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Insectivorous bat diversity in relation to proximity and type of water source at two sites in the Limpopo Valley, South Africa

By

NELUFULE MURUNWA

Student number: 11614169

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Supervisor: Prof. Peter John Taylor, SARCHI Chair on Biodiversity Value & Change, University of Venda

Co-supervisor: Prof. Daniel Parker, University of Mpumalanga

Co – supervisor: Dr Sina Weier, SARCHI Chair on Biodiversity Value & Change, University of Venda

ABSTRACT

Water availability plays an important role in the habitat requirements of bats. Previous studies have shown that water bodies (both natural and artificial) are used by bats and other animals for drinking water and foraging. I collected my data in the semi-arid landscape of the Venetia Nature Reserve (VNR) and the Mapungubwe National Park (MNP) which is bordered by the Limpopo River. I sampled bats acoustically for 25 nights in total at VNR and MNP, and in three austral seasons (autumn, winter and summer). A total of 21030 bat echolocation calls were recorded, and 23 different species were identified. These species represented the families Vespertilionidae, Molossidae, Emballanuridae, Miniopteridae and Rhinolophidae. *Mops condylurus*, *Chaerephon pumilus, Rhinolophus smithersi* were the most commonly recorded species at MNP, while *Neoromicia capensis* and *Mops condylurus* were the most commonly recorded species at VNR. Rarefaction analysis showed no significant differences in the estimated richness/diversity between MNP and VNR. However, VNR sites near artificial water bodies had a higher species richness and diversity compared to sites 500-750 m away. No such trend was evident at MNP, likely because all sampling sites were not more than two kilometers away from riparian habitats along the Limpopo river. These results show both the importance of riparian habitats (contributing to higher diversity and activity associated with proximity to the Limpopo River) and how important artificial water bodies are for bats in semi-arid habitats. My results illustrate that MNP has higher overall bat activity compared with VNR, probably because of its proximity to the Limpopo river. Sampling season and moon phases were also important predictors of bat activity and species richness in this study; there was more activity in autumn than in summer and winter, while winter had the lowest activity. VNR and MNP are protected areas where future research about the biology, morphology and behaviour of bats which are biological indicators should take place in order to improve the understanding of challenges faced such as climate change.

Keywords: Artificial water bodies, Acoustical monitoring, AnalookW, Water availability, Chiroptera.

DECLARATION

I **MURUNWA NELUFULE,** hereby declare that the dissertation for the degree of Master of science in Zoology in school of Mathematical and Natural Sciences at the University of Venda for Science and Technology, hereby submitted by me, has not been previously submitted for a Degree at this university or any other university, that it is my own work in design and execution and that all reference material contained therein has been duly acknowledged.

Signature

Date 25 November 2019

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CHAPTER ONE: INTRODUCTION

Bats (Order Chiroptera) are a large group of mammals that make up a major proportion of mammalian diversity, with insectivorous bats constituting to about 70% of all bats worldwide (Monadjem *et al.,* 2010), this is associated with a higher abundance of insects (including aquatic insects) in riparian habitats (Belwood & Fenton, 1976). Bats are important volant mammals that provide many ecosystems services such as pollination, feeding on agricultural pests and serving as bio-indicators of good ecosystem health (Monadjem *et al.,* 2017), which means they contribute to regulating (insect pest control) and supporting (pollination and seed dispersal) ecosystem services (Warren *et al.,* 2011). Promoting activity and diversity of insectivorous bats provides an alternative strategy for arthropod pest control (MacSwiney *et al.,* 2008) that is less harmful to the biodiversity in farming landscapes than the use of chemicals and pesticides (Maas *et al.,* 2015). Studies such as Boyles *et al.* (2011) and Stahlschmidt *et al.* (2012) have shown that bats play a major role in agroecosystems across the world. In southern Africa, research on the diet of bats using both microscopic and molecular analyses has determined their potential as predators of pest insects in macadamia (*Macadamia integrifolia*) agroecosystems (Taylor *et al.,* 2013a; Taylor *et al.,* 2017). The predation of pests by insectivorous bats has a positive economic impact that benefits farmers (Lopez-Hoffman *et al.,* 2014). While bat species provide many ecosystem services that are valuable to support the sustainability of biodiversity (Kunz *et al.,* 2011), many species face extinction due to various reasons, including the global increase in temperatures, habitat transformation and habitat loss (Mickleburgh *et al.,* 2002). Thomas *et al.* (2004) demonstrated that in some regions over 30% of both plant and animal species will become extinct by 2050 due to climate change. The loss of foraging habitat due to human-induced habitat alterations, such as the conversion of natural landscapes for agricultural production and urban development, also adds major threats to bat species (Racey & Entwistle, 2003). Basic information on bat species is therefore needed to mitigate human - bat conflict and to promote human-bats co-existence (Kunz *et al.,* 2011). Singaravelan *et al.* (2009) found that in many countries bats are not protected legally and, in some countries, they are still categorized as pests.

1.1. Importance of water to bats

Natural water bodies and riparian vegetation play an important role in bat ecology (Sirami *et al.,* 2013). Riparian areas are important for insectivorous bats as they provide key foraging habitats (Hagen & Sabo, 2011). Numerous studies have shown that there is a link between the distribution and activity of bat species and riparian habitats (Racey & Swift 1985; Sullivan *et al.,* 1993). There is more aquatic insects in riparian habitats and they are indeed a food source for bats. Insects (including aquatic insects) are more abundant in riparian habitats (Belwood & Fenton, 1976).Several studies such as Bader *et al.* (2015) and Hagen & Sabo (2011) have shown that riparian habitats, which are characterized by a high concentration of water, will ultimately support a higher availability of resources and therefore a higher bat activity and species richness. The higher rate of bat foraging activity within riparian habitat in comparison to more arid habitats is often attributed to higher insect availability along waterways (Berdon *et al.,* 2017).

While aquatic ecosystems are important foraging habitats for bats (Stahlschmidt *et al.,* 2012), there is a drastic decrease in natural wetlands in many parts of the world. As a result, there has been an increasing developmental interest in the ecological role of artificial wetlands (Berdon *et al.,* 2017). Bats can serve as important indicators of how effective the development of artificial wetlands is to support ecosystem functioning (Stahlschmidt *et al.,* 2012) and bat species are valuable indicators to monitor the impact of agricultural practices. Artificial wetlands can provide foraging habitats and drinking water to bats and other animals, although many bats survive in very arid areas with no drinking water and rely purely on metabolic water. While some species are adapted to very arid environments others dependent on regular water supply and artificial wetlands are additionally important to provide foraging habitats. This is especially important for some bats as they have high metabolic rates and dependent on a regular water supply (Lisón & Calvo, 2011).

Water is a critical resource for bats, especially during dry seasons in arid countries such as Namibia, Botswana and South Africa (Adams *et al.,* 2015). A study by López-González *et al.* (2015) has shown that ponds are important foraging hotspots for insectivorous bats and that they use them more during the dry season than in the wet season. Artificial wetlands may be of critical value to bats for foraging–in arid environments (Berdon *et al.,* 2017). Artificial wetlands are also suggested to be important to mitigate the negative impact of agricultural intensification on bat diversity (Sirami *et al.,* 2013).

Water is of critical importance to many vertebrate and invertebrate taxa in arid landscapes and, as indicated by Oakley *et al.* (1985), bats do depend on water bodies to forage on insects above the surface of the water (Sherwin *et al.,* 2013). The drying out of those water bodies can therefore result in a lower bat activity (Jones *et al.,* 2009).

Natural and Artificial water bodies are important resources for the survival of wildlife animals in arid and semi-arid environments (Korine *et al*., 2016). Bats use both artificial and natural water bodies to forage on aquatic insects and as a source for drinking water (Korine *et al*., 2016). A study by Korine *et al.* (2016) has evidently shown that, In Africa there is evidence that bat activity is higher around areas of water bodies than in arid areas. Also, Monadjem & Reside. (2008) found that the riverine habitat has higher species richness and diversity than dry area in Swaziland.

1.2 Bat diversity in Africa, South Africa and Limpopo

Bats in Africa are understudied and there are only a few studies assessing the conservation status of bats in Africa (Monadjem *et al*., 2018). Basic information on many bats species in Africa is still lacking (Monadjem *et al*., 2010). There have been fewer studies about bat species in Africa than there have been in either Europe or the Americas (Walters *et al.,* 2012), despite Africa having a much more diverse bat fauna. River systems have much higher bat diversity and activity than South Africa (Herkt *et al.,* 2016) and a strong climatic gradient across the country supporting in a high diversity of bat species (Monadjem *et al*., 2018, Rutherford *et al.,* 2006).

1.3 Background information about the sampling of bats

To gain more insight and knowledge about bats, more surveys must be conducted (Mickleburgh *et al.,* 2002). Live- capture methods and acoustic methods are two main sampling methods used in surveying bats (Adams *et al.,* 2012). Insectivorous bats use echolocation to find food and to avoid obstacles at night (Monadjem *et al.,* 2010). Powered flight and the ability to echolocate allow bats to occupy a diverse range of habitats and prey on a variety of insect species (Monadjem *et al.,* 2010, Jones & Teeling, 2006). However, not all bat species echolocate. For example, most species from the family Pteropodidae are not capable of echolocation. Bat detectors, recording echolocation calls, can help increase our understanding of bat species richness and activity in bat studies (Adams *et al.,* 2012). The use of bat detectors can assist in collecting large quantities of data over short periods of time (Adams *et al.,* 2015), and can be placed at various suitable locations (Skalak *et al.,* 2012). Bat detectors can also detect species that are hard to trap using harp traps or mist nets (Berry *et al.,* 2004). For example, rare species like *Nycteris thebaica* are not easily caught (Flaquer *et al.,* 2007), because those species are gleaners and can hover right in front of the net or trap and likewise common Molossidae species are difficult to catch as they are high flying above vegetation (Monadjem *et al.,* 2010). Additionally, bat detectors can result in higher estimates of species richness than live capture methods (O'Farrell & Gannon, 1999), because bat detectors can record large amounts of data in a short time (Adams *et al.,* 2012), with the additional advantage that they can be placed anywhere (Brinkley, 2018).

1.3.1 Acoustic sampling using bat detectors

The introduction of bat detectors have resulted in more opportunities to monitor bats without capturing them (Linden *et al.,* 2014). Bat detectors are now one of the most effective tools preferred and recommended to survey bats across the world (Monadjem *et al*., 2017). Surveys of bats using acoustic detectors can either be active or passive (Adams *et al.,* 2012). Active monitoring allows the researcher to record one sampling site at a time and requires the researcher to be present with the detector when recording (Britzke *et al*., 2013). In active monitoring, the researcher has to physically record and save the detected calls onto the detector (Britzke *et al*., 2013). Passive monitoring, on the other hand, involves detectors that record automatically without the researcher being present at the sampling site (Britzke *et al*., 2013). Passive monitoring can record more than one sampling area simultaneously and on a larger scale if more than one detector is used (Britzke *et al*., 2013).

A study by Monadjem *et al*. (2017) has shown that the use of acoustic surveys has an important role in studying bat ecology in Africa. Taylor *et al.* (2013a) have developed a localized echolocation call library in the northern part of the Limpopo province that helps in the identification of species recorded by the bat detectors. However, several species have calls that overlap with each other, making identification difficult and can result in false positive results

(Brinkley, 2018). The study by Britzke *et al*. (2013) indicated that increasing sensitivity does not necessarily equate to a greater detection.

1.4 Research Objectives and Aims

The aim of this study was to compare the insectivorous bat communities of two adjacent protected areas in northern South Africa: the Venetia Nature Reserve (VNR) and the Mapungubwe National Park (MNP). The main objective was to examine the effects of the proximity to water, and two different kinds of water sources, on insectivorous bat activity, species richness and diversity.

1.5 Hypotheses

I hypothesized that:

- Richness, diversity and activity of bat species will be lower at VNR than at MNP, based on Herkt *et al.* (2016) showing that river valleys like the Limpopo River support high bat diversity.
- Richness, diversity and activity of bat species will be higher closer to water bodies at VNR where water is scarce. This effect will be less pronounced at MNP because of the presence of the Limpopo River.

CHAPTER TWO: MATERIALS AND METHODS

2.1 Study Area

The study took place at Mapungubwe National Park (MNP) and at the Venetia Nature Reserve (VNR). Both reserves are between 300 m and 780 m above sea level, south of the Limpopo River where their topography tends to be flat with sandstone and conglomerate ridges (Götze *et al.,* 2008).The geology of both areas is diverse and the climate that of a semi-arid landscape (Wilcox, 1996), consisting of the topography which is flat with sandstones and provide habitat for a diverse range of plants and animals. The mean annual rainfall at both VNR and MNP is between 300mm and 400mm and main rains occur during summer and extends from the month of October to March (Harrison, 1984). Summers are hot with maximum temperatures reaching over 45ºC while winters are slightly warmer with average temperatures of 10 ºC - 27 ºC (Parker & Bernard, 2018).

2.1.1 Venetia Nature Reserve

The VNR is situated in the north-western corner of the Limpopo Province, South Africa (22º 21'13.42'S; 29º 18'12.55'E). The reserve comprises an area of 35 000 ha owned by De Beers Consolidated Mines. Approximately 3 000 ha are devoted to diamond mining. The nearest towns are Alldays (50km) and Musina (90km) (Götze *et al.,* 2008). The VNR has a monthly average mean minimum temperature that ranges from 16ºC (June – July) to 26ºC (September), while the monthly average maximum temperatures ranging from 27º C to 40º C (October to December) (Cunningham, 1996). VNR is a semi-arid dry habitat with many artificial water points that animals utilize (Cunningham, 1996). The vegetation type of VNR bears close resemblance to landscape units (Savanna biome, Mopane veld, woodlands and Bushveld) of Kruger National Park (Gertenbach, 1983) and is dominated by Musina Mopane Bushveld (Mucina & Rutherford, 2010). The vegetation includes plants such as: *Adansonia digitata, Adenium* spp. (*A. oleifolium* and *A. obesum) Aloe littoralis*, *Peristrophe* spp. (*P. cliffordii* & *P. gillilandiorum – acanthaceae*) and *Sesamothamnus lugardii*, and a rich large mammal fauna, including *Equus quagga* (*zebra)*, *Connochaetes taurinus* (wildebeest)*, Aepyceros melampus* (impala)*, Loxodonta africana* (elephant)*, Taurotragus oryx* (eland) and many others.

The area lies in the central zone of Limpopo mobile belt and it includes the southern edge of more recent Limpopo Karoo sedimentary basin (O'Connor, 1991). The Limpopo Belt consisting of three zones based on structural signature (Cox *et al.,* 1965): the northern and southern Marginal Zones and the Central Zone. Where the Northern Marginal Zone lies within Zimbabwe with structural fabric trending east-northeast to west-southwest (Mkweli *et al.,* 1995). The Southern Marginal Zone lies within South Africa and comprises high-grade metamorphic equivalents of the flanking Archaean granite-greenstone terrains of the Kaapvaal Craton (Du Toit *et al.,* 1983). The Central Zone is situated between the two marginal zones, with folds that trend almost northerly (Watkeys, 1983).

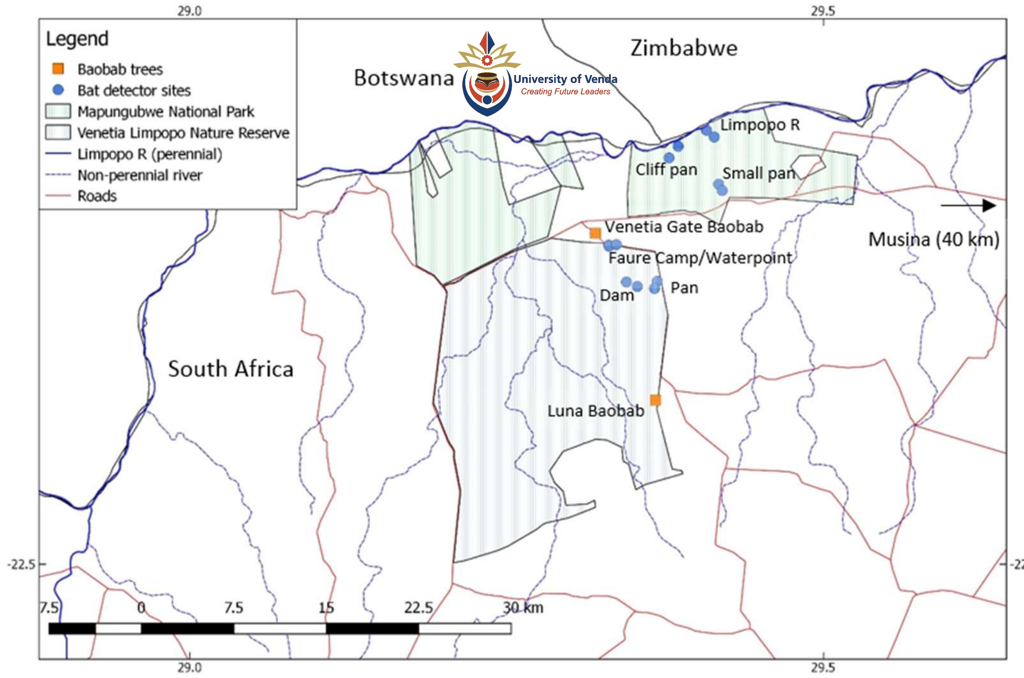


Figure 1: Map showing the locations of bat detector sites and two Baobab trees that were sampled using acoustic sampling (Venetia Gate Baobab) or capture of bats from roosts (Luna Baobab) within Limpopo Province of South Africa. Each bat detector site comprised two stations, one at a water body and the second placed 500-750m away.

2.1.2 Mapungubwe National Park

The Mapungubwe National Park (MNP) is situated at the confluence of the Limpopo and Shashi Rivers in the Limpopo Valley, Limpopo Province, South Africa and is adjacent to the VNR (Figure 1). The MNP shares its border with Botswana and Zimbabwe (Robinson, 1996). The Park is situated 80 km away from Musina town (22º13'19.37'S; 29º20'50.17'E). Similar to the VNR, the MNP is situated in the Musina Mopane Bushveld (Mucina & Rutherford, 2010). The climate is semi-arid, with a mean annual rainfall of 350 mm per annum (Robinson, 1996). Rainfall is highly variable and usually main rainfalls occur during the summer months between October and March (Mucina & Rutherford, 2006). Surface drainage is mostly in a northerly direction towards the Limpopo River. None of the rivers in the area, including the Limpopo, are perennial (Cunningham, 1996). In 1922, MNP was recognized as a site of natural and cultural significance and then declared a wildlife sanctuary in 1947 (Parker & Bernard, 2018). The sites in my study (Figure 1), which are concentrated in the area of the confluence of the Limpopo and Shashi Rivers, are of major importance and scientific value (Rautenbach *et al.,* 1984). The park was started preserve the most endangered mammals animals species such as the *Lycaon pictus* (African wild dog; Robinson, 1996). The vegetation of MNP has also has rich founa consisting of many common mammals such as: *Loxodonta africana* (elephant)*, Equus quagga* (*zebra)*, *Connochaetes taurinus* (wildebeest)*, Philantomba monticola* (blue duiker), *Phacochoerus africanus* (warthog) (Götze *et al.,* 2008).

2.2 Data Collection

Data collection took place during the months of March and June 2017 and April 2018, with five sampling nights per month; and November 2017 with 10 sampling nights, for each site in the MNP and the VNR (25 sampling nights in total at each site). My sampling stations were divided among six sites at both MNP and VNR. Three stations were located at water bodies and another three were 500-750m away from water bodies. For the summer sampling, I sampled for 10 days as I sampled both the MNP and VNR simultaneously from 15 to 26 November 2017. During the winter and autumn sampling, I sampled for 5 days per sampling month at each site concurrently. For MNP, the sampling was delayed for the first two samplings seasons during 2017 due to the delay of the approval of permit to allow me to sample within the park.

2.3. Acoustic sampling

Six bat detectors (at each of MNP and VNR, with one additional detector placed at Faure Camp site at VNR during the March sampling) were placed on trees pointing in the direction where bats were assumed to be foraging (i.e. along potential flight paths; Linden *et al.,* 2014). I monitored bat activity for 25 nights at each of VNR and MNP using SM2 bat detectors (Wildlife Acoustics, Inc., Maynard, MA, USA) for passive monitoring at each sampling station. My selected sampling stations were in open savanna landscapes in both MNP and VNR for all of the sampling nights (Kusch *et al.,* 2004, Monadjem *et al.*, 2010). Bat detectors were activated to record from sunset to sunrise in each season to record during the observed bi-modal peaks in the nocturnal activity of bats (Parker & Bernard, 2018). I also recorded the mean and minimum environmental temperatures (using SM2 bat detectors temperature sensors), moon phase (Lunar calendar, 2018) and sample seasons.

2.4. Capture sampling

I used a harp trap (Faunatech Austbat, Bairnsdale, Victoria, Australia) and mist nets (Ecotone Gdynia, Pomerania, Poland) of either 6-, 9- or 12-meter length to capture bats to verify acoustic identification of species and to add other species such as slit-faced bats (Nycteridae) which are rarely recorded by bat detectors due to their low intensity echolocation calls. As Clement *et al.* (2014) indicated, if acoustic data are not used with other techniques such as live-capture, acoustic surveys of bats may lead to misidentification errors. I set up the mist nets at the sampling sites for at least three hours after sunset. The nets were constantly monitored to ensure that when bats were caught, they did not free themselves from the net or ended up damaging themselves (Barlow, 1999). I also used a harp trap, which was placed near possible roosts such as cavities in a Baobab. The harp trap did not require active monitoring and was left in the selected place from the time set up until the next morning. Individuals captured were processed manually, photographed, and identified to species level using measurements from Monadjem *et al.* (2010), namely; body mass (in grams), age, sex and forearm length (in millimetres) for each individual. After processing, the bats were released and I recorded their release calls for comparison and confirmation of acoustic species identification using Taylor *et al.* (2013b) and Monadjem *et al.* (2017). To identify calls to species level, I used these recent publication and referred to call parameters such as Fc = Characteristic frequency, the frequency at the end or flattest portion of the call; Fk = Frequency at the 'knee' or the point at which the slope of the call abruptly changes from a downward slope to a more level slope; Fmin = Minimum call frequency; Fmax = Maximum frequency and Duration = Total duration of the call, from Monadjem *et al.* (2010) and Taylor *et al.* (2013a).

2.5 Acoustic identification and accuracy

Bat calls were analysed using AnalookW software (version 0.3.8.13; Corben, 2006). The WAV files were converted to ZC format using Kaleidoscope viewer software (version 1.1.15; www.wildlifeacoustics.com). The calls were identified to species level using the library of reference calls, which included identified bat calls from the Soutpansberg and Blouberg Mountains from northern South Africa (Taylor *et al*., 2013a) as well as several studies including identification keys (Taylor *et al*., 2013a; Monadjem *et al.,* 2010; Monadjem *et al.,* 2017). Although AnalookW characteristically measures 10 call parameters (Monadjem *et al.,* 2017), I only used four measurements which have been shown to be useful in identifying bats in other areas of southern Africa (Taylor et al., 2013a). The calls were identified based on the characteristics of their call duration (number of calls per seconds), frequency minimum (Fmin), frequency maximum (Fmax), band width and frequency at the knee (F_k), Characteristic frequency (Fc), the frequency at the end or flattest portion of the call (Monadjem *et al*., 2010; Taylor *et al*., 2013b; Parker & Bernard, 2018)(Table 5). Molossidae species were identified by low frequency calls (F_k<30 kHz) with a long duration (>10 ms) and narrow bandwidth (<10 kHz). Bats belonging to family Vespertilionidae and Miniopteridae were identified by their high frequency calls (F_k> 30 kHz) with short durations (<10 ms) and broad bandwidth (>20 kHz*).* The Rhinolophidae were identified through medium to high peak frequency (>30 kHz), with long durations (10-100 ms) (Monadjem *et al*. 2010, Taylor *et al.* 2013a) (Table 5). Out of the 23 species I identified with the help of the library reference and guidance of senior colleagues, I am confident in the identification of all 23 (Table 3). I did not record or label any calls as unknown.

2.6 Data analysis

Bat activity was measured as the number of bat calls passes recorded per night of sampling (Monadjem *et al.,* 2017). The activity was also calculated as the number of active minutes per night based on Miller's index (Britzke *et al*., 2011), but since both measures gave the same results, and since log values were used to account for biases in numbers of passes, I only included the number of passes in the final presented analysis. The positively identified calls were arranged according to the date recorded and number of files recorded per night (Linden *et al.,* 2014). Each file recorded per night gave the number of recordings for each particular species. The activity index was calculated based on the number of passes per night regardless of which species was occurring. For statistical analyses, I used the program *R* (version 3.1.0; R Core Team 2014). The difference between bat activity during the sampling seasons was tested using generalized linear mixed models (glmer). Simple linear regression was applied to test for possible differences in the activity of bats at VNR and MNP (Taylor *et al.,* 2015). Generalized linear mixed models (glmer) were also applied to the data with site as a random factor with a Poisson distribution to test whether there were significant differences between the richness, diversity and activity of bat species near water and at sites 500-750m away from water as well as between sample seasons, reserves and moon phases, in each sampling season included all the number of sampling days. All models were tested for normality of the response variables (Shapiro-Wilk test) and constant errors were tested and their logarithms were used to test those models. I used log-transformed values of activity (number of passes) and richness (number of species) to account for the fact these count variables are usually right-skewed (Colwell *et al*., 2013).

The package “iNEXT” was used calculate species diversity from the acoustic data. The rarefaction does this for three situations corresponding to “Hill numbers” (or q-values), 0, 1 and 2. i.e. species richness (q=0), exponential of Shannon’s index (q=1) and inverse of Simpson’s index (q=2). So, q=1 and q=2 are measures of species diversity which include evenness. This was calculated for each site separately and also for the different seasons. Rarefaction and extrapolation estimators were calculated using the “iNEXT" and “ggplot2”.

Estimated species richness (Chao2) was calculated for each sampling site per night to plot rarefaction curves. The Rarefaction and extrapolation of data using Hill numbers were used to analyse diversity data using rarefaction analysis (Chao *et al*., 2014). This was done to compute estimators of rarefaction and extrapolation species richness in order to calculate the sampling efficiency in generating an estimated species richness within sampling surveys (Parker & Bernard 2018). The “iNEXT” package of Colwell *et al.* (2013) was used to test and calculate the Incidence – frequency sample – based approach for Incidence – based Rarefaction Extrapolation (R/E curves) separating plots by site. This type of sampling curve plots the diversity estimates with respect to sample size. The “iNEXT” package was also based on sample-size-based differences in R/E sampling curves to calculate the diversity estimates for rarefied and extrapolated samples up to an appropriate size in the study area. In addition, I also constructed a coverage-based R/E sampling curves using iNEXT to compute diversity estimates for rarefied and extrapolated samples with sample completeness to a suitable coverage. Another standard way to analyse diversity data is to use rarefaction analysis to compute estimators of species richness and diversity I used the data of an “incidence-based” approach (the number of nights for which each bat species was recorded) to give a list of species and number of calls/nights recorded for each sampling sites.

2.7 The IUCN Redlist conservation status for all recorded bat species at VNR and MNP

All the species recorded by both acoustic and live capture technique surveyed in this study are listed as “Least Concern”, except for the *Rhinolophus smithersi* which is listed as “Near threatened”. Although near threatened, their population is said to be stable according to IUCN Redlist (IUCN, 2017).

CHAPTER THREE: RESULTS

A total of 23 insectivorous species were acoustically recorded and positively identified in this study, 22 species each at MNP and VNR with *Nycteris thebaica* recorded at VNR only and *Nycticeinops schlieffeni* recorded only at MNP. Extrapolated richness based on rarefaction did not vary among sites (wide overlap in 95% confidence intervals) although both diversity measures showed higher values at MNP than VNR with minimal overlap between 95% confidence intervals among species richness and species diversity (Figure 2). On average, more species (about 11 per night) were recorded per night at MNP compared with VNR (about 7 per night) (Figure 3). The species recorded belonged to six families of bats: Vespertilionidae, Molossidae, Emballonuridae, Miniopteridae, Rhinolophidae, and one species belonging to Nycteridae recorded from live capture only. I recorded 21030 calls in total in both MNP and VNR, MNP had more calls (12958 calls) than VNR (8072 calls) (Figure 8 and Table 5). Live capture sampling techniques resulted in eleven individuals of four species being captured on VNR in this study (Table 6).

3.1. Species composition

Out of a total 21,030 calls recorded in MNP and VNR, *Mops condylurus* (23.61%) and *Neoromicia capensis* (15.87%) were the most recorded species. *Laephotis botswanae, Myotis welwitschii* and *Rhinolophus darlingi* were the least recorded species (only 0.15% of total calls recorded) (Figure 8). My results showed that season and water were significant predictors of bat species richness at VNR (Figure 6, 7), but not at MNP. Also, in general, combining data from different reserves, sample seasons and moon phase (but not reserve proximity to water or minimum nightly temperature), were the only other significant predictors of species richness (Table 1a). Although there was a higher species richness in MNP than VNR (Figure 3), there was no statistically significant difference between the sites at MNP (which were at water bodies and 750m away from water bodies) (Figure 6). In autumn, species richness was higher than in summer and winter seasons (Figures 4, 7).

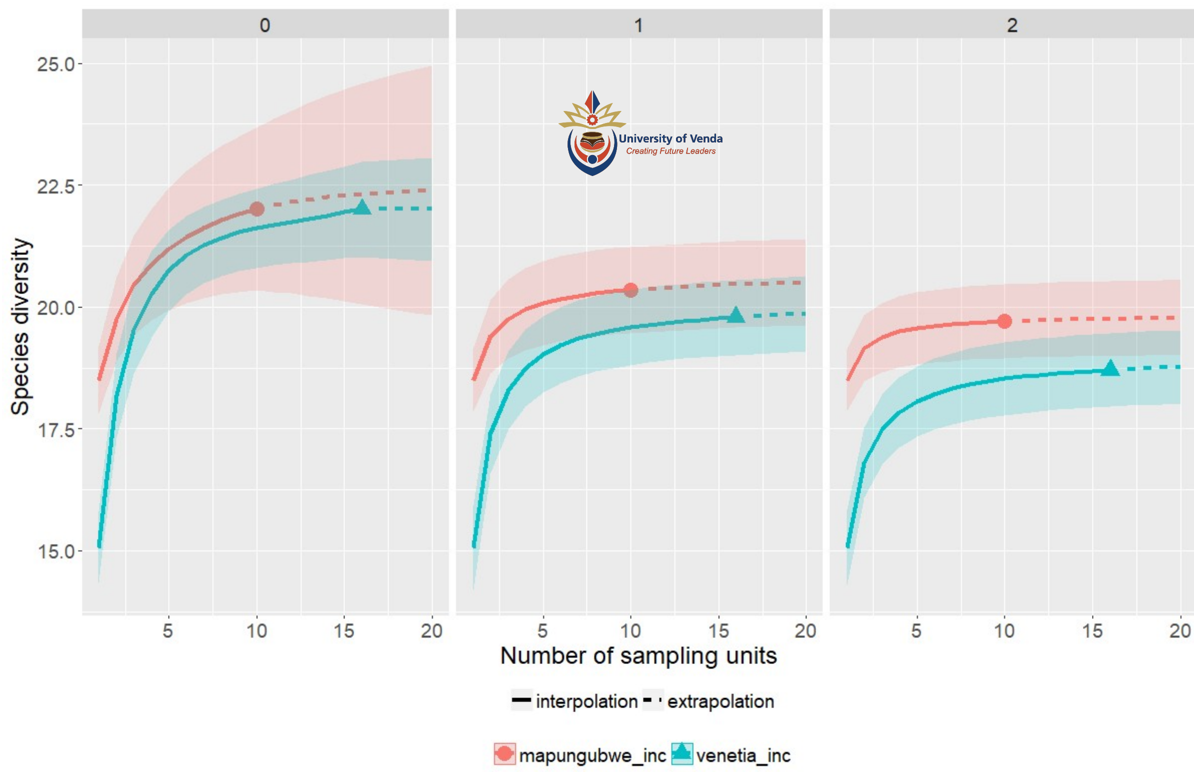


Figure 2: Comparison of sample-size-based rarefaction (solid lines) and extrapolation (dashed curves), up to sample units (number of nights) of 20 for species richness (left panel), Shannon diversity (middle panel), and Simpson diversity (right panel). The shaded area represents the 95% confidence intervals.

3.1.3 Species richness from capture sampling

Eleven individuals of four species were caught using the mist nets and the harp trap. Of these species caught, two individuals were *Nycteris thebaica*, four were *Rhinolophus smithersi*, four were *Nycticeinops schlieffeni* and one *Chaerephon pumilus* (Table 6). Seven individuals were caught from the Luna Baobab at VNR including two individuals of *Nycteris thebaica,* four individuals of *Rhinolophus smithersi* and one individual of *Nycticeinops schlieffeni* (Table 6). Four individuals were caught from the Faure Waterpoint (Figure 1).

Table 1: Generalized linear mixed models (glmer) models showing the relationship of species richness and b) bat activity (log number of passes) with the different predictors; sample season (autumn, summer and winter), moon phase (new moon and last quarter) and reserve (MNP and VNR). In the tables below, variables were compared with default values for MNP (for reserve), last moon quarter (for moon phases) and autumn (for season). Thus “Moon phase (New Moon == 0)” tests for significant differences between New Moon and Last Quarter, and “Sample. Season (summer==0)” tests for differences between summer and autumn. Note that the variables, water body proximity and temperature were included in earlier models but excluded by selecting based on AIC the best models using the “dredge” function. P (>|z|) is the tail area in a 2-tail test, with the z value as the Wald statistic for testing the hypothesis that the regression coefficient is zero.

a)

<table>
<tr><th></th><th>Estimate</th><th>Std. Error</th><th>z value</th><th>Pr (>|z|)</th></tr>
<tr><td>(Intercept) ==0</td><td>1.9719</td><td>0.2541</td><td>7.759</td><td><0.001</td></tr>
<tr><td>Moon phase (New Moon == 0)</td><td>0.9243</td><td>0.2013</td><td>4.591</td><td><0.001</td></tr>
<tr><td>Reserve (Venetia Nature Reserve==0)</td><td>0.3502</td><td>0.2427</td><td>1.443</td><td>0.149</td></tr>
<tr><td>Sample.season (Summer== 0)</td><td>-1.1486</td><td>0.1659</td><td>-6.923</td><td><0.001</td></tr>
<tr><td>Sample.season (Winter ==0)</td><td>-0.7127</td><td>0.1175</td><td>-6.064</td><td><0.001</td></tr>
</table>

b)

<table>
<tr><th></th><th>Estimate</th><th>Std. Error</th><th>z value</th><th>Pr (>|z|)</th></tr>
<tr><td>(Intercept) ==0</td><td>3.3575</td><td>0.7709</td><td>4.355</td><td><0.001</td></tr>
<tr><td>Moon phase (New Moon == 0)</td><td>3.2169</td><td>0.6645</td><td>4.841</td><td><0.001</td></tr>
<tr><td>Reserve (Venetia Nature Reserve==0)</td><td>1.5606</td><td>0.7363</td><td>2.120</td><td>0.034</td></tr>
<tr><td>Sample. Season (Summer== 0)</td><td>-3.4851</td><td>0.5279</td><td>-6.601</td><td><0.001</td></tr>
<tr><td>Sample.season (Winter ==0)</td><td>-1.7587</td><td>0.3839</td><td>-4.581</td><td><0.001</td></tr>
</table>

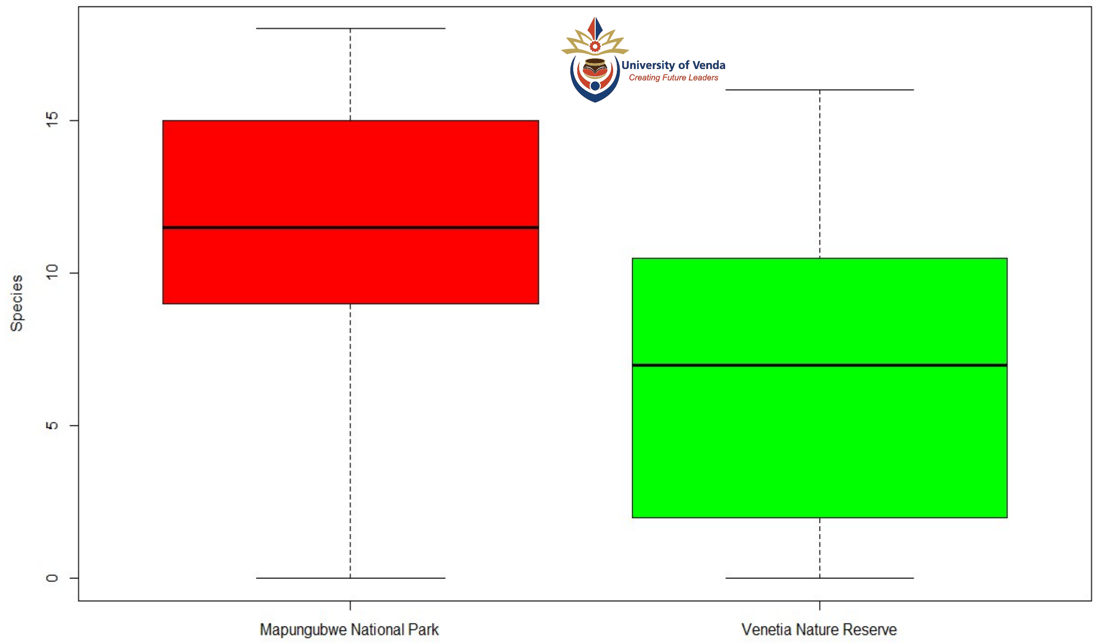


Figure 3: Box plots showing bat observed species richness at MNP and VNR combined determined by the (glmer) models. The error bars indicating the standard error of the mean, with the black middle lines indicating the median and the lower and upper quartile observed.

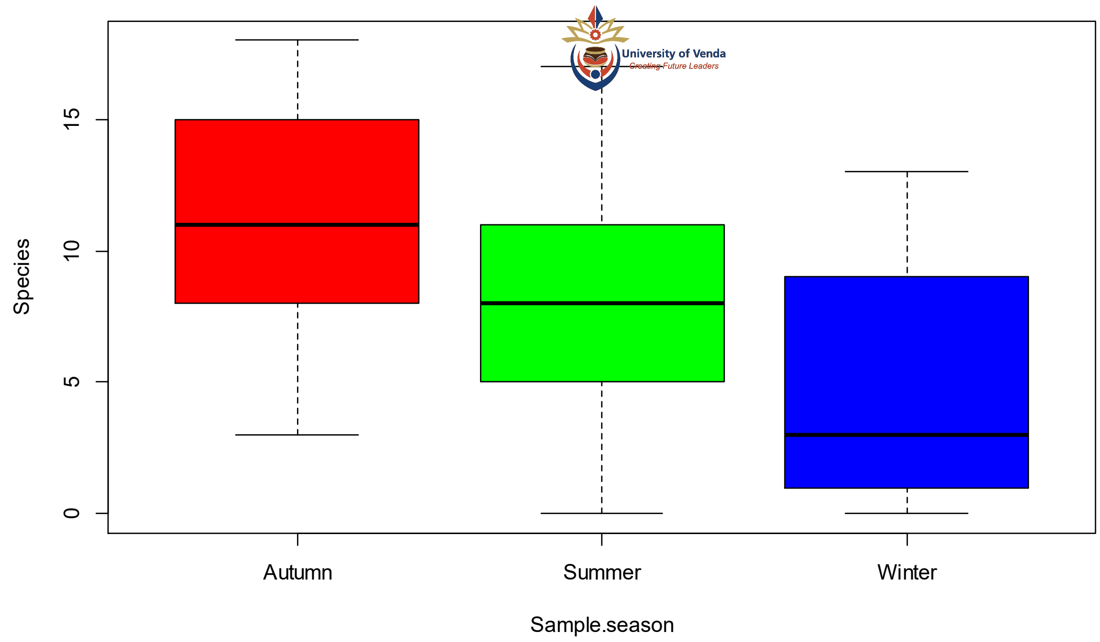


Figure 4: Box plots showing bat species richness for three different seasons of autumn, summer, and winter at VNR and MNP. The error bars indicating standard error of the mean, with the black middle lines indicating the median and the lower and upper quartile observed ($p < 0.001$).

3.2 Activity

Water had a significant, positive influence on bat activity (log number of passes per night) at VNR ($t=-6.29$, $df=91$, $p < 0.001$) but not at MNP ($t=1.125$, $df=47$, $p = 0.268$) (Table 1b, Figure 6). The activity of bats around water was not as pronounced at MNP, as there was higher activity away from the water bodies at MNP than at VNR. The new moon had a higher rate of passes than the last quarter (Figure 5). There were more passes of bats in autumn than in winter and summer (Figure 7), also summer had more passes than winter. The acoustic sampling on the 17 November 2017 at Venetia Gate Baobab tree resulted in 274 calls being recorded per night (Table 2). This activity was compared to the mean of 560 calls per night from the 20th to 22nd November 2017 at the Faure water point which was 1.5 km away from Venetia gate Baobab (see Table 2). The activity was also compared to a site which was 750m away from Faure water point and 2 km away from the Venetia Gate Baobab over six nights of sampling (from 20th to 25th November 2017) where there was no activity recorded (Table 4).

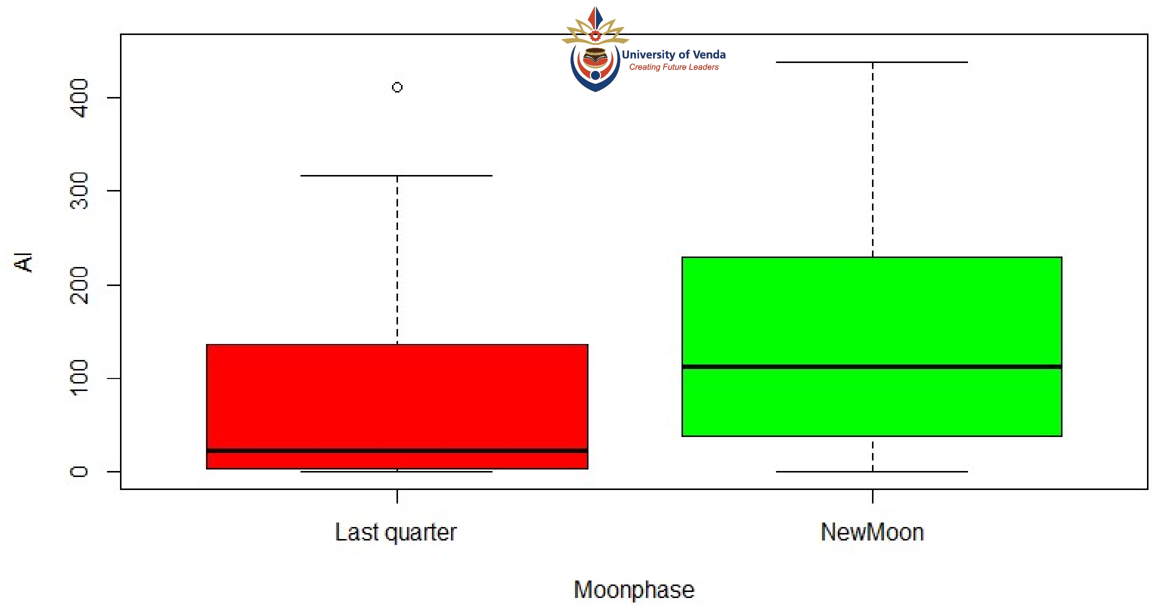
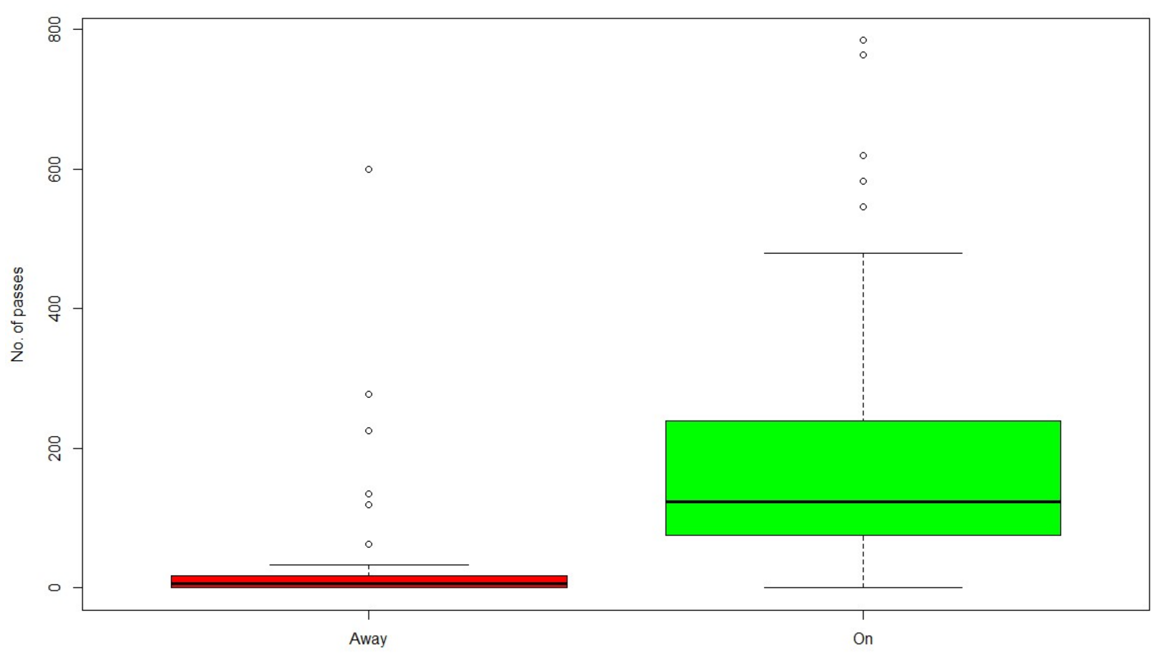


Figure 5: Box plots showing Activity index for two different moon phases' new moon and last quarter at VNR and MNP. The error bars indicating standard error of the mean, with the black middle lines indicating the median and the lower and upper quartile observed.

a)



b)

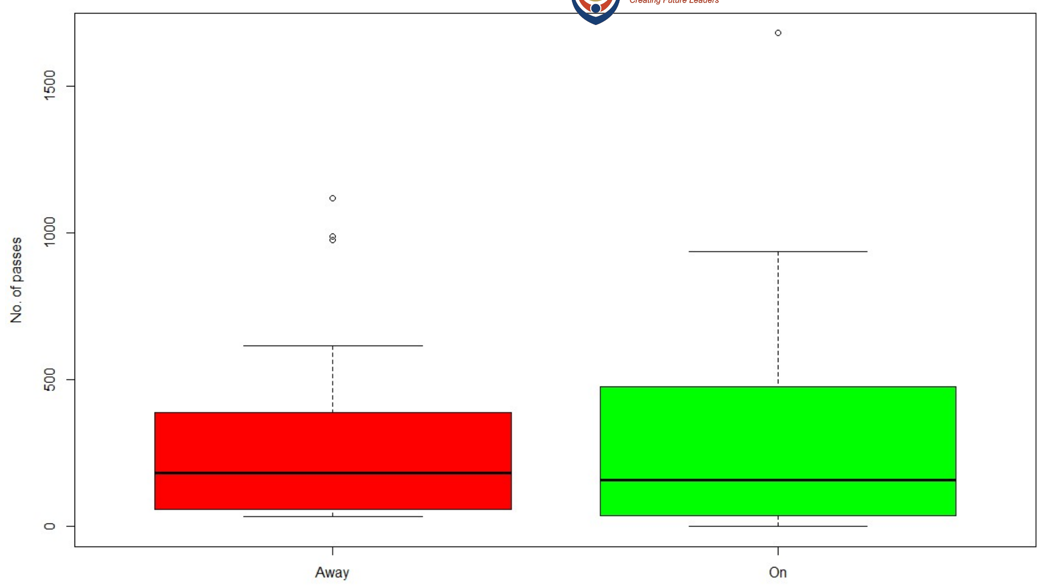


Figure 6: Box plots showing bat activity (number of passes per night) at and away from water points at a) VNR, and b) MNP. The error bars indicating standard error of the mean, with the black middle lines indicating the median and the lower and upper quartile observed. With more outliers in sites away from water bodies in both VNR and MNP.

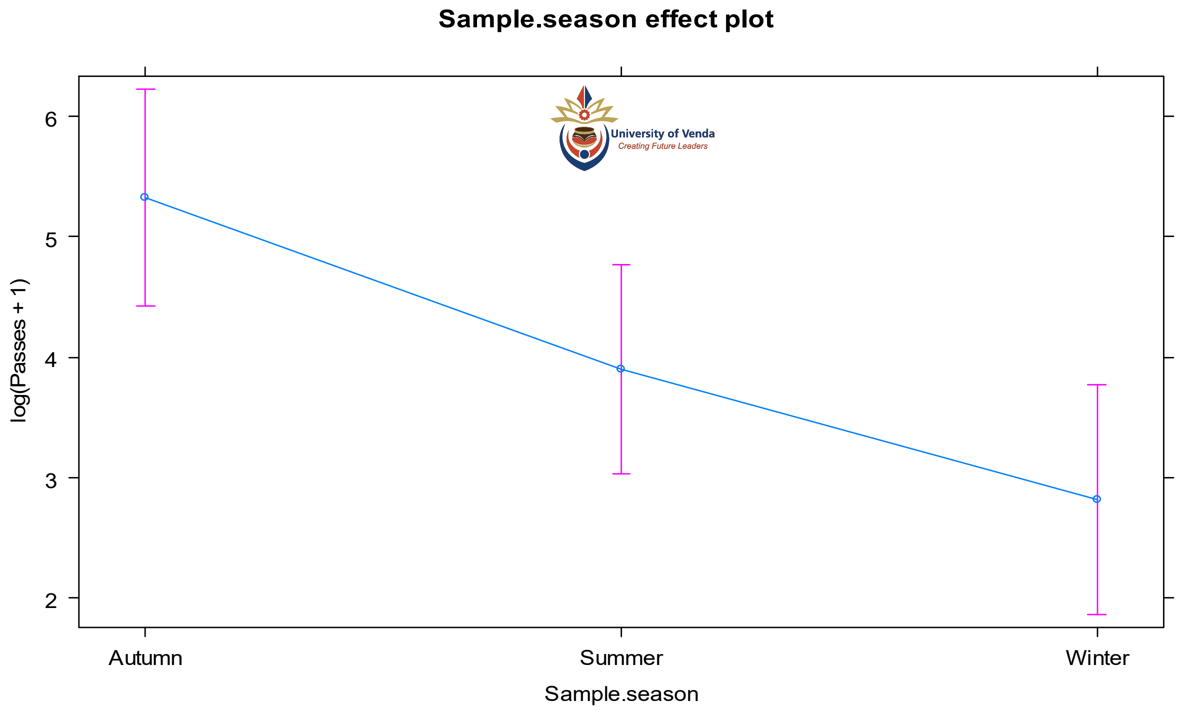


Figure 7: Plot showing bat activity of sampling seasons for three seasons (autumn, summer and winter) at both VNR and MNP combined. With summer and winter bars representing a no significance different between the two seasons, but autumn bar showing a significant different compared to winter.

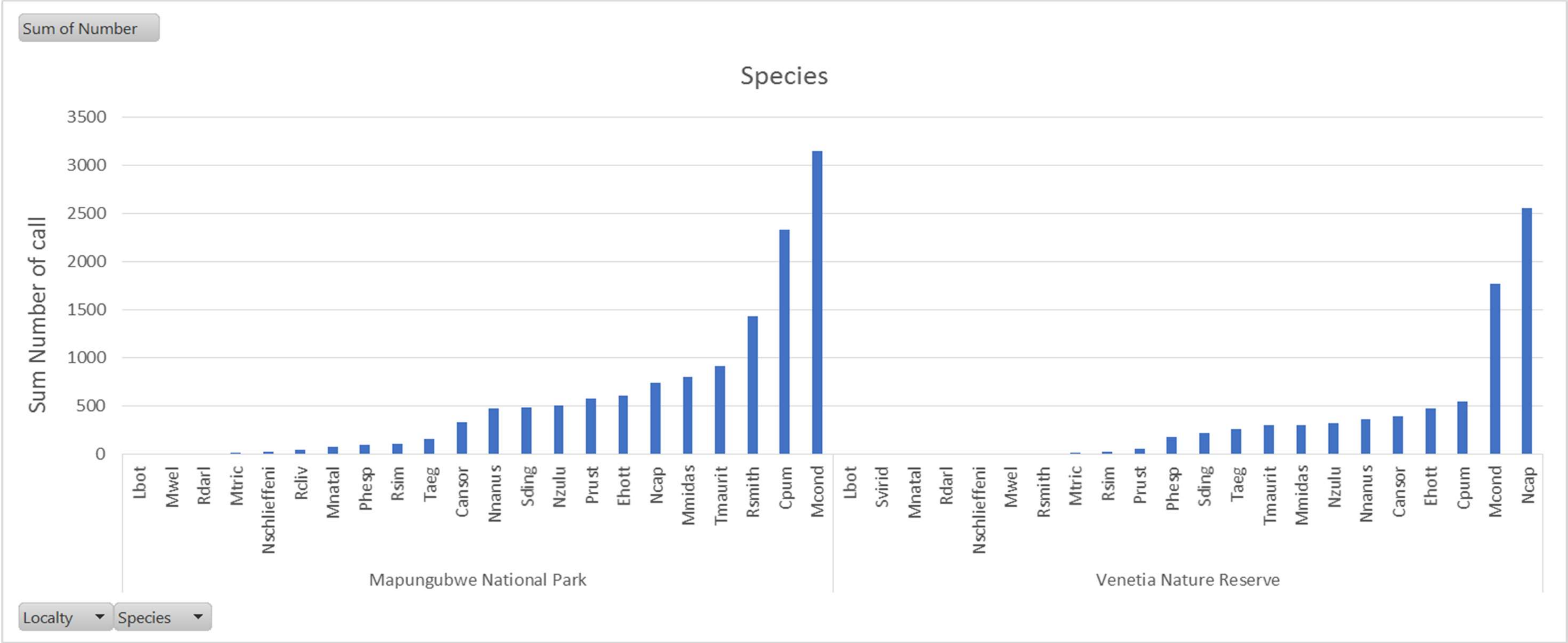


Figure 8: The relative number of calls of the bat species at Mapungubwe National Park and Venetia Nature Reserve (for full species names refers to species codes list (Appendix A).

Table 2: Summary data showing the activity index (referring to the overall bat activity for each night) and number of passes for each species across Venetia Nature Reserve at Venetia Gate Baobab situated 1.5 km away Faure Water point during the summer flowering seasons of Baobab on the 17 November 2017.

Family/Species	AI	Number of Passes
Rhinolophidae		
Rhinolophus smithersi	1	5
Molossidae		
Chaerephon ansorgei	1	3
Mops midas	1	3
Chaerephon pumilus	11	40
Mops condylurus	30	61
Vespertilionidae		
Eptesicus hottentotus	1	3
Nycticeinops schlieffeni	1	5
Scotophilus dinganii	2	6
Neoromicia nana	3	12
Pipistrellus hesperidus	4	20
Neoromicia zuluensis	5	27
Neoromicia capensis	25	89
Total	**103**	**274**

Table 3: Summary table of the foraging groups and detections of 23 bat species recorded within the MNP and VNR in South Africa during seasons of autumn (March 2017 and 2018) for both MNP and VNR, winter (June 2017) which I only sample at VNR and summer (November 2017) for both MNP and VNR.

Species	Site		Foraging group	Recorded by bat detector	% of bat calls recorded in total
	VNR	MNP			
Vespertilionidae					
Eptesicus hottentotus	Yes	Yes	Clutter-edge	Yes	5.23%
Laephotis botswanae	Yes	Yes	Clutter-edge	Yes	0.01%
Myotis tricolor	Yes	Yes	Clutter-edge	Yes	0.19%
Myotis welwitschii	Yes	Yes	Clutter-edge	Yes	0.07%
Neoromicia capensis	Yes	Yes	Clutter-edge	Yes	15.87%
Neoromicia nana	Yes	Yes	Clutter-edge	Yes	4.05%
Nycticeinops schlieffeni	Yes	Yes	Clutter-edge	Yes	0.20%
Neoromicia zuluensis	Yes	Yes	Clutter-edge	Yes	3.99%
Pipistrellus hesperidus	Yes	Yes	Clutter-edge	Yes	1.35%
Pipistrellus rusticus	Yes	Yes	Clutter-edge	Yes	3.09%
Scotophilus dinganii	Yes	Yes	Clutter-edge	Yes	3.42%

Scotophilus viridis	Yes	No	Clutter-edge	Yes	0.04%
Molossidae					
Chaerephon ansorgei	Yes	yes	Clutter-edge	Yes	3.48%
Chaerephon pumilus	Yes	yes	Clutter-edge	Yes	13.85%
Mops condylurus	Yes	yes	Clutter-edge	Yes	23.63%
Mops midas	Yes	yes	Clutter-edge	Yes	5.34%
Tadarida aegyptiaca	Yes	yes	Clutter-edge	Yes	2.01%
Emballanuridae					
Taphozous mauritianus	Yes	yes	Clutter-edge	Yes	5.83%
Miniopteridae					
Miniopterus natalensis	Yes	yes	Clutter-edge	Yes	0.41%
Rhinolophidae					
Rhinolophus smithersi	Yes	Yes	Clutter-edge	Yes	6.96%
Rhinolophus simulator	Yes	yes	Clutter-edge	Yes	0.68%
Rhinolophus darlingi	Yes	yes	Clutter-edge	Yes	0.08%
Rhinolophus clivosus	No	yes	Clutter-edge	Yes	0.22%

Table 4: The activity of bats recorded across the sampling sites at VNR and MNP during the 2017/2018 acoustic sampling surveys. The number for each site is the total number of calls recorded per site in that particular sampling month, while there is a total number of calls recorded for each reserve for that particular month. N/D representing "No Detection" for that particular month.

	Months				
Sites/Reserve	**March**	**April**	**June**	**Nov**	**Total**
MNP		**1369**		**2129**	**3498**
750m Small Pan	N/D	N/D	N/D	79	79
750mRiver	N/D	228	N/D	1029	1257
750mSmallDamCliff	N/D	395	N/D	48	443
River	N/D	630	N/D	N/D	630
SmallDamCliff	N/D	116	N/D	493	609
SmallPan	N/D	N/D	N/D	480	480
VNR	**990**		**517**	**1008**	**2515**
750mFaureWaterPoint	15	N/D	4	N/D	19
750mPan	N/D	ND	9	55	64
Dam	286	N/D	N/D	49	335
FaureCamp	107	N/D	95	N/D	202
Faure Waterpoint	261	N/D	239	560	1060
Pan	313	N/D	169	97	579
750mDam	8	N/D	N/D	247	256
Total	**990**	**1369**	**517**	**3137**	**6013**

Table 5: Summary of echolocation call parameters of 23 bat species recorded in both VNR and MNP during the 2017/2018 sampling survey. The recordings were made with SM2 bat detectors and analysed with AnalookW software. The characteristic of the calls included, N = number of bats in sample; Fc = Characteristic frequency, the frequency at the end or flattest portion of the call; Fk = Frequency at the 'knee' or the point at which the slope of the call abruptly changes from a downward slope to a more level slope; Fmin = Minimum call frequency; Fmax = Maximum frequency and Duration = Total duration of the call.

Species	N	Duration (m)	Fmin (KHZ)	F max (KHZ)	Fc (KHZ)	Fk (KHZ)
Vespertilionidae						
Eptesicus hottentotus	88	3 – 4	28 - 32	54 -70	30-34	34 -37
Laephotis botswanae	2	2-3	31- 32	50-53	32-33	35—35
Myotis tricolor	22	2-3	31 - 50	76 - 91	45 - 62	48 – 67
Myotis welwitschii	9	2	33	73	50	52
Neoromicia capensis	112	2-5	35 - 41	41- 61	35 - 41	37-42
Neoromicia nanas	65	3 – 4	64 - 67	74 - 80	65 - 67	66 -70
Nycticeinops schlieffeni	26	2	42	50	41	44
Neoromicia zuluensis	79	2 – 3	46 - 51	59 - 93	46 - 51	48 – 56
Pipistrellus hesperidus	61	2 – 5	41 - 47	48 - 82	42 - 49	45 -55
Pipistrellus rusticus	56	3	55	62	55	58

Scotophilus dinganii	86	3 -5	32 -34	42 -65	32 -35	34 -37
Scotophilus viridis	4	4	41	57	43	46
			Molossidae			
Chaerephon ansorgei	58	4 -12	17 -20	19 -27	17 -21	18 -22
Chaerephon pumilus	70	5 -11	20 -27	23 -37	21 -28	22 -31
Mops condylurus	101	4 -7	24 -28	32 -38	25 -29	27 -32
Mops midas	45	8 -16	12 -14	13 -16	12 -14	12 -15
Tadarida aegyptiaca	54	3 -11	17 -24	25 -34	21 -25	22 -26
			Emballanuridae			
Taphozous mauritianus	69	3 – 3	22 - 29	29 - 31	25 - 28	27 – 30
			Miniopteridae			
Miniopterus natalensis	28	2 – 4	52 - 55	59 - 80	53 - 56	56 – 57
			Rhinolophidae			
Rhinolophus smithersi	46	10 – 25	44 - 47	47 - 48	46 - 47	44 – 45
Rhinolophus simulator	37	9 – 14	75 - 80	83 - 84	80 - 82	79 – 81
Rhinolophus darlingi	9	13 – 21	72 - 76	85 -86	84 - 86	84 – 85
Rhinolophus clivosus	13	8 – 19	79 - 90	91 - 93	90 - 92	89 – 91

Table 6: Summary of the total species recorded by means of live trapping using mist net a harp trap in VNR.

		Co-Ordinates					
Species/Family	**Locality**	**Latitude**	**Longitude**	**Sex**	**Mass**	**FA**	**Date**
Nycteris thebaica	Venetia: Luna baobab	-22.3805	29.368	F	10.5g	46.41	22/06/2017
Rhinolophus smithersi	Venetia: Luna baobab	-22.3805	29.368	F	28g	64.49	22/06/2017
Rhinolophus smithersi	Venetia: Luna baobab	-22.3805	29.368	F	28g	65.70	22/06/2017
Nycticeinops schlieffeni	Venetia: Luna baobab	-22.3805	29.368	M	5g	30.42	22/06/2017
Rhinolophus smithersi	Venetia: Luna baobab	-22.3805	29.368	F	25g	65.05	22/06/2017
Nycteris thebaica	Venetia: Luna baobab	-22.3805	29.368	F	N/A	N/A	22/06/2017
Rhinolophus smithersi	Venetia: Luna baobab	-22.3805	29.368	F	25g	63.46	22/06/2017
Nycticeinops schlieffeni	Venetia: Faure Waterpoint	-22.2681	29.330	F	5.5g	31.03	20/06/2017
Nycticeinops schlieffeni	Venetia: Faure Waterpoint	-22.2681	29.330	F	5g	30.20	21/06/2017
Nycticeinops schlieffeni	Venetia: Faure Waterpoint	-22.2681	29.330	F	5g	30.83	22/06/2017
Chaerephon pumilus	Venetia: Faure Waterpoint	-22.2681	29.330	M	11.5g	37.96	23/06/2017

CHAPTER FOUR: DISCUSSION

4.1 Species richness, diversity and activity of bats

4.1.1 Importance of water and riparian habitats

There was a higher species diversity and activity of bats at sites that were close to water bodies at VNR but the same did not apply at MNP. This might be due to the fact that bats at VNR depend on artificial water bodies to a greater extent and therefore concentrate activity at sites close to those artificial water bodies. In my study, at VNR, the nearest natural permanent water supply was located 20 km away from the sampled artificial water bodies, while all the sampled sites at MNP were 1-2 kilometers away from the Limpopo River. A similar study conducted by García- Sosa (2008) found that 20% more bats in their study were captured near a small pond habitat, compared to arid habitats which had been sampled. This shows that water bodies in arid environment can have higher and more concentrated bat activity. Moreover, my results are consistent with previous studies such as Adams & Thibault (2006) and Bader *et al.* (2015) showing that artificial water bodies have an important role in arid environments where water availability is scarce playing an important role in promoting both bat activity and diversity.

My results showed that there was a higher bat diversity and activity at MNP along the river valley of the Limpopo River compared to the drier VNR. This is supported by the bat species distribution model of Herkt *et al.* (2016), who showed an association of bat diversity with hydrological networks. Large perennial rivers increase the activity of bats compared to small water sources like pans (Brinkley, 2018), which is in agreement with the results of my study showing that MNP next to the Limpopo River has a much higher bat activity than VNR. Riparian vegetation along rivers such as the Limpopo River presumably also provide more roosting sites through vegetation such as old trees and a greater food availability by promoting a higher insect abundance (Downs & Racey, 2006). The overall higher bat activity in MNP might therefore also be a result of a generally higher insect abundance (Kunz *et al.,* 2011). A study by Hagen & Sabo (2011) suggests that bats assemble along rivers as they provide ideal foraging habitats for them.

A study by Sleep & Brigham (2003) indicates that bats typically prefer areas with high structural clutter (MNP) in comparison to those with low structural clutter (like VNR). Although I did not measure those variables in in detail, my results suggest an effect of riparian vegetation on bat activity, with a higher bat activity at MNP sites (not further than 2 km away from River) situated within the riparian habitats of the Limpopo River. VNR had an overall lower activity of bats than MNP, which could also be due to lower vegetation cover at VNR. A study by Piksa *et al*. (2011) indicated that differences such as riparian (dominated in MNP) and non-riparian vegetation (mostly in VNR) have a strong influence on the distribution of bats.

Fewer bat calls were detected in the arid landscape of the VNR, at the sites which were 750 meters away from the artificial water bodies, suggesting that water abundance has an important influence on the distribution of bats species (Stahlschmidt *et al.,* 2012). This also suggests that bat activity decreases at a high rate with the distance from water bodies, especially in arid regions. My results support that artificial and natural water bodies are a critical habitat for bats. The studies by Dalhoumi *et al.* (2015) and Bader *et al.* (2015) indicate that artificial water bodies play an important role for bats in environments where water availability is scarce. Similarly, a study by Lisón & Calvo. (2011) showed that small ponds in a semi-arid Mediterranean environment concentrate and increase activity of bats compared to arid habitats. It is predicted that sites which are near water bodies will have greater insect abundance would have a correspondingly positive influence on bat activity than sites located 750m away from water bodies, And based on studies which demonstrated an increase in bat activity in habitats supplying water in arid landscapes (Everette *et al.,* 2001), and the assumed habitat characteristics of VNR and MNP.

4.2 Season and moon phase

My results show higher species richness and bat activity in autumn, which contradicts the findings of other studies such as Taylor *et al.* (2013) and Parker & Bernard (2018) who found greater activity of insectivorous bats occurs during the summer season. Molossidae species were most active in autumn, than summer and the least activity was recorded in winter, followed by the Vespertilionidae and the Rhinolophidae species (Table 3). This is likely because changes in Molossidae activity account for seasonal differences in overall bat activity (Monadjem *et al.,* 2017), and echolocate at low frequencies (<20 kHz) (Monadjem *et al.,* 2010) in contrast to other common families such as Vespertilionidae and the Rhinolophidae. My study also looked at the relationship between species diversity, richness and activity and the moon phases. Moon phase has been shown to have a significant effect on bat activity in previous studies such as Meyer *et al*. (2004). My study found that there was a significant effect as there was a higher activity of insectivorous species recorded during the new moon phase.

4.3 Species identification

I recorded 23 species acoustically at both MNP and VNR. Of all these 23 species, *Rhinolophus clivosus* was recorded in MNP only, and *Scotophilus viridis* was recorded in VNR only. *Rhinolophus clivosus* occurs in the eastern parts of southern Africa and is absent in three countries of Namibia, Botswana and Angola (Monadjem *et al.,* 2010). In South Africa, it is absent in the arid regions (Monadjem *et al.,* 2010). The results of my study support those findings as there were no records of *Rhinolophus clivosus* at the sites I sampled in the arid region of VNR. Records indicate that these species roost in caves and they often form large colonies, and are found in habitats consisting of savanna and riparian forest. By comparison, *Scotophilus viridis* has been recorded in the Kruger National Park (KNP) (Monadjem *et al.,* 2010) and in open habitats of both reserves, they were absent in VNR.

Otomops martiensseni was confidently identified in MNP in similar studies of Parker & Bernard (2018) and Adams *et al.* (2012) but not in my study. This species might have incorrectly been assigned a *Mops midas* identification in my study as the two species overlap in their echolocation call frequencies as well as in other parameters. Besides *Rhinolophus clivosus*, *Nycticeinops schlieffeni* and *Scotophilus viridis*, all 21 species which were acoustically recorded in this study were also recorded previously in the close by western Soutpansberg mountains by Taylor *et al.* (2013a). Although, *Nycteris thebaica* was caught in mist nets at the Luna Baobab at VNR, the species was not recorded acoustically because it is difficult to record acoustically as it echolocates at low intensity with a high main peak frequency (90-1.3 kHz) (Monadjem *et al.,* 2010).

In the arid region of VNR, my results show *Neoromicia capensis* as the most abundant species, followed by *Mops condylurus* (Figure 8). In the MNP the most dominant species were *Mops condylurus*, followed by *Chaerephon pumilus* and *Rhinolophus smithersi*. The dominance of *N. capensis* in the more arid VNR is supported by the study by Monadjem *et al*. (2010) which indicates that *Neoromicia capensis* is the only bat species from the Vespertilionidae family that is recorded as a “resident” bat in all arid habitats of South Africa as they are said to be dominant and tolerable to habitats were water is scarce at a local level. These species roost in small groups usually under the bark of trees or under the roofs of houses (Monadjem *et al.,* 2010).

Families of Molossidae (*Mops condylurus* and *Chaerephon pumilus*) were the most abundant numerically based on detections in MNP. This could be due to the fact that MNP is bordered by the Limpopo River and having a dominant riparian vegetation and although these species are open air foragers that feed at over 500 m above ground and prey high above the ground and far from vegetation and they have no problems with clutter echoes and obstacles (Taylor *et al*., 2012), their abundance was very high at MNP. By comparison, *Rhinolophus smithersi* were more abundant at MNP where there is a riparian canopy forest. These species are gleaners and they capture their prey from the ground or branches (Monadjem *et al.,* 2010; Taylor *et al.,* 2012).

4.4 Comparison of bat species recorded at VNR and MNP bats with other previous studies

The results of the species recorded in this study showed close comparisons with other studies that took place in the region such as the study by Brinkley (2018) that took place along the Limpopo River at KNP and Parker & Bernard (2018) which took place at MNP. There were three different insectivorous species that were recorded by Brinkley (2018) and Parker & Bernard (2018) at KNP that I did not record in my study, those species were: *Hipposiderous caffer, Rhinolophus fumigatus* and *Otomops martiensseni.*

Hipposiderous caffer, a small leaf nosed bat that echolocates at high peak frequencies (142.3-0.6 kHz) and has an intermediate duration (8.4-0.7 ms), was not recorded by my study. Although the species is widely distributed across southern Africa, and roost in caves and in anthropogenic cavities and culverts, it was not recorded in both VNR and MNP in my study. These species appear to forage in and around thickets and undergrowth vegetation, avoiding open areas and their low ability to fly slowly in cluttered environments (Aldridge & Rautenbach, 1987), as well as the lack of clutter vegetation around my study sites could be the reason why this species was not recorded in my study. *Rhinolophus fumigatus* a medium sized bat was also not recorded in my study. However, it echolocates at an intermediate peak frequency (53.7-1 kHz) with a long duration of 40.3-6.2 ms (Schoeman & Jacobs, 2008). The absence of this species in my study could be because this species is roosting in trees (particularly Baobabs) which were approximately more than 10 kilometres away from my sampling sites except from Luna baobab in VNR. Also, I have use mist nests to capture bats there and with a reason that with the set-up of my bat detectors they could not have match their detection range to record those species. These is related because these species are distributed across east and west of southern Africa (Rautenbach *et al*., 1993; Monadjem *et al.,* 2010).

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

My acoustic surveys recorded 23 insectivorous species in both VNR and MNP, while my live capture survey recorded four different species. Water is important to insectivorous bats (Adams *et al.,* 2015) and artificial water bodies can reduce the negative anthropogenic impact on water availability for bats and other groups of animals. Artificial water bodies in dry landscapes of the VNR had more bat activity than sites 750m further away from those water bodies, indicating how significant artificial water bodies (and associated insect prey faunas) are in a dry landscape. MNP had a higher overall bat activity than VNR with the Limpopo River being a significant factor. Although the live-capture techniques were only used for the purpose of validation of acoustic calls, the method showed to be critical as *Nycteris thebaica* was not acoustically recorded. Moreover, my study supports conclusions from previous studies such Fenton & Rautenbach. (1986) that show that Baobabs serve as roosts for several insectivorous bat species.

5.2 Recommendations

Future studies should use both live capture methods in parallel with acoustic recordings. With artificial waterbodies sites having a significantly higher activity of bats at VNR, the management of VNR should maintain those artificial water bodies as they are valuable to bats within the reserves. Baobab trees serve as a roosts for insectivorous bats, and there should be more focus on those trees and their protection. All of the species in my study, have a preference for habitats close to water. One way of to improve the conservation of these species could be identifying the areas (close to water) critical to this species. The roosting sites of all the species in my study for example should be included in determining conservation zones within areas (IUCN, 2017).

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Appendix

Appendix A: List of species codes

Cansor	*Chaerephon ansorgei*
Cpum	*Chaerephon pumilus*
Ehott	*Eptesicus hottentotus*
Lbot	*Laephotis botswanae*
Mcond	*Mops condylurus*
Mmidas	*Mops midas*
Mnatal	*Miniopterus natalensis*
Mtric	*Myotis tricolor*
Mwel	*Myotis welwitschii*
Ncap	*Neoromicia capensis*
Nnanus	*Neoromicia nanas*
Nschlieffeni	*Nycticeinops schlieffeni*
Nzulu	*Neoromicia zuluensis*
Phesp	*Pipistrellus hesperidus*
Prust	*Pipistrellus rusticus*
Rcliv	*Rhinolophus clivosus*
Rdarl	*Rhinolophus darlingi*
Rsim	*Rhinolophus simulator*
Rsmith	*Rhinolophus smithersi*
Sding	*Scotophilus dinganii*
Svirid	*Scotophilus viridis*

Taeg	*Tadarida aegyptiaca*
Tmaurit	*Taphozous mauritianus*