

Forest mammalian community dynamics and human-wildlife interactions in the Southern Mistbelt Forests of KwaZulu-Natal and Eastern Cape, South Africa

Mbalenhle Thabile Sosibo

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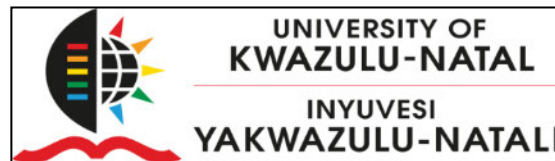
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ABSTRACT

African and Asian forests are well known for their high faunal and floral diversity; however, many forests have been left degraded or cleared because of anthropogenic activities from the past and present. In particular, African forests have been heavily exploited for their timber resources and land conversion for anthropogenic activities such as agriculture,. South African forests, specifically the Southern Mistbelt Forests, have been subjected to heavy logging by colonial settlers and subsistence harvesting in recent times because of the logging of trees such as yellowwood species (*Podocarpus* and *Afrocarpus* spp.) and hunting of bushmeat species blue duiker (*Philantomba monticola*). The aim of the study was to assess the anthropogenic impacts on mammals occurring in the Southern Mistbelt forests of KwaZulu-Natal and Eastern Cape provinces, as well as other uses of the forest and human-wildlife interactions.

Study areas included the disjunct Southern Mistbelt Forests of the northern Eastern Cape and southern KwaZulu-Natal provinces, South Africa. It was conducted in three different forest cluster areas: uMthatha, Glengarry/Weza [termed iNgeli hereafter] and Creighton with forest patches of varying size. We conducted camera-trap surveys between May 2018 – February 2019 during the wet (summer/spring) and dry (winter/autumn) seasons, resulting in one full 21-day survey for each camera-trap location per season. We used infrared motion detection camera-traps to monitor mammalian forest species at set camera-trap locations determined using a 400 m x 400 m systematic grid system overlaid onto Southern Mistbelt Forest patches in Arc GIS v10.5.1. We also conducted semi-structured interviews in all three areas from October to November 2019.

When assessing microhabitat use by mammalian species, we found that mammalian species most often photographed during sampling seasons were bushbuck (*Tragelaphus scriptus*)

and samango monkey (*Cercopithecus albogularis labiatus*), with the least photographed species being serval (*Leptailurus serval*) and African wild cat (*Felis silvestris cafra*). Land-use data around each forest patch were extracted, with settlements, exotic timber plantations and grasslands identified as the dominant adjacent land-uses. The importance of exotic tree plantations surrounding indigenous forest patches to the persistence of mammalian species was highlighted. The maturity and condition of exotic timber plantations surrounding forest patches in our study also varied and may have influenced the area's use and suitability by mammalian species. Creighton was the only study area where human settlements were a dominant land-use around patches. The samango monkey had the second highest mean occupancy across all sampling areas and land-use types. Forest mammals make considerable contributions to the functioning of forest ecosystems.

We evaluated the response of forest mammal functional diversity and species richness to factors such as patch size. Species β -diversity was greatly driven by turnover and functional β -diversity was driven by nestedness; therefore, management implications of these forests and associated mammalian communities suggest that all patches should be considered a priority for conservation. Due to different management implications, if nestedness is dominant, forest patches that have a higher diversity of species traits and species richness should be prioritised for conservation.

Lastly, we aimed to quantify and assess the dynamics of forest use and hunting of mammalian species in communities close to forest patches and found that ungulates are the preferred choice for consumption in lower-income settlements which is supported by many other studies. Different species were hunted for various reasons such as: consumption, monetary gain (bushmeat trade and selling of hides) as well as retaliatory killing of predators hunting livestock.

However, respondents shared that the forests are important to them and to protect them guards would be a good choice as well as education and awareness about sustainable use. There is a paucity of information about the overall mammal community inhabiting these forests and this study has highlighted which species inhabit these forests as well as their forest utilisation and how anthropogenic activities affect species populations. Furthermore, it highlighted that communities close to these forests see these forests as areas of high conservation importance.

PREFACE

The data described in this thesis were collected in the Southern Mistbelt Forests of northern Eastern Cape and southern KwaZulu-Natal, the Republic of South Africa, from May-August 2018 and October 2018 – February 2019. Experimental work was carried out while registered at the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Prof Colleen T. Downs, Dr David A. Ehlers Smith and Dr Yvette C. Ehlers Smith.

This thesis, submitted for the degree of Doctorate of Philosophy in Science in the College of Agriculture, Engineering and Science, University of KwaZulu-Natal, School of Life Sciences, Pietermaritzburg campus, represents original work by the author and has not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others, it is duly acknowledged in the text.



.....
Mbalenhle Thabile Sosibo

September 2021

I certify that the above statement is correct, and as the candidate's principal supervisor, I have approved this thesis for submission.



.....
Professor Colleen T. Downs

Supervisor

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DECLARATION 1 - PLAGIARISM

I, Mbalenhle Thabile Sosibo, declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.
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3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.
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DECLARATION 2 - PUBLICATIONS

DETAILS OF CONTRIBUTION TO PUBLICATIONS that form part and/or include research presented in this thesis.

Publication 1- in prep.

MT Sosibo, CT Downs, DA Ehlers Smith, YC Ehlers Smith, ST Gumede, SP Ngcobo

How does microhabitat structure influence large and medium-sized mammalian species communities in Southern Mistbelt Forest patches of South Africa?

Author contributions:

MTS conceived paper with DES, YES and CTD. CTD sourced funding. MTS, STG and SPN collected the data. MTS analysed the data and wrote the draft paper. CTD, DES and YES contributed valuable comments to the manuscript.

Publication 2- provisionally accepted

MT Sosibo, CT Downs, DA Ehlers Smith, YC Ehlers Smith, ST Gumede, SP Ngcobo

Mammalian assemblages in Southern Mistbelt Forests of the northern Eastern Cape, and southern KwaZulu-Natal Provinces, South Africa, and their response to bordering land-use

Author contributions:

MTS conceived paper with DES, YES and CTD. CTD sourced funding. MTS, STG and SPN collected the data. MTS analysed the data and wrote the draft paper. CTD, DES and YES contributed valuable comments to the manuscript.

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MT Sosibo, CT Downs, DA Ehlers Smith, YC Ehlers Smith, ST Gumede, SP Ngcobo

Testing the response of mammalian species richness and functional diversity to forest patch size and isolation in Southern Mistbelt Forests of South Africa

Author contributions:

MTS conceived paper with DES, YES and CTD. CTD sourced funding. MTS, STG and SPN collected the data. MTS analysed the data and wrote the draft paper. CTD, DES and YES contributed valuable comments to the manuscript.

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MT Sosibo, CT Downs, DA Ehlers Smith, YC Ehlers Smith

The use and value of Southern Mistbelt Forests to surrounding rural communities in northern Eastern Cape, and southern KwaZulu-Natal, South Africa

Author contributions:

MTS conceived paper with DES, YES and CTD. CTD sourced funding. MTS collected and analysed data and wrote the draft paper. CTD, DES and YES contributed valuable comments to the manuscript.



Signed:

Mbalenhle Thabile Sosibo

September 2021

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“The Lord himself goes before you and will be with you; he will never leave you nor forsake you. Do not be afraid; do not be discouraged”

Deuteronomy 31:8



Mbalenhle T. Sosibo and examples of camera trap data from Southern Mistbelt Forests in the northern Eastern Cape and southern KwaZulu-Natal, South Africa, in the present study.

TABLE OF CONTENTS

ABSTRACT	i
PREFACE	iv
DECLARATION 1 - PLAGIARISM	v
DECLARATION 2 - PUBLICATIONS	vi
ACKNOWLEDGEMENTS	viii
TABLE OF CONTENTS	x
LIST OF FIGURES	xii
LIST OF TABLES	xiv
CHAPTER 1	1
INTRODUCTION	1
1.1 The forest biome.....	1
1.2 Threats to forests	3
1.3 Forest use and human-wildlife interactions	7
1.4 Occupancy modelling and camera trapping	8
1.5 Forest mammal functional diversity.....	10
1.6 Problem statement and significance of the study	11
1.7 Aims and objectives	12
1.8 Study outline	13
1.9 References	13
CHAPTER 2	20
How does microhabitat structure influence large and medium-sized mammalian species communities in Southern Mistbelt Forest patches of South Africa?	20
2.1 Abstract	21
2.2 Introduction	22
2.3 Methods.....	23
2.4 Results	28
2.5 Discussion	35
2.6 Acknowledgements	38
2.7 References	38
CHAPTER 3	43
Mammalian assemblages in Southern Mistbelt Forests of the northern Eastern Cape and southern KwaZulu-Natal Provinces, South Africa, and their response to bordering land-use	43
3.1 Abstract	44

3.2 Introduction	45
3.3 Methods	48
3.4 Results	52
3.5 Discussion	57
3.6 Acknowledgements	63
3.7 References	63
CHAPTER 4	69
Testing the response of mammalian species richness and functional diversity to forest patch size and isolation in Southern Mistbelt Forests of South Africa	69
4.1 Abstract	70
4.2 Introduction	71
4.3 Methods	74
4.4 Results	79
4.5 Discussion	83
4.6 Acknowledgements	86
4.7 References	87
CHAPTER 5	92
The use and value of Southern Mistbelt Forests to surrounding rural communities in northern Eastern Cape, and southern KwaZulu-Natal, South Africa.....	92
5.1 Abstract	93
5.2 Introduction	94
5.3 Methods	96
5.4 Results	100
5.5 Discussion	106
5.6 Acknowledgements	110
5.7 References	110
5.8 Appendices	115
CHAPTER 6	123
Conclusions and Recommendations	123
6.1 Introduction	123
6.2 Research findings and Recommendations.....	123
6.3 Concluding remarks	126
6.4 References	127

LIST OF FIGURES

Figure 1.1 Distribution of Southern Mistbelt Forests in KwaZulu-Natal and northern Eastern Cape, South Africa. (Adapted from Mucina <i>et al.</i> (2006)).....	3
Figure 1.2 Hypothetical analysis of the sensitivity of a species in terms of occupancy of habitat, a and b represent limits between phases of sensitivity. (Adapted from Cortelezzi <i>et al.</i> (2017)).....	10
Figure 2.1 The Southern Mistbelt Forest study areas in the present study situated in inland southern KwaZulu-Natal and northern Eastern Cape Provinces, South Africa.....	26
Figure 2.2 Percentage microhabitat cover (mean \pm SE) during the dry and wet sampling seasons for the understory and canopy cover layers based on the foliage profile data recorded at Southern Mistbelt Forests camera-trap stations (BG = bare ground; LL = leaf litter; SGC = short grass cover; TGC = tall grass cover; SHC = short herbaceous cover; THC = tall herbaceous cover; SP = woody plants and saplings; SD2 – 5 m = stem density of trees 2 – 5 m; SD6 – 10 m = stem density of trees 6 – 10 m; SD11 – 15 m = stem density of trees 11 – 15 m; SD16 – 20 m = stem density of trees 16 – 20 m; SD > 25 m = stem density of trees > 25 m; CC = crown cover).....	30
Figure 2.3 Constrained species-environmental RDA biplot showing the influence of microhabitat variables on the Southern Mistbelt Forest large and medium-sized mammalian community in the present study for a) the wet season with variance on the 1st axis is 51 % and an additional 21 % on the 2nd axis and b) the dry season with variance on the 1st axis is 55 % and an additional 16 % on the 2nd axis.....	33
Figure 2.4 Non-metric multidimensional scaling (NMDS) plot using Euclidean similarity index showing the microhabitat structure dissimilarity of camera-trap locations in the three study areas	

in the present study. The dry season a) NMDS with plot axes 1 + 2; 3D dimensionality (stress: 0.121) and wet season b) with plot axes 1 + 2; 3D dimensionality (stress: 0.0964). The squares (blue), triangles (green) and stars (red) represent Creighton, iNgeli and uMthatha study areas, respectively.....34

Figure 3.1. Land-use map of the Southern Mistbelt Forest study areas in southern KwaZulu-Natal and northern Eastern Cape, South Africa, with camera-trap sites used in natural forest patches in the present study shown.....49

Figure 3.2 Mammalian species found in Southern Mistbelt Forests mean (a) occupancy (ψ) and (b) detection probability (r) per study site area with the standard error shown in the present study.....56

Figure 4.1 Location of surveyed Southern Mistbelt Forests in the southern KwaZulu-Natal and northern Eastern Cape Provinces of South Africa in the present study.....75

Figure 4.2 Forest patch mammalian species response to functional diversity indices and species richness from the most parsimonious models for each response variable derived from linear mixed-effects. Plots with an asterisk (*) in the top right corner significantly affect the mammalian functional diversity indices it is plotted against.....82

Figure 5.1 The study areas where questionnaire surveys were conducted in the Eastern Cape and KwaZulu-Natal Provinces, South Africa, to ascertain forest product use.....98

Figure 5.2 The tree species parts that respondents collected and their uses in Southern Mistbelt Forests, South Africa.....105

Figure 5.3 Community residents responses to how the native forests can be protected in the present study.....106

LIST OF TABLES

Table 1.1 A summary of studies conducted on various forest mammalian species across Africa between the years 2000 and 2021.....	4
Table 2.1 Southern Mistbelt Forest large and medium-sized mammalian species recorded during wet and dry seasons, including the number of camera-trap stations they were captured at in the present study.....	29
Table 3.1 Mammalian species richness in the three study areas of Southern Mistbelt Forests during a single South African wet and dry season in the present study.....	53
Table 3.2 Forest-dependent and common mammalian species detections (N), occupancy (ψ) and detection probability (r) across different land-uses in the present study.....	55
Table 4.1 Eigenvalues of principal coordinate analysis of functional traits derived from mammalian species identified in the select Southern Mistbelt Forests in eastern South Africa.....	78
Table 4.2 The β -diversity components, including nestedness (β_{nes}), turnover (β_{sim}) and total (β_{sor}) calculated for mammalian communities for each forest patch included in the overall analysis in the Southern Mistbelt Forests in eastern South Africa.....	80
Table 4.3 Summary results of the Global Moran's I tool showing the indices used to determine functional diversity of mammals in the Southern Mistbelt Forests.....	81
Table 4.4 Model coefficients obtained from the most parsimonious models to assess the response of forest mammal functional diversity indices and species richness to forest patch size (logged), forest structural complexity (FSC; logged) and altitude in the present study.....	81
Table 5.1 Demographics of villages and respondents sampled in Eastern Cape and KwaZulu-Natal Provinces, South Africa, to ascertain forest product use.....	100

Table 5.2 Reasons for the physical change in size of forests over ten years by interviewed respondents living adjacent.....101

Table 5.3 Mammalian species hunted in the Southern Mistbelt Forests identified by settlement residents in the present study.....102

Table 5.4 Multiple linear regression analysis of parameters that may influence settlement residents to hunt mammalian species in the Southern Mistbelt Forests.....103

Table 5.5 Tree species commonly used in the communities close to the Southern Mistbelt Forests of KwaZulu-Natal and Eastern Cape in the present study.....104

CHAPTER 1

INTRODUCTION

1.1 The forest biome

There are five major biomes on earth: Tundra, Desert, Aquatic, Grassland, and Forest. The Forest biome covers 30% of terrestrial land on earth, with half of the world's forest still intact (Farwig et al., 2008). African forests have been heavily exploited for their timber resources, and land conversion for anthropogenic activities, such as agriculture, logging, and road expansion for ease of access, have resulted in the degradation of natural forests (Laurence et al., 2008; Maicher et al., 2021). Both Morgan et al. (2019) and Maicher et al. (2021) have identified selective logging in natural forests as a major cause for the decline in Western and Central African forests in countries such as Cameroon, Gabon and the Republic of Congo. Selective logging can also result in gaps in the canopy, which exposes the understory to additional sunlight, inadvertently stimulating the growth of vines that may suffocate indigenous vegetation (Lamperty et al., 2020). Additionally, logging increases fragmentation and isolation effects which alter forest system dynamics such as the microclimate (Alohou et al., 2017). In South Africa, the forest biome is the smallest (Mucina et al., 2006) and includes the Afromontane forest type, also known as the Southern Mistbelt Forest. Published research about Southern Mistbelt Forest type has mostly provided information on its vegetation and avifauna (e.g., Symes et al., 2001, 2002; Wethered and Lawes, 2003; Hart et al., 2013; Downs et al., 2014) and relatively little on the mammalian communities (e.g., Allen-Rowlandson, 1986; Lawes, 1990; Bowland and Perrin, 1995,1998; Hayward et al., 2005; Lawes et al., 2007a; Hayward, 2009).

The Southern Mistbelt Forest is exclusively located in the northern Eastern Cape (EC) and KwaZulu-Natal (KZN) provinces in South Africa (Fig. 1.1) at altitudes between 850–1 600

m (Mucina et al., 2006). The Southern Mistbelt Forests comprise an archipelago of forest islands (patches) that occur within a larger biome. In KZN and EC, the Southern Mistbelt Forest is embedded within the larger Grassland biome. This forest type is found in varying patch sizes with different anthropogenic land-use activities surrounding them, such as exotic pine tree (*Pinus* spp.) plantation roads which further fragment the patches. The proximity of the roads to forests has been identified as a contributing driver of deforestation globally as they enable or facilitate exploitation (Soares-Filho et al., 2001; Nagendra et al., 2003).

A number of tree species occur in the Southern Mistbelt Forests, such as the endemic *Eugenia zuluensis* and the near endemic *Podocarpus henkelii*, tree species to the forest type (Mucina et al., 2006). The canopy of these forests has species such as *Afrocarpus falcatus* and *Celtis africana*, and the sub-canopy has species such as *Cassinopsis ilicifolia* and *Diospyros whyteana* (Lawes et al., 2007b). The Southern Mistbelt Forest understory is a dense shrub layer and a well developed herb layer consisting of species like *Carissa bispinosa*, which is native to southern Africa (Mucina et al., 2006). The canopy species have been documented to be important for avifauna, such as the Cape parrot (*Poicephalus robustus*), which use the cavities in these trees as nesting sites and feed on the seeds of *Afrocarpus* and *Podocarpus* spp. (Downs and Symes, 2004; Downs et al., 2014). However, these forests have been subject to heavy logging by colonial settlers and subsistence harvesting in recent times, which has altered the structure and composition of the forests (Lawes et al., 2007c; Adie et al. 2013). The forests harbour forest-dependent mammalian species that are listed in the International Union for Conservation of Nature (IUCN, 2021) as rare/vulnerable, such as blue duiker *Philantomba monticola* and the tree hyrax *Dendrohyrax arboreus*, making the Southern Mistbelt Forests important areas to study.

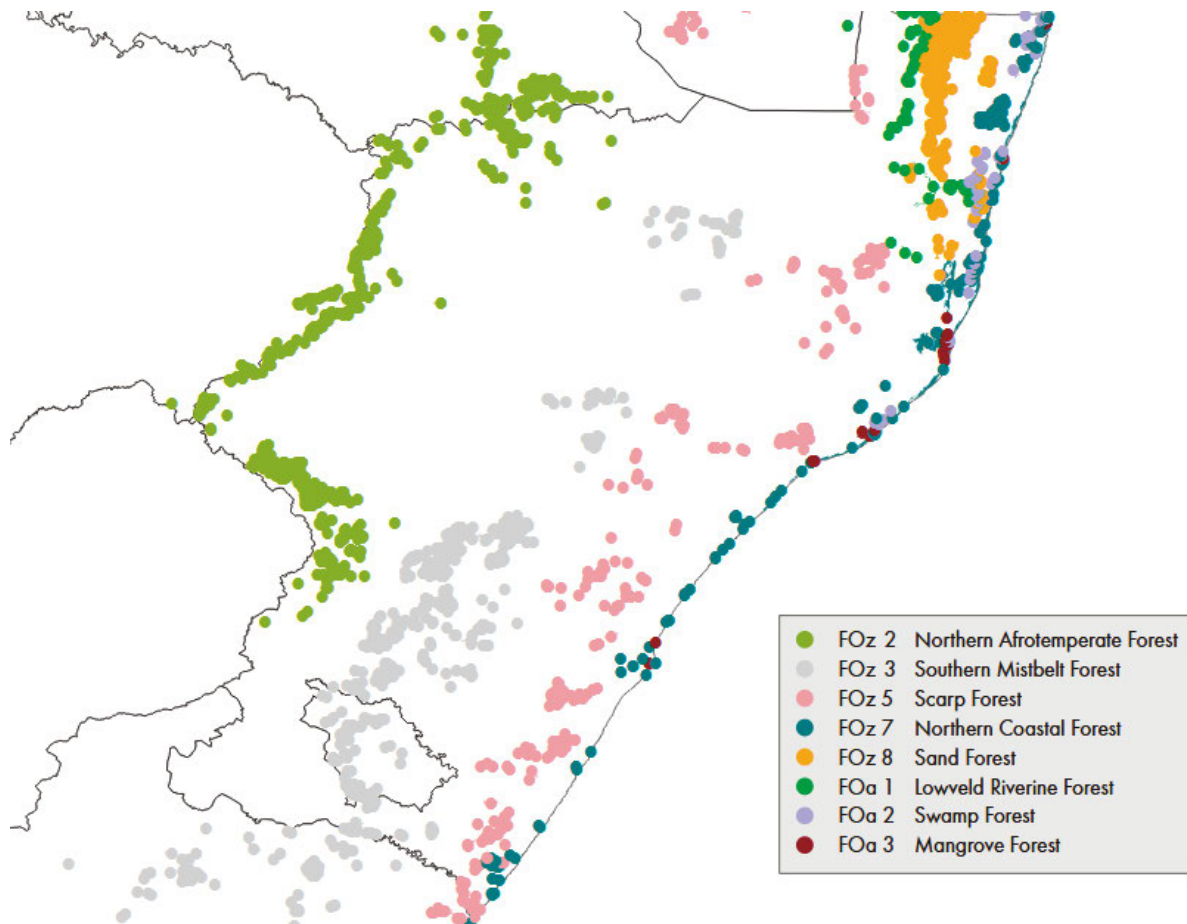


Figure 1.1 Distribution of Southern Mistbelt Forests in KwaZulu-Natal and northern Eastern Cape, South Africa. (Adapted from Mucina et al. (2006)).

1.2 Threats to forests

Tropical regions of Africa and Asia host the largest species richness of forest mammals as well as the highest diversity, with several species that are highly threatened (Han et al., 2016). Various studies have studied the effects of anthropogenic activities on different forest mammalian species across Africa (Table 1.1). In the last few decades, forests have dramatically declined because of anthropogenic activities and the conversion of natural landscapes to meet the needs of a growing human population (Farwig et al., 2008; Ehlers Smith et al., 2017). Anthropogenic activities have resulted in habitat loss and fragmentation across different landscapes (Rovero et al., 2014; Edelsparre et al., 2018). Despite conservation efforts from

environmental protection agencies and various governments, there is still a decline in biodiversity worldwide (Hatfield et al. 2018; da Silva et al. 2020). Threats to forests and other habitats include harvesting of timber for poles, furniture and firewood; land clearance for the development of roads and agriculture; mismanaged burning regimes in surrounding areas and; invasive species (Farwig et al., 2008; Rovero et al., 2014; Ehlers Smith et al., 2017; Edelsparre et al., 2018; Fischer, 2018; Toews et al., 2018).

Habitat loss and fragmentation affect resource availability (Swihart et al., 2003; Edelsparre et al., 2018; Toews et al., 2018), therefore influencing changes in habitat configuration, structure, and driving isolation of mammal populations (Ehlers Smith et al., 2017). Threats to forest habitats cause a disruption in forest mammal interactions and the carrying capacity of populations, leading to a decline in abundances and reduction in distributions (Edelsparre et al., 2018; Toews et al., 2018). Edge effects also increase as forests are fragmented into smaller units, and greater edges present higher risks of anthropogenic impacts (Ehlers Smith et al., 2017). Climate change also plays a direct and indirect role in affecting forest dynamics, whereby habitat and food resources (Renton et al., 2017) may be insufficient to support mammalian populations. Fire, both natural (caused by lightning) and anthropogenic, have also posed threats to forests (Lawes, 1990, Kotze and Samways, 2001; Carmenta et al., 2021).

Table 1.1 A summary of studies conducted on various forest mammalian species across Africa between the years 2000 and 2021.

Common name	Latin name	Forest type	Country	General notes from studies	Reference
Brush-tailed porcupine	<i>Atherurus africanus</i>	Rainforest	Cameroon	Conducted interviews to determine the species hunted in the forests as well as evaluating the reliability of indigenous knowledge as a means to assess trends in wildlife.	(Kamgaing et al., 2019)

Black-footed Mongoose	<i>Bdeogale nigripes</i>	Mangrove forests	Nigeria	Data about the species diet and distribution were collected along with other small carnivores in the study area.	(Angelici et al., 2014)
African golden cat	<i>Caracal aurata</i>	Afromontane forest	Kenya	The first of the species found dead on the Kieni Forest Reserve since 1946.	(Hatfield et al., 2019)
			Gabon	Camera-trap study to show impacts of human land use.	(Bahaa-el-din, et al., 2016).
Caracal	<i>Caracal caracal</i>	Afromontane forest	South Africa	Showed how the species is influenced by both the indigenous vegetation (forest and grassland) in a modified landscape (monoculture) along with human-carnivore conflict.	(Ramesh et al., 2017)
Harvey's duiker	<i>Cephalophus harveyi</i>	Rainforest	Tanzania	Non-invasive infrared-triggered camera-traps were used to determine species densities along transects.	(Rovero and Marshall, 2009)
Ogilby's duiker	<i>Cephalophus ogilbyi</i>	Rainforest	Gabon	Determined animal density and variation in spatial distribution at a landscape scale.	(Nakashima et al., 2020)
Abbott's duiker	<i>Cephalophus spadix</i>	Rainforest	Tanzania	Determined the distribution and status of the species as well as collected dung pellets to perform genetic analyses.	(Bowkett et al., 2014)
Samango monkey	<i>Cercopithecus albogularis labiatus</i>	Afromontane forest	South Africa	Assessed the behaviour of the endemic species in a modified landscape.	(Nowak., 2017)
Moustached monkey	<i>Cercopithecus cephus cephodes</i>	Tropical rain forest	Gabon	Assesed the hunting pressure on these species based on: snares; human footprints as well as encounters with hunters.	(Laurance et al., 2006)
Blue monkey	<i>Cercopithecus mitis</i>	Semi-deciduous tropical rain forest	Uganda	Primate surveys to estimate group size using various sampling methods.	(Plumptre, 2000)
Crowned monkey	<i>Cercopithecus pogonias nigripes</i>	Tropical rain forest	Gabon	How these species are affected by hunting pressure. Also looking at the effects of road proximity.	(Laurance et al., 2006)
African civet	<i>Civettictis civetta</i>	Rainforest	Nigeria	The study looked at changes in mammal population such as the african civet, which is hunted because it is a source of civetone, a chemical used for perfume fixation.	(Uchechi et al., 2020)
Black and white colobus	<i>Colobus guereza</i>	Semi-deciduous tropical rain forest	Uganda	Estimation of population densities.	(Plumptre, 2000)
Tree hyrax	<i>Dendrohyrax arboreus</i>	Afromontane forest	South Africa	The effect of tree harvesting on this species as it uses them for dens and as a source of food.	(Opperman et al., 2018)

Rusty-spotted Genet	<i>Genetta maculata</i>	Tropical rainforest	Gabon	They used camera-trap surveys to assess the distribution of the forest-dependent rusty-spotted genet along with other small carnivores in the region.	(Bahaa-el-din et al., 2013)
Servaline Genet	<i>Genetta servalina</i>	Equatorial rainforest	Congo	Niche modelling of <i>Genetta</i> spp. in central African rainforests.	(Gaubert et al., 2005)
Grauer's gorillas	<i>Gorilla beringei graueri</i>	Tropical rainforest	Democratic Republic of the Congo (DRC)	The authors of the investigate what is part of the species diet at the Nkuba Conservation area.	(van der Hoek et al., 2021)
Mountain gorilla	<i>Gorilla beringei beringe</i>	Tropical rainforest	Uganda	Estimated population size as well structure and distribution of populations.	(McNeilage et al., 2006)
Western lowland gorilla	<i>Gorilla gorilla gorilla</i>	Tropical rainforest	Gabon	A study on the seed dispersal ability of the species as well as the germination success after gut passage.	(Haurez et al., 2018)
Long-nosed Mongoose	<i>Herpestes naso</i>	Tropical rainforest	Gabon	Investigated species community dynamics, provide baseline information about species richness and abundance as well as determine what influences species occurrences.	(Hedwig et al., 2018)
Water chevrotain	<i>Hyemoschus aquaticus</i>	Rain forest	Sierra Leone	Examined how forest fauna may have been affected by civil unrest close to the Gola forest.	(Lindsell et al., 2011)
Grey-cheeked mangabey	<i>Lophocebus albigena albigena</i>	Tropical rain forest	Gabon	Assessed the effects of hunting pressure on these mammals.	(Laurance et al., 2006)
African forest elephant	<i>Loxodonta cyclotis</i>	Tropical rainforest	Gabon	A comprehensive camera-trap survey was conducted in the Batéké Plateau National Park to compile an inventory of the mammal community.	(Hedwig et al., 2018)
Suni	<i>Neotragus moschatus</i>	Afromontane forest	Tanzania	Assessed species richness, occupancy, detection probability of forest-dwelling mammals in the Udzungwa Mountains National Park.	(Rovero et al., 2014)
Leopard	<i>Panthera pardus</i>	Tropical rainforest	Democratic Republic of the Congo (DRC)	Reported on a leopard's predator-prey interactions with a troop of bonobos (<i>Pan paniscus</i>) and nine other species of primates.	(Corredor-Ospina et al., 2021)
Tree pangolin	<i>Phataginus tricuspis</i>	Rainforest	Cameroon	Conducted interviews to determine the species hunted in the forests as well as evaluating the reliability of indigenous knowledge as a means to assess trends in wildlife.	(Kamgaing et al., 2019)
Blue duiker	<i>Philantomba monticola</i>	Afromontane forest	South Africa	Forest patch occupancy of three forest-dependant mammals.	(Lawes et al., 2000)
Central African oyan	<i>Poiana richardsonii</i>	Equatorial rainforest	Rwanda	First study in Rwanda to show the species is present in Rwanda using camera-trap surveys.	(Moore and Niyigaba, 2018)

Bushpig	<i>Potamochoerus larvatus</i>	Rainforest	Ethiopia	Using semistructured interviews, they asked community members which species are causing human-wildlife conflict due to livestock predation and crop-raiding.	(Shanko et al., 2021)
Red river hog	<i>Potamochoerus porcus</i>	Rainforest	Sierra Leone	Estimated population size and composition as well as performed occupancy analyses to determine the human impact on these species.	(McCollum et al., 2016)
African forest buffalo	<i>Syncerus caffer</i>	Rainforest	Ethiopia	Using the feeding quadrat survey method, the authors aimed to determine the diet composition of the species.	(Erena et al., 2019)
Bongo	<i>Tragelaphus eurycerus</i>	Rainforest	Sierra Leone	To determine the occupancy of forest mammals.	(McCollum et al., 2018)
Bushbuck	<i>Tragelaphus scriptus</i>	Rainforest	Burkina Faso	Examined how the population dynamics of medium-sized ungulates and primates over several years is affected by anthropogenic activities (e.g. Poaching).	(Hema et al., 2017)

1.3 Forest use and human-wildlife interactions

As human populations change and cultural needs and environmental uses change, the landscape will also be altered (Fischer, 2018). On a smaller scale, humans can alter landscapes by introducing invasive plant species, fires and involuntarily introducing disease that then spread to surrounding forest patches (Fischer, 2018). Increasingly, harmful pathogenic infectious diseases have been passed from domestic animals to wildlife, and this is a threat to wildlife conservation (Cook and Karesh, 2012). Forest-dependent mammals are hunted for consumption, sport, financial gain as well as retaliatory killing (Fa and Brown, 2009; Rogan et al., 2018). Excessive hunting in forest areas has decreased mammal numbers and species diversity (Topp-Jørgensen et al., 2009; van Velden et al., 2020). The main species that are hunted for consumption are ungulates which are considered a good source of protein (Hayward, 2009). However, in the bushmeat trade market in Nigeria, the African civet (*Civettictis civetta*) is hunted for a chemical it produces, which is used for perfume fixation (Uchechi et al., 2020).

Kamgaing et al. (2019) conducted interviews in two areas in Cameroon and found that similar species are being hunted, but the level of prey depletion varies between sites; with overall species abundance having decreased over the years.

Species such as caracal (*Caracal caracal*) and black-backed jackal (*Lupulella mesomelas*) have been documented to prey on livestock (Grobler, 1981; Minnie et al., 2018). The predation of livestock by these types of predators leads to communities and farmers resorting to indiscriminate retaliatory killing as they are perceived as a threat to their livelihoods (Merson et al., 2019). It has become increasingly difficult for wildlife conservation to protect carnivores like those mentioned above because farmers and community members whose livelihoods are threatened by livestock predation feel they should be eradicated from their areas (Kissui et al., 2019).

Timber harvesting is an important practice in communities closer to forest areas (Rist et al., 2012). At varying degrees timber products are of high socio-economic value and are predominantly used for fuelwood, building fences and structures and are sold for financial gain (Shackleton and Shackleton, 2004; Leaver and Cherry, 2020). However, as mentioned before, excessive logging has changed the forest structure and quality over time, resulting in low biodiversity and resource availability (Lindsey et al., 2011).

1.4 Occupancy modelling and camera trapping

Occupancy modelling calculates the probability that an area is occupied by a species of interest (Mackenzie et al., 2002; Mackenzie et al., 2003; Cortelezzi et al., 2017; Mackenzie et al., 2017). Occupancy modelling can also be defined as determining the presence and absence of species of interest in discrete habitat patches (Mackenzie et al., 2002; Rich et al., 2016; Cortelezzi et al., 2017; Martin et al., 2017). This species modelling method can further be used as a tool to determine the drivers of occupancy and assess the sensitivity of a species to varying levels and

kinds of habitat resources (Cortelezzi et al., 2017; Hepler et al., 2018). Cortelezzi et al. (2017) stated that the probability of a species occurring in an area would decrease or be non-existent if the habitat is in a degraded state, which is depicted in Fig. 1.2. More advanced methods of occupancy modelling have emerged over the years, such as hierarchical multi-species modelling. Multi-species modelling fundamentally uses the species community data collectively to determine occupancy. Compared with older methods, the modelling method controls for confounding observed changes in land-use that may affect species (Zipkin et al., 2010; Wearn et al., 2017). This avoids the discrepancies and wide variation in species responses to land-use change in previous studies (Wearn et al., 2017).

Camera-traps have been widely used around the world for animal conservation and monitoring (Brodie et al., 2014; Campos et al., 2018; Drouilly et al., 2018; Gray, 2018; Hepler et al., 2018). Camera-trapping is a non-invasive passive method of determining species richness, diversity and distribution (Colyn et al., 2017, Drouilly et al., 2018, Hepler et al., 2018). The detection data obtained from camera-trapping helps to measure habitat use and connectivity (Swihart et al., 2003; Brodie et al., 2014). They are also very useful tools to provide information on multiple species presence and absence as well as population densities and foraging habits (Colyn et al., 2017; Drouilly et al., 2018).

Occupancy modelling coupled with camera-trapping has various factors that influence the final result. For instance, the density and abundance of vegetation may positively attract mammals and increase biodiversity; however, the vegetation may reduce the detectability of mammals because of vegetation causing an obscure view for the camera-trap (Hepler et al., 2018).

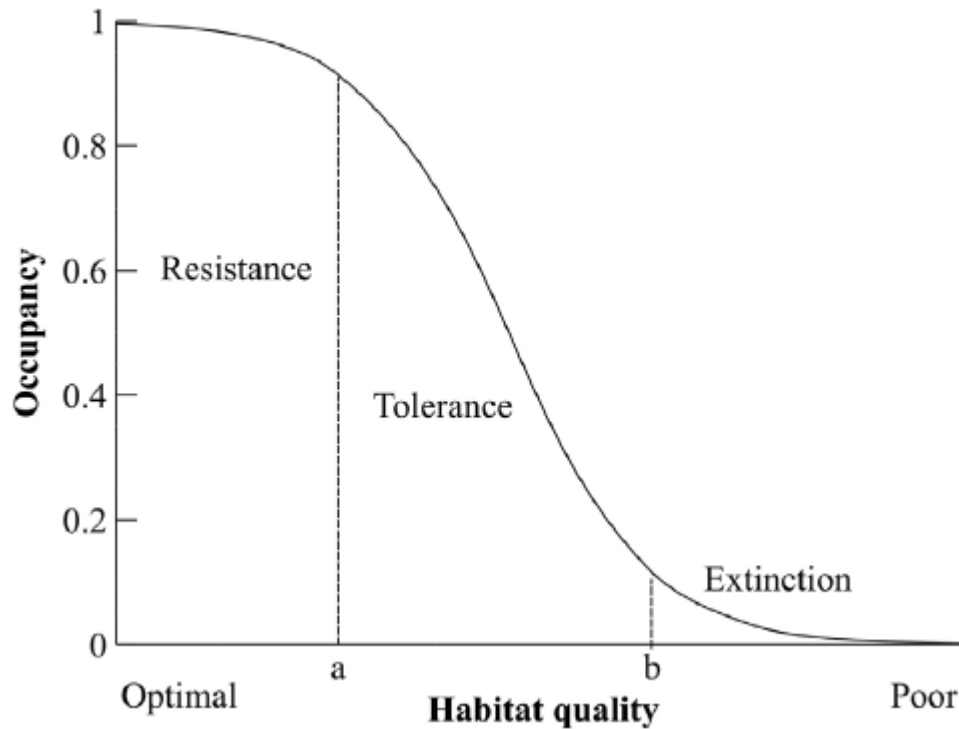


Figure 1.2 Hypothetical analysis of the sensitivity of a species in terms of occupancy of habitat, a and b represent limits between phases of sensitivity. (Adapted from Cortelezzi et al. (2017)).

1.5 Forest mammal functional diversity

Functional diversity measures the value, range, and density of functional traits in a community that influence how ecosystems function (Petchey et al., 2004; Mason et al., 2005). It is a means to measure the interaction between ecosystem functions whereby the functional traits of species are included to understand the relationship between species and the ecosystem they reside in (Magioli et al., 2015; Thakur and Chawula, 2019). Ecosystem functioning has benefited from the presence of mammals as they perform different functional roles to varying functional traits (Garmendia et al., 2013). Functional diversity is measured by various indices, including functional richness (Cornwell et al., 2006), functional evenness (Villéger et al., 2008), functional dispersion (Laliberté and Legendre, 2010), and functional divergence (Villéger et

al., 2008). For an environmental system to function along with ongoing processes, diversity of traits, rather than individual species, may be the primary driver (Gorzynski et al., 2021).

Larger environmental systems commonly harbour more species because of having rich and diverse niches and resources that can be utilised effectively because of the diversity of species traits (Magioli et al., 2015). According to Petchey et al. (2004), if there is greater resource use, it will result in an elevated functional diversity. Increased isolation as a result of increased fragmentation disturbs ecological processes and reduces habitat cohesiveness (Ramesh et al., 2016). A statistical method used to assess the changes observed in species' structure or functional traits present within communities across landscapes is the β -diversity component, which acts under the processes of species nestedness and spatial turnover (Palmeirim et al., 2018; Regolin et al., 2020). Nestedness describes the difference of species richness or functional diversity between communities (Baselga, 2010), and if this component is the dominant driver, the conservation implication is to prioritise the communities that are species-rich (Angeler, 2013). Turnover measures the replacement of species or traits between communities (Baselga, 2010), and if this component is dominant over nestedness, all species communities should be prioritised for conservation (Angeler, 2013).

1.6 Problem statement and significance of the study

Gaining knowledge on forest mammalian species occurrence, habitat associations, and human-wildlife interactions in and around the Southern Mistbelt Forests of South Africa motivated this study. There is a paucity of information about the overall mammal communities inhabiting these forests. Firstly, to address this knowledge gap, I sought first to understand how mammal presence, abundance and habitat use is influenced by microhabitat vegetation structure. Secondly, I estimated site occupancy using the hierarchical multi-species modelling method and the detection probability of individual mammalian species. Thirdly, I evaluated how

mammalian species functional diversity inhabiting Southern Mistbelt Forests responded to factors such as patch size, forest structural complexity, forest patch isolation, along with the number of neighbouring patches. Lastly, I investigated the level of forest use by communities residing around Southern Mistbelt Forest patches in uMthatha, Eastern Cape and Ingeli, KwaZulu-Natal, South Africa. The study highlighted the importance of forests concerning mammals and forest conservation in the selected areas, which may contribute to the already existing management and conservation strategies of these forests and those that may have been neglected.

1.7 Aims and objectives

The overall aim of the study was to assess the anthropogenic impacts on mammals occurring in the Southern Mistbelt Forests of KwaZulu-Natal and Eastern Cape provinces. To achieve this, various objectives were derived:

1. Investigate the influence of microhabitat complexity, using foliage profiles and vegetation composition on forest mammal communities within the Southern Mistbelt Forests of KwaZulu-Natal and Eastern Cape provinces.
2. Assess the impact of anthropogenic landscapes and human disturbance on forest mammal occupancies in the Southern Mistbelt Forests of KwaZulu-Natal and Eastern Cape provinces by using occupancy modelling.
3. Evaluate the response of forest mammal's functional diversity and species richness to factors such as patch size, forest structural complexity, forest patch isolation along with the number of neighbouring patches.
4. Investigate the cultural perceptions, beliefs and practices associated with forest mammals in the Southern Mistbelt Forests of KwaZulu-Natal and Eastern Cape provinces using questionnaires.

1.8 Study outline

This thesis consists of six chapters, four of which are data chapters (2-5) for publication in relevant international peer-reviewed journals. Some repetition in chapters was unavoidable, especially for method sections, as the mammalian species datasets obtained from camera traps were used to address different questions and objectives. The chapters are outlined as follows:

Chapter 1: Introduction/Overview

Chapter 2: How does microhabitat structure influence large and medium-sized mammalian species communities in Southern Mistbelt Forest patches of South Africa?

Chapter 3: Mammalian assemblages in Southern Mistbelt Forests of the northern Eastern Cape, and southern KwaZulu-Natal provinces, South Africa, and their response to bordering land-use.

Chapter 4: Testing the response of mammalian species richness and functional diversity to forest patch size and isolation in Southern Mistbelt Forests of South Africa

Chapter 5: The use and value of Southern Mistbelt Forests to surrounding rural communities in northern Eastern Cape, and southern KwaZulu-Natal, South Africa

Chapter 6: Conclusions and recommendations.

Note: I have used plural pronouns throughout the thesis and documented my contributions in the preface for the data chapters. I am the first author of all of these manuscripts.

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CHAPTER 2

How does microhabitat structure influence large and medium-sized mammalian species communities in Southern Mistbelt Forest patches of South Africa?

Mbalenhle T. Sosibo, David A. Ehlers Smith, Yvette C. Ehlers Smith, S.

Thobeka Gumede, Samukelisiwe P. Ngcobo, Colleen T. Downs*

Centre for Functional Biodiversity, School of Life Sciences, University of KwaZulu-Natal,

Private Bag X01, Scottsville, 3209, Pietermaritzburg, South Africa

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* **Corresponding Author:** Colleen T. Downs

Email: downs@ukzn.ac.za; **ORCID:** <http://orcid.org/0000-0001-8334-1510>

Other emails and ORCIDs:

M. Sosibo Email: mbalisosibo5@gmail.com; ORCID: 0000-0003-3801-3539

D.A. Ehlers Smith Email: ehlerssmithd@ukzn.ac.za; ORCID: 0000-0002-6357-0751

Y.C. Ehlers Smith Email: ehlerssmithy@ukzn.ac.za; ORCID: 0000-0002-2564-7359

S.T. Gumede Email: thobekagumede123@gmail.com; ORCID: 0000-0001-7879-4312

S.P. Ngcobo Email: sam.p.ngcobo@gmail.com; ORCID: 0000-0002-3924-6089

Running header: Microhabitat structure effects on forest mammals

2.1 Abstract

Microhabitats play an important role in the persistence of mammalian species and communities, influencing their abundance, distribution, and interspecific relationships. In South Africa, the forest biome is the smallest of the eight biomes and includes the naturally fragmented Southern Mistbelt Forest group. Here, little is known about contemporary mammalian assemblage dynamics in relation to these forest's microhabitats. Therefore, we determined the microhabitat characteristics that best predict or explain the presence and habitat use of large and medium-sized mammalian species in the Southern Mistbelt Forests of the northern Eastern Cape and southern KwaZulu-Natal Provinces. We deployed a minimum of 60 camera-traps at any time for 24 h /day for 21 days to monitor forest large and medium-sized mammalian species presence/absence at stratified survey locations. We recorded a habitat structure foliage profile within a 20 m radius around each camera-trap. The mammalian species most often photographed during sampling seasons were bushbuck *Tragelaphus scriptus* and samango monkey *Cercopithecus albogularis labiatus*, with the least photographed species being serval *Leptailurus serval* and African wild cat *Felis silvestris cafra*. All mammalian species detected in our study had a statistically significant negative association with bare ground. Samango monkeys showed a positive association with crown closure, which was expected for an arboreal species that requires a dense connecting canopy for movement. Our study highlighted that microhabitat variables, such as leaf litter, crown closure and grass cover, play an important role in the presence and persistence of large and medium-sized mammalian species that inhabit the Southern Mistbelt Forests, which are of benefit for informing forest conservation management.

Keywords Assemblage structure; Camera-traps; Foliage profile; Forest mammals; Redundancy analysis; Tree diversity; Vegetation plot

2.2 Introduction

It is essential to understand the factors that structure mammalian communities and which environmental characteristics promote the persistence of diverse and abundant mammalian communities for conservation purposes. Studies in the last few decades have developed an emerging picture of essential drivers of mammalian communities (Yahner 1986; Eisenberg and Redford 1999; Miklos and Kias 2002; Ehlers Smith et al. 2017a; Zungu et al. 2020). Mammalian communities, particularly in forest habitats, are generally affected by habitat availability, dietary requirements, habitat heterogeneity, microhabitat structure and climate change (Yahner 1986; Lima et al. 2010; Choat et al. 2012; Torre et al. 2013; Suchomel et al. 2014; Cusack et al. 2015; Correa et al. 2017). Seasonality is also an important driver for mammalian species habitat occupation and use (Santos-Filho 2012; Atnafu and Yahune 2018).

The microhabitat, the small specific area within a larger habitat determined by foliage profile and habitat community structure, plays an important role in the persistence of mammalian species, as it influences their abundance, distribution, interspecific relationships and survival of mammalian species (Morris 1978a; Miklos and Kias 2002; Naxara et al. 2009; Schlinkert et al. 2016; Corrêa et al. 2018). Most importantly, microhabitats provide food, shelter and cover from predators. In forest microhabitats, factors, such as vertical stratification, influence mammalian species richness, abundance, and habitat use (Eisenberg and Redford 1999; Naxara et al. 2009). Habitat heterogeneity, together with microhabitat, further promotes the coexistence and distribution of different mammalian species because of the provision of various resources and structures (Yahner 1986; Morris 1987b).

In South Africa, the forest biome is the smallest of the eight biomes (Eeley et al. 1999; Mucina et al. 2006; Grieve and Downs 2015) and includes the naturally fragmented Southern Mistbelt Forest group. The Southern Mistbelt Forests occur in the Eastern Cape and KwaZulu-Natal Provinces of South Africa (Eeley et al. 1999). The research conducted on Southern

Mistbelt Forests has mostly provided information on its vegetation, avifauna and mammalian communities (see Lawes 1990; Symes et al. 2001; 2002; Wethered and Lawes 2003; Hayward et al. 2005; Lawes et al. 2007; Hart et al. 2013; Botzat et al. 2015 and references therein). However, there is a paucity of research at a microhabitat level for single-species studies. Research into the role of forest microhabitat on species in South Africa has also grown in recent years (Lawes 1991; Ehlers Smith et al. 2017a, 2017b; Maseko et al. 2019). Little is known about the current large (mass > 7 kg) and medium-sized (mass between 2 – 7 kg) (Porrás et al. 2016; Monsarrat and Kerley 2018) mammalian species dynamics in relation to forest microhabitats and the role these play in shaping the mammalian forest communities. Our study aimed at determining the microhabitat vegetation structure that best explained the presence, abundance and habitat use of the large and medium-sized mammalian species in the Southern Mistbelt Forests in the Eastern Cape and KwaZulu-Natal Provinces of South Africa. Our specific objective was to examine patterns of microhabitat use and what influences species presence and abundance in the Southern Mistbelt Forests. We predicted that despite differences in the large and medium-sized species composition, they would have a positive association with open spaces dominated by leaf litter cover and a negative association with bare ground cover.

2.3 Methods

2.3.1 Study area

Our study areas included the disjunct Southern Mistbelt Forests of the northern Eastern Cape and southern KwaZulu-Natal Provinces, South Africa, at ~ 1000- 1500 m a.s.l. Our study took place in three different forest cluster areas (uMthatha, Glengarry/Weza [termed iNgeli hereafter] and Creighton; (Fig. 2.1) with Southern Mistbelt Forest patches of varying size (5.75 – 718.28 ha). The grey polygons signify where the selected Southern Mistbelt Forest patches

for each forest cluster are, and the green dots are the nearest large towns (Fig. 2.1). The landscape structure in each study area consisted of a relatively large (> 400 ha) “mainland” patch, namely Nqadu in uMthatha (31°25’48.71” S 28°45’12.33” E, 548.70 ha), iNgeli in Glengarry/Weza (30°31’38.2” S 29°41’33.2” E, 568.94 ha), and Xgalingenwa in Creighton (29°58’34.91” S 29°44’1.61” E, 506.15 ha), with smaller satellite forest patches nearby them. The forest type is also referred to as yellowwood forest because the forest patches are dominated by *Podocarpus* or *Afrocarpus* genera (Mucina et al. 2006). The inland Southern Mistbelt Forest areas receive a mean 846 mm rainfall p.a., and ambient temperatures range from 3 °C – 27 °C, with a temperate climate (Mucina et al. 2006). The South African (east coast) wet and dry seasons occur from October to March and June to August, respectively. The Southern Mistbelt Forest patches are nested in the grassland biome, with other land-use practices surrounding them, predominantly exotic tree plantations (*Pinus patula*, *Acacia mearnsii* and *Eucalyptus* spp.) and human settlements.

2.3.2 Data collection

We used infrared motion detection camera-traps to monitor large and medium-sized mammalian species presence/absence at set camera-trap locations determined using a 400 m x 400 m systematic grid system overlaid onto Southern Mistbelt Forest patches in Arc GIS v10.5.1 (ESRI 2017). Data collection protocols for this study followed Ramesh and Downs (2013, 2015) and Ehlers Smith et al. (2017a, 2018), who sampled in forests along the KwaZulu-Natal coastline and are detailed below. We used stationary camera-traps (60 Cuddeback Black Flash® model 1231 and 15 Moultrie® model 880, EBSCO Industries, Inc., USA), triggered by passive infrared sensors to “capture” digital photographs of passing animals. Camera-traps were set at the height of 20 – 30 cm above ground, attached to a robust tree. A minimum of 60 camera-traps at a time was deployed for 24 h /day (with a single shot 30 s time-lapse setting

whereby photographs were taken every 30 s when the camera-trap was triggered by movement in its range) at uMthatha, iNgeli and Creighton for a maximum of 21 days (c.f. Ehlers Smith et al. 2017a), to minimise the likelihood of a change in site occupancy of study species and for comparison with the 21-day data in similar landscape studies (Ramesh and Downs 2014). Each photograph provided information on the date and time. We conducted surveys between May 2018 – June 2020 during the wet (summer/spring) and dry (winter/autumn) seasons, resulting in one full 21-day survey for each camera-trap location per season.

At each camera-trap location, we recorded the habitat structure in terms of a foliage profile within a 20 m radius around each. The foliage profile at each camera-trap location consisted of two understory vegetation classes: 1) percentage coverage of bare ground; leaf litter, grass cover, and herbaceous plants; and 2) percentage cover of scrub/woody plant saplings <2 m. To determine the foliage profile, we measured lengths of plants average plant height and visually estimated percentage understory coverage of each of the vegetation class layers relative to each other, within individual quarters of the circular plots (totalling 100 % coverage in each; c.f. Ehlers Smith et al., 2017a). We counted tree stems density that reached varying heights of 2 – 5 m, 6 – 10 m, 11 – 15 m, 16 – 20 m and > 25 m, and visually estimated percentage crown cover.

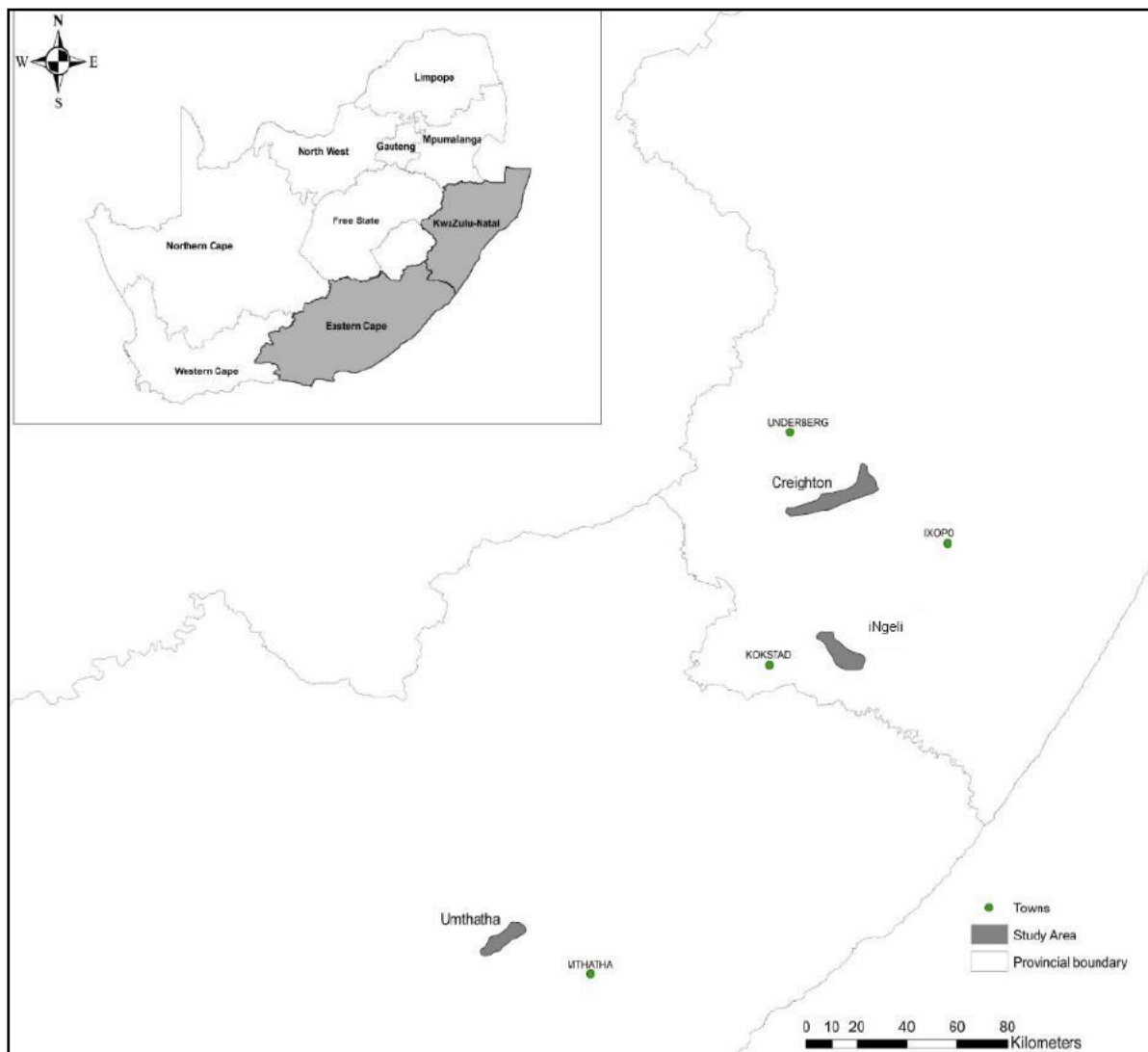


Figure 2.1 The Southern Mistbelt Forest study areas in the present study situated in inland

2.3.3 Statistical analyses

To determine if there was a significant difference in large and medium-sized mammalian species abundance per camera-trap location between sampling seasons, we used Welch's sample t-test. Microhabitat variables measured in the field were percentage coverage of bare ground (BG), leaf litter (LL), short grass cover (SGC, ≤ 0.25 m), tall grass cover (TGC, > 0.25 m), short herbaceous cover (SHC, ≤ 0.25 m), tall herbaceous cover (THC, > 0.25 m), saplings 0 – 2 m (SP), and number of trees with varying heights of 2 – 5 m (SD2), 6 – 10 m (SD6), 11 – 15 m (SD11), 16 – 20 m (SD16), and percentage tree crown closure (CC; Ehlers Smith et al. 2017a). Correlation analyses between microhabitat variables were conducted in SPSS software

using Pearson's correlation coefficient to determine whether there was multicollinearity; highly correlated variables were removed. We used the number of images per species as a community metric and expressed as a capture index (the number of photographed forest mammals per 21 trap-days). Species photographed more than once in an hour were only counted as one occurrence. Abundance was measured as a response variable to microhabitat predictor variables.

To visualise the relationship between response and predictor variables, we conducted redundancy analyses (RDA). For both RDAs, the species abundance matrix was standardised using the Hellinger association index. The "envfit" function from the *vegan* package was used to select the best set of predictor variables for the RDAs. We used a generalised linear model (GLM) approach to determine the presence of significant relationships between response (species abundance) and predictor (foliage profile variables) variables. P-values were calculated using 999 resampling iterations by PIT-trap block resampling to account for correlation in testing. We conducted analyses using packages 'mvabund' (Wang et al. 2012), 'vegan' (Oksanen et al. 2018) and 'car' (Fox and Weisberg 2019) using the statistical software package R v. 3.6.1 (R Core Team 2019). The Euclidean similarity index in three-dimensional non-metric dimensional scaling (NMDS) was used to assess the similarities and dissimilarities among study areas in terms of which microhabitat variables played a significant role in shaping the mammalian communities (Hammer et al. 2001).

2.4 Results

We recorded a total of 1774 images of large and medium-sized mammals over a total of 8820 trap-days. There were 1051 images of 15 species captured during the dry season and 723 images of 15 species captured during the wet season (Table 2.1). The most photographed species during the dry and wet seasons were bushbuck *Tragelaphus scriptus* (32 %, n = 564) and the samango monkey *Cercopithecus albogularis labiatus* (18 %, n = 319, Table 2.1). The serval *Leptailurus serval* and the African wild cat *Felis silvestris cafra* were excluded from analyses because of only having one photograph captured in iNgeli, and Creighton areas, respectively. For data collection, we used two camera-trap models; we incorporated random effects into the analysis to determine if camera-trap model should be included in the model and we excluded it as it did not have a significant effect on the model (Wet: $\chi = 9.39$, $p = 0.152$; Dry: $\chi = 5.36$, $p = 0.497$). Using Welch's sample t-test, we found that seasonality did have a significant effect on overall species abundance ($t = -2.740$, $df = 376.13$, $p = 0.00642$). During the dry season, leaf litter (LL) had the highest forest understory cover (30 ± 8.6) in comparison with the wet season (18 ± 1.98) and the other understory microhabitat variables (Fig. 2.2). The 2 – 5 m tree stem density category had the greatest percentage cover amongst the tree stem density categories for both the dry (53 ± 1.98) and the wet sampling seasons (48 ± 1.84 ; Fig. 2.2).

Table 2.1 Southern Mistbelt Forest large and medium-sized mammalian species recorded during wet and dry seasons, including the number of camera-trap stations they were captured at in the present study.

Common name	Scientific name	Forest habitat association	Number of species records in camera-traps		Number of camera-traps with species records	
			Dry	Wet	Dry	Wet
African wild cat	<i>Felis silvestris cafra</i>	Generalist	1	0	1	0
Black-backed jackal	<i>Lupulella mesomelas</i>	Generalist	28	21	16	12
Blue duiker	<i>Philantomba monticola</i>	Specialist	61	51	11	13
Bushbuck	<i>Tragelaphus scriptus</i>	Specialist	402	162	100	68
Bushpig	<i>Potamochoerus larvatus</i>	Generalist	54	16	18	9
Cape-grey mongoose	<i>Herpestes ichneumon</i>	Generalist	27	10	14	10
Cape porcupine	<i>Hystrix africaeaustralis</i>	Generalist	123	24	50	19
Caracal	<i>Caracal caracal</i>	Generalist	34	16	19	12
Chacma baboon	<i>Papio ursinus</i>	Generalist	34	51	10	6
Common duiker	<i>Sylvicapra grimmia</i>	Generalist	0	14	0	11
Large-spotted genet	<i>Genetta tigrina</i>	Generalist	183	117	69	62
Tree hyrax	<i>Dendrohyrax arboreus</i>	Specialist	4	3	4	3
Samango monkey	<i>Cercopithecus albogularis labiatus</i>	Specialist	91	228	38	55
Serval	<i>Leptailurus serval</i>	Generalist	0	1	0	1
Vervet monkey	<i>Cercopithecus pygerythrus</i>	Generalist	5	0	3	0
Water mongoose	<i>Atilax paludinosus</i>	Generalist	5	10	3	4

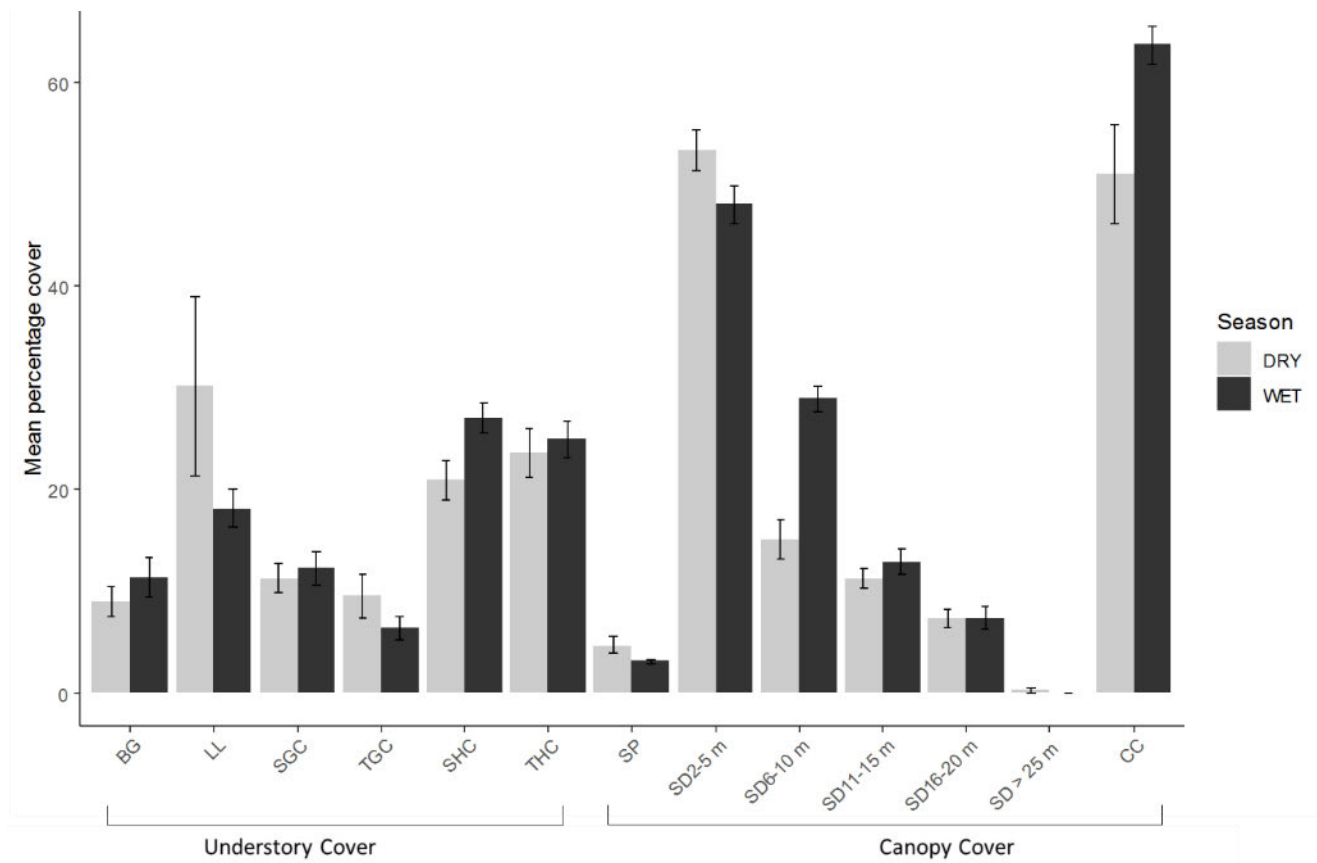


Figure 2.2 Percentage microhabitat cover (mean \pm SE) during the dry and wet sampling seasons for the understory and canopy cover layers based on the foliage profile data recorded at Southern Mistbelt forests camera-trap stations (BG = bare ground; LL = leaf litter; SGC = short grass cover; TGC = tall grass cover; SHC = short herbaceous cover; THC = tall herbaceous cover; SP = woody plants and saplings; SD2 – 5 m = stem density of trees 2 – 5 m; SD6 – 10 m = stem density of trees 6 – 10 m; SD11 – 15 m = stem density of trees 11 – 15 m; SD16 – 20 m = stem density of trees 16 – 20 m; SD > 25 m = stem density of trees > 25 m; CC = crown cover).

The same microhabitat variables were collected for both sampling seasons; however, during the forward stepwise selection process indicated microhabitat variables that were important in the species richness and abundance varied between seasons. Important microhabitat variables during the dry season were bare ground (BG) ($R^2_{adj} = 0.096$, $p = 0.001$), tall grass cover (TGC) ($R^2_{adj} = 0.121$, $p = 0.001$), saplings 0 – 2 m (SP) ($R^2_{adj} = 0.037$, $p =$

0.020), short herbaceous cover (SHC) ($R^2_{\text{adj}} = 0.066$, $p = 0.005$), and tall herbaceous cover (THC) ($R^2_{\text{adj}} = 0.047$, $p = 0.009$). The important microhabitat variables during the wet season were leaf litter (LL) ($R^2_{\text{adj}} = 0.193$, $p = 0.001$), percentage crown closure (CC) ($R^2_{\text{adj}} = 0.044$, $p = 0.024$), short grass cover (SGC) ($R^2_{\text{adj}} = 0.040$, $p = 0.037$), short herbaceous cover (SHC) ($R^2_{\text{adj}} = 0.067$, $p = 0.007$), and tall herbaceous cover (THC) ($R^2_{\text{adj}} = 0.042$, $p = 0.030$). The selected microhabitat characteristics accounted for 72% of the total number of species richness and abundance variation in the wet season and 71% of total species variation for the dry season on the 1st and 2nd axes of both RDAs (Fig. 2.3).

The same microhabitat variables used for the constrained RDAs were applied to GLMs. Models applied to the community data showed constant variance and were a good fit for analyses. There were 12 models that best predicted large and medium-sized mammalian richness and abundance during the wet season. Samango monkey abundance was positively influenced by leaf litter (LL) ($p = 0.006$, $\beta = 1.543$), LL+SHC ($p = 0.015$, $\beta = 0.164$), CC+SGC ($p = 0.018$, $\beta = 0.873$), and LL+THC ($p = 0.040$, $\beta = 0.605$). Blue duikers *Philantomba monticola* were positively influenced by leaf litter (LL) ($p = 0.015$, $\beta = 4.414$) whereas chacma baboons *Papio ursinus* were negatively influenced by LL+CC+SGC ($p = 0.001$, $\beta = -6.600$) and bushbuck were negatively influenced by leaf litter ($p = 0.006$, $\beta = -1.524$). Bushpigs *Potamochoerus larvatus* were negatively influenced by short grass cover ($p = 0.039$, $\beta = -4.555$) and water mongooses *Atilax paludinosus* were negatively influenced by CC+SGC ($p = 0.018$, $\beta = -37.573$).

There were nine models that best predicted large and medium-sized mammalian richness and abundance during the dry season. Blue duikers were positively influenced by BG+SHC ($p = 0.022$, $\beta = 0.921$) and negatively influenced by BG+THC ($p = 0.013$, $\beta = -5.765$) and TGC+SP+THC ($p = 0.048$, $\beta = -40.312$). Cape porcupines *Hystrix africaeaustralis*, Cape or large-spotted genets *Genetta tigrina* and water mongooses were positively influenced by

BG+THC ($p = 0.005$, $\beta = 0.731$), BG ($p = 0.040$, $\beta = 0.100$) and BG+SHC ($p = 0.035$, $\beta = 1.519$) respectively. Bushbuck were positively influenced by tall grass cover ($p = 0.001$, $\beta = 0.503$) and negatively influenced by short herbaceous cover ($p = 0.009$, $\beta = -0.251$) and BG+TGC+SHC ($p = 0.049$, $\beta = -3.135$). Chacma baboons were negatively influenced by BG+THC ($p = 0.021$, $\beta = -0.961$). Bushpigs were negatively influenced by SP+THC ($p = 0.016$, $\beta = -24.154$) and SHC+THC ($p = 0.001$, $\beta = -2.816$).

The Euclidean similarity index in non-metric multidimensional scaling (NMDS; Fig. 2.3a) for the dry season showed that the camera-trap locations in the uMthatha study area cluster were more similar in microhabitat structure to each other, as indicated by the clustering of study area camera-trap locations around short herbaceous cover and bare ground, whereas the iNgeli and Creighton study area clusters were characterised by tall grass cover, tall herbaceous cover and saplings 0 – 2 m. During the wet season (Fig. 2.4b), the uMthatha camera-trap locations were predominantly characterised by leaf litter, and the Creighton area camera locations were characterised by leaf litter, crown closure, short grass cover and short herbaceous cover. The iNgeli camera-trap locations were characterised by tall herbaceous cover, short grass cover, crown closure and short herbaceous cover; however, they were not distinctly characterised by leaf litter. It is important to note that during the data cleaning process, leaf litter and bare ground showed high multicollinearity. Therefore, the absence of leaf litter meant there was a higher percentage of bare ground cover at camera-trap locations and vice versa.

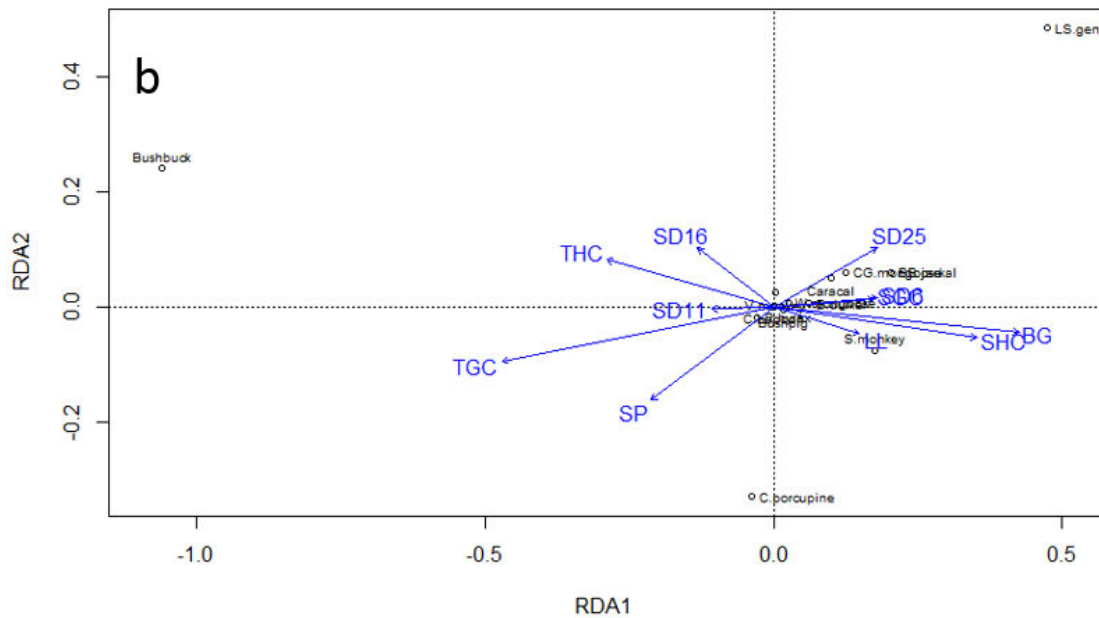
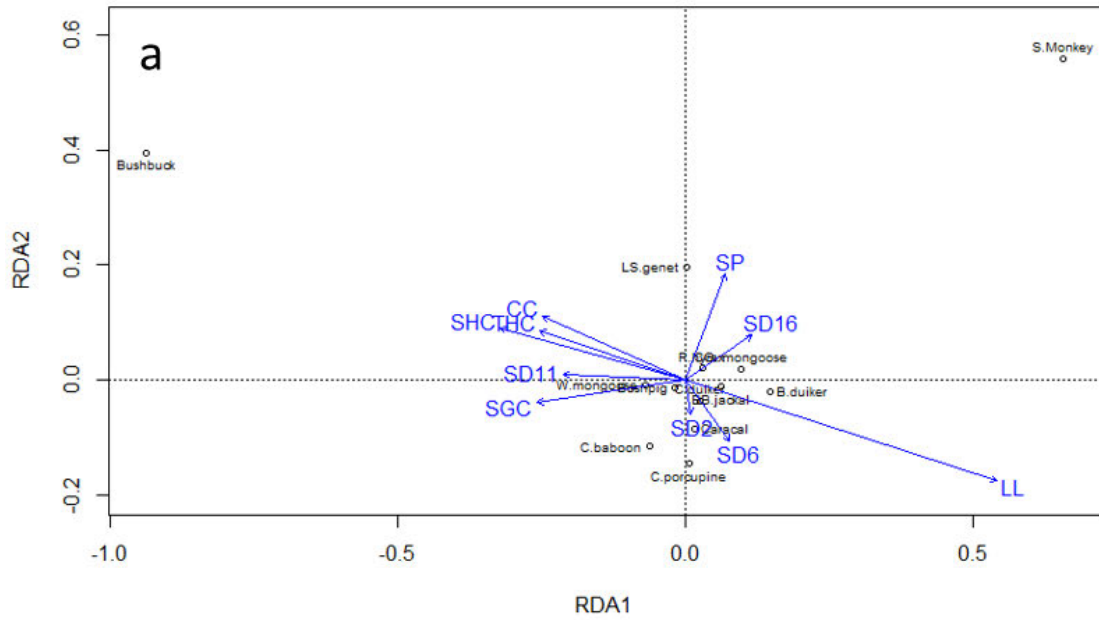


Figure 2.3 Constrained species-environmental RDA biplot showing the influence of microhabitat variables on the Southern Mistbelt Forest large and medium-sized mammalian community in the present study for a) the wet season with variance on the 1st axis is 51 % and an additional 21 % on the 2nd axis and b) the dry season with variance on the 1st axis is 55 % and an additional 16 % on the 2nd axis (BG = bare ground; LL = leaf litter; SGC = short grass cover; TGC = tall grass cover; SHC = short herbaceous cover; THC = tall herbaceous cover;

SP = woody plants and saplings; SD2 – 5 m = stem density of trees 2 – 5 m; SD6 – 10 m = stem density of trees 6 – 10 m; SD11 – 15 m = stem density of trees 11 – 15 m; SD16 – 20 m = stem density of trees 16 – 20 m; SD > 25 m = stem density of trees > 25 m; CC = crown cover).

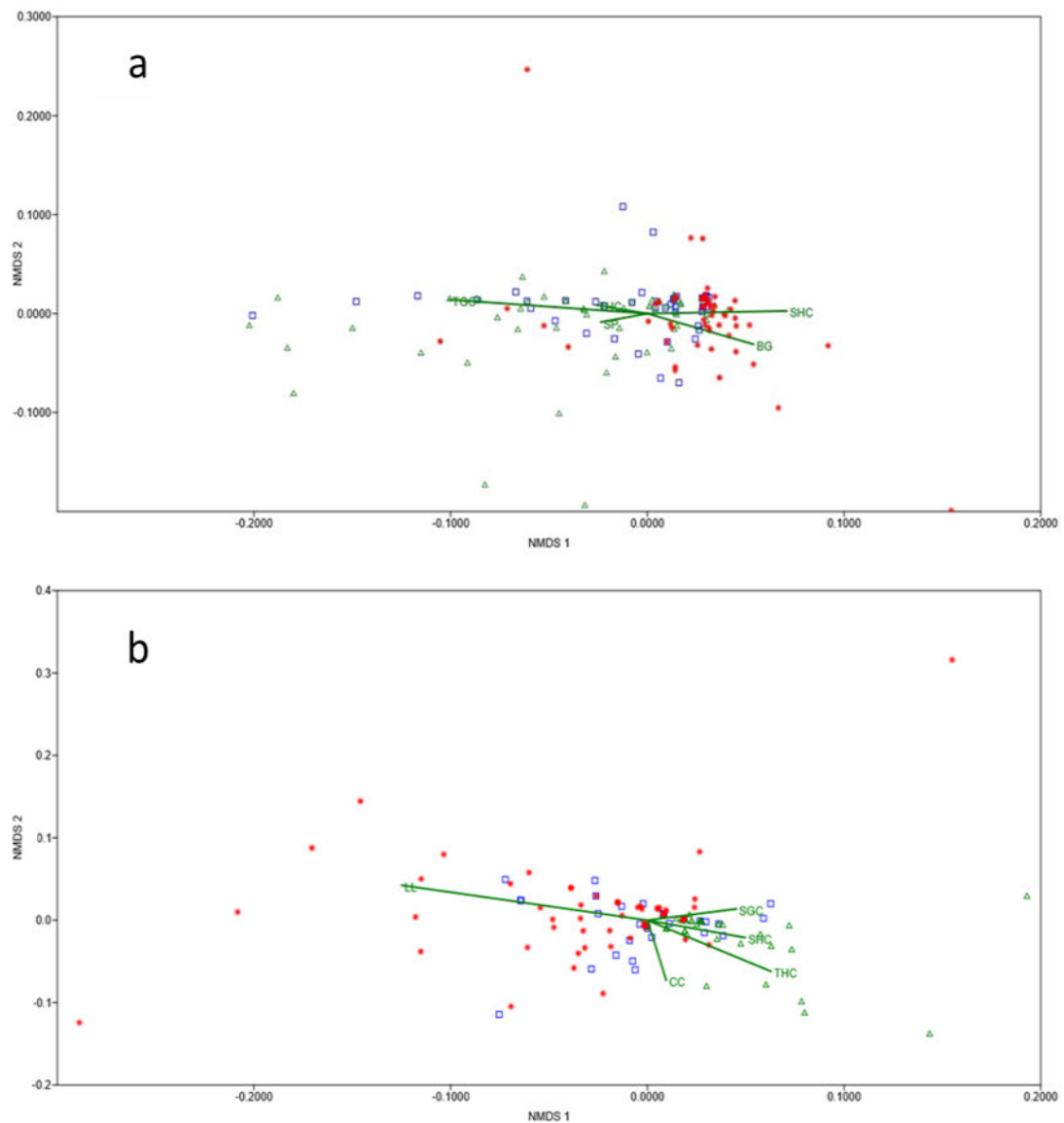


Figure 2.4 Non-metric multidimensional scaling (NMDS) plot using Euclidean similarity index showing the microhabitat structure dissimilarity of camera-trap locations in the three study areas in the present study. The dry season a) NMDS with plot axes 1 + 2; 3D dimensionality (stress: 0.121) and wet season b) with plot axes 1 + 2; 3D dimensionality (stress:

0.0964). The squares (blue), triangles (green) and stars (red) represent Creighton, iNgeli and uMthatha study areas, respectively.

2.5 Discussion

Our research highlighted the role of microhabitat structure in Southern Mistbelt Forest patches on the abundance of large and medium-sized mammalian forest species present in these. We found large and medium-sized mammalian forest species abundance did vary significantly between sampling seasons; however, species richness remained the same. The dry season had a significantly higher abundance of large and medium-sized mammals than in the wet season. A study conducted by Atnafu and Yahune (2018) on forest mammals found that species abundance was higher during the dry season, and this may indicate that there are still resources available that meet mammalian species habitat requirements (Santos-Filho et al. 2012). Furthermore, different microhabitat variables influenced mammalian forest species differently per season. Different microhabitat variables were significantly associated with the mammalian forest communities, with structurally complex microhabitats providing more structures and resources. Consequently, supporting more diverse niches and more diverse species assemblages as found in other studies (Ricklefs 1977; Williams et al. 2002; Tews et al. 2004; Dorph et al. 2020). Our study areas varied in the microhabitat vegetation composition; however, there was more overlap between the iNgeli and Creighton study areas. The uMthatha study area supported more abundant populations of the Vulnerable samango monkey as the microhabitat may be more suitable and less disturbed (Child et al. 2016, 2017). In addition, blue duikers were more abundant in the uMthatha study area.

Blue duikers, which are forest specialists (Child et al. 2016, 2017), were detected in all three forest study areas. However, the overall number of detections and locations where the species was detected was lower than other recent studies conducted in KwaZulu-Natal Province in Coastal and Scarp Forests (Ehlers Smith et al. 2017a, 2018; Zungu et al. 2019). Blue duiker,

a forest floor leaf gleaner, had a positive association with leaf litter, which is consistent with their feeding behaviour (Hanekom and Wilson 1991; Bowland and Perrin 1995; 1998; Ehlers Smith et al. 2017a). Bare ground and tall herbaceous cover were negatively associated with blue duiker abundance. The habitat requirements of blue duikers result in avoiding areas with little to no ground coverage (Hanekom and Wilson 1991). An increase in bare ground and a decrease in tall herbaceous cover means there is limited food availability as well as increased exposure to predation for the blue duiker.

Other forest specialists, such as bushbuck and samango monkeys, which are listed as Least Concern, and Vulnerable, respectively on the red list of mammals of South Africa (Child et al. 2016, 2017), were the two most abundant species captured on camera-traps. Bushbuck were previously shown to be common in our iNgeli study region (Allen-Rowlandson 1986). In our study, the cryptic bushbuck had a negative association with leaf litter, bare ground and short herbaceous cover. This is supported by a study conducted by Coates and Downs (2006), which found that bushbuck mainly use dense vegetation, which they utilise for shelter during the daytime. They may also use dense vegetation as refugia from predators and hunters. Bushbuck detectability was relatively higher during the dry season than the wet season, which may be because of bushbuck venturing out of the forest to forage during the wet season as found in other studies (Skinner and Chimimba 2005; Bayih and Yihune 2018). Several species in this study had lower detections during the wet season; this may be because of considerable vegetation growth, which obstructs the view of the camera-traps, resulting in fewer detections (Rovero and Zimmermann 2016).

Samango monkeys showed a positive association with crown closure, which we expected for an arboreal species that requires a dense connecting crown for movement as well as cover from aerial predators (Chapman and Perez 2001; Piña et al. 2019). The species also was positively associated with the understory microhabitat, namely short herbaceous cover

and short grass cover. They were frequently photographed on the ground where there was relatively short vegetation. Samango monkeys not only forage in the canopy of the forest but also on the ground in short vegetation cover (Nowak et al. 2014), where they forage for fallen ripe fruit (Schlinkert et al. 2016). This allows them to keep a lookout for predators in the open, compared with dense vegetation cover where they could be ambushed while foraging. Samango monkeys also come down to the ground to drink water and forage on insects (Kaplin 2001), particularly those that may be found in the leaf litter. Samango monkeys are typically frugivorous; however, they may supplement their diet with leaves and insects when fruits are limited because of fruiting phenological fluctuations (Lawes et al. 1990). The large-spotted genet and water mongoose had a positive association with bare ground and short vegetation cover, which may be because of not being easily detected in taller vegetation cover. Both mesocarnivores are listed as Least Concern, with a fairly wide range distribution (Child et al. 2016, 2017). Water mongoose also had a positive association with open areas, and Ehlers Smith et al. (2017a) and Streicher et al. (2020) suggested it may be because of the species foraging on insect species in open spaces.

2.5.1 Conclusions

Microhabitat variables played varying roles in the presence of large and medium-sized mammalian species in the native Southern Mistbelt Forest communities. Our prediction that most species identified in our study would be more associated with open or less dense microhabitat (namely leaf litter and bare ground) was supported by our results, which played a role in structuring the large and medium-sized mammalian communities in the surveyed forest patches. However, our study highlighted several microhabitat variables (namely leaf litter, bare ground, crown closure and both types of grass cover) that play a significant role in shaping the overall large and medium-sized mammalian community structure, with variation between the

wet and dry seasons. We believe that maintaining these microhabitat variables as well as the entirety of the forest patches will support the different large and medium-sized mammalian species microhabitat requirements in this forest type. Information detailing the patterns of microhabitat use by forest large and medium-sized mammalian species in forests as well as the specific microhabitat variables that influence their behaviour is important for informing management decisions of conserving and the restoration of forest areas and for promoting the persistence of forest mammals.

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CHAPTER 3

Mammalian assemblages in Southern Mistbelt Forests of the northern Eastern Cape and southern KwaZulu-Natal Provinces, South Africa, and their response to bordering land-use

Mbalenhle T. SOSIBO, David A. EHLERS SMITH, Yvette C. EHLERS SMITH, S. Thobeka GUMEDE, Samukelisiwe P. NGCOBO, Colleen T. DOWNS*

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*Centre for Functional Biodiversity, School of Life Sciences, University of KwaZulu-Natal,
Private Bag X01, Scottsville, 3209, Pietermaritzburg, South Africa*

* **Corresponding Author:** Colleen T. Downs

Email: downs@ukzn.ac.za; **ORCID:** <http://orcid.org/0000-0001-8334-1510>

Other emails and ORCIDs:

M. Sosibo Email: mbalisosibo5@gmail.com; ORCID: 0000-0003-3801-3539

D.A. Ehlers Smith Email: ehlerssmithd@ukzn.ac.za; ORCID: 0000-0002-6357-0751

Y.C. Ehlers Smith Email: ehlerssmithy@ukzn.ac.za; ORCID: 0000-0002-2564-7359

S.T. Gumede Email: thobekagumede123@gmail.com; Orcid: 0000-0001-7879-4312

S.P. Ngcobo Email: sam.p.ngcobo@gmail.com; ORCID: 0000-0002-3924-6089

Running header: Mammalian assemblages in Southern Mistbelt Forests

3.1 Abstract

Anthropogenic activities have resulted in habitat loss and fragmentation across different landscapes. Anthropogenic land-uses adjacent to forest patches may further influence the movement and occupancy of a species. Therefore, we investigated how dominant land-uses, i.e. grassland, human settlement and commercial exotic timber plantations surrounding a forest patch and proximity to the forest edge, influenced the occupancy and detectability of mammalian species in selected Southern Mistbelt Forests. Using camera-traps deployed at 200 points per sampling season, we determined the mammalian species richness, occupancy and detection probability in disjunct Southern Mistbelt Forests in southern KwaZulu-Natal and Eastern Cape Provinces, South Africa. We applied the Royle–Nichols multi-session multi-species hierarchical model to estimate species richness and occupancy of 14 mammalian species. The large-spotted genet *Genetta tigrina* had the highest mean occupancy (0.54; Table 3.2), and the bushbuck *Tragelaphus scriptus* had the highest detection probability (0.14) across all sampling areas. Detection probability was low across all mammalian species (≤ 0.14 ; Table 3.2), whereas occupancy was more variable (0.044 – 0.54; Table 3.2). For most mammalian species, detectability was not influenced by distance from the edge; however, forest specialists, such as the bushbuck and the tree hyrax *Dendrohyrax arboreus* were more likely to be detected at the core as predicted. The core is typically associated with a dense connecting canopy and dense vegetation where these species can take shelter and forage with reduced predation risk. Some species, such as the samango monkey, were influenced by tree plantations as they may aid their movement between patches and provide additional resources. Our results highlighted how adjacent land-uses of grassland, human settlements and commercial exotic timber plantations played varying roles in determining mammalian species occupancy and detectability in the Southern Mistbelt Forest patches.

Keywords: African mammals; Camera-traps; Detection probability; Exotic timber plantation; Forest patches; Grassland; Matrix; Occupancy

3.2 Introduction

Mammalian species are fundamental contributors to seed dispersal, plant recruitment, nutrient cycling and the overall functionality of forests and other habitats (Hedwig et al. 2018). With increasing anthropogenic and natural pressures, including extreme natural environmental changes over time such as the last glacial maximum (Lawes et al. 2007), and wildfires that have contributed to shaping mammalian communities (Breman et al. 2012), there has been an accelerated decline in mammalian communities and populations (Pardini 2004; Lawes et al. 2007; Umetsu and Pardini 2007; Hedwig et al. 2018). The spatial distribution and abundance of mammalian forest species have declined worldwide because of increasing anthropogenic demand for resources resulting in encroachment into their natural habitat, overhunting, heavy logging, habitat loss and fragmentation (Lino et al. 2019; Leaver and Cherry 2020). Hunting and human-wildlife conflict have also resulted in the decline of mammalian forest species abundance and occupancy within patches across mixed land-use matrices (Topp-Jørgensen et al. 2009; Linsey et al. 2011).

Land-uses surrounding forest patches typically shape species community assemblages and the presence/ absence of species within forest patches. Understanding these interactions allows for informed management strategies (McDonald et al. 2015; Ehlers Smith et al. 2018; 2020). Modified habitats may compensate for lack or loss of natural habitats, such as areas for breeding and foraging (Cook et al. 2002). In central Amazonia, Brazil, forest-dependant species are capable of utilising modified habitats, especially to reach more resource-rich tropical rainforest (Gascon et al. 1999). In Ibiúna Plateau, Brazil, eucalyptus plantations *Eucalyptus globulus* increase the connectivity of the landscape, thus facilitating species migration between

habitats (Umetsu et al. 2008). These studies demonstrate the potential importance of the modified habitats for forest specialists and species associated with forests. However, modified habitats still have negative impacts on the persistence of mammals in a fragmented landscape (Fletcher et al. 2018).

Findings by Newark et al. (2014) in northeast Tanzania indicate that small forest-dependent mammals cannot use adjacent habitat types, leading to the species populations genetic variability being restricted. Fragmentation affects mammalian species at different magnitudes within these fragmented habitats (Azeria et al. 2007). The fragmentation of forests results in disjunct patches that may inhibit the movement of mammalian species (Lawes et al. 2000; Singleton et al. 2002; 2004; Fletcher et al. 2018). In the disjunct Afromontane forests of Ethiopia, degraded adjacent habitat types restricted mammalian species use, and movement between these forests, which may negatively affect mammalian populations (Kasso et al. 2017). The disjunction of forest patches also increases edge effects, which negatively impact edge intolerant species (Pardini 2004).

Monitoring strategies that have been implemented for mammalian species include combining cost-effective, non-invasive camera-trapping and occupancy modelling (Ramesh and Downs 2013; 2014). The latter models the probability of a species' occurrence across a broad landscape (McDonald et al. 2015; Ramesh et al. 2016; Hedwig et al. 2018; Li et al. 2018). Camera-trapping is an effective tool that is used for capturing images and identifying mammals and other fauna that are then used for modelling to inform management strategies (Drouilly et al. 2018). The use of non-invasive camera trapping is especially beneficial in detecting evasive species (Tobler et al. 2015; Ramesh et al. 2016) that normally hide at the sound or sight of a human approaching.

Mammals such as the blue duiker (*Philantomba monticola*) and the samango monkey (*Cercopithecus albogularis labiatus*) in the Southern Mistbelt Forests of KwaZulu-Natal and

Eastern Cape Provinces, South Africa, have previously been studied (Lawes 1990, 1992; Eeley et al. 1999; Lawes et al. 2000, 2007; Hayward et al. 2005). However, overall mammalian community dynamics and persistence in KwaZulu-Natal and Eastern Cape Southern Mistbelt Forests likely change over time as the landscape changes because of natural and anthropogenically driven factors. Mammalian species found in these forest patches are also found in different forest types (Scarp and Coastal). Lawes et al. (2007) highlighted that because of the last glacial maximum, mammals from other forest types sought refuge in Mistbelt Forests. Therefore, similar forest-dependent and common species are found in the different forest types. Historically, climate has strongly contributed to the fragmentation of these forests when there have been long periods of drought with frequent fires (Scott et al. 1997). Due to heavy logging between 1860-1940, the quality and size of these forests has considerably reduced and further fragmented by commercial and agricultural practices (McCracken 1986; Lawes et al. 2000; Adie et al. 2013).

Additionally, hunting for bushmeat for the livelihoods of the communities that live close to the forests is a major threat to mammalian species persistence in Mistbelt Forests (Manqele et al. 2018). The increase of bushmeat hunting for sustenance and trade has increased pressures on mammalian species and has resulted in a decline in species numbers (Martins and Shackelton 2019). With increasing pressures from anthropogenic activities and climate change, the mammalian communities that inhabit the inland Southern Mistbelt Forests must be known to inform conservation and management strategies (McDonald et al. 2015; Ehlers Smith et al. 2018).

We used camera-traps to investigate the species richness and multi-species occupancy and detection of mammals (excluding bats) in the natural inland Southern Mistbelt Forests of southern KwaZulu-Natal and northern Eastern Cape Provinces. We then related these to the associated adjacent land cover in the landscape mosaic. Our study aimed to estimate site

occupancy and detection probability of individual mammalian species in the region's inland Southern Mistbelt Forest patches that occur in a mixed land-use mosaic. We predicted that mammalian forest specialists were more likely to be detected at the core of forest patches but have lower occupancy rates than habitat generalists.

3.3 Methods

3.3.1 Study area

Our study area included the disjunct Southern Mistbelt Forests of the northern Eastern Cape and southern KwaZulu-Natal Provinces, South Africa, at ~1000-1500 m a.s.l. Our study took place in three separate forest clusters/ areas (uMthatha, Kokstad and Creighton) with Southern Mistbelt Forest patches of varying size (Fig. 3.1). Each area has a relatively large mainland source forest patch that was presumed to have all or most species present compared with smaller satellite patches (Hanski 1994; Lawes et al. 2000). These mainland source forest patches in each area were Nqadu in uMthatha (31°25'48.71"S 28°45'12.33"E, 548.70 ha), iNgeli in Kokstad (30°31'38.2"S 29°41'33.2"E, 568.94 ha), and Xgalingenwa in Creighton (29°58'34.91"S 29°44'1.61"E, 506.15 ha) with smaller satellite forest patches surrounding them. The dominant tree species include *Afrocarpus* and *Podocarpus* spp. which are near-endemic genera in this forest type (Mucina et al. 2006), and the endemic *Eugenia zuluensis*. The inland Southern Mistbelt Forest areas receive an average of 846 mm of rainfall p.a. and temperatures range from 3°C to 27°C with a temperate climate (Mucina et al. 2006). The Southern Mistbelt Forest patches are nested in the grassland biome, and with other anthropogenic land-use practices such as commercial agriculture (sugarcane (*Saccharum officinarum*)), dairy farming, pecan nut plantations (*Carya illinoensis*), exotic timber plantations (*Pinus patula*, *Acacia mearnsii* and *Eucalyptus* spp.) and human settlements interspersed.

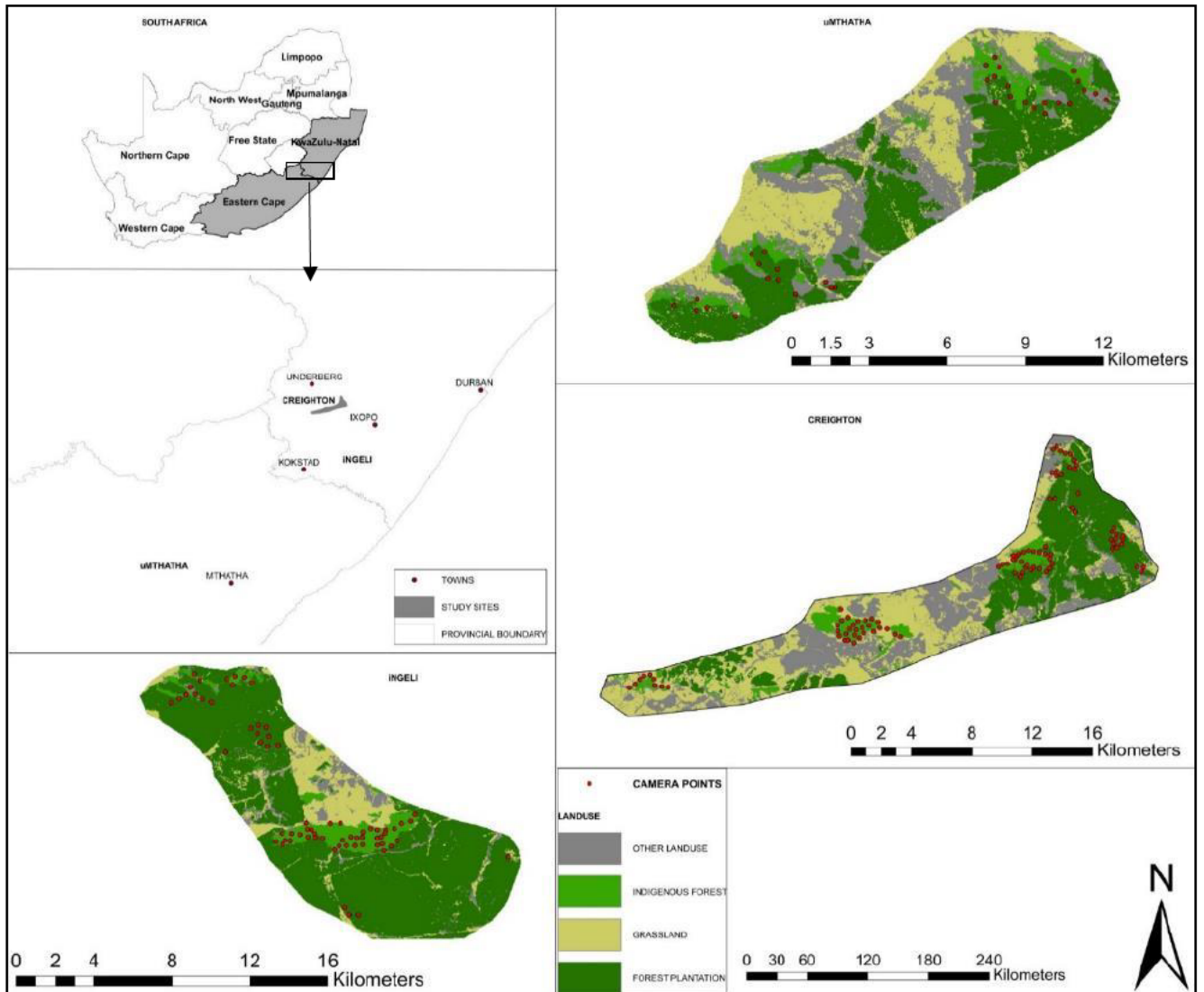


Figure 3.1 Land-use map of the Southern Mistbelt Forest study areas in southern KwaZulu-Natal and northern Eastern Cape, South Africa, with camera-trap sites used in natural forest patches in the present study shown.

3.3.2 Data collection and analyses

We used camera-traps to monitor mammalian species presence/absence at set points determined using a 400 m x 400 m systematic grid system overlaid (Ehlers Smith et al. 2017, 2018) onto Southern Mistbelt Forest patches in ArcGIS v10.5.1 (ESRI 2017). A minimum of 60 infrared motion detection camera-traps at any time were deployed for 24 h a day (with a 30

s motion-triggered delay setting) at each of these locations for a minimum of 21 days, to minimise the likelihood of a change in occupancy (Ramesh and Downs 2014). Each photograph provided information on the date and time. Surveys were conducted between May 2018 – June 2020 during the wet (summer/spring) and dry (winter/autumn) seasons, resulting in one full 21-day survey for each camera-trap site per season. We used fixed camera-traps (60 Cuddleback Black Flash® M-1231 and 15 Moultrie® M-880, EBSCO Industries, Inc., USA), triggered by passive infrared sensors to “capture” digital photographs of passing animals. Camera-traps were each set at the height of 20 – 30 cm above the ground and generally attached to a robust tree on a game trail or within a clear open area according to protocols followed from Ramesh and Downs (2013, 2015) and Ehlers Smith et al. (2017, 2018). Species photographed more than once within an hour were only counted as one occurrence.

To determine the land-use around each camera-trap survey point, we used a Geographic Information System (GIS) program ArcGIS v10.5.1 (ESRI 2017) to extract the land-use classification within a 1 km buffer around each forest patch sampled. We extracted the land-use cover data from the latest land-cover GIS layer map (GeoTerra Image 2014). The following land-use covers were identified: natural/indigenous forest, woodland, low shrubland, exotic timber plantations, bare ground, urban/settlements, water/wetlands, thicket/dense bush, cultivated land, and grassland. We calculated the shortest distance of each camera-trap from the forest patch edge in ArcGIS v10.5.1 (ESRI 2017). To categorise the different zones, we used the minimum, medium and maximum of our values as well as taking into account that edge effects can penetrate up to about 100 m into the forest (Laurance et al. 1998) and made categories suitable for this study. We classified the distance to edge categories as edge zone (0 – 100 m), interior/intermediate zone (101 – 300 m) and core zone (301 – 605 m). We used the extended version of the multi-session Royle-Nichols (RN) multi-species occupancy model (Royle and Nichols 2003; Tobler et al. 2015) with additional hierarchical levels for sessions.

We calculated estimates of relative species richness for each study site using the mammalian species detected (MacKenzie et al. 2006; Russell et al. 2009; Burton et al. 2012). The observed data were y_{ij} , the number of sampling occasions out of a total of k_j sampling occasions (two sampling 21-day surveys per study site) that the species i was detected at camera-trap j . The 21-day session index t was modelled as a random effect on occupancy and detection for the analyses. The modelled observed data included three hierarchical levels under Royle–Nichols multi-session multi-species occupancy model (Tobler et al. 2015): the session-level mammalian community, the camera-trap level community and the detection process. We treated sampling days as a random factor to improve parameter estimates (i.e., occupancy and detection probability) for species with low detections by making use of information across sessions and allowing for a variation between sessions (Schaub and Kery 2012). We modelled the variance component for the random factor (sampling days) using a half-Cauchy distribution (Gelman 2006). Firstly, we modelled species abundance a_{ij} governed by the Poisson rate parameter λ_{ij} , representing the number of individuals using the area around a camera-trap. Secondly, we replaced the detection parameter p_{ij} in the detection process of the previous model by a function of r_{ij} , the per-individual detection probability, and of a_{ij} , the total number of individuals of species i exposed to detection at study site j . Thus, our model can be described concisely as follows:

$$w_{it} \sim \text{Bernoulli}(\Omega_i)$$

$$a_{ij} \sim \text{Poisson}(\lambda_{ij})$$

$$y_{ij} \sim \text{Binomial}(k_j, 1 - (1 - r_{ij})^{a_{ij} \times w_{it}})$$

and

$$\text{logit}(r_{ij}) = v_i + v.xi_i \times v.eta_{it} + v.path_{ij}$$

$$\text{logit}(r_{ij}) = u_i + u.xi_i \times u.eta_{it} + u.habitat_{ij}$$

Occupancy probability is a deterministic function of the estimated abundance distribution and can be expressed as $\Psi_{ij} = 1 - \exp(-\lambda_{ij})$ (Royle and Nichols 2003). Therefore, occupancy was modelled as a function of dominant landscape variables tree plantations, human settlements and grassland. We conducted analyses in the program R (R Core Team 2016) using the packages: R2WinBUGS (Sturtz et al. 2005), R2JAGS (Su and Yajima 2014), reshape (Wickham 2018), reshape2 (Wickham 2020), ggplot2 (Wickham 2016), and coda (Plummer et al. 2006). We ran the models with three parallel chains, 999 iterations, with a burn-in of 300 and thinning rate 20. We analysed all the data where we considered each sampling day as a sampling occasion, and we used 7-day pooled data to reduce heterogeneity. To assess convergence, we visually inspected the chains and the R-hat values for each parameter estimate. To assess model fit, we used Pearson's residuals by comparing the observed residuals (χ^2_{obs}) to residuals (χ^2_{sim}) from data simulated under the model. We calculated the Bayesian P -value as $\Pr(\chi^2_{\text{obs}} > \chi^2_{\text{sim}})$ with values outside the range 0.05 to 0.95 indicating a lack of fit as well as a 'lack-of-fit' statistics $\chi^2_{\text{obs}} / \chi^2_{\text{sim}}$ which is expected to be equal to 1 if the model fits the data perfectly (Kery and Schaub 2012).

3.4 Results

Of the 210 camera-trap points, we had to remove 41 from analyses because of theft and malfunction; however, the data obtained from the remaining cameras were sufficient for analyses. Total mammalian species captures counted for 1774 incidences for 8820 trap-days. Using Welch's sample t-test, we found that seasonality did not have a significant effect on mammalian species abundance ($p = 0.826$, $t = -0.237$, $df = 3.488$, Table 3.1) in the Southern Mistbelt Forest patches. Land-use data around each forest patch were extracted, with settlements, exotic timber plantations and grasslands identified as the dominant adjacent land-uses. The dominant land-uses had the highest proportion, therefore, they were selected for

analyses. Creighton was the only study area where human settlements were a dominant land-use around patches. Mammalian species detections across all sampling areas ranged from 6 – 583 incidences (Table 3.2), with the bushbuck *Tragelaphus scriptus* having the highest detections across all three sampling areas, and the vervet monkey *Cercopithecus pygerythrus* having the lowest. The goodness-of-fit test showed an acceptable fit of the RN model to our data (Bayesian p -value = 0.86, lack of fit = 1.07).

Table 3.1 Mammalian species richness in the three study areas of Southern Mistbelt Forests during a single South African wet and dry season in the present study.

Study site	Season	
	Dry	Wet
Creighton	10.67	11.95
iNgeli	11.43	12.21
uMthatha	13.27	10.55

3.4.1 Species occupancy and detection in relation to sampling sites

In our study of Southern Mistbelt Forest patches, the samango monkey had the highest species' occupancy in both of the uMthatha area (0.69) and iNgeli area (0.60), and the Cape or large-spotted genet *Genetta tigrina* had the highest occupancy in the Creighton area (0.56). The blue duiker occupancy was relatively low across all three sampling areas ranging from 0.045 – 0.13. The large-spotted genet had a relatively similar occupancy rate across all three sampling areas ranging from 0.50 – 0.56 and was ranked one of the species with the highest occupancy (Fig. 3.2a).

In our study, species detection probability was relatively low across all species and between sampling areas (0.047 – 0.29, Fig. 3.2b) in the Southern Mistbelt Forests. The species

with the highest detection probability in a sampling area was the blue duiker in the uMthatha area (0.29, Fig. 3.2b). However, its detectability in the other two sampling areas varied significantly, with relatively low values (0.047 – 0.064). The tree hyrax *Dendrohyrax arboreus* had the lowest detection probability in Creighton (0.052) and uMthatha (0.051, Fig. 3.2b). Four species showed relatively consistent detection probability and low variance across all three sampling areas: the Cape porcupine *Hystrix africaeaustralis* (0.070 – 0.14), black-backed jackal *Lupulella mesomelas* (0.10 – 0.11), bushpig *Potamochoerus larvatus* (0.084 – 0.098) and the common duiker *Sylvicapra grimmia* (0.063 – 0.073).

3.4.2 Species occupancy and detection relative to land-use

Most of the mammalian species (n = 9; 64 %) were most likely to occupy forest patches surrounded by exotic timber plantations. The mammalian species that showed higher occupancy rates in forest patches adjacent to exotic timber plantations were samango monkey (0.65; Table 3.2), large-spotted genet (0.49; Table 3.2) and tree hyrax (0.39; Table 3.2). The forest specialist blue duiker's occupancy rates were relatively low across all land-use types (0.07 – 0.17; Table 3.2). However, species occupancy in indigenous forests with an exotic timber plantation adjacent/dominant was 0.24 in comparison with grassland (0.09; Table 3.2) and human settlements (0.15) adjacent/dominant area (Table 3.2). The detection probability of the large-spotted genet was relatively higher in forest patches surrounded by human settlements (0.28; Table 3.2).

2 **Table 3.2** Forest-dependent and common mammalian species detections (N), occupancy (ψ) and detection probability (r) across different land-uses in the present study.

Common name	Latin name	Regional red	Forest habitat	Detections						
		list	association	(N)	Plantation (ψ)	Grassland (ψ)	Settlement (ψ)	Edge (r)	Interior (r)	Core (r)
Black-backed jackal	<i>Lupulella mesomelas</i>	LC	Generalist	49	0.24	0.09	0.15	0.10	0.10	0.11
Blue duiker	<i>Philantomba monticola</i>	VU	Specialist	116	0.17	0.07	0.07	0.13	0.13	0.13
Bushbuck	<i>Tragelaphus scriptus</i>	LC	Generalist	583	0.33	0.67	0.23	0.14	0.14	0.15
Bushpig	<i>Potamochoerus larvatus</i>	LC	Generalist	70	0.22	0.11	0.08	0.09	0.09	0.09
Cape porcupine	<i>Hystrix africaeaustralis</i>	LC	Generalist	176	0.28	0.32	0.23	0.13	0.13	0.13
Cape-grey mongoose	<i>Herpestes ichneumon</i>	LC	Generalist	150	0.25	0.10	0.20	0.07	0.07	0.07
Caracal	<i>Caracal caracal</i>	LC	Generalist	50	0.26	0.19	0.14	0.07	0.06	0.07
Chacma baboon	<i>Papio ursinus</i>	LC	Generalist	96	0.08	0.11	0.06	0.07	0.06	0.07
Common duiker	<i>Sylvicapra grimmia</i>	LC	Generalist	35	0.23	0.07	0.09	0.07	0.07	0.07
Large-spotted genet	<i>Genetta tigrina</i>	LC	Generalist	319	0.17	0.09	0.28	0.05	0.05	0.05
Samango monkey	<i>Cercopithecus albogularis labiatus</i>	VU	Specialist	302	0.65	0.46	0.50	0.13	0.13	0.13
Tree hyrax	<i>Dendrohyrax arboreus</i>	VU	Specialist	7	0.58	0.35	0.64	0.08	0.08	0.09
Vervet monkey	<i>Cercopithecus pygerythrus</i>	LC	Generalist	6	0.06	0.03	0.04	0.06	0.06	0.06
Water mongoose	<i>Atilax paludinosus</i>	LC	Generalist	15	0.06	0.04	0.04	0.11	0.11	0.11

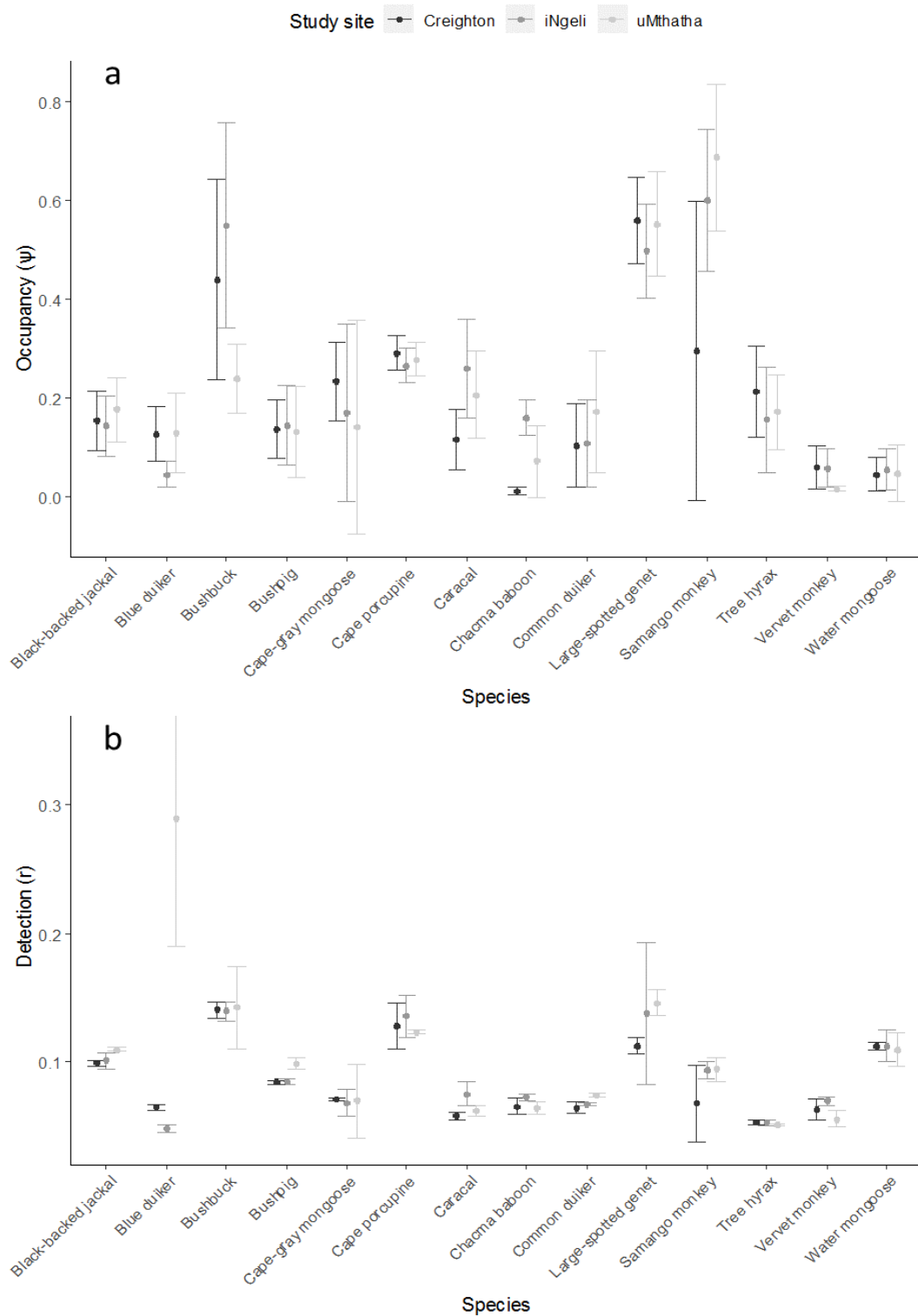


Figure 3.2 Mammalian species found in Southern Mistbelt Forests mean (a) occupancy (ψ) and (b) detection probability (r) per study site area with the standard error shown in the present study.

3.4.3 Overall species detection and occupancy

The positioning of camera-traps at the core, interior, and edge of a forest patch did not significantly affect species detection. Generalist mammalian species, the Cape porcupine, the water mongoose *Atilax paludinosus* and the black-backed jackal detection ranged from 0.10 – 0.13 (Table 3.2). Forest specialist species, the blue duiker and the samango monkey, showed a higher detection probability overall (0.13 – 0.15; Figure 3.2b). Overall, the large-spotted genet had the highest mean occupancy (0.54; Figure 3.2a), with the bushbuck having the highest detection probability (0.14) across all sampling areas and types of the dominant land-use present. The samango monkey had the second highest mean occupancy across all sampling areas and land-use types (0.53; Figure 3.2a), with the vervet monkey having the lowest occupancy (0.044) and detection (0.062).

3.5 Discussion

Our findings demonstrated that varying anthropogenic land-use surrounding indigenous forests influenced the occupancy rates of forest-dependent and generalist mammalian species. Additionally, the prediction that habitat generalists would have higher occupancy rates was rejected as the forest-dependent species, samango monkey and tree hyrax, had relatively higher occupancy rates. It has become crucial to understand how our anthropogenically changing landscapes affect native species and their habitats, given the accelerating loss of natural habitats because of anthropogenic activities, especially in Africa (Adie et al. 2013; Tilman et al. 2017; Ehlers Smith et al. 2020). In southern Africa, forest habitats, a relatively small biome but high in biodiversity, are threatened by anthropogenic activities (Leaver et al. 2019; Gumede et al. 2020; Zungu et al. 2020a,b).

The land-use around each Southern Mistbelt Forest patch in our study varied, but settlements, exotic timber plantations and grasslands were the dominant adjacent land-uses. Various anthropogenic land-use types, such as the commercial pine, wattle, and eucalyptus plantations, have typically resulted in fragmented forest patches across the landscape, resulting in decreased species populations and forest clear-felling or reduction in size (Armstrong et al. 1998; Wethered and Lawes 2003). However, it is noteworthy that climatic periods of drought and frequent fires resulted in reduced forest sizes and altered forest structure and composition, inadvertently affecting mammalian species (Scott et al. 1997). Frequent fires on the forest edge change structure and composition of the vegetation on the edge, increasing the area that is unable to support species that are dependent on conditions mainly found in the interior, which are generally forest-dependent species (Fisher and Wilkinson 2005; Pires et al. 2005). This may then increase the amount of habitat that generalist species may exploit.

One of the key findings in our study was the importance of exotic tree plantations surrounding indigenous forest patches to the persistence of mammalian species. Exotic tree plantations can be important for mammalian species in a mixed land-use mosaic. These plantations are typically at different ages of maturity with structural and compositional differences so that they can support certain mammalian species with varying habitat requirements and life-history traits (Fernández et al. 2021). The maturity and condition of exotic timber plantations surrounding forest patches in our study also varied and may influence the area's use and suitability by mammalian species, particularly forest specialists. The iNgeli and uMthatha study areas had more mature exotic timber plantations that were taller and gave more cover around the forest patches than newly planted adjacent timber plantations (pers. obs.).

In our study, site-specific occupancies for samango monkeys were higher in uMthatha and iNgeli Southern Mistbelt Forests. Here, the dominant surrounding land-use was mature pine plantations that have been considered arboreal corridors by Lawes et al. (2000). These may have contributed to the higher occupancy rates at the sites in these areas. For example, samango monkeys have been known to forage in adjacent black wattle plantations (Lawes et al. 2000), and mature exotic timber plantations, although structurally homogenous, can facilitate the movement of these species within their canopies in comparison with on the ground in open areas (e.g., grasslands). Forest associated primate species are rarely found in open areas where there is limited proximity to trees and shrubs, which would increase their exposure to predation (Emerson et al. 2011; Coleman and Hill 2014). This also lowers the cover they receive from a dense canopy that may be a refuge from avian predators such as the African crowned eagle (*Stephanoaetus coronatus*) (McPherson et al. 2016a,b; 2019). Travelling or foraging on the ground also exposes primates to terrestrial predators (Emerson et al. 2011; Coleman and Hill 2014), such as black-backed jackal, domestic hunting dogs *Canis lupus familiaris* and caracal *Caracal caracal*.

Generalist mammalian species such as the large-spotted genet were positively influenced by human settlements adjacent to Southern Mistbelt Forests in our study, most likely because of the species' ability to successfully exploit different habitats, including urban environments as found in other studies (Ramesh and Downs 2014; Widdows et al. 2015). The large-spotted genet uses open areas to forage for insects and small rodents and uses dense areas such as forests for shelter, reducing predation risk (Ramesh and Downs 2014). Bushbuck had the second-highest occupancy in the iNgeli sampling area, which was dominated by adjacent pine plantations (*Pinus patula*) in the landscape mosaic. Allen-Rowlandson (1986) similarly found high densities of bushbuck here and in surrounding exotic timber plantations. This was further supported by

bushbuck having a higher occupancy in areas with exotic timber plantations on the periphery of forests in our analyses. Our study concurred with Ramesh and Downs (2015) by showing that bushbuck were more likely to use areas where there were exotic timber plantations, and these plantations may act as a buffer zone that may provide resources in different seasons (Irwin et al. 2010).

The generalist black-backed jackal was similarly more likely to occupy Southern Mistbelt Forest areas where the dominant bordering land-use was exotic timber plantations. This species preys on smaller mammals such as rodents in dense forest/woodland areas (Hayward et al., 2017) and livestock from neighbouring communities (Ramesh and Downs 2015; Humphries et al. 2016). As a generalist species, the black-backed jackal is able to exploit various environments such as forest/woodland, savanna, arid regions like the Nama Karoo and grasslands (Klare et al. 2010; Humphries et al. 2016). In the case of our study, black-backed jackal may use the grassland area, particularly those close to human settlements, as a hunting ground to prey on livestock that openly grazes throughout the day in grassland nearby beside forests (pers. obs.). Black-backed jackals tend to hunt in pairs or groups when there is an opportunity to take down larger prey, such as domestic sheep *Ovis aries* (Hayward et al. 2017).

The mammalian forest specialist, the blue duiker, had a relatively low occupancy in Southern Mistbelt Forests in our study across all adjacent land-use types. However, the blue duiker had the highest detection probability at the uMthatha study area, and the forest core, interior and edge did not influence blue duiker detectability. Detection probability for most mammalian species in our study in Southern Mistbelt Forests showed little to no variation; however, the bushbuck and the tree hyrax were more likely to be detected at the core as predicted. However, exotic timber plantations are known to alter the forest margin microclimate, and they grow taller, which results

in shading and drying out the forest margin (Pryke and Samways 2012). This would further affect species occupancy within the forest margin and the transitional area into the bordering vegetation (ecotone). Furthermore, natural and human-induced fires in grasslands often result in the depletion of the forest canopy on the forest edge (Kertesz et al. 2017; Puttker et al. 2020), inadvertently creating unfavourable conditions for species that require a closed canopy and dense vegetation. Food availability and quality at the edge may be lower or vary significantly compared with the core area, and that may also influence the habitat use and species density of mammals, particularly forest specialists (Irwin et al. 2010).

Other factors that may have influenced mammalian forest species detectability in our study were livestock grazing, particularly at the forest edge, and hunting, which were both observed during data collection. Livestock grazing at the edge degrades the vegetation quality by trampling saplings and decreasing vegetation diversity, making the habitat less suitable for mammals (Soofi et al. 2018), particularly for ungulates that forage on similar vegetation (Schielitz and Rubenstein 2016). While sampling, we occasionally saw hunters with packs of hunting dogs around the forest patches and found snares mostly in the forest patch edges. We also recorded hunters on camera-traps occasionally. Hunting for bushmeat, animal skins and/or medicinal purposes has resulted in the decline of mammalian species abundance and diversity (Hayward 2009; Hegerl et al. 2017) and maybe why some species are not detected at the edge because of the possible fear of a higher level of exposure to hunters. Hayward (2009) and Jones et al. (2019) noted that protected areas with fences and guards positively reduce hunting pressure. However, most forest patches sampled in our study have protected status but do not have measures in place to prevent unwarranted entry, such as fences (pers. obs.).

3.5.1 Conclusions

In our study, mammalian species found in the Southern Mistbelt Forests of southern KwaZulu-Natal and northern Eastern Cape had varying site occupancies and responses to bordering land-use as found in other recent southern African forest studies (Ehlers Smith et al. 2020; Zungu et al. 2020a,b). Some species, such as the samango monkey, were influenced by plantations as they may aid their movement between patches and provide additional resources. Land-use directly surrounding forest patches also played a role in the occupancy of forest patches by mammals such as the blue duiker and common duiker and how they used and distributed themselves within the forest patches. These species would also forage for resources in the adjacent land-use when resources were scarce in the indigenous forests. Our results highlight how the bordering land-uses of human settlements, grassland and commercial pine plantations play an integral role in mammalian occupancy in the Southern Mistbelt Forest patches as well as their detectability. Exotic timber plantations adjacent to these forests have notably been documented as a type of habitat conversion that negatively affects mammalian forest communities. However, they are frequently considered “forests” in landscape assessments and can provide corridors between forest patches of conservation value. By identifying and conserving these habitats, such as grasslands and tree plantations, within a landscape, we increase the chances of species populations success over time. In our study, forest specialists, bushbuck and tree hyrax, were more likely to be detected at the core rather than the edge of the Southern Mistbelt Forests. More research is needed to examine the role of these forests' core structure, especially for the conservation of forest specialists that depend on the core forest structure for survival.

3.6 Acknowledgements

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CHAPTER 4

Testing the response of mammalian species richness and functional diversity to forest patch size and isolation in Southern Mistbelt Forests of South Africa

Mbalenhle T. SOSIBO ¹, David A. EHLERS SMITH ¹, Yvette C. EHLERS SMITH ^{1,2}, S. Thobeka GUMEDE ¹, Samukelisiwe P. NGCOBO ¹, Colleen T. DOWNS ^{1*}

¹ *Centre for Functional Biodiversity, School of Life Sciences, University of KwaZulu-Natal, Private Bag X01, Scottsville, 3209, Pietermaritzburg, South Africa*

² *Ezemvelo KwaZulu-Natal Wildlife, Queen Elizabeth Park, Peter Brown Drive, Montrose, Pietermaritzburg, 3201, South Africa*

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* **Corresponding Author:** Colleen T. Downs

Email: downs@ukzn.ac.za; **ORCID:** <http://orcid.org/0000-0001-8334-1510>

Other emails and ORCIDs:

M. Sosibo Email: mbalisosibo5@gmail.com; ORCID: 0000-0003-3801-3539

D.A. Ehlers Smith Email: ehlerssmithd@ukzn.ac.za; ORCID: 0000-0002-6357-0751

Y.C. Ehlers Smith Email: ehlerssmithy@ukzn.ac.za; ORCID: 0000-0002-2564-7359

S.T. Gumede Email: thobekagumede123@gmail.com; ORCID: 0000-0001-7879-4312

S.P. Ngcobo Email: sam.p.ngcobo@gmail.com; ORCID: 0000-0002-3924-6089

Running header: Mammalian forest functional diversity and species richness

4.1 Abstract

Anthropogenic land-use change affects species movement, resource use, persistence and causes declines in species diversity. In Africa, forest mammals are particularly affected. In recent years, researchers worldwide have used functional diversity metrics to understand changes in the landscape and how they affect species communities and the ecosystem functioning in habitats that they inhabit. Our study aimed to evaluate the response of forest mammal's functional diversity and species richness to factors such as forest patch size and isolation distance, forest structural complexity, and landscape configuration (via the number of neighbouring forest patches). We used linear mixed-effects models to assess the response of functional diversity indices and species richness to patch size, forest structural complexity and other continuous explanatory variables. We calculated β -diversity and partitioned it into its additive components of species spatial turnover (β_{sim}) and nestedness (β_{nes}). Forest patch size and forest structural complexity were associated with the highest functional diversity indices. Patch size often had a positive association with higher species richness and diversity. The more fragmented a landscape was, the lower the number of species present in forest patches, implying difficulty of movement between patches. We highlight that patch size is an important explanatory variable in understanding mammalian species' persistence in a constantly changing disjunct mosaic landscape. We show the importance of forest structural complexity as it promoted functionally diverse mammalian communities and enhanced ecosystem functioning. The conservation of larger, structurally diverse forest patches in the Southern Mistbelt Forests may result in the continued persistence of the forest mammal communities.

Keywords Fragmentation, forest structural complexity, traits, beta diversity, resource availability

4.2 Introduction

Biodiversity declines are attributed to increased anthropogenic land-use intensification and transformation (Betts et al. 2014; Hatfield et al. 2018; da Silva et al. 2020). Land-use transformations include agriculture, mining, urbanisation and more (Santos-Filho et al. 2012). The loss of biodiversity has resulted in the impairment of the ecosystem functioning as the provisioning of ecosystem services become constrained (da Silva et al. 2020). The continuous disturbance of natural environments has had detrimental effects on wild species and populations as habitat area has been significantly reduced and habitat patches become isolated from each other (Fahrig 2003). This then results in the impediment of species dispersal, loss of genetic diversity, and declines in abundances, particularly for those sensitive to disturbance (Harrington et al. 2001; Fahrig 2003; Santos-Filho et al. 2012; Lino et al. 2019). The functionality of an ecosystem that is able to support a diverse array of species is highly dependent on the maintenance of species functional diversity (Flynn et al. 2009).

Functional diversity measures the value, range and density of functional traits in a community that influence how an ecosystem functions (Petchey et al. 2004; Mason et al. 2005; Villéger et al. 2008; Sukma et al. 2019; Thakur and Chawula, 2019). Functional diversity has been used as a means to gauge the relationship between biodiversity and ecosystem functions (Magioli et al. 2015). Measures of functional diversity incorporate the functional traits present within community assemblages, which gives insight into the relationship of species and the ecosystem as well as what may cause changes to the overall system (Thakur and Chawula 2019).

Changes in species' compositions within communities may be assessed using the β -diversity component, which acts under the processes of species nestedness and spatial turnover (Palmeirim et al. 2018; Zungu et al. 2019; Regolin et al. 2020). Nestedness describes dissimilarity

or difference of species richness between communities, which may contain nested subsets of communities present in the larger γ (gamma diversity) pool (Baselga 2010; Regolin et al. 2020). Nestedness has been used in ecological studies to help determine which species or traits in communities are likely to go extinct if there are any further advancements to biotic or abiotic disturbances that the species may be sensitive to (Zungu et al. 2019). With the loss or extinction of species, there may be a loss of biological traits or ecological functions within a species community and habitat (da Silva et al. 2020). Species turnover measures the replacement of species or traits between communities as certain species with vulnerable traits may be replaced by other tolerant species along an ecological gradient (Baselga 2010).

Forest mammals make considerable contributions to the functioning of forest ecosystems (Garmendia et al. 2013), and the removal or disturbance to this group of species may be detrimental to forest dynamics (Rovero et al. 2014; Lacher et al. 2019). Tropical regions of Africa and Asia host the larger species richness of forest mammals as well as the highest diversity, with several species that are highly threatened (Han et al., 2016). African mammalian species have been subjected to various threats throughout Africa, including extensive logging, urbanisation and agricultural expansion, climate change, increasing human population growth, roads and overhunting (Laurance et al. 2005; Thuiller et al. 2006; Di Marco et al. 2014). As road networks are expanding, human accessibility to forest habitats has increased, resulting in easier access for hunters. With increasing populations and especially in impoverished communities, bushmeat is an important source of protein and possible income through the selling of meat and hides (Fa and Brown 2009; Topp-Jørgensen et al. 2009). The alteration of the landscape by human activity may also result in disturbances to mammal behaviours such as migration (Thuiller et al. 2006).

The Southern Mistbelt Forests (Afromontane) in KwaZulu-Natal and Eastern Cape Provinces, South Africa, have been subjected to extensive anthropogenic disturbance over long periods of time. Historically, the Southern Mistbelt Forests were extensively logged by colonial settlers from the 1850s to the early 1940s, particularly for their yellowwood species (*Podocarpus* and *Afrocarpus* spp.) (King 1941; Wirminghaus et al. 1999). However, illegal harvesting has continued (Adie et al. 2013). Cattle and other livestock grazing in the forest are considered a threat to these forests as their intrusion into the forests has resulted in the trampling of vegetation and increased competition for resources that are used by forest mammals (Lamperty et al. 2020). Furthermore, livestock decreases the vegetation diversity, which makes the habitat less suitable for forest mammals to inhabit (Scoofi et al. 2018). The frequent burning of the forest margin has resulted in an altered vegetation structure, composition, and microclimate, affecting the plants and the forest mammals (Lawes et al. 2006). Hunting for bushmeat has also plagued the Southern Mistbelt Forests. Forest species in these forests are hunted for meat, hides, sport, retaliatory killing and cultural purposes (Lawes et al. 2004). Historically, communal hunting in the Eastern Cape by inhabitants was conducted on a large scale which may have resulted in mammal population numbers decreasing drastically (Castley and Kerley 1996).

Our study aimed to evaluate the response of forest mammal's functional diversity and species richness to factors such as patch size, forest structural complexity (FSC), forest patch isolation and landscape configuration (via the number of neighbouring forest patches). Our focus was a subset of Southern Mistbelt Forest patches that lie in a habitat mosaic in the Eastern Cape and KwaZulu-Natal provinces of South Africa. We predicted that functional diversity indices and species richness would have a positive association with increasing patch size and a negative association with increasing isolation distance from neighbouring forest patches. We also predicted

that forest structural complexity would have a positive association with the functional diversity indices and mammalian species richness, as more diverse forest structures provisioned a higher number of utilisable resources and niches.

4.3 Methods

4.3.1 Study areas

Our study areas included the historically disjunct Southern Mistbelt Forests (Mucina and Geldenhuys 2006) of the northern Eastern Cape and southern KwaZulu-Natal Provinces, South Africa, at ~ 1000- 1500 m a.s.l. These forests have been affected by both anthropogenic activities and climate change which has reduced the size of forest patches and increased isolation effects (Eeley et al. 1999; Hughes et al. 2005). Today Southern Mistbelt Forests of KwaZulu-Natal are smaller in size and are within an extensively modified landscape matrix (Eeley et al. 2001) because of the historical events that shaped these forest patches (Lawes 1990). Our study took place in three different forest areas (uMthatha, Glengarry/Weza [termed iNgeli hereafter] and Creighton; (Fig. 4.1) within Southern Mistbelt Forest patches of varying size (5.75 – 718.28 ha). The forest type is also referred to as yellowwood forest because the forest patches are dominated by the *Podocarpus* or *Afrocarpus* genera (Mucina et al. 2006). The inland Southern Mistbelt Forest areas receive a mean 846 mm rainfall p.a., and ambient temperatures range from 3 °C – 27 °C, with a temperate climate (Mucina et al. 2006). The South African (east coast) wet and dry seasons occur from October to March and June to August, respectively. The Southern Mistbelt Forest patches are nested in the grassland biome, with other land-use practices surrounding them, predominantly exotic tree plantations (*Pinus patula*, *Acacia mearnsii* and *Eucalyptus* spp.) and human settlements.

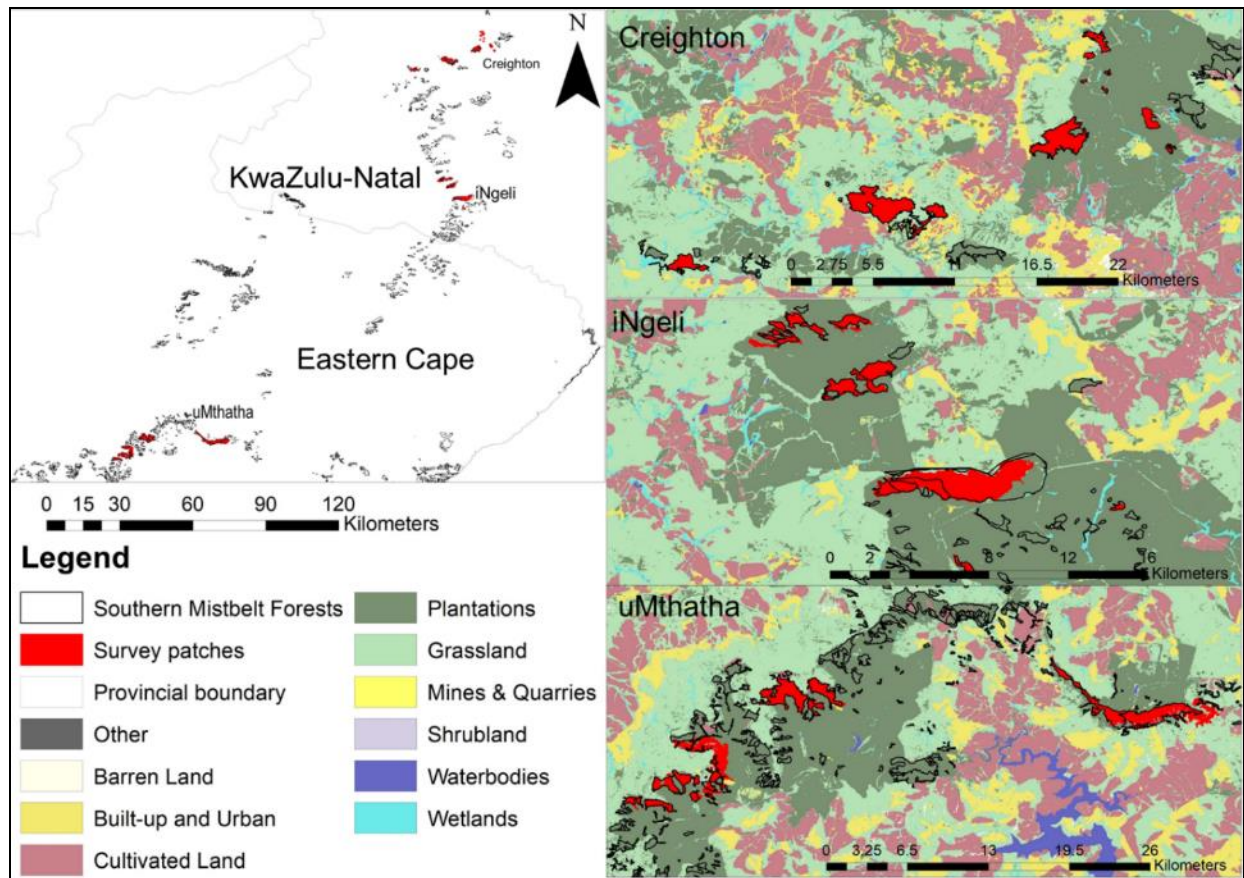


Figure 4.1 Location of surveyed Southern Mistbelt Forests in the southern KwaZulu-Natal and northern Eastern Cape Provinces of South Africa in the present study.

4.3.2 Mammal surveys

We used infrared motion detection camera-traps to monitor mammalian forest species at set camera-trap locations determined using a 400 m x 400 m systematic grid system overlaid onto Southern Mistbelt Forest patches in Arc GIS v10.5.1 (ESRI 2017). Data collection protocols for this study followed Ramesh and Downs (2013, 2015) and Ehlers Smith et al. (2017, 2018) and are detailed below. We used stationary camera-traps (60 Cuddeback Black Flash® model 1231 and 15 Moultrie® model 880, EBSCO Industries, Inc., USA), triggered by passive infrared sensors to “capture” digital photographs of passing animals. Camera-traps were set at the height of 20 – 30

cm above ground, attached to a robust tree. A minimum of 60 camera-traps at a time was deployed for 24 h /day (with a single shot 30 s time-lapse setting whereby photographs were taken every 30 s when the camera-trap was triggered by movement in its range) at each of these geographical locations for a maximum of 21 days (c.f. Ehlers Smith et al. 2017). We conducted surveys between May 2018 – June 2020 with cameras-traps being deployed for both South African (east coast) wet and dry seasons to account for seasonality.

4.3.3 Mammalian trait selection

Based on a similar study conducted by Ehlers Smith et al. (2020) on the east coast forests of KwaZulu-Natal in South Africa and additional information from other literature (Skinner and Chimimba, 2005), we selected five forest mammalian functional traits to be used for our study. The traits included body mass (in kilograms); activity patterns (nocturnal, diurnal); feeding guild (omnivore, carnivore, insectivore, herbivore and frugivore); habitat fidelity (forest specialist, generalist) and gregariousness (large group, small group, pair, solitary). Species traits influence individual species and their ability to interact with their surrounding environment (Sukma et al. 2019).

4.3.4 Vegetation surveys

At each camera-trap location, we recorded the habitat structure in terms of a foliage profile within a 20 m radius around each survey point. The foliage profile at each camera-trap location consisted of two understory vegetation classes: 1) percentage coverage of bare ground; leaf litter, grass cover, and herbaceous plants; and 2) percentage cover of scrub/woody plant saplings <2 m. To determine the foliage profile, we measured height of plants within the 20 m radius and visually

estimated percentage understory coverage of each vegetation class layer relative to each other within individual quarters of the circular plots (totalling 100 % coverage in each; c.f. Ehlers Smith et al. 2017). We counted tree stems density that reached varying heights of 2 – 5 m, 6 – 10 m, 11 – 15 m, 16 – 20 m and > 25 m, and visually estimated percentage crown cover. To determine forest structural complexity, we calculated the Shannon-Weiner diversity index for each forest patch using the formula below:

$$H = - \sum_{i=1}^S p_i \ln (p_i)$$

The mean height scores for each vegetation class were converted into a foliage height index, where p_i is the proportion of the total foliage which lies in the i th layer of the chosen horizontal layers (Bibby et al. 2000; Ehlers Smith et al. 2017).

4.3.5 Data analyses

Species richness was the pooled number of species present at each forest patch sampled. To determine the four functional diversity metrics used in this study, we used species presence-absence data, abundance data, along with species traits data (Villéger et al. 2008; Laliberté and Legendre, 2010). To calculate abundance, we used the number of species encountered on the camera-traps over the 21 days of deployment as a community metric. A species was only recorded once an hour to reduce the error of recording the same individuals more than once. The four functional metrics were functional richness (FRic) which is the convex hull of the total number of traits in a species community (Cornwell et al. 2006), functional evenness (FEve), which is the regularity in abundance-weighted functional traits across the species community in a defined niche space (Villéger et al. 2008), functional dispersion (FDis) which is the mean distance of species traits from the centroid of traits of the whole species community sampled (Laliberté and Legendre

2010), and functional divergence (FDiv) which is the species traits diverge from the main of traits for the whole species community sampled (Villéger et al. 2008). All indices were calculated using the FD package (Laliberté and Legendre, 2010) in R v 4.1.0 (R core team, 2015). A minimum community size of three species for each forest patch is required to conduct the functional diversity calculations. Therefore, eleven forest patches were removed from the analyses as they did not reach the necessary criteria. Gowers’s distance (Gower, 1966) was used to calculate pairwise distance matrices of species community traits. A principal coordinate analysis (PCoA) was performed to calculate each functional measure for all forest patches used in the analysis using the functional distance matrix of species traits (Villéger et al. 2008). We retained the first three PCoA axes, which explained 86 % (Table 4.1) of total inertia in the mammalian community.

Table 4.1 Eigenvalues of principal coordinate analysis of functional traits derived from mammalian species identified in the select Southern Mistbelt Forests in eastern South Africa.

	Axis 1	Axis 2	Axis 3
Eigenvalue	0.4643	0.307	0.2895
Proportion Explained	0.3783	0.2502	0.2358
Cumulative Proportion	0.3783	0.6284	0.8643

We calculated β -diversity and partitioned it into its additive components of species spatial turnover (β_{sim}) and nestedness (β_{nes}). Furthermore, to describe overall functional and species β -diversity, we applied the Simpsons diversity index to turnover and nestedness then applied the Sørensen dissimilarity index to the pairwise species traits (Baselga 2010). To conduct these analyses, we used the “betapart” package (Baselga and Orme 2012;) in R v 4.1.0 (R Core Team

2015). In Arc GIS v10.5.1 (ESRI 2017), spatial autocorrelation of mammalian species' diversities among forest patches was tested using Morans I (Diniz et al. 2003). Using the data generated from the Simpson's and Sørensen dissimilarity index, we integrated them into multiple regression of distance matrices (MRM) which analysed the effect of isolation and patch size on spatial turnover, nestedness and functional β -diversity (Lichstein 2007). To determine the dominant component between β_{nes} and β_{sim} we calculated the ratio (β_{ratio}) between β_{sor} and β_{nes} shown in the calculation below where if the value is greater than 0.5 then β_{nes} is the dominant component and if it is less, then β_{sim} is dominant (Dobrovolski et al., 2012; Si et al. 2015). The resultant p-values were calculated by permutation test (9,999 runs). Linear mixed-effects models were used to assess the response of functional diversity indices and species richness to patch size, forest structural complexity, number of neighbouring patches and altitude. In the mixed-effects models, elevation was kept as a random variable.

$$\beta_{ratio} = \beta_{nes} / \beta_{sor}$$

4.4 Results

Small to large non-volant mammals triggered 1774 camera images over 8820 trap-days with 16 species identified (native and non-native). Small mammals were not included in this study. β -diversity was greatly driven by turnover ($\beta_{ratio} = 0.71$) and functional β -diversity was driven by nestedness ($\beta_{ratio} = 0.55$, Table 4.2). The overall β -diversity was not significantly influenced ($r^2 = 0.0035$, $F = 0.36$, $p = 0.88$) by isolation and patch size. The mammalian species nestedness ($r^2 = 0.26$, $F = 33.63$, $p = 0.001$) increased with increasing patch size and decreased with increasing isolation. Mammalian species turnover ($r^2 = 0.096$, $F = 9.88$, $p = 0.042$) was significantly influenced by patch size and isolation negatively and positively respectfully. The overall

mammalian functional β -diversity was not influenced ($r^2 = 0.012$, $F = 1.10$, $p = 0.75$) by patch size and isolation nor by functional nestedness ($r^2 = 0.077$, $F = 7.80$, $p = 0.87$). Functional nestedness increased with increasing isolation, however, decreased with decreasing patch size. Functional turnover ($r^2 = 0.071$, $F = 7.21$, $p = 0.37$) increased with increasing isolation and also increased with increasing patch size.

Table 4.2 The β -diversity components, including nestedness (β_{nes}), turnover (β_{sim}) and total (β_{sor}) calculated for mammalian communities for each forest patch included in the overall analysis in the Southern Mistbelt Forests in eastern South Africa.

β -diversity components		Mean \pm SD*	β_{nes} resultant ratio
Taxonomic	Bsor	0.42 \pm 0.14	0.29
	Bnes	0.12 \pm 0.10	
	Bsim	0.3 \pm 0.18	
Functional	Bsor	0.65 \pm 0.24	0.55
	Bnes	0.36 \pm 0.28	
	Bsim	0.29 \pm 0.30	

*Standard deviation

All four indices used in this study to determine mammal functional diversity were not spatially autocorrelated (Table 4.3). The linear mixed-effects models showed that the predictor variables influenced the response variables differently. Patch size influenced four of the response variables models and forest structural complexity in four models. Patch size significantly ($p = 0.0022$) influenced species richness positively (Table 4.4; Fig. 4.2); however, a decrease in forest structure complexity negatively influenced species richness. Functional richness was also significantly influenced by patch size ($p = 0.0015$; Table 4.1; Fig. 4.2). Functional divergence was significantly affected by isolation ($p = 0.04$) and number of neighbouring fragments ($p = 0.05$).

Table 4.3 Summary results of the Global Moran's I tool showing the indices used to determine functional diversity of mammals in the Southern Mistbelt Forests.

Indice	Moran's Index	z-score	p-value
Species richness	0.12	1.2	0.2
Functional dispersion	0.08	0.9	0.36
Funtional richness	0.07	0.8	0.43
Functional evenness	-0.2	-0.9	0.4

Table 4.4 Model coefficients obtained from the most parsimonious models to assess the response of forest mammal functional diversity indices and species richness to forest patch size (logged), forest structural complexity (FSC; logged) and altitude in the present study.

Response variables	Predictor variables	Value	Std.Error	DF	t-value	p-value
Species richness	(Intercept)	-4.04	3.67	15	-1.10	0.29
	Log of FSC	-12.29	6.54	15	-1.88	0.08
	Log of Patchsize	2.28	0.62	15	3.68	0.00
Functional richness (FRic)	(Intercept)	-9.66	4.66	15	-2.07	0.06
	Log of Patchsize	3.24	0.84	15	3.87	0.00
	Log of FSC	-13.00	8.51	15	-1.53	0.15
Functional evenness (FEve)	(Intercept)	1.22	0.54	15	2.25	0.04
	Log of FSC	1.36	1.26	15	1.08	0.30
	Neighbouring Fragments	0.00	0.01	15	0.18	0.86
Functional dispersion (FDis)	(Intercept)	1.97	0.46	15	4.31	0.00
	Log of Patchsize	0.08	0.08	15	0.99	0.34
	Log of FSC	1.57	0.84	15	1.88	0.08
Functional divergence (Fdiv)	(Intercept)	0.90	0.13	12	6.79	0.00
	Log of Isolation	-0.15	0.06	12	-2.36	0.04
	Log of Patchsize	0.01	0.06	12	0.23	0.82
	Neighbouring Fragments	0.03	0.01	12	2.17	0.05

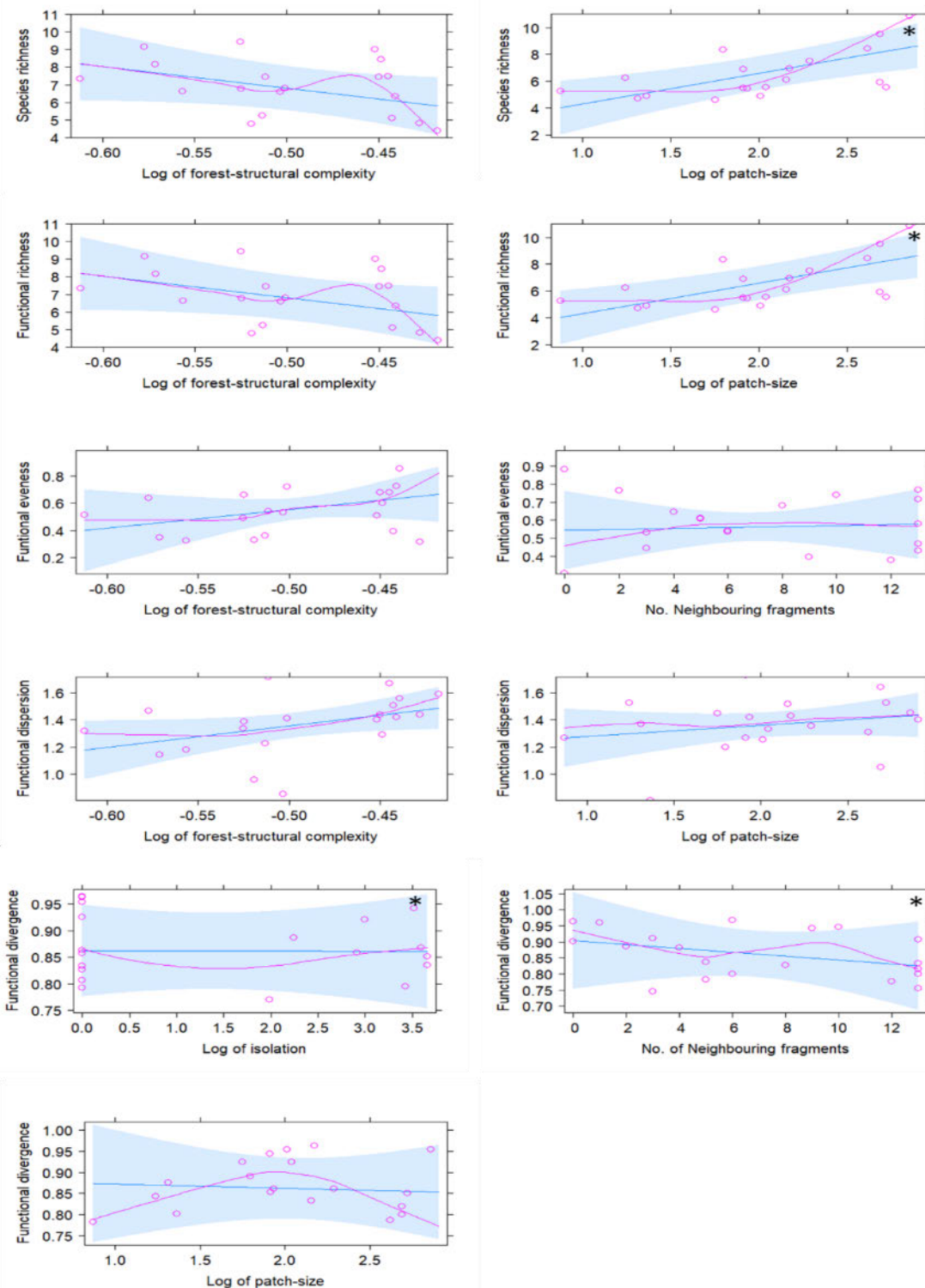


Figure 4.2 Forest patch mammalian species response to functional diversity indices and species richness from the most parsimonious models for each response variable derived from linear mixed-

effects. Plots with an asterisk (*) in the top right corner significantly affect the mammalian functional diversity indices it is plotted against.

4.5 Discussion

Our prediction that forest patch size would have a positive influence on the functional diversity indices used in this study was supported. All indices used showed they have a positive association with increasing forest patch size. Mammalian species richness as well as functional diversity both significantly increased with increasing forest patch size. This is supported by multiple studies as larger forest patches typically support a higher diversity of species as well as abundances irrespective of the taxon (MacArthur and Wilson 1967; Bowers and Matter, 1997; Viera et al. 2009; Santos-Filho et al. 2012; Fahrig 2013; Garmendia et al. 2013; Ramesh et al. 2016; Fahrig et al. 2019). Theoretically, higher functional diversity increases the functioning of an ecosystem resulting from greater resource use (Petchey et al. 2004). Relatively larger forest patches tend to support more species because there is a higher diversity of niches and resources that can be utilised effectively because of the diversity of species traits (Magioli et al. 2015). However, we cannot say the relatively large size of a patch is an indication of an abundance of resources that will support a higher diversity and abundance of species. Increased isolation results in increased fragmentation, and disrupts ecological process as well as reduce habitat connectivity (Ramesh et al. 2016).

Similarly, in studies conducted by Aveneger (2013) and Svenning et al. (2001), turnover was found to be dominant; therefore, management implications of these forests and associated mammalian communities suggest that all patches should be considered a priority for conservation (Si et al., 2013). Conversely, functional nestedness was the driving component for this study. Due to different management implications, if the nestedness is dominant, forest patches that have a

higher diversity of species traits and species richness should be prioritised for conservation (Dobrovolski et al., 2012). Forest mammalian species taxonomic and functional nestedness was significantly driven by patch size. The species community was nested with similar subsets of species found in various patches; however, nestedness decreased with increased isolation. Functionally the forest mammalian species subsets between patches were significantly dissimilar because of decreasing patch sizes. These forest patches may not fulfil the various needs related to different mammalian species traits; therefore, species are missing or persisted at lower abundances as found in other studies (Palmeirim et al. 2018). Forest mammalian species turnover was also significantly influenced by patch size. Taxonomically patch size decreased, and isolation increased, which resulted in a more circuitous landscape for forest dependant species. This resulted in them being replaced by generalist species resulting in homogenised assemblages (Ehlers Smith et al. 2020). Conversely, functional species turnover increased with both patch size and isolation.

Mammalian species richness and functional richness significantly increased with patch size, which supported our prediction and decreased with decreasing forest structural complexity. As mentioned above that larger patches tend to support more species (Santos-Filho et al. 2012). Our study area also has many relatively smaller fragments, which are still considered important according to Magnago et al. (2014), who noted that they are of conservation importance as they harbour subsets of species from larger fragments. Functional richness was relatively high with increasing patch size, which may indicate that resources within the forest patches are being used efficiently (Magioli et al. 2015). In concurrence with our study, Sukma et al. (2019) found that forest structural complexity may have a negative association with mammals occupying a high resource system where a few mammalian species become dominant. In this instance, the diversity

or number of functional traits may decline. There is high competitive dominance for resources, especially in the absence of disturbance (Huston, 1979; Sitters et al. 2016).

We found mammalian functional evenness and functional dispersion both increased with increasing forest structural complexity. Functional evenness was relatively high, which may indicate balanced niche occupancy and distribution of traits (Schirmel et al. 2012). With a positive association, the forest niche spaces may be evenly distributed and resources well utilised by mammalian species, promoting a higher abundance and diversity of species within these forest patches (Mason et al. 2005; Zellweger et al. 2013; Magioli et al. 2015). Higher forest structural complexity provides diverse niche availability, suitable breeding areas, food, and suitable habitat to inhabit (Zellweger et al. 2013, 2016). Additionally, Sukma et al. (2019) also had a positive association of vegetation structural complexity with functional dispersion, suggesting good resource partitioning in the forested habitats as in our study. Ehlers Smith et al. (2020) suggested if there is an increase in the number of neighbouring patches adjacent to each other, there will be a reduced influence of isolation. Furthermore, the negative impacts of isolation, species with short dispersal distances will be most severely impacted by increasing distances between isolated patches of suitable habitat (Holland and Bennett, 2009), are improved when more neighbouring patches allow species to occupy and use the niches available in these spaces.

We found functional divergence was significantly negatively influenced by increasing forest patch isolation and positively influenced by an increasing number of neighbouring forest patches. Our results show a high functional divergence in our study area, which indicated a higher variation of species traits, niche availability, and high resource partitioning amongst mammalian species as found in other studies (Mason et al. 2005; Mouchet et al. 2010). Typically the more isolated or fragmented a landscape is, the lower the number of species present in forest patches

(Ehlers Smith et al. 2020); therefore, fewer niches are occupied, and resources are used efficiently. An example of a species that would be highly affected by increasingly isolated forest patches is the blue duiker (*Philantomba monticola*), a forest specialist known to disperse up to 800 m (Bowland 1990; Lawes et al. 2010). The ability of certain species that cannot disperse long distances outside of their specialised habitat would be heavily impeded by increasing isolation of their habitats and hindering them from occupying available niche space.

The results of our study highlight that forest patch size is an important explanatory variable in understanding mammalian species persistence in a dynamic, disjunct landscape. The larger forest patches supported a higher number of mammalian species, further showing their value in promoting a more diverse species community. Therefore, it is fundamental that these larger forest patches are well maintained. Relatively smaller forest patches (remnants) do have an important role as they also act as stepping stones in the landscape which further increases the connectivity and reduces the effects of isolation. Our study also highlighted the importance of forest structural complexity as it promotes functionally diverse mammal communities and enhanced ecosystem functioning (Sukma et al. 2019). Therefore, the conservation of larger forest patches along with structurally complex vegetation in the Southern Mistbelt Forests can result in the continued persistence of the forest mammal communities.

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CHAPTER 5

The use and value of Southern Mistbelt Forests to surrounding rural communities in northern Eastern Cape, and southern KwaZulu-Natal, South Africa

Mbalenhle T. SOSIBO ¹, Yvette C. EHLERS SMITH ^{1,2}, David A. EHLERS SMITH ¹, and
Colleen T. DOWNS ^{1*}

¹ *Centre for Functional Biodiversity, School of Life Sciences, University of KwaZulu-Natal,
Private Bag X01, Scottsville, 3209, Pietermaritzburg, South Africa*

² *Ezemvelo KwaZulu-Natal Wildlife, Queen Elizabeth Park, Peter Brown Drive, Montrose,
Pietermaritzburg, 3201, South Africa*

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* **Corresponding Author:** Colleen T. Downs

Email: downs@ukzn.ac.za; **ORCID:** <http://orcid.org/0000-0001-8334-1510>

Other emails and ORCIDs:

M. Sosibo Email: mbalisosibo5@gmail.com; ORCID: 0000-0003-3801-3539

D.A. Ehlers Smith Email: ehlerssmithd@ukzn.ac.za; ORCID: 0000-0002-6357-0751

Y.C. Ehlers Smith Email: ehlerssmithy@ukzn.ac.za; ORCID: 0000-0002-2564-7359

5.1 Abstract

African forests have been negatively affected over time because of human impacts. The use of forest products is of high socio-economic value, especially for lower-income communities. Excessive logging alters the forest patch structure and composition, affecting their quality and causing degradation. In addition, increases in bushmeat hunting for sustenance and trade result in increased pressures on forest mammalian species. We investigated forest use by rural communities residing around forest patches in uMthatha, Eastern Cape, and iNgeli and Creighton, KwaZulu-Natal, South Africa. We selected villages to conduct interviews based on their proximity to forest patches that we sampled during camera trap surveys (May 2018 – June 2019). We conducted 313 interviews using semi-structured questionnaires composed of open- and closed-ended questions, whereby the open-ended questions allowed for more in-depth responses. To assess the hunting pressure in this study, the proportion of people dependent on hunting in each settlement, we performed a multiple linear regression. A higher proportion of respondents (38%, n = 117) conveyed that the forest extent increased over ten years, mainly because the settlement residents did not use the forest often. Results show that the most hunted species included the southern bushbuck *Tragelaphus scriptus* and common duiker *Sylvicapra grimmia*. We found that the most significant reason for residents hunting was for consumption followed by financial gain. *Afrocarpus falcatus* and *Ptaeroxylon obliquum* were the preferred tree species to be logged because of their sturdiness and durability for building structures and fencing. Ungulates are the preferred choice for consumption in lower-income settlements and are an important source of protein. Some participants in our study expressed that mammalian species' numbers are dwindling because of people hunting for sport. An emerging trend in our study was that of high cultural importance placed on the forest. Forest resources are more likely to be used sustainably if

appropriate measures such as capacity building for security guards as well as clear rules and regulations about hunting and plant harvesting are applied. Incorporating socioeconomic aspects into ecological management is of benefit for forest conservation.

Keywords: Bushmeat, forest resources, low income, tree harvesting, hunting, mammals

5.2 Introduction

Mammalian species have important functional roles in the forests they inhabit, including seed dispersal, vegetation regulation, nutrient cycling and dung deposition for fertilisation (Garmendia et al., 2013; Rovero et al., 2014). African forests have changed over time because of human impacts (Brodie et al., 2015; Aleman et al., 2018). Logging, the increase of bushmeat hunting for sustenance and trade, and fires have contributed to the alteration of forest habitat structures, which has led to local extinctions of forest mammals (Topp-Jørgensen et al., 2009; Lindsey et al., 2011). In Africa, forest products are of high socioeconomic value, especially for lower-income communities, and have assisted in poverty alleviation (Leaver and Cherry, 2020). Lower-income households, at varying degrees, are dependent on the resources provided by forests to generate income, consumption, cultural practices, and recreational activities (Shackleton and Shackleton, 2004; Paumgarten and Shackleton, 2011; Ofoegbu et al., 2017).

Existing work shows that the encroachment into forest areas has altered microhabitats and microclimates for forest mammalian species (Fa and Brown, 2009; Lamperty et al., 2020). Forests are further threatened by livestock grazing within forest patches, which also leads to trampling and altering the understory, altering the habitat of the indigenous fauna (Lawes et al., 2000; Adie et al., 2013). Frequent fires along forest edges, whether natural or human-induced, further alter the plant composition and environment (Otodo et al., 2013; Zhao et al., 2021). The close proximity of roads to forests is a contributing driver of deforestation (Soares-Filhoh et al., 2001; Nagendra et

al., 2003). Most roads close to forests have been constructed because of nearby land-uses such as agriculture and exotic timber plantations. In turn, this has resulted in ease of access for hunters and for those who may harvest trees and other plant material directly from the forests (Laurance et al., 2008). Excessive logging alters the structure and composition of the forests, contributing to degradation (Menton, 2003). However, logging is significant for the livelihoods of communities close to forests as they typically both use and sell forest timber products (Rist et al., 2012).

One of the major drivers of forest alteration and degradation is livelihood insecurity (Kimengsi et al., 2020). The increase of bushmeat hunting for sustenance and trade has resulted in increased pressures on forest mammalian species as well as the ecosystem functioning of the forest areas (Castilho et al., 2017). Furthermore, excessive unselective hunting for either animal hides or bushmeat may result in local extinctions of functionally important forest species (Lindsey et al., 2011). In South Africa and other parts of Africa, bushmeat is a vital part of the lives of rural communities that may not be able to purchase meat and other basic necessities like middle- and upper-class communities because of financial constraints (Fa and Brown, 2009; Manqele et al., 2018). Bushmeat is also one of the only protein sources available and accessible to rural communities (Carpeneto et al., 2007; Topp-Jørgensen et al., 2009). For sustenance, people in rural communities hunt and sell animal hides, particularly those used for decoration and traditional attire such as the leopards (*Panthera pardus*, Naude et al., 2020) across southern Africa and bushmeat as it is also considered a luxury buy (Chaber et al., 2010; Nguyen et al., 2021).

We aimed to quantify and assess the dynamics of forest use and hunting of mammalian species in communities close to forest patches in uMthatha, Eastern Cape, and iNgeli, KwaZulu-Natal, South Africa. Furthermore, the results obtained from this study may contribute to conservation action planning for the management of these forests, especially if there has been a

shift in use and human-wildlife interactions from the past. Given the paucity of information about the overall mammalian community use and recent bushmeat trade patterns in these areas of study, the results arising from this study will give a more current overview. Our research questions were: 1) Which forest plants are harvested, if any? What are they used for? 2) Are mammals hunted in the forest? Which ones? For what reasons? 3) Has the forest plant and mammal diversity and abundance changed over time? 4) In what ways do community members believe that the forest resources can be sustainably used? We predicted that the most hunted species would be ungulates as they have been documented as a preferred choice for consumption in rural areas (van Velden et al., 2018). We also predicted that the most common use for wood harvested in the forests would be for fuelwood.

5.3 Methods

5.3.1 Study area

Our study was conducted October – November 2019 within the three study areas in South Africa, namely, uMthatha (31°25'48.71" S 28°45'12.33" E) situated in the Eastern Cape Province, Glengarry/Weza (hereafter referred to as iNgeli) (30°31'38.2" S 29°41'33.2" E) and Creighton (29°58'34.91" S 29°44'1.61" E) situated in KwaZulu-Natal Province (Figure 5.1). The Southern Mistbelt Forest patches are nested in the grassland biome. Other land-use practices also surround them, predominantly exotic tree plantations (*Pinus patula*, *Acacia mearnsii* and *Eucalyptus* spp.) and include human settlements. The latter were the focus areas of our study.

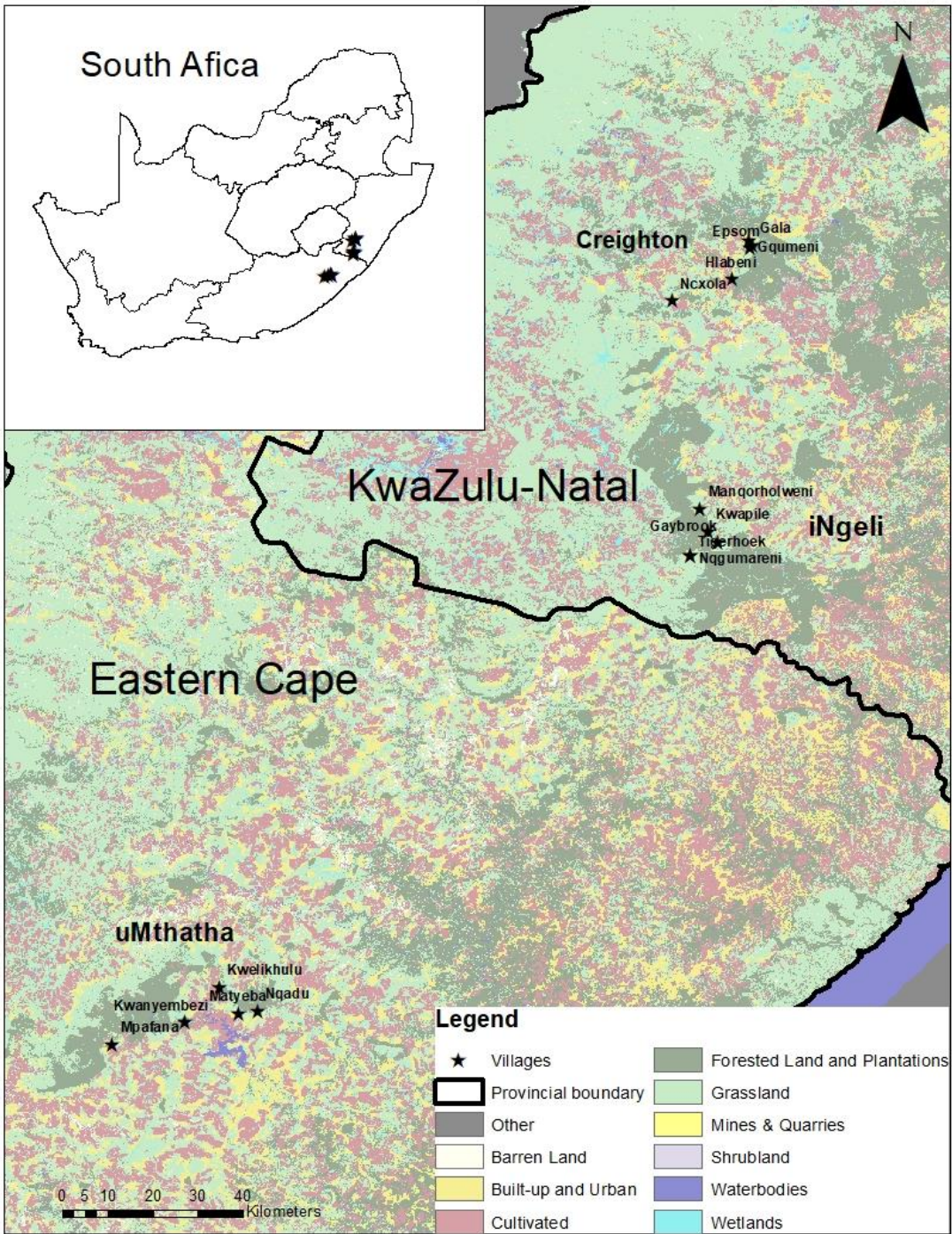


Figure 5.1 The study areas where questionnaire surveys were conducted in the Eastern Cape and KwaZulu-Natal Provinces, South Africa, to ascertain forest product use.

5.3.2 Sampling methods

We selected villages based on their proximity to forest patches (Table 5.1) that we sampled during camera trap surveys (May 2018 – June 2019) to determine which mammalian species were present (Sosibo et al. in prep.). The species we selected for the questionnaire were based on those captured on camera-traps, as well as previous studies on human-wildlife interactions within the region (Lawes et al., 2004). We conducted interviews using a semi-structured questionnaire (Appendix S1) composed of open- and closed-ended questions, whereby the open-ended questions allowed for more in-depth responses based on previous studies (Manqele et al., 2019; Ehlers Smith et al., 2021). Before we conducted interviews, we obtained permission to conduct interviews in each village from the *INduna* (head community councillor/community leader) or *INkosi* (Chief) as a sign of respect. Households were randomly selected. If residents were not at home when interviews were being conducted, we proceeded to the next house. To avoid confusion about which mammalian species the respondents were being questioned about, we presented images of species (Appendix S2), especially since the species names may vary between areas. When asked whether they had seen mammalian species, each respondent was also asked which species they hunt by identifying them and confirming based on the images they were presented.

5.3.3 Data analyses

We performed a multiple linear regression to assess the relationship between hunting pressure in this study using the number of people dependent on hunting in each settlement selected for interviews with the various explanatory variables. The response variable used for the study was the number of hunters per settlement as we wanted to see what are the main drivers for their desire to hunt mammals. The explanatory variables included: proximity of settlements to the forest (in

meters); the proximity of roads to the forest (in meters); consumption (number of respondents who consume bushmeat per settlement); financial gain (number of respondents who sell bushmeat or hides). The explanatory variables above were chosen based on accessibility and socioeconomic factors that influence the hunting of wild animals (Deere et al., 2020). Statistical analyses were performed using the DAAG package (Maindonald et al., 2015) in R version 4.1.0 (R core team, 2015).

Table 5.1 Demographics of villages and respondents sampled in Eastern Cape and KwaZulu-Natal Provinces, South Africa, to ascertain forest product use.

	No. of Respondents	% of Repondents*
Gender		
Female	142	45.4
Male	161	51.4
Age		
18 -20	6	1.9
21 - 30	92	29.4
31 - 40	82	26.2
41 - >50	123	39.3
Village		
Epsom	18	5.8
Gala	20	6.4
Hlabeni	16	5.1
Ncxola	19	6.1
Gqumeni	20	6.4
Gaybrook	29	9.3
Kwapile	19	6.1
Manqorholweni	30	9.6
Tigerhooek	28	9.0
Nqgumareni	11	3.5
Kwanyembezi	15	4.8
Kwelikhulu	17	5.4
Matyeba	9	2.9
Mpafana	7	2.2
Nqadu	10	3.2

* % = Proportion

5.4 Results

5.4.1 Have the forest patch sizes changed over time? How?

We received a total of 313 interview responses for the questionnaire, of which 142 (45%) were female, and 171 (55%) were male (Table 5.1). A number of respondents (12%, $n = 38$) were not sure if the forest had changed. A higher proportion of respondents (38%, $n = 117$) conveyed that the forest extent increased over ten years, with the main reasons being the settlement residents did not use the forest often ($n = 48$), climate brought in more rainfall for growth ($n = 27$) and the forests are protected ($n = 27$) (Table 5.2).

Table 5.2 Reasons for the physical change in size of forests over ten years by interviewed respondents living adjacent.

	Decreased	Increased	Stayed the same
Climate	7	27	3
Fires	40	0	0
Logging	67	0	0
People don't use the forest as often	0	48	45
Protected	0	27	12

5.4.2 Mammal presence and consumption

The most hunted species included the southern bushbuck *Tragelaphus scriptus* ($n = 124$), common duiker *Sylvicapra grimmia* ($n = 112$), Cape porcupine *Hystrix africaeaustralis* ($n = 105$), and the bushpig *Potamochoerus larvatus* ($n = 102$) (Table 5.3). The most significant model explained 93% of the variance in the model ($R^2 = 0.93$, $\text{Adj.}r^2 = 0.89$, $F = 23.41$, $p < 0.05$, $df = 9$) and the second significant model explained 92% of the variance in the model ($R^2 = 0.92$, $\text{Adj.}r^2 = 0.90$, $F = 43.09$, $p < 0.05$, $df = 11$) (Table 5.4). We found that the most significant reason for residents hunting was

for consumption, then for financial gain (selling of bushmeat and animal hides) and retaliatory killing (Table 5.4).

Table 5.3 Mammalian species hunted in the Southern Mistbelt Forests identified by settlement residents in the present study.

Common name	Latin name	No. of	
		respondents	Percentage (%)
Southern bushbuck	<i>Tragelaphus sylvaticus</i>	124	39.6
Common duiker	<i>Sylvicapra grimmia</i>	112	35.8
Bushpig	<i>Potamochoerus larvatus</i>	105	33.6
Cape porcupine	<i>Hystrix africaeausstralis</i>	102	32.6
Black-backed jackal	<i>Lupulella mesomelas</i>	64	20.5
Tree hyrax	<i>Dendrohyrax arboreus</i>	52	16.6
Samango monkey	<i>Cercopithecus mitus</i>	35	11.2
Caracal	<i>Caracal caracal</i>	23	7.4
Large-spotted genet	<i>Genetta tigrina</i>	22	7.0
Blue duiker	<i>Philantomba monticola</i>	15	4.8

Table 5.4 Multiple linear regression analysis of parameters that may influence settlement residents to hunt mammalian species in the Southern Mistbelt Forests

	Estimate	95% CI	t-value	p-value	
Model 1 (Full)					
Proximity to forest patch	-0.4616	(-1.99, 1.07)	-0.683	0.5121	
Proximity to roads	-0.1569	(-1.08, 0.77)	-0.384	0.7099	
Consumption	11.5276	(8.23, 14.82)	7.916	2E-05	***
Financial gain	3.7581	(1.61, 5.91)	3.96	0.0033	**
Retaliatory killing	3.4878	(1.46, 5.51)	3.895	0.0037	**
Model 2					
Consumption	11.3075	(8.31, 14.30)	8.314	5E-06	***
Financial gain	3.3348	(1.60, 5.07)	4.231	0.0014	**
Retaliatory killing	3.4288	(1.58, 5.28)	4.084	0.0018	**

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
 CI = confidence interval

5.4.3 Forest product consumption

The majority of respondents (85%, $n = 267$) reported that they collected wood from the nearby Southern Mistbelt Forests and the outskirts of the native forests. The most collected types of tree plants were black wattle ($n = 137$) and pine ($n = 120$) which are exotic and commercially planted adjacent to native forests (Table 5.5). The most collected native tree species are sneezewood *Ptaeroxylon obliquum* ($n = 98$) and yellowwood *Afrocarpus falcatus* ($n = 58$) (Table 5.5). A larger proportion of respondents (89%, $n = 238$) collected the tree trunk of the identified tree species

(Figure 5.2a) along with firewood (93%, $n = 248$) being the most frequent use for the wood that has been collected by respondents (Figure 5.2b).

Table 5.5 Tree species commonly used in the communities close to the Southern Mistbelt Forests of KwaZulu-Natal and Eastern Cape in the present study

Latin name	Common name	Native/Exotic	No. of respondents	Percentage (%)
<i>Pinus pinaster</i>	Pine	E	120	38.3
<i>Acacia mearnsii</i>	Black wattle	E	137	43.8
<i>Podocarpus falcatus</i>	Yellowwood	N	58	18.5
<i>Ptaeroxylon obliquum</i>	Sneezewood	N	98	31.3
<i>Zanthoxylum capense</i>	Knobwood	N	12	3.8
<i>Podocarpus latifolius</i>	Real yellowwood	N	6	1.9
<i>Rapanea melanophloeos</i>	Cape beech	N	5	1.6
<i>Warburgia salutaris</i>	Pepper-bark tree	N	6	1.9
<i>Ocotea bullata</i>	Stinkwood	N	26	8.3
<i>Solanum mauritianum</i>	Bugweed	E	1	0.3
<i>Salix mucronata</i>	Cape willow tree	N	4	1.3

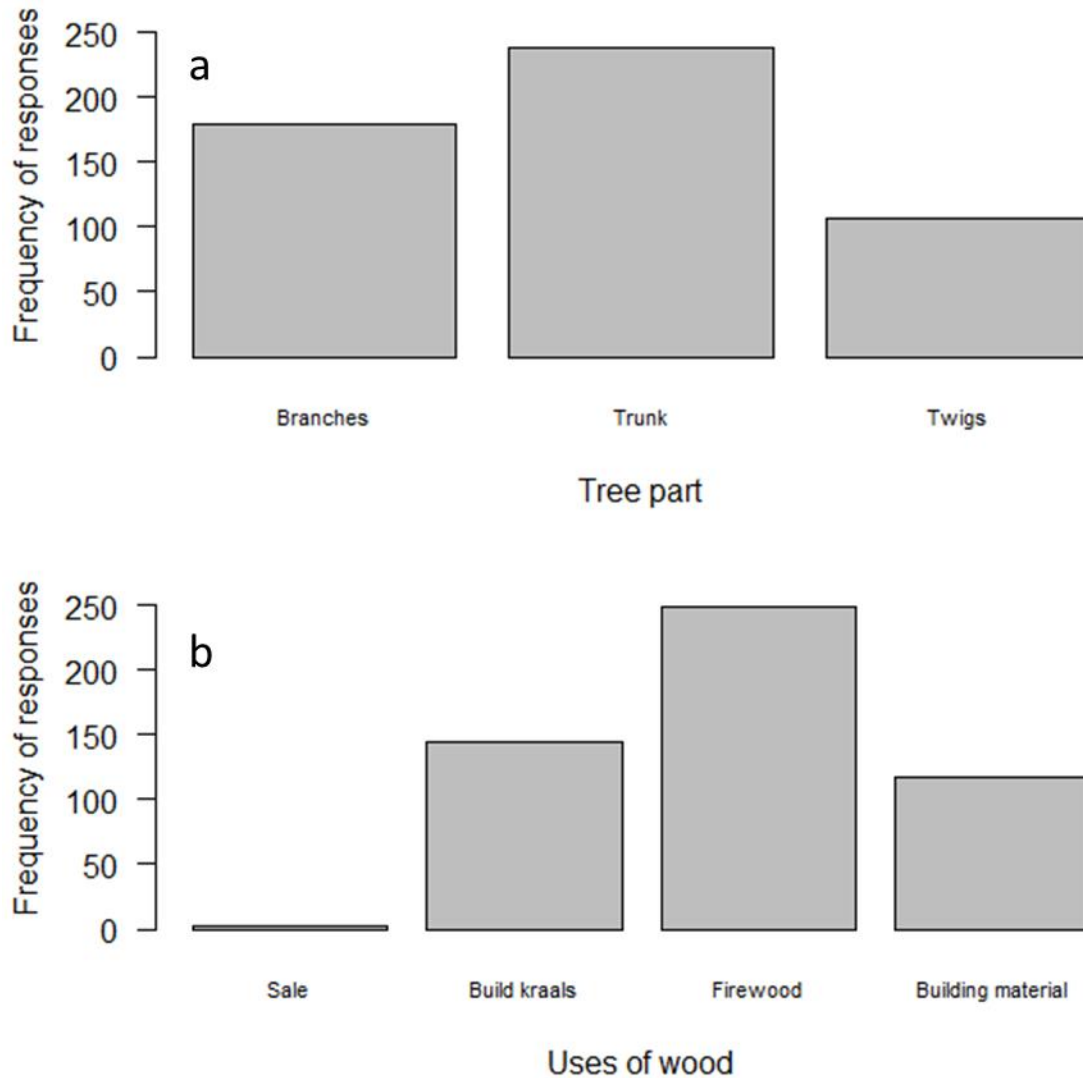


Figure 5.2 The tree species parts that respondents collected and their uses in Southern Mistbelt Forests, South Africa.

5.4.4 Other uses and emerging trends

When asked if there are any other uses of the forests, six major uses emerged. The uses were: the collection of the leaves of *umlahlankosi* (IsiZulu) *Ziziphus mucronata* ($n = 10$), which are used to fetch the deceased soul of their loved ones; cultural practices ($n = 106$), which include sangoma

initiations (healers as well as mediums between the living and dead) and healing rituals; the collection of water ($n = 13$) for consumption and healing rituals; thieves using the forest to hide stolen livestock ($n = 2$); and witchcraft ($n = 4$).

5.4.5 How can we create a balance between conservation and use?

Residents felt that using security guards to protect the forest area would be the best way to protect the forest ($n = 130$ (42 %), Figure 5.3). The second most frequent response ($n = 76$ (24 %), Figure 5.3) was to educate residents about the important roles that forest plays.

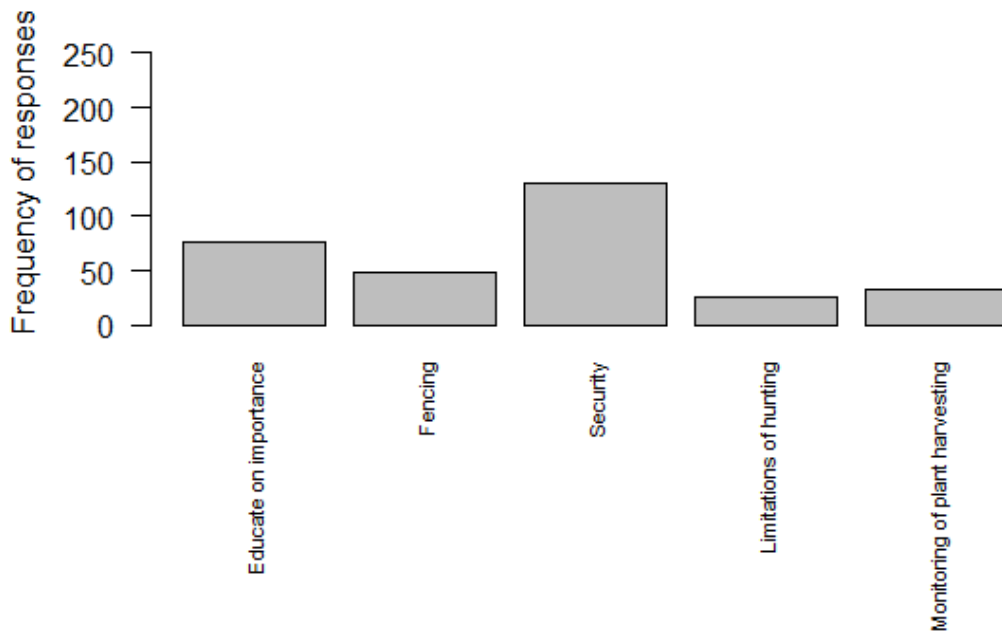


Figure 5.3 Community resident's responses to how the native forests can be protected in the present study.

5.5 Discussion

5.5.1 Change in forest patch size over time and forest plant use

The most collected native tree species in surveyed communities were *A. falcatus* and *P. obliquum*. Respondents harvested these species for various reasons, which include building, fencing and fuelwood. It has been documented that *A. falcatus* is harvested in KwaZulu-Natal and Eastern Cape forests because it is a sturdy and durable species to use to build structures and fencing (Lawes et al., 2004). Furthermore, *A. falcatus* dries easily and grows straight, so they are ideal for making poles (Nomtshongwana, 1999). Respondents also harvested from adjacent pine *Pinus* spp. and black wattle *Acacia mearnsii* plantations, both classified as invasive species (IUCN, 2021); therefore, the harvesting of these two species is encouraged. Black wattle has previously been documented by Lawes et al. (2004) to be a preferred tree to harvest for fuelwood which corresponded with our study. Shackleton et al. (2015) further encouraged the harvesting of these species because they were used in communities and contributed to livelihoods as households would sell some of the parts they harvested. If there is a greater focus on harvesting these species instead of harvesting indigenous forest species, this could contribute to the conservation and decrease the overharvesting of indigenous species. However, not all non-native species should be propagated and sold as they still threaten indigenous forest species persistence (Low, 2012; Shackleton et al., 2015). Some respondents collected fallen branches and dry wood for fuelwood. Pine trees were harvested in nearby plantations for fencing and building.

5.5.2 Reasons for hunting

Consumption of bushmeat was the leading reason for hunting, followed by financial gain and retaliatory killing. The most hunted species for consumption were two ungulates, namely southern

bushbuck and common duiker. Ungulates are the preferred choice for consumption in lower-income settlements (Fa and Brown, 2009; Hayward, 2009; van Velden et al., 2018), which was supported by our study. Bushmeat is an important source of protein for lower-income communities, especially since it is a free resource readily available in the absence of livestock (Barnet, 2000; Ziegler et al., 2016). However, hunting for bushmeat is also a serious threat to the mammalian populations, as overhunting may result in mammalian populations dwindling or becoming locally extinct (Topp-Jørgensen et al., 2009; van Velden et al., 2020). Some participants in our study expressed that species numbers are dwindling because of people simply hunting for sport. As a result, the ecological implications of overhunting are that forests will be depleted of resources and mammals if hunting is not sufficiently regulated (Ripple et al., 2016). Brodie et al. (2009) also noted that unsustainable hunting for bushmeat would be detrimental, whereby forests may be structurally intact but devoid of mammals, especially frugivores that disperse tree seeds.

Due to livestock predation, respondents resorted to retaliatory killing. One respondent in the Eastern Cape said they hunted caracals *Caracal caracal* because of livestock loss; however, they had not physically seen caracals preying on their livestock. When asked how they know it is caracals preying on their livestock, they responded with the same description of how caracals kill their prey as described by Grobler (1981). However, their prey preference is wild animals such as the rock hyrax and common duiker, and caracals prey on livestock when there is lower availability of other animals (Avenant et al., 2018). This could be viewed as a cascading effect of humans depleting resources, resulting in predators seeking other food options. Black-backed jackal *Lupulella mesomelas*, which are documented as opportunistic feeders, whose diet adapts to the surrounding resource availability, were also hunted as they were also preying on livestock which they a notably known to do (Minnie et al., 2018). Community members in our study did not only

hunt the species because of some preying on their livestock; they also hunted it for its meat. The trade of bushmeat is an important source of income for many households in the surveyed communities. It is a low-cost resource that is relatively profitable and has been used to sustain households, especially those that do not have another source of income (Rogan et al., 2018).

5.5.3 Other uses of the forest

One of the emerging trends in our study was that the forest has high cultural importance. Respondents identify the forest as a sacred place where certain cultural and spiritual rituals take place. Of these is the practice of consulting with ancestors in the forest as the forest is viewed as a sacred place. Similarly, Constant and Taylor (2020) wrote about the Vhavenda community and their ancestral beliefs along with the association with the native forests. However, respondents in our study expressed that there are those who perform dark rituals or witchcraft in the forests because they can harness certain dark spirits. Respondents expressed that they collected water from the forests and the leaves of *uMlahlankosi* (IsiZulu) *Z. mucronate*. Coopoosamy et al. (2011) interviewed Zulu residents of Durban in KwaZulu-Natal and found that *Z. mucronate* twigs are frequently collected and used to guide the deceased's spirit to their final resting place, which is in line with what the respondents in our study stated. Respondents expressed that their livestock grazed daily in the nearby forests. Trampling alters the microhabitat and microclimate in the forest understory altering the complexity and diversity of available vegetation, therefore supporting fewer forest mammals (Lamperty et al., 2020).

5.5.4 Conservation perceptions

When asked, most respondents thought that the appointments of security guards would be the best way to monitor and regulate the use of forest resources. In a study conducted by Banana and Gombya-Ssembajjwe (2000), to monitor the use of natural forests, the local government hired guards who were not residents of the communities adjacent to forests. The reason for hiring outside of the community was because the guards would be less likely to collude with community members and break the rules. There is no emotional attachment, merely doing their job without bias. However, an emerging trend in our study saw that respondents who suggested having security guards wanted them to be hired from their villages. They believed that the salaries to be paid should benefit their own people.

The main driver of hunting was for consumption driver was consumption, as many respondents in our study conveyed bushmeat is a staple commodity. If hunting is not regulated in these areas, it could pose a severe threat to mammalian species populations, and local extinctions may occur. Excessive uncontrolled hunting is known to reduce mammalian densities (Topp-Jørgensen et al., 2009; Gardner et al., 2021). Forest resources are more likely to be used sustainably if appropriate measures such as the deployment of security guards as well as educating community members about sustainable use and harvesting, which were the sentiments of some respondents. Fa and Brown (2009) suggested that more research should be employed to determine hunted mammals' biological characteristics (e.g. reproduction seasonality and fecundity). Education and awareness creation about South African hunting regulations so that people are aware that they should not hunt certain species at different times of the year as well as species that may not have reached maturation. This should also apply to the tree species that are harvested. While they are still saplings, harvesting tree species may be quite problematic as they are required for the

regeneration of tree species (Fisher, 2004). Therefore, we recommend that only fully grown trees are harvested in low quantities.

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5.8 Appendices

Appendix S1

a. PERSONAL											
1. Gender/ ubulili											
M					F						
2. How old are you?/ uneminyaka engaki?											
15-20		21-30			31-40			41-above			
3. Have you lived here all your life? Wakhula kulendawo?											
Yes					No						
4. If no when did you move into the area? Wfika nini kwilendawo? In he last:											
5 yrs ago		10 yrs ago			15 yrs ago			20 yrs ago		more than 20 yrs ago	
a. FOREST											
5. In the last 10 years has the forest size: Kwiminyaka eyishumi edlule ubukhulu behlathi selishintshe kanjani?											
Decreased/ linciphile			Increased/ linyukile				stayed the same/ liyafana				
Why?											
6. How healthy are the forests? Sinjani isimo sehlathi?											
Deteriorated/ sehlile			Improved/ lincono				stayed the same/ liyafana				
Why? Yondaba/ ngobani?											
7. Is the forest area important to you or your family: Libalulekile ihlathi kumndeni wakho?											
Yes/ yebo					No/ cha						
Why? Yindaba/ ngobani?											
8. In what way do you utilise the forest? Ihlathi niisebenzisa kanjani?											
Hunting/ ukuzingela	Wood/ izinkuni			medicinal plants/ umuthi			Fodder/ ukudla yemfuyo	weaving mats & baskets/ ocansi		Other	
9. Do you normally see mammals in the forest? If yes have you seen: Nijwayele ukuzibona izilwane ehlathini?											
Yes					No						
Samango monkey/ Insimango	Blue duiker/ uphuthi	Bush buck/ imbabala	Tree Hyrax/ imbila	Cape porcupine/ umgungubane	Caracal/ Inggawa	Common duiker/ impunzi	Large-spotted genet/ insimba	Bush pig/ ingulube lehlathi	Other		
10. Do you or a family member hunt for animals in the forest? Niyazingela izilwane zehlathi?											
Yes					No						
Daily/ nsuku zonke	Weekly/ ngesonto			Monthly/ ngenyanga			Seasonally/ izikhathi zonyaka		Yearly/ ngonyaka		
11. How do you or members of your household hunt? Izilwane nizingela kanjani?											
Dogs/ Izinja		Guns/ izibhamu			Snares/ izingibe			Other			
12. Which species do you or members of your household normally hunt for? Eziphi izilwane enijwayele ukuzizingela?											
Samango monkey/ Insimango	Blue duiker/ uphuthi	Bush buck/ imbabala	Tree Hyrax / imbila	Cape porcupine/ umgungubane	Caracal/ Inggawa	Common duiker/ impunzi	Large-spotted genet/ insimba	Bush pig/ ingulube lehlathi	Other		
13. Do you or members of your household sell/eat the animals you hunt? Niyazidla noma niyazidayisa izilwane enizingelayo?											
Yes					No						
14. Do you think animal numbers are going down? Ngombono wakho ubningi yezilwane sezinyukile noma zehlile?											
Yes/ yebo					No/ cha			No change/ alukho ushintsho			
Why?											
b. LOGGING											
15. Do you or a member of your household collect wood? Niyazithath izinkuni ehlathini?											
Yes/ yebo					No/ cha						
Daily/ nsuku zonke	Weekly/ ngesonto			Monthly/ ngenyanga			Seasonally/ izikhathi zonyaka	Yearly/ ngonyaka	Daily/ nsuku zonke		
16. Which tree species do you or a member of your household normally collect? Eziphi izihlahla enizithathayo ehlathini?											
<i>P. falcatus/ umgeyi/ umsonti</i>	<i>Warburgia salutaris/ isibhaha</i>	<i>P. latifolius/ umkhoba/ umcheya</i>	<i>Calodendrum capense/ umbaba/ umsithana</i>	<i>Cryptocarya latifolia/ Umdlengwenya / Umthungwa</i>	<i>Ocotea bullata/ umnumbithi/ umtungwa/ umnukani</i>	<i>Rapanea melanophloeos/ isiCalabi/ isiqalati</i>	<i>Euclea natalensis/ umAnyanya hi/ umKhasa</i>	Other			
17. Which part of the tree do you or a member of your household collect?											
Branches/ amagatsha		Stump/ isiqu			Twigs/ uluthi			Leaves/ inhlamvu		Other/ okunye eg. Bark	

18. What do you or a member of your household do with the wood you collect?								
sell them	build kraals	Firewood	Woven mats	Figurines	Building			
19. Do you or a member of your household use the trees for muthi purposes?								
Yes			No					
20. Which specific trees are specifically used for medicine?								
<i>P. falcatu</i> umgeyi/ umsoni	<i>Warburgia</i> <i>salutaris</i> / isibhaha	<i>P.</i> <i>latifolius</i> / umkhoba/ umcheya	<i>Calodendrum</i> <i>capense</i> / umbaba/ umsitshana	<i>Cryptocarya</i> <i>latifolia</i> / Umdlengwenya/ Umthungwa	<i>Ocotea</i> <i>bullata</i> / umnumbithi/ umtungwa/ umnukani	<i>Rapanea</i> <i>melanophloeos</i> / isiCalabi/ isiqalati	<i>Euclea</i> <i>natalensis</i> / umAnyathi/ umKhasa	Other
21. Which part of the tree is used? Eziphi izingxeny zezihlahla enisebenzisayo?								
Branches/ amagatsha	Stump/ isiqu	Twigs/ ulu hi	Leaves/ inhlamvu	Other/ okunye eg Bark				
22. How frequently do you or a member of your household harvest that part? Izingxeny zezihlahla nizithatha kangaki?								
Daily/ nsuku zonke	Weekly/ ngesonto	Monthly/ ngenyanga	Seasonally/ izikhathi zonyaka	Yearly/ ngonyaka				
a. HERDING (GRAZING)								
23. How many domestic animals does your household have? Ninezingaki izilwane zemfuyo?								
Cattle/ Izinkomo								
0	1 to 10	11 to 20	21 to 30	31 & above				
Sheep/ Amaghusa								
0	1 to 10	11 to 20	21 to 30	31 & above				
Goats / Izimbuzi								
0	1 to 10	11 to 20	21 to 30	31 & above				
Pigs/ Izingulube								
0	1 to 10	11 to 20	21 to 30	31 & above				
24. Do you have any grazing system for your animals? Lukhona uhlelo lokhuthi imfuyo idlaphi?								
Yes			No					
If no, do you allow them to freely go feed anywhere? Niyazi dedela izilwane zemfuyo ukuthi zihambele ndawo zonke?								
Yes			No					
25. How frequent do they feed in the forest? Zijwayele ukudla ehlathini kangaki?								
Daily/ nsuku zonke	Weekly/ ngesonto	Monthly/ ngenyanga	Seasonally/ izikhathi zonyaka	Yearly/ ngonyaka				
b. PEOPLE AND CONSERVATION								
26. Is there any other way people utilize the forests or forest products? Zikhona ezinye izindlela abantu bendawo besebenzisa ihlathi?								
Yes			No					
If yes, how?								
27. What can we do to protect natural forests? Singalivikela kanjani ihlathi?								
28. Why do you think we need to protect forests? Yindaba ucabanga ukuthi kumele sivikele ihlathi?								
For future generations/ izingane zethu nabazukulu		Financial gain/ lidlala indima yokuletha imali emphakathini		Cultural value/ idlala indima kwisiko lomphakathi				
29. What is the greatest value of the forest to you or your family? Ihlathi libaluleke ngani kumndeni wakho?								

Timber/ Poles/ ugodo	Water/ amanzi	Medicinal/ umuthi	Traditional/ cultural/ isiko	Other/ okunye
30. How do you think the forest plays a role in the community? Ihla hi lidlala eliphi indima emphaka hini?				
Timber/ Poles/ ugodo	Water/ amanzi	Medicinal/ umuthi	Traditional/ cultural/ isiko	Other/ okunye

Appendix S2



Bushbuck (Imbabala)



Bushpig (ingulube yehlathi)



Blue duiker (uphuti/ uphiti)



Large-spotted genet (Insimba)



Tree hyrax (Imbila)



Samango monkey (Insimango)



Cape porcupine (Ingungubane)



Common duiker (Impunzi)



Caracal (Ingqawa)



Black-backed jackal (Inkanka)

CHAPTER 6

Conclusions and Recommendations

6.1 Introduction

This final chapter summarises the main findings of the research. Based on the aims and objectives of the research, we discuss the findings of the research as well as giving brief management recommendations. African forests have been heavily exploited for their timber resources and land conversion for anthropogenic activities such as agriculture, logging and road expansion for ease of access (Laurence et al., 2008). Both Morgan et al. (2019) and Maicher et al. (2021) have identified selective logging in natural forests as a major cause for the decline in forest cover. In South Africa, the forest biome is the smallest (Mucina et al., 2006) and includes the Afromontane Forest type, also known as the Southern Mistbelt Forest. There are several endemic tree species that occur in the Southern Mistbelt Forest type, such as *Eugenia zuluensis* and *Podocarpus henkelii* (Mucina et al., 2006), as well as rare forest-dependent fauna such as blue duiker *Philantomba monticola* and the tree hyrax *Dendrohyrax arboreus*, which increases the need to conserve and study these forests. These forests face threats like habitat loss and fragmentation, which affect resource availability (Edelsparre et al., 2018; Toews et al., 2018), therefore influencing change in habitat structure and isolation of mammal populations (Ehlers Smith et al., 2017). Additionally, excessive hunting in the forest areas is prevalent as these mammals are hunted for consumption, sport, financial gain as well as retaliatory killing (Rogan et al., 2018; van Velden et al., 2020).

6.2 Research findings and Recommendations

In Chapter 2, we investigated the influence of microhabitat complexity, using foliage profiles and vegetation composition on forest mammal communities within the Southern Mistbelt Forests of

KwaZulu-Natal and Eastern Cape Provinces. In our study, the forest microhabitat variables played varying roles in the presence of large and medium-sized mammalian species in the native Southern Mistbelt Forest communities. Our results supported the prediction that most species identified in our study would be more associated with open or less dense microhabitat (namely leaf litter and bare ground), which played a role in structuring the large and medium-sized mammalian communities in the surveyed forest patches (Chapter 2). However, our study highlighted several microhabitat variables that play a significant role in the overall large and medium-sized mammalian community structure, with variation between the wet and dry seasons (Chapter 2). We believe that maintaining preserving large patches of forest that are in proximity to each other will support the different large and medium-sized mammalian species microhabitat requirements in this forest type (Chapter 2). Information detailing the patterns of microhabitat use by forest large and medium-sized mammalian species as well as the specific microhabitat variables that influence their behaviour is important for informing management decisions of conserving and the restoration of forest areas and for promoting the persistence of forest mammals.

We also assessed the impact of anthropogenic landscapes and human disturbance on forest mammal occupancies in the Southern Mistbelt Forests of KwaZulu-Natal and Eastern Cape Provinces by using occupancy modelling (Chapter 3). Site occupancies and responses to bordering land-use varied amongst mammalian species as found in other recent southern African forest studies (Ehlers Smith et al. 2020; Zungu et al. 2020a,b) (Chapter 3). Land-use directly adjacent to forest patches played a role in the occupancy of forest patches by mammals and how they used and distributed themselves within the forest patches (Chapter 3). Our results highlight how the bordering land-uses of human settlements, grassland and commercial pine plantations influence mammalian occupancy in the forest patches as well as their detectability (Chapter 3). Exotic timber

plantations adjacent to these forests have notably been documented as a type of habitat conversion that negatively affects mammalian forest communities. However, they are frequently considered “forest” in landscape assessments and can provide corridors between natural forest patches of conservation value (Lawes et al. 2000) (Chapter 3). By identifying and conserving these habitats within a landscape, we increase the chances that species can persist in meaningful population sizes. . In our study, forest specialists, bushbuck (*Tragelaphus scriptus*) and tree hyrax were more likely to be detected at the core rather than the forest edge (Chapter 3). Additional research is required to examine the role of these forests' core structure, especially for conserving forest-dependent species (Chapter 3).

For Chapter 4, we evaluated the response of forest mammal’s functional diversity and species richness to factors such as patch size, forest structural complexity, forest patch isolation and number of neighbouring patches. The results of our study highlight that forest patch size is an important explanatory variable in understanding mammalian species persistence in a dynamic, disjunct landscape similar to other studies (Ramesh et al. 2016; Fahrig et al. 2019) (Chapter 4). Therefore, it is fundamental that these larger forest patches are well maintained. Relatively smaller forest patches (remnants) are important as they also act as stepping stones in the anthropogenic landscape which further increases the connectivity and reduces the effects of isolation (Chapter 4). Our study also highlighted the importance of forest structural complexity as it promotes functionally diverse mammal communities and enhanced ecosystem functioning (Sukma et al. 2019) (Chapter 4). Therefore, the conservation of larger forest patches along with structurally complex vegetation in these forests can result in the continued persistence of the forest mammal communities.

Finally, we investigated the cultural perceptions, beliefs and practices associated with forest mammals in the Southern Mistbelt Forests of KwaZulu-Natal and Eastern Cape Provinces using questionnaires (Chapter 5). Based on the results and discussions, most common driver of bushmeat harvesting was for personal consumption of a protein source, as many respondents in our study conveyed bushmeat is a staple commodity. If hunting is not regulated in these areas, it could pose a severe threat to mammalian species populations, and local extinctions may occur. Excessive uncontrolled hunting is known to reduce mammal densities (Topp-Jørgensen et al., 2009; Gardner et al., 2021). Timber extraction was quite important for fuelwood, and the native species *P. falcatus* was the most harvested, especially for building material. Forest resources are more likely to be used sustainably as educating community members about sustainable use and harvesting, which were the sentiments of some respondents (Chapter 5). Fa and Brown (2009) suggested that more research should be employed to determine the biological characteristics of hunted mammals. Education and awareness creation about South African hunting regulations so that people are aware that they should not hunt certain species at different times of the year as well as species that may not have reached maturation (Chapter 5). This should also apply to the tree species that are harvested. Harvesting tree species, while they are still saplings, may be quite problematic as they are required for the regeneration of tree species (Fisher, 2004). Therefore, we recommend only fully grown trees be harvested in low quantities (Chapter 5).

6.3 Concluding remarks

Gaining knowledge on forest mammal species occurrence, habitat associations, and human-wildlife interactions in and around the Southern Mistbelt Forests of South Africa motivated this study. There was a paucity of information about the mammalian communities inhabiting these

forests prior. The overall study highlighted the role that forests play regarding mammalian and forest conservation in these areas, which contributes to the already existing management and conservation strategies for the forests under management and those that may have been neglected or are not managed. The study also highlighted the importance of the forests as well as the mammals who inhabit them are to the livelihoods of surrounding human settlements.

6.4 References

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