [de Winton, 1897]), Namaqua rock mouse (*Micaelamys namaquensis* [A. Smith, 1843]), bushveld gerbil (*Tatera leucogaster* [Peters, 1852]), Smith's bush squirrel (*Paraxerus cepapi* [A. Smith, 1836]), multimammate mouse (*Mastomys natalensis* [Smith, 1834]), and chestnut climbing mouse (*Dendromus mystacalis* [Heuglin, 1863]). Specifically, I investigated if they would facultatively feed on the seeds and seedlings of several bushveld savanna tree species, including marula (*Sclerocarya birrea* subsp. *caffra* [A. Rich, 1831]), jackalberry (*Diospyros mespiliformis* [Hochst]), false marula (*Lannea schweinfurthii* [Stuhlmanii engl]), and knobthorn acacia (*Acacia nigrescens* [Oliv.]). Rodents were trapped in Balule Nature Reserve, Limpopo, South Africa and put through feeding trials where they were presented the seeds and seedlings of these native tree species. Results showed significant differences in rodents' feeding preferences for seeds. Rodents of each species attacked seedlings, excising cotyledons and inflicting other damage, though there was no evidence of preferences among tree species. These results suggest that rodents may be influencing the recruitment of these tree species.

Introduction:

There is currently a decline in the abundance of large, old trees across many ecosystems and this is concerning because it has negative ecological effects ranging from soil erosion and fluctuations in ground temperature to extirpation of cavity-nesting birds and mammals (Lindenmayer, et al., 2012). This decline has been attributed to several phenomena, namely fires, herbivory and trampling by large herbivores, deforestation, and general anthropogenic disturbances (Lindenmayer et al., 2012). Before trees reach maturity, they must first be recruited into the population, then survive adolescence. Throughout these early stages, trees are subject to herbivory from all functional groups of herbivores. African savanna ecosystems are experiencing a decline in the abundance of some large, old trees by a reduction of seedling recruitment (Helm & Witkowski, 2012; Helm et al., 2011).

Savannas are commonly misrepresented as vast open spaces without trees. However, trees are an important structural component of the bushveld savanna, impacting nutrient cycling, water availability, and patterns of space use by wildlife (Belsky, 1994; Shaw et al., 2014). Savanna trees provide ecosystem services such as increasing the primary production in their subcanopy areas, providing nesting sites and food to many animal species as well as food, timber, and other commercial resources to local people (Belsky, 1994; Lindenmayer et al., 2012; Munondo, 2005).

In South Africa’s savannas, older trees are in decline, and there also appears to be a reduction in the recruitment of seedlings into the populations of certain species such as the ecologically and economically important marula (*Sclerocarya birrea* subsp. *caffra*) (Helm & Witkowski, 2012 Jacobs & Biggs, 2002). For example, Cook et al. (2017) found only two marula seedlings in their sampling along eight, 40 m x 200 m transects between marula trees within Jejane Private Nature Reserve, part of the greater Kruger National Park (KNP). In Jejane, there were no reported fires between 2000 and 2016, so burning could not have been a cause of seedling mortality in that study. Elephants are often implicated in marula decline, but they are unlikely to influence the survivorship of sub-adult trees, as elephants do not preferentially target seedlings and smaller size-classes of trees as forage (Boundja & Midgley, 2010; Gadd, 2002; Jacobs & Biggs, 2002). Cook et al. (2017) showed that elephants in the South African lowveld have a significant preference for trees in the 5–8 m height class, followed by those in the 8–11 m height class. If the reduction in recruitment is not caused by elephant, there must be other factors.

Rodents can impact plant community composition via seed dispersal, as well as seed and seedling predation (Bricker et al., 2010; Edwards et al., 1999; Linzey & Washok, 2000; Midgley et al., 2012; Ostfeld et al., 1997). Bricker et al. (2010) showed that excluding rodents from a western Montana, USA, grassland habitat increased the emergence and establishment of several plant species, implying that post-dispersal seed predation by rodents can severely limit the abundance of plants in early life stages. Additionally, protecting seeds from predation by deer mice (*Peromyscus maniculatus* [Gloger, 1841]) increased abundance of plant species of interest for up to three years after the seeds were added to the habitat (Bricker et al., 2010). Ostfeld et al. (1997) found that rodents were primary predators of seeds and seedlings of woody plants invading an old field ecosystem in New York, USA. Moreover, Ostfeld & Canham (1993) established that meadow voles (*Microtus pennsylvanicus* [Ord, 1815]) act as keystone species in their environments. Meadow voles control invasion by woody plants by eating invading seedlings, concentrating surviving seedlings in certain microsites, and altering relative abundances of invading species such as red maple (*Acer rubrum* [L.]), sugar maple (*A. saccharum* [Marshall]), white ash (*Fraxinus Americana* [L.]), white pine (*Pinus strobus* [L.]), and tree-of-heaven (*Ailanthis altissima* [Mill]) (Ostfeld & Canham, 1993). Although rodents clearly influence plant communities, much of Africa's rodent ecology has gone unstudied, creating a void of knowledge concerning species that are abundant, widely distributed, and potentially influence at-risk savanna tree species (Bakker et al., 2006; Midgley et al., 2012; Root-Bernstein & Ebensperger, 2012; Shaw et al., 2014). Understanding the factors that impact recruitment of trees is critical to management and conservation efforts.

To protect adult trees, current management strategies employed in bushveld savannas include wrapping wire fencing around tree trunks to reduce bark stripping and employing beehives to deter elephant foraging. Though these methods can be effective in reducing mortality of adult trees by elephants (Derham et al., 2016; King et al., 2011; King et al., 2017), they are ineffective at protecting seedlings. Kruger National Park and its associated nature reserves, such as Balule Private Nature Reserve (BNR), exemplify the lowveld savanna that is suffering from a decline in recruitment of large, ecologically and economically important tree species (Helm & Witkowski, 2012). Therefore, managers of these areas are searching for new management strategies to increase tree recruitment (C. Spencer, pers. communication, 2016).

A primary focus of this project is the marula tree, a protected species in South Africa since 1962 (Cook et al., 2017). Marula produce many fruits that are consumed by humans and other animals (Nghitoolwa et al., 2003). There are also commercial uses for every part of the tree. The marula tree has experienced a severe decline in abundance within Kruger National Park in recent years with some populations in the northwestern portion of the park becoming locally extinct (Helm & Witkowski, 2012). Between 2001 and 2010, annual mortality rates of adult trees ranged from 3—5% (Helm & Witkowski, 2012).

The purpose of this research was to investigate through a series of feeding trials whether bushveld savanna rodents consume seeds and seedlings of local tree species. Sources such as Skinner & Chimimba (2005) and De Graaff (1981) report many of these species as seed predators or seed crop pests. Therefore, I hypothesized that, 1) rodents will facultatively consume seeds of the tree species of interest. De Graaff (1981), Skinner & Chimimba (2005), and Keesing (1998) list many of the native rodent species as opportunistic foragers that readily consume vegetative matter. Therefore, I also hypothesize that, 2) rodents will facultatively consume seedlings of the tree species of interest.

Methods

Study organisms and Study site:

BNR is a ca. 52,400 ha nature reserve sharing an open border with KNP (Mucina and Rutherford, 2006). This ecosystem exhibits a considerable diversity of rodents (Kok et al., 2012). Rodent species used in this experiment and known to be seed and seedling predators include: red veld rat (*Aethomys chrysophilus* [de Winton, 1897]), Namaqua rock mouse (*Micaelamys namaquensis* [A. Smith, 1843]), bushveld gerbil (*Tatera leucogaster* [Peters, 1852]), Smith's bush squirrel (*Paraxerus cepapi* [A. Smith 1836]), multimammate mouse (*Mastomys natalensis* [Smith, 1834]*)*, and chestnut climbing mouse (*Dendromus mystacalis* [Hueglin, 1863]) (Abu Baker & Brown, 2012; De Graaff, 1981; Lancaster, 2009; Linzey & Chimimba, 2008; Midgley et al., 2012; Pienaar, 1968; Skinner & Chimimba, 2005). Notable large tree species in this area include marula, jackalberry (*Diospyros mespiliformis* [Hochst. ex A. DC]), false marula (*Lannea schweinfurthii* [Stuhlmanii engl]), and knobthorn acacia (*B*[Oliv.]).

The project of which this thesis is a part set out to determine the palatability of several savanna tree species' seeds and seedlings to the native rodents through trapping and feeding trials in 2014 and 2016. In 2014, trials were conducted from mid-June until mid-August by undergraduates from Western Kentucky University. In 2016 I conducted trials March-July. In 2014, seeds for feeding trials were collected locally by BNR staff. In February-March of 2016, relatively few trees set seed due to drought conditions, therefore seeds were ordered from Silverhill Seeds and Books of Cape Town, South Africa (P.O. Box 53108, Kenilworth, 7745 Cape Town, ZA).

During both years, rodent trapping sites were chosen under the guidance of Olifants West Nature Reserve (part of BNR) staff to include diverse habitats based upon the following variables: ground cover, canopy cover, proximity to surface water, presence of tree species of interest, and overall vegetation community composition. Trapping techniques approved by the American Society of Mammalogists and the Western Kentucky Institutional Animal Care and Use Committee were used during both periods (Sikes & Gannon, 2011). Three models of traps, LNG12 and LNG traps (H. B. Sherman Traps Inc.®, 3731 Peddie Drive, Tallahassee, FL, USA), and model 201 traps (Tomahawk Live Trap ®, 6151 U.S. Hwy 51, Hazelhurst, WI, USA) were used at each site. Combining different trap types and sizes within an experimental design is understood to be the most effective technique for determining small mammal community composition (Manley et al., 2006). Traps were also deployed in maintenance buildings on the property.

Three different baits were used in attempts to improve the success rate of trapping. In June-August 2014, each trap was baited with a small amount of a grain and peanut butter mixture that consisted of a 1:16 ratio of peanut butter to commercial bird feed containing corn, sorghum and sunflower seeds. From March-April 2016, traps were baited with a mixture of peanut butter and rolled oats, a readily available and standard bait for trapping rodents. To increase trapping success, traps were baited with sunflower seeds from 19 March, 2016 onwards. Traps were set in the late afternoon and checked soon after sunrise. Traps were opened in the late afternoon and closed during the day to avoid confining the rodents during the heat of the day.

Rodents were manually restrained and secured by the nape while measuring and marking. This is considered the best way to handle them and is not considered to be painful (Sikes & Gannon, 2011; Manley et al., 2006). For each individual, weight, total length, tail length, hind foot length, and ear length were recorded. Sex and reproductive status were determined by visual inspection. Each rodent's morphological measurements and general appearance were compared to De Graaf (1981) for identification. Individuals not chosen for the feeding trials were released at the site of their capture immediately. Lactating or pregnant females were measured, marked, and then released immediately at site of capture to avoid causing them undue stress or separating them from their offspring. The goal was to use all rodents that were captured for seed and seedling trials.

The number of individuals of a species captured determined how many could be used for seed and seedling preference trials.

During 2014, captured rodents were held for a total of three days and nights. The first 24 h was an acclimation period, followed by the feeding trial beginning the night of the second day. Checks on feeding behavior were made throughout the third day, and research subjects were release on the fourth morning. Rodents were held in cages 88 cm wide x 113 cm long x 40 cm tall constructed from 13 mm hardware cloth. When conducting seed preference trials, the seeds were presented on a tray consisting of four, 5 cm tall plastic cups. Cups were distributed approximately 2 cm apart. Seeds were presented in a random order, with two seeds of different species in each cup. Each tray contained two marula seeds, two red bushwillow seeds, two knobthorn seeds, and supplemental grain (three sunflower seeds, three sorghum seeds, and three pieces of cracked corn). Feeding trays were placed in the enclosure at 1630 h on the second day. On day three, checks were done for seed fate at 0730 h, 1230 h, and 1630 h. After the last check, the tray was removed and more supplemental food was added. The animal remained in the enclosure overnight and was released at its original capture site on the morning of day four. Each seed in the trial was given a ranking: completely eaten (1), partially eaten (2), moved but not eaten (3), and untouched (4).

In 2014 trials, seed fates did not differ between days two and three, thus a curtailed protocol was developed for 2016 trials—holding rodents for two days and two nights, the first day and night being an acclimation period and the second night being the testing period, with release on the third morning. During captivity, rodents had constant access to ad lib. water and to food in the form of a commercial rodent food mixture and apple slices.

During 2016, rodents were initially housed in 1 m x 1 m x 70 cm arenas made from lumber and 13 mm hardware cloth. These arenas were harassed by vervet monkeys (*Chlorocebus pygerythrus* [F. Cuvier, 1821]) and baboons (*Papio ursinus* [Kerr, 1792]), thus I moved trials to 1 m x 57 cm commercial rodent cages (plastic base with wire top) and 65 cm x 47 cm clear plastic tubs with wire mesh tops, both located in a plant nursery constructed of shade cloth. A layer of soil ca. 1 to 3 cm thick was spread over the bottom of each arena to create a more natural environment. In both types of cages, a Sherman trap that was fixed open served as a shelter. From late May to early August, rodents were provided with cotton wool as nesting material during cold nights. Between test subjects, each arena and its accessories (water and food dishes) were thoroughly rinsed with water to remove odors associated with the arena's previous inhabitant that may affect feeding behavior.

During the 2016 seed preference trials, animals were presented with functionally unlimited water, two seeds of each tree species, and approximately 15 ml of sunflower seeds on the feeding trays used in the 2014 study. Seeds were presented in a random arrangement of cups to avoid spatial bias. The fates of the seeds were recorded at first light the following morning. Seed fates were ranked undisturbed (1), undamaged and cached (2), partially consumed (3), and fully consumed (4). Seed fate was determined based on the seeds' flesh rather than the seed coat and external features. Supplemental sunflower seeds and grain were not assessed for damage as they were almost always completely consumed.

To test for rodents' inclination to facultatively feed on seedlings of the tree species of interest, the following procedure was followed. Seedlings were germinated in the on-site screenhouse from 22 March through 16 June under a heat lamp within a house due to low soil temperatures. Seedlings along a gradient of growth and development states were selected for trials. The number of leaves and cotyledons on each seedling were recorded before and after each trial to provide a quantitative basis for the degree of damage done during the trial. Photos were taken of each seedling before and after each trial. After photographs were taken, seedlings were planted in a random arrangement in the arena by pouring approximately 350 ml of damp soil into the arena and packing it around the base of the seedling, maintaining it in an upright position.

Seedlings were planted between 19:00 and 21:00 pm. Fates of seedlings were checked at first light. All seedlings were examined to determine the nature and extent of damage and whether damage was caused by the rodents (detectable by bite patterns) or insects. Categories of damage for seedlings are as follows: undisturbed (1), minor herbivory (2), major herbivory (3), uprooted with no other damage (4), and completely consumed (5). Minor herbivory scores were assigned when less than half of the leaves were removed and there was no significant damage to the main stem. Major herbivory scores were assigned when at least half of a seedling's leaves were removed or there was significant damage done to the stem or cotyledons.

Seed preference trials from 2014 were analyzed using Bonferroni-corrected Kruskal-Wallis tests in Statistica© (StatSoft 2013) to determine if there were statistically significant differences in the damage done to seeds of all species. Seed predation data from 2016 were analyzed using Kruskal-Wallis and Wilcoxon Rank Sum Tests within R

Studio version 0.00.903. Some seedlings were uprooted without damage done the seedling. This would still cause mortality of the seedling. Therefore, seedling fates were lumped into either lethal (scores 1 and 2) or nonlethal (scores 3, 4, and 5) groups. Due to this lethal: nonlethal binary relationship, seedling trial results were analyzed using a logistic regression. The regression was performed on a GLM containing tree species and damage (lethal and nonlethal). Model fits were evaluated with AIC values. The logistical regression analysis was also performed within the statistical environment of R Studio version 0.00.903.

Results

In 2014, seed predation trials were conducted with eighteen Namaqua rock mice and eleven red veld rats. Tables 11 and 12 display the results of Kruskal-Wallis analyses performed on the seed trial data. Asterisks denote statistically significant differences in pairwise comparisons. For both rodent species, marula seeds were preferred, followed by knobthorn acacia, then red bush willow.

Table 11) Kruskal-Wallis and Wilcoxon Rank Sum Test results for 18 seed predation trials by Namaqua rock mice on *S. birrea, C. apiculatum*, and *A. nigrescens* seeds

Kruskal-Wallis Test	n=18		P<0.0001
Seed Type	*S. birrea*	*C. apiculatum*	*A. nigrescens*
S. birrea		<0.001*	0.02*
C. Apiculatum	<0.001*		0.68
A. nigrescens	0.02*	0.68*	

Table 12) Kruskal-Wallis and Wilcoxon Rank Sum Test results for 18 seed predation trials by red veld rats on S. birrea, C. apiculatum, and A. nigrescens seeds.

Kruskal Wallis Test:	n=11		P=0.0009
Seed Type	*S. birrea*	*C. apiculatum*	*A. nigrescens*
S. birrea		0.01*	0.03*
C. Apiculatum	0.01*		1.00
A. nigrescens	0.03*	1.000	

In 2016, 24 seed damage assessment trials were completed with Namaqua rock mice, six with red veld rats, one with a bushveld gerbil, one with a multimammate mouse, and one with an animal tentatively identified as a chestnut climbing mouse. Each trial included two seeds of each tree species. A Kruskal Wallis test returned a p-value <.001, indicating a significant difference among tree species. Results of a Wilcoxon Rank Sum Test show distinct differences in preferences of rodents for seeds of different species, with knobthorn being the most preferred, followed by jackalberry, false marula, and marula (Table 13).

Table 13) Wilcoxon Rank Sum pairwise comparisons over 33 seed trials (66 evaluations) for marula, knobthorn acacia, false marula, and jackalberry.

Comparison	P-value
Marula-Knobthorn	<0.001*
Marula-Jackalberry	<0.001*
Marula-False Marula	<0.001*
Knobthorn-Jackalberry	0.02*
Knobthorn-False Marula	0.17
Jackalberry-False Marula	0.52

Thirty-four trials were completed with marula seedlings, twenty-one with knobthorn acacia seedlings, sixteen with false marula seedlings, and nine with jackalberry seedlings. When a logistic regression is performed in R, the first category in alphabetical order is used as a reference for the others, therefore false marula has a Z value of 1.00 in Table 14. The closer a species' Z value is to one, the more similarly rodents interacted with that species' seedlings compared to false marula seedlings. There is no strong evidence of a preference for a tree species. Forty-five observations of major damage and 36 observations of minor damage were made across species. Table 15 displays the distribution of minor and major damage done to seedlings. More lethal interactions occurred than nonlethal interactions, in three of the five species. Marula only had two fewer lethal interactions than nonlethal interactions, the numbers of lethal and nonlethal interactions were tied for false marula.

Thirty trials were completed with Namaqua rock mice, six trials with red veld rats, three trials with multimammate mice, three trials with individuals tentatively identified as *Dendromus*, and two trials with bushveld gerbils. Rodent species was not used in the GLM as there were severe differences in the abundances of each species and it did not improve the fit of the regression model (model=Tree + Rodent: AIC=119.92, model=Tree: AIC=114.69). Further, a $\chi 2$ test was performed to evaluate the significance of each coefficient within the logistic regression. This returned a result of p=0.3323, indicating that rodent species should be removed from the model. This showed that there is not a statistically significant difference between observations of lethal and nonlethal damage done to seedlings of tree species.

Table 14) Z values between seedling species and damage done by rodents across thirty-four feeding trials.

Tree Species	Coefficient
Reference/False Marula	1.00
Marula	.85
Knobhtorn	.19
Jackalberry	.79

Table 15) Distribution of major and minor damage done across tree species by rodents

Tree	Major	Minor
Marula	16	18
False marula	8	8
Knobthorn	16	6
Jackalberry	5	4
Total	45	36

Discussion

This project demonstrated that native bushveld savanna rodents will feed facultatively on seeds of marula, knobthorn, false marula, and jackalberry. This supports reports by De Graaf (1981) and Skinner & Chimimba (2005) that proposed Namaqua rock mice, red veld rats, bushveld gerbils, *Dendromus* spp., and multimammate mice are seed predators. Results of the 2014 seed trials showed that the Namaqua rock mice and red veld rats significantly preferred marula seeds out of the three choices. However, in the 2016 trials, rodents avoided eating marula seeds. The most preferred seed was knobthorn, followed by jackalberry, false marula, and finally marula. In 2016 seed trials, more supplementary food was provided to investigate how an increased abundance of palatable and easy to manipulate food could change rodents' likelihood to consume native tree seeds. Access to palatable supplementary food on a functionally unlimited based likely made the labor necessary to penetrate the tough endocarp of the marula endocarp unappealing. In Jejane Private Nature Reserve, Cook et al. (2017) found 1033 endocarps under 30 female marula trees, 97.1% (n=1003) had at least one missing seed missing. Of these, bite marks were present on 307 endocarps. Further, a total of 2289 locules were counted from the 1033 endocarps, of which 1928 had been opened and were empty (Cook et al., 2017). This suggests that rodents prey upon marula seeds to a significant extent. Damage to seeds likely leads to the mortality. Dalgleish et al. (2012) found that even slight damage to a chestnut seed's meat done by a weevil will drop germination rate from 94 to 32%. Similarly, they found that seeds with more than 50% damage would not germinate (Dalgleish et al., 2012). Rodents did severe damage to the flesh of seeds. Additionally, partially consumed seeds in this study were not cached or covered with soil, further reducing the probability of germination and survival.

Feeding trials also demonstrated that the savanna rodents will feed on seedlings of the native trees. This is undocumented in literature. Young seedlings with fleshy, untapped cotyledons were preferentially attacked. This was evident across all tree species. In marula seedlings, young fleshy cotyledons were excised and completely consumed. This would likely kill the seedlings. Cotyledon damage often produces persistent and severe effects on the target's survivorship, growth rates, reproductive phenology, and ability to compete for space and resources (Bonfil 1998; Dube et al., 2009; Hanley & Fegan, 2007; Kitajima, 2003; Zhang et al., 2011). In addition to being preyed upon, some seedlings were uprooted. This would likely be lethal to the seedling.

The extent to which different categories of damage impact seedling success and survival within bushveld savanna trees needs to be investigated further. This is especially true for damage to cotyledons during early stages of development. During and after germination, cotyledons transfer reserve materials (e.g. lipid, carbohydrates, mineral nutrients) into developing shoots and roots (Dube et al., 2009). Losing these cotyledons during development could reduce the ability for the seedling to continue developing and compete with other surrounding plants for resources. It is important to investigate the timing of herbivory on seedlings because this influences subsequent growth and development (Bonfil, 1998; Dube et al., 2016). The tree species examined in this study maintain their cotyledons for varying amounts of time (pers. observation, 2016).

Bonfil (1998) found that survival of seedlings was greatly reduced by cotyledon removal in both of their study species, and cotyledon damage had lasting effects even up to one month after germination. This suggests that analyzing how long each tree species retains their cotyledons should be assessed because time before the seedlings drop their cotyledons is seemingly when they are most appealing to rodents. The ability to achieve rapid independence from the cotyledons may provide a significant advantage over neighbours, whose growth and reproductive potential are limited by herbivore damage at the same age (Hanley & Fegan, 2007). This would potentially decrease the seedlings' allure to predators and reduce the amount of resources lost in an herbivory event. Further, the time of damage during a seedling's development can be important.

To investigate whether rodents can affect the recruitment of bushveld savannah tree species via seedling predation, additional research needs to be conducted. There may be a gradient of how important the cotyledons are to the development of the four tree species in this study. Similarly, what role cotyledons play within each tree species' development needs to be investigated. Damage to cotyledons that play a more photosynthetic role may have a different impact than damage done to cotyledons that serve as nutrient reservoirs during development (Hanley & Fegan, 2007). For example, BNR staff has plans in place for studies in which cotyledons are manually removed from nursery raised individuals and their survivorship recorded.

Results of this experiment supported the hypotheses that rodents will consume the seeds and seedlings of these four tree species, even when other palatable food is available. Additionally, observations of the preferential utilization of young cotyledons by the rodents leads to more questions concerning the physiological effects on seedlings when major damage occurs to their cotyledons as well as the roles that cotyledons play in the development in each tree species' seedling development. Increased mortality of seedlings may explain at least part of the decline in marula recruitment.

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Appendix I: Habitat evaluations for the seven trapping sites used for this research. Five transects, spaced 7 m apart, were spread evenly across each trapping site. At 1 m intervals along each transect, the groundcover as well as any overhead canopy were noted. Woody plants and grasses were identified to species when possible with help by reserve staff and consulting appropriate references (Van Wyk & Van Wyk, 2011; Van Oudtshoorn, 1999). The legend for the coded matrices is Table A.8.

Table A.1) Transect Evaluation for Trapping Site 1

Species	No ID	No ID	No ID	No ID	No ID No ID	No ID No ID No ID	No ID No ID	
Transect 5	Grass /Forb	Grass	Woody /Forb	Woody /Forb	Woody /Grass	Woody /Grass /Woody	Forb /Woody /Grass	Forb
Species	ff 1			No ID		E 1		
Transect 4	Woody	Soil	Forb	Soil/Grass	Forb	Woody	Soil	Soil
Species	D 5	D 5	D 6	No ID	No ID	N	W	L 1
Transect 3	Woody /Grass	Woody	Woody	Grass	Grass	Grass /Forb	Woody	Woody
Species	No ID	Q			No ID	D 2	No ID	
Transect 2	Grass /Forb	Grass	Forb	Soil	Grass /Forb	Woody	Grass	Forb
Species	No ID			N				
Transect 1	Grass	Forb	Soil	Grass	Forb	Soil	Forb	Soil

		No ID	No ID	No ID	No ID	No ID	No ID	No ID	No ID	No ID No ID
Forb	Soil	Woody /Forb	Grass	Grass /Forb	Grass	Grass /Forb	Grass /Forb	Grass	Woody	Woody /Woody
L 3	No ID	No ID	No ID	No ID						
Woody	Grass	Grass	Grass	Grass /Forb	Forb	Forb	Forb	Forb	Forb	Forb
		D 7			D 8,		No ID		L 2	
Soil	Forb	Woody	Soil	Soil	Woody /Grass	Forb	Grass	Forb	Woody	Forb
Forb	N	N	D 3	O	O	F1			V 1	
Forb	Grass	Grass	Woody	Grass /Forb	Grass	Woody	Forb	Soil	V 1	Soil
No ID	Q	No ID				No ID			J1	SJ1
Grass	Grass	Grass	Forb	Soil	Grass /Forb	Grass	Forb	Forb	Woody	Woody

No ID						No ID	No ID		No ID	No ID
Grass /Forb	Forb	Soil	Forb	Forb	Forb	Grass	Grass	Soil	Grass	Grass
No ID	O	J7	O		gg	N		No ID	No ID	No ID
Grass	Grass	Woody	Grass	Forb	Grass	Grass /Forb	Forb	Grass	Grass /Forb	Grass
			No ID	F2		Q	No ID	N		D 9, J2
Forb	Forb	Soil	Grass	Woody	Forb	Grass z/Forb	Grass	Grass	Soil	Woody /Woody
					V 1		No ID			D 4
Soil	Soil	Soil	Soil	Soil	Woody	Forb	Grass	Soil	Forb	Woody
					C				V 1	D 1
Forb	Soil	Soil	Forb	Forb	Woody	Soil	Forb	Soil	Woody (down)	Woody

Table A.2) Vegetation Evaluation Transects for Trapping Site 2

Transect 1	Grass	Grass/Forb	Grass	Grass	Grass	Grass	Grass	Woody /Grass /Forb	Woody /Grass	Wood y/Grass
Species	Q	Q	Q	Q	Q	Q	Q	D 1, Q	D 1, N	D 1, N
Transect 2	Forb	Grass	Woody /Grass	Woody/Gr ass	Woody /Grass /Woody	Forb	Grass	Forb	Forb	Grass
Species		Q	D 3, T	D 3	D 3, K		T			No ID
Transect 3	Forb /Grass	Soil	Woody /Forb	Soil	Grass	Woody	Forb	Woody	Grass	Woody
Species	Q		H 1		T	R 1		I	T	R 2
Transect 4	Woody	Grass /Forb	Woody /Woody	Woody	Grass	Woody	Forb	Forb	Forb	Woody
Species	K 3	Q	C 1, R	D 7	Q	E 5	D 4	D 4		K 4
Transect 5	Soil	Forb	Forb	Forb/Grass	Grass	Grass	Soil	Grass	Forb	Woody
Species				N	N	N		N		L 1

No ID	ii	N	M 1			N	D 9		M 2, K 5	No ID
Grass	Grass	Grass	Woody	Forb	Forb	Grass	Woody /Forb	Soil	Woody /Woody	Grass
					Q	I	C 2, E 6		D 8	K 4
Soil	Soil	Soil	Forb	Forb	Grass	Woody	Woody	Forb	Woody	Woody
	hh 1		D 5			I		I	No ID	Q
Soil	Woody /Grass	Soil	Woody /Grass	Stone	Forb	Woody	Forb	Woody /Grass	Grass	Grass
		N	E 3, T	E 2, T	E 3, T	A 1			A 2, E 4	E 3, B 2
Forb	Forb	Grass	Woody /Grass /Forb	Woody /Grass /Forb	Woody /Grass /Forb	Woody	Soil	Soil	Woody	Woody /Grass
D 1, N		B 1	T	T	E 1	A 1	A 1, T	E 2	A 2	Q
Woody /Grass /Forb	Stone/Forb	Woody	Grass	Grass /Forb	Woody /Grass	Woody	Woody /Grass	Woody /Grass	Woody	Grass

K 6		M 3, K 7		T			K 7	N, K 7
Woody	Forb	Woody /Woody	Forb	Grass	Forb	Soil	Woody	Woody /Grass
		T	N	N, T	E 7	K 4	T	K 4
Soil	Forb	Grass	Grass	Soil	Woody	Woody /Forb	Grass /Forb	Woody
T		D 6		K 1	K 1, T	K 1		K 2
Grass	Forb	Woody	Forb	Woody	Woody /Grass	Woody	Soil	Woody
E 4, T, N	E 3, Q, O	No ID	N		D 4	D 4	No ID	R 1
Woody /Grass	Woody /Grass	Grass	Grass	Forb	Woody/ Grass	Woody /Forb	Grass /Forb	Woody
D 2, Q			Z				I	I
Woody /Grass	Soil	Soil	Grass	Forb	Forb	Forb	Woody	Woody/Gr ass

Table A.3) Vegetation Evaluation Transects for Trapping Site 3

Species						No ID	No ID No ID	No ID No ID	No ID No ID	No ID No ID
Transect 5	Soil	Forb	Stone	Soil	Stone	Woody	Woody /Woody	Woody /Woody	Woody /Woody	Woody /Woody
Species	E 3	E 3: K 3	E 3K 3	E 3,K 3	E 3: K 3					
Transect 4	Woody	Woody/ Woody	Woody/ Woody	Woody/ Woody	Woody/ Woody	Soil	Soil	Stone	Stone	Stone
Species		R	N, U				No ID			
Transect 3	Forb	Woody	Grass / Woody	Soil	Forb	Forb	Forb	Soil	Forb	Soil
Species			N							
Transect 2	Forb	Forb	Grass	Forb	Forb	Forb	Soil	Soil	Soil	Forb
Species	O	N	B 1	B 1	B 1	No ID	N	N	K	K
Transect 1	Forb	Grass	Woody	Woody /Forb	Woody /Forb	Forb /Grass	Forb /Grass	Grass	Woody	Woody

No ID	No ID				No ID	No ID	No ID	No ID	No ID	No ID
Woody	Woody	Stone	Stone	Soil	Woody	Woody	Woody	Woody	Woody	Woody
			B 1	E4	E 4, K 4	E 4, K 4	E 4, K 4	K 3	K 3	D1
Soil	Soil	Forb	Woody	Woody	Woody /Woody	Woody /Woody	Woody /Woody	Woody	Woody	Woody
K 2	B 4		N	N				B 1 5		
Woody	Woody	Soil/Moss	Grass	Grass/Mos s	Soil	Soil	Soil	Woody	Soil	Soil
					K 2	U1		L	N	
Soil	Forb	Forb	Soil	Stone	Woody	Woody	Forb	Woody	Forb/Grass	Forb
K						I		ee		N
Woody	Forb	Forb	Forb	Forb	Forb	Woody	Soil	Woody	Soil	Grass

No ID	No ID	No ID	No ID	No ID	No ID	No ID	No ID	No ID
Woody	Woody	Woody	Woody	Woody	Woody	Grass	Grass	Grass
D1	E 5	E 5, K 5	E 6	E 6	E 6	E 6	No ID	No ID
Woody	Woody	Woody /Woody	Woody	Woody	Woody	Woody	Woody	Woody
			H		N	N		
Soil	Soil	Forb /Grass	Woody	Forb	Forb /Grass	Forb /Grass	Forb	Soil
	Q: Q	E 1		N	E 2			
B 3	Forb /Grass	Woody	Soil	Forb /Grass	Woody	Stone	Forb	B 2
No ID								
Woody	Forb	Forb	Soil	Soil	Soil	Soil	Soil	Soil

Table A.4) Vegetation Evaluation Transects for Trapping Site 4

Species	No ID	No ID				No ID	No ID	No ID	No ID	No ID
Transect 5	Woody	Woody	Forb	Forb	Forb	Woody	Grass /Forb	Grass /Forb	Grass /Forb	Grass /Forb
Species		No ID	A 1	A 1	Woody	A 1	A 1		E 3	E 3
Transect 4	Soil	Grass	Woody	Woody	A 1	Woody	Woody	Forb	Woody	Woody
Species		No ID	No ID	No ID	No ID					
Transect 3	Soil	Grass	Grass	Grass	Woody (down) /Forb	Forb	Forb	Soil	Soil	Forb
Species				N	N			No ID	E 2	V 1
Transect 2	Forb	Soil	Forb	Grass/Forb	Grass /Forb	Forb	Soil	Forb /Grass	Woody	Woody
Species			N					N		D1
Transect 1	Soil	Forb	Grass	Forb	Forb	Forb	Soil	Grass/Forb	Forb	Woody

No ID	No ID	No ID			No ID				No ID	No ID
Grass	Grass	Grass	Soil	Woody	Grass	Forb	Forb	Forb	Grass	Forb /Grass
E 3	E 3	D3	V 2				No ID	No ID	No ID	No ID
Woody	Woody	Woody	Woody	Soil	Soil	Forb	Grass	Woody	Woody	Grass
					No ID		No ID			No ID
Tree (down)	Tree (down)	Tree (down)	Tree (down)	Tree (down)	Grass	Soil	Grass	Forb	Soil	Grass
		No ID		D				No ID		K 2
Soil	Soil	Soil/Grass	For/Stone	Woody	Forb	Forb	Soil	Soil /Grass	Soil	Woody
		I	K 1	N	K 2					No ID
Forb	Forb /Stone	Woody	Woody /Forb	Grass	Woody	Forb	Soil	Forb	Forb/ Stone	Forb

No ID	No ID		No ID	No ID	No ID	No ID	No ID	No ID
Grass	Grass	Woody (down)	Grass	Grass	Grass	Grass	Grass	Grass
				D4	D4	D4	R1	R1
Forb	Woody (down)	Stone	Woody (down)	Woody	Woody	Woody	Woody	Woody
						D3	D3	D3
Soil	Soil		Soil	Stone	Soil	Woody	Woody	Woody
U1			N			N	Q	
Woody	Soil	Soil/Forb	Grass	Soil	Soil	Grass	Grass	Soil
I				H	E 1			
Woody	Forb	Forb	Forb	Woody	Woody	Forb	Soil	Soil

Table A.5) Vegetation Evaluation Transects for Trapping Site 5

Transect 1	Species	Transect 2	Species	Transect 3	Species	Transect 4	Species	Transect 5	Species

N	D 7	D 7, N	N	O, N	No ID		N,	D 8	No ID	N
Grass /Forb	Woody /Grass	Woody /Grass /Forb	Grass	Grass	Grass /Forb	Forb	Grass	Woody	Grass /Forb	Grass/Forb
N	N	N	N	N, N	aa	N	D 5, N	D 5, O	N	N
Grass	Grass	Grass	Grass	Grass	Grass	Grass	Woody /Grass	Woody /Grass	Grass	Grass/Forb
L 1, O	C 1	O, N	N	N,	No ID	C 2,	N,		N	N
Woody /Grass	Woody /Grass	Grass	Grass	Grass	Grass	Woody /Grass	Grass /Forb	Soil	Grass	Grass
			No ID	No ID	O	N	N	No ID	cc, Q	D 2
Forb	Forb	Forb	Grass	Grass	Grass	Grass /Forb	Grass /Forb	Grass	Grass	Woody /Grass
V 1, D 1	V 1, O	V 1	V 2, O	W 1	dd, O	W 2, O		N	N	N
Woody	Woody /Grass	Woody /Forb	Woody /Grass	Woody /Forb	Woody /Grass	Woody /Grass	Forb	Grass	Grass	Grass

E 2	E 2,	E 2, I	O	B 1	N	N	N		N,	Q, N
Woody /Forb	Woody /Forb /Grass	Woody /Woody	Grass	Woody /Grass	Grass	Grass	Grass	Forb	Grass	Grass
Q	N		E 1	E 1, T	E 1, Q	E 1, D 6	E 1, M, X	Q	N	N
Grass	Grass	Soil	Woody	Woody /Grass /Forb	Woody /Grass /Forb	Woody	Woody /Grass	Grass	Grass	Grass
N,	O	No ID						D 4, N, O	Y 2	N
Grass	Grass	Grass	Forb	Forb	Soil	Soil	Soil	Woody /Grass	Woody/Gr ass	Grass
	O	O		N	No ID	Z, O	I	bb	V 3	V 3, O, T
Forb	Grass	Grass /Forb	Forb	Grass	Grass	Grass /Forb	Woody	Grass	Woody /Grass	Woody /Grass /Forb
N	Y 1	N	N	N	N	N, O	Q	N, O	Q, N	O, N
Grass/Forb	Woody	Grass	Grass	Grass	Grass/Forb	Grass	Grass	Grass	Grass	Grass /Forb

Grass	N	Woody /Grass /Forb	D 3, O	Grass	N	Grass	N	Grass	Q
Forb		Woody /Grass	F1	Forb		Grass	N	Grass	No ID
Grass/ Forb	N	Grass	N	Grass /Forb	N	Grass /Forb	N	Woody	D 9
Grass /Forb	N	Grass	No ID	Grass	N	Grass /Forb	N	Woody	D 9
Grass /Forb	N	Grass	No ID	Forb		Grass	N, N	Grass	No ID
Grass /Forb	N	Woody	U1	Grass	N	Forb		Woody /Grass	D 10, N, T
Grass	N	Grass	O, N	Grass	N	Grass /Forb	N	Grass /Forb	T, Q
Grass /Forb	N	Grass /Forb	N	Woody /Grass /Forb	C 3, N	Forb		Grass	N

Table A.6) Vegetation Evaluation Transects for Trapping Site 6

Transect 1	Species	Transect 2	Species	Transect 3	Species	Transect 4	Species	Transect 5	Species

No ID	No ID	No ID			No ID	No ID	No ID	No ID	No ID	
Woody	Grass	Grass	Forb	Forb	Grass	Grass	Grass	Woody /Forb	Woody	Forb
D3	No ID	SC	D4	P				D4		K
Woody	Grass	Woody	Woody	Grass	Soil	Forb	Forb/Soil	Woody	Forb	Woody /Forb
		D2	D2	D2	D2	D2	D2		D3	
Soil	Soil	Woody	Woody	Woody	Woody	Woody	Woody	Soil	Woody	Soil
	D			K		No ID		R1	R1	
Soil	Tree (downed)	Forb	Soil	Woody	Soil	Grass	Soil	Woody	Woody	Soil
B 1	B 1	B 1	P	P	R	O				C
Woody	Woody	Woody	Grass /Forb	Grass /Forb	Woody	Grass	Forb	Forb	Forb	Woody

		No ID					No ID			
Soil	Forb	Forb /Grass	Forb	Forb	Soil	Soil/branc hes	Woody	Forb	Woody	Forb
P	No ID					C				
Grass	Grass	Soil	Forb	Forb	Soil	Woody	Forb	Soil	Soil	Forb
K	K	G 1	G 1	G 1			L 2	L 2	L 2	
Woody	Woody	Woody	Woody	Woody	Soil	Soil	Woody	Woody	Woody	Soil
E 1	E 1	E 1	E 1	E 1	E 1	E 1				
Woody	Woody	Woody	Woody	Woody	Woody	Woody	Forb	Soil	Forb	Soil
		No ID	B 2	B 2	Q: Q				S	P
Forb	Forb /Grass	Forb	Woody	Woody	Grass	Forb	Forb	Forb	Grass	Forb

Forb/ Grass	O	Grass	No ID	Soil		Forb		Forb /Grass	No ID
Forb	P	Soil		Grass	No ID	Forb		Woody	No ID
Grass	Q	Woody	L	Soil		Forb		Forb	
Forb		Woody	L	Grass	No ID	Forb		Forb	
Forb		Forb		Forb		Forb		Forb	
Forb		Grass	No ID	Soil		Forb		Forb/ Grass	No ID
Forb		Soil/ “Moss”		Soil		Forb		Grass	No ID
Forb/ Grass	P, F1	Grass	No ID	Soil/ “moss”		Forb		Grass	No ID

Table A.7) Vegetation Evaluation Transects for Trapping Site 7

Transect 1	Species	Transect 2	Species	Transect 3	Species	Transect 4	Species	Transect 5	Species

			A4	A 4						
Stone	Stone	Soil	Woody	Woody	Stone	Gravel	Gravel	Gravel	Gravel	Gravel
P		O			O			A 2		
Grass	Gravel	Grass	Gravel	Gravel	Grass	Forbs /Gravel	Forb	Woody	Forb	Gravel
		No ID	N					M		
Gravel	Forb /Gravel	Grass /Gravel	Grass /Gravel	No ID	Soil	Forb	Forb	Woody /Forb	Forb	Gravel
		D 2	No ID	Grass		No ID	I2	I2	I3	
Gravel	Gravel	Woody	Gravel /Grass	Gravel /Forb	Woody	Grass	Woody	Woody /Forb	Woody	Forb
				O						
Soil	Forb	Soil	Forb	Grass	Forb	Gravel	Forb	Soil	Soil	Forb

						No ID	No ID	No ID	No ID	No ID
Gravel	Gravel	Gravel	Gravel	Gravel	Grass	Woody /Forb /Gravel	Woody /Forb	Woody	Woody	Woody
		I6	I6			D 3	D 3			
Soil	Gravel	Woody	Woody	Soil	Soil	Woody	Woody	Stone	Soil	Soil
				I5						
Gravel	Gravel	J1	Grass/Forb	Woody	Soil	Soil	Soil	Soil	Soil	Gravel
I4	Forb	Woody		O						
Woody /Forb	Forb /Gravel	Forb /Gravel	Gravel	Grass	Forb	Soil	Gravel	Gravel	Gravel	Gravel
I1										
Woody	Soil	Stone	Woody	Stone	Stone	Stone	Stone	Stone	Forb	Gravel

		No ID				No ID	No ID
Forb	Forb	Grass	Stone	Soil	Soil	Woody /Forb	Woody
	A 3				D 4	D 4	D 4
Soil	Woody	Soil	Soil	Soil	Woody	Woody	Woody
	D 2		No ID	No ID.			
Soil	Woody	Soil	Grass	Grass	Soil	Soil	Soil
	broad				B 1	B 1	
Gravel	Woody	Soil	Soil	Soil	Woody	Woody	Soil
C 1		A 1	A 1			D 1	D 1
Woody	Soil	Woody	Woody	Forb	Soil	Woody	Woody

Table A.8) Legend for coded habitat evaluation tables. Species are presented in no particular order.

Symbol	**Species**
A	*Acacia caffra*
B	*Acacia nigrescens*
C	*Boscia Albitrunca*
D	*Combretum apiculatum*
E	*Commiphera mollis*
F	*Commiphera shimperi*
G	*Combretum hereonse*

H	*Dichrostachys cinerai*
I	*Grewia Bicolor*
J	*Grewia monticola*
K	*Artabotrys brachypetalus*
L	*Terminalia phanerophlebia*
M	*Commiphora glandulosa*
N	*Enneapogon cenchroides*
O	*Panicum maximum*
P	*Digitaria eriantha*
Q	*Aristada transvaalensis*
R	*Grewia flavescens*
S	*Diplachne fusca*
T	*Brachiaria deflexa,*
U	*Grewia villosa*
V	*Sclerocarya birrea*
W	*Dichrostachys cineria*
X	*Microchloa caffra*
Y	*Terminalia prunioides*
Z	*Hyperhtelia dissoluta*
aa	*Bothriochloa radicans*
bb	*Digitaria arianther*
cc	*Digitaria longiflora,*
dd	*Premna mooiensis,*
ee	*Ximenia microphylla*
ff	*Ximenia caffra*
gg	*Eragrostis superba*
hh	*Psydrax lvida*
ii	*Pogonarthia squarrosa*