QUANTIFYING THE EFFECTS OF CLIMATE CHANGE AND ANTHROPOGENIC DISTURBANCE ON BAT COMMUNITIES IN A MONTANE GRASSLAND ECOSYSTEM

By

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Abstract

The Drakensberg mountains of South Africa and Lesotho are known for their high level of biodiversity and endemism with two known Drakensberg endemic bat species, namely *Laephotis cf. wintoni,* and *Rhinolophus cervenyi,* and another South African and Lesotho montane endemic bat species, *Cistugo lesueuri*. The Afromontane grasslands of the Maloti-Drakensberg, like most grasslands, are under threat from climate change and anthropogenic activities, necessitating the monitoring, particularly of rare and endemic species. Using acoustic and capture surveys, I therefore assessed the distribution of bats along elevational (as a proxy for climate change) and anthropogenic gradients in Witsieshoek Community Conservation Area, Golden Gate Highlands National Park and Phuthaditjhaba located in the Maloti-Drakensberg Afromontane grasslands in the Free State Province. Sampling was done during late 2021 to early 2023 making use of SM4 mini bat detectors, harp trapping and mist netting in four sessions. I also collected faecal pellets of *Laephotis capensis*, a common bat species in the area, to identify its diet. I further assessed perceptions of primary and high school leaners and the effectiveness of environmental education in changing negative perceptions of the learners towards bats. My findings uncovered the occurrence of at least eight species of bats in my study area. Increasing isothermality was positively correlated with bat species richness, while increasing minimum temperature of the coldest month and distance to rivers were positively correlated with bat activity along the elevation gradient. Human footprint negatively correlated with species richness, whereas the relationship between distance to buildings and bat activity varied across different functional groups along the anthropogenic gradient. I captured one Drakensberg endemic bat species, *Rhinolophus cervenyi* and the South African and Lesotho endemic bat species, *Cistugo lesueuri*. The notable absence of the Drakensberg endemic bat species, *Laephotis cf. wintoni*, might be an indication of the negative impact of both climate change and anthropogenic activities on bats in the high Drakensberg.

Based on macroscopic inspection of faecal pellets, the species *Laephotis capensis* had a broader diet breadth in a more natural landscape compared to agricultural and township landscapes. Its diet was rich in Coleoptera in all sampled landscapes. This suggests that the species may be highly specialized in its feeding habits, relying heavily on beetles as a primary food source. Such dietary specialization might suggest vulnerability to environmental changes, whether due to climate change or habitat alterations caused by human activity. I further found out that perceptions of learners towards bats were initially negative, but that environmental education served as an effective tool in turning these perceptions more positive. The findings of my study are important because they show the vulnerability of endemic species to both climate change and anthropogenic disturbance and also show the value of incorporating environmental education and awareness to ensure more effective conservation actions. I present the distribution ranges of bats in the Maloti-Drakensberg which will help in implementing conservation strategies and predict the future effects of climate change on these species.

Keywords: Acoustic survey; Afromontane grasslands; Anthropogenic disturbance; Bat diet; Climate change; Elevational gradient; Endemic species.

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List of Abbreviations

Acronym	Meaning
AIC	Akaike Information Criterion
Approx.	Approximately
Asl	above sea level
Car	Companion to Applied Regression
CCA	Canonical Correspondence Analysis
Clmm	Cumulative Link Mixed Models
COVID	Coronavirus Disease
Df	Degrees of freedom
GH	Golden Gate High
GGHNP	Golden Gate Highlands National Park
GL	Golden Gate Low
GLMMs	Generalized Linear Mixed Models
GML	Golden Gate Mid Low
GMH	Golden Gate Mid High
Ggpredict	Predictions using Generalized Linear Models
Ggplot	Grammar of Graphics Plot
Hfootprint	Human footprint
Isthr	Isothermality
iNEXT	Interpolation and Extrapolation
IUCN	International Union for Conservation of Nature
KHz	Kilohertz
LE	Least concern
log-Lik	Log-Likelihood
MA	Massachusetts (USA)
Mndrn	Mean diurnal range
Mntmp	Minimum temperature of the coldest month
MuMIn	Multi-Model Inference
M	Metres
NE	Not Evaluated
PERMANOVA	Permutational Multivariate Analysis of Variance

PF	Percent frequency
PV	Percent volume
SAPAD	South African Protected Areas Database
Sf	Simple Features
SM4	Song Meter 4 Bat Detectors (Wildlife Acoustics)
Spp	Species
VIF	Variance Inflation Factor
WL	Witsieshoek Low
WH	Witsieshoek High
WMH	Witsieshoek Mid High
WML	Witsieshoek Mid Low

Chapter 1

General introduction

1.1 Bats

Bats are small mammals in the order Chiroptera and comprise over 1300 extant species making them the second largest mammalian order (Voigt & Kingston, 2015; Burgin et al., 2018) accounting for 20% of all mammal species in the world (Kunz & Pierson, 1994). There are 116 bat species that have been recorded in southern Africa (Monadjem et al., 2020). Bats differ from other small mammals in their evolution of powered flight and their ability of flight that has enabled their widespread distribution around the globe as bats currently inhabit all continents except for Antarctica, with a lifespan that can stretch up to 41 years (Podlutsky et al., 2005). Bats have a forelimb that has been modified into a wing with the long finger bones connected by a thin and large membrane which is rich in blood flow hence allowing for effective flight (Madej et al., 2013).

Bats also show a high physiological and ecological diversity (Hutson et al., 2001) as evident from their body sizes which can range from two grams to one kilogram for adult bats (Fenton, 2003) and from their diverse diets, which include insects, nectar, fruits, seeds, frogs, fish, small mammals, and blood (Kunz et al., 2011). Hence, they can be classified into insectivorous, animalivorous, hematophagous, frugivorous and nectivorous groups depending on what they forage on. They are generally nocturnal animals only coming out at night to forage. Insectivorous bats are the most common around the world making up 70% of the world's bat species. Bats evolved several roosting and feeding patterns, and most species of bats are known to roost during the day in rock crevices, hollows of trees, under exfoliating bark, below bridges and in other different kinds of infrastructure (Jones et al., 2009). Most bats have also evolved echolocation as one of their most important traits. Not all bats echolocate but those that do produce ultrasonic frequencies ranging from 10 to 200 kHz during foraging (Kasso & Balakrishnan, 2013). Some bats hibernate during winter whilst others migrate to other areas. The bat species *Miniopterus natalensis* in the Western Cape in South Africa can migrate up to 260 km (Van & Van Der Merwe, 1973; Van der Merwe, 1975) from warm maternity caves utilized in summer for giving birth to very cold caves in winter to mate and hibernate (Monadjem et al., 2020).

Insectivorous bats can be categorised based on their wing morphology and echolocation into three functional foraging groups (Schnitzler et al., 2003). The first group are the open-air foragers which forage in open areas where there is little, or no vegetation and they prey on insects that fly high above the ground. This group has wing morphology designed for high speed and agility. The second group are the clutter-edge foragers which are bats that forage on insects close to edges of forests and gaps. The last group are the clutter foragers which are bats that are adapted for foraging in areas of dense vegetation close to the ground and these bats possess short and broad wings capable of slow, manoeuvrable flight effective for hunting insects in clutter habitats (Monadjem et al., 2020; Shapiro et al., 2020)

1.2 Bat ecosystem services

Bats provide several important ecosystem services and have played a significant role in agriculture acting as biological control of certain insects (Taylor et al., 2018; Weier et al., 2018). Over two thirds of extant bats in the world are insectivorous and hence have contributed greatly to insect and arthropod suppression in most agricultural landscapes (Kunz et al., 2011). In Texas alone, Boyles et al. (2011) estimated the economic value of pest control services that bats offered for agriculture was around $30 per hectare annually. In South Africa, bats which occur at the De Hoop Guano Cave have been reported to consume around 100 tons of insects.

This saves farmers in Bredasdorp from incurring losses in their crops due to pests (McDonald et al., 1990). Taylor et al. (2018) estimated the value of insectivorous bats to be around 59 and 139$ (USD) per hectare for the macadamia industry in South Africa where bats assist the industry by reducing stinkbug pest species. The presence of these pest controlling bats allows for the reduction in the use of pesticides which in turn results in stable populations of most predator populations such as birds and spiders which are essential for the long-term control of pests (Knight & Gurr, 2007; Taylor et al., 2018). Bat faeces which are found under bat roosts are also used as fertilizer for some crops by farmers (Jones et al., 2009).

Bats also have important ecological roles as they form part of the diet for some vertebrate predators such as fish, amphibians, birds, reptiles, and mammals with the main predators for bats being owls, hawks, falcons and snakes (Speakman, 1991; Kasso & Balakrishnan, 2013). Other bats are known to form the diet of other bats i.e. Phyllostomid bats such as the *Phyllostomus hastatus* feed on other small bats (Paradiso et al., 1961; Kasso & Balakrishnan, 2013). Bats also play a huge role in pollination of plants. Bats such as *Epomophorus wahlbergi* and *Eidolon helvum* are known to pollinate flowers of the baobab tree which is an economically important species in the African savanna (Kunz et al., 2011). Bats are also good seed dispersers. In places like the tropics where the forests are cleared, fruit eating bats have helped disperse the seeds from which a diverse forest can reemerge (Buddenhagen, 2008). Some tropical tree species such as the tropical almond tree, *Terminalia catappa*, are dependent on bats for dispersal and these trees are of great importance to people as they are used for timber, tannin extraction and fuel (Kasso & Balakrishnan, 2013).

Although bats provide all the mentioned positive services, they do; however, have negative implications on human society. Bats can also act as pests in many agricultural landscapes and frugivorous bats can cause great losses by feeding on fruits that are of economic importance (Kasso & Balakrishnan, 2013). Bats usually leave the walls and ceilings dirty from their urine and guano and spoil the food inside the house they have infested (Greenhall, 1964). Bats have also been reported to be capable of collisions with aircrafts which might threaten the safety of humans and cause economic losses from aircraft damage although such incidents are low risk and often have minimal economic effect (Biondi et al., 2013). Bats are also hosts to a number of zoonotic pathogens and may result in the transmission of diseases such as rabies, histoplasmosis, pseudotuberculosis and others (Greenhall, 1964; Wibbelt et al., 2007).

1.3 Bats and climate change

The implications of climate change on bats are not yet known. Climate change is likely to result in the decline of bat species because of decreasing food sources such as insects. Studies have revealed insect declines in some parts of the world, with climate change being amongst the major reasons for this insect decline (Wagner et al., 2021). The alteration of the timing of reproductive cycles of temperate bats is also proposed as these cycles are dependent on weather conditions especially temperature (Racey & Swift, 1981; Ransome & McOwat, 1994). The major proposed implication of climate change is range shifts of bat species. It has been predicted that species adapted to cool temperatures are under threat from the increasing global temperatures and if they are not able to adapt to the increase in temperatures, they may be in danger of becoming extinct (Thomas et al., 2004). Climate change can result in changes in the loss of endemic/indigenous vegetation (Hannah et al., 2005) and food sources especially insects available in a habitat (Martin, 2001) and hence force bats to be pushed out of that habitat.

Studying bats along elevational gradients can help offer insight on how climate change affects bats. A study by LaVal (2004) showed the capture of 24 species of bats previously known to occur in lowlands occur at higher elevations after a period of 27 years. Climate change was one of the main drivers of this observed shift in this study. Species richness and diversity of bat species tends to decline with altitude (Patterson et al., 1998; Linden et al., 2014; Weier et al., 2017; Monadjem et al., 2024) but with climate change persisting lowland species might be slowly shifting to higher altitudes. Also bat species occurring in high elevations might be running out of suitable habitats due to climate change (Urban, 2018). Unfortunately, not much research has focused on determining how bat species along altitudinal gradients respond to climate change. This is unfortunate because knowledge on how altitude influences bat species diversity and distribution is critical if conservation at small geographical scales is to be carried out successfully (Sánchez-Cordero, 2001).

1.4 Bats as ecological indicators

Anthropogenic activities impact biodiversity at various scales, but limited funding, trained personnel, and time make it impractical to study these effects for every taxon (Moreno et al., 2007). This highlights the need for indicator species, whose responses to human activities can serve as proxies for broader ecological impacts. Bats have shown great potential as bio indicators and have been suggested to be an appropriate taxon for ascertaining the state of natural ecosystems which have been impacted by anthropogenic changes such as agriculture (Jones et al., 2009). The stable taxonomy, wide distribution, ease of surveying/sampling and observable short- and long-term effects of bats allows them to be good ecological indicators of disturbance and contamination of ecosystems (Fenton et al., 1992; Fenton, 2003; Jones et al., 2009).

Bats are easily affected by human activities which affect other animal species. Bats will show fluctuations in their numbers based on climate change, use of pesticides, loss or fragmentation of natural habitats, reduced water quality and many others and this is one of the qualities which makes them good ecological indicators (Wickramasinghe et al., 2003, 2004; Jones et al., 2009). From these fluctuations, the impacts of human practices on other taxa can be inferred without having to monitor each taxon in every ecosystem which has experienced anthropogenic change (Jones et al., 2009).

1.5 Bats and Wetlands

Wetlands are one of the most important foraging habitats for most bat species around the world and bats are more closely associated with wetlands than other mammal taxonomic groups (Merritt, 1987). Wetlands are, however, declining around the world, and their quality is being degraded (Turner, 1997). In South Africa, wetlands cover approximately 2.9 million ha of the land surface area (Driver et al., 2012). Despite the usefulness of wetlands in the country, wetlands have been reported by the 2011 National Biodiversity Assessment to be the most threatened ecosystem type in South Africa (Driver et al., 2012) with one of the biggest threats to wetlands being agriculture. This decline of wetlands may result in the loss of certain biodiversity associated with this ecosystem.

Several studies such as that of Catto et al. (1994) and Vaughan (1997) have revealed higher bat activity in wetlands than in other land use types with more bat passes recorded on the banks of rivers and lakes. A study by Taylor et al. (2020) showed enhanced bat species richness, diversity and activity at areas closer to the Limpopo River and the *Rhinolophus spp* was found to be more abundant in these areas that were closer to the river. Studies by Sirami et al. (2013) and Laverty & Berger (2020) also showed bat activity to be positively correlated with availability of water and wetland size. The findings of these studies show how important wetlands are for bats and such importance stems from the availability of water for the bats to drink and the abundance of insects, as plenty of insects will use water for a certain part of their lifecycle (Imes, 1992). The abundance of aquatic insects in wetlands explains why insectivorous bats have been shown to prefer foraging over open water since their main diet is heavily comprised of insects (Grindal & Brigham, 1999). Bat foraging, however, has been shown not to be limited to natural wetlands, but bats also forage in artificial aquatic systems such as sewage treatment works (Park & Cristinacce, 2006; Sirami et al., 2013). With the persisting decline of wetlands, the creation of wetlands or ponds in areas dominated by agriculture has been shown to be beneficial for bats in terms of food resources and hence creation of artificial wetlands has been suggested to be possibly the only way to keep bat populations alive in such agricultural landscapes (Stahlschmidt et al., 2012). In Southern Africa, from the 116 recorded bat species, 14 species are data deficient whilst 17 are near threatened (Monadjem et al, 2020). This suggests that there are still a lot of bat studies that need to be conducted if bats are to be conserved. In addition, there is a great need to determine the type of aquatic habitats that are preferred by bats so as to implement proper management of these wetlands enabling the survival of more bat species especially in southern Africa (Vaughan, 1997).

1.6 Bats and agriculture

The expansion and intensification of agriculture is one of the leading causes of global bat species and population declines (Park, 2015). Agriculture results in a fragmented landscape that has lost natural habitats for most bat species hence the loss of bat species in these landscapes. In Britain, agriculture intensification and the resulting habitat loss has been reported to have resulted in the loss of six out of 16 species (Wickramasinghe et al., 2003). A study by Freudmann et al. (2015) also showed that oil palm plantations had negative impacts on the species richness of bats of the family Phyllostomidae in the Neotropics whilst a study by Mtsetfwa et al. (2018) showed that sugarcane monocultures had negative impacts on clutter foragers. This, however, is not true for all bat species. Some species have been shown to be able to make use of landscapes that have been altered by agriculture with their numbers being observed to increase in such areas (Heim et al., 2016; Mtsetfwa et al., 2018). Open-air foragers such as *Mops pumilus* and *Mops condylurus* (family Molossidae) have been found to prefer foraging in agricultural landscapes (Noer et al., 2012). Bright (1993) mentioned that bat species which tend to be negatively affected by habitat fragmentation are specialist species which include *Myotis* (*M. myotis, M. nattereri, M. mystacius*) and *Rhinolophus* species. *Rhinolophus* species have been shown to disappear even at low levels of agricultural land use (Russo & Jones, 2003). Generalist species such as open-air foragers can adapt in altered habitats and the abundance of such species coupled with the decline/absence of specialist species may indicate habitat disturbance (Mtsetfwa et al., 2018).

Agriculture also affects bats that are dependent on wetlands or water habitats. Some bats such as the *Myotis* species use water habitats as foraging areas (Wickramasinghe et al., 2003); however, agriculture may affect the quality of the water that these bat species forage from. Agrochemicals often jeopardize the quality of wetlands located in agricultural landscapes and a negative correlation of agricultural intensification and water quality has been reported (Racey et al., 1998; Berka et al., 2001). Water pollution often results from the pesticides used in agricultural plantations (Angier et al., 2002) and this results in the loss of many insect species that make up the diet of most insectivorous bats. The loss of insects in these aquatic habitats results in the decline of bat species foraging in those aquatic ecosystems (Vaughan et al., 1996). Also, the use of fertilizers containing nitrogen and phosphorus may result in eutrophication which increases the nutrient content of aquatic habitats, which may disrupt seasonal changes of invertebrates thus affecting organisms like bats which feed on them (Mason, 2002).

1.7 Bats and Rangelands

Rangelands are one of the most important landscapes in grasslands and they cover about 27% of the world's terrestrial surface (Trubitt et al., 2019). Grasses, forbs, or shrubs often make up the natural vegetation of rangelands; however, due to low and erratic precipitation, rough topography, poor drainage, or cold temperatures rangelands often are not good landscapes for cultivation (Foley et al., 2005; Squires, 2010). In South Africa, rangelands make up about 75% of the agricultural land surface in the arid to semi-arid environments and are only utilized by livestock and game farming (Van Der Westhuizen & Snyman, 2014). Bats have been known to utilize rangeland landscapes (Trubitt et al., 2019); however, the impacts of livestock farming on bats has been understudied which is unfortunate because livestock farming is the dominating human activity on rangelands around the world (Fleischner, 1994; Alkemade et al., 2013). The effects of livestock farming on grasslands is most often the removal of vegetation cover such as grass cover due to overgrazing. This has been shown to reduce the biodiversity of other fauna, but some studies suggest that grazing in rangelands might actually promote bat activity because of the resultant semi open habitats which some species of bats have been shown to prefer (Duverge & Jones, 2003; López-González et al., 2015). However, the distribution of bats in overgrazed rangelands remains to be investigated. The availability of livestock in rangelands is likely to result in higher insect abundance such as dung beetles and other insects that make use of dung which then means more food for insectivorous bats (Shiel et al., 1991; Catto et al., 1996; Ransome, 1996; Duverge & Jones, 2003). Livestock overgrazing also contributes to increase of termite populations, and thus, bats potentially play a significant role in reducing new nest formation, when they feed on the alate during nuptial flights.

Although most bats prey on dung beetles in rangelands, bats have also been discovered to feed around cows (Downs & Sanderson, 2010). Since bats can feed on ectoparasites of livestock, they therefore may contribute to suppressing pests that lowers livestock productivity. Such ectoparasites can include dipterans such as mosquitos. In 1981, ectoparasites accounted for about 10% of livestock productivity loss in the US in which 70% of the loss was attributed to dipterans (Byford et al., 1992). This means that livestock rearing may not just be beneficial for some bat species that feed on cow pests but also bats may be beneficial for the livestock industry.

1.8 Bats and human settlements

Bats are known to occupy human occupied areas and have been observed to inhabit cities (Gehrt & Chelsvig, 2003). Human settlements in most cases are able to harbour native fauna and are capable of having a higher biodiversity but this is determined by the qualities of the landscapes surrounding these areas (Gehrt & Chelsvig, 2003) The effects of human settlements on bats are not fully known; however, some studies have suggested that human settlements especially urban areas result in the loss of abundance and diversity of bats (Kurta & Teramino, 1992; Pierson, 1998). Other studies have shown that bats are able to explore resources that are a result of human infrastructure features such as insects gathered by lights and finding roosting sites in man-made structures (Gehrt & Chelsvig, 2003). Some bats use barns and farm buildings as night or temporary day roosts whilst others use bridges and rock crevices (Razgour et al., 2013). As with other taxa, generalist bat species tend to be the ones that mostly occupy human occupied areas and make use of the resources that come with human settlements. The species *Desmodus rotundus* in a study by Zeppelini et al. (2017) in Brazil was found to be more abundant in the villages than in a protected area and this was attributed to more food resources being available in human settlements and its ability to make use of man-made roosts such as culverts and buildings (Corrêa Scheffer et al., 2014).

1.9 Bat Diet

About 70% of species of bats globally consume insects (Jones & Rydell, 2004). Bats are capable of eating insects amounting to 80% of their body mass in one night (Kurta et al., 1989). Bats in Southern Africa feed on a wide variety of insects and the group of insects that bats eat is influenced by the bats' body size, wing shape, jaw construction, habitat use and the nature of their echolocation calls (Monadjem et al., 2020). Bats feed on almost all flying insects (Whitaker et al., 2009). They have been shown to be important predators for a variety of insects including moths and mosquitos (Whitaker et al., 2009; Monadjem et al., 2020). Most bats are efficient predators of night-flying insects and have been shown to be important for biological pest control in agriculture. Research over the years has tried to quantify or estimate the value of bats in agricultural landscapes and avoided cost models based on diet have been mostly used to evaluate the importance of bats in agriculture (Taylor et al., 2017; Weier et al., 2018). There is great potential for use of bats in agricultural practices in reducing the use of pesticides, but this requires in-depth knowledge on the diet of bats. With the use of molecular techniques to analyse faecal pellets of bats, it has become possible to determine the family of insects that bats consume especially within agricultural landscapes. The amplification of prey DNA and DNA sequencing enables the identification of all prey whether hard or soft bodied to species level (Symondson, 2002).

Bats have been shown to be important biological pest control for several agricultural crops. The *Pipistrellus pygmaeus* bat species was shown to consume the rice borer moth *(Chilo supressalis)* in rice paddies in the Mediterranean (Puig-Montserrat et al., 2015) whilst the Brazilian free-tailed bats *(Tadarida brasiliensis)* were shown to consume corn earworm moth (*Helicoverpa zea*) in Texas (Lee & McCracken, 2005). Bats have also shown great potential in reducing pests in vineyards. In a study by Charbonnier et al. (2021) bats showed increased hunting activity in the presence of grapevine moths whilst also their molecular analysis of faecal pellets revealed that three grapevine moths were consumed by at least 10 species in their study area. Some studies have even shown increases in crop damage in areas where bat foraging is absent (Boyles et al., 2011; Maas et al., 2016). In South Africa, four major macadamia nuts insect pest species, namely the twin-spot stinkbug (*Bathycoelia distincta*), the green vegetable bug (*Nezara viridula*), the macadamia nut borer (*Thaumatotibia batrachopa*) and the litchi moth (*Cryptophlebia peltastica*) were found to be consumed by bats in the families Molossidae, Nycteridae, Rhinolophidae and Vespertilionidae (Weier et al., 2018).

1.10 Bat perceptions amongst people

Often, research has found perceptions of people towards bats to be largely negative (Prokop & Tunnicliffe, 2008). These negative perceptions are a consequence of superstitions and myths that have been passed on from one generation to another through folklores and stories that associate bats with death, bad omens, and even witchcraft. Most of these superstitions stem from misconceptions about bats, i.e., some people believe that bats feed on blood even though it is only three species of bats capable of this and it is not human blood that they feed on (Knight et al., 2003; Prokop & Tunnicliffe, 2008). Some believe that bats are carriers of diseases, such as rabies and some coronaviruses (Cousins & Compton, 2005; Castilla & Viña, 2014). This has increased public anxiety and significantly contributed to stigmatization of bats especially after the outbreak of the corona virus. This is despite the rarity of bat-transmitted diseases in humans. Misinformation about bats and ill-informed media coverage have perpetuated fear of bats by people and has led to widespread intolerance towards bats and even the extermination of bats in certain areas of the world. The fact that bats have little resemblance to humans does very little to help as humans usually show more preference to animals that resemble them more (Knight et al., 2003). Amongst the major threats to bats such as climate change and anthropogenic activities (Jones et al., 2009) also is human perceptions and behaviour towards bats. Despite this, some studies have shown that people tend to have positive attitudes towards bats if they are aware of their importance in the environment (Castilla et al., 2020) suggesting that educational intervention and bat awareness programs might lead to the change in these negative perceptions that humans hold towards bats.

1.11 Justification

Grasslands are amongst the most important biomes in the world owing to the significant ecosystem services they provide such as supporting ecosystem functioning and productivity, providing critical catchment and carbon storage services, and the immense economic value of sustainable livestock industry (Tilman et al., 1996). In South Africa, the Northern Drakensberg (including the Maloti-Drakensberg) is an important Strategic Water Source area, a reservoir of very high biodiversity and endemism, and supply of ecosystem services which include communal and commercial livestock production and ecotourism. Despite this, the Drakensberg grasslands are threatened by unprecedented habitat loss and degradation through anthropogenic changes such as urbanization, livestock over-grazing, alien plant invasion, bush encroachment and climate change (Driver et al. 2012; Taylor et al. 2016; Skowno, 2019). To conserve the endemic grassland species of this area, it is of crucial importance that the response of biodiversity towards prevailing anthropogenic changes be determined so at to assess the quality of these grasslands. The monitoring of the response of bat species of the Drakensberg to anthropogenic activities should be investigated and determining how these two endemic species are responding to both anthropogenic and climate change might be the first step in making sure the Drakensberg does not lose its endemic species or species richness generally. The findings of this study provide base line data for bat distributions which help in identifying how bats are affected by climate and anthropogenic changes in the Drakensberg Afromontane Grassland whilst also providing new knowledge about bat distribution in highly diverse and highly threatened areas like the Maloti-Drakensberg which will be represented by Golden Gate Highlands National Park and Witsieshoek Community Conservation Area. This area remains one of the least explored parts of the Drakensberg. Since this study includes both unprotected (settlements around Phuthaditjhaba) and informally protected community conservation area (Witsieshoek) and a formally protected area (Golden Gate Highlands National Park), it determines the tolerance of different species (habitat generalists and specialists) to human disturbance in terms of habitat transformation. The study also provides insight on what one of the local species (*Laephotis capensis*) feeds on. Ascertaining the diet of bats helps in showing the potential value of bats in the Free State especially since agriculture is the dominant land use in this province. Previous studies have shown the value of bats in agricultural landscapes and hence the importance of this study. Finally, I note that no conservation of bats is possible if people either wrongly perceive bats or are just uninformed about them. It is for this reason that the study also sheds light on the perceptions of primary and high school learners towards bats in the area and whether it is possible to influence their attitudes towards bats as perceptions are crucial if conservation strategies are to be implemented. Most studies in the Maloti-Drakensberg tend to be monodisciplinary whilst sustainable conservation needs a multidisciplinary approach to address both ecological and social aspects of conservation of species (Delves et al., 2021). The multidisciplinary nature of this study fills gaps that monodisciplinary studies would not have been able to address.

1.12 The study area

The study was conducted in the eastern Free State Province of South Africa (Figure 1.1). It lies between latitudes 26.6 °S and 30.7 °S and between longitudes 24.3 °E and 29.8 °E.

The Free State area has two main seasons namely the warm to hot summers with an average maximum daily temperature of 26.4 °C in December and cool to cold winters with an average minimum temperature of -1.7°C in July. The summers are wet with rain falling from October to March. The annual average rainfall is about 750–800 mm.

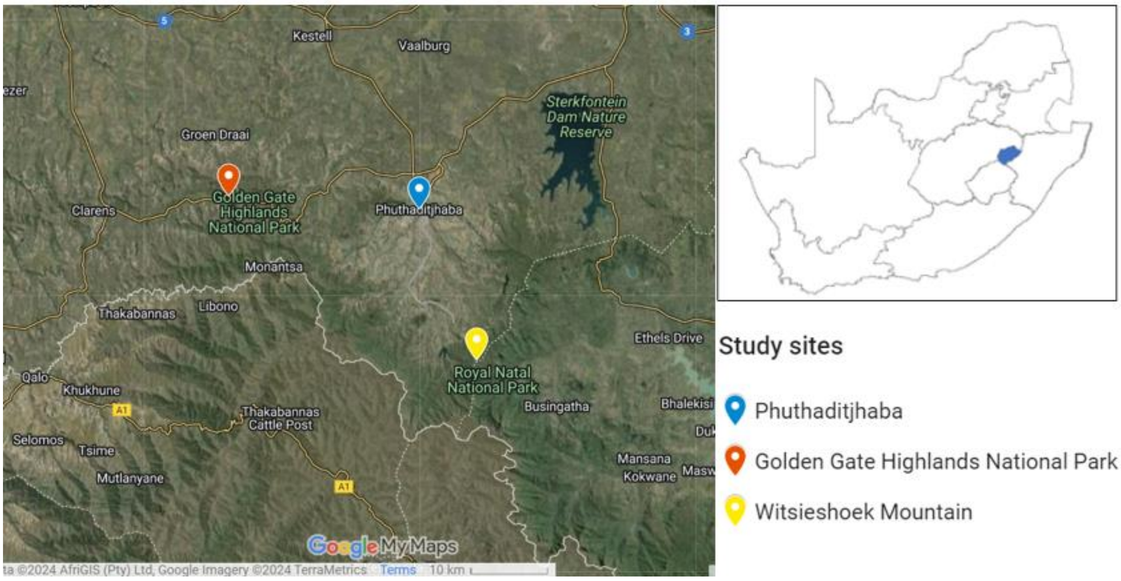

Figure 1.1: Google map image showing the location of Phuthaditjhaba, Golden Gate Highlands National Park and Witsieshoek Community Conservation Area with a South African map showing the location of QwaQwa marked with blue shading.

Sampling focused on the QwaQwa Maloti Highlands, including the Witsieshoek Community Conservation Area, as well as the neighbouring Golden Gate Highlands National Park (Figure 1.1). The major land use in QwaQwa is pastoralism and the commonly reared animals are cattle, sheep and goats (Shezi et al., 2021). For this study, Golden Gate National Park which is a protected area served as a natural and least disturbed grassland. Wildlife grazing is the dominant form of grazing in this area. This park is 11 600 hectares in size, and it comprises of a diversity of fauna which include black wildebeest (*Connochaetes gnou*), eland (*Tragelaphus oryx*), blesbuck (*Damaliscus pygargus phillipsi*), oribi (*Ourebia ourebi*), springbok (*Antidorcas marsupialis*), zebras (Equus quagga) and birds (Kotze, 2002). Witsieshoek Community Area, however, served as a community conservation area of low intensity of grazing in communal rangelands. It covers an area of 16000 hectares, and it has been proclaimed as a community conservation area with good potential for tourism. Phuthaditjhaba on the other hand comprises of highly disturbed rangelands comprising of commercial rangelands and urban settlements. This urban area has a population of 54 661 people according to the 2011 census with a density of 2 300 people per km^2. Phuthaditjhaba represented an area of extreme anthropogenic influence. I also used Phuthaditjhaba to identify school learners who would form part of this study.

1.13 Aim and objectives

The overarching aim of my study was to understand the vulnerability of bats at high elevations to climate change and anthropogenic disturbance within an Afromontane grassland ecosystem. To address this aim, I focused on four specific objectives: (1) investigating the dynamics of bat activity and distribution across elevational gradients, (2) investigating the dynamics of bat activity and distribution across an anthropogenic gradient, (3) assessing bat diet composition to understand their diet breadth in different land uses, and (4) investigating the effectiveness of environmental education on changing negative public perceptions towards bats to inform conservation strategies. I have written this thesis such that each chapter is publishable by itself except for the first and last chapters which are the general introduction and general conclusion to the study. The chapter that assesses the impact of environmental education on negative public perceptions towards bats has already been submitted for publishing. The remaining three publishable chapters will also be submitted for publications to various journals. Each of the chapters addresses a specific objective of the study as explained below.

The first objective of my study was to determine the factors underlying variation in bat activity and distribution in a natural landscape along an elevational gradient in the Drakensberg

Afromontane Grassland. This objective is addressed by chapter 2 of this thesis. For this objective, elevation served as a proxy for climate change to determine the potential impacts of climate change on bat communities in Afromontane grasslands. To address this objective, I used acoustic and capture surveys to determine both the activity and distribution of bats along the elevational gradient. I hypothesised declining bat activity and richness along an increasing elevational gradient (Weier et al., 2017). The data to this objective will act as the baseline to test whether bat species exhibit an upward range shift, with their distribution retreating towards higher altitudes due to increased temperatures associated with climate change as reported by other studies (LaVal, 2004; Arias et al., 2021).

My second objective was to determine the factors underlying variation in bat activity and foraging activity across a human disturbance gradient ranging from an unprotected area to a fully protected area in the Drakensberg Afromontane Grassland. I addressed this objective in the third chapter of this thesis. I, again, made use of acoustic and capture surveys to determine both the foraging activity and distribution of bats along this gradient. I hypothesised bat activity to be higher in human occupied areas as a previous study revealed more insectivorous bats occurring in human settlements compared to communal rangelands and agricultural fields in Limpopo and this may be attributed to higher insect abundance (such as moths, mosquitos) around lights and the presence of artificial roosts such as houses and planted trees (Foord et al., 2018).

My third objective was to determine the variation in the diet of *Laephotis capensis* which is the most common bat in the area across multiple land uses in the Drakensberg Afromontane Grassland. Understanding the diet of Drakensberg bats is crucial because it reveals the food sources they rely on, helping to assess whether these resources are vulnerable to both climate change and anthropogenic disturbances. It also reveals the potential value that bats have in the ecosystem which might serve to strengthen the need for their conservation. I addressed this objective in the fourth chapter of this thesis. I used microscopic analysis of bat faecal pellets to determine the order of the insects whose fragments were found in the pellets. I hypothesised a broader diet breath in least disturbed areas compared to highly disturbed areas.

The final objective of my study was to determine the impacts of environmental education on the perception of school learners towards bats in the Free State region of South Africa. I addressed this objective in the fifth chapter of this thesis. For this objective, I used a standardised questionnaire to ascertain if perceptions of bats in school learners would change before and after educational classes and engagement interactive research. I hypothesised more positive perceptions towards bats after an educational intervention.

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Chapter 2

Bat communities along an elevational gradient in the Maloti-Drakensberg grassland

Abstract

When trying to predict the impact of climate change on species distributions, researchers often turn to montane environments, as they exhibit significant climatological variation across relatively short distances. This can effectively mimic the changing environmental conditions expected under climate change. Bats are highly sensitive to environmental changes, making them valuable indicators of how biodiversity is impacted by climate change. The Maloti-Drakensberg mountains cover an extensive elevational gradient and have high endemism and therefore have a huge potential to investigate impacts of climate change on biodiversity. Using acoustic surveys, I assessed the change in distribution of bat communities along an elevational gradient of 1750-3100m above sea level in the Maloti-Drakensberg mountains, Free State Province, South Africa. My sampling during late 2021 to early 2023 uncovered a total of eight species of bats in the area. I found that both bat species richness and echolocation activity were higher at low elevations compared to higher elevations. Isothermality was positively correlated with species richness whereas minimum temperature of coldest month and increase in distance to rivers were positively correlated with bat activity. I captured two endemic bat species, namely *Cistugo lesueuri* and *Rhinolophus cervenyi*. I also showed that the distribution of the recently described and still poorly known *Rhinolophus cervenyi*, encompassed the entire elevational range of the Maloti-Drakensberg mountains up to 3000m above sea level. In contrast, *Rhinolophus acrotis*, a paramontane species, occurred at lower elevations up to 2000m above sea level. The absence of the endemic *Laephotis cf. wintoni* in my study might be evidence of the negative impact of climate change on Afromontane species occurring in the

high Drakensberg. My findings provide a baseline for future studies on effects of climate change on such elevation gradients. My study further contributes to a better description of the bat communities at different elevations in the Afromontane Drakensberg Mountain and predicts upward range shifts with increasing temperatures.

2.1 Introduction

Mountains are known for being hotspots of biodiversity, providing many key ecosystem services that enable the livelihoods of people residing around them and even shaping their cultures (Mengist et al., 2020). They act as water sources for most areas and provide services such as regulation of natural hazards and carbon sequestration. The complex topography and high elevation of mountains create a lot of climatic variation resulting in highly complex environmental heterogeneity that supports high species diversity (Körner, 2004; Perrigo et al., 2020), and form bridges and/or barriers for dispersal (Monadjem et al., 2023). Mountains also have the potential to act as refugia for biodiversity through time since biodiversity can move to ideal niches within a short distance on that mountain (Chen et al., 2011; Sandel et al., 2011). Due to their nature, mountains give rise to elevation gradients that have found importance in ecological research studies of biodiversity (Monadjem et al., 2024).

Elevational gradients are commonly used in models as a proxy for climate change enabling assessment of animal and plant responses to changes in biotic and abiotic factors (Mccain & Colwell, 2011). Monitoring species along elevational gradients has provided insight on how species might be affected by climate change overtime due the different climatic conditions that occur in a relatively short horizontal distance up a mountain (Körner, 2007; Ashton et al., 2011). This rapid change in environmental conditions along elevational gradients creates diverse ecosystems that support a wide variety of organisms, resulting in observable altitudinal patterns (Hodkinson, 2005; Perrigo et al., 2020). Such patterns for vertebrate taxa include a reduction in species richness with rise in elevation (Monadjem et al., 2024), a peak in richness at mid-elevation, low plateau with a mid-peak in richness and a low plateau pattern (McCain & Grytnes, 2010). This variation along elevational gradients makes it possible to investigate ecological processes at small spatial scales, that would otherwise have needed a far larger study area on the scale of latitudinal gradients (Sundqvist et al., 2013).

Bats are useful in the study of diversity along elevational gradients because of their sensitivity to changes in environmental conditions (Jones et al., 2009). Previous studies have shown that bat species richness can exhibit a hump shaped distribution or linear decline with increasing elevation whilst bat activity tends to exhibit a linear decline with increasing elevation (Curran et al., 2012; Linden et al., 2014; Weier et al., 2017; Monadjem et al., 2024). Such patterns of bat species richness and activity are influenced by water availability linked with temperature (McCain, 2007). McCain's theory suggests higher richness of insectivorous bats where high water availability coincides with high temperatures along an elevational gradient (McCain, 2007). A recent study by Taylor et al., (n.d) also showed a nested elevational pattern with the number of bat species and activity decreasing with increasing elevation along the Maloti-Drakensberg Mountains.

The Maloti-Drakensberg Mountains are one of the highest mountains in Southern Africa that reach 3473 metres above sea level. They are also known for being topographically diverse and are an important centre of plant and animal endemism (Stewart & Mitchell, 2018) and are biodiversity hotspots (Cooper-Bohannon et al., 2016). Like other cooler temperate regions, the Drakensberg generally has low diversity of bats compared to tropical and subtropical savannas in South Africa (Gelderblom et al., 1995; Schoeman et al., 2013; Cooper-Bohannon et al., 2016). In the Drakensberg, bats are likely to be among the species most affected by climate change, as they are highly sensitive to environmental changes (Jones et al., 2009). Mohamed and Mukwada (2019) reported that the region has experienced rising temperatures, with the long-term annual mean maximum and mean minimum temperatures increasing by 0.03 °C and 0.01 °C per year, respectively, between 1960 and 2016. These mountains then serve as an ideal elevation gradient to conduct studies on how climate change is influencing biodiversity. Despite this, there has been limited research focused on determining how bat species along elevational gradients are likely to be influenced by climate change. Knowledge on how elevation influences bat species diversity and distribution is critical if conservation at small geographical scales is to be carried out successfully (Sánchez-Cordero, 2001). This is especially important for the range restricted species endemic to alpine habitats since it will reveal their current range of elevation preference. In this paper, I therefore investigated bat species richness, diversity and activity along an elevational gradient in a natural landscape. I used bats in the Drakensberg mountains as a model system for the prediction of how climate change will affect bat distribution in the future. I hypothesised a decline in species richness, diversity and activity of bats with elevation in the natural landscape along the elevational gradient based on previous studies (Linden et al., 2014; Weier et al., 2017).

2.2 Methods and Materials

2.2.1 Study Area

I conducted this study in the eastern Free State Province of South Africa (Figure 2.1). The Free State Province lies between latitudes 26.6 °S and 30.7 °S and between longitudes 24.3 °E and 29.8 °E. The Free State area has two main seasons namely the warm to hot summers with an average maximum daily temperature of 26.4 °C in December and cool to cold winters with an average minimum temperature of -1.7°C in July. The summers are wet with rain falling from October to March. The annual average rainfall is about 750–800 mm. This area served as an ideal area for my study because of the extensive elevational gradient across natural/protected habitats all the way from the base of the mountain to the very top. Sampling was conducted in Witsieshoek Community Conservation Area and in Golden Gate Highlands National Park (Figure 2.1). Golden Gate Highlands National Park is 11 600 hectares in size, and it comprises of a diversity of fauna that includes the black wildebeest (*Connochaetes gnou*), eland (*Tragelaphus oryx*), blesbuck (*Damaliscus pygargus phillipsi*), oribi (*Ourebia ourebi*), springbok (*Antidorcas marsupialis*), zebras (*Equus quagga*) and birds (Kotze, 2002). Witsieshoek Community Conservation Area covers an area of 16 000 hectares, and it has been proclaimed as a community conservation area with good potential for tourism (Chingombe et al. 2014). There is low intensity of grazing in communal rangelands of the area from sheep, goats and cattle.

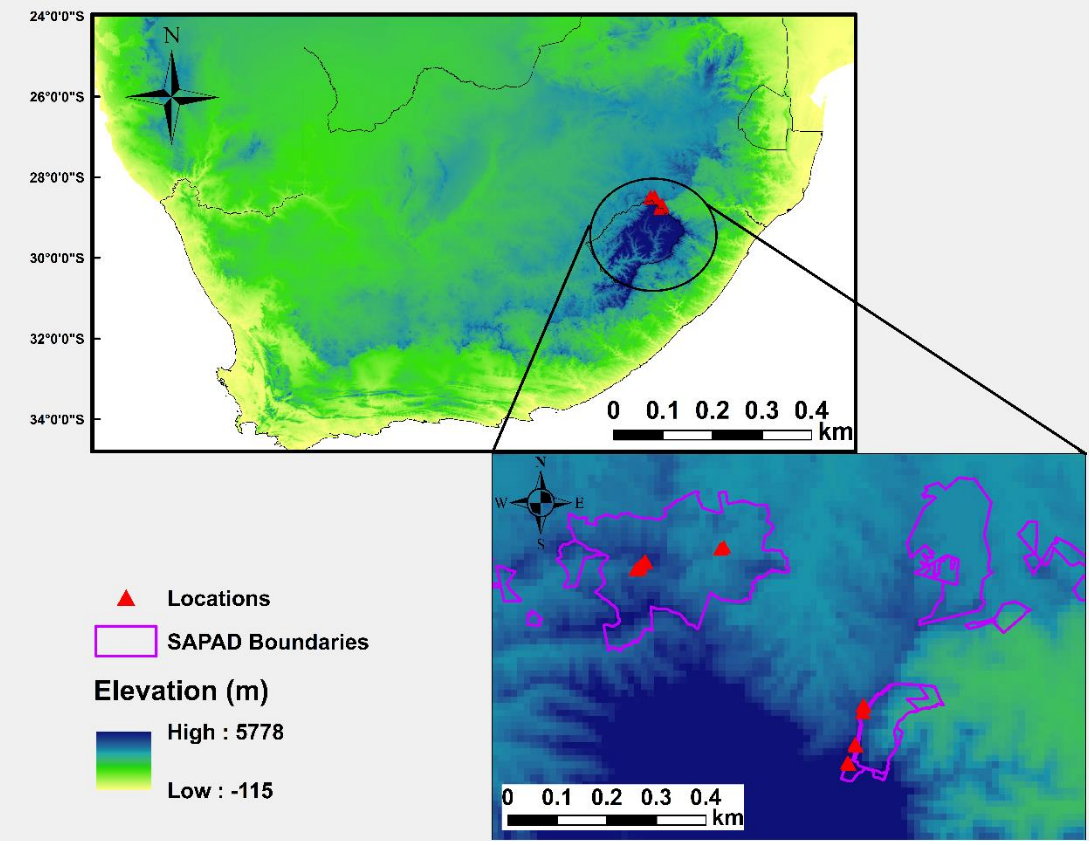

Figure 2.1 Map showing the locations of study sites marked with red triangles in the map of south Africa.

2.2.2 Acoustic data collection

I conducted acoustic surveys along an elevational gradient ranging from 1750m asl to 3000m asl. I randomly selected four sites in each of the two sampling areas namely Golden Gate Highlands National Park and Witsieshoek Community Conservation Area. Golden Gate Highlands National Park comprised of the sites Low (GL), Mid-low (GML), Mid-high (GMH), High (GH) at elevations 1750m asl, 1897m asl, 2030m asl, and 2400m asl respectively (Figure 2.1). Witsieshoek Community conservation area comprised of the sites Low (WL), Mid-low (WML), Mid-high (WMH), High (WH) at elevations 2000m asl, 2200m asl, 2500m asl and 3000m asl respectively. In each of the eight sites, I deployed two Song Meters (SM4 Wildlife Acoustics Mini bat detectors) to obtain passive acoustic recordings of bat echolocation. I deployed the bat detectors at least 100m apart in each site thus each site had two sampling localities. At each sampling locality, the SM4 detector was set to passively record bat echolocation calls from sunset until sunrise. I ran all Song Meter mini bat detectors concurrently in each sampling site. I attached the detectors to trees/shrubs facing the direction where bats were anticipated to fly by. I sampled for three consecutive nights in each sampling station. I conducted live-capture of bats in both sampling areas to confirm presence of species observed to be potentially occurring from acoustic surveys. I conducted these surveys using harp traps and mist nets. Acoustic and physical sampling at all sites was conducted during the wet season, starting in October 2021, followed by February 2022, October 2022, and March 2023. This ensured that each site was surveyed four times over the duration of the study. October corresponds to early summer, while February and March represent late summer.

2.2.3 Acoustic call analysis

I used the program Kaleidoscope Pro (Wildlife Acoustics, Maynard, MA, United States), to analyse bat calls. I used the program to extract calls and organize them into files for analysis. While the program assisted in call extraction and data organization, I manually performed the identification and analysis of the calls by going through each and every call. I used call parameters such as peak frequency (kHz) of an echolocation call for each species to do the call identifications. Identifications were based on reference calls. I obtained these reference calls from release calls of captured field-identified individuals which were then released and as well as from calls that had been obtained in previous studies in Southern Africa provided by Peter Taylor (Monadjem et al., 2020; Taylor et al., 2020; Weier et al., 2020). Due to the overlap of the calls of the species *Pipistrellus hesperidus* with *Cistugo lesueuri* and *Tadarida aegyptiaca* with *Mops pumilus,* each pair of these species were lumped together and labelled as Cistugo_Pip and Molossid respectively.

2.2.4 Statistical analyses

I showed species richness and diversity at each sampling site using rarefaction and extrapolation curves for Hill numbers in the iNEXT package (Hsieh et al., 2016). I used rarefaction and extrapolation of Hill numbers because they account for differences in sample size when comparing species diversity across multiple assemblages (Chao et al., 2014). Species richness, Shannon diversity, and Simpson diversity were represented by $q = 0$, $q = 1$, $q = 2$, respectively, where q is a parameter which determines the measures' sensitivity to species relative abundances or frequencies (Chao et al., 2014; Hsieh et al., 2016). Furthermore, I created heat maps to show the nestedness and the turnover of bat species in the Low, Mid and High sites using the function "ggplot" from the "ggplot2" package (Wickham, 2016).

To investigate the effects of environmental variables on bat activity and species richness, I initially fitted simple linear models and examined residual plots for deviations from model assumptions. Residuals exhibited left-skewness; indicative of potential violations due to zero-inflated count data. To account for this, I used generalised linear models (GLMs), which are more appropriate for count data and less susceptible to such violations. Model fit was assessed through residual diagnostics and comparisons of Akaike Information Criterion (AIC) values. For the GLMs, I ran Generalized Linear Mixed Models (GLMMs) to identify important environmental variables influencing species richness and bat activity using the function ‘dredge’ in the package MuMIn (Barton, 2015) using the family “negative binomial”. I used sampling session as the random variable when I ran GLMMs for species richness whilst I used site as a random variable when I ran GLMMs for bat activity. My sampling was conducted during the wet season (except for sampling done in the second sampling session in the protected area to replace lost data which had been initially collected in the wet season) and hence I did not use season as a random variable. For predictor variables, I tested environmental variables which included mean annual temperature, minimum temperature of coldest month, mean diurnal range, isothermality, distance to river, distance to buildings and distance to roads (Table 2.1). To determine the climatic predictor variables, I obtained all 19 bioclimatic data from www.worldclim.com which I then tested using variance inflation factor (VIF) using the function “vif” in the package “car” (Fox et al., 2012) to select less correlated variables which were minimum temperature of coldest month, isothermality and mean diurnal range. I also added mean annual temperature as it is a biologically significant variable considered in ecological studies despite not being selected by the VIF test._All the environmental variables were scaled to improve normality.

I obtained the distance between localities and roads, buildings and water sources, from shapefiles for roads, buildings and rivers of South Africa (Table 2.1). I used the “sf” package (Pebesma, 2018), to calculate the shortest distances between my localities and these environmental features. I selected the model with the lowest Akaike Information Criterion (AIC) score as the best performing model and I considered models with delta AIC less than one to be competing models (Burnham & Anderson, 2004; Johnson & Omland, 2004). I then plotted graphs showing how the environmental variables of the best performing models affected bat species richness and activity using output values extracted from best models. To achieve this, I used the function “ggpredict” in the package ggeffects (Lüdecke, 2018). I used the package “ggplot2” (Wickham et al. 2016) to draw the graphs showing the relationship of the predictor variables and bat activity and richness. All statistical analyses were done in the software R (R Core Team, 2019).

Table 2. 1: The predictor variables that were used in the study, their definitions and the links to where they were obtained.

Predictor variable	Definition	Source
Mean diurnal range	Mean of monthly (max temp - min temp)	https://www.worldclim.org/data/bioclim.html
Isothermality	(Mean diurnal range/Temperature annual range) ×100	https://www.worldclim.org/data/bioclim.html
Min temperature of coldest month	Min Temperature of Coldest Month	https://www.worldclim.org/data/bioclim.html
Mean annual temperature	Total temperature for one year/12	https://www.worldclim.org/data/bioclim.html
Distance to road	Shortest distance from a sampled locality to the nearest road	http://www.ngi.gov.za
Distance to river	Shortest distance from a sampled locality to the nearest river	http://www.dwa.gov.za/iwqs/gis_data/river/rivs500k.html
Distance to building	Shortest distance from a sampled locality to the nearest building	http://www.ngi.gov.za

To identify the climatic variables that were associated with the community composition of bats, I ran a permutational multivariate analysis of variance (PERMANOVA) using the adonis2 function in the package “vegan” (Oksanen 2013). I tested the climatic variables namely isothermality, mean diurnal range, min temperature of coldest month and temperature. I used sampling session as a random variable. I then further showed a visual representation of the influence of each of the significant environmental variables that I determined to be associated with bat species composition using a canonical correspondence analysis (CCA) plot. CCA is a multivariate analysis that allows assemblages of species to be related to environmental variables (ter Braak & Verdonschot, 1995) and has been of great use in ecological studies because it assumes unimodal species relationships when it extracts synthetic environmental gradients from ecological datasets (ter Braak & Verdonschot, 1995; Borcard et al., 2018; Monadjem et al., 2024). To accurately represent the bat community structure, I excluded three localities that were clear outliers in the data. Two of these localities were illuminated by spotlights at night, likely leading to significantly elevated bat activity in those areas. As this artificially inflated activity could skew the results, I chose to remove them from the analysis (Appendix 1.10). The third locality accounted for 1,952 of the 1,953 *Myotis tricolor* calls recorded, with all these calls captured during the first sampling session and none in subsequent sessions. This anomaly created a substantial imbalance in the data, further justifying its exclusion to avoid distorting the overall analysis.

2.3 Results

I recorded a total of 68,838 bat calls over the duration of the study with 16,442 and 52,396 calls recorded in the community conservation area and the protected area respectively. I identified a total of eight species belonging to five families (Table 2.2). The Molossid species had the highest number of recorded calls accounting for over half of the total recorded calls followed by Cistugo_Pip and *Laephotis capensis* (Figure 2.2). The recorded number of calls of the remaining species was very low compared to these three species. During the study, I successfully trapped seven of the species (Table 2.2; Appendix 1.10). I conducted sufficient acoustic sampling in both the community conservation area and the protected area as evidenced by rarefaction curves (Figure 2.3). Species richness was higher in the community conservation area compared to the protected area. I observed the same trend for both the Shannon and Simpson diversity as they were both higher in the community conservation area compared to the protected area (Figure 2.3). Within the community conservation area, the Low site exhibited the highest species richness as well as the highest Shannon and Simpson diversity indices (Figure 2.4). In contrast, within the protected area, species richness was highest at both the Low and High sites (Figure 2.5). Both Shannon and Simpson diversity were highest at the Low site in the protected area (Figure 2.5). Additionally, I observed higher nestedness of bats along an elevational gradient in both the community conservation area and the protected area compared to species turnover (Figure 2.6). This means that sites at higher elevations contain subsets of species found at lower elevations. The results indicate that nestedness, rather than turnover, is the dominant component of beta diversity in both the protected and community conservation areas, implying that as elevation increases, species richness declines instead of species being replaced by new ones. I recorded eight species at the Low site, seven at the Mid sites and five species at the High site of the community conservation area whilst I recorded seven species at the Low site, six species at the Mid sites and five species at the High sites of the protected area.

Table 2. 2: The recorded number of bat species, and the families and functional groups (Monadjem et al. 2020) that each species belongs to, the species whose call frequency they overlap with, state of physical capture of each species, the current global (IUCN 2019 Red List category) conservation status: LC= Least Concern, NE = Not Evaluated.

Family	**Species**	**Functional group**	**Overlap species**	**Capture**	**Release calls**	**IUCN red list status**
Rhinolophidae	*Rhinolophus acrotis*	Clutter	-	Yes	Yes	LC
Rhinolophidae	*Rhinolophus cervenyi*	Clutter	-	Yes	Yes	NE
Molossidae	*Mops pumilus*	Open-air	*Tadarida aegyptiaca*	No	No	LC
Molossidae	*Tadarida aegyptiaca*	Open-air	*Mops pumilus*	Yes	Yes	LC
Miniopteridae	*Miniopterus natalensis*	Clutter-edge	-	Yes	No	LC
Cistugidae	*Cistugo lesueuri*	Clutter-edge	*Pipistrellus hesperidus*	Yes	Yes	LC
Vespertilionidae	*Eptesicus hottentotus*	Clutter-edge	-	Yes	No	LC
Vespertilionidae	*Myotis tricolor*	Clutter-edge	-	No	No	LC
Vespertilionidae	*Laephotis capensis*	Clutter-edge	-	Yes	Yes	LC
Vespertilionidae	*Pipistrellus hesperidus*	Clutter-edge	*Cistugo lesueuri*	No	No	LC

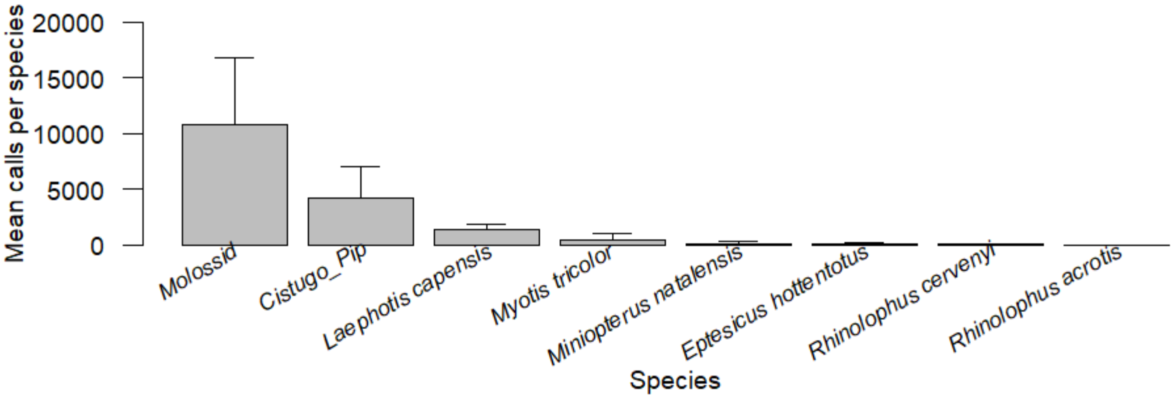

Figure 2. 2: Bar chart showing the mean number of calls per session recorded for each bat species during the duration of the study with error bars showing standard deviation.

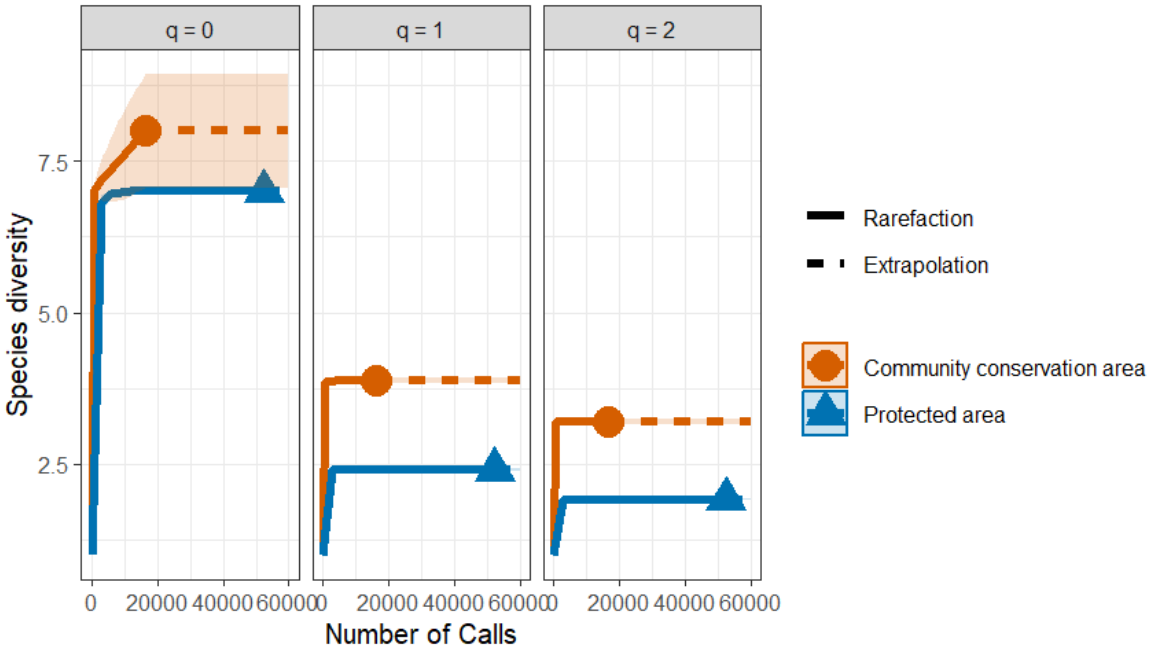

Figure 2. 3: Rarefaction (solid lines) and extrapolation (dashed lines) curves for bats based on Hill numbers (q = 0, 1, 2) for Golden Gate Highlands National Park and Witsieshoek Community Conservation Area, where q = 0 refers to species richness, q = 1 to Shannon's diversity, and q = 2 to Simpson's diversity, respectively at 95% confidence intervals.

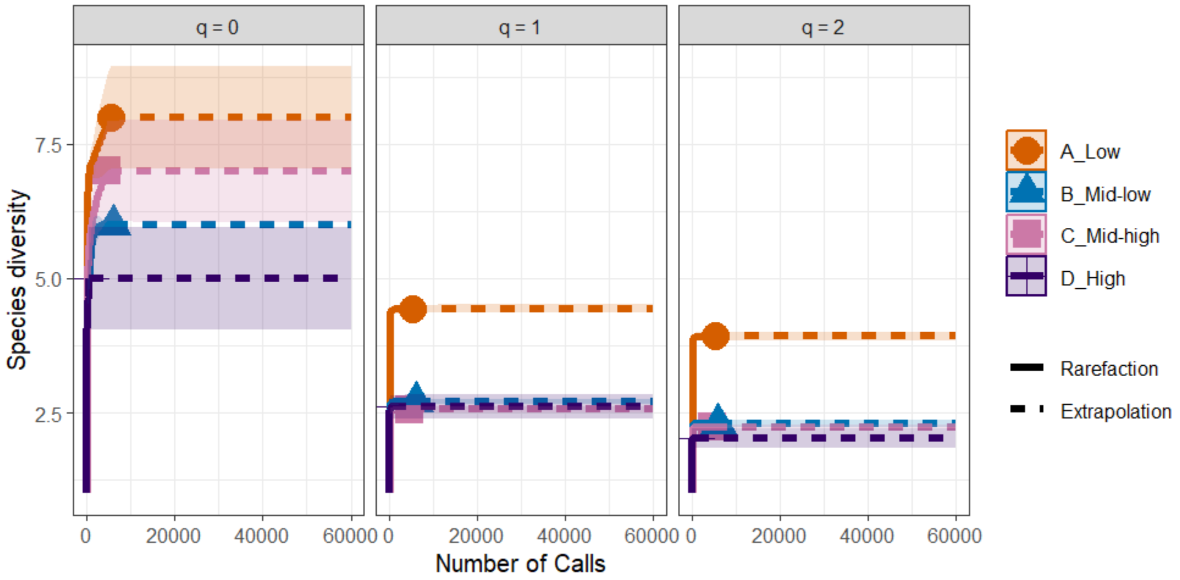

Figure 2. 4: Rarefaction (solid lines) and extrapolation (dashed lines) curves for bats based on Hill numbers (q = 0, 1, 2) for the four sites Low, Mid-low, Mid-high and High (2000m, 2200m, 2500m and 3000m asl respectively) in the Witsieshoek Community Conservation Area, where q = 0 refers to species richness, q = 1 to Shannon's diversity, and q = 2 to Simpson's diversity, respectively at 95% confidence intervals.

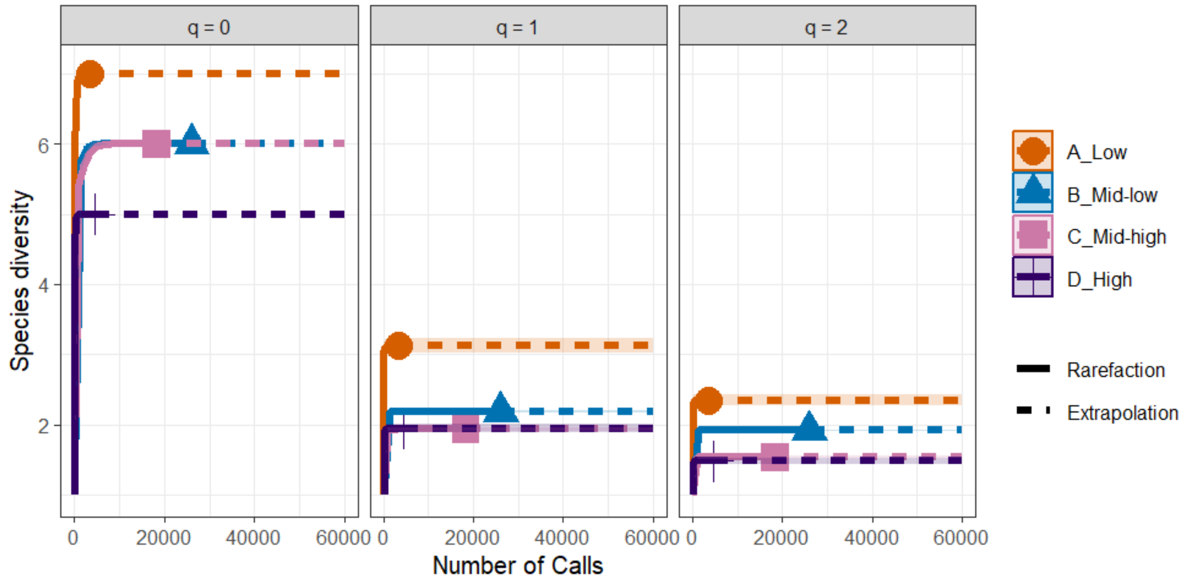

Figure 2. 5: Rarefaction (solid lines) and extrapolation (dashed lines) curves for bats based on Hill numbers (q = 0, 1, 2) for the four sites Low, Mid-low, Mid-high, and High site (1750m, 1897m, 2030m, and 2400m asl respectively) in the protected area Golden Gate Highlands National Park, where q = 0 refers to species richness, q = 1 to Shannon's diversity, and q = 2 to Simpson's diversity, respectively at 95% confidence intervals.

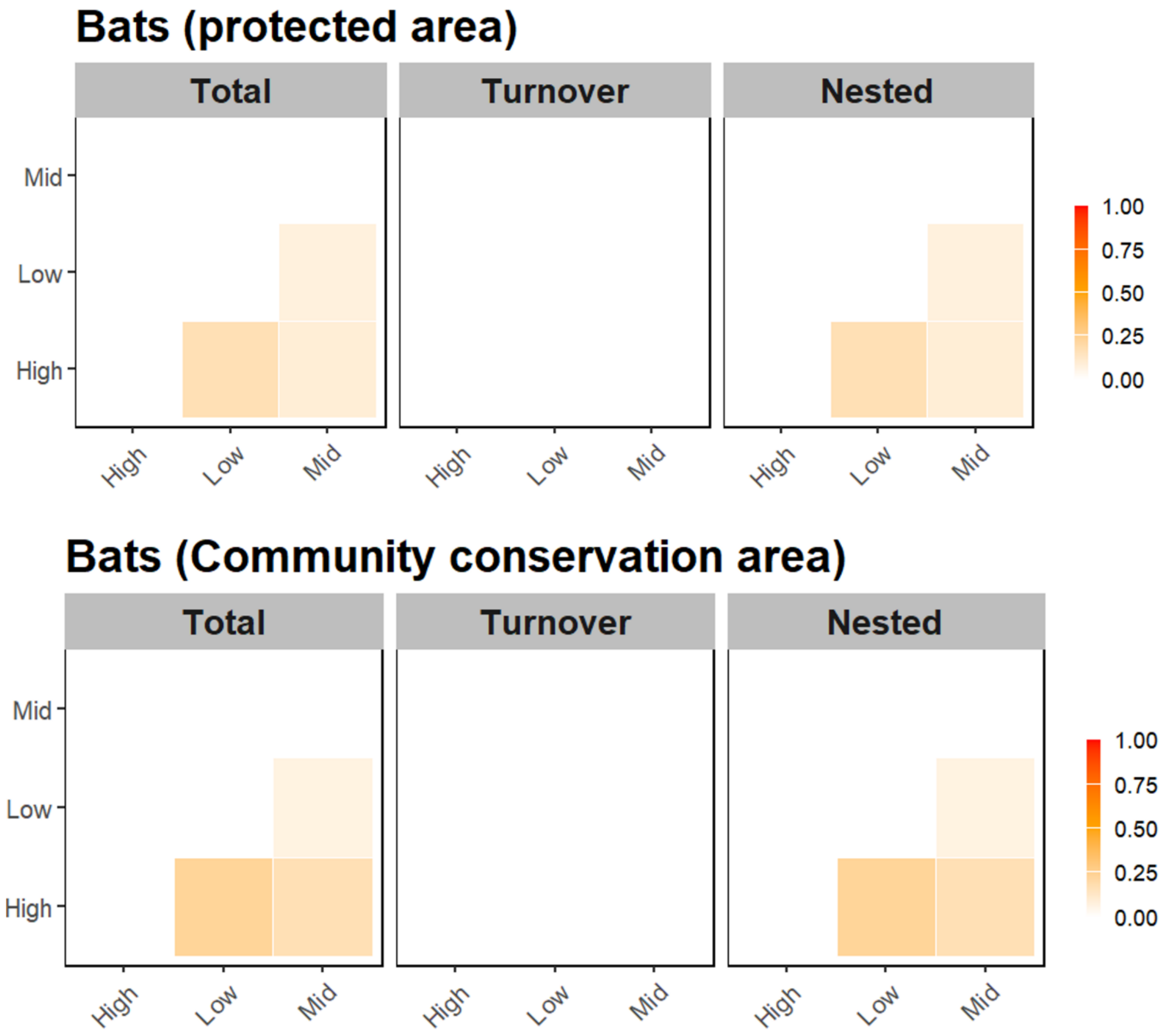

Figure 2. 6**:** Heat maps representing total beta diversity and its components of turnover and nestedness of bats between Low, Mid and High sites in the Witsieshoek Community Conservation Area and the Golden Gate Highlands National Park protected area. Total beta diversity (left panel in each section) represents the overall dissimilarity in bat species composition between sites, with darker shading indicating higher dissimilarity. Turnover (middle panel in each section) measures species replacement between sites, where a lack of shading suggests minimal species replacement between elevations. Nestedness (right panel in each section) captures patterns where species at higher elevation sites are a subset of those found at lower elevations. The darker shading between Low and Mid sites suggests species loss rather than replacement as the primary driver of beta diversity.

For GLMMs, the best performing model comprised of isothermality as a predictor variable when it came to species richness. The competing model was the one of minimum temperature of the coldest month. Isothermality showed an increase with elevation whilst minimum temperature of coldest month showed a decrease (Appendix 1.1). Species richness was positively influenced by isothermality ($\chi^2 = 3.936$, p = 0.047). Minimum temperature of coldest month did not have a significant association with species richness (χ 2 = 3.416, p = 0.065; Table 2.3 and Figure 2.7).

Table 2. 3**:** A sample of the ranked models that were tested, with the best performing model at the top with the lowest AIC value where the response variable was the number of species recorded per locality per session. The table shows the model names, the intercept for each model, the predictor variables (namely buildings for distance to buildings, Isthr for isothermality, Mndrn for mean diurnal range, Mntmp for minimum temperature of coldest month, river for distance to river, roads for distance to roads), the degrees of freedom (Df), the log-likelihood (log-Lik), the AICc values, the delta AICc values and weights for the models. The best models have been shown in bold.

Model names	(Intercept)	Buildings	Isthr	Mndrn	Mntmp	River	Road	Tmprt	Df	logLik	AICc	Delta	Weight
Isothermality	**1.532**		**0.126**						**4**	**-117.363**	**243.4**	**0.00**	**0.054**
Minimum temperature of coldest month	**1.533**				**0.116**				**4**	**-117.654**	**244.0**	**0.58**	**0.041**
Distance to road + Mean annual temperature	1.530						0.132	0.196	5	-116.809	244.7	1.260	0.029
Distance to buildings + Mean annual temperature	1.530	-0.092						0.099	5	-116.830	244.7	1.300	0.028
Distance to buildings + Mean diurnal range	1.530	-0.147		0.107					5	-116.856	244.8	1.360	0.028
Distance to buildings + Isothermality	1.530	-0.062	0.103						5	-116.865	244.8	1.380	0.027
Mean annual temperature	1.534							0.101	4	-118.079	244.9	1.430	0.027

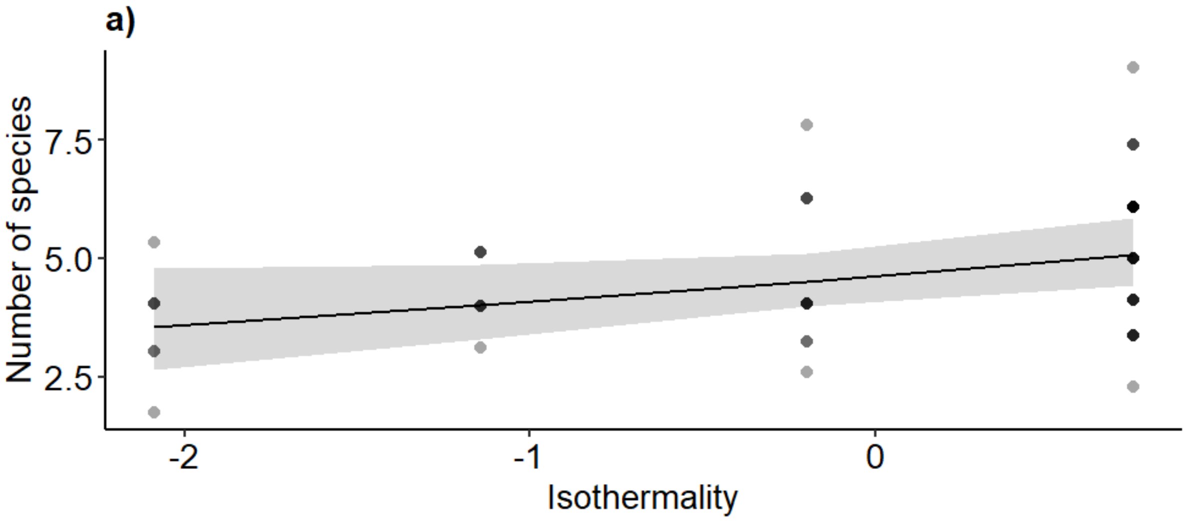

Figure 2. 7: A plot showing the relationship between the environmental variable of the best model (Isothermality) and bat species richness from predicted values, extracted from the best model (Isothermality). The figure uses scaled values of isothermality.

For bat activity, the best performing model comprised of distance to river whilst the competing model comprised of minimum temperature of coldest month (Table 2.4). The greater the distance to river, the higher the bat activity observed ($\chi^2 = 4.012$, $p = 0.045$; Figure 2.8). Higher bat activity was also observed with higher minimum temperature of coldest month ($\chi 2 = 4.727$, $p = 0.030$).

Table 2. 4: A sample of the ranked models that were tested, with the best performing model at the top with the lowest AIC value where the response variable was bat activity (mean calls recorded per locality). The table shows the model names, the intercept for each model, the predictor variables (r distance to buildings (buildings), isothermality (Isthr), mean diurnal range (Mndrn), minimum temperature of coldest month (Mntmp), distance to river (river), distance to roads (roads), the degrees of freedom (Df), the log-likelihood (log-Lik), the AICc values, the delta AICc values and weights for the models. The best models have been shown in bold.

Model names	**(Intrc)**	**Buildings**	**Isthr**	**Mndrn**	**Mntmp**	**River**	**Road**	**Tmprt**	**DF**	**logLik**	**AICc**	**Delta**	**Weight**
Distance to river	**5.581**					**0.689**			**4**	**-92.494**	**197.4**	**0.00**	**0.171**
Minimum temperature of coldest month	**5.592**				**0.520**				**4**	**-92.918**	**198.3**	**0.85**	**0.112**
Distance to river + Distance to road	5.540					0.704	-0.392		5	-90.469	198.4	1.00	0.103
Mean diurnal range + Distance to river	5.542			0.399		0.659			5	-90.537	198.6	1.14	0.097
Minimum temperature of coldest month + Distance to river	5.558				0.3460	0.345			5	-91.283	200.1	2.63	0.046
Isothermality + Minimum temperature of coldest month + Distance to river	5.492		-0.870		1.077	0.511			6	-88.160	200.3	2.89	0.040
Isothermality + Mean diurnal range + Distance to river	5.495		-0.635	0.864		1.177			6	-88.316	200.6	3.20	0.035
Isothermality + Minimum temperature of coldest month	5.503		-0.763		1.249				5	-91.585	200.7	3.24	0.034

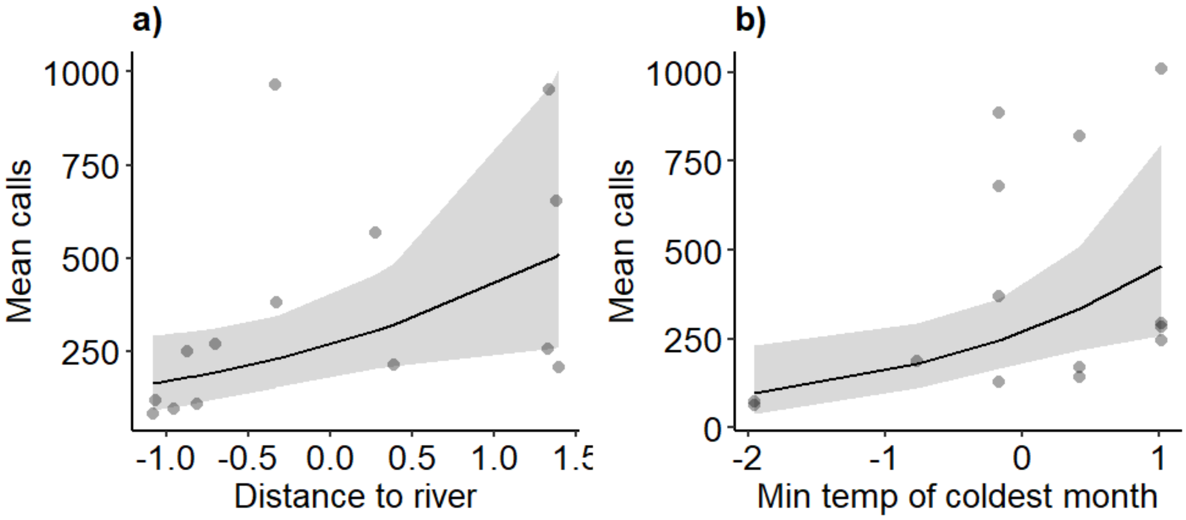

Figure 2. 8**:** A plot showing the relationship between the environmental variable of the best model (distance to river) and the competing model (minimum temperature of coldest month) with bat activity from predicted values, extracted from the best and competing model (distance to river and min temp of coldest month). The figure uses scaled values of distance to river and minimum temperature of coldest month.

For species composition, I was able to determine that isothermality, minimum temperature of coldest month and mean diurnal range significantly influenced species composition of the localities at different elevations (Table 2.5). *Rhinolophus acrotis* emerged as a key species distinguishing bat community composition along the elevational gradient in all three CCA plots (Figures 2.9, 2.10, and 2.11). Its distribution was closely associated with sites at lower elevations within the protected area, suggesting a preference for these conditions. The species was negatively correlated with min temperature of the coldest month (Figure 2.9), indicating a stronger presence in colder environments. Additionally, *R. acrotis* showed a positive association with mean diurnal range (Figure 2.11), suggesting that it is more likely to occur in areas where daily temperature fluctuations are high. The weak association with isothermality (Figure 2.10) suggests that *R. acrotis* is not strictly dependent on thermal stability but may still be influenced by broader climatic factors. One of the high-elevation sites in the community conservation area exhibited low isothermality and correspondingly low species richness, further emphasizing the role of temperature variation in shaping bat distributions across the gradient

Table 2. 5**:** Output of PERMANOVA showing relationship of environmental variables with species composition. The table shows the degrees of freedom (DF), the Sum of squares (SumOfSqs), the proportion of variance explained by each factor (R^2), the F value (F) and the p-value (Pr(>F))

	Df	**SumOfSqs**	**R^2**	**F**	**Pr(>F)**
Session	1	0.0182	0.00252	0.1635	0.941
Road	1	0.1479	0.02053	1.3297	0.274
Buildings	1	0.1202	0.01668	1.0803	0.311
River	1	0.1896	0.02631	1.7041	0.174
Temperature	1	0.0677	0.00940	0.6089	0.552
Mean diurnal range	1	0.4302	0.05972	3.8680	0.013 *
Isothermality	1	0.8077	0.11212	7.2616	0.001 ***
Min temp cold month	1	0.8622	0.11969	7.7518	0.002 **
Residual	41	4.5604	0.63303		
Total	49	7.2041	1.00000		

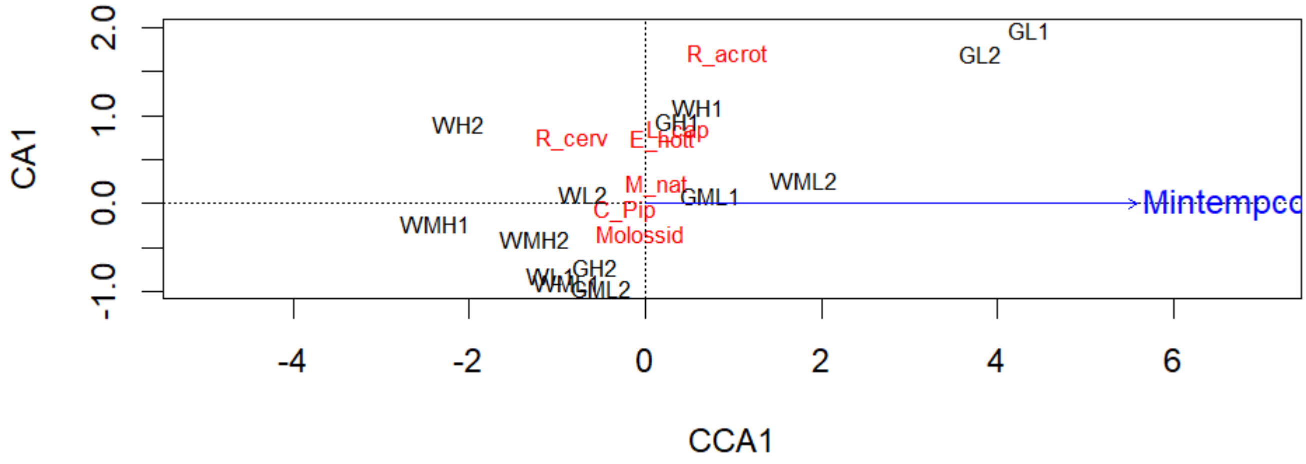

Figure 2. 9: Canonical correspondence analysis (CCA) plot showing species compositions of the different localities namely WL and GL for the low sites in Witsieshoek and Golden Gate respectively, WML and GML for the Mid-low sites and WMH and GMH for the Mid-high sites and WH and GH for the High sites in Witsieshoek and Golden Gate Highlands National Park respectively with minimum temperature of the coldest month as the predictor variable.

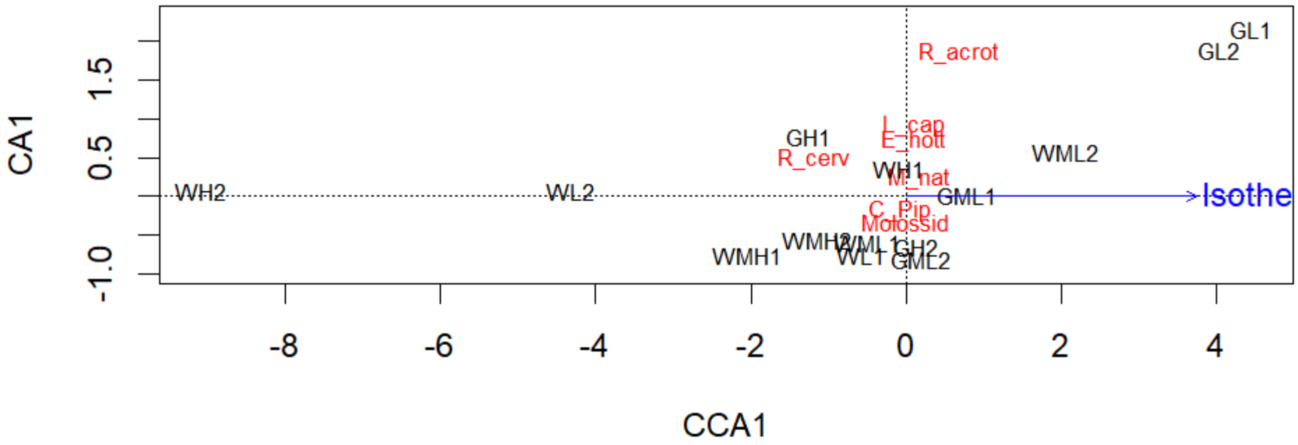

Figure 2. 10: Canonical correspondence analysis (CCA) plot showing species compositions of the different localities namely WL and GL for the low sites in Witsieshoek and Golden Gate respectively, WML and GML for the Mid-low sites and WMH and GMH for the Mid-high sites and WH and GH for the High sites in Witsieshoek and Golden Gate Highlands National Park respectively with isothermality as the predictor variable.

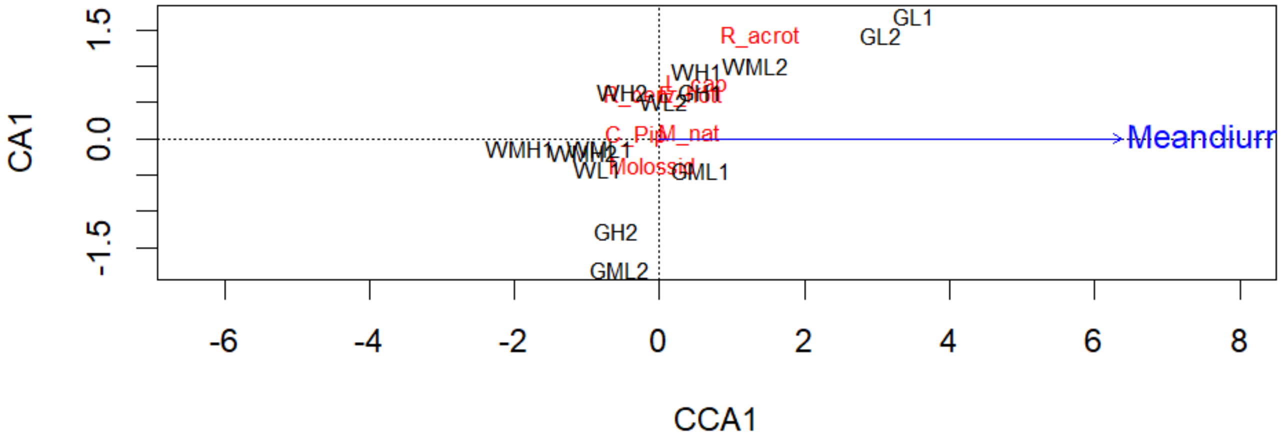

Figure 2. 11**:** Canonical correspondence analysis (CCA) plot showing species compositions of the different localities namely WL and GL for the low sites in Witsieshoek and Golden Gate respectively, WML and GML for the Mid-low sites and WMH and GMH for the Mid-high sites and WH and GH for the High sites in Witsieshoek and Golden Gate Highlands National Park respectively, with mean diurnal range as the predictor variable.

During the study, I was able to capture the endemic species *Cistugo lesueuri* (*Pipetsrellus_Cistugo*) thus confirming the presence of the species in the area. *Pipistrellus_Cistugo* showed an even distribution along the elevational gradient with recordings captured at the lowest elevation and all the way up to the highest elevations (Figure 2.12). The newly described rare species *Rhinolophus cervenyi* also showed an even distribution along the elevational gradient occurring at low elevation and at high elevations (Figure 2.13). *Rhinolophus acrotis*; however, showed a distribution that spread no higher than 2000 m above sea level (Figure 2.13).

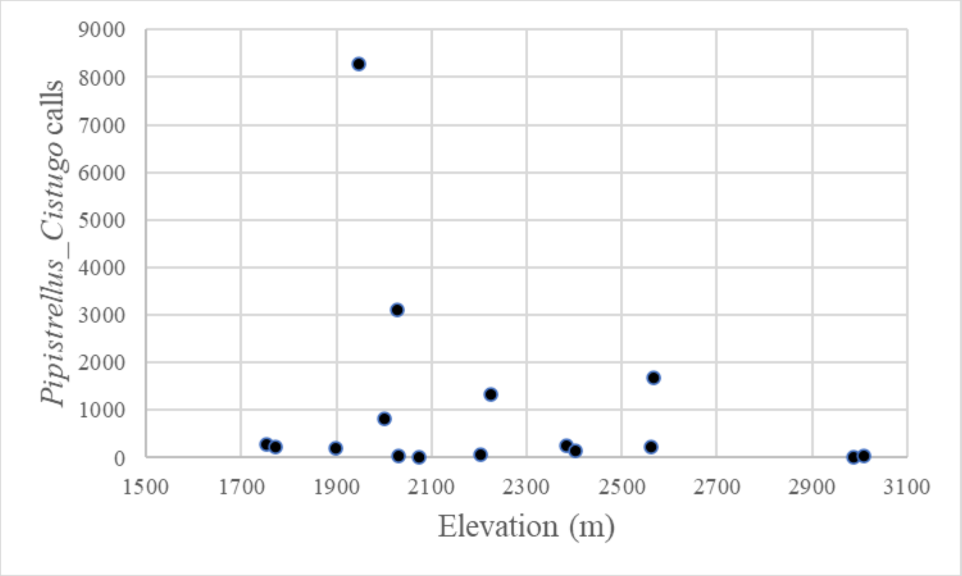

Figure 2. 12: The number of calls for *Pipistrellus_Cistugo* that were recorded at different elevations during the study period.

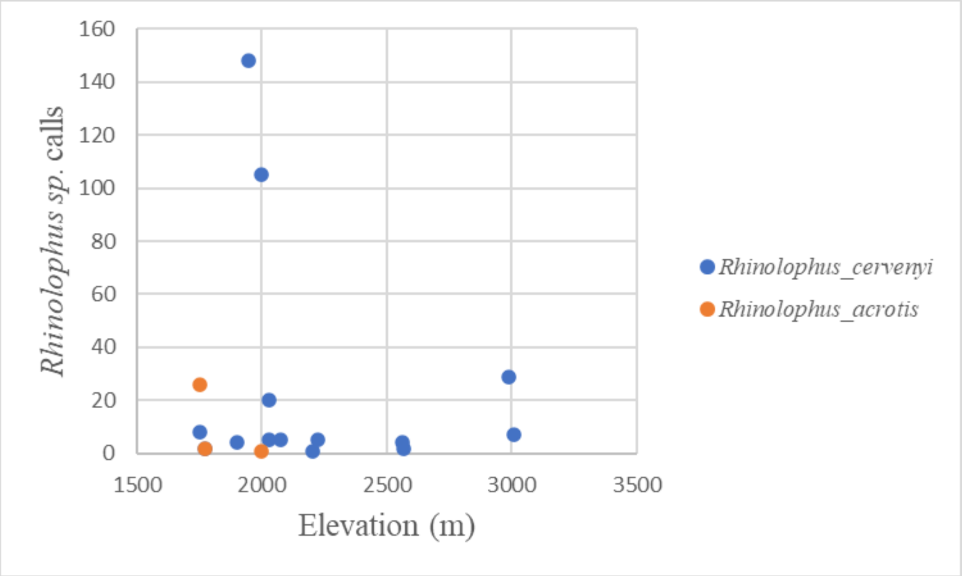

Figure 2. 13: The number of calls for the two *Rhinolophus* species (*Rhinolophus cervenyi* and *Rhinolophus acrotis*) that were recorded at different elevations during the study period.

2.4 Discussion

This study was the first of its kind to be done in the Drakensberg Afromontane mountains. Even though records of bat species that were collected historically in the area exist in museums, no study has extensively conducted bat surveys in this area using both acoustic and physical capture techniques. This study was also the first time the alpine summit of thes South African Maloti-Drakensberg mountains were extensively surveyed for bats. My study revealed the occurrence of eight bat species in the area. I determined species richness and diversity to be highest at the sites at lowest elevations. At the highest elevations (> 2800m asl), only five species were recorded namely Cistugo_Pip, Molossid, *Laephotis capensis, Eptesicus hottentotus* and *Rhinolophus cervenyi*. The occurrence of these four species at both low and higher elevations suggests that their range in the Drakensberg is broad. The occurrence of the remaining species' namely *Rhinolophus acrotis, Miniopterus natalensis* and *Myotis tricolor,* occurrence; however, was confined to mid high and mid low elevations with *Rhinolophus acrotis* only occurring only at two sites between the elevations 1700-2030m asl which was expected as this is a paramontane species (Taylor et al., 2024). Due to rarefaction curves showing sufficient sampling in both sampled areas, the absence of the remaining three species at the high elevation may not have been due to poor sampling but rather due to their distribution that is limited to lower elevation in the Drakensberg. The recording of the paramontane species *Myotis tricolor* in my study was expected as the species distribution range as per the IUCN Redlist assessment was very close to my study area with the species previously recorded in Lesotho (Appendix 1.2) and the species had been recorded before in the Free State (Monadjem et al., 2020). In my study, however, the distribution of this species was below 2400m asl despite it being a paramontane species. It is worth noting that it is difficult to determine the validity of the occurrence of this species through acoustics because I did not physically capture it for its release call. *Miniopterus natalensis* is another paramontane species whose distribution was determined to reach 2500m asl by this study, a new record in the area as it had not been recorded in the area before (Monadjem et al. 2020). My record of this species does, however, fall within the predicted distribution range of the species as determined by the IUCN (Appendix 1.3). I additionally determined *Cistugo lesueuri* to be occurring at the highest elevations (>2800m asl). This species is a montane endemic and my record falls within the distribution range of the species (Monadjem et al. 2020; Appendix 1.4). This species is also known to occur in the Cederberg in the Western Cape and thus it is not a Drakensberg endemic (it is endemic to South Africa and Lesotho). The study also confirmed the presence of both *R. acrotis* and *R. cervenyi* in the area—two species whose distributions remain uncertain due to a recent reclassification and a newly published description, respectively (Benda et al., 2024; Uvizl et al., 2024). This highlights the study's significance in helping to fill a distribution gap for these paramontane species.

In this study, species richness and activity of bats declined along the elevation gradient with low species richness and diversity recorded at higher elevations. This was in line with the hypothesis of the study which was based on the findings of previous studies in other elevational gradient studies conducted in Africa (Curran et al., 2012; Linden et al., 2014; Weier et al., 2017, 2020). The same trend was reported in bat studies conducted outside Africa where bat species richness, diversity and activity were lower at high elevations (Jaberg & Guisan, 2001; Sánchez-Cordero, 2001; Erickson & Adams, 2003; McCain, 2007). Such findings support McCains's (2007) hypothesis which suggests a decline in richness with elevation due to water availability linked with temperature. I also showed high nestedness rather than turnover in both my sampling sites. This was my expectation as high mobile species tend to show higher nestedness compared to turnover (Patterson et al., 1998; Taylor et al., n.d.). Due to flight, bats are able to move longer distances hence displaying connectivity of sites in terms of species composition. I observed in this study that the species found at the high sites were a subset of those recorded at the mid sites which were also a subset of species observed at the low sites.

In my study, isothermality was the most significant factor influencing species richness, with species richness increasing as isothermality increased. Isothermality quantifies the extent to which daily temperature variations compare to annual temperature fluctuations (O’Donnell & Ignizio, 2012). It has been recognized as a key driver of species richness across various taxa, including butterflies, American monkeys, and frugivorous bats (Vallejos-Garrido et al., 2017; Chattopadhyay et al., 2019; Rueda-M et al., 2021). A higher isothermality indicates a more stable and consistent thermal environment, which may be particularly favourable for many species. The observed higher species richness of bats in regions with greater isothermality suggests that most bat species thrive in environments with long-term temperature stability. In my study, areas in high elevation had lower isothermality scores compared to those in low elevation areas hence the higher species richness in low elevation areas. Based on a study by Alves-Ferreira et al. (2022), higher isothermality is associated with increasing gain of climatically suitable areas with climate change. Conversely, low isothermal species (from higher elevations/latitudes) will tend to lose habitat with climate change. This is because the habitat area decreases with elevation. So, a species like *R. acrotis* with a wider range will be predicted to gain more habitat or lose less habitat than narrow distribution species like *R. cervenyi*. It is worth noting, however, that the range of isothermality is very low in my study (53-56) so this needs to be tested across a broader range of values.

Low bat activity along an elevational gradient has been attributed to several factors such as the decline of females available for reproduction at high elevations due to reduced food abundance and high thermoregulatory costs imposed by lower temperatures (Grindal & Brigham, 1999; Cryan et al., 2000; Erickson & Adams, 2003; Dunna & Watersb, 2012). In my study, I determined that bat activity was influenced by minimum temperature of coldest month and distance to river. Bat activity was higher in areas with higher minimum temperatures. This supports findings of studies that have determined low temperatures create less ideal foraging conditions for bats. Low temperatures result in the reduced occurrences of insects which are important for the diet of insectivorous bats. The increase of bat activity with increasing distance from rivers was an unexpected finding. Research has shown that bats often favour areas near rivers, particularly in hot, dry regions. This preference is likely due to their need to replenish water lost through evaporation during foraging, as well as the higher abundance of insects typically found in riverine vegetation near water sources (Hagen & Sabo, 2011; Lisón & Calvo, 2011; Rainho & Palmeirim, 2011). Due to water shortages not being an issue in this region, bats may not only be restricted to rivers for water consumption. Water might be available for bats in small ponds or water escaping from rock crevices and hence their activity is not necessarily reliant on the bats being close to rivers. Due to the low temperatures of the region, being close to rivers might be crucial in hot regions rather than in cool regions.

For species composition, I was able to determine that isothermality, minimum temperature of coldest month and mean diurnal range significantly influenced species composition. I showed that *R. acrotis* was influenced by all these environmental variables. The occurrence of this species at low sites was due to higher isothermality, higher minimum temperature of the coldest month and higher mean diurnal range. These are all correlated to temperature highlighting the significance of temperature in determining species composition. Temperature is a significant factor in climate change (Akpodiogaga-a & Odjugo, 2010) and it is also important for models predicting future species distributions and extinctions (Thomas et al., 2004; McCain, 2007). The impact climate change will have on bats in the Drakensberg will depend on the extent to which temperature is altered. Between the years of 1960 and 2016, temperatures have been shown to be on the rise in the Drakensberg (Mohamed & Mukwada, 2019). This means that temperatures are likely to increase to a point where high elevation areas are conducive for bat species that currently cannot make use of this niche. This suggests an upward range shift for most bat species as already observed by other studies in other parts of the world where bats migrate to upper elevations during summer (Mollhagen & Bogan, 1997) or a more permanent shift over a long time (LaVal, 2004). Species distribution models show that the high Drakensberg may provide a climate refuge for climate change (Taylor et al., 2024), especially for *R. cervenyi* and *C. lesueuri* (and probably *L. cf. wintoni* if it still occurs in this region). The highest alpine and subalpine elevations (> approx. 2400 m) in Lesotho (and the Witsieshoek area) are important habitats for these species. Given that much of the alpine parts of Lesotho are unprotected and much of it degraded by settlements over-grazing, and mining, this makes the Witsieshoek area and the highest parts of the Maloti-Drakensberg Transfrontier Park critical for the long-term survival of these alpine and subalpine species. With changing climate, the temperature in this area might reach a threshold beyond which bats might not be able to survive and the risk of these endemic species becoming extinct in the area will be high.

For endemic species, I was able to determine the occurrence of the endemic species *Cistugo lesueuri* from 1750m to 3000m asl. The occurrence of *Cistugo lesueuri* across the full elevational gradient suggests a broad climatic tolerance, which may provide some initial resilience to minor temperature increases. However, long-term climate change and associated ecological changes could still pose a risk, particularly for populations at higher elevations where further upslope movement is not possible. Future monitoring is needed to assess whether climatic changes impact this species over time. For the *Rhinolophus* species, their occurrence was determined to be limited to certain parts of the elevation gradient with *R. acrotis* occurring at elevations lower than 2000m asl whilst *R. cervenyi* occurred throughout the elevation gradient but had higher activity at elevations above 2000m asl. The finding that *R. acrotis* reaches its maximum elevation around 2000m asl where the two species occur together makes this very important in terms of future monitoring of climate change. Future warming should theoretically lead to *R. acrotis* moving up slope, by regular acoustic monitoring at points like Witsieshoek Lodge (Mid-low) and Sentinel Car Park (Mid–high) sites in the community conservation area; it will be possible to test this change upslope range shift. *Rhinolophus acrotis* can still shift its range upwards with increasing temperature. It may be difficult to determine the upward range shift of *R. cervenyi* since it occurs along the full elevation gradient. This species is likely to experience a distribution range contraction, with predicted increasing temperatures shrinking its range. According to Taylor et al., (2024), the ranges of southern African paramontane species such as *R. acrotis, R. cervenyi* and *C. lesueuri* are not predicted to change considerably by 2070, suggesting that elevational heterogeneity in the Drakensberg may act to buffer the effects of future climate change. The notable absence of the endemic species *Laephotis cf. wintoni* suggests that this species might have already been driven out or eliminated from this region. The only record of this species in the region of my study is from two localities, namely Schaaplaats Farm in the Bethlehem District and Sehlabethebe National Park in Lesotho in the months of September and November in the year 1988 respectively (Bloemfontein Museum record). Another survey reported capturing the species in 2012 in Schaaplaats Farm. Its absence could be due to several interacting factors such as a localized distribution of the species or changes in climate change and anthropogenic disturbance. The detection probability of the species is low, and my sampling effort may not have been sufficient to capture this species. Furthermore, the call of this species is unknown and hence it might be present in my acoustic recordings, possibly overlapping with the call frequency of another species. Until a release call of the species is obtained, it is hard to be certain that the species was truly absent. Further sampling in this region will determine whether the species is absent from the region or just missing in my study. The absence of this species in areas where anthropogenic disturbance was low does suggests that climate change might have played a role in the elimination of this species.

Maxent models of paramontane species including *R. cervenyi* by Taylor et al., (2024) predicted stable ranges of temperate-montane species associated with the higher-elevation Maloti-Drakensberg until the year 2070. Since my findings reveal the occurrences of species along an elevation gradient, I can infer from the maxent models that the highest Maloti-Drakensberg will harbour stable ranges for species occurring at high elevations (>2400). For species at elevation lower than 2400m, my findings can be used to compare future distributions of species when ascertaining the impact of climate change. A limitation with regards to my study is that I only had one elevation gradient that reached 3000masl. My elevation gradient in Golden Gate HNP only reached 2400m asl. One more elevation gradient in Lesotho would have been ideal but due to financial constraints I could not achieve this. Despite this limitation, my study still provides strong evidence for the vulnerability of bat species in the area due to temperature-related environmental variables being the main factor influencing their distribution.

2.5 Conclusion

With this study, I present results that show higher bat species richness and activity in low elevation areas compared to high elevation areas. Factors such as isothermality, minimum temperature of coldest month and distance to river were determined to influence bat species richness and activity along the elevation gradient. I therefore conclude that these factors suggest that changes in temperature as predicted by climate change models are likely to affect the bat communities and result in upward shift of their distribution ranges and elimination of species that are already occurring at the highest available elevation areas. The impact of climate change might already be evident in the absence of the endemic species *Laephotis cf. wintoni* and the occurrence of endemic species at high elevation areas is an indication of that these species are in danger of getting eliminated by climate change. I further acknowledge the Maloti-Drakensberg as a refuge of species during climate change and I propose that the

Witsieshoek Community Conservation Area is an important area for conservation of rare and endemic species as it has the most potential for proper protection compared to most areas of the Drakensberg which are either unprotected or are limited in resources to uphold proper conservation strategies. My study provides baseline data for further monitoring of bats along the Drakensberg elevation gradient and future studies of impacts of climate change on bats of the Drakensberg Afromontane elevation gradient.

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Chapter 3

Bat communities along an anthropogenic gradient in the Maloti-Drakensberg

Abstract

The Drakensberg Afromontane grasslands are threatened by unprecedented habitat loss and degradation through anthropogenic land use changes such as urbanization, livestock overgrazing and other forms of agriculture. In this study, I aimed to ascertain the impact of human disturbance on bat communities in the Maloti-Drakensberg Afromontane grasslands, South Africa. My objective was to ascertain the factors underlying variation in bat species richness and activity across areas of different human footprints. To achieve this, I conducted acoustic surveys from late 2021 to early 2023 using SM4 mini bat detectors in a protected area, a partially protected area and an unprotected area in QwaQwa. I categorised bats into three functional groups based on their foraging ecology namely open-air; clutter-edge; and clutter species. I recorded eight species of bats in the area of which two are endemic to South Africa and Lesotho namely, *Cistugo lesueuri* and *Rhinolophus cervenyi*. Bat species richness and activity was found to be highest in the partially protected area which is a community conservation area. The distance to buildings was the common significant predictor of bat activity of the functional groups and its effect varied with functional groups. I suggest prioritization of both clutter groups and Drakensberg montane grassland endemic species by strengthening the coexistence between the community and conservation through the Witsieshoek partially protected area and ensuring the persistence of the local protected area, Golden Gate Highlands National Park.

3.1 Introduction

Natural landscapes around the globe continue to experience degradation due to the high human pressures exerted on them. These human pressures stem from the ever-increasing demand in resources such as food and shelter. Previously pristine ecosystems have been invaded by human activities such as urbanization and agriculture. The overall impact of human activities and presence on the environment is described as the "human footprint" (Leu et al., 2008; Sanderson et al., 2002). The human footprint can affect ecosystems both directly through human activities that cause changes in land cover (Meyer & Turner, 1992) and indirectly through actions that impair ecosystem functions (Noss et al., 1995). Features of human footprint such as urbanisation and agriculture result in altered landcover, reduction and fragmentation of natural habitats, increased human disturbance (McKinney, 2002), which can result in local extinction (Vale & Vale, 1976; Luniak, 1994; Marzluff, 2001; McKinney, 2002; Foley et al., 2005; McKinney, 2008). Human structures such as roads associated with human disturbance have been shown to reduce bird and some mammal taxa through noise and vehicles colliding with animals (López et al., 2010) whilst buildings reduce natural spaces for wildlife to inhabit and forage in.

Bats are amongst the most sensitive taxa, showing susceptibility to land-use and land-cover changes (Jones et al., 2009). Some bat species usually prefer areas of low human presence and undisturbed ecosystems (Jung & Kalko, 2011). Bat species richness has been shown to decrease in urban areas compared to rural areas (Avila-Flores & Brock Fenton, 2005). Several studies have shown that bats mostly avoid areas with high density residential settlements and commercial industries (Gaisler et al., 1998; Gehrt & Chelsvig, 2003; Duchamp et al., 2004; Sparks et al., 2005; Hourigan et al., 2006; ; Walters et al., 2007; Loeb et al., 2009). This is due to loss of forests, wetlands and natural roosting sites brought about by urbanisation (Mickleburgh et al., 2002; van der Ree & McCarthy, 2005). The high density of roads in urban areas has been shown to reduce bat species richness whilst vehicles colliding with bats has been reported (Lodé, 2000). Such findings highlight human footprint as a threat to bat species. This is not characteristic of all bat species as some species are well adapted to urban environments, with these species dominating urban landscapes (Kurta & Teramino, 1992; Sparks et al., 1999; Ulrey et al., 2005). Common traits of bat species predisposed to urban life include low echolocation call frequencies, relatively long call durations, small body size, and flexibility in roost type selection (Wolf et al., 2022). Some bats have adapted to use man-made structures such as buildings and bridges as roosts (Voigt & Kingston, 2016). Additionally, some bats exploit lights in urban landscapes for foraging, as these lights attract insect species that serve as prey (Hickey et al., 1996).

Despite the abundance of studies highlighting the impacts of urbanization on bat communities (Gaisler et al., 1998; Gehrt & Chelsvig, 2003; Gili et al., 2020), most research has focused on bats in forested and savanna landscapes, with limited attention to grassland ecosystems. Grasslands, unlike forests and savannas, lack the structural complexity and three-dimensional features that many bats rely on for foraging and roosting, such as tall trees and dense vegetation. Consequently, urbanization in grasslands may result in a more pronounced loss of critical resources, such as natural roosting sites and prey diversity, compared to forested or savanna areas. Urban areas, while providing artificial roosts and potential are therefore likely to vary among species and functional groups, depending on their ecological requirements and adaptability to altered habitats. For instance, grassland bats that rely on open spaces for foraging or ground-level insect prey might be disproportionately affected by habitat fragmentation and changes in prey availability due to urbanization. Conversely, more adaptable species capable of using artificial structures as roosts and exploiting urban insect populations may thrive in such landscapes. The decline of bat species, particularly rare and specialized grassland species, underscores the importance of understanding how urbanization influences bat species richness, activity, and functional diversity. This knowledge is crucial for developing conservation strategies for bats in grasslands.

The Afromontane grassland, which is the biotic zone where the Maloti-Drakensberg lies, is an important area for endemic bats (Cooper-Bohannon et al., 2016; Monadjem et al., 2020; Taylor et al., 2024), even though the diversity of bats is lower here compared to tropical and subtropical savannas in South Africa (Gelderblom et al., 1995; Schoeman et al., 2013) . Currently, there are at least two species that are endemic to the Maloti-Drakensberg, namely *Rhinolophus cervenyi,* and *Laephotis cf. wintoni ((*Monadjem et al., 2020; Taylor et al., 2024; Uvizl et al., 2024). The Maloti-Drakensberg also harbours *Cistugo lesueuri*, a South African and Lesotho endemic only occurring in the Drakensberg and the Cederberg in the Western Cape (Monadjem et al., 2020). Despite this level of endemism of this grassland, biodiversity is being threatened by rapid conversion of this biome into settlements, bush encroachment, and livestock overgrazing (O'Connor, 2005; Shezi et al., 2021). To help in biodiversity conservation, several protected areas were established such as Golden Gate Highlands National Park and Royal Natal National Park. A partially protected area exists called Witsieshoek Community Conservation Area. This area is owned by the Batlokoa Community but is ran and managed by the Witsieshoek Lodge. The community is still able to use this area for grazing livestock with shepherds having access to the area.

There have been lack of studies investigating the impact of human footprint on endemic species in the Drakensberg Afromontane Grassland. I therefore aimed to investigate the factors underlying variation in bat species richness and activity across a human footprint gradient ranging from highly human transformed areas such as settlements, specifically Phuthaditjhaba, to medium-intensity grazed rangelands and least disturbed natural landscapes in the Drakensberg Afromontane Grassland. I hypothesised variation in bat species distributions in the different land uses with high bat activity in human occupied areas due to more lighting attracting insects but higher richness and occurrence of rare species in low human footprint natural landscapes.

3.2 Methods and materials

3.2.1 Study Area

The study was conducted in QwaQwa, an area located in the Thabo Mofutsanyane Municipality District in the eastern Free State Province of South Africa (Figure 3.1). The Free State Province is located between latitudes 26.6 °S and 30.7 °S and between longitudes 24.3 °E and 29.8 °E. The Free State area has two main seasons namely the warm to hot summers with an average maximum daily temperature of 26.4 °C in December and cool to cold winters with an average minimum temperature of -1.7°C in July. The summers are wet with rain falling from October to March. The annual average rainfall is about 750–800 mm. The major land use in QwaQwa is pastoralism and the commonly reared animals are cattle, sheep and goats (Shezi et al., 2021). For my study, I made use of three sampling areas in QwaQwa namely Golden Gate Highlands National Park, Witsieshoek Community Conservation Area and Phuthadithjaba (Figure 3.1). Golden Gate Highlands National Park is a protected area which served as a least disturbed area of sampling. Wildlife grazing is the dominant form of grazing in this area with very little livestock grazing. This park is 11,600 ha in size, and it comprises of a diversity of fauna which include black wildebeest (*Connochaetes gnou*), eland (*Tragelaphus oryx*), blesbok (*Damaliscus pygargus phillipsi*), oribi (*Ourebia ourebi*), springbok (*Antidorcas marsupialis*), and zebras (Equus quagga). (Kotze, 2002) and will be referred to as the “protected area” from here forth.

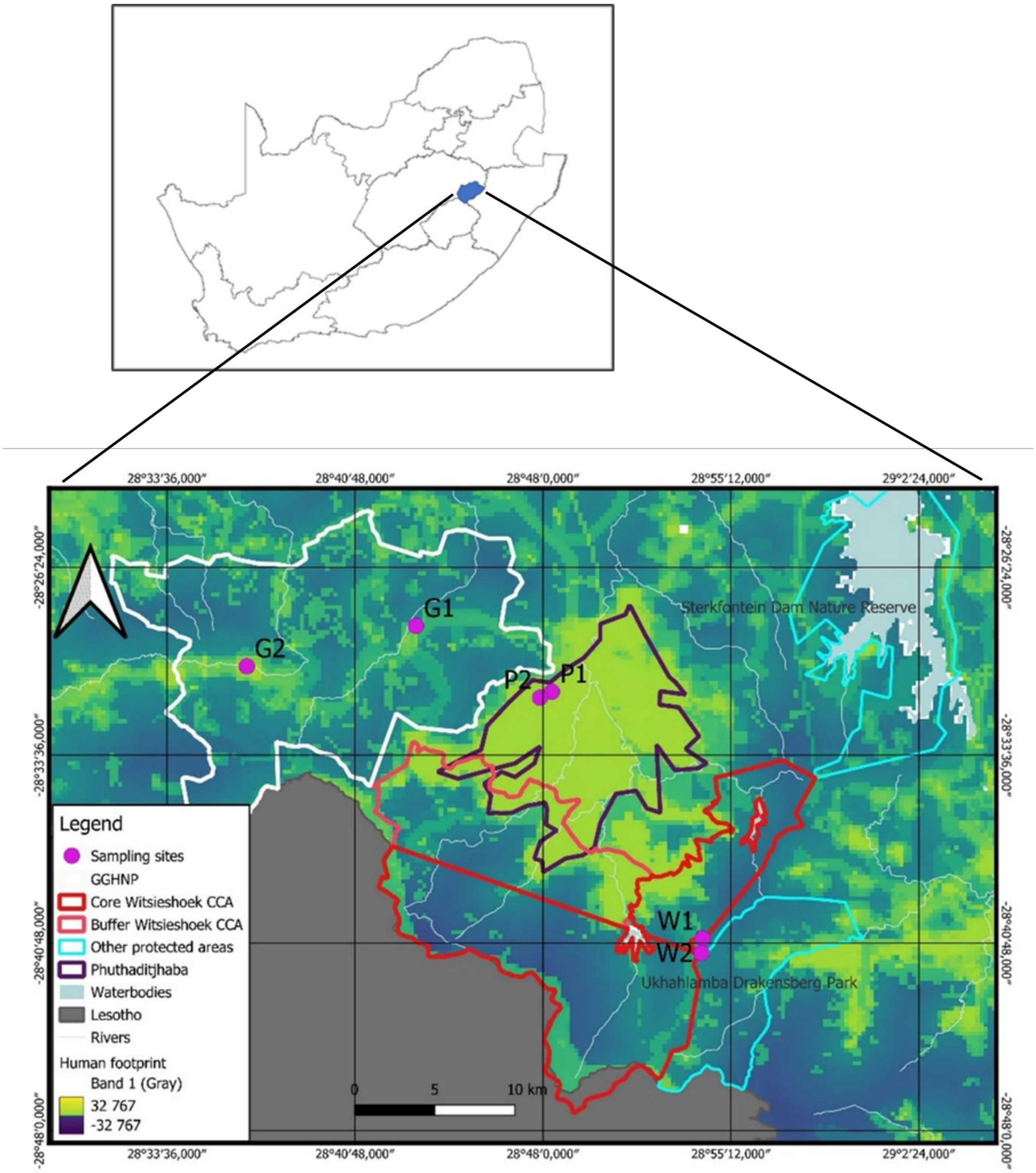

Figure 3. 1: Map showing the location of Thabo Mofutsanyane Municipality District marked in blue inside the map of South Africa, the sites in Golden Gate Highlands National Park, Witsieshoek Community Conservation area and Phuthaditjhaba unprotected and the human footprint in the area. The yellow colouration indicates high levels of human footprint whilst the blue colouration represents areas of low human footprint.

Witsieshoek Community Conservation Area is a partially protected area of low intensity grazing in communal rangelands. It covers an area of 16,000 ha, and it has been proclaimed as a partially protected area with good potential for tourism (Taylor et al., n.d.). This area served as an intermediate disturbed area for sampling and will be referred to as the “partially protected area” from here forth. Phuthaditjhaba on the other hand is the major town of QwaQwa, an area established in 1974 as a homeland for the South African Basotho people during the apartheid government. The town comprises of highly disturbed rangelands comprising of commercial rangelands and urban settlements (Figure 3.2). This town is within a peri-urban region owing to the villages surrounding it (Mocwagae & Nel, 2023). This urban area has a population of 54 661 people according to the 2011 census with a density of 2300 people per km^2. From the year 1989 to 2019, the built area of Phuthaditjhaba increased by 270.83%, increasing from 24 km^2 to 89 km^2 whilst the native vegetation decreased from 44.68% to 15.11% during this period (Onaolapo et al., 2022). Phuthaditjhaba thus served as the most disturbed sampling area for this study and will be referred to as the “unprotected area” from here forth.

3.2.2 Acoustic data collection

I conducted acoustic surveys along an anthropogenic gradient ranging from areas of highest human footprint to areas of low human footprint. I randomly selected two sites in each of the three land uses namely protected area, the partially protected area and the unprotected area. The protected area comprised of the sites G1 and G2, whilst the partially protected area comprised of the sites W1 and W2. The unprotected area comprised of the sites P1 and P2 (Figure 3.1). The sites in each sampled land use were at least 1 km away from each other. At each site, I deployed two Song Meters (SM4 Wildlife Acoustics Mini bat detectors), at least 100m apart where the terrain was too rough, to obtain passive acoustic recordings of bat echolocation calls from sunset until sunrise. I ran all Song Meter mini bat detectors concurrently in each sampling site. I sampled for three consecutive nights at each sampling station. I sampled four times during this study, sampling twice in early summer (October 2021 and October 2022) and twice in late summer (February 2022 and March 2023). Physical capture of bats was conducted in both sampling areas to confirm presence of species observed to be potentially occurring from acoustic surveys. For these surveys, I used two harp traps and mist nets (12m and 9m long).

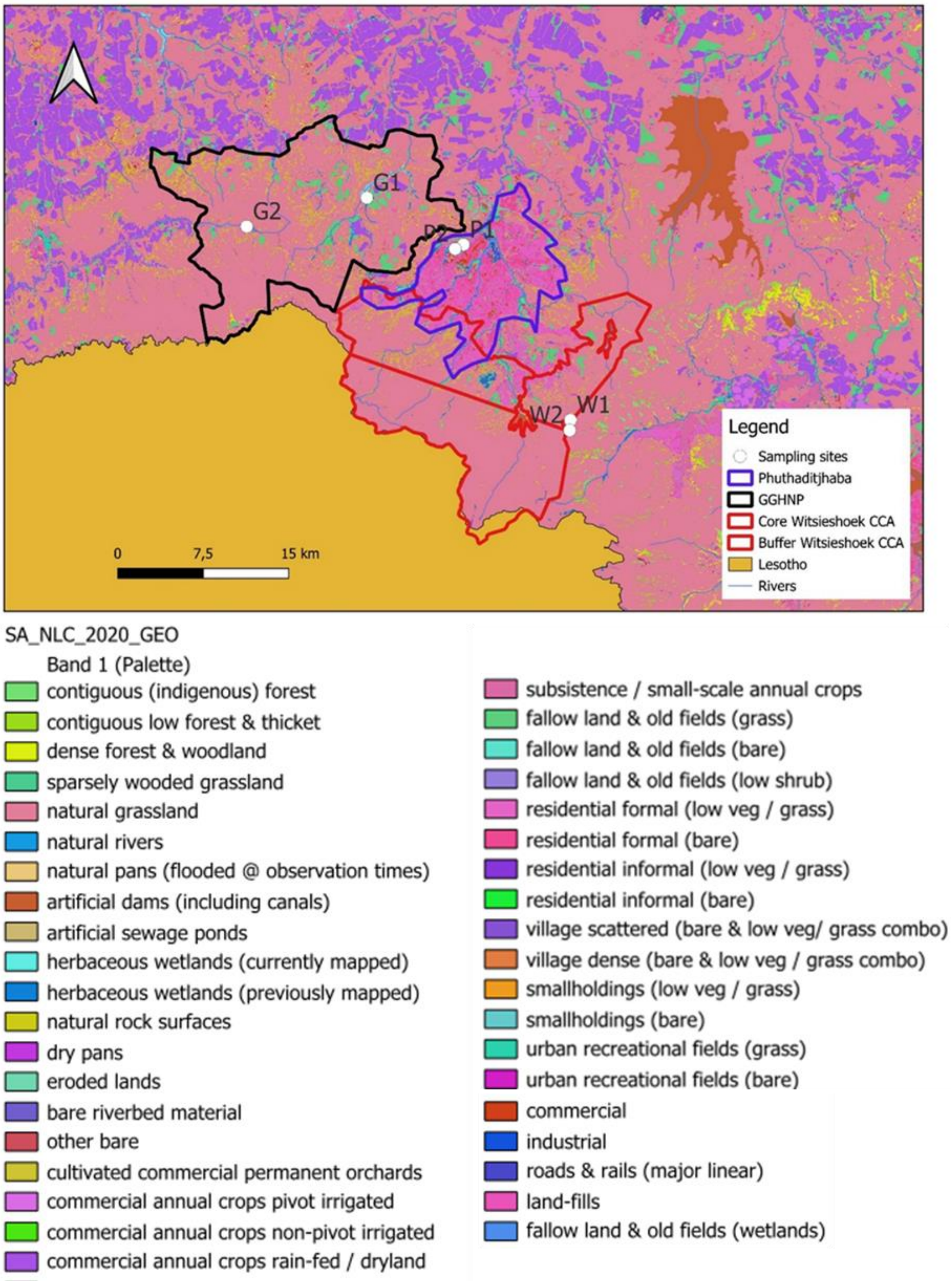

Figure 3. 2**:** Map showing different land covers found in the three sampling sites namely Golden Gate Highlands National Park, Witsieshoek partially protected area and Phuthaditjhaba unprotected and the human footprint in the area.

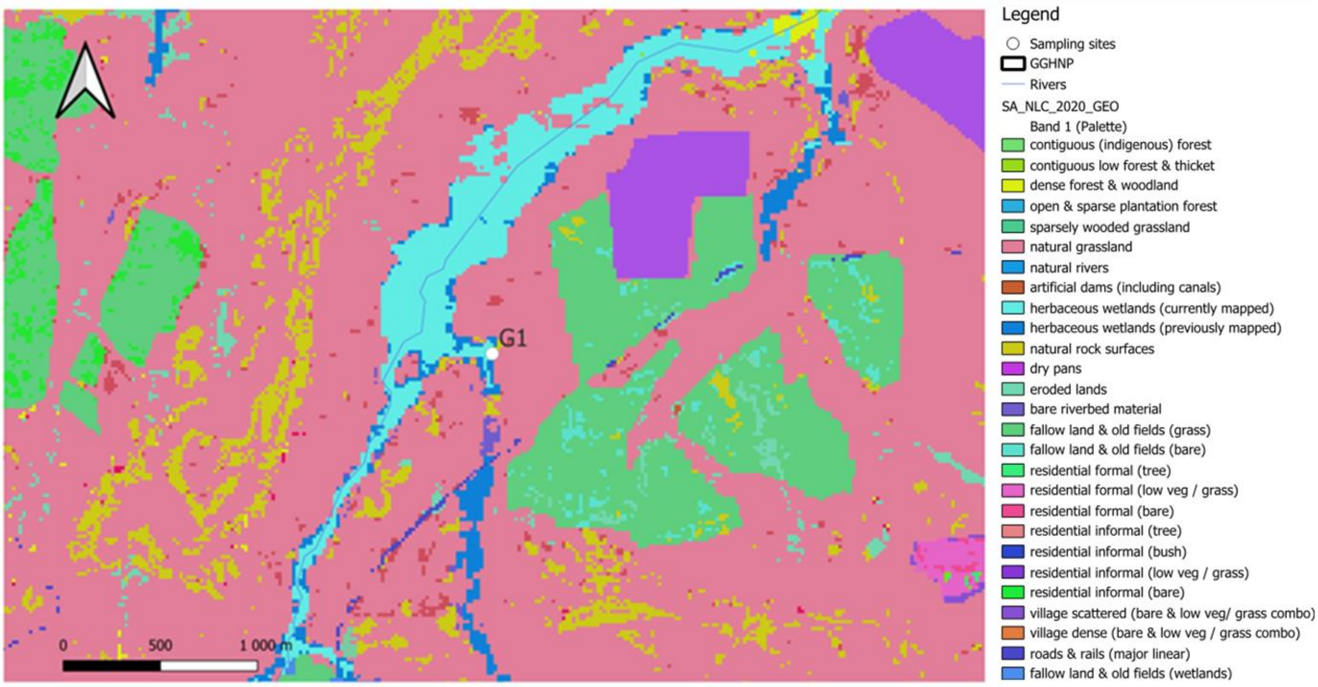

Figure 3. 3: A close-up map showing different land covers found the site G1 inside Golden Gate Highlands National Park.

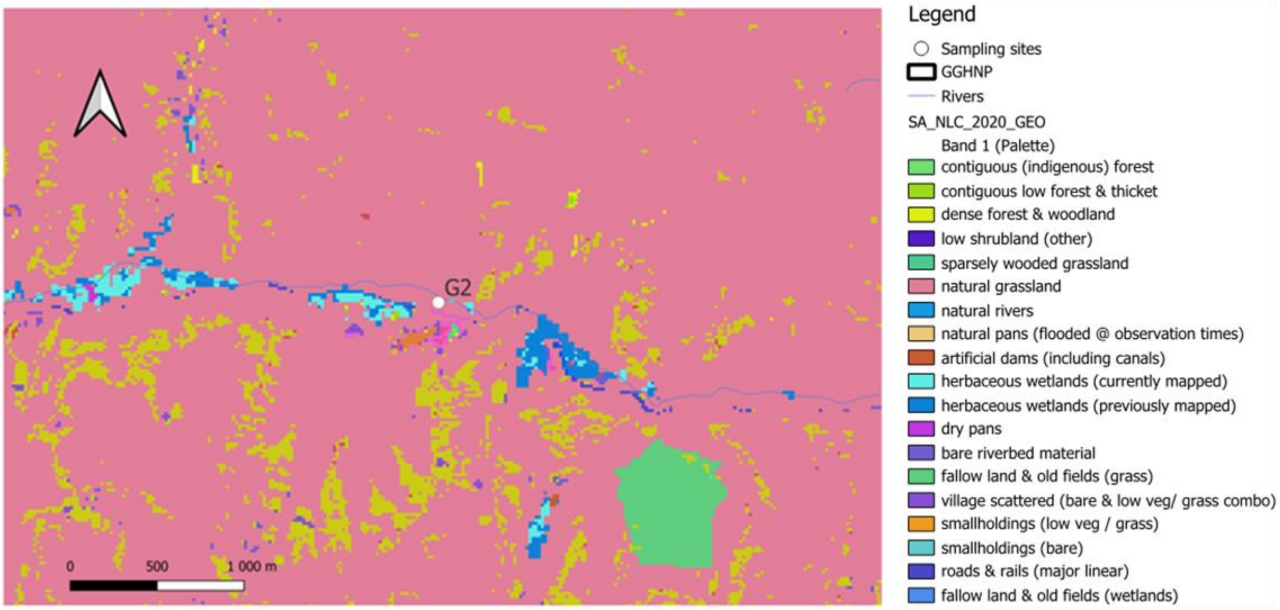

Figure 3. 4: A close-up map showing different land covers found the site G2 inside Golden Gate Highlands National Park.

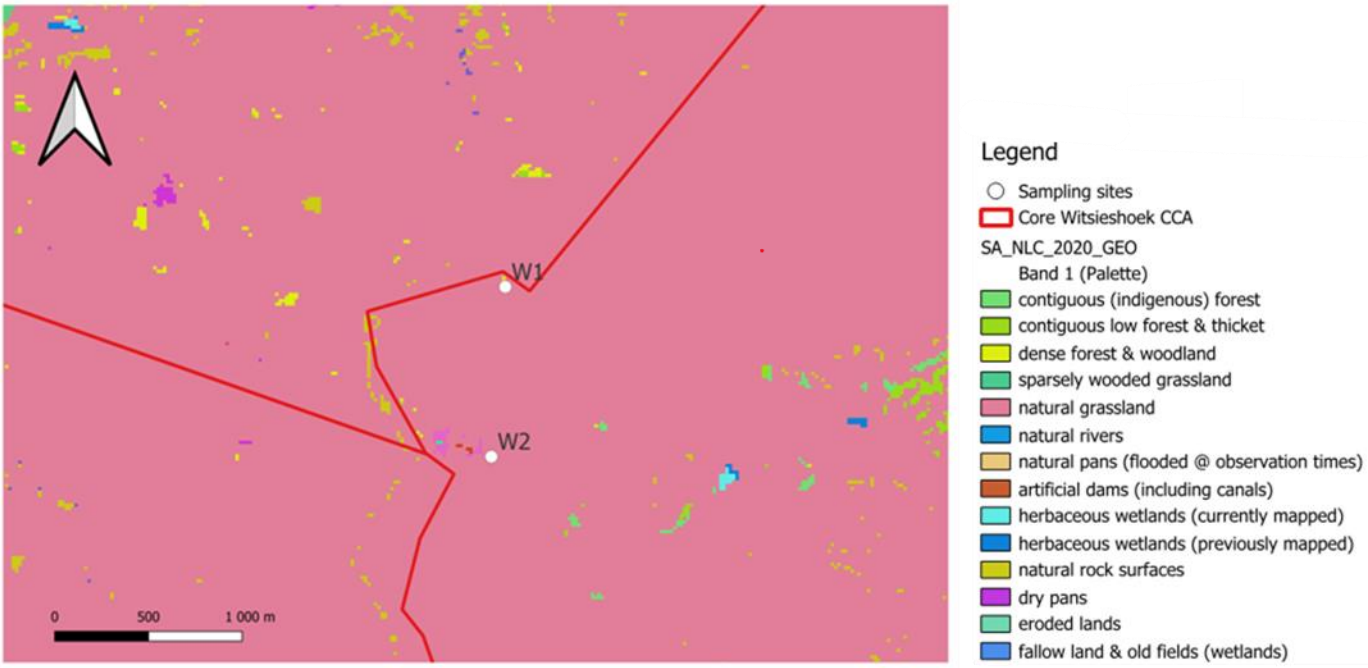

Figure 3. 5**:** A close-up map showing different land covers in the sites W1 and W2 within Witsieshoek, the partially protected area.

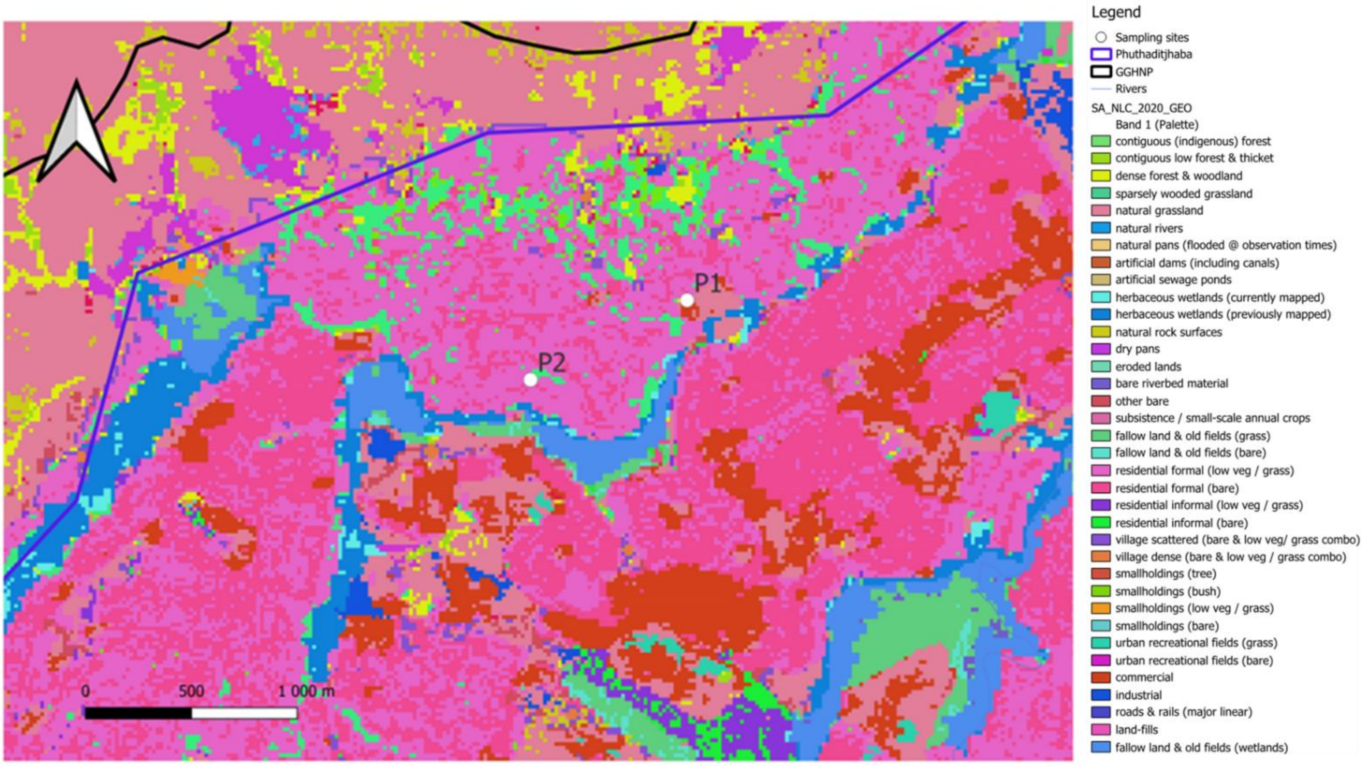

Figure 3. 6**:** A close-up map showing different land covers in the sites P1 and P2 within Phuthaditjhaba, the unprotected area.

3.2.3 Acoustic call analysis

I used the Kaleidoscope Pro software (Wildlife Acoustics, Maynard, MA, United States) to analyse bat calls. Bat calls were manually identified based on reference calls obtained from two sources: release calls of captured, field-identified individuals that were released after recording, and calls from previous studies in Southern Africa provided by Peter Taylor (Monadjem et al., 2020; Taylor et al., 2020; Weier et al., 2020) (Appendix 3.1). No automated clustering cut-off point from Kaleidoscope was used; instead, I manually classified calls by comparing them with the reference dataset to ensure accurate identification. Due to the overlap of the calls of the species *Pipistrellus hesperidus* with *Cistugo lesueuri* and *Tadarida aegyptiaca* with *Mops pumilus,* each pair of these species lumped together and labelled as Cistugo_Pip and Molossid *respectively*. I then grouped identified bat species into three foraging functional groups namely open-air species, clutter-edge species and clutter species according to Monadjem et al., (2020). This classification of bats into open-air, clutter-edge, and clutter species was based on their foraging ecology, wing morphology, and echolocation call characteristics. Open-air foragers typically have high aspect ratio wings and low-frequency echolocation calls, allowing them to efficiently travel through open spaces. Clutter-edge species exhibit intermediate wing morphology and echolocation frequencies, enabling them to forage near vegetation edges and more complex environments. Clutter specialists, in contrast, have short, broad wings and high-frequency calls adapted for manoeuvring through dense vegetation (Monadjem et al., 2020).

3.2.4 Statistical analyses

I used rarefaction and extrapolation curves for Hill numbers in the iNEXT package (Hsieh et al., 2016) to calculate species richness and diversity, to account for differences in sample size across multiple assemblages (Chao et al., 2014). Species richness, Shannon diversity, and Simpson diversity were represented by q = 0, q = 1, q = 2, respectively, where q is a parameter which determines the measures' sensitivity to species relative abundances or frequencies (Chao et al., 2014; Hsieh et al., 2016)

To assess the effects of environmental variables on bat activity and species richness, I initially fitted simple linear models and examined residual plots for deviations from model assumptions. Residuals exhibited left-skewness; indicative of potential violations due to zero-inflated count data. To account for this, I then used generalised linear models (GLMs), which are more appropriate for count data and less susceptible to such violations. Model fit was assessed through residual diagnostics and comparisons of Akaike Information Criterion (AIC) values. For the generalised linear models, I ran Generalized Linear Mixed Models (GLMMs) to identify the key environmental variables influencing species richness and bat activity. For this, I used the function 'dredge' in the MuMIn package (Barton, 2015) and specified the family "negative binomial." The full model included multiple predictor variables simultaneously to account for their combined effects. Sampling session was included as a random effect in all GLMMs to account for variability between sessions. By using the dredge function, I systematically compared models with different combinations of predictor variables to identify the most important factors influencing species richness and bat activity. My sampling was conducted during the wet season (except for sampling done in the second sampling session in the protected area to replace lost data which had been initially collected in the wet season) and hence I did not use season as a random variable. For predictor variables, I tested environmental variables which included land cover, human footprint, distance to river, distance to buildings and distance to roads and light (Table 3.1).

Table 3. 1**:** The predictor variables that were used in the study and their definitions.

Predictor variable	Definition	Reference
Human footprint	The human footprint shows the gradient of human influence, from city centres, through suburbs, past farms and fields, to the least impacted corners of the planet. Higher values indicate greater human impacts, lower values, less impact.	http://www.wcshumanfootprint.org
South African National Land Cover	South Africa's different land covers (SANLC) generated by the Computer Automated Land cover (CALC).	https://egis.environment.gov.za/sa_national_land_cover_datasets
Distance to road	Shortest distance from a sampled locality to the nearest road	http://www.ngi.gov.za
Distance to river	Shortest distance from a sampled locality to the nearest river	http://www.dwa.gov.za/iwqs/gis_data/river/rivs500k.html
Distance to building	Shortest distance from a sampled locality to the nearest building	http://www.ngi.gov.za
Artificial light	Bright spotlight that illuminates Brandwag Buttress opposite the GGHNP Hotel each night at one of the mid-low and mid-high sites in Golden Gate	Observation

I then extracted the values of human foot and land cover from the global human footprint raster and the South African National Land Cover raster file respectively. According to the SANLC file, my sites were classified under four landcover classes namely natural grassland, herbaceous wetlands, informal residential and fallow land & old fields classes (Appendix 3.2). For the distance between localities and roads, buildings and water sources, I used shapefiles for roads, buildings and rivers of South Africa. I then calculated the shortest distances between my study sites and predictor variables (Table 3.1) using the package “sf” (Pebesma, 2018). All these environmental variables were scaled during the GLMMs analysis. I also used the presence and absence of light from a spotlight that the protected area shines during the evenings as another predictor variable. I did not use any other sources of light as a predictor variable. Once I ran the GLMMs, I selected the model with the lowest Akaike Information Criterion (AIC) score as the best performing model and I considered models with delta AIC less than one to be competing models (Burnham & Anderson, 2004; Johnson & Omland, 2004). I then plotted graphs showing how the environmental variables of the best performing models affected bat species richness and activity using output values extracted from best models. To achieve this, I used the function “ggpredict” in the package ggeffects (Lüdecke, 2018). I used the package “ggplot2” (Wickham et al., 2016) to draw the graphs showing the relationship of the predictor variables and bat activity and richness. Using the same environmental variables, I ran GLMMs for the activity with respect to the three functional groups. All statistical analyses were done using the R software (R Core Team, 2019).

3.3 Results

I recorded a total of 52,302 bat calls over the duration of the study. I recorded the highest activity in the protected area with 29,520 calls while the partially protected area and the unprotected had 11,292 and 11,490 calls, respectively. I identified a total of eight species belonging to five families (Table 3.2). The *Mops pumilus- Tadarida aegyptiaca* species pair henceforth referred to as Molossid had the highest number of recorded calls accounting for almost half of the total recorded calls followed by the *Pipistrellus hesperidus-Cistugo lesueuri* species-pair referred to as Cistugo_Pip from here forth and *Laephotis capensis* (Figure 3.7). The recorded number of calls of the remaining species was very low compared to these three species. During the study, I successfully captured seven of the species (Table 3.2). I conducted sufficient acoustic sampling in all three land use sampling areas as evidenced by rarefaction curves (Figure 3.8). Species richness was higher in the partially protected area compared to the other two land uses, and it was lower in the unprotected area. I observed the same trend for both the Shannon and Simpson diversity as they were both also highest in the partially protected area and lowest in the unprotected area (Figure 3.8).

Table 3. 2**:** The number of bat species, and the families and functional groups (Monadjem et al. 2020) that each species belongs to, the species whose call frequency they overlap with (names of both species written together), state of physical capture of each species and the current global (IUCN 2019 Red List category) conservation status: LC= Least Concern, NE = Not Evaluated.

Family	**Species**	**Functional group**	**Capture**	**Release calls**	**Conservation Status**
Rhinolophidae	*Rhinolophus acrotis*	Clutter	Yes	Yes	LC
Rhinolophidae	*Rhinolophus cervenyi*	Clutter	Yes	Yes	NE
Molossidae	*Mops pumilus/Tadarida aegyptiaca*	Open-air	No	No	LC
Miniopteridae	*Miniopterus natalensis*	Clutter-edge	Yes	No	LC
Cistugidae	*Cistugo lesueuri/ Pipistrellus hesperidus*	Clutter-edge	Yes	Yes	LC
Vespertilionidae	*Eptesicus hottentotus*	Clutter-edge	Yes	No	LC
Vespertilionidae	*Myotis tricolor*	Clutter-edge	No	No	LC
Vespertilionidae	*Laephotis capensis*	Clutter-edge	Yes	Yes	LC

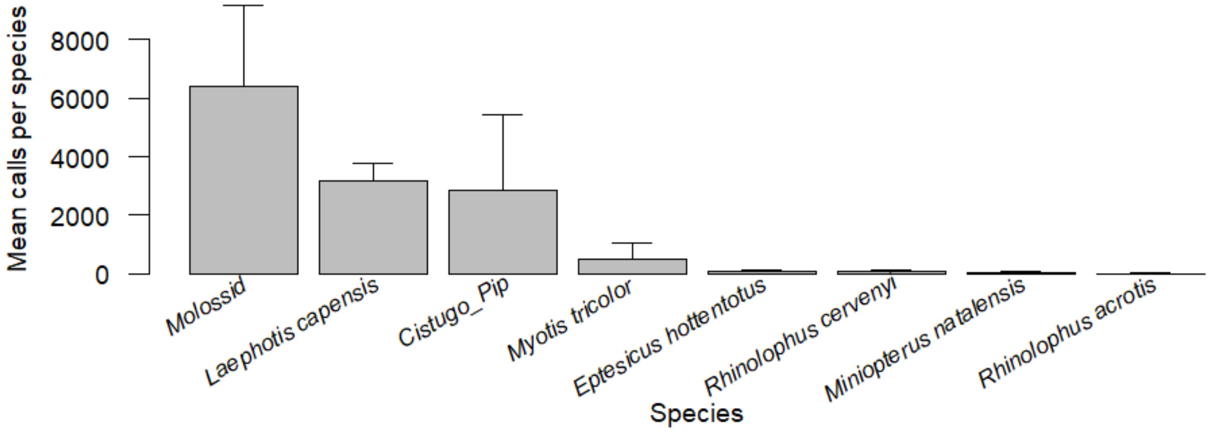

Figure 3. 7**:** The mean (± SD) number of calls recorded for the eight bat species per session.

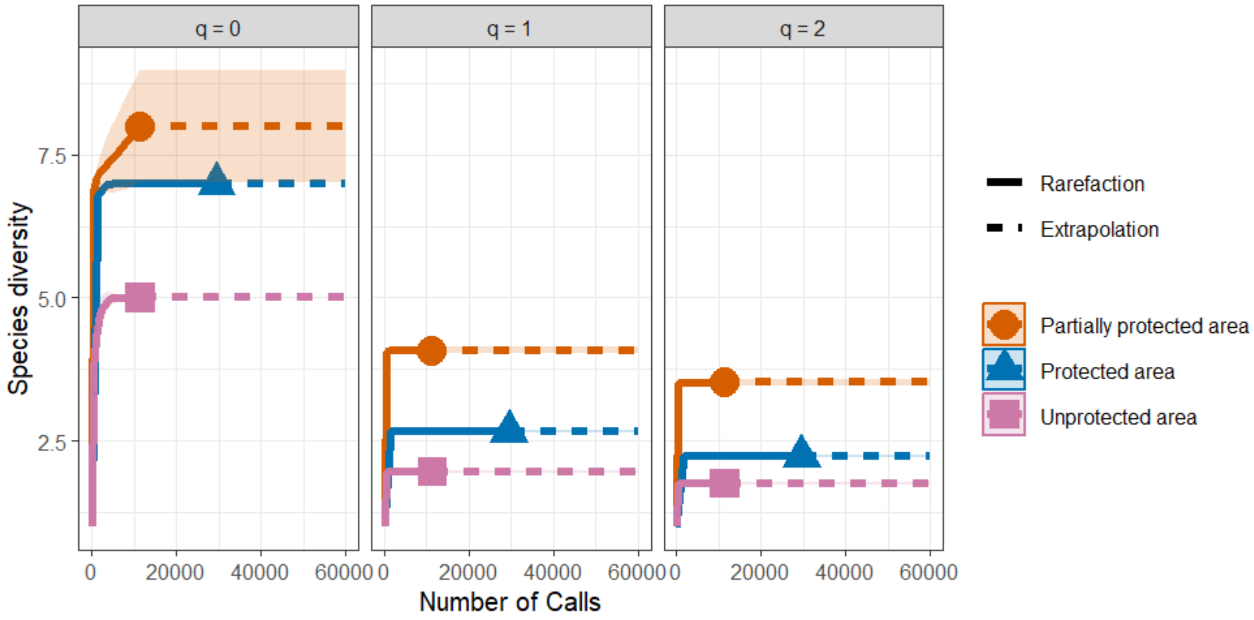

Figure 3. 8: Rarefaction (solid lines) and extrapolation (dashed lines) curves for bats based on Hill numbers (q = 0, 1, 2) for the three sampling areas namely, the protected area, the partially protected area, and the unprotected where q = 0 refers to species richness, q = 1 to Shannon's diversity, and q = 2 to Simpson's diversity, respectively at 95% confidence intervals.

My best performing model predicting species richness comprised of human footprint and artificial light as predictor variables (Table 3.3). Species richness was negatively influenced by human footprint ($\chi^2 = 9.002$ p = 0.003; Figure 3.9). Light was not a significant predictor of species richness (χ 2 = 2.941, p = 0.086).

Table 3. 3**:** A sample of the ranked models that were tested, with the best performing model at the top with the lowest AIC value where the response variable was the number of species recorded per locality per session where session was the random variable. The table shows the model names, the intercept for each model, the predictor variables (namely buildings (distance to buildings), landcover (class name), human footprint (Hfootprint), light, distance to river (river), distance to roads(roads), and the degrees of freedom (df), the log-likelihood (log-Lik), the AICc values, the delta AICc values and weights for the models. The best models have been shown in bold.

Model names	Intercept	Buildings	Class name	Hfootprint	Light	River	Roads	df	logLik	AICc	Delta	Weight
Hfootprint + Light	**1.448**			**-0.220**	**+**			**5**	**-85.628**	**182.7**	**0.00**	**0.201**
Hfootprint	**1.487**			**-0.198**				**4**	**-86.925**	**182.8**	**0.08**	**0.193**
Buildings + Hfootprint	1.486	0.051		-0.191				5	-86.688	184.8	2.12	0.070
Hfootprint + River	1.486			-0.222		-0.045		5	-86.743	185.0	2.23	0.066
Hfootprint + Roads	1.487			-0.225			-0.0428	5	-86.783	185.0	2.31	0.063
Buildings + Hfootprint + Light	1.440	-0.045		-0.231	+			6	-85.527	185.2	2.43	0.060

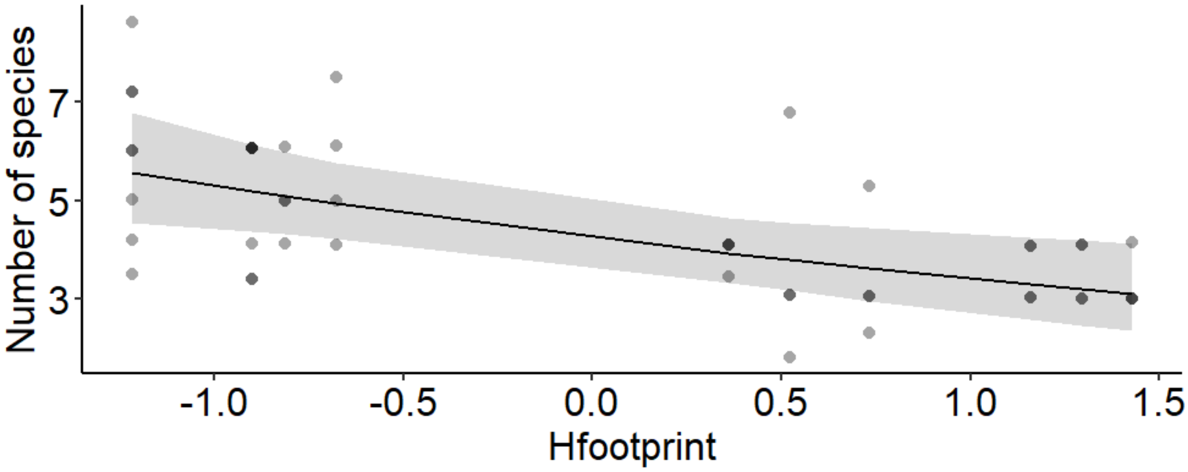

Figure 3. 9**:** A plot showing the relationship between human footprint (ranging from low to high levels) and bat species richness, based on predicted values extracted from the best model (human footprint + light). The figure uses scaled values of human footprint.

For bat activity, my best performing model comprised of distance to buildings and artificial light whilst the competing model comprised of distance to buildings, human footprint and artificial light (Table 3.4). There was a negative correlation between distance to buildings and bat activity ($\chi^2 = 5.994$, $p = 0.014$; Figure 3.10). I also found artificial light to be a significant predictor of bat activity ($\chi 2 = 27.817$, $p < 0.001$) with more bat activity in the lit area. Human footprint did not have a significant positive association with bat activity ($\chi 2 = 1.958$, $p = 0.161$).

Table 3. 4**:** A sample of the ranked models that were tested, with the best performing model at the top with the lowest AIC value where the response variable was bat activity (mean calls recorded per locality) where session was the random variable. The table shows the model names, the intercept for each model, the predictor variables namely distance to buildings (buildings), landcover (class name), human footprint (Hfootprint), light, distance to river (river), distance to roads(roads), and the degrees of freedom (df), the log-likelihood (log-Lik), the AICc values, the delta AICc values and weights for the models. The best models have been shown in bold.

Model names	**Intercept**	**Buildings**	**Class name**	**Hfootprint**	**Light**	**River**	**Roads**	**Df**	**logLik**	**AICc**	**Delta**	**Weight**
Buildings + Light	**6.303**	**-0.469**			**+**			**5**	**-356.425**	**724.3**	**0.00**	**0.194**
Buildings+ Hfootprint + light	**6.259**	**-0.567**		**-0.212**	**+**			**6**	**-355.457**	**725.0**	**0.70**	**0.137**
Buildings + Light + Roads	6.280	-0.416			+		0.180	6	-355.651	725.4	1.09	0.113
Buildings + Light + River	6.281	-0.365			+	0.203		6	-355.657	725.4	1.10	0.112
Light + River	6.365				+	0.3167		5	-357.338	726.1	1.83	0.078
Light + River + Roads	6.305				+	1.399	-1.044	6	-356.026	726.2	1.84	0.077

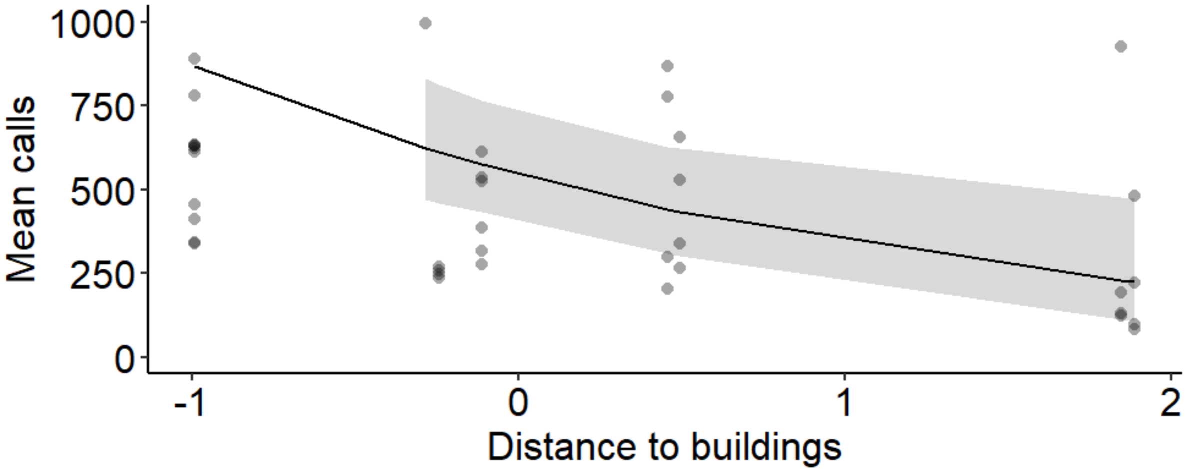

Figure 3. 10**:** A plot showing the relationship between the environmental variable of the best model (distance to buildings) and total bat activity from predicted values, extracted from the best model (Buildings + light). The figure uses scaled values of distance to buildings.

For the open-air species group, my best performing model comprised of distance to buildings (Table 3.5). There was a positive correlation between increasing distance to buildings and open-air species activity ($\chi 2 = 9.030$, $p = 0.003$; Figure 3.11). Artificial light was not used as a random variable due to failure of the best model to converge when light was included as a variable.

Table 3. 5**:** A sample of the ranked models that were tested, with the best performing model at the top with the lowest AIC value where the response variable was bat activity of open-air foragers (mean calls recorded per locality) where site was the random variable. The table shows the model names, the intercept for each model, the predictor variables namely distance to buildings (buildings), landcover (class name), human footprint (Hfootprint), light, distance to river (river), distance to roads(roads), and the degrees of freedom (df), the log-likelihood (log-Lik), the AICc values, the delta AICc values and weights for the models. The best models have been shown in bold.

Model names	**Intercept**	**Buildings**	**Class name**	**Hfootprint**	**River**	**Roads**	**df**	**logLik**	**AICc**	**Delta**	**Weight**
Buildings	**5.887**	**0.778**					**4**	**-83.379**	**180.5**	**0.00**	**0.790**
Buildings +Hfootprint	5.863	0.817		0.248			5	-82.918	185.8	5.36	0.054
Buildings + Roads	5.886	0.789				0.038	5	-83.369	186.7	6.27	0.034
Buildings + River	5.886	0.794			0.034		5	-83.373	186.7	6.27	0.034
Roads + River	5.895				-3.234	2.843	5	-83.548	187.1	6.62	0.029
Null model	6.052						3	-89.343	187.7	7.21	0.021

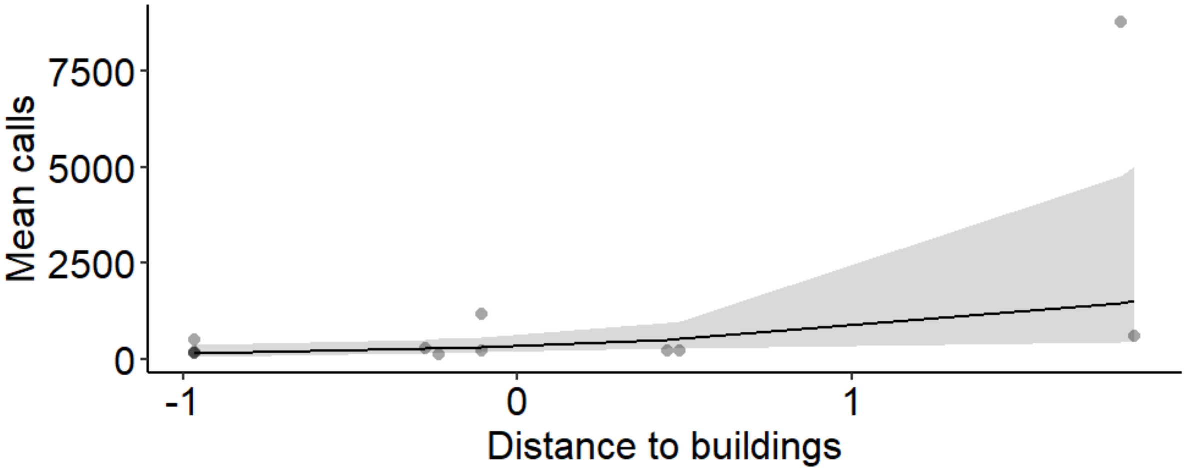

Figure 3. 11**:** A plot showing the relationship between environmental variables of the best model (distance to buildings) and open-air bat species activity from predicted values, extracted from the best model (Buildings). The figure uses scaled values of distance to buildings.

For the clutter-edge species group, my best performing model comprised of distance to buildings and artificial light (Table 3.6). There was a negative correlation between increasing distance to buildings and clutter-edge species activity (χ 2 = 6.193, p = 0.013; Figure 3.12). I found artificial light to be a significant predictor of the activity of clutter-edge species (χ 2 =15.171, p < 0.001).

Table 3. 6**:** A sample of the ranked models that were tested, with the best performing model at the top with the lowest AIC value where the response variable was bat activity of clutter-edge foragers (mean calls recorded per locality) where session was the random variable. The table shows the model names, the intercept for each model, the predictor variables namely distance to buildings (buildings), landcover (class name), human footprint (Hfootprint), light, distance to river (river), distance to roads(roads), and the degrees of freedom (df), the log-likelihood (log-Lik), the AICc values, the delta AICc values and weights for the models. The best models have been shown in bold.

Model names	Intercept	Buildings	Class name	Hfootprint	Light	River	Roads	Df	logLik	AICc	Delta	Weight
Buildings + light	**5.807**	**-0.580**			**+**			**5**	**-337.528**	**686.5**	**0.00**	**0.272**
Buildings + Hfootprint + light	5.764	-0.696		-0.202	+			6	-336.928	687.9	1.42	0.134
Light + River + Roads	5.826				+	2.073	-1.833	6	-337.463	689.0	2.49	0.078
Buildings + Light + River	5.807	-0.569			+	0.018		6	-337.524	689.1	2.61	0.074
Buildings + Light + Roads	5.807	-0.577			+		0.007	6	-337.527	689.1	2.62	0.074
Hfootprint + Light + River + Roads	5.758			-0.419	+	3.302	-3.211	7	-336.278	689.4	2.87	0.065

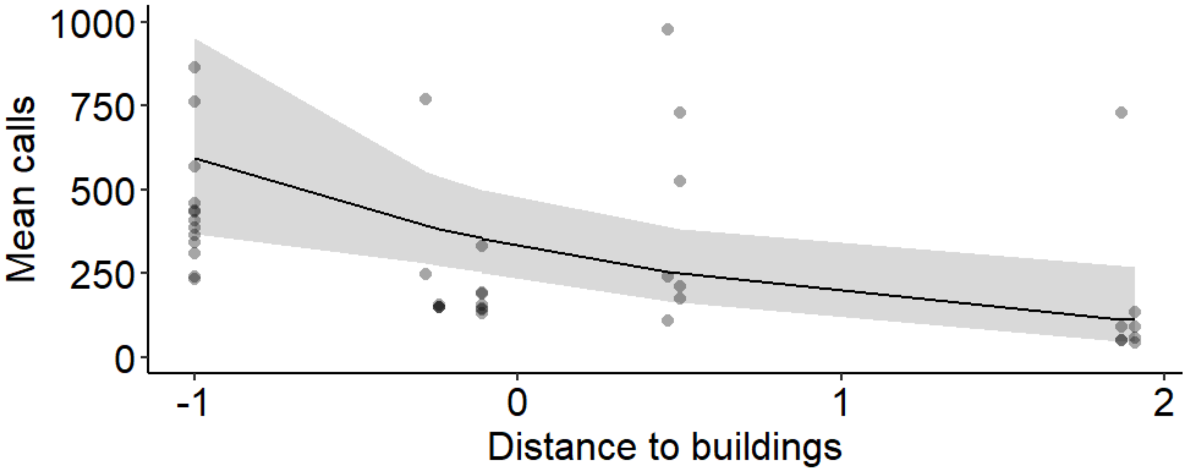

Figure 3. 12**:** A plot showing the relationship between the environmental variable of the best model (distance to buildings) and clutter-edge bat species activity from predicted values, extracted from the best model (Buildings + light). The figure used scaled values of distance to buildings.

For the clutter species group, my best performing model comprised of human footprint, distance to buildings, distance to river and distance to roads (Table 3.7). Activity of clutter species was only recorded in sampling points furthest from buildings ($\chi 2 = 119.539$, $p < 0.001$; Figure 3a) and roads ($\chi 2 = 100.055$, $p < 0.001$; Figure 3d). Furthermore, activity of this group was recorded only in sites of lowest human footprint ($\chi 2 = 193.462$, $p < 0.001$; Figure 3.13b) and in the sampling points nearest to rivers ($\chi 2 = 88.745$, $p < 0.001$; Figure 3.13c).

Table 3. 7**:** A sample of the ranked models that were tested, with the best performing model at the top with the lowest AIC value where the response variable was bat activity of clutter foragers (mean calls recorded per locality) where site was the random variable. The table shows the model names, the intercept for each model, the predictor variables namely distance to buildings (buildings), landcover (class name), human footprint (Hfootprint), light, distance to river (river), distance to roads(roads), and the degrees of freedom (df), the log-likelihood (log-Lik), the AICc values, the delta AICc values and weights for the models. The best models have been shown in bold.

Model names	**Intercept**	**Buildings**	**Class name**	**Hfootprint**	**Light**	**River**	**Roads**	**df**	**logLik**	**AICc**	**Delta**	**Weight**
Buildings + Hfootprint + River + Roads	**-16.010**	**9.84**		**-15.010**		**-14.770**	**15.030**	**7**	**-39.769**	**96.4**	**0.00**	**0.209**
Class name + Hfootprint + River +	-1.838		+	-6.442		-3.905		8	-39.093	98.0	1.56	0.095
Class name + Hfootprint + River + Roads	-11.600		+	-18.200		-36.450	27.930	9	-37.672	98.2	1.80	0.085
Buildings + Hfootprint + Light	-2.416	1.387		-2.812	+			6	-42.300	98.7	2.29	0.066
Buildings + Hfootprint + Light + River + Roads	-13.880	8.211		-13.120	+	-13.120	13.240	8	-39.618	99.0	2.62	0.056
Class name + Hfootprint + Roads	-0.718		+	-5.166			-3.432	8	-39.664	99.1	2.71	0.054

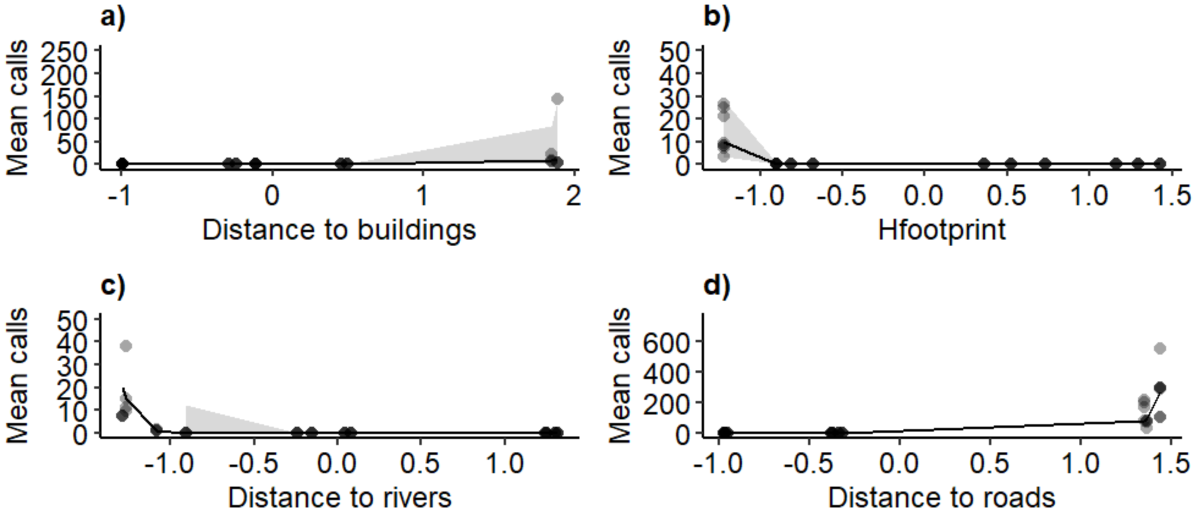

Figure 3. 13**:** A plot showing the relationship between environmental variables of the best model (distance to buildings, human footprint, distance to river and distance to road) and clutter bat species activity from predicted values, extracted from the best model (Buildings + Hfootprint + Rivers + Roads). The figure uses scaled values of the environmental variables.

For *Cistugo lesueuri*, labelled as Cistugo_Pip due to its overlap with *Pipistrellus hesperidus*, the best performing model comprised of distance to buildings, distance to roads, light and class name. There was a positive correlation between increasing distance to buildings and Cistugo_Pip activity (χ 2 = 38.951, p < 0.001; Figure 3.14). There was also a positive correlation between Cistugo_Pip activity and increasing distance to roads (χ 2 = 53.552, p < 0.001; Figure 3.14). I also found that class name (χ 2 = 20.892, p < 0.001) and light (χ 2 = 20.683, p < 0.001) had a significant influence on the activity of Cistugo_Pip with higher activity in natural grassland cover and lit areas.

Table 3. 8**:** A sample of the ranked models that were tested, with the best performing model at the top with the lowest AIC value where the response variable was bat activity of Cistugo_Pip (mean calls recorded per locality) where session was the random variable. The table shows the model names, the intercept for each model, the predictor variables namely distance to buildings (buildings), landcover (class name), human footprint (Hfootprint), light, distance to river (river), distance to roads(roads), and the degrees of freedom (df), the log-likelihood (log-Lik), the AICc values, the delta AICc values and weights for the models. The best models have been shown in bold.

Model names	**Intercept**	**Buildings**	**Class name**	**Hfootprint**	**Light**	**River**	**Roads**	**df**	**logLik**	**AICc**	**Delta**	**Weight**
Buildings + Class name + Light + Roads	**2.640**	**1.685**	**+**		**+**		**1.911**	**9**	**-225.807**	**474.5**	**0.00**	**0.363**
Buildings + Class name + Light + River	2.760	2.136	+		+	2.049		9	-226.578	476.0	1.54	0.168
Class name + Light + Roads + River	2.443		+		+	-6.830	8.075	9	-226.780	476.4	1.95	0.137
Buildings + Class name + Light + River + Roads	2.540	1.158	+		+	-2.330	4.044	10	-225.502	477.1	2.64	0.097
Buildings + Hfootprint + Class name + Light + Roads	2.683	1.579	+	-0.169	+		1.744	10	-225.716	477.5	3.06	0.078
Buildings + Hfootprint + Class name + Light + River	2.822	1.842	+	-0.346	+	1.697		10	-226.142	478.4	3.92	0.051

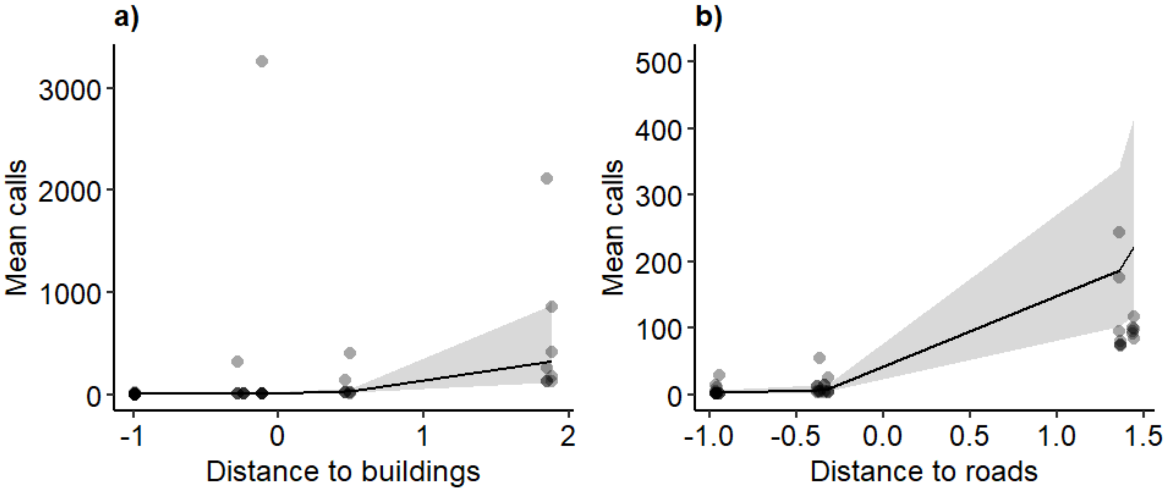

Figure 3. 14**:** A plot showing the relationship between environmental variables of the best model (distance to buildings, distance to roads) and Cistugo_Pip species activity from predicted values, extracted from the best model (Buildings + Class name + light + Roads). The figure uses scaled values of both variables.

3.4 Discussion

The findings of my study showed that urbanization and human land use activities negatively affect the number of bat species within the landscape. I also showed that human activities impose selective pressures which restrict the presence of specialist and sensitive bat species. My study comprised of different treatments of land use which included an unprotected rangeland which had more built-up areas and settlements, a protected rangeland and a semi-protected rangeland with low built-up areas. A study by Onaolapo et al. (2022), showed a significant increase in built up areas in the unprotected area suggesting the exacerbation of human disturbance in the area. My study shows that species richness was generally lower in the unprotected area and higher in the protected area and highest in the semi protected area. This suggests that urbanization and human land use activities negatively affect the number of bat species within the landscape. This is because these anthropogenic disturbances create environmental conditions that favour urban adapted and urban exploiting bat species but not the overall native biodiversity. My finding demonstrates that human activities impose selective pressures which restrict the presence of specialist and sensitive bat species. The decreasing species richness and diversity along the anthropogenic land use gradient was an expected finding as urbanization has been shown to result in natural habitat transformation and fragmentation thus affecting composition of species and resulting in homogenized landscapes (Alberti, 2005; Grimm et al., 2008; Voigt & Kingston, 2016). Further investigation in my study showed that species richness in this study was significantly influenced by human footprint. My findings corroborate studies that have shown that bat species richness tends to be reduced with increasing anthropogenic disturbance (Avila-Flores & Brock Fenton, 2005; Jung & Kalko, 2011; Gili et al., 2020).

I also showed that activity of bats was low in the human disturbed areas which were the unprotected area and the partially protected area. A first look at the influence of the variables showed more bat activity in sampling points close to buildings to buildings. Upon further investigation, this result was found to be driven primarily by the clutter-edge species, which were the most frequently recorded group. This group's response to human structures skewed the overall results, making it appear as though all bat species were more active near buildings. Despite distance to buildings being the predictor of bat activity for the three functional groups' species distributions in the Drakensberg, the influence of the proximity to human structures/buildings on bat activity was not uniform across the different functional groups. The activity of the open-air and clutter foragers increased with increasing distance from buildings whilst that of clutter-edge foragers decreased. The difference in responses of the different functional groups to distance from buildings might have been due to their basic physiology/biology and location of suitable roosts and this is explored further with regards to each functional group below.

Open-air foragers in my study comprised of the Molossid species. This species is most likely *Tadarida aegyptiaca* and it is known to forage well above vegetation canopies and avoids foraging in forests (Monadjem et al., 2020). Molossid species are known to use urban environments for foraging and roosting (Avila-Flores & Fenton, 2005). Furthermore, I observed some roosts of this species in roofs of two buildings during the study. Urbanization generally does not negatively impact this group of bats. The decrease in activity within proximity to buildings of this group of species might be a result of these open-air foragers foraging on insects that may have been in higher densities away from buildings. Since my sampling sites were not that far from rivers and wetlands, there is a possibility that these areas harboured more insects than the built-up areas. Even though this group is adapted to exploit urban environments, it may prefer areas with natural vegetation and water within those urban environments where insects' biodiversity may be more abundant compared to the diversity of insects attracted by artificial lights in buildings.

The clutter foragers in this study were the two *Rhinolophus* species namely *R. acrotis* (Uvizl et al., 2024) and the newly described *R. cervenyi* (Benda et al., 2024). Both these species are specialist species which are not accustomed to foraging in human disturbed areas. These species were only recorded in the protected area and partially protected area where human disturbance was lower. Their absence in the unprotected township area where there is high building density is in line with other studies that showed that specialist species fail to adapt to human disturbed areas and usually shift their home ranges away from such areas (Mtsetfwa et al., 2018; Toffoli & Rughetti, 2017). To further confirm their vulnerability is the fact that the activity of this species was influenced by human footprint. My findings show that these species occurred mostly in areas of lower human footprint. These species probably avoid light pollution. They also have high wing loading and thus may not fly far from their roosts which are often undisturbed caves. This explains why increasing human footprint resulted in low activity and even elimination of this functional group. Additionally, I found the activity of this group to be in the sampling points furthest away from any road. This was in line with my expectation as roads present challenges to bats and other biota that include collision risks, reduced connectivity of habitats and noise from moving vehicles (Trombulak & Frissell, 2000; Bissonette, 2002; Coffin, 2007). A study by Russell et al. (2008) showed that bats were subject to colliding with moving vehicles on highways. Low-flying bats were also shown to be more vulnerable to car collisions compared to high-flying bat species (Fensome & Mathews, 2016). Bats have also been shown to avoid areas with loud background noise because of the difficulty of using acoustic information to capture insects hence resulting in low foraging success (Schaub et al., 2008; Siemers & Schaub, 2011). This group was also active near rivers suggesting that water sources can determine the distribution of this species as observed with other species (Laverty and Berger 2020; Taylor et al., 2020).

The clutter-edge foragers' activity increased closer to buildings. This might have been due to that these species use buildings as roosting areas. Unlike the open-air foragers, this functional group might have preferred insects that are attracted by artificial light associated with buildings. Areas near buildings usually have high insect pest species populations (mosquitoes have more breeding sites and availability of blood meals, houseflies and cockroaches increase due to abundance of waste and pest moth species increase due to small home gardens with low to no pest management). This therefore means more food availability for any bats that might utilise this niche. Clutter-edge foragers are usually adapted for both clutter and open environments (Monadjem et al., 2020). The bat species that made up the clutter-edge functional group were namely *Laephotis capensis, Miniopterus natalensis, Eptesicus hottentotus, Myotis tricolor* and Cistugo_Pip (*Pipistrellus hesperidus* was never captured in my study and since my study area was just outside its distribution, I assumed that the calls of Cistugo_Pip belonged to *Cistugo lesueuri*). Most species of bats are unable to build their own roosts and thus make use of already available structures for roosting (Kunz & Anthony, 1982; Kunz & Lumsden, 2003; Voigt & Kingston, 2016). Buildings serve as an alternative for roosting areas especially where natural roosts are scarce. During the study, four roosts of bats were confirmed in three chalets and in a toilet building. Two of those roosts belonged to *Tadarida aegyptiaca* and one of these was a maternity roost. Species such as *Laephotis capensis* are known to use houses for roosting (Monadjem et al., 2020), a behaviour that I observed during the study. This further confirmed the importance of buildings as roosting sites in the area. Some bats are known to use buildings as temporary shelters during foraging (Ormsbee et al., 2007) and for hibernation (Michaelsen et al., 2013). To further corroborate this finding, I found that light also influenced the distribution of clutter-edge group. Its mean activity was higher (more than two times higher than the highest activity in non-lit areas) near the bright floodlight that is shone onto Brandwag Buttress during the evenings in the protected area. This then suggests that activity of this group was higher in areas closer to buildings because of the lighting that is associated with buildings. Light attracts insects and this may attract bats to forage on the available insects (Rydell, 1991; Rowse et al., 2018).

It should be noted, however, that some species that belonged to the clutter-edge functional group exhibited their own different responses to proximity to buildings. The species *Myotis tricolor* was only recorded in the partially protected area in only one sampling station/locality. I therefore recognize that there might be other factors influencing the distribution of this species. Furthermore, the endemic species *Cistugo lesueuri* also showed a different pattern despite being in the clutter-edge group. I showed that the activity of this species was highest in areas far from buildings. The species was influenced by distance to roads and was mostly recorded in areas far from roads. This suggests that even the small disturbance that our less busy roads present, is still enough to affect this species. This endemic species shows more vulnerability than all the clutter-edge species as it is also affected by land cover with the species only found in natural grassland covered areas of the Drakensberg (Monadjem et al., 2020; Taylor et al., 2024). Despite this vulnerability, the highest activity of this species was recorded at the site with the spotlight. This suggests that this species finds light useful during foraging either due to greater visibility of insects or due to more insects being around the spotlight.

My findings show that the local land uses in the Drakenberg Afromontane grassland are having an impact on the local bat communities. The increase in urbanization threatens the reduction in occurrence of the endemic species *Cistugo lesueuri* and *R. cervenyi*. The observed absence of *Laephotis c.f. wintoni* in my study, a previously recorded endemic bat in the area might suggest that this endemic species is very rare with a low detection probability or has been eliminated on the part of the Drakensberg I sampled. The only other southern locality of this species is Sehlabathebe in Lesotho. The eastern African records of this species may represent a distinct species given the huge geographical distance between these ranges. The distribution of the two newly described rare *Rhinolophus* species show that elimination of the species from the area is very possible if no measures are implemented to mitigate the effects of these land uses on these bats. The occurrence of the rare species in the partially protected area suggest that these ecosystems are still largely intact and that efforts should be made to strengthen the collaboration of the community and the managers of the partially protected area. Due to urbanization and settlements invading most areas of QwaQwa, stakeholders should try ensuring the success and survival of the community protected area and more awareness should be spread about its significance in saving rare and endemic species. Despite the vulnerability of the rare species, my findings show that they can still tolerate mild land use changes such as livestock grazing and hence it is not that the anthropogenic changes must completely disappear but rather that they should not occur at extremities such as that of the unprotected rangelands surrounding Phuthaditjhaba. Perhaps a rural setting with maintenance of natural patches and controlled grazing and low housing density can still allow the occurrence of these rare species in the region especially near the mountains.

The limitation of my study was that I was not able to use light intensity as a predictor variable. I only considered light from the floodlight which is shone in the protected area. This is high intensity light compared to the normal lights from buildings. Light is a very common variable in urbanised areas so it would have been ideal to measure the light intensities in the different sites no matter how low the intensity was. With how I incorporated light as a predictor variable, it is difficult to conclude on the general impact of light and as such, it is only the impact of the floodlight that I can make conclusions about. Furthermore, I was not able to separate the calls of *Pipistrellus hesperidus* from those of *Cistugo lesueuri* because I was only able to capture *Cistugo lesueuri*. The absence of *Pipistrellus hesperidus* from my recorded species might be because this species is not present in the area. The distribution of this species is broad, mainly occurring in the Eastern part of the country. It has been recorded before in the western Free state and KwaZulu-Natal (Monadjem et al., 2020), all areas that are near my study area hence my expectation record it. I also hypothesize the same for *Mops pumilus* as I was not able to capture it. This species has a much broader distribution in South Africa and its distribution is throughout Southern Africa with it being recorded even the Free State and KwaZulu-Natal. Its absence in my study area was unexpected. Furthermore, the land uses could have also included agriculture, especially fruit plantations and crop farms, which are present in the area and rural areas to see if they accommodate the rare species.

3.5 Conclusion

The persisting anthropogenic activities in the Drakensberg Afromontane grasslands were found to significantly affect bat communities. Their effect, however, varies with different bat functional groups. The endemic species exhibit more vulnerability to human activities especially urbanisation/settlements. I also showed that the spotlight shone in the protected area tends to increase bat activity. I conclude that human footprint, especially the proximity to artificial structures has negative influence on bat richness and activity. I suggest therefore that conservation efforts should prioritise these groups of species before they are eliminated completely from the region through the strengthening of the community conservation project as it serves both the community and biodiversity.

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Chapter 4

Diet of *Laephotis capensis* in the Maloti-Drakensberg

Abstract

Understanding the dietary habits of bats is crucial for comprehending their ecological roles and the functioning of ecosystems they inhabit. Dietary studies provide insights into bat foraging behaviour, habitat preferences, and potential interactions with prey populations. Such insight can form the baseline data for conservation planning or economic estimates. For this study, I determined the diet of the insectivorous bat species, *Laephotis capensis,* in the Afromontane grasslands of the eastern Free State using faecal pellets. Pellets were collected from four colony roosts located at four different sites in QwaQwa. I collected pellets from a protected area, an apple farm, a horse farm and a township area. Faecal pellet analysis was conducted through identification of undigested insect fragments found in the pellets with the use of a microscope. Insect fragments were only identified to order level. The percentage frequency of occurrence (PF) and percentage volume (PV) of insects from the pellets was calculated. I then reviewed diet studies of *Laephotis capensis* and other species belonging to the family Vespertilionidae and present a comparison of my findings to relevant literature. The analysis showed that Coleoptera was the most eaten insect order by these bats in the area whilst the orders Hemiptera, Diptera, Hymenoptera and Blattodea seemed to form supplementary food in the diet of *Laephotis capensis*. Consumed insect orders differed in percentage volume across the four sites with a higher diet breadth recorded in the protected area compared to the agricultural sites whilst the frequency of occurrence did not differ between sites. The findings of my study were corroborated by findings from reviewed studies with minor differences which might have been due to the varying environmental conditions of habitats that were sampled in the different

studies. I recommend further studies to ascertain if the bats feed on insects of human importance either in health or agriculture.

4.1 Introduction

Diet analysis has gained increased importance in bat studies globally. Studies of bat diet are critical in procuring insight on the population ecology, foraging ecology, echolocation behaviour, home range size, nutritional needs and potential consequences of population declines on species (Fenton, 2003). Furthermore, bat dietary studies have even been used to show the ecosystem services that bats provide (Boyles et al., 2011; Taylor et al., 2018; Weier et al., 2018). The economic value of pest control services that bats offer for agriculture has been estimated at $30/ha per annum in Texas (Boyles et al., 2011), and between $59/ha and $139/ha per annum for the South African macadamia industry (Taylor et al., 2018; Weier et al., 2018). In South Africa, bats from the De Hoop Cave have been reported to consume around 100 tons of insects per year, which saves farmers in Overberg region from incurring crop losses due to these pests (McDonald et al., 1990). Despite the success of diet analysis studies in South Africa, such studies have not been yet conducted in most areas of the country and thus the value of bats in many areas remains to be determined.

Diet analysis studies employ either molecular or microscopic techniques to analyse present insect DNA or insect fragments in bat pellets respectively. (Whitaker at al., 2009; Bohmann et al., 2011;). Due to the presence of insect DNA in the faecal pellets, it is possible to use molecular barcoding to find out what species and family of insects the bat consumed. Due to the high costs of using molecular techniques, some studies use microscope techniques to identify insect fragments in bat faecal pellets. The success of this method is due to the undigested insect fragments that are observable in the pellets. Insect body parts such as the legs, wings, and antennae can go through the bat’s digestive tract without getting digested due to their hard chitin layer (Whitaker et al., 2009). These undigested fragments can be used for microscopic analysis of what insect was consumed by the bats and the proportions of the different insects that the bat consumed although this is usually to a much coarser taxonomic level.

Insectivorous bats often can be categorized using their diet into four groups namely, generalists, hard bodied insect feeders, soft bodied insect feeders and Lepidopteran specialists (Freeman, 1979; Bogdanowicz et al., 1999; Aguirre et al., 2003). The diet group in which each species of bats falls into may be flexible as locality, season, habitat and climate influences the type of diet for bats (Fenton & Thomas, 1980; Aldridge & Rautenbach, 1987; Leelapaibul et al., 2005; Zhang et al., 2005). Previous studies have shown that insects such as coleopterans, lepidopterans and dipterans all form part of bat diet (Racey, 2011; Parker, 2020). A study by Goldman and Henson (1977) showed how other species of bats failed to crush and eat beetles despite their ability to catch them hence suggesting that the hardness of the prey determined the diet for certain species. The diet of bats is also likely to be influenced by the landscapes that the bats inhabit and the availability of insects. Bats are known to be sensitive to anthropogenic changes and hence the changes from natural landscapes to human disturbed landscapes also has implications on the feeding patterns of bats. Processes such as agriculture, human settlements and urbanization can result in major changes in the type of insects that are available for bats to forage on, which might influence the diet of bats. The use of pesticides in agricultural landscapes results in the loss of insects that could have been potentially eaten by bats, whilst the increased conversion of natural areas to suit human activities is important to bat diet because nocturnal insects which bats forage on are influenced by several factors which include the loss of native vegetation, increased housing densities and artificial lights (Russo & Ancillotto, 2015). Some studies have shown that human settlements can reduce insect density such as moth density (Conrad et al., 2006) and resulting in reduced bat foraging activity in areas of dense housing (Threlfall et al., 2011). However, some insects can be attracted to streetlights and hence allow light tolerant bats to forage on the insects (Russo & Ancillotto, 2015; Schoeman, 2016). The changes in bat distribution with anthropogenic activities may not only be due to habitat loss for bats but may also be a consequence of changes in insect availability. With this study, I therefore aimed to compare the diet breadth of *Laephotis capensis* commonly known as the cape serotine bat (Smith, 1829) in human modified habitats comprising of agricultural landscapes, an urban settlement and a protected natural area in high elevation grasslands of the Maloti-Drakensberg. As a widespread and abundant member of the Vespertilionidae family, *L. capensis* serves as an excellent representative for studying insectivorous bats in Afromontane grassland ecosystems. Its adaptability to a range of habitats, including both natural and anthropogenic landscapes (Monadjem et al., 2020), makes it an ideal model species for understanding bat dietary dynamics in the Maloti-Drakensberg region. Using literature, I additionally aimed to compare the findings with those of other bat diet studies in the southern African region. I hypothesised that bat diet will differ amongst the different landscapes with a broad diet for *Laephotis capensis* in the protected area.

4.2 Materials and methods

4.2.1 Study area

The study was conducted in the Golden Gate Highlands National Park, Heritage Farm located in Harrismith, Masechaba Gardens located in Phuthaditjhaba and at Bruwershoop Farm located in Bethlehem, with all the mentioned areas found in the Maloti-Drakensberg of the Free State in South Africa (Figure 4.1). Golden Gate Highlands National Park is a protected area located at latitude 28.507884 °S and the longitude 28.60314 °E. This area is the most natural and least disturbed grassland of all the study sites investigated. Wildlife grazing is the dominant form of grazing in this area. This park is 11 600 hectares in size, and it comprises of a diversity of fauna which include black wildebeest (*Connochaetes gnou*), eland (*Taurotragus oryx*), blesbok (*Damaliscus pygargus phillipsi*), oribi (*Ourebia ourebi*), springbok (*Antidorcas marsupialis*), zebras (*Equus quagga*) (Kotze, 2002). Phuthaditjhaba is a township located in latitudes 28.57415 °S and 28.77630 °S and longitudes 28.49415 °E and 28.85630 °E with an average elevation of 1,739 m asl. This area is dominated by industrial disturbance and settlements with high density of houses and roads. The area is 23 km^2 with a population of about 55 000 inhabitants. Phuthaditjhaba falls within the Maloti-a-Phofung Municipality under the Thabo Mofutsanyane District Municipality. Heritage Farm is in the latitude -28.51742 °S and longitude 28.42716 °E. It is dominated by apple orchards and maize crops; however, there is also farming livestock such as sheep and cattle. For this study, the apple orchards were the areas of sampling. Bruwershoop Farm is at latitude 28.261175 °S and longitude 28.37946078 °E and it is dominated by free-range livestock grazing of natural pastures.

Figure 4. 1: ArcGIS map of South Africa indicating Thabo Mofutsanyane district in blue where all the sampling sites are found.

4.2.2 Bat faecal pellet collection

I collected bat faecal pellets from roosts known to be occupied by bats during the months of August and October 2022. The faecal pellets collected all belonged to colonies of *Laephotis capensis* as determined through acoustic and live trap surveys. A mix of both fresh and old bat faecal pellets were collected although the freshest pellets were used for diet analysis. Collected faecal pellets were then stored in a freezer set at -10°C to prevent decomposition and growth of mould on the pellets.

4.2.3 Diet analysis

For the guano analysis, I randomly selected 20 faecal pellets from each site to be analysed under the microscope. I used a stereo-light microscope (Model Stemi 305, Zeiss) to identify fragments of insects in the pellets. I allowed pellets to defrost, and I then moistened them using 70% ethanol. I poured a few drops of the ethanol on the pellet using a pipette. The moist pellet was then dissected in the search of insect fragments (Figure 4.2). Insect fragments found were then identified to order level. The pellet was then separated into piles with insect fragments in the same order being put into the same pile. The diet of bats was then quantified based on the percent frequency (PF) of prey orders which was defined as the proportion of the number of faecal pellets containing an order divided by the total occurrences of all orders (Razgour et al., 2011). The percent volume (PV) was also calculated and was defined as proportion of the total volume of each insect order divided by the total volume of the pellet contents. The insect parts from the pellets were identified using an insect fragment reference key from (Whitaker et al., 2009). No program was used to do this, proportions were purely from my estimations. Light trapping in Golden Gate and Phuthaditjhaba was also done in August and October of 2022 to collect flying insects/arthropods occurring in the area to create a reference key (Appendix 4.1). This reference key was used to help in the identification of insect fragments in the collected bat pellets. Since insects contained a hard exoskeleton, some of their contents remained undigested and using a microscope, it was possible to identify remains of consumed insects up to the order level.

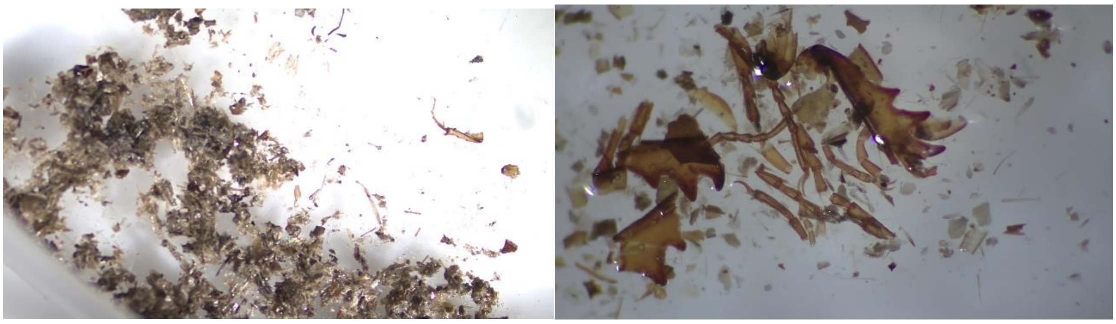

Figure 4. 2: Images of a dissected pellet with undigested insect fragments.

4.2.4 Statistical analysis

The obtained PV and PF values were tested for normality. Due to the non-normal distribution of this data, I tested for differences in the PV and PF values using Kruskal Wallis test between the different sites using the program R Studio version 4.3.3 (R Core Team, 2019).

4.2.5 Literature comparison

To further corroborate my findings in this study, I obtained relevant literature on diet studies that had been conducted in South Africa. I only considered studies that used faecal pellet analysis to determine the diet of insectivorous bats. Since I wanted to determine the diet of *Laephotis capensis* in the Free State, I searched for studies that were focusing on the same species; however, due to the scarcity of such studies, I also incorporated studies that focused on *Myotis tricolor*, *Miniopterus natalensis* and *Scotophilus dinganii* which belong to the family of Vespertilionidae, the same family of *Laephotis capensis.* Studies that had focused on bat species that did not belong to the Vespertilionidae family were not used for comparison with my study. I searched for the relevant studies using the search engine “Google Scholar”. Studies that were conducted using other methods for diet analysis such as molecular methods were excluded. Six studies were found to be relevant and used for this study. These six studies had reported on the percent volume (PV) of prey in the pellet. In studies where the exact volume of prey was not provided, I estimated the volume of prey from the graphs provided.

4.3 Results

4.3.1 Faecal pellet analysis

A total of 20 pellets from each of the four sites was analysed. Some of these pellets contained unidentifiable chitin and tissue while others had unidentifiable wing remains. Analysis of insect fragments in the faecal pellets yielded a total of five insect orders namely Coleoptera, Diptera, Hemiptera Hymenoptera and Blattodea (Table 4.1). Coleoptera was the most consumed insect order across sites with the highest percent frequency of 82.9%. The legs, wings, and antennae were found in the remains inside pellets. Hemiptera had the second highest percent frequency value of 8.5% with wings mostly found for this order. Diptera was the third most fed on order with a percent frequency of 6.1%. Only wings could be found in pellets that could be used to confirm their presence. Hymenoptera and Blattodea appeared only in a single pellet hence had the lowest percent frequency values of 1.2%. There was no significant difference in the frequencies of orders in the pellets between the different sites (H = 0.696, df = 3, p-value = 0.874).

Table 4. 1**:** The percent frequencies of the orders of insects found in pellets in the four sites.

Insect orders	Golden Gate	Heritage farm	Bruwershoop	Phuthaditjhaba
Coleoptera	13.4	24.4	23.2	21.9
Diptera	3,7	1.2	0	1.2
Hemiptera	2.4	2.4	3.7	0
Hymenoptera	1.2	0	0	0
Blattodea	0	0	0	1.2

With regards to percent volumes, Coleoptera had the largest percent volume of 91.6% followed by Hemiptera, Diptera, Blattodea and Hymenoptera which had a percent volume of 3.4%, 2.2%, 1.7% and 0.9% respectively. With regards to insect orders found in the pellets collected from the four sites, Golden Gate had the highest number of recorded insect orders of four, followed by Phuthaditjhaba and Heritage farm with three orders whilst Bruwershoop farm had the least number of orders with only two identified orders. Coleoptera had the highest percentage volume in all the sites whilst all the other orders had percent volumes below twenty percent in all the sites (Figure 4.3). There were significant differences in the volume of insect's orders in pellets across the different sites (H = 10.086, df = 3, p-value = 0.018).

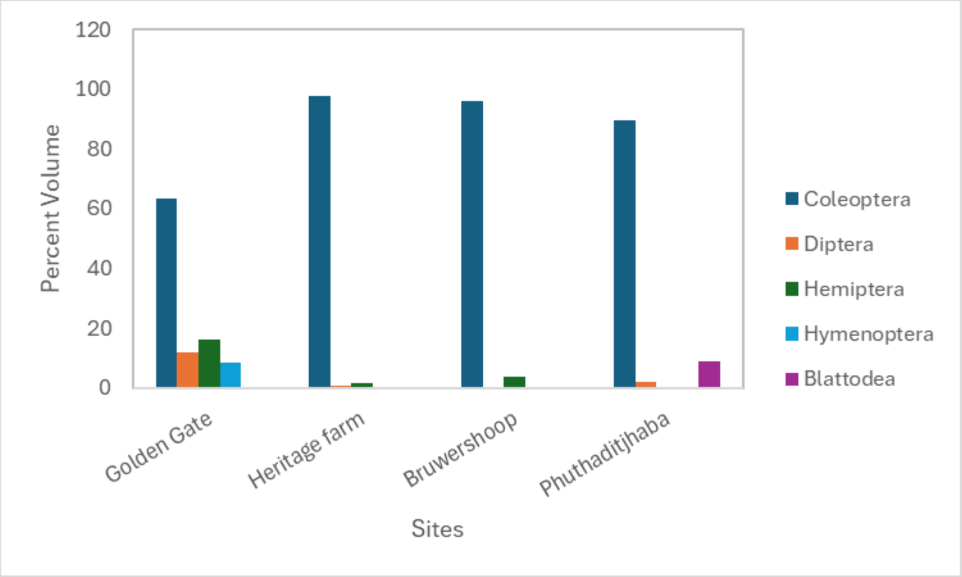

Figure 4. 3: Bar graph showing the percent volumes of the insect orders across the four sites. Insect orders represented according to the colour code.

4.3.2 Literature comparison

For literature comparison, I was able to obtain a total of six relevant studies investigating the diet of insectivorous bats using the same methods of faecal analysis. Out of the six studies, only three diet studies were found to have been conducted on *Laephotis capensis* in South Africa whilst the remaining studies had focused on other vesper species (Table 4.2). Generally, the studies showed that most insectivorous bats fed predominantly on insects in the order Coleoptera, Hemiptera, Diptera and Lepidoptera (Table 4.2).

Coleoptera was the order that was mostly found in high volume within faecal pellets in almost all the studies except in a study by Schoeman and Jacobs (2003) where Coleoptera formed the third highest volume after Hemiptera and Diptera. Hemiptera formed the second highest prey volume although it was missing in the diet of *Laephotis capensis* in two studies (Minnaar et al., 2015; Bailey et al., 2019). It was found to be the order that formed the highest volume of prey in faecal pellets of *Laephotis capensis* in a study by Schoeman and Jacobs (2003). Diptera was the order making up the third highest volume of prey in faecal pellets and it was part of the diet of vesper bats in all the six studies. Lepidoptera made up the fourth highest percent volume of prey, only being found in diets of bats in four studies. Hymenoptera appeared in two of the reviewed studies but not in any of the diets of *Laephotis capensis*. Neuroptera, Trichoptera, Isoptera and Ephemeroptera were also found in some faecal pellets of bats; however, these were found in very few cases and in low percentages, only appearing as part of diets of bats in only a single study of the reviewed publications (Schoeman & Jacobs, 2003; Stoffberg et al., 2004; Moyo & Jacobs, 2020)

Table 4. 2**:** Details of papers reviewed, showing the name of reference, the bat species the study focused on, the faecal analysis technique, and the PV values for my study and the other six studies

Study	**My study**	**Moyo and Jacobs (2020)**	**Bailey et al. (2019)**	**Minnaar et al. (2014)**	**Taylor et al. (2013)**	**Stoffbergs and Jacobs (2004)**	**Schoeman and Jacobs (2003)**
Site location	Qwaqwa, Free State	De Hoop Nature Reserve	Kleinrivier Wilderness, Eastern Cape	Rietvlei	Soutpansberg range, Limpopo	De Hoop Nature Reserve	Cederberg, Western cape
Bat species	*Laephotis capensis*	*Miniopterus natalensis*	*Laephotis capensis*	*Laephotis capensis*	*Scotophilus dinganii*	*Myotis tricolor*	*Eptesicus capensis*
Analysis technique	Faecal analysis under microscope	Faecal analysis under microscope	Faecal analysis under microscope	Faecal analysis under microscope	Faecal pellets under microscope	Faecal analysis under microscope	Faecal analysis under microscope
Coleoptera	36.8	45.9	>90	>80	43.3	32.0	12.5
Hemiptera	1.4	8.1	_	_	30.3	29.0	46.6
Diptera	0.9	3.0	>10	<5	2.3	15.5	37.6
Hymenoptera	0.4	15.0	_	_	3.0	_	_
Neuroptera	_	_	_	_	_	14.6	_
Lepidoptera	_	13.5	>20	<10	21.3	_	_
Trichoptera	_	1.4	_	_	_	_	_
Plecoptera	_	_	_	_	_	_	_
Isoptera	_	9.5	_	_	_	_	_
Ephemeroptera	_	_	_	_	_	_	2.3
Blattodea	0.7						

4.4 Discussion

My study presents the first published information on the diet of any insectivorous bat species in the Free State. From this study, Coleopterans were the most eaten insect order in all study sites. Several studies have shown that coleopterans usually form the main diet of certain bats (Pavey & Burwell, 1998; Lee & McCracken, 2005; Adrianaivoarivelo et al., 2006; Rakotoarivelo et al., 2009; Whitaker et al., 2009). Since the pellets that were analysed belonged to *Laephotis capensis,* my finding is therefore in line with a study by Robinson and Stebbings (1993) which showed that *Eptesicus serotinus,* another bat belonging to the family Vespertilionidae like the *Laephotis capensis* also fed predominantly on beetles. Stebbings & Griffith, (1986), also reported serotine bats feeding on large insects and targeting beetles that were emerging from pastures. My finding thus suggests that the *Laephotis capensis* bats in the area feed mostly on beetles; however, I noted that the fragments reflected that bats were feeding on much smaller beetles. This might be due to that beetles are very slow fliers, and they are noisy flyers that make them easier targets compared to much better manoeuvrable flying insects. Another reason might be that *Laephotis capensis* selects for insects with higher nutrition or protein/energy content. Since Coleoptera insects are usually larger, it might mean that the beetles have higher energy content compared to the other insect orders available such as Diptera. The bias of this speculation cannot be ignored as insects of the Coleoptera group have the hardest parts which end up undigested making up a larger volume of the pellet compared to other insect orders. More volume of a Coleoptera insect will remain undigested compared to a Diptera insect of the same size. Despite this, the high percent frequency of Coleoptera confirms that Coleoptera is the most fed on insect order by the *Laephotis capensis*. When comparing the percent volume and percent frequency of prey items for this study, the ratio appeared to be lower for the orders Diptera, Hymenoptera, Hemiptera and Blattodea and hence these seemed to serve as supplementary foods for these bats. Even though the percent volume of the order Diptera was low, the amount of Diptera eaten by the bats could have been greatly underrepresented in the pellets due most of the parts of Diptera insects getting digested (Dickman & Huang, 1988). Diptera insects are usually small, and their bodies are often softer than insects from the other orders hence bats get to digest most of the insect with very little remaining undigested for identification (Lease & Wolf, 2010).

The protected area, Golden Gate Highlands National Park had the highest number of insect orders recorded from faecal pellets. This might relate to high diversity of insects available for feeding by bats in this site compared to the other three sites. Like in all the other sites, Coleoptera was the most fed on order for these bats and Hymenoptera was only recorded in this site. Heritage farm had one less insect order compared to Golden Gate. Since this is an apple orchard, this finding was not in line with my hypothesis as I expected this site to have less insect diversity due to the frequency of pesticide spraying on the farm. Furthermore, there is a high possibility that the precent volume and percent frequency underrepresented the amounts of insects belonging to Diptera and Hemiptera which the bats feed on. The orders Coleoptera, Hemiptera and Diptera are known to comprise of pest insects which might be harmful to the yield of apples in the farm. The extent and value to which bats might be contributing towards insect suppression in this farm; however, remains to be investigated. This confirms the findings of Aldridge & Rautenbach, (1987) that the type of habitat determines the diet of bats. In Phuthaditjhaba, the bats also fed on insects of the order Blattodea possibly due to the availability of cockroaches in the township. Some bats have been shown to feed opportunistically on Blattodea in urban environments (Aspetsberger et al., 2003; Taylor et al., 2017). Even though I show that undisturbed natural landscapes ensure a diverse diet for bats, bats have the potential to feed on available insects in a particular landscape suggesting that their diet is quite flexible depending on the available insects in the type of landscape or habitat they are foraging in.

From the study, I expected to find Lepidoptera as part of the diet of these bats as my light trapping revealed a high abundance of this order of insects in the area. I, however, was not able to record any traces of Lepidoptera. The bodies of Lepidoptera are soft and easily digested; however, identification of this species is still possible from wing scales which remain undigested. Lepidoptera is known to be one of the main orders consumed by bats globally (Pavey & Burwell, 1998). Species belonging to vesper bats such as *Myotis tricolor* and *Scotophilus dinganii* have been shown to have Lepidoptera as a main part of their diet through both microscopic studies (Bailey et al., 2019; Moyo & Jacobs, 2020) and molecular studies (Bohmann et al., 2011). The reason for the missing of Lepidoptera in bat faecal pellets in my study might have to do with hearing adaptation of most moths. Families of tympanic-eared moths have been shown to have a frequency range of optimal hearing between 20 and 50 kHz

(Fullard, 1987) and studies have shown that bats that echolocate at this frequency do not have much Lepidoptera in their diet as the moths can detect their call and avoid them (Pavey & Burwell, 1998). Since the pellets analysed belonged to *Laephotis capensis* with a call frequency at 40 kHz (Monadjem et al., 2020), the allotonic frequency hypothesis might explain Lepidoptera missing in the diet of these bats. A study by Minnaar et al. (2015), also showed little consumption of moths by *Laephotis capensis* under natural darkness but reported an increase in moth consumption under lit conditions. This suggests that light might also have played a role in influencing my findings. The roosts from which pellets were collected did not have too much artificial light. Even in the most human disturbed site of Phuthaditjhaba, the roost was located right on the edge of the township, not where lighting was extreme and hence lack of light might be another reason why there were fewer moths to feed on. A study by Robinson and Stebbings (1993) showed that bats selected for Lepidoptera in the southern hemisphere autumn between the months of June and August. This means that the diet of bats may vary during the duration of the year, depending on when moths are abundant, and hence would explain why Lepidoptera was not recorded in this study. More research at the sites which focus on seasonal variation of diet of bats throughout the year coupled with studies on seasonal variation of moth abundance is recommended. Future studies on this area should also couple the microscopic technique of bat faecal analyses with molecular techniques as I could only identify insect fragments to order. This is particularly a limitation in that I cannot say for sure whether these bats are suppressing any pest insects or disease-carrying insects in the area. There is a great potential for bats to be suppressing insects such as coddling moths and false coddling moths which affect apple and citrus fruits respectively. Not only might bats be valuable to fruit farmers but they might be supressing insects such as the maize borer and the African bollworm which are likely affecting the harvests of local subsistence farmers in QwaQwa. More research is still needed in this regard.

With regards to the literature that I reviewed, I noted that there have been very few studies conducted on the diet of *Laephotis capensis* thus revealing a gap in research on this widespread and relatively common bat species, especially in the Free State region. The findings of my study were for the most part like what had been found in the South African literature. As in my study, Coleoptera dominated as the main order of insects that bats fed on in reviewed studies. Despite these studies being conducted in different habitats and areas of the country ranging from the Western Cape to Limpopo Provinces, they still concluded that Coleoptera was the main or almost the main preferences for these bats. This confirms that Coleoptera might be the main insect order that *Laephotis capensis* selects for even with different environmental conditions. In my study, I noted minimal consumption of Hymenoptera unlike findings by Robinson and Stebbings (1993) and Taylor et al. (2013), where bats exhibited higher consumption rates. This discrepancy might be a result of varying local ecological factors influencing prey availability and foraging behaviour. The absence of Lepidoptera in the diet of vesper bats is not unique to this study as two of the studies I reviewed also found no Lepidoptera remains in the pellets (Schoeman & Jacobs, 2003; Stoffberg et al., 2004) and one of those studies was focused on the diet of *Laephotis capensis* (Schoeman & Jacobs, 2003). My study further revealed disparities in the consumption of other insect orders such as Neuroptera and Trichoptera, which were recorded in one study respectively; however, failing to appear in the other reviewed studies including my own. Both of these orders were absent in the insects I caught, suggesting that their absence or lack of abundance might be the reason why I didn’t find them in the bat pellets. These varying consumption patterns may be highlighting the ecological diversity across different study sites Another reason for this might be seasonality. Perhaps if sampling had been done in all seasons, I might have found Neuroptera and Trichoptera in the diet of *Laephotis capensis*.

The limitation of my study was that I could not compare the diet of *Laephotis capensis* across seasons because bats move away and/or are inactive in my study area during winter. Season has been shown to influence the diet of bats and it would have been ideal for this study to address how seasonality affected the diet of *Laephotis capensis*. Evaluating the availability of insects from an entomology perspective through the seasons to compare with the faecal samples would be helpful in future studies.

4.5 Conclusion

My study showed that more insect orders were consumed by *Laephotis capensis* in the protected area suggesting that land use or habitat type influences the diet of this species. Coleoptera was the main insect order that was eaten by sampled bats suggesting that *Laephotis capensis* might be specializing more on coleopteran prey than other orders in this region or sampled season. Diptera and Hemiptera are also potential orders that the bats feed on even. Other studies corroborated my findings; however, more research still needs to be on the diet of bats in the Malot-Drakensberg.

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Chapter 5

Impact of education intervention on negative perceptions of learners towards bats in the Maloti-Drakensberg

Abstract

Bats are important ecosystem service providers in the world. This is in part due to their diversity as they are the second largest group of mammals with a widespread global distribution. Despite this, most cultures around the world have negative stereotypes towards bats, largely influenced by myths and beliefs stemming from misconceptions about them. In this study, I aimed to assess the impact of environmental education on enhancing awareness and positive perceptions towards bats and their natural ecosystem services by school learners in QwaQwa in the eastern Free State Province of South Africa. My study addressed negative stereotypes about bats through informed and interactive engagement of scientific and public communication in schools with the use of bat awareness classes, posters, a children’s book on bats, and engagement in bat research revolving around bat houses installed at each school. I used a standardized questionnaire to assess individual attitudes towards bats pre- and post-intervention, targeting for each survey, approximately 200 learners from two primary and one secondary school in QwaQwa. Perception of students were divided into six categories namely scientistic, positivistic, behavioural negativistic, emotional negativistic, cognitive negativistic and myth categories. The intervention resulted in a significant change in negative perceptions of students towards bats for all categories, becoming more positive. I also found gender and age to be significant predictors of perceptions, with females exhibiting more emotionally negative perceptions towards bats, while younger students displayed more cognitively negative perceptions. Considering the findings, I argued that intervention through environmental

education can be a useful tool for changing negative perceptions of learners towards bats in local South African communities.

5.1 Introduction

Human-wildlife conflict results in the persecution of wild animals across the globe. Such conflict most frequently stems from threats that wild animals pose to human safety and wellbeing such as food and property (Conover, 2002; Peterson et al., 2010). This phenomenon usually results in aggressive and retaliative behaviour from humans towards wildlife which is often fatal to the species of concern (Nyhus, 2016). This in turn has negative implications on the conservation of these species (Redpath et al., 2013). The main driver behind human wildlife conflict is the perceived threats posed by wildlife, which is often exaggerated compared to the actual risk (Siex & Struhsaker, 1999; Dickman, 2010). Perceptions constitute subjective beliefs and emotions influenced by cultural, social, religious and individual factors, including personal experiences, media influence, and cultural norms (Sjöberg et al., 2004; Dickman, 2010; Davis et al., 2016) meaning that the perceptions that people have towards wildlife can determine the success or failure of conservation of species. Since negative perceptions towards wildlife may lead to harming or killing of animals and destruction of their habitat (Redpath et al., 2013; Nyhus, 2016), it is important to cultivate positive perceptions towards wildlife. It's been suggested to be easier to change the perceptions of children than adults (Charlesworth et al., 2020). We therefore should focus on children rather than adults. As such, the schooling space provides an enabling environment to redress the negative perceptions.

One of the groups of animals that humans typically have a negative perception towards is bats. Bats are small mammals in the order Chiroptera comprising over 1400 extant species and forming the second largest mammalian order (Voigt & Kingston, 2015; Burgin et al., 2018), accounting for 20% of all mammalian species in the world (Kunz & Pierson, 1994). Not only are they important due to their widespread distribution, occupying every continent except for Antarctica, but bats have also been shown to have great ecological and economic roles (Boyles et al., 2011; Kunz et al., 2011; Taylor et al., 2018; Linden et al., 2019; Weier et al., 2018). Ecosystem services provided by bats include pollination, seed dispersal and pest insect suppression (Jones et al., 2009). Pest insect suppression has been estimated for only a small number of crops, and only a few regions of the world, but even so, the economic savings are enormous (Boyles et al., 2011; Taylor et al., 2018; Linden et al., 2019; Charbonnier et al., 2021; Maslo et al., 2022; Nsengimana et al., 2023). Despite this, bats continue to suffer from a bad image (Prokop & Tunnicliffe, 2008), perhaps linked to the often overexaggerated belief that they are instrumental in the spread of zoonotic diseases (Olnhausen & Gannon, 2004; Whitaker & Douglas, 2006; Olival et al., 2015; López-Baucells et al., 2018; Weber et al., 2023). Despite their significance, many bat populations are globally threatened (Jones et al., 2009; Voigt & Kingston, 2015), with human activities such as land-use changes resulting from agriculture, logging, livestock ranching, hunting, persecution and urbanization being the main culprits (Voigt & Kingston, 2015; Coleman et al., 2024).

Bats have been shown to be amongst animal groups that humans tend to have phobias of together with snakes, mice and spiders (Davey, 1994; Arrindell, 2000). The long history of negative stereotypes towards bats can be accredited to misconceptions which have been perpetuated through myths. Bats in some cultures are believed to be associated with witchcraft due to their nocturnal nature (Musila et al., 2018) and are also often depicted as vampires in art and literature even though vampire bats do not typically consume human blood (Mayen, 2003). They are disdained for occupying the roofs of houses, causing annoyance to residents through chattering sounds at night and through accumulation of urine and faeces (Euren et al., 2020) . Some farmers view bats as pests due to foraging on fruit tree farms and hence lowering potential yield from those plantations (Jacobsen & Du Plessis, 1990; Voigt & Kingston, 2015).

Bats have also been implicated in transmission of zoonotic diseases such as coronaviruses, lyssaviruses, and filoviruses to humans (Markotter et al., 2020). These negative stereotypes have further escalated due to the belief that bats were responsible for the COVID-19 pandemic (Zhao, 2020; Hassanin et al., 2024; Meyer et al., 2024). In fearing and hating bats for potential disease transmission, people overlook that the transfer of zoonotic diseases from animals to people mostly occurs when people handle animals, for example to kill them. Since the outbreak of the covid pandemic, bats have been subject to stigmatizations in places such as in Indonesia where some bats have even been killed due to the fear of the transmission of the COVID-19 virus (Lu et al., 2021). However, persons who were aware of the importance of bats in ecosystem functioning were less likely to have negative perceptions towards bats, even during the pandemic (Lu et al., 2021). Not all cultures view bats negatively others. A study showed that some pastoralists in Namibia believed that bats were a sign of good luck and good rains (Laverty et al., 2023). Some cultures in China also believe that bats are a sign of good luck because the word “bat” is pronounced the same as that of “fortune” in Mandarin Chinese (Voigt & Kingston, 2015).

Environmental education may be the key to changing negative perceptions; indeed, it has been used successfully to change people’s attitudes and perceptions towards wildlife species that were previously considered harmful to humans (Rakotomamonjy et al., 2015). For example, environmental education has proved to be effective in reducing negative attitudes toward owls in South Africa (Williams et al., 2021), and in mediating conflict with elephants in Zimbabwe (Scrizzi et al., 2018). Educational awareness classes come in different forms, including the use of presentations, workshops and citizen science projects. The effectiveness of the intervention lies in that it equips people with knowledge, skills, and values critical in informed decision-making about the environment. Environmental education must be informative and relevant to its target audience. It is therefore crucial that before the implementation of such a tool, gaps in knowledge have already been addressed. Although environmental education has become a popular tool to spread awareness about the importance of wildlife, the attitudes and perceptions of the people who have received the education are rarely assessed. There is also a dearth of studies that quantify the degree to which environmental education can influence the perception of the people in question (Pérez et al., 2021), particularly in Africa.

Therefore, I aimed to ascertain the perception of grade six and eight learners towards bats and to determine whether environmental education could be used as an effective tool to change negative perceptions that school learners might have regarding bats. Studies focusing on perceptions of people towards bats in South Africa are lacking despite the common interaction of bats and people in this region. I focused on schools located in QwaQwa, a low-income area (Nishimwe-Niyimbanira, 2020) where most residents are likely to be encountering bats as most lack resources to ensure their housing infrastructure is not easily accessible to bats. QwaQwa is one of the areas located in the Maloti-Drakensberg region where endemic bats have been recorded, making it critical that the people in the area know the value of bats. Based on a similar study by Williams et al. (2021) focusing on owls, I hypothesised that educational intervention would result in reduced negative perceptions towards bats.

5.2 Methods and materials

5.2.1 Study site

The study was conducted in the township of Phuthaditjhaba inside QwaQwa, an area in the Maloti-Drakensberg located in the eastern part of the Free State Province in South Africa near Lesotho. This region is under the Maloti-A-Phofung Local Municipality and the Thabo Mofutsanyane District (Figure 5.1) and is situated on the foothills of the Maloti-Drakensberg mountains (Mocwagae & Mphambukeli, 2023). QwaQwa is mostly inhabited by traditional farmers and herders of livestock. The population in Maloti-A-Phofung is 335,784 people (Statistics South Africa, 2022). This region was established as a homeland for the Basotho people in the 1970s and was reincorporated into the Free State Province in 1994 following the end of apartheid (Slater, 2002).

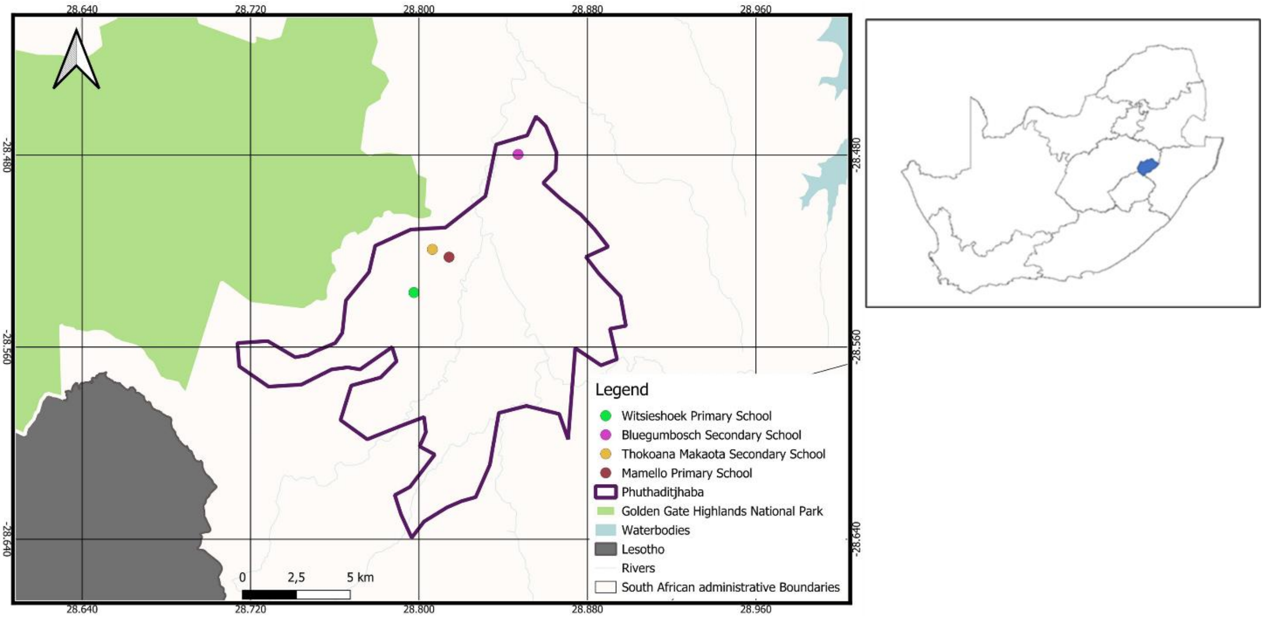

Figure 5. 1**:** Map showing the location of the four schools in QwaQwa in the township of Phuthaditjhaba with an insert of the map of South Africa showing the location of Thabo Mofutsanyane Municipality District marked in blue where QwaQwa is situated.

Despite QwaQwa’s beautiful scenery, which includes the Golden Gate Highlands National Park, and several educational institutions such as the QwaQwa campus of the University of the Free State, the region faces several challenges, including high levels of poverty, unemployment, and crime (Tsotetsi & Omodan, 2022), all of these having been worsened by the recent COVID-19 pandemic. Additionally, access to basic services such as clean water and electricity is limited in this region.

5.2.2 Sampling participants

The study was conducted over a period of two years. Two high schools (Thokoana Makaota Secondary and Bluegumbosch Secondary School) and two primary schools (Mamello Primary and Witsieshoek Primary School) were initially selected in QwaQwa for data collection. During the first year of the study (September 2021), a preliminary study was conducted in the four schools which focused on grade 7 learners in the primary schools and grade 8 learners in the high schools (with ages ranging from 11 to 13 years and 13 to 15 years of age respectively) to test the suitability my methodology before the actual study began. The actual study commenced in 2022 with both pre-intervention and post intervention sessions taking place the same year as shown in Figure 5.2. For this survey, I focused on grade six and grade eight learners. Grade six and grade eight learners were utilized because they were at a stage where they understand the concept of answering questionnaires and have better understanding of English compared to lower grades whilst they were also still young enough to be considered children. Pre-intervention survey was defined as the handing out of questionnaires to learners before learners were exposed to any bat awareness environmental education (Figure 5.2). Post intervention was defined as surveying learners through questionnaires after a bat awareness educational session, about six months after the pre intervention. Complete data collection could only be done in three schools (unfortunately, the post-intervention exercise at Bluegumbosch Secondary School had to be abandoned due to unforeseen circumstances).

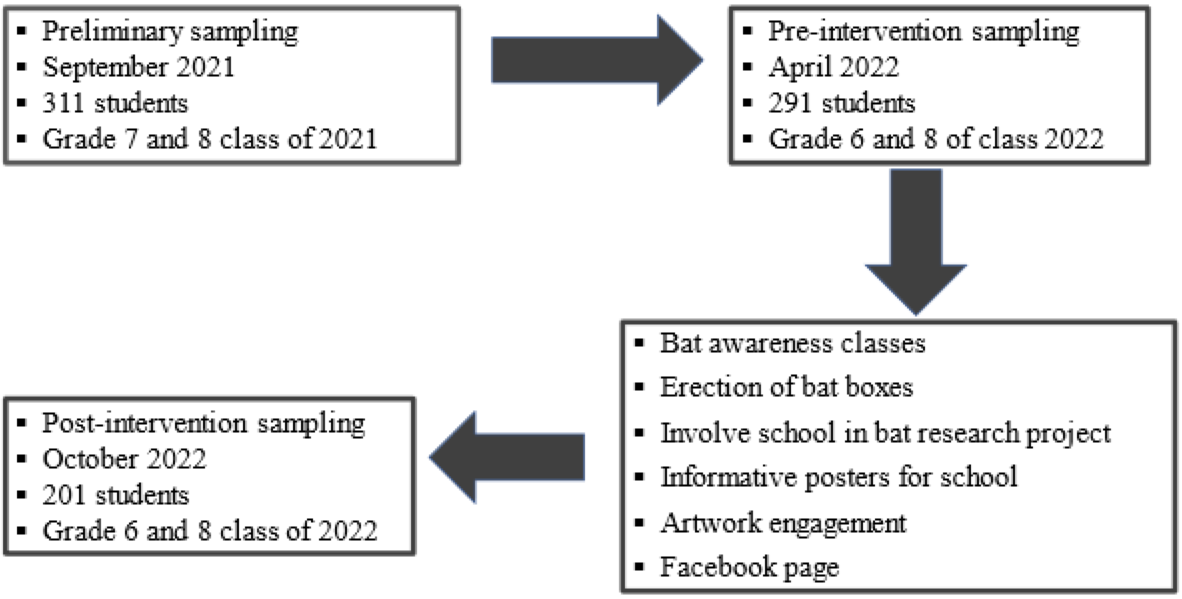

Figure 5. 2**:** A schematic outlining the sampling process for the study

Figure 5. 3**:** The four schools where the survey was conducted where A is Mamello Primary, B is Witsieshoek Primary, C is Thokoana Makaota Secondary, and D is Bluegumbosch Secondary all located in QwaQwa.

5.2.3 Questionnaire structure

The study utilized a standardized questionnaire designed to assess the attitudes of people to bats (following Perez et al., 2021). The questionnaire comprised of 35 statements (which students could agree or disagree with) which were divided into six categories namely scientistic, positivistic, emotional negativistic, behavioural negativistic, cognitive negativistic and myths (Table 5.1). It is worth noting that these categories used in this study are derived from the standardized questionnaire developed by Pérez et al. (2021), where these terms are specifically defined and contextualized. The scientistic section comprised of statements which assessed whether the learners were willing to learn about bats and if they were willing to share their knowledge with others. The statements of the positivistic section assessed whether learners knew about the ecological and economic importance of bats. The emotional negativistic section comprised of statements assessing the learners' emotions towards bats, such as whether they feared them. The behavioural negativistic assessed whether they felt bats should be removed from the environment, while the cognitive negativistic assessed whether learners perceived bats as being harmful to humans. The myth section assessed whether learners believed in myths. Due to the study being conducted after the COVID-19 pandemic, a statement on whether learners believed COVID came from bats was added to the statements formulated by Perez et al. (2021). Each of the six categories comprised of varying number of statements (Appendix 5.1). The questionnaire was initially in a Likert-scale format with each of the statements having a set of choices rating their response from 1 (Strongly disagree) to 5 (Strongly agree), with a score of 3 represented a neutral response (Appendix 5.2).

Table 5. 1**:** The six categories of statements with the different perceptions of learners towards bats before and after the educational intervention which each category was assessing.

Category	Perception/attitude assessed
Scientistic	The learner's interest, curiosity, and engagement in scientific activities related to bats.
Positivistic	The learner's belief in the positive contributions of bats to the ecosystem, agriculture, and human well-being and in the importance of protecting and conserving bats.
Emotional negativistic	The learner's negative emotional responses and perceptions towards bats, including fear, aversion, and negative aesthetic judgments
Behavioural negativistic	The learner’s advocacy for or endorsement of actions that involve harmful or aggressive behaviour towards bats.
Cognitive negativistic	The learner’s beliefs or perceptions that attribute negative consequences to bats, particularly in relation to agricultural activities, environmental contamination, and potential dangers to humans and animals
Myths	The learner’s beliefs or narratives about bats that are not based on scientific evidence or factual knowledge.

5.2.4 Sampling design

In September of 2021, learners' perceptions were assessed using the standardized questionnaire in the four schools as part of a preliminary survey. Upon completion of the questionnaire, learners were then given a 40-minute bat awareness presentation, using PowerPoint to convey scientific knowledge that sought to inform learners about the nature and behaviour of bats, the critical roles that bats play in the ecosystem, and to challenge common misconceptions about bats. The importance of bat conservation, especially with regards to the two bat species endemic to the Maloti-Drakensberg mountains namely *Rhinolophus cervenyi* and *Laephotis cf. wintoni* (Monadjem et al., 2020; Benda et al., 2024) was also a major aspect of the presentation. Learners were allowed to ask questions at any point of the presentation. The content and format of the presentation was deemed suitable for the learners by the Faculty of Education at the University of the Free State. In addition, I obtained a Human Research ethics permit (number: UFS-HSD2021/0914/21). Consent for the involvement of students in this study was procured from each student and at least one parent or guardian.

The pre-intervention survey was conducted in April of 2022 in the four schools with a new group of learners (Figure 5.2). This survey focused on grade six and grade eight learners. After completion of the pre-intervention survey, the learners were then given a bat awareness class. Once the class was finished, two posters containing the taught information were also donated to each school to allow learners to refer to them whenever they needed to. A Facebook page entitled QQ Bat Education Project on the link (https://www.facebook.com/profile.php?id=100076140791500) was set up to allow students to engage with conductors of the study, and to ask questions. This page was accessible to all the students in this study, as well as to all members of the general public. Less than a week after presentations were made, four bat boxes were erected in each of the two high schools, and two bat boxes were erected in each of the two primary schools (Figure 5.4). These bat boxes were used as a citizen science tool to engage and involve learners. The bat boxes were part of another study, analysing the diet of bats; however, they allowed the students to engage with the researchers to observe the bats roosting on the premises of each school. Part of the intervention also included an artwork competition for students where they got to draw anything that they wanted on the topic of bats and the winning artwork was included in a children's fictional book that I authored, set in QwaQwa which includes educational facts promoting bats (Appendix 5.3). The book itself was an intervention strategy although it had not been published by the time of the post intervention survey. The post intervention survey was conducted six months later on the same learners who had been part of the pre-intervention survey. For the pre-intervention survey, which took about an hour of learners filling in the questionnaire before any educational intervention, responses from 290 learners were used for analysis whilst for the post-intervention survey, responses from 201 learners were analysed.

Figure 5. 4: Examples of pairs of black and white bat boxes erected in each of the four schools as part of school and student engagement.

5.2.5 Data analysis

Data from the three schools was used to test whether the educational intervention had changed the perceptions of learners with regards to the six categories defined above. For testing, I combined the "strongly agree" and "agree" responses into an "agree" category. The same was done for the “strongly disagree” and “disagree” responses. This left me with three responses: agree, neutral and disagree. I then used the clmm (Cumulative Link Mixed Model) function from the "ordinal" package (Christensen, 2018) in R to run mixed ordinal regression analysis assessing the influence of predictor variables on the ordinal response variable consisting of the three categories namely, "agree," "disagree," and "neutral". The mixed ordinal regression models comprised of school and grade as a random variable while intervention (before and after), gender (male and female) and age were the predictor variables. The Akaike’s Information Criterion (AIC) was used to compare models from each of the categories. The model with the lowest AIC value was selected as the best model, while those with ΔAIC less than 2 were deemed to have equal support (Burnham & Anderson, 2004; Johnson & Omland, 2004). Plots were created using ggplot2 (Wickham, 2016) in R version 4.3.0 (R Core Team, 2019).

5.3 Results

In this study, a total of 284 students participated before the intervention, comprising 149 females (52.5%) and 135 males (47.5%). After the intervention, the number of respondents was 192, with 109 females (56.8%) and 83 males (43.2%). Students who had not revealed their gender were excluded from the analysis to ensure accurate comparisons. For all six perception categories, the best-performing models included intervention as a significant predictor of changes in learners' perceptions toward bats (Table 5.2). This suggests that the educational intervention had a positive impact on learners' perceptions and attitudes toward bats. With regards to the different perception categories, responses to scientistic statements were mostly positive before my educational intervention. Despite this, my intervention still resulted in even higher positive perceptions amongst students for this category (Figure 5.5a). Age was also a significant factor in perceptions of students with increase in age showing more positive responses (Table 5.2a). For the positivistic category, fewer students initially agreed that bats play a beneficial role in ecosystem functioning and that bat conservation is important, but perceptions improved significantly after the intervention (Figure 5.4b). Males showed a noticeable increase in positivistic views after the intervention compared to females, indicating gender differences in conservation attitudes (Figure 5.5b).

For emotional negativistic views, both the intervention and gender had significant effects on learners' perceptions of bats (Table 5.2c), with females initially showing higher emotional negative views (Figure 5.5c). Similarly, for behavioural negativistic statements, educational intervention and gender were significant predictors (Table 5.2d), with males exhibiting initial higher behavioural negativistic views than females. For cognitive negativistic views, intervention, gender, and age were all significant predictors (Table 5.2e). Males had higher cognitive negativistic views than females, and younger participants showed slightly higher cognitive negativistic responses compared to older participants. For myths, there was a noticeable decrease in the number of learners believing in myths about bats, suggesting that the intervention significantly influenced perceptions (Figure 5.4f). However, age and gender were not significant predictors for myths (Table 5.2).

Table 5. 2: Results of mixed ordinal regression analysis assessing the influence of predictor variables on the ordinal response variable for the six perception categories with the estimates, standard errors, z-values, and p-values provided for each predictor variable. The predictor variables were intervention (before and after), gender (male and female) and age (younger and older). Statistically significant results are indicated by asterisks (*).

	Estimate	**Std. Error**	**z value**	**Pr (>|z|)**	
(A) Scientistic					
InterventionAfter	0.364	0.123	2.960	0.003	**
GenderMale	0.448	0.102	4.384	P < 0.0001	***
AgeYounger	-0.331	0.164	-2.019	0.043	*
(B) Positivistic					
InterventionAfter	**-0.212**	**0.078**	**-2.725**	**0.006**	******
GenderMale	-0.277	0.059	-4.713	P < 0.0001	***
(C) Emotional negativistic					
InterventionAfter	**0.753**	**0.145**	**5.198**	**P < 0.0001**	*******
GenderMale	0.543	0.106	5.125	P < 0.0001	***
(D) Behavioural negativistic					
InterventionAfter	**0.524**	**0.140**	**3.739**	**P < 0.0002**	*******
GenderMale	-0.306	0.107	-2.857	0.004	**
(E) Cognitive negativistic					
InterventionAfter	**0.378**	**0.090**	**4.192**	**P < 0.0001**	*******
GenderMale	-0.198	0.068	-2.926	0.003	**
AgeYounger	0.228	0.109	2.096	0.036	*
(F) Myths					
InterventionAfter	**0.547**	**0.104**	**5.256**	**P < 0.0001**	*******

GenderMale	-0.150	0.081	-1.858	0.063	.
AgeYounger	0.200	0.131	1.528	0.127	

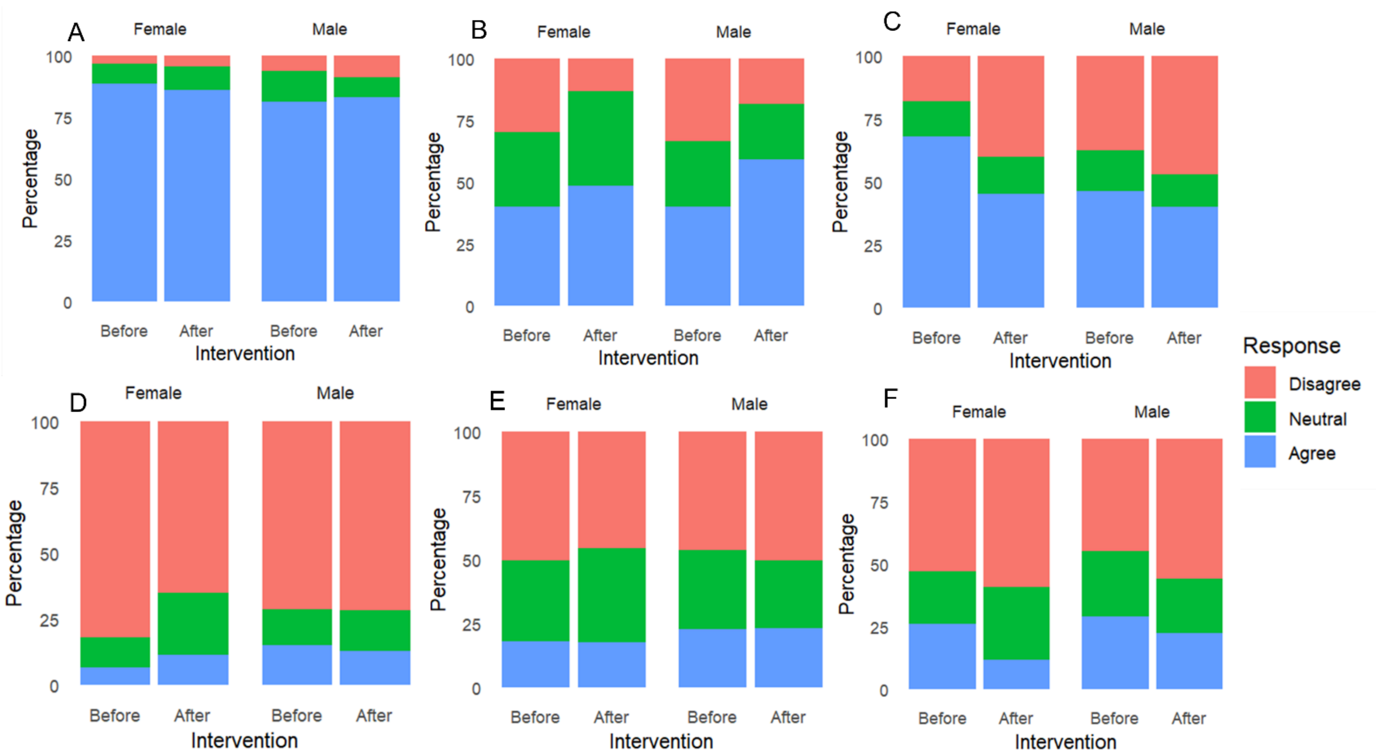

Figure 5. 5**:** Percentage of responses for male and female learners by (A) scientistic statements, (B) positivistic statements, (C) emotional negativistic statements, (D) behavioural negativistic statements, (E) cognitive negativistic statements, (F) myth statements at the three schools before and after the educational intervention. The blue, green and red colours represent the proportions of learners who agree, remained neutral and disagreed respectively. For the scientistic (A) and positivistic categories (B), agree responses (blue) are pro bats whilst disagree responses (red) are anti bat. For all the remaining categories (C-F), the agree responses (blue) are anti bat whilst the disagree responses (red) are pro bat.

5.4 Discussion

My study showed the success of educational intervention in changing perceptions of leaners toward bats. Learners initially had higher negative perceptions towards bats before any intervention or environmental education. This could be attributed to a lack of knowledge and misinformation that learners had about bats before commencement of the study. Cohen (1973) found that a group of high school learners with more environmental information showed different attitudes than the group with less environmental information, hence highlighting the importance of access to information in shaping perceptions and attitudes (Cohen, 1973). Other studies have shown the significance of environmental knowledge in determining people's attitudes and behaviour (Mangas et al., 1997; Bradley et al., 1999). Furthermore, increased awareness and knowledge about bats has been shown to be positively related to improved attitudes towards bats (Musila et al., 2018). Hence my study supports the findings of previous studies, demonstrating the effectiveness of this intervention tool, in this region of southern Africa. The results further revealed that educational interventions can assist in reshaping perceptions and attitudes towards bats for young learners. The study was able to show that learners were keen on learning about bats and being involved in classes about bats. The negative beliefs that they held towards bats did not stop or discourage the learners from wanting to learn and spread their knowledge about bats to others as observed from student's responses to the scientistic statements. The desire for learners to learn about bats is particularly significant in that it gives them a chance to learn and get proper information which can help them make informed decisions on whether a species is to be hated or not. As expected, the study showed a low number of learners who knew about the importance and significance of bats economically and ecologically as shown by the responses to the positivistic group responses which might explain overall negative perceptions towards bats (Prokop & Tunnicliffe, 2008). This suggests the need for the role of bats ecologically and economically to be made known to people and if possible, be demonstrated practically. If a practical way can be used to show bats significance, such as taking students to fruit farms to see how pests damage fruits and how much losses can be incurred from these pest damage, the impact of such intervention could be stronger.

Excursions to local bat roosts, encouraging protection of cave roosts in QwaQwa, collaborating with rehab centres and citizen science “bat walks” which uses smartphones or even virtual tours and documentaries can also serve as a practical approach to getting people to grow interest towards bats. Interventions that give people a hands-on and personal experience, has been shown to change people’s perceptions about bats even more effectively (Kaninsky et al., 2018; Johnson & Price, 2023; Gili et al., 2024). For behavioural responses, the change in perceptions was small. Due to the highly positive nature of the initial responses to this section, the little change in perceptions is not harmful. Learners disagreed with behaviour aimed at harming bats. This was a good sign in that it showed, not all love was lost for bats, and it is helpful in that interventions do not need to go as far as to convince them not to harm bats as they were already against that, so educational intervention can focus more on making them aware of the importance of bats. There was also little change in perceptions regarding cognitive negativistic statements, this could also be due to the lack of a practical demonstration to learners. This section showed how much learners lacked knowledge on bats and can be seen by the high number of learners who remained neutral in their responses. With emotional negativistic views, there was a noticeable change from negative responses to more positive ones. The demonstrated lack of aggression towards bats might be why learners felt emotionally different towards bats after the intervention.

My study showed that educational intervention can be effective in changing perceptions of learners towards bats. The study showed that with proper education it is possible to undo negative stereotypes towards bats. The extent to how effective an intervention may be is also dependent on the type of intervention (Williams et al., 2021). The success in changing perceptions of learners towards bats might have been because learners were able to see me conduct research on bats without falling victim to any of the negative myths, be it having our hair eaten or be subjected to ill omen as these were the prevailing local myths. This might have been why some of the learners changed their minds when it came to the myths from agreeing with the myths to disagreeing with them.

The surveyed learners from the QwaQwa community also held a belief that bats eat the hair of humans, and this was particularly why most of the learners were not fond of bats. This belief was one that had not been known previously to me. Even though it had not been included in the questionnaire, the learners verbally “confirmed” the authenticity of this myth during intervention interactions. This myth was passed on by adults, especially parents to the young children, wanting the children home by nightfall and to encourage good behaviour. Even though none of the learners saw a bat eat hair and despite the lack of evidence for it, the belief in the myth was prevailing across all schools sampled. This is evidence to as to how much cultural and social beliefs can shape attitudes towards species even in the absence of authentic evidence. Misconceptions about bats, such as the belief that they tangle in human hair or eat hair, are not unique to Qwaqwa schoolchildren. These myths are pervasive across various cultures worldwide and have been well-documented in the literature (Kingston, 2016; Sieradzki & Mikkola, 2022; Laverty et al., 2023). Such beliefs often stem from bats' nocturnal habits, cryptic behaviour, and cultural narratives that portray them negatively. For instance, similar myths have been recorded in Europe, Asia, and the Americas, where bats are often associated with danger, misfortune, or vampirism (Kingston, 2016). In Africa, misconceptions about bats have also been linked to folklore, where they are sometimes viewed as harbingers of death or disease (Prokop & Tunnicliffe, 2008; Kingston, 2016). These widespread negative perceptions hinder conservation efforts by fostering fear and hostility toward bats. While many of the beliefs held by Qwaqwa schoolchildren align with global patterns, such as the misconception about bats tangling in hair, some perceptions may have unique cultural or regional origins. Addressing these beliefs is critical, as they influence how local communities interact with and value bats, ultimately impacting conservation initiatives. Educational campaigns that dispel myths and emphasize the ecological importance of bats, particularly their role in pest control and pollination, are essential to mitigating these negative perceptions. From this study, I noted that even though cultural beliefs influence most children, it is not all those children who will be influenced as there is a lot of factors influencing this which was beyond the scope of this study

With regards to gender, both genders showed high willingness to learn more about bats. The gap in the knowledge of bats in both genders proved to be high as less than 50% of both males and females agreed to bats being important in the ecosystem. This shows the need to educate learners about the roles that species such as bats play in the environment. I found gender to have an impact on emotional perceptions of students towards bats. Females had more negative perceptions towards bats. This was in line with the findings of another study which showed that females are more fearful and indifferent to most animals (Kellert & Berry, 1987) The authors attributed this to low knowledge about animals. Another study also revealed that boys show more positive attitudes than girls toward bats and spiders (Prokop & Tunnicliffe, 2008). Despite this, my study showed that fewer females agreed to negative behaviour towards bats suggesting that they did not view exterminating bats and eliminating them from the ecosystem as an ideal solution. This might suggest that females had more empathy towards bats (Herzog et al., 1991; Taylor & Signal, 2005). The difference in preferences towards species has been documented in previous studies where gender plays a role in liking certain species of animals over others (Davey, 1994; Bjerke & Østdahl, 2004). Females have been shown to be more likely to prefer more popular and neutral animals whilst males prefer less popular animals (Bjerke & Østdahl, 2004). In this study, there was no significant impact of gender on believing in false myths about bats. Mystical beliefs of bats can lead to negativistic behaviour towards them (Prokop & Tunnicliffe, 2008). Even though the study revealed that learners also believe in false myths about bats, this was about fifty percent of the learners in total in both males and females suggesting that not all the learners believed in the false myths.

Age was also found to significantly influence perceptions of students in the categories of scientistic and cognitive views. Younger students were more enthusiastic to learn about bats; however, they were more cognitively negative towards them. Another study found that older people had more positive attitudes towards bats (Musila et al., 2018) which is in line with my findings showing more cognitive negative perceptions toward bats by younger respondents. The impact of age was not visible in the rest of the categories. This might have been due to the very little age difference amongst the learners.

The success of my study may have been due to the multi technique approach of the study. The standard practice for most interventions is to just give an awareness class and probably a demonstration. Even though this might educate the target audience, feelings that the target group have may require more time of engagement. The use of multiple techniques aligns with findings from behavioural science research, which shows that combining different approaches can produce synergistic effects on behaviour change. For instance, Barnidge et al. (2015) found that integrating education with access to resources significantly improved fruit and vegetable consumption in a rural African American community, demonstrating that behaviour change is more effective when individuals receive both knowledge and tools to act on it. Similarly, Bianchi et al. (2018) showed that interventions targeting multiple conscious determinants of behaviour, such as awareness and habits, were more effective in reducing meat consumption than interventions focusing on a single determinant. Furthermore, research by Boncu et al. (2023) highlights the value of interactive and gamified tools in fostering pro-environmental behaviour among university students. This underscores the importance of engagement and experiential learning, both of which were integral to this intervention. The combination of techniques used in this study—providing educational content to address misconceptions, hands-on activities to foster positive interactions with bats, and opportunities for participants to express and reflect on their beliefs—created a comprehensive framework that targeted multiple aspects of behaviour. This multidimensional approach not only increased knowledge but also influenced attitudes and behaviors toward bats, as suggested by the literature on complex interventions (Fitzgerald et al., 2017; Cole et al., 2019).

My awareness class provided essential foundational knowledge about bats, addressing misconceptions and fears. A single lesson may not be enough to change emotional or deeply ingrained beliefs, but it was crucial in sparking initial interest and curiosity in the learners. Knowledge-based interventions are important but can sometimes lack the emotional connection needed for behaviour change. Leaving posters at the schools thus served as a continuous reminder of the information learned. This visual reinforcement might have helped learners internalize the knowledge, making it more memorable. Posters also created an ongoing presence of the topic in their daily environment, keeping bats on their minds long after the class. The passive nature of posters still contributed significantly to keeping the message alive over time. The artwork competition was perhaps one of the most powerful tools because it encouraged learners to think creatively about bats and process what they had learned. This cognitive engagement likely led them to form a more personal relationship with the subject. Asking the learners to actively participate beyond just absorbing information made them reflect and internalize the knowledge, which could be key in shifting their feelings or perspectives about bats. The bat book set in QwaQwa made the message relatable and culturally relevant. Having the story in a familiar context allowed learners to connect with the material on a deeper level. They could see themselves in the narrative, which likely helped them feel more invested in the story and the importance of bat conservation. This emotional connection can be crucial for long-term attitudinal change. Lastly, my being present and visibly comfortable handling bats through bat box construction was a powerful, practical demonstration. Learners saw firsthand that bats posed no threat to me, which may have helped demystify and reduce fear of bats.

The limitation of the study was that a control group could not be sampled as the engagement efforts like posters and bat boxes were on display for all students to access and hence these would have served as biases for any student selected to be part of a control group in each school.

5.5 Conclusion

My study demonstrated the usefulness of educational intervention as a tool in changing negative perceptions of learners towards bats. The extent to which perceptions were changed differed amongst the survey categories. With a more practical approach, it is likely that my intervention would have yielded better success. For species such as bats, awareness programs targeted at both young and adult individuals are crucial to promote these misconceived and misunderstood species.

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Chapter 6

General Discussion and Recommendations

6.1 Introduction

My study succeeds as the very first ever study focusing on bats in the mountains of the Maloti-Drakensberg. Although some studies have shown the distribution ranges of most bat species in South Africa falling in the Maloti-Drakensberg, these studies at most only estimated the presence of these species in the region. The ecology of bats of the Maloti-Drakensberg remains poorly studied with the endemic bats being no exception. I present community structures of bats along an elevational and anthropogenic gradient. I also determine the diet *Laephotis capensis*, one of the most common species in the region. Lastly, I also ascertain the perceptions of young children towards bats and test whether environmental education can serve as an effective tool in eliminating any negative perceptions they might have towards bats. My study forms the baseline from which future research on bats can build on and can be used for reference in implementation of conservation efforts towards bats in the region.

6.2 Bat communities along an elevational gradient

The change in composition and structure of bat communities in the Maloti-Drakensberg remained unexplored prior to this study. This presented a challenge in predicting how climate change might affect bat species occurring in the Maloti-Drakensberg. With my study, I was able to uncover how species richness and activity of bats varied with elevation. I showed that the area consisted of eight bat species, and only four of those occurred at my highest sampled elevation of 3000m asl. As with other elevation studies in other areas, I showed highest activity at lower elevations compared to high elevations (Monadjem et al., 2024). This highlighted the varying niche preferences of bats with regards to elevations. From this finding, it is now possible to conclude on the high possibility of upward range shifts for at least four species whose distribution had only been limited to lower elevations below 3000m asl. Now that the distribution of species such as *R. acrotis* has been found to be confined at about 2000m asl, I can safely predict that such species will shift their range upwards with the prevailing climate change (LaVal, 2004; Urban, 2018). I therefore noted a risk of either local extinction for species that are occurring at the highest elevations due to being no more elevation to shift to, a phenomenon termed escalator to extinction (Urban, 2018).

An important component of my study was ascertaining which environmental variables affected the distribution and activity of the bats along the Maloti-Drakensberg elevation gradient. To precisely predict how climate change is likely to affect bat species, it was important to find out which climatic variables are influencing bat communities in the area. Through this study, I was able to determine that the community structure of bats along the elevational gradients was associated with isothermality, minimum temperature of coldest month and distance to rivers. Both isothermality and minimum temperature of coldest month are correlated (positively and negatively respectively) to temperature suggesting that temperature changes resulting from climate change are likely to alter the bat community structure in the Drakensberg. Since isothermality was positively correlated with species richness and minimum temperature of coldest month was positively correlated with bat activity, I concluded that the observed increase in temperatures in the region is likely to result in shifting of low elevation species to higher elevations although paramontane species distribution models predict that species in the Drakensberg are not likely to shift their ranges before the year 2070.

I was also able to capture two endemic bat species namely *Cistugo lesueuri* and *Rhinolophus cervenyi*. Through this study, I determined a broad distribution range of both species from the lowest sampled elevation to the highest. This broad distribution range highlights how both endemics are well adapted to this region, encompassing the Maloti-Drakensberg mountains up to 3000m above sea level. These species thus show vulnerability to climate change as climate change will alter the condition that these endemics are accustomed and adapted to. In contrast, *Rhinolophus acrotis*, occurred at lower elevations of up to 2000m above sea level. This suggests that this species still has about 1000m of elevation for upward range shifting due to climate change.

The findings of my study generally align with studies done in other regions of the globe. Research on elevational gradients and their impacts on biodiversity has been well-documented in the Global North (Cryan et al., 2000; McCain, 2006; Mena et al., 2011). These studies often report similar patterns to those observed in my study which is species richness and activity peak at lower elevations, tapering off at higher elevations due to harsher climatic conditions and resource scarcity. Such responses are not only evident in bats as other small mammals such as rodents and shrews have been widely studied in montane ecosystems. Similar to bats, these taxa show shifts in species composition and richness with elevation (McCain, 2005; Rowe et al., 2010).

Comparing my findings to these Northern studies reveals parallels in the ecological pressures driving bat distributions along elevational gradients. However, distinct differences exist, particularly in the biodiversity of African montane ecosystems. For example, the Maloti-Drakensberg hosts endemic species such as *Cistugo lesueuri* and *Rhinolophus cervenyi*, whose distributions and vulnerabilities to climate change are unique to the region. This underscores the need for localized conservation efforts tailored to the ecological nuances of Southern Hemisphere montane environments.

My findings emphasize the need for more research on bats and other taxa in montane regions across the Global South. Such research is essential for developing a comprehensive understanding of global biodiversity patterns and informing conservation strategies. For instance, the absence of *Laephotis cf. wintoni* in this study highlights the need to monitor elusive or rare species, as their absence could signal early impacts of climate change or habitat degradation. Expanding research efforts to include genetic, acoustic, and ecological modeling approaches would further enhance our ability to predict and mitigate biodiversity loss in these regions.

6.3 Bat communities along an anthropogenic gradient

Due to the high human disturbance in the Maloti-Drakenberg grassland, it was also necessary to determine how bat communities are affected by anthropogenic activities. No current studies have shown how bats communities are affected by human footprint in the area. My study provides the first ever insight into the state of bat species richness and activity from protected areas to partially protected and unprotected areas. I showed that species richness and activity was lowest in the unprotected area. Further investigation showed that bat species richness in this study was negatively influenced by human footprint. This highlights the negative impact that urbanization and human disturbance has on the local bat species (Loeb et al., 2009; Jung & Kalko, 2011; Russo & Ancillotto, 2015). I also found that distance to buildings was the common significant predictor of bat activity. The effect of distance to buildings differed with functional groups. Both open-air and clutter species had lower activity in areas that are near buildings whilst clutter-edge species had high activity near buildings. This showed how bat species and bat functional groups respond differently to certain environmental variables. I also determined that artificial light in the protected area was another significant predictor of bat activity. This suggests that the big spotlight on the protected area is influencing the activity of bats, especially that of clutter-edge species. I, however, did not measure light intensity in the study to find out how bat activity was influenced by light intensity but from my findings, I conclude on the importance of light in the determination of bat activity.

From this study, I noted that the increase in urbanization threatens the reduction in occurrence of the endemic species *Cistugo lesueuri* and *R. cervenyi.* Both endemics had the highest activity much further away from buildings, suggesting a negative interaction of these bats with human infrastructure. *Cistugo lesueuri* also occurred further away from roads highlighting the vulnerability of this species to human infrastructure. Furthermore, my failure to capture or record *Laephotis c.f. wintoni*, a previously recorded endemic bat in the area might (Monadjem et al., 2020) suggest that this endemic species has been eliminated on the part of the Drakensberg I sampled. I cannot not be certain on what caused the elimination; however, I suspect climate change or the increasing anthropogenic activities or even both. It might also be that more sampling effort is needed to capture it. The distribution of the two newly discovered rare *Rhinolophus* species suggests that their local extinction is highly likely if no actions are taken to mitigate the impact of current land use on these bats. The presence of rare species in the partially protected area indicates that the ecosystem remains largely intact. This then highlights the need to strengthen collaboration between the local community and the managers of the partially protected area to ensure its conservation. Due to urbanization and settlements invading most areas of QwaQwa, stakeholders should try ensuring the success and survival of the Witsieshoek Community Conservation Area and more awareness should be spread about its significance in saving rare and endemic species.

6.4 Bat diet

As the first step in ascertaining the diet of bats in the Maloti-Drakensberg, I investigated the diet of *Laephotis capensis.* This species was one of the species that was mostly recorded in the different land uses I sampled. No previous studies had determined what bats in the Free State are likely to be eating. The Free State Province in South Africa boasts as an agricultural province. The impact bats have on agriculture in this area remains to be determined. Determining the value of bats in agriculture begins through determining the diet of the local bats (Taylor et al., 2018; Weier et al., 2018). My study showed that Coleoptera was the most eaten insect order by these bats in the area whilst the orders Hemiptera, Diptera, Hymenoptera and Blattodea seemed to form supplementary food in the diet of *Laephotis capensis*. By comparing the percent volumes of insect orders found in the bat faecal pellets, I noted that diet seemed to be determined by land use, with a broader diet observed in protected areas compared to the other land uses. It is worth noting that my sample size was small for me to confidently come to this conclusion. However, my findings suggest that anthropogenic lands uses are so critical such that they determine the diversity of food items the bats fed from. This is an important finding especially in pushing for conservation of natural landscapes for bats and other taxa.

The findings of my study were also corroborated by findings other studies that I reviewed in this thesis (Robinson & Stebbings, 1993; Minnaar et al., 2015; Bailey et al., 2019; Moyo & Jacobs, 2020) with minor differences that might have been due to different bat species studied and varying environmental conditions of habitats that were sampled in the different studies. Seasonality and insect abundance might play a crucial role in determining the diet of *Laephotis capensis*. Despite showing the presence of lepidoptera insects in the area through light trapping, moths were not recorded in the faecal pellets of bats. I suggest molecular analysis of bat faecal pellets in determining whether lepidoptera are not consumed by this species in the area. Species such as the Maize borer or the African Bollworm affect the maize crops grown by subsistence and commercial farms in QwaQwa. Furthermore, species such as coddling moths might be harmful to apple trees whilst false coddling moths affect citrus, and these orchards are found about 50 kilometres from QwaQwa. The value of bats in the area can be proven if studies can show that these bats eat moths. My study was unable to show consumption of lepidoptera. The diet of bats remains largely unexplored, and I encourage diet studies of bats in the area to determine their value in the local agricultural areas. I recommend further studies to ascertain if the bats feed on insects of human importance either in health or agriculture.

6.5 Impact of educational intervention on people's perceptions towards bats.

Perceptions are important in determining how people treat and respond to animals. Despite the shown importance of bats, no studies in South Africa have ever determined how people perceive bats. I present the first ever insight into how people think about bats in Maloti-Drakensberg. After showing how climate and anthropogenic activities affect bats, it was crucial to find out how people view bats. It was also necessary to find out if environmental education can help in changing any negative attitudes people might have towards bats. The findings of this study showed that learners initially had higher negative perceptions towards bats before any intervention or environmental education. This could be attributed to a lack of knowledge and misinformation that learners had about bats before commencement of the study. I showed in the study how some students believed that bats were harmful and aggressive to humans whilst also not knowing positive ecosystem services that bats provide. Whilst this was the case, some students did not view bats in a bad light. I showed that students, even though they feared bats, they were eager to learn more about bats. After giving them a bat awareness class, most of the students changed their negative perceptions although a few did not. The results reveal that educational interventions can assist in reshaping perceptions and attitudes towards bats for young learners. The study showed that with proper education it is possible to undo negative stereotypes towards bats. The extent to how effective an intervention may be is also dependent on the type of intervention (Williams et al., 2021). I attribute the success of my study in changing perceptions of learners towards bats to that learners were able to see me conduct research on bats without falling victim to any of the negative myths, be it having my hair eaten or be subjected to ill omen as these were the prevailing local myths. This might have been why some of the learners changed their minds when it came to the myths from agreeing with the myths to disagreeing with them.

I also showed that gender and age had an impact on some perceptions of the learners. Through this study, I showed gender to have an impact on emotional perceptions of students towards bats. Females exhibited more negative perceptions of bats, consistent with my expectations and aligned with findings from another study, which indicated that females tend to be more fearful and indifferent towards most animals (Kellert & Berry, 1987; Prokop & Tunnicliffe, 2008). I also found that age had a significant impact on students' perceptions in the areas of scientistic and cognitive viewpoints. Older students were more enthusiastic to learn about bats; however, they were more cognitively negative towards them.

6.6 Synthesis

My study has shed some light on the complex interactions between bat community structures and the elevational and anthropogenic gradients of the Maloti-Drakensberg. Through this study, I revealed the vulnerability of the rare and endemic bat species to the environmental pressures of the Maloti-Drakensberg. Climate change and anthropogenic land uses will likely increase existing pressures on the Maloti-Drakensberg ecosystem (Mohamed & Mukwada, 2019; Mukwada, 2022; Taylor et al. 2024). Rising temperatures and altered rainfall patterns might affect species distributions (Jewitt et al., 2023; Taylor et al., 2024) whilst anthropogenic land uses might affect habitat suitability (McKinney, 2008). I saw that the rare bat species identified in this study demonstrated a clear preference for habitats with minimal human disturbance. Both the Witsieshoek Community Conservation Area and Golden Gate Highlands National Park were shown to serve as vital refuges for these species. This shows the broader need for habitat protection, rewilding, and restoration efforts in community-managed conservation areas and formally protected regions like Witsieshoek Community Conservation area and Golden Gate Highlands National Park respectively. Efforts such as rewilding and rangeland restoration initiatives in Witsieshoek could further enhance habitat quality, ensuring that these areas not only serve as strongholds for bats but also for other biodiversity dependent on these ecosystems. Such efforts require the community to be involved especially for rewilding and restoration. The success of these efforts will depend on how engaged the community is and how much value the community sees in these efforts. There is a clear need for the strengthening of collaborative management between local communities and conservation authorities. This need then exposes the shortcomings of ecological research which identifies the problems species are facing in the region but fails to identify social challenges that are critical to the conservation of these Maloti-Drakensberg species. The prevalence of only monodisciplinary studies in the Maloti-Drakensberg has been reported on (Delves et al., 2021). The multidisciplinary nature of my study attempts to address this by not only focusing on the environmental pressures from climate and anthropogenic change but from also finding out the views and perceptions that the community has towards wildlife. The positive results of the environmental education offered to the learners who represent the community emphasizes the need for addressing the social aspect in conservation. From my study, it can be inferred that bat conservation cannot occur in isolation. It requires the integration of ecological research with social, economic, and cultural dimensions. The involvement of the QwaQwa community, for instance, is critical to the success of conservation efforts in Witsieshoek. Transdisciplinary research helps to create conservation solutions that benefit both wildlife and local livelihoods, giving a sense of shared responsibility and stewardship.

Looking forward, future research should build on this study by refining our understanding of bat diets using molecular techniques. Due to financial constraints, my study could not properly investigate the diets of bats in the region, and it was limited to one outdated microscopic technique and only focused on one species. Further studies on bat responses to anthropogenic changes, such as light pollution will be vital. From my study, I was able to determine that light is another important variable that must be considered in future studies. The floodlight that is shone at Brandwag buttress every night at Golden Gate Highlands National Park resulted in exceptionally high bat activity. I assume that this is because the light attracts more insects which the bats then feed on (Barghini & Medeiros, 2012; Shimoda & Honda, 2013). This is evidence that human intervention or footprint can alter the behaviour of species in natural environments.

6.7 Conclusion

Through this study, I was able to show the bat community structures along an elevation and anthropogenic gradient along the Maloti-Drakensberg. I uncovered variables that influenced bat communities along both these gradients offering insight on how climate change and anthropogenic changes are likely to affect the rare and endemic bat species of the Maloti-Drakensberg. I further showed the value of the Witsieshoek Community Area and that of Golden Gate Highlands National Park as a protected area. The rare species of the region were found to make use of both areas thus showing a preference to areas with little human footprint.

Efforts should therefore be made to strengthen the collaboration of these protected area and the community of QwaQwa. I further recommend more diet studies especially those that will employ molecular techniques to determine what the bats of the area are eating. My study failed to show moths as diet of the *Laephotis capensis.* I acknowledge that this might be due to the weakness of the diet analysis method I employed. I also recommend environmental awareness classes to be employed in the area to inform people of the value of conservation of not only just bats but of the beautiful and special biodiversity of the Maloti-Drakensberg. I encourage future research to build up on the findings of my study and encourage more multidisciplinary type of studies in the Maloti-Drakensberg.

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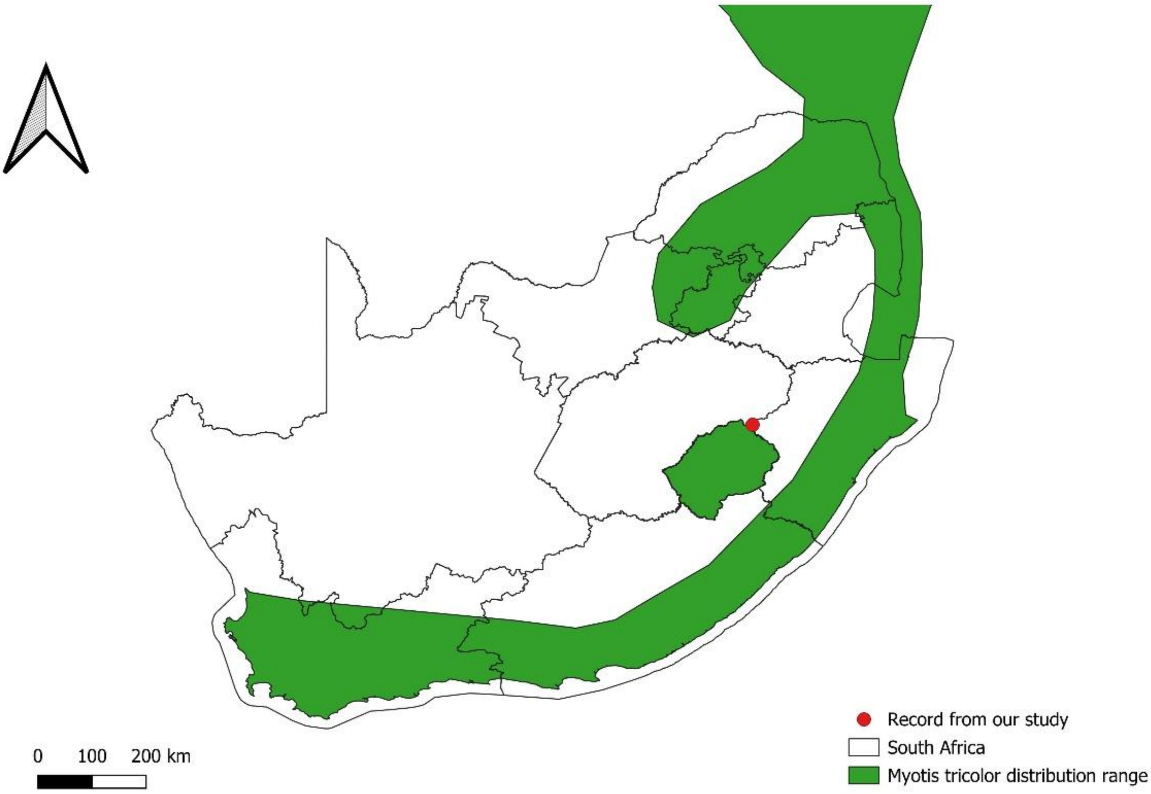
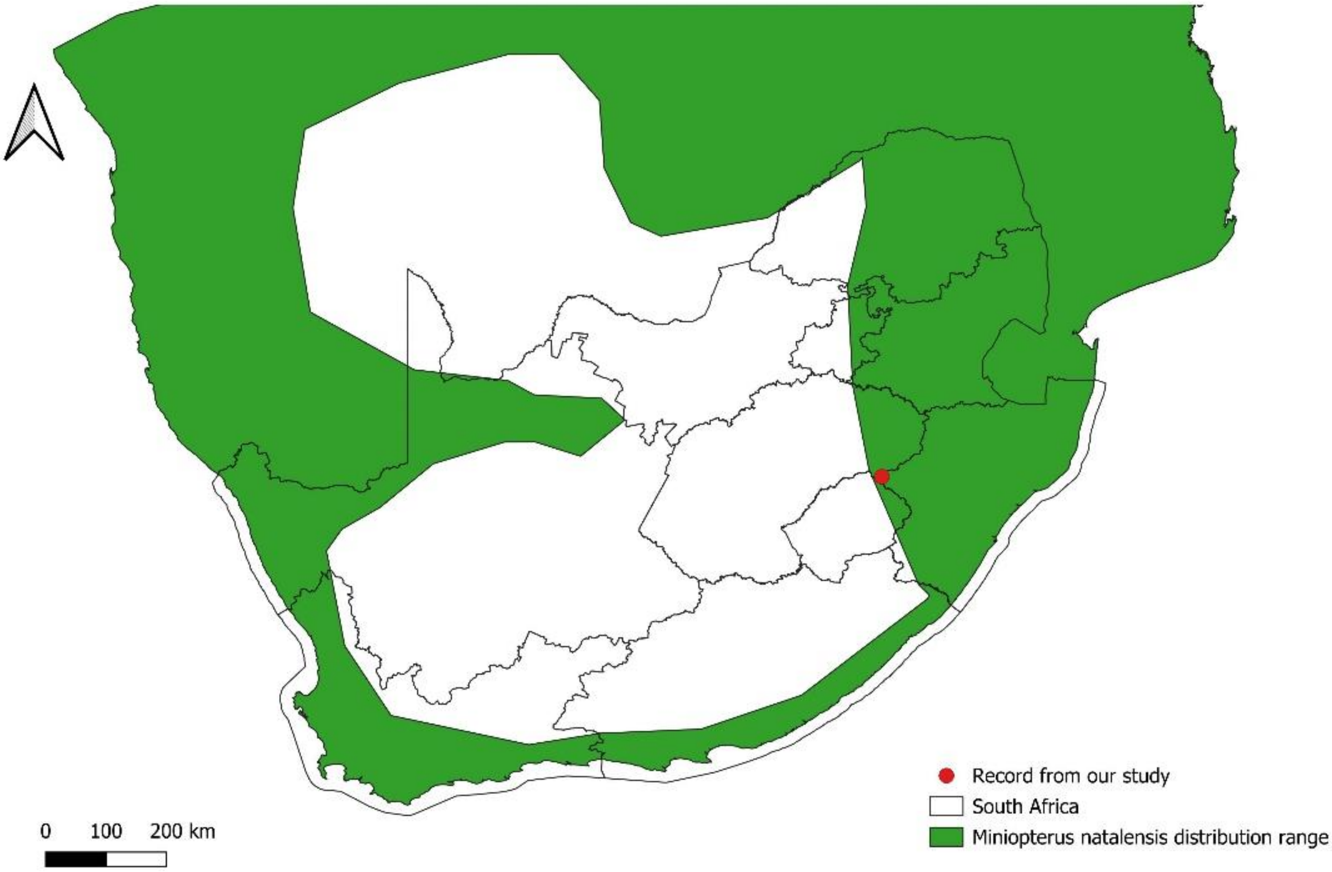
Appendices

Appendix 1. 1 Table showing the sampling areas, the sites they harboured, site elevations, and the corresponding climatic variables, including mean diurnal range, isothermality, and minimum temperature of the coldest month.

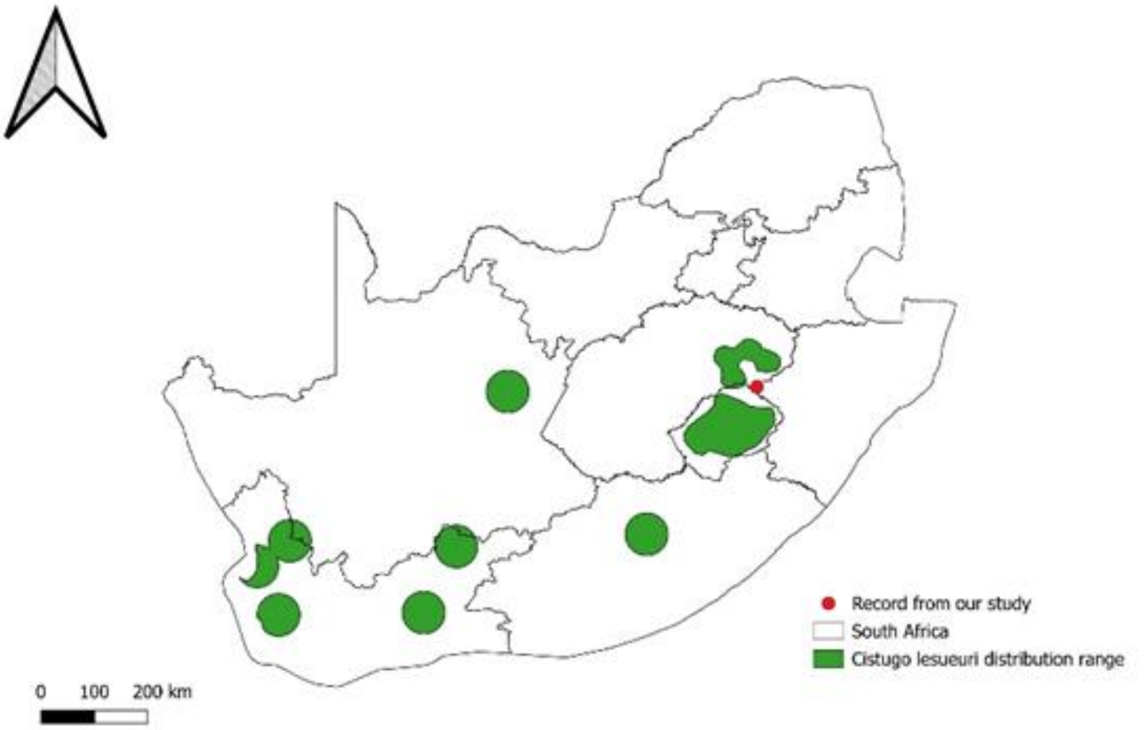
Sampling areas	Site	Elevation (m)	Longitude	Latitude	Mean diurnal range	Isothermality	Min temp of coldest month (℃)
Protected area	GL	1754	28.7189	-28.4773	14	56	0
Protected area	GL	1772	28.7229	-28.4751	14	56	0
Protected area	GML	1898	28.6109	-28.5032	14	56	-1
Protected area	GML	1947	28.6134	-28.5031	14	56	-1
Community conservation area	WL	2000	28.9019	-28.6771	12	56	-1
Protected area	GMH	2028	28.6138	-28.5027	14	56	-1
Community conservation area	WL	2030	28.9023	-28.6793	12	56	-1
Protected area	GMH	2074	28.6160	-28.4994	13	55	-2
Community conservation area	WML	2202	28.9011	-28.6864	12	56	0
Community conservation area	WML	2226	28.9011	-28.6864	12	56	0
Protected area	GH	2385	28.6229	-28.4942	13	54	-2
Protected area	GH	2402	28.6213	-28.4936	13	54	-2
Community conservation area	WMH	2561	28.8909	-28.7274	12	55	-3
Community conservation area	WMH	2567	28.8923	-28.7292	12	55	-2
Community conservation area	WH	2986	28.8815	-28.7510	11	53	-5
Community conservation area	WH	3008	28.8832	-28.7528	11	53	-5



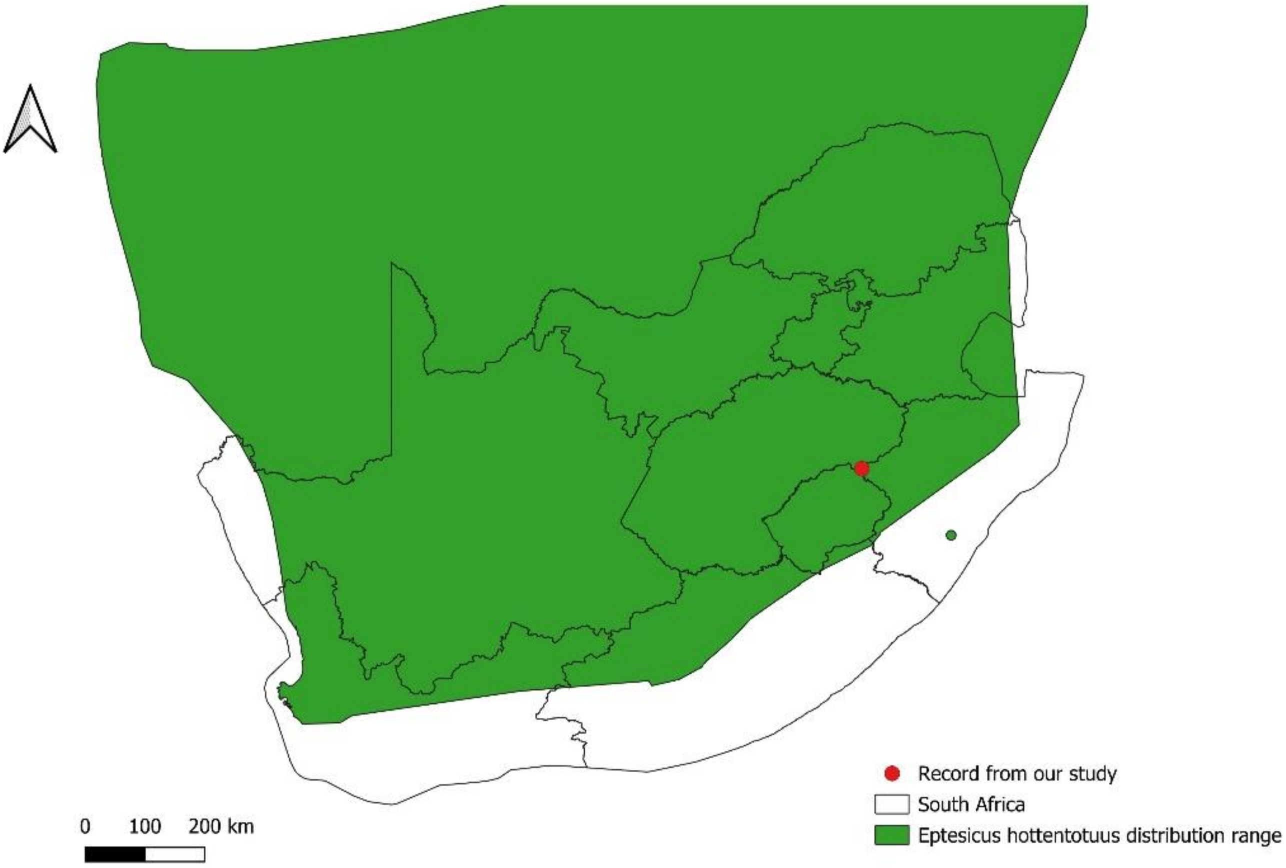
Appendix 1. 2: The distribution range of *Myotis tricolor* as per the 2016 IUCN Redlist assessment together with my acoustic record of the species.



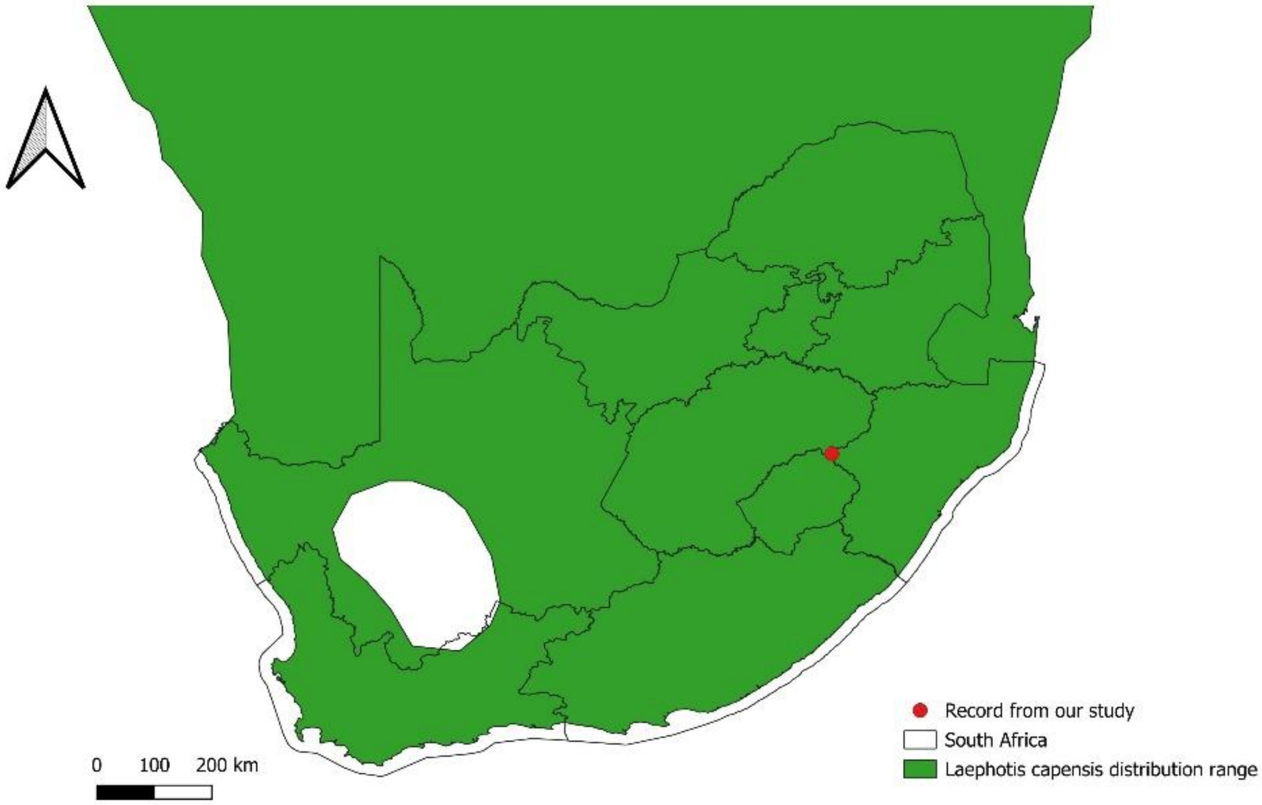
Appendix 1. 3: The distribution range of *Miniopterus natalensis* as per the 2016 IUCN Redlist assessment together with my acoustic record of the species.



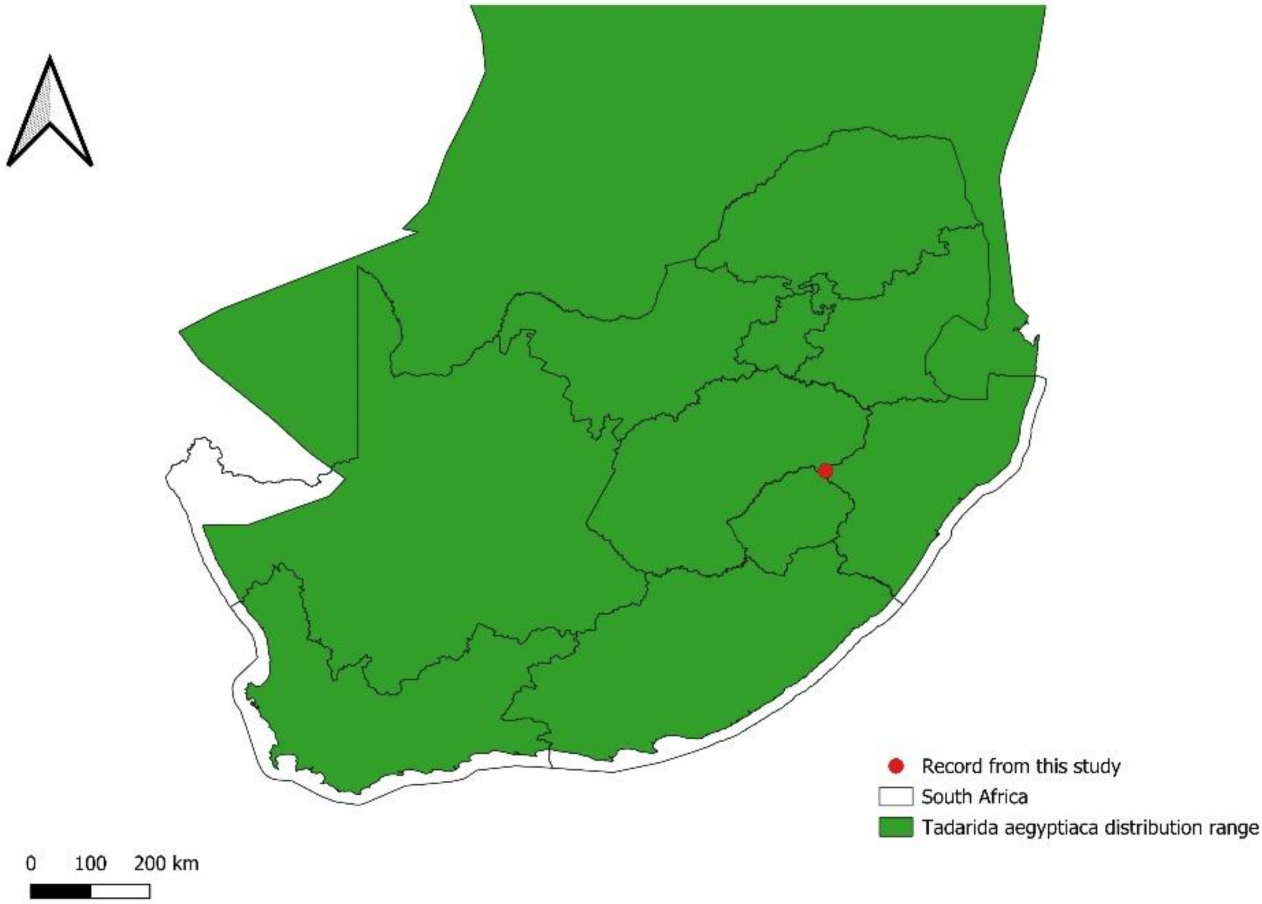
Appendix 1. 4: The distribution range of *Cistugo lesueuri* as per the 2016 IUCN Redlist assessment together with my acoustic record of the species.



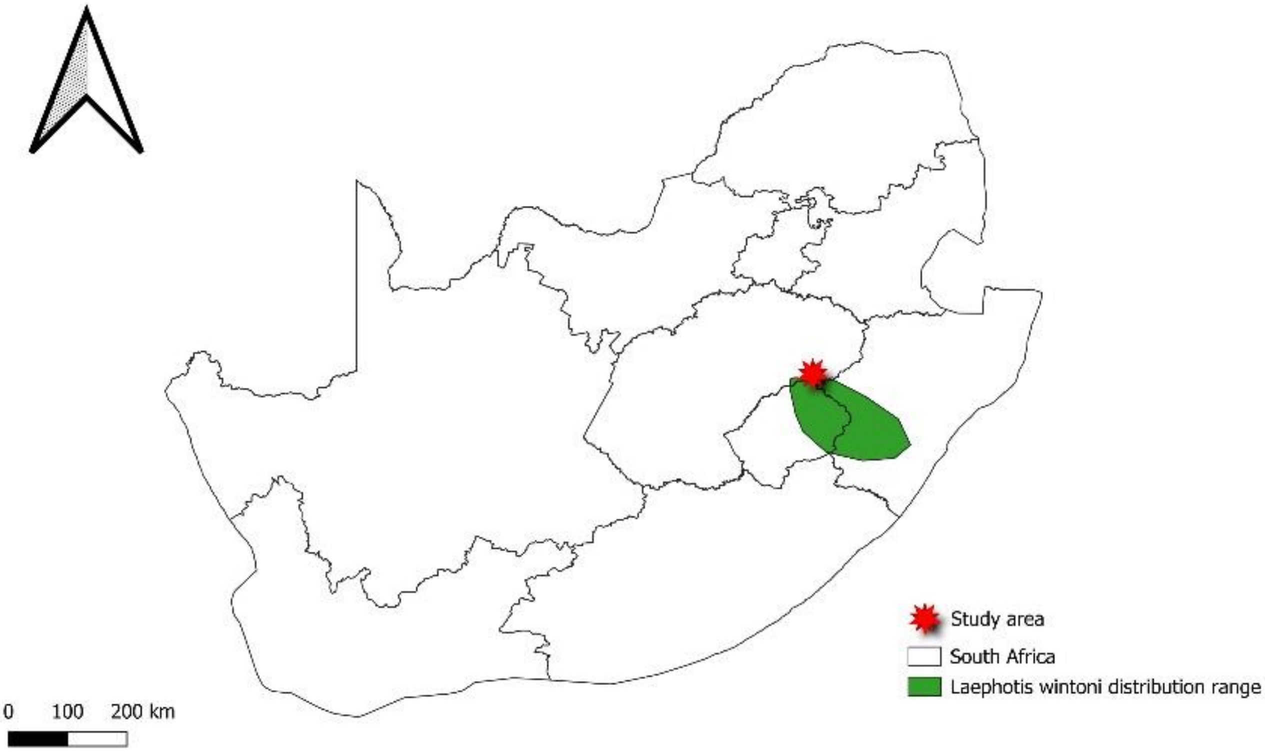
Appendix 1. 5: The distribution range of *Eptesicus hottentotus* as per the 2016 IUCN Redlist assessment together with my acoustic record of the species



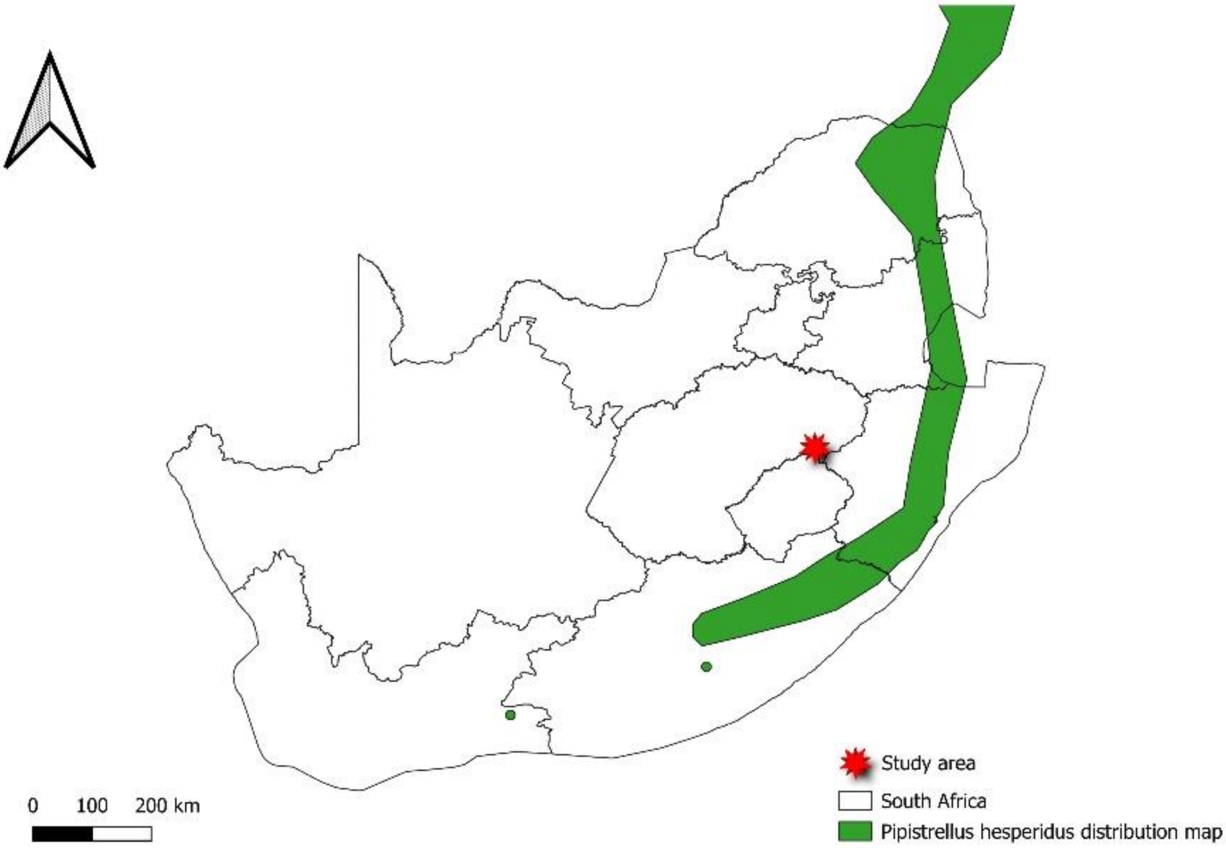
Appendix 1. 6: The distribution range of *Laephotis capensis* as per the 2016 IUCN Redlist assessment together with my acoustic record of the species



Appendix 1. 7: The distribution range of *Tadarida aegyptiaca* as per the 2016 IUCN Redlist assessment together with my acoustic record of the species.



Appendix 1. 8: The distribution range of *Laephotis wintoni* as per the 2016 IUCN Redlist assessment together with the location of my study area.



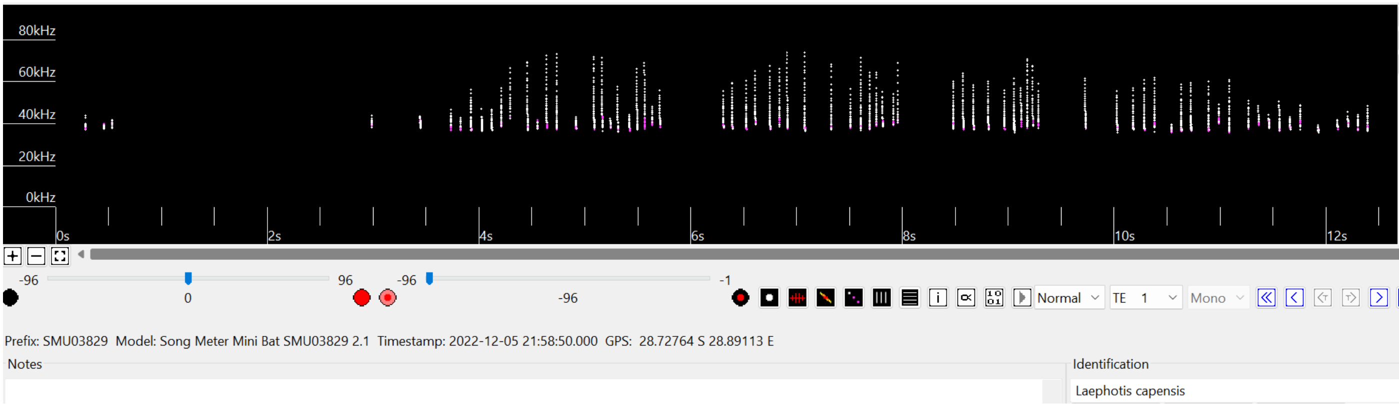
Appendix 1. 9: The distribution range of *Pipistrellus hesperidus* as per the 2016 IUCN Redlist assessment together with the location of my study area.

Appendix 1. 10: Table showing bat activity in the different sampled localities and whether they were described as outliers or not.

Site	Locality	Mean calls	Spotlight	Outlier
Community conservation area	Alpine summit_Far from water	69	Absent	No
Community conservation area	Alpine_summit_Near_water	54	Absent	No
Protected area	BCV_Far from water	257	Absent	No
Protected area	BCV_Near water	240	Absent	No
Protected area	Buttress Far from water (On top of Brandwag)	2972	Present	Yes
Protected area	Buttress_Near water	85	Absent	No
Community conservation area	Chalet 4	819	Absent	No
Community conservation area	Chalet Pine trees/Backpacker trees	171	Absent	No
Protected area	River_Far from water (Below Brandwag)	4231	Present	Yes
Protected area	River_Near water	110	Absent	No
Community conservation area	Sentinel car park_grass	495	Absent	No
Community conservation area	Sentinel car park_roof	188	Absent	No
Community conservation area	Witsieshoek dam_Far from water	46	Absent	No
Community conservation area	Witsieshoek dam_near water	635	Absent	Yes (Inconsistent *Myotis spp* presence)
Protected area	Woodhouse_Far from water	346	Absent	No
Protected area	Woodhouse_Near water	560	Absent	No

Appendix 1. 11: Table showing the number of species that were captured using live capture sampling in the three sampling areas and in Schaaplaats, a farm just outside Golden Gate Highlands National Park.

Sampling area	Genus	Species	Number of individuals
Golden Gate Highlands National Park	*Episticus*	*hottentottus*	1
Golden Gate Highlands National Park	*Laephotis*	*capensis*	18
Golden Gate Highlands National Park	*Tadarida*	*aegyptiaca*	13
Phuthaditjhaba	*Laephotis*	*capensis*	6
Witsieshoek Lodge	*Laephotis*	*capensis*	1
Witsieshoek Lodge	*Miniopterus*	*natalensis*	6
Schaaplaats Farm	*Cistugo*	*lesueuri*	2
Schaaplaats Farm	*Rhinolophus*	*acrotis*	1
Schaaplaats Farm	*Rhinolophus*	*cervenyi*	2



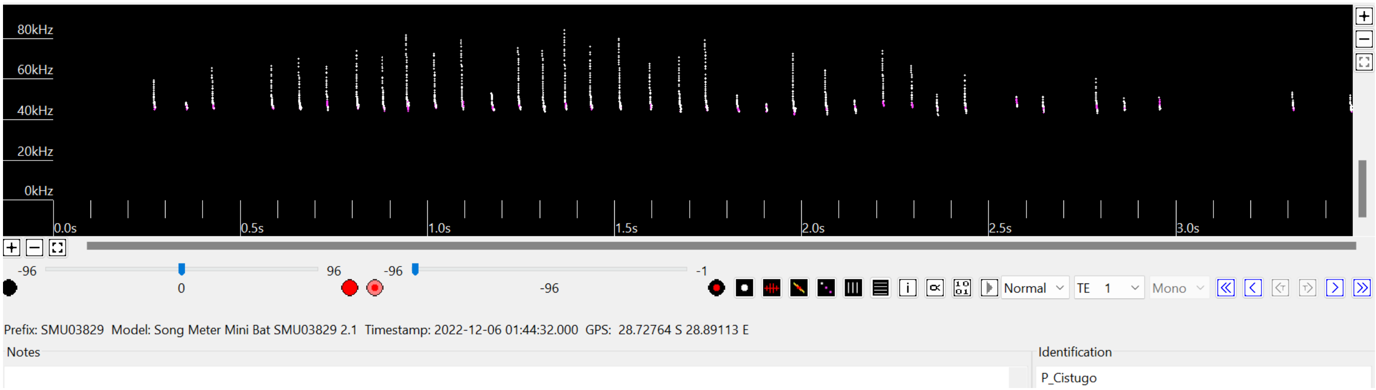
Prefix: SMU03829 Model: Song Meter Mini Bat SMU03829 2.1 Timestamp: 2022-12-05 21:58:50.000 GPS: 28.72764 S 28.89113 E

Notes

Identification

Laephotis capensis

Appendix 2. 1: Figure showing spectrograms for *Laephotis capensis*



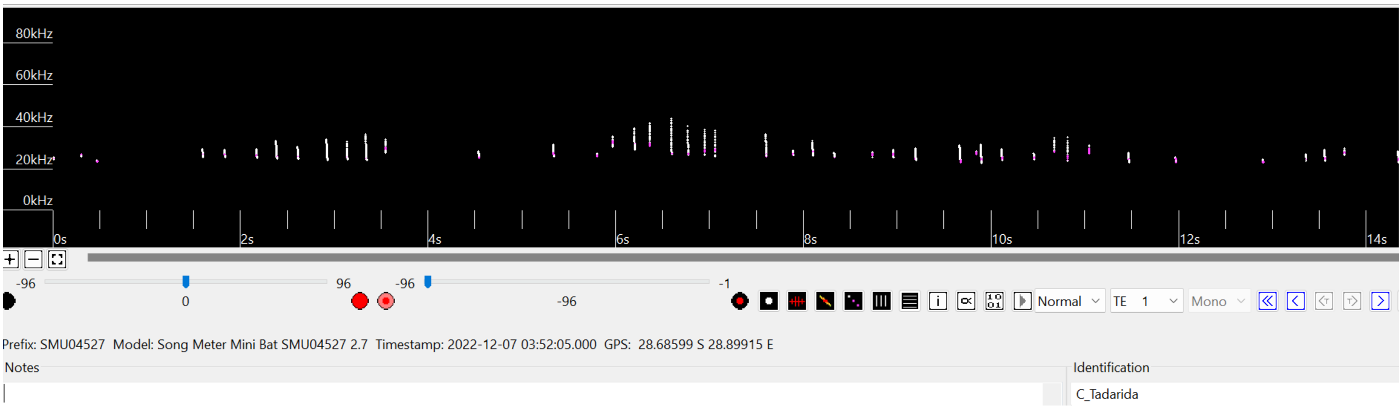
Prefix: SMU03829 Model: Song Meter Mini Bat SMU03829 2.1 Timestamp: 2022-12-06 01:44:32.000 GPS: 28.72764 S 28.89113 E

Notes

Identification

P_Cistugo

Appendix 2. 2: Figure showing spectrograms for Cistugo_Pip



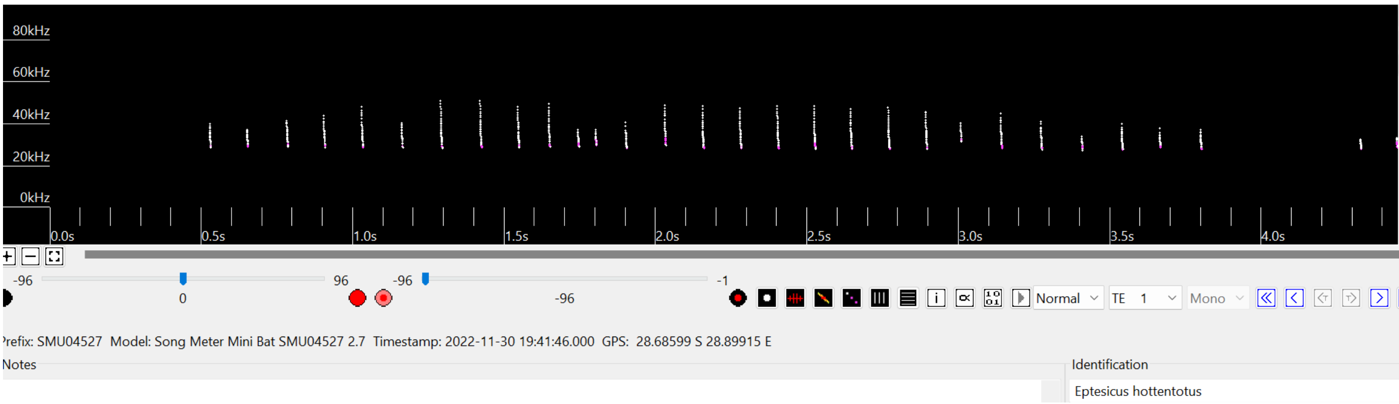
Prefix: SMU04527 Model: Song Meter Mini Bat SMU04527 2.7 Timestamp: 2022-12-07 03:52:05.000 GPS: 28.68599 S 28.89915 E

Notes

Identification

C_Tadarida

Appendix 2. 3: Figure showing spectrograms for Molossid species



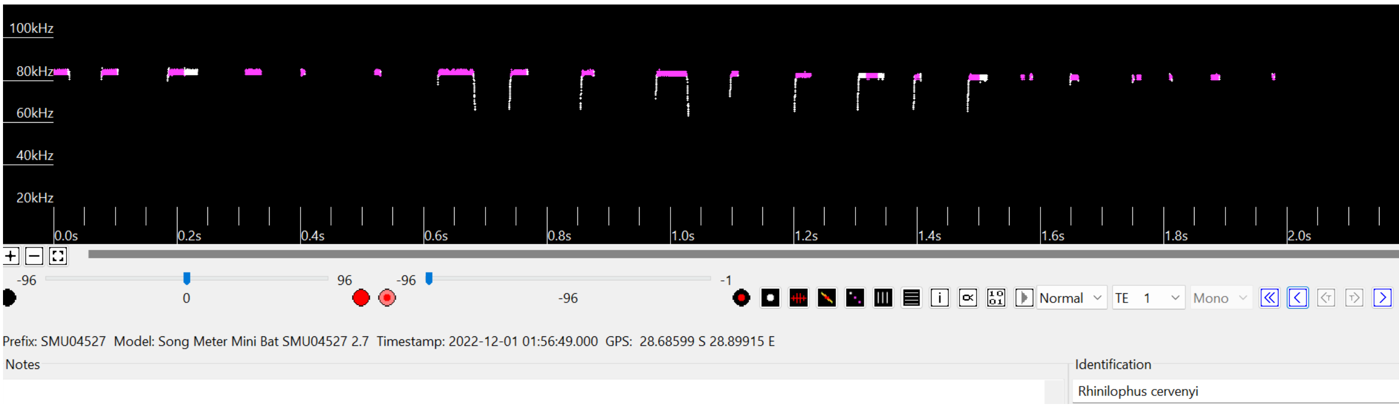
refix: SMU04527 Model: Song Meter Mini Bat SMU04527 2.7 Timestamp: 2022-11-30 19:41:46.000 GPS: 28.68599 S 28.89915 E

Notes

Identification

Eptesicus hottentotus

Appendix 2. 4 Figure showing spectrograms for *Eptesicus hottentotus*



Prefix: SMU04527 Model: Song Meter Mini Bat SMU04527 2.7 Timestamp: 2022-12-01 01:56:49.000 GPS: 28.68599 S 28.89915 E

Notes

Identification

Rhinilophus cervenyi

Appendix 2. 5: Figure showing spectrograms for *Rhinolophus cervenyi*

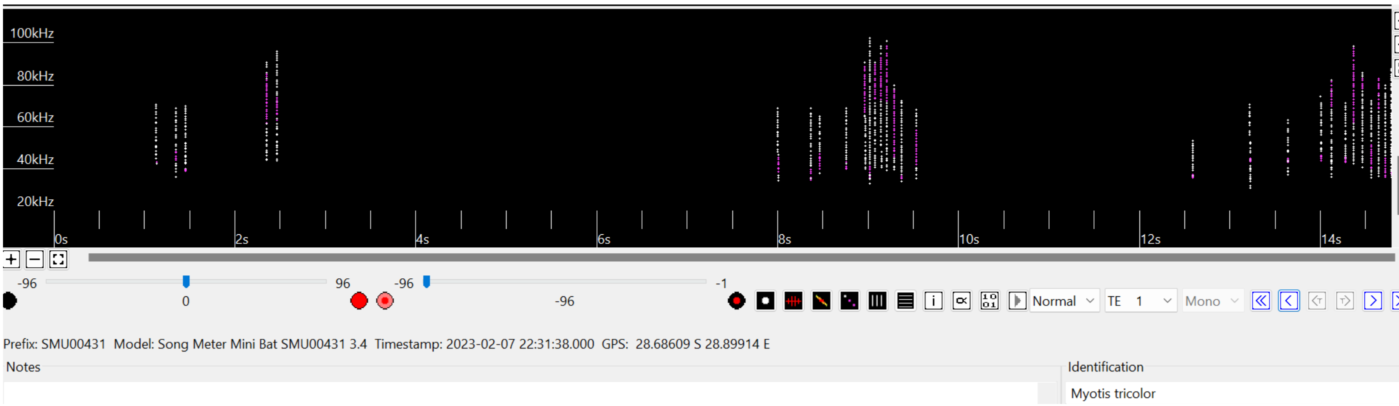
Prefix: SMU04527 Model: Song Meter Mini Bat SMU04527 2.7 Timestamp: 2022-12-02 00:49:43.000 GPS: 28.68599 S 28.89915 E

Notes

Identification

Rhinolophus acrotis

Appendix 2. 6: Figure showing spectrogram for *Rhinolophus acrotis*



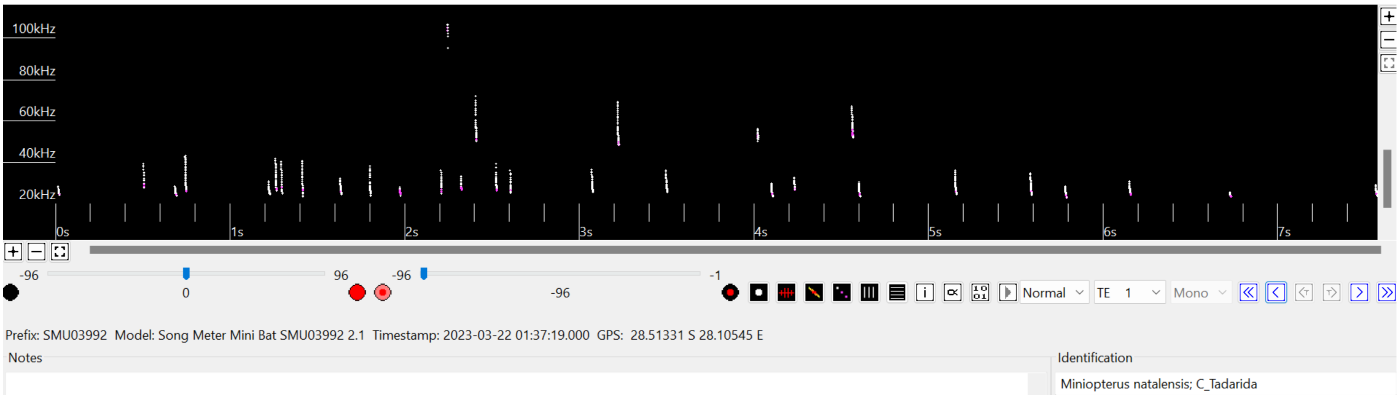
Prefix: SMU00431 Model: Song Meter Mini Bat SMU00431 3.4 Timestamp: 2023-02-07 22:31:38.000 GPS: 28.68609 S 28.89914 E

Notes

Identification

Myotis tricolor

Appendix 2. 7: Figure showing spectrograms for *Myotis tricolor*



Prefix: SMU03992 Model: Song Meter Mini Bat SMU03992 2.1 Timestamp: 2023-03-22 01:37:19.000 GPS: 28.51331 S 28.10545 E

Notes

Identification

Miniopterus natalensis; C_Tadarida

Appendix 2. 8: Figure showing spectrograms for *Miniopterus natalensis* and Molossid species

Appendix 2. 9: Table showing the different environmental variables and landcover class names of sampled points in the different sampling areas.

Site	Elevation (m)	River (m)	Roads (m)	Buildings (m)	Hfootprint	Landcover Class name
Golden Gate	1772	651	220	7514	923	Fallow Land & Old Fields (Grass)
Golden Gate	1754	370	321	7706	1114	Herbaceous wetlands
Witsieshoek	2226	4112	18676	4564	800	Natural grassland
Witsieshoek	2202	4109	18677	4560	800	Natural grassland
Phuthaditjhaba	1711	2231	5029	0	3700	Residential Formal (low veg / grass)
Phuthaditjhaba	1706	2182	5190	0	4075	Herbaceous wetlands
Golden Gate	1947	72	179	14729	2573	Natural grassland
Golden Gate	1898	39	204	14940	2800	Natural grassland
Phuthaditjhaba	1708	1860	4701	0	3100	Natural grassland
Phuthaditjhaba	1706	1722	4786	0	3888	Natural grassland
Witsieshoek	2030	4224	18128	3885	352	Natural grassland
Witsieshoek	2000	4195	18034	3666	352	Natural grassland

Appendix 3. 1: Table showing the call parameters for the eight species recorded in my study which are the Fk for Fknee, Fmean, the duration, the Fmax for F maximum and N for the number of calls.

Species	Fk (kHz)	Fmean (kHz)	Duration (ms)	Fmax (kHz)	N
Laephotis capensis	39.240	41.954	4.431	56.539	74
Cistugo_Pip	46.702	49.087	4.870	64.737	36
Eptesicus hottentotus	29.818	32.889	4.570	43.147	30
Molossid	26.940	27.858	5.867	31.650	44
Rhinolophus cervenyi	82.578	82.445	20.956	84.175	23
Rhinolophus acrotis	91.213	90.522	25.859	92.566	15
Myotis tricolor	60.029	54.888	2.811	79.333	29
Miniopterus natalensis	48.257	48.598	5.811	49.623	14

Appendix 4. 1: Table showing the number of insect orders captured from light trapping conducted in October and August in Golden Gate Highlands National Park and Phuthaditjhaba.

Insect order	Golden gate	Phuthaditjhaba	Month/Year
Lepidoptera	28	18	Aug-22
Diptera	19	12	Aug-22
Coleoptera	9	3	Aug-22
Hemiptera	6	0	Aug-22
Hymenoptera	7	1	Aug-22
Second sampling			
Lepidoptera	35	44	Oct-22
Diptera	81	21	Oct-22
Coleoptera	11	8	Oct-22
Hemiptera	21	3	Oct-22
Hymenoptera	2	0	Oct-22
Mantid	3	0	Oct-22

Appendix 5. 1**:** The different categories and the statements that the standardized questionnaire comprised of.

Scientistic
1 I would like to learn more about bats
2 Knowing about the activity of bats is important for me
3 I would like to take part in a trip or a congress, or other activity, to
learn about bats.
4 It would be interesting to take part in a scientific activity about bats
5 I would like to exchange knowledge about bats with other people
6 It would be interesting to be able to teach others about bats
7 I would like to read a scientific article or see a documentary
about bats
Positivistic
8 Bats are important for the functioning of our ecosystem
9 Humans should protect bats
10 Spaces should be set aside for bat conservation in farmland
11 Humans must learn to coexist with bats
12 Bat excrement is a source of good fertiliser for farming
13 Bats help in the biological control of pests
14 Bats help food security
15 Some species of bat help to disperse tree seeds
16 The activity of bats gives added value to crops in the market
Emotional Negativistic
17 Bats are ugly
18 Bats are dangerous for humans
19 I am afraid of bats
Behavioural Negativistic
20 Bats should be exterminated
21 We should attack bats
22 Bat refuges should be eliminated to prevent them from breeding (block up caves, cut down trees, etc.)
23 We should stop bats from reproducing
Cognitive Negativistic
24 Bats' activity contaminates crops
25 Bats attract other species of rodents
26 Bats can be dangerous for domestic animals
27 Bats contaminate water resources
28 Bats damage machinery/buildings
29 Bats harm agriculture
30 Bats are aggressive
Myths
31 The bat is a symbol of ill omen
32 When you see a bat, it is a sign that someone wants to harm you
33 Bats become vampires
34 Bats should be burnt to prevent witchcraft
35 Do you think bats are responsible for the current COVID-19 pandemic?

Appendix 5. 2: The standardized questionnaire that was used in the study.

Design and Psychometric Properties of the BAtSS: A New Tool to Assess Attitudes towards Bats - Perez et al. 2021

Bat Education and Citizen Science Project

Coordinator: Veli Monday Mdluli

Name of School:…..

Age of participant: ………………………………… Gender of participant:……………

Questionnaire questions to be translated if necessary and answered on a scale of 1 to 5

Scientistic	**1 – strongly disagree**	**2 – disagree**	**3 - neutral**	**4 - agree**	**5 – strongly agree**
1 I would like to learn more about bats					
2 Knowing about the activity of bats is important for me					
3 I would like to take part in a trip or a congress, or other activity, to learn about bats.					
4 It would be interesting to take part in a scientific activity about bats					
5 I would like to exchange knowledge about bats with other people					
6 It would be interesting to be able to teach others about bats					
7 I would like to read a scientific article or see a documentary about bats					

Positivistic	**1 – strongly disagree**	**2 – disagree**	**3 - neutral**	**4 - agree**	**5 – strongly agree**
8 Bats are important for the functioning of our ecosystem					
9 Humans should protect bats					
10 Spaces should be set aside for bat conservation in farmland					
11 Humans must learn to coexist with bats					
12 Bat excrement is a source of good fertiliser for farming					
13 Bats help in the biological control of pests					
14 Bats help food security					
15 Some species of bat help to disperse tree seeds					
16 The activity of bats gives added value to crops in the market					

Emotional Negativistic	**1 – strongly disagree**	**2 - disagree**	**3 - neutral**	**4 - agree**	**5 – strongly agree**
17 Bats are ugly					
18 Bats are dangerous for humans					
19 I am afraid of bats					

Behavioral Negativistic	**1 – strongly disagree**	**2 - disagree**	**3 - neutral**	**4 - agree**	**5 – strongly agree**
20 Bats should be exterminated					
21 We should attack bats					

22 Bat refuges should be eliminated to prevent them from breeding (block up caves, cut down trees, etc.)					
23 We should stop bats from reproducing					

Cognitive Negativistic	**1 – strongly disagree**	**2 - disagree**	**3 - neutral**	**4 - agree**	**5 – strongly agree**
24 Bats’ activity contaminates crops					
25 Bats attract other species of rodents					
26 Bats can be dangerous for domestic animals					
27 Bats contaminate water resources					
28 Bats damage machinery/buildings					
29 Bats harm agriculture					
30 Bats are aggressive					

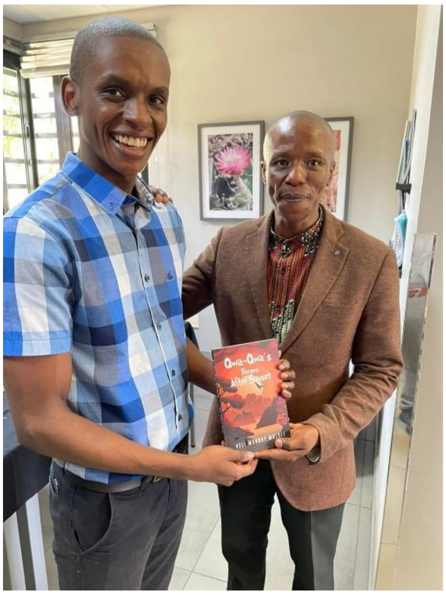
Myths	**1 – strongly disagree**	**2 - disagree**	**3 - neutral**	**4 - agree**	**5 – strongly agree**
31 The bat is a symbol of ill omen					
32 When you see a bat, it is a sign that someone wants to harm you					
33 Bats become vampires					
34 Bats should be burnt to prevent witchcraft					
35 Do you think bats are responsible for the current COVID-19 pandemic?					

Appendix 5. 3: Details of the children's book used in the study

Title: **QwaQwa's Heroes After Sunset**

ISBN: 978-1-7764559-6-6

Summary
After getting lost on top of the QwaQwa Mountain, a ten-year-old boy becomes friends with a bat that helps him navigate his way down the mountain and back home. The boy grows passionate about bats and their conservation. With the help of his science teacher, he starts giving awareness talks at his school, but this is met by heavy backlash from some of the community elders who believe that bats are a symbol of ill omen which results in the boy and teacher almost getting suspended for showing a live bat to students. It takes a great courageous effort by the bats and the Chief of QwaQwa to finally convince everyone that the bats are important for the well-being of both the community and ecosystem.



Picture of Veli Mdluli and the Chief in QwaQwa holding the children's bat book

Book Reviews

Please see the reviewers below from several people who provided helpful advice:

"I've just finished reading Mondays book and it is a real tear jerker. Such a beautiful story so imaginatively written and will be a fascinating read for any child, never mind a wonderful learning experience. The whole story is so vivid, with details and descriptions to capture the imagination of any child. Congratulations to Monday! You do need the right beautiful illustrations to complete this book which will be one for young people to treasure forever!"

- Ms Felicity Keats of Umsinzi Publishers

"This is a story of fiction based on real scientific facts to try change the minds of children regarding the negative perceptions that many South African have of bats.
The book is a great mix of fantasy and educational for both young and old with easy-to-relate-to characters as I appreciate the use of the local South African names, setting and location. I hope the relevant location of being set in Qwaqwa will be relatable to the students and even

more so when translated into multiple languages. I think the pace is fast enough to illustrate the themes of growing up, helping your community and that anyone can make a difference to protect our heritage. With the addition of illustrations from the scholars in Qwaqwa, I have no doubt this will be a great book for environmental education in South Africa.
Well done Mr Mdluli!"

- Alexandra Howard of the Mountain Bat Lab at UFS (PhD student)

"The story addresses most of the beliefs that our local people have about bats. It is a great book to teach young children and even adults about how much valuable bats are in the environment. I like that the story has been localized to Qwaqwa as it makes it easier for the reader to relate to the characters. The way the story has been written is also easy to follow and great job on having a seSotho version of this story. As a teacher, I too have learned things about bats which I did not know and hence I believe that this book is very valuable in changing the ways that people see bats and how they think of them. I wish that more work like this can be done in our region to empower our young people to take better care of all animals and the environment. "

- Tsietsi Ntlangoe, Teacher at Mamello Primary School