ECOLOGY AND CONSERVATION OF THE CAPE VULTURE IN THE EASTERN CAPE PROVINCE, SOUTH AFRICA

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ABSTRACT

The most threatened group of birds is scavengers, particularly vultures, of which 61 % are listed on the International Union for Conservation of Nature's Red List of Threatened Species. As a result of their adaptations for locating unpredictable food sources (large-bodied, soaring locomotion, far-ranging, and highly social), vultures are exposed to numerous threats across large areas. Conservation of vulture species is therefore difficult to conduct and plan. This thesis aims to dissect current and potential pressures on a sub-population of vultures and provide recommendations for the management and conservation of the species.

The main causes for global vulture population declines include collisions with power line infrastructure, electrocutions, poisoning, and direct persecution. An emerging threat; wind energy infrastructure, is projected to have further negative impacts on vulture populations, especially in developing countries of Africa. In the Eastern Cape Province, South Africa, wind energy installation is increasing within the range of the endangered Cape Vulture (*Gyps coprotheres*, Forster 1798). As this area contains 20 % of the global population of Cape Vultures and is a mosaic of land uses from protected areas to highly modified environments it is an ideal location to understand the species' ecology and provide recommendations for their conservation.

The eastern portion (east of 27° E) of the Eastern Cape Province contains the majority of active Cape Vulture breeding colonies and roosts. Previously, this area was a Bantustan homeland known as the Transkei, which was created under segregation laws of the former apartheid government of South Africa. The dominant land use is communal farming. However, changing cultural attitudes has resulted in more of the population residing in cities and an abandonment of farming. To assess these land use changes on vulture populations, community interviews (n = 202) were conducted in places around the Msikaba Cape Vulture colony that differed in the amount of transformed land. Although reductions of vulture observations were not significant across the different land uses, livestock ownership was perceived to have declined more in transformed places. Availability of livestock carcasses was found to be independent of land use; however type of livestock consumed by vultures varied. The use of poison to eliminate livestock predators was not reported by any of the respondents. Poaching of vultures for traditional medicine was perceived to be the greatest threat to vultures. Despite this persecution, the majority of respondents (67 %) stated that vultures benefited the community, which suggests a beneficial relationship.

Solar-powered GPS/GSM transmitters fitted on Cape Vultures provided further insight into the beneficial relationship between vultures and subsistence agriculture. Using the Bonferroni Z-statistic, results highlighted that vultures captured at the Msikaba Cape Vulture colony used communal farmland more than expected. The vultures did not prefer commercial farmland. Minimum convex polygon (MCP) home range estimates overlapped 92 % between the vulture breeding and non-breeding seasons. The larger MCP home range was in the non-breeding season with a mean ± SE of 16,887 km^2 ± 366 km^2. This home range estimate was much smaller than Cape Vultures tracked in Namibia (21 %) and the North West Province of South Africa (86 %).

In North West Province and before their extinction in Namibia in 2005, most of the breeding Cape Vultures were located at a handful of large breeding colonies, whereas, in Lesotho, Eastern Cape and KwaZulu-Natal Provinces, breeding colonies are rarely larger than 300 breeding pairs. As breeding colonies are the focus of many conservation efforts, understanding how nest density and physical cliff characteristics influence nest site selection and breeding success is vital. Using nest monitoring data from the Msikaba Cape Vulture colony, elevation, ledge depth, and nest density were found to be important factors in nest site selection. Nest sites on ledges that were 1 m deep and 180 m above sea level were selected for the most. Year and nest density influenced the breeding success at a particular nest site. The breeding success of the nest site was important in both nest site selection and the outcome of a breeding attempt, which supports that Cape Vultures use the ‘win-stay, lose-switch’ nesting strategy. These results also highlight that breeding colonies may require a minimum nest density to compensate predation losses.

Cape Vulture breeding colonies are ephemeral and are prone to desertion as a result of human disturbance. Installation of wind turbines within the Eastern Cape Province has the potential to disturb breeding colonies and roosts in addition to causing fatalities. GPS data were used to investigate spatial variables that influenced the probability of vultures flying at risk height of wind turbine collisions. Average wind speed, topography, and distance from nearest breeding colony and roost site were important variables in predicting Cape Vulture presence and risk of collision. Risk assessment maps detailing the probability of vultures being in an area and flying at risk height for the Eastern Cape Province were generated. These maps can be used by government, non-profits, and the industry sector to aid in their environmental impact assessments.

This study investigated specific threats and management conflicts in a sub-population of the endangered Cape Vulture. Each aspect of the research provides results that can be used in current and future conservation planning for the species throughout its range.

PREFACE

The data described in this thesis were collected in the Republic of South Africa from March 2012 to November 2015. Field work was carried out while registered at the School of Life Sciences, University of KwaZulu-Natal, Pietermaritzburg, under the supervision of Professor Colleen T. Downs and co-supervision of Dr Jan A. Venter.

This thesis, submitted for the degree of Doctor of Philosophy in the College of Agriculture, Engineering, and Science, University of KwaZulu-Natal, 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.

Morgan Pfeiffer

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Morgan Pfeiffer

May 2016

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

…………………………..
Professor Colleen T. Downs
Supervisor
May 2016

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DECLARATION 1 - PLAGIARISM

I, Morgan B. Pfeiffer, declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.

2. This thesis has not been submitted for any degree or examination at any other university.

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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

M Pfeiffer, CT Downs and JA Venter. 2014. Identifying anthropogenic threats to Cape Vultures (*Gyps coprotheres*) using community perceptions in communal farmland, Eastern Cape Province, South Africa. Bird Conservation International. 25: 353 – 365.

Author contributions:

MP conceived paper with CTD and JAV. MP collected and analysed data, and wrote the paper. CTD and JAV contributed valuable comments to the manuscript.

Publication 2

M Pfeiffer, CT Downs and JA Venter. Foraging range and habitat use by Cape Vulture Gyps coprotheres from the Msikaba colony, Eastern Cape province, South Africa. Koedoe, 57: 1 – 11.

Author contributions:

MP conceived paper with CTD and JAV. MP collected and analysed data, and wrote paper. CTD and JAV contributed valuable comments to the manuscript.

Publication 3

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MP conceived paper with CTD and JAV. MP, SCK, DGS, NF, and SR contributed data. MP analysed data, and wrote paper. CTD, JAV, SCK, DGS, NF, and SR contributed valuable comments to the manuscript.

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Author contributions:

MP conceived paper with CTD and JAV. MP collected and analysed data, and wrote paper. CTD and JAV contributed valuable comments to the manuscript.

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May 2016

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TABLE OF CONTENTS

ABSTRACT ..... **ii**

PREFACE ..... **v**

DECLARATION 1 - PLAGIARISM ..... **vi**

DECLARATION 2 - PUBLICATIONS ..... **vii**

ACKNOWLEDGMENTS ..... **ix**

TABLE OF CONTENTS ..... **xi**

LIST OF FIGURES ..... **xv**

LIST OF TABLES ..... **xviii**

CHAPTER 1: **1**

Introduction **1**

1.1 Threats to African Vultures 2

1.1.1 Large-bodied and fatalities from power lines 3

1.1.2 Soaring flight strategy and collision with wind turbine blades 4

1.1.3. Far-raging and exposed to diverse land uses and livelihoods 8

1.1.4. Highly social nature and mass poisoning incidents 10

1.2 Consequences of vulture population declines 12

1.3 Cape Vulture 13

1.4 Cape Vulture sub-population of Lesotho, KwaZulu-Natal and Eastern Cape Provinces 16

1.4.1. Msikaba Cape Vulture Colony 19

1.5 Problem statement and significance of the study 20

1.6 Aims and Objectives 21

1.8 Study Outline 23

1.9 References 23

CHAPTER 2: **31**

Identifying anthropogenic threats to Cape Vultures *Gyps coprotheres* using community perceptions in communal farmland, Eastern Cape Province, South Africa **31**

Summary 33

Introduction 33

Methods 35

Study Area 35
Questionnaire survey 36
Statistical analyses 36
Results 36
Demographics of respondents 36
Livestock ownership trends in relation to Cape Vulture numbers 37
Safety of carcasses for vultures 38
Management of deceased livestock 38
Community perceptions of the Cape Vulture and its threats 39
Discussion 39
Livestock ownership trends and vulture observations 39
Safety of carcasses for vultures 40
Management of dead livestock 40
Community perceptions of the Cape Vulture and its threats 41
Management implications 42
Supplementary material 42
Acknowledgements 42
References 42
ADDENDUM TO CHAPTER 2 47
CHAPTER 3: 48
Foraging range and habitat use by Cape Vulture *Gyps coprotheres* from the Msikaba colony, Eastern Cape province, South Africa 48
Introduction 49
Methods 50
Study area 50
Data collection 51
Cape Vulture captures and marking 51
Data analysis 51
Habitat use and GPS tracking 52
Foraging ranges 52
Habitat use 53
Discussion 53
Conservation implications 55
Conclusion 55
Acknowledgments 55
Competing interests 56
Authors’ contributions 56

References 56
Appendix 1 58
ADDENDUM TO CHAPTER 3 60
CHAPTER 4: 61
4.1 Methods 66
4.1.1 Study site and species 66
4.1.2 Nest monitoring 69
4.1.3 Predictor variables 71
4.1.4 Data preparation 72
4.1.5 Regression models 73
4.2 Results 74
4.2.1 Nest site occupation 77
4.2.2 Breeding success 81
4.3 Discussion 85
4.4 Acknowledgments 89
4.5 References 90
CHAPTER 5: 94
Threatened at home: Collision risk of endangered vultures to wind turbines is highest at roost sites and breeding colonies 94
5.1 ABSTRACT 95
5.2 Introduction 96
5.3 Materials and methods 98
5.3.1 Study Area 98
5.3.2 Focal Species 99
5.3.3 Vulture Captures and GPS Deployment 100
5.3.4 Spatial Data 103
5.3.5 Data Processing 106
5.3.6 Cape Vulture Species Distribution Models 107
5.3.7 Buffer Size Recommendations 109
5.4 Results 109
5.5 Discussion 116
5.6 Conclusion 118
5.7 Acknowledgments 119
5.8 References 119
CHAPTER 6: 123

Conclusion 123

6.1 Introduction 123

6.2 Research Findings 124

6.3 Discussion and Recommendations 126

6.4 Future Work 130

6.5 Concluding Remarks 131

6.7 References 132

Appendix A: Sample Interview 135

LIST OF FIGURES

Fig. 1.1 A map of South Africa illustrating the location of the former Transkei homeland. 19

Fig. 4.1 Location of the Msikaba Cape Vulture breeding colony, Eastern Cape Province, South Africa. 68

Fig. S4.1 Example of a cliff formation (Mamba) with Cape Vulture nest sites at the Msikaba Cape Vulture breeding colony, Mkambati Nature Reserve, Eastern Cape Province, South Africa. 70

Fig. 4.2 Total number of Cape Vulture (*Gyps coprotheres*) breeding attempts (n = 1767) and successful attempts (n = 1391) at the Msikaba Cape Vulture colony in the Mkambati Nature Reserve, Eastern Cape Province, South Africa. No data were collected in 2009 or 2011. 75

Fig. 4.3 Model-averaged estimates (± 95 % confident intervals) of top variables from the GLMM showing the probability of nest occupation (n = 3627) based on cliff characteristics and neighbour requirements at the Msikaba Cape Vulture colony, Mkambati Nature Reserve, Eastern Cape Province, South Africa.79-80

Fig. 4.4 Model-averaged estimates (± 95 % confident intervals) of top variables from the generalized linear model showing the probability of a nest being successful (n = 1767) based on cliff characteristics and neighbour requirements at the Msikaba Cape Vulture colony, Mkambati Nature Reserve, Eastern Cape Province, South Africa. No data were collected in 2009 or 2011 83-84

Fig. S5.1 Detail of the weak link of the GPS transmitter harness. Teflon® is sewn together using dental floss or cotton thread. 103

Fig. S5.2 Flying GPS locations of the nine Cape Vultures in the Eastern Cape Province, South Africa. 1,121 flying points at risk height and 2,410 flying points above risk height were used in the creation of the risk flying height and flying distribution model. 107

Fig. 5.1 Cape Vulture movement mode classifiers. Frequency distributions of the mean (a) exploratory movement mode and (b) encamped movement mode from all GPS locations of nine Cape Vultures. Mean movement is distance travelled between consecutive points in 1 hour intervals 110

Fig. 5.2 Model evaluations for the species distribution model and the risk flying height model for the Cape Vulture in the Eastern Cape Province, South Africa. (a) Area under the curve (AUC) as a model evaluation for the Cape Vulture flying distribution model for the study area in the Eastern Cape Province. (b) Area under the curve (AUC) as indicator of model performance for the risk flying height model. The risk was identified as the probability of Cape Vultures flying at a height in which they may collide with wind turbine blades. 111

Fig. S5.3 Variable importance plot for the flying distribution model for the Cape Vulture in the Eastern Cape Province, South Africa. Predictor variables ranked in order of their importance. The model predicted where Cape Vultures were more likely to fly based on the predictor variables…………………………111

Fig. S5.4 Predictor variable effects plots for the flying species distribution model for Cape Vultures in the Eastern Cape Province, South Africa. Probability that Cape Vultures would be flying based on (a) distance from nearest roost site, (b) distance from nearest breeding colony, (c) average wind speed and (d) topography…………………………………………………………………..112

Fig. S5.5 Predictor variable effects plots for the risk height species distribution model for Cape Vultures in the Eastern Cape Province, South Africa. Probability that Cape Vultures would fly at risk height based on (a) distance from nearest roost site, (b) distance from nearest breeding colony, (c) average wind speed and (d) topography…………………………………………………………………..113

Fig. S5.6 Risk flying height and species distribution maps for the Cape Vulture in the Eastern Cape Province, South Africa. The machine learning species distribution model was used to predict the probability of tagged vultures flying in the area based on the spatial predictor variables (distance from nearest roost site, distance from nearest breeding colony, average wind speed and topography)…………………………………………………………………114

Fig. 5.3 Risk flying height map for the Cape Vulture in the Eastern Cape Province, South Africa. The regression species distribution model displaying the probability of vultures flying at risk height based on the spatial predictor variables. Probability results were not reported for the northern part of the Eastern Cape Province because no data on average wind speed was available…………………………………………………………………..115

Fig. S5.7 Probability plots to determine the buffer size around Cape Vulture (a) roost sites and (b) breeding colonies. The probability outcomes of the two SDMs were plotted in relation to distance from roost site. Non-linear trend lines were added to each data set based on the best R^2 value. At the intersection of the trendlines, a recommendation for buffer size is given. For roosts sites the recommendation is 14 km and for breeding colonies it is 16 km…………...115

LIST OF TABLES

Table S4.1 Cliff and neighbour measurements recorded for nest sites at the Msikaba Cape Vulture colony, Mkambati Nature Reserve, South Africa. 71-72

Table S4.2. Cliff and neighbour breeding pair characteristics of the Msikaba Cape Vulture colony, Mkambati Nature Reserve, South Africa (Means + SD)..75-76

Table 4.1 Results from the top GLMs ($\Delta AIC_c < 2$) for factors influencing Cape Vulture (n = 3627, observations from 2000 to 2015) nest site occupation at the Msikaba colony. Model parameters: Height (height of nest site), Depth (ledge depth), Productivity (total productivity of the nest site), Direct Neighbours (number of direct neighbours), Neighbours (number of ledge neighbours), Previously Active (if the nest was active the previous year), Overhang (ledge depth of the overhang of the nest site)……………………………………..77

Table 4.2 Model-averaged coefficients for predicting Cape Vulture nest site occupation (n = 3627) at the Msikaba colony. Model parameters: Height (height of nest site), Depth (ledge depth), Productivity (total productivity of the nest site), Direct Neighbours (number of direct neighbours), Neighbours (number of ledge neighbours), Previously Active (if the nest was active the previous year), Overhang (ledge depth of the overhang of the nest site); RI = relative importance of the variable………………………………………78

Table 4.3 Results from the top GLMs ($\Delta AIC_c < 2$) for factors influencing Cape Vulture (n = 1767 observations from 2000 to 2015) breeding success at the Msikaba colony. Model parameters: Height (height of nest site), Depth (ledge depth), Productivity (total productivity of the nest site), Direct Neighbours (number of direct neighbours), Neighbours (number of ledge neighbours), Previously Active (if the nest was active the previous year), Overhang (ledge depth of the overhang of the nest site), and Year…………………………81-82

Table 4.4 Model-averaged coefficients (with shrinkage) for predicting Cape Vulture breeding success (n = 1767) at the Msikaba colony. Model parameters: Height (height of nest site), Depth (ledge depth), Productivity (total productivity of the nest site), Direct Neighbours (number of direct neighbours), Neighbours (number of ledge neighbours), Previously Active (if the nest was active the previous year), Overhang (ledge depth of the overhang of the nest site), and Year……………………………………………………………………..85

Table 5.1 Information on the nine individual Cape Vultures (*Gyps coprotheres*) with GPS transmitters used for analysis……………………………………101-102

Table S5.1 Grid size and data sources for the predictor variables of the risk assessment models for Cape Vultures (*Gyps coprotheres*) in the Eastern Cape Province, South Africa…………………………………………………...104

Table S5.2 Topography reclassification for the topography predictor variable for use in species distribution models for the Cape Vulture (*Gyps coprotheres*) in the Eastern Cape Province, South Africa... 104

Table S5.3 Variable importance mean square error and node purity values for the flying species distribution model of Cape Vultures for the Eastern Cape Province, South Africa. 112

Table 5.2 Variable importance for the risk flight height species distribution model of Cape Vultures (*Gyps coprotheres*) for the Eastern Cape Province, South Africa……………………………………………………………………..113

CHAPTER 1:

Introduction

Scavengers, particularly New World and Old World vultures, are considered the most threatened group of birds and as scavengers they range widely outside of protected areas, therefore traditional conservation planning and management is difficult (Mandel et al. 2008, Phipps et al. 2013a, Spiegel et al. 2013). Declines in vulture populations can have major consequences, resulting in the loss of the ecosystem services they provide (Wenny et al. 2011, Ogada et al. 2012a). As the only obligate scavengers, vultures perform important ecosystem services by consuming carrion (Wilbur and Jackson 1983, Ogada et al. 2012b). Vultures recycle organic material, prevent possible mammalian disease transition, and provide a free carbon neutral waste removal service (Dupont et al. 2012, Ganz et al. 2012, Ogada et al. 2012b). It is imperative to halt further vulture population declines before they become irreversible and extinctions occur.

In this chapter, I first review the major threats inflicting Old World vulture species, which inhabit Europe, Asia, and Africa. Economic costs and biological consequences of vulture population declines are then discussed. Next, the study species, the Cape Vulture (*Gyps coprotheres*), is introduced and aspects of its ecology are reviewed. The Lesotho, Eastern Cape, and KwaZulu-Natal Provinces, South Africa, contain an important sub-population of the Cape Vulture and are described. The research questions, aims and objectives, in addition to the significance of the study are outlined. Lastly, an outline of the thesis is provided.

1.1 Threats to African Vultures

The accelerated growth of the human population and land use changes associated is one of the major threats to biodiversity and ecosystem services (Cincotta et al. 2000, Hansen et al. 2004, McKee et al. 2004). To mitigate these effects, protected areas where human-modification is minimal are created (Jenkins et al. 2013, Trimble and Van Aarde 2014). The benefits of protected areas not only include conservation of biodiversity, but economic benefits and cultural enrichment (Dixon and Sherman 1990, McNeely 1994, Jenkins et al. 2013). However, the borders of the protected areas are not a barrier to all outside threats. Poachers, pollution, and environmental changes caused by global climate change effect ecosystems regardless of protection (Root et al. 2003, Chape et al. 2005, Robinson et al. 2011). Furthermore, the habitat conserved in protected areas represents a small percentage of the land uses encountered by migratory animals and those unable to be contained by fences (Boardman 1981, Thirgood et al. 2004).

Worldwide, 61% of vulture species face the risk of extinction (Ogada et al. 2012a). Causes for global vulture population declines include collisions with power line infrastructure, poisoning, and direct persecution (Ogada et al. 2012a). In Africa, 7/8 vulture species assessed have declined at a rate of 80 % or more over three generations (Ogada et al. 2015b). At least 6 of these vulture species satisfy the requirements of uplisting their conservation status to ‘Critically Endangered’ (Ogada et al. 2015b). These dramatic population declines have been described as the “African Vulture Crisis’, intensifying the need to prevent further declines before wide-spread extinctions occur (Ogada et al. 2015b). Vultures are relatively long-lived with low reproductive rates, making them susceptible to dramatic population declines (Mundy et al. 1992). The adaptations that help vultures locate unpredictable food sources (large bodies, soaring locomotion, far-raging, and highly social nature) also make them vulnerable to multiple threats. Each one of these adaptations is discussed in terms of how it exposes vultures to threats in human modified environments.

1.1.1 Large-bodied and fatalities from power lines

The body mass of African vulture species in the *Gyps* genus ranges between 4-11 kg and their wingspans range between 1.96 - 2.8 m (Mundy et al. 1992). These large birds require space and short vegetation in order to accomplish landings and take-offs from the ground (Bamford et al. 2009). To avoid predation and human disturbance, vultures will roost off the ground during periods of bad weather and overnight when thermals are absent (Mundy et al. 1992, Dermody et al. 2011). In the last century, the use of electricity has dramatically increased in Africa resulting in the installation of power line infrastructure, which has been used by some vultures as nesting platforms, vantage points, and roost sites (Mundy et al. 1992, Anderson and Hohne 2008, Boshoff et al. 2011, Phipps et al. 2013b). However, electrocutions and collision with power lines are a wide spread threat to vultures and other large birds (Boshoff et al. 2011, Naidoo et al. 2011). Fatalities from power line collisions occur during both periods of high and low visibility, providing evidence that vultures obtain and process visual information differently than humans (Martin 2011). *Gyps* vultures have a small binocular visual field and large blind areas in many directions, which maximizes ground coverage but also makes them temporally blind in the direction of travel (Martin et al. 2012). The limitations of their vision coupled with large proportions of time spent near power lines can result in substantial risk of collision with the man-made structures (Phipps et al. 2013b). Raptor electrocutions occur mainly on non-conductive, wooden pylons when the birds are able to touch both conductors (Janss 2000). This action sends high-voltage electricity through the bird, killing it most of the time (Ledger and Annegarn 1981).

In the Eastern Cape Province, power-line related mortalities (electrocutions and collisions) were estimated to remove a minimum of 80 Cape Vultures a year from the sub-population (Boshoff et al. 2011). It is suggested that vultures in the Eastern Cape Province breed in the currently relatively low electrocution areas, which have few documented electrocution cases, but migrate to high electrocution areas during the non-breeding season so increasing potential fatalities (Boshoff et al. 2009a, Boshoff et al. 2011). Out of 181 Cape Vulture power-line fatalities recorded between 1996-2008, all but one occurred in the commercial farmland areas of the Eastern Cape, and not within the subsistence farmland areas (Boshoff et al. 2011). However, these results require caution. During the four years of this study, one incident of electrocution was reported near Colleywobbles Cape Vulture colony in subsistence farmland (pers. obs.). Cape Vulture power line fatality incidents in subsistence farmland is likely under reported and vulture carcasses may be collected for traditional medicine purposes, therefore to determine the distribution of incidents, reporting rates must be standardized. Regardless of distribution of power line incidents, they are considered a major threat to vultures and related incidents are the major cause of vultures being admitted into rehabilitation (Naidoo et al. 2011). Mitigation methods for preventing electrocutions involve changing the structure of the pole to prevent birds from touching both conductors (Jenkins et al. 2010). Adding hanging plastic discs from power lines aim to alert the birds of the object when they move in the wind (Jenkins et al. 2010).

1.1.2 Soaring flight strategy and collision with wind turbine blades

The limited visual field of vultures makes them susceptible to collisions with power lines and also wind turbine blades. Furthermore, vultures use slope-soaring, which is their main form of locomotion and amplifies their risk of collision with wind turbine blades (Mundy et al. 1992, Katzner et al. 2012). Steep topographic features, such as cliffs, are more suitable for orographic lift (Katzner et al. 2012). This lift is a low-energy resource for low-altitude soaring, but also places raptors within the risk zone of wind turbine blades (Kerlinger 1995, Katzner et al. 2012). Since wind turbines are typically located in steep terrain to take advantage of high average wind speeds, it is certain they will be encountered by slope-soaring raptors (Barrios and Rodríguez 2004, Smallwood and Thelander 2008, Katzner et al. 2012, Reid et al. 2015).

High collision rates between wind turbines and *Gyps* vultures in Spain have been recorded. Upwards of 350 vultures were found dead at 34 wind farms and a collision rate of 0.15 vultures per turbine per year was calculated for other facilities (Barrios and Rodríguez 2004, Carrete et al. 2012). Distribution of vulture fatalities were not uniform, but clumped around few wind turbines (de Lucas et al. 2012). Environmental impact assessments, which typically include estimates of abundance, are conducted for each wind turbine installation (Retief et al. 2013). However, studies from Spain have highlighted a weak correlation between raptor abundance and collision fatalities, suggesting that environmental impact assessments do not accurately predict raptor mortalities at wind turbine facilities (de Lucas et al. 2008, Ferrer et al. 2012). In Africa, wind energy installation has been increasing, and only recently developed within any African vulture ranges (Doty and Martin 2013, Smallie 2013, 2014). Small scale wind farms proposed in Lesotho would drastically increase the decline of the Drakensburg Cape Vulture population from -2.2% per annum to -3.4 per annum, thus increasing the time to local extinction by 80 years (Rushworth and Krüger 2014).

In order to prevent these vulture fatalities, a number of mitigation methods have been proposed and tested (de Lucas et al. 2012, Bennett and Hale 2014, Reid et al. 2015). From 2008 to 2009, the vulture mortality rate was reduced by 50 % at one wind farm by selectively stopping the blades from spinning when a vulture was near (de Lucas et al. 2012). Turbines were stopped after the control office received phone calls from observers, which highlights the limitations of this method if no observers are present (de Lucas et al. 2012). Similar to power-line mitigation, lights have been placed on turbines to alert animals of their presence, but this technique has not been successful (Bennett and Hale 2014). The most widely accepted method to prevent wind turbine related fatalities is the placement of wind turbines in areas where risks to biodiversity are the lowest (Marques et al. 2014). This method requires detailed spatial knowledge of the species' biology and drivers of its flight height (Belaire et al. 2014, Reid et al. 2015). Although this method is reliable, it is species-specific and has only been incorporated into wind turbine planning for two vulture species, the southern African population of Bearded Vulture (*Gypaetus barbatus*) and the Balkan Cinereous Vulture population (*Aegypius monachus*)(Reid et al. 2015, Vasilakis et al. 2016).

South Africa and Lesotho have set renewable energy goals that include the installation of wind farms (Doty and Martin 2013, Rushworth and Krüger 2014). A total of 4,000 turbines are planned in the Lesotho highland region in the foraging ranges of the critically endangered Bearded Vulture and Cape Vulture (Allan 2015, Reid et al. 2015). South Africa aims to produce 10,000 GWh of energy which would require thousands of turbines (Doty and Martin 2013). Most of the wind turbine installations in South Africa are located in the Western and Eastern Cape Provinces (Doty and Martin 2013). There are no documented reports of vulture mortalities at wind energy facilities in South Africa, but other raptor species such as Jackal Buzzards (*Buteo rufofuscus*) and Verreaux's Eagle (*Aquila verreauxii*) have died from colliding with wind turbine blades at these facilities (Simmons et al. 2011, Smallie 2015). The first wind farm in South Africa, a four turbine facility, the Darling Wind Farm, was constructed in the Western Cape north of Cape Town in 2008 (Becker 2016). It was not until 2014 that wind energy installations became more prominent with 560 MW of energy generated from wind power that year alone (Becker 2016).

An Avian Wind Farm Map for South Africa has been created using bird census data in combination with species priority scores based on physical characteristics that make species vulnerable to collision with wind farms (Retief et al. 2013). According to this criterion, the Bearded and Cape Vultures are ranked as the top conservation priority species

(Retief et al. 2013). 5 x 5 minute grid cells were then assigned a value based on all species data and areas near bird congregation areas such as roosting sites or breeding colonies that had high risk values. Known roost sites or breeding colonies of priority species were surrounded by buffers to discourage the establishment of wind farms (Jenkins 2012, Retief et al. 2013). The extent of these buffers (20 km for roosts and 40 km for breeding colonies) for the Cape Vulture were based on empirical information, such as the energy budget of breeding vulture pairs, movement data from a single Cape Vulture and observations at different distances from breeding colonies (Ruxton and Houston 2002, Boshoff and Minnie 2011, Retief et al. 2013). This approach is biased to identifying and protecting breeding colonies of Cape Vultures, but not roost sites.

Current best management practices for avian monitoring and impact mitigation at wind energy sites in South Africa includes an extensive review of existing bird abundance and density data from the proposed development areas (Jenkins 2012, Retief et al. 2013). This data comes from citizen science programs, which may not have total coverage in proposed development areas and may not contain enough information to make informed decisions about the presence and abundance of vulnerable species to wind turbine collisions. Therefore, intense monitoring surveys are conducted for 12 months at proposed sites. These surveys include both day and nighttime observations, and attempt to document flight activity and relative use of the area. Tracking individual priority species has been conducted in some areas, however it requires an in depth analysis to produce meaningful results (Kendall et al. 2014, Reid et al. 2015). Another monitoring technique that has great potential is the use of radar to obtain accurate information on bird movements through a proposed development area. This technology has accurately identified Cape Vultures and obtained accurate estimates of flight heights throughout the day (Becker 2016).

1.1.3. Far-raging and exposed to diverse land uses and livelihoods

African vultures have large foraging ranges which expose them to a diversity of land uses and human livelihoods (Bamford et al. 2007, Phipps et al. 2013a). African White-backed Vultures (*Gyps africanus*) fitted with GPS/GSM transmitters captured in the North West Province, South Africa had large foraging ranges with a mean minimum convex polygon ± SE area of 269,103 ± 197,187 km^2 (Phipps et al. 2013a). Cape Vultures fitted with GPS/GSM transmitters in South African and Namibia also ranged far with mean MCPs between 21,320 km^2 to 492,300 km^2, making the Cape Vulture the most wide ranging *Gyps* vulture species that has been documented (Phipps et al. 2013b). Therefore, changing land use in Africa can pose a threat to vultures as they travel great distances (Boshoff and Vernon 1980, Monadjem and Garcelon 2005, Murn and Anderson 2008, Phipps et al. 2013b). Limited availability of carrion is considered to be a major threat to the vultures in some areas, and is influenced by changes in local land use and livelihoods (Boshoff and Anderson 2006). During ungulate seasonal migrations, vultures had a steady food provision comprised of the young, old and weak animals in addition to carrion from large predator kills (Boshoff and Vernon 1980, Mundy et al. 1992, Kendall et al. 2012a., Ogada et al. 2012a, Kendall et al. 2014). Most of Africa's migratory ungulates have been extirpated or are restricted to protected areas (Boshoff and Vernon 1980, Kendall et al. 2014). In substitute of migratory ungulate herds, domestic livestock in subsistence and commercial agriculture systems has become a major alternate source of food (Boshoff and Vernon 1980, Boshoff et al. 2009b). Consequently, vultures that rely on domestic livestock for food may experience population changes based on livestock ownership trends. For example, the Colleywobbles Cape Vulture colony (32°0'S 28°35'E 511 m.a.s.l.) experienced dramatic declines from 1980 to 1990, and during this period the number of large stock units declined from 2.6 million to 1 million (Vernon 1998). Continued livestock ownership in subsistence agricultural systems is more common among wealthier households, because they are able to adapt to seasonal fluctuations (Shackleton et al. 2013), whereas in poorer households, livestock ownership oscillates (Shackleton et al. 2013). As subsistence agricultural areas have some of the highest unemployment rates in South Africa, declines in livestock numbers may be widespread (Statistics South Africa 2011b).

African vultures can also be persecuted by being killed for use in traditional medicine or as misplaced revenge for killing livestock (Brown and Piper 1988, Whiting et al. 2011). Some commercial farmers blame vultures for attacking and killing their livestock and will destroy individual vultures for revenge (Mundy et al. 1992). Fortunately, this persecution is not as common as it was in the past (Brown and Piper 1988, Hiltunen 2009). Although the killing of vultures for traditional medicine in South Africa may not have increased, the demand will likely increase with the growing human population (Cunningham and Zondi 1991, Mander et al. 2007). Consuming crushed vulture brains, vertebrae, wings, and feathers in traditional medicine is believed to give the consumer clairvoyance powers as well as relief from headaches (Mundy et al. 1992, Beilis and Esterhuizen 2005, Mander et al. 2007). This is especially popular among school-aged children during examinations as well as for gamblers (Mander et al. 2007). The reasons for this belief stem from the perceived great eye-sight of vultures, its speed, and the ability to congregate quickly (Mundy et al. 1992). This mystical property is not necessarily perceived as the body part, but as a ‘worm’ in the vulture’s brain, so a misconception (Mundy et al. 1992). It was estimated that 160 vultures are sold p.a. for use in traditional medicine, with an estimated sales of R1,185,600, despite the sale of vulture parts being illegal (Mander et al. 2007). Illegal hunting, by use of poison or firearm, of the Cape Vulture for traditional medicine was estimated to remove a minimum of 27 individuals from the Eastern Cape, KwaZulu-Natal, and Lesotho population each year (Mander et al. 2007).

1.1.4. Highly social nature and mass poisoning incidents

Most vulture species rely on cues from other scavenging species and conspecifics to locate unpredictable food resources (Cortés-Avizanda et al. 2014, Kane et al. 2014). Once located, carcasses can attract large numbers of vultures. In Kenya, carcasses were visited by a mean of 100 individuals (Kendall et al. 2012b.). To avoid competition and predation, vultures are able to fill their crops in a matter of minutes and have the potential to consume an entire carcass in 20 minutes (Mundy et al. 1992). This highly social feeding strategy makes vultures particularly susceptible to poisoning incidents (Ogada et al. 2012a).

The use of poisoned carcasses to kill livestock predators is a common technique for many African farmers and has been occurring for decades (Brown and Piper 1988, Ogada et al. 2012a, Ogada et al. 2015b). Some farmers will hide poison inside animal carcasses to kill livestock predators, however the poison is not species-specific and can cause mass mortalities of vultures (Brown and Piper 1988, Ogada et al. 2012a). It is unknown how many vultures are killed by poison intended for livestock predators, however the effects can be detected in declining vulture populations (Mundy et al. 1992, Ogada and Buij 2011). In and around the Masai Mara National Park, Kenya, road side counts of raptor species conducted between 1976 and 1988, and 2003 and 2005 showed a decline in all scavenging raptors, except Bateleurs (*Terathopius ecaudatus*) (Virani et al. 2011). The Egyptian Vulture (*Neophron percnopterus*) was absent from the more recent surveys. Poison set for livestock predators was considered the main cause for this decline (Virani et al. 2011). In the same area, 4 out of 17 (26 %) vultures with transmitters died within the first year from ingesting poison (Kendall and Virani 2012). In South Africa, extensive poison use amongst small stock farmers in the Drakensberg midlands region of South Africa is suggested to have caused declines of the Cape Vulture there (Brown and Piper 1988).

For scavengers, the presences of lead in the environment and carcasses have the potential to be deadly or cause endocrine dysfunction (Fisher et al. 2006, Warner et al. 2016). Although birds generally appear to cope with high lead levels better than most mammals, it can affect reproduction (Naidoo et al. 2012). Blood lead concentrations of 100 µg/dl causes clinical signs of toxicity and 20 to 100 µg/dl produces high incidences of embryonic death and egg infertility (Naidoo et al. 2012). In Botswana 147 vultures (30 %) had high blood lead concentrations that exceed the background 10 µg/dl level (Kenny et al. 2015). Ammunition from carcasses killed by hunters is considered the principal source for lead found in wild California Condors (*Gymnogyps californianus*) (Church et al. 2006). In 18 wild condors the average blood lead levels 24.6 µg/dl, which is detrimental to their survival (Church et al. 2006).

In the 1990s, incidental vulture poisonings from livestock injections toxic to vultures caused the ‘Asia Vulture Crisis’ (Oaks et al 2004). Vulture populations in Asia collapsed during this crisis with a staggering rate of decline of 80 – 99 % p.a. (Green et al. 2004, Pain et al. 2008). The cause for this decline was linked to the livestock non-steroid anti-inflammatory drug diclofenac (Green et al. 2004, Pain et al. 2008). Livestock injected with diclofenac before they died were toxic to vulture feeding on their carcasses (Green et al. 2004). A ban on using diclofenac has slowed the vulture population decline, however, an alternative, nimesulide, is also toxic to vultures, accentuating that toxic livestock injections are still a major threat (Cuthbert et al. 2016). Diclofenac is available in southern Africa, but is not preferred. Instead, Flunixin meglumine, Phenylbutazone and Ketoprofen are the commonly used livestock anti-inflammatory drugs (Naidoo et al. 2010). Ketoprofen and diclofenac livestock drugs are known to be toxic to African vulture species (Naidoo et al. 2010). A commonly used livestock de-wormer, Fenbendazole, may also be toxic to wild scavenging birds (Sharma 2016). These drugs and possibly more that are unknown are potentially causing vulture population declines, but are difficult to identify and detect (Green et al. 2004, Pfeiffer 2014).

Unlike incidental veterinary poisonings, intentional poisoning related to African bush elephant (*Loxodonta africana*) poaching has increased rapidly since 2012 and the negative effects are extremely noticeable (Ogada et al. 2015a, Ogada et al. 2015b). Poachers will lace elephant carcasses with poison after hacking off ivory and other trophies, to intentionally kill vultures, whose circling flights above the elephant carcass may alert anti-poaching units (Ogada et al. 2015a), and so give the poachers time to evade capture and flee the scene of the crime. A single poisoned elephant carcass can eliminate over 500 vultures (Ogada et al. 2015a). A total of 11 known vulture poisoning incidents at elephant carcasses occurred across seven African countries between 2012 and 2014, killing over 2,000 vultures (Ogada et al. 2015a). As some of these poisoning incidences occur during the breeding season, it is assumed the young of the poisoned vultures also died increasing the numbers decimated.

This list of threats to Cape Vultures is not comprehensive, but highlights what threats are important to address with conservation management plans and identifies research needs.

1.2 Consequences of vulture population declines

The culminations of all the threats described above have caused major declines in vulture populations. These declines have had economic, ecological, and human safety consequences (Ogada et al. 2012a, Ogada et al. 2015b). Major declines of vultures in Asia, from consuming carcasses with diclofenac, correlated with an increase in the feral dog populations, which has increased rabies *Lyssavirus* transmissions (Markandya et al 2008). Between 1993 and 2006, India spent $ 34 billion on health costs related to high densities of feral dog populations (Ogada et al. 2015b). Loss of vulture populations also means high monetary costs for carcass removal and increases in CO_2 emissions (Dupont et al. 2012, Morales-Reyes et al. 2015, Ogada et al. 2015b). Using a private company for the free waste removal service vultures provide was estimated to add up 77,344 MT of CO_2 entering the environment per year (Morales-Reyes et al. 2015). The monetary cost for removing all livestock carcasses was estimated at $50 million (Morales-Reyes et al. 2015). Even guano of some vulture species is beneficial to the environment because it contains a high diversity of favourable bacteria which may help prevent the spread of disease (Ganz et al. 2012). Carrion resources that have been scavenged also create biodiversity hotspots that last for several years (Beasley et al. 2012). However, many more links likely exist between an ecosystem's health and the vital role of vultures but have yet to be quantified (Beasley et al. 2012).

1.3 Cape Vulture

The Cape Vulture (Forster 1798) is one of the African vulture species expected to decline by 92% over the next three generations (Allan 2015, Ogada et al. 2015b), however some regions may experience population increases (Benson 2015). This species has just been up-listed to 'Endangered' on both the Red List of Threatened Species of the International Union for the Conservation of Nature (IUCN) and the South Africa, Lesotho, and Swaziland regional Red Data assessment (Allan 2015, BirdLife International 2015). Out of all the Old World vulture species, the Cape Vulture has the smallest distribution (Mundy *et al.* 1992). It is 90% restricted to South Africa and Lesotho, and therefore considered endemic (Mundy et al. 1992, Piper 2005). This obligate cliff-nesting scavenger has an estimated population of 8,800 mature individuals, of which 4,400 are breeding pairs (Allan 2015). It is a large bird, weighing on average 9 kg with a 2.55 m wingspan (Mundy et al. 1992). The Cape Vulture is monogamous, probably pairing for life (Mundy et al. 1992, Piper 2005). They nest in colonies and rarely singly. At most, a pair raises one chick per year (Piper 2005). The breeding season occurs in winter from May-October (Mundy et al. 1992, Piper 1994). Cape Vultures reach sexual maturity at 5 years of age (Mundy et al. 1992), but do not necessarily breed every year (Borello and Borello 2002). Mean egg laying date ranges from late May to late June (Robertson 1986, Vernon 1998). Incubation lasts about 57 days (Mundy et al. 1992). Towards the middle of winter when vulture chicks start to hatch, carcasses are more plentiful from starvation deaths and the low temperatures deter insects that compete for food resources making it an ideal season to raise chicks (Boshoff et al. 1984, Mundy et al. 1992).

Cape Vultures may be restricted to 40 km from the colony during the breeding season based on empirical evidence (Boshoff and Minnie 2011). Because the air is cooler in the winter, thermals are present for a shorter period than in the summer, which also suggests smaller foraging ranges (Boshoff et al. 1984, Mundy et al. 1992, Kerlinger 1995, Spiegel et al. 2013). A rehabilitated radio-tracked adult bird from the Potberg Colony (34°22’S 20°33’E) in the Western Cape, South Africa, showed a limited range of 10-15 km from the colony during the 32 day period, with the winter foraging site located closer to the colony (Boshoff et al. 1984). During the summer non-breeding season, Cape Vultures show a partial migration in the Eastern Cape Province, South Africa, with an increase in vulture observations in the western parts, however age structure of the migrants has not been verified (Boshoff et al. 2009a, Boshoff et al. 2011). It is possible, that after dispersal events juveniles will congregate in ‘nursery areas’ away from core breeding areas of the adult vultures (Wilbur *et al.* 1983; Piper 1994).

GPS tracking studies have emphasized the differences in home range sizes between adult and juvenile Cape Vultures, with the younger non-breeding population traveling greater distances during juvenile dispersal events (Bamford et al. 2007, Phipps et al. 2013a). Using the Minimum convex polygon method, two juvenile Cape Vultures had a mean home range of 482,279 km^2, whereas five adult vultures produced a mean home range of 21,320 km^2 (Bamford *et al.* 2007). In comparison, adult non-breeding Eurasian Griffon Vultures (*Gyps fulvus*) were found to have mean MCP of 7,419 km^2 (García-Ripollés et al. 2011).

The stronghold for the Cape Vulture is concentrated in the central part of northern South Africa (representing about 3,000 pairs) and southern Botswana (representing 600 pairs), however, a few colonies remain outside of this area scattered around southern Africa (Boshoff and Currie 1981, Piper and Ruddle 1986, Benson et al. 1990, Borello and Borello 2002). Namibia was once considered part of the Cape Vulture's range, but it is now functionally and locally extinct (Bamford et al. 2007, BirdLife International 2013). Long-term data sets of breeding dynamics exists at a handful of Cape Vulture colonies: south-east Botswana (Borello and Borello 2002), Colleywobbles, Eastern Cape Province (Vernon and Piper 1991, Vernon 1998), Potberg, Western Cape Province (Boshoff and Currie 1981), and Kransberg, Blouberg, and Magaliesberg, North West and Gauteng Provinces (Benson et al. 1990, Benson 2000, Wolter et al. 2007). The longer a nest site was used for breeding, the higher the productivity, however without marked birds it was unknown if this was a consequence of repeated pair use (Borello and Borello 2002).

Cape Vulture breeding colonies are not static; colony numbers fluctuate and relocation of breeding sites occurs (Vernon 1998, Borello and Borello 2002, Wolter et al. 2007). The latter was observed in Botswana, where a breeding colony moved to another location for a period and then some pairs returned to the original site (Borello and Borello 2002). This behaviour might be in response to human disturbances at the breeding cliffs (Borello and Borello 2002, Wolter et al. 2007). Between 1995-1996 there was a complete abandonment of the Bonwalenong cliff, Botswana, and the vultures rapidly relocated to other sites (Borello and Borello 2002). At the colonies in the Little Karoo,Western Cape, small increases at one colony matched decreases found at nearby colonies (Boshoff and Currie 1981)

1.4 Cape Vulture sub-population of Lesotho, KwaZulu-Natal and Eastern Cape Provinces

Although the strong hold of the Cape Vulture is in the northern parts of South Africa, study of outlying colonies is important for preventing contraction of the species' current range (Boshoff and Minnie 2011). The country of Lesotho and the South Africa provinces of the Eastern Cape and KwaZulu-Natal comprised the south-eastern node of the global Cape Vulture population (Allan 2015). Lesotho is a relatively small country characterized by rugged terrain, high altitudes (2,200 to 3,100 m), and average rainfall between 500-1,000 mm (Mundy et al. 1992). These high rainfall areas can support montane forests and heather communities, but in recent decades habitats have degenerated to scrub and grasslands (Mundy et al. 1992). Dense mist and high winds are common amongst the vast basalt and sandstone cliffs and temperatures often are below freezing in the winter (Mundy et al. 1992, Sycholt 2002). A large portion of the border between Lesotho and KwaZulu-Natal is part of The Maloti Drakensberg Park (MDP), a world heritage site, and incorporates the Maloti-Drakensberg Mountains. Land use outside of the protected areas in Lesotho is dominated by communal farmland, used mainly by small stock farmers (Kruger et al. 2014). The majority of the Cape Vulture activity occurs on the Drakensberg escarpment of the KwaZulu-Natal Drakensburg, but in 2012 about 120 individuals were observed near nests during a helicopter monitoring survey of the interior of Lesotho (Botha et al. 2012).

The KwaZulu-Natal Drakensberg is separated into the High 'Berg' and Low 'Berg'. The former starts at Lesotho and descends with many sheer basalt cliffs to grassy slopes (Brown and Piper 1988). From about 1,980 m to 1,500 m the Little 'Berg' consists of sandstone cliffs intersected by numerous rivers that form valleys (Brown and Piper 1988). The typical vegetation is *Themeda triandra* and *Festuca* sp. High winds, and low temperatures are common with snow recorded in all months of the year (Brown and Piper

1988, Mundy et al. 1992). Rainfall is highest on the Little ‘Berg’ with about 2,000 mm p.a., and human and domestic animal populations increase with decreasing altitude (Brown and Piper 1988). The Little ‘Berg’ has a number of former homelands that use communal rangelands. Below the Little ‘Berg’, large areas are cultivated and are commercially farmed (Brown and Piper 1988). Breeding Cape Vultures nest along the escarpment in the southern Drakensberg. At least 370 individual Cape Vultures were recorded in 2012 along the escarpment near nests by helicopter survey (Botha et al. 2012).

In the Eastern Cape Province, Cape Vultures once bred from the former Transkei river gorges to the river cliffs in the Karoo (Boshoff and Vernon 1980, Mundy et al. 1992). Within this area, seven biomes are found: Fynbos, Forest, Grassland, Savanna, (Subtropical) Thicket, Nama-Karoo, and Succulent Karoo (Mucina et al. 2006, Boshoff et al. 2009b). The dominant biome is grassland (40 %). Elevation ranges from sea level to about 2,000 m in the Drakensberg Mountain’s southern range and average summer-rainfall averages about 900 mm p.a. (Mundy et al. 1992). A number of rivers carve through Table Mountain sandstone to create gorges which Cape Vultures use as breeding locations (Piper and Ruddle 1986, Mundy et al. 1992). Between 1905 and 1960 historical records reveal that Cape Vulture populations in the Eastern Cape expanded their range (Boshoff and Vernon 1980). Since 1960, the Cape Vulture’s range in the Eastern Cape was rapidly reduced because of livestock predator poisoning incidents on commercial farms (Boshoff and Vernon 1980, Boshoff et al. 2009b).

All the active Cape Vulture breeding colonies in the Eastern Cape Province are located in or near (within 50 km) of communal farmland (Boshoff et al. 2009b). The largest communal farmland is the former Transkei (Fig. 1). The former Transkei was once one of ten Bantustan homelands, which gained self-rule in 1976 under South African apartheid rule (Kepe 1997). In 1994, with new dispensation, it became part of South Africa again and was incorporated into the Eastern Cape Province (Kepe 1997). The ethnic majority of the area is the amaXhosa people. The livelihoods of the local people include remittances from mines, farming small garden plots, use of natural resources, and ownership of a variety of livestock which use communal farmland (Kepe 1997, Boshoff et al. 2009b, Shackleton et al. 2013). A large percentage of the local male population travels to the North West and Gauteng Provinces, South Africa to work in a variety of mining operations leaving an unbalanced sex and age ratio in the Eastern Cape (Shackleton et al. 2013). In the Ingquza Hill municipality in the Eastern Cape Province, 95% of the settlement type is tribal areas and only 5% of the area is considered urban (Statistics South Africa 2011a). Tribal areas usually consist of numerous villages that contain multi-building homesteads. Villages are typically near grazing land for livestock. Firewood is used for cooking and heating in the homesteads and gathered from small forest patches or plantations. With the abandonment of fields in the former Transkei, natural woody vegetation has almost doubled between 1961 and 2009 (Shackleton et al. 2013).

The extent of communal farmland in the former Transkei creates a unique landscape in contrast with other parts of the Cape Vulture’s range. Native predators (African lions *Panthera leo* and African leopards *Panthera pardus pardus*) have been exterminated in this area (Skead 1987). Feral dogs (*Canis lupus familiaris*), vultures, and other scavenging birds are the main scavengers in the area. Livestock deaths are common in communal farmland areas because of starvation from excessive grazing of communal rangelands and deaths from numerous tick borne diseases that are too expensive for farmers to treat (Brown and Piper 1988, Boshoff et al. 2009b). An abundance of carrion, relatively few predators, and abundant cliffs for roosting and breeding is thought to benefit the Cape Vulture in this area (Boshoff and Vernon 1980, Piper and Ruddle 1986). According to monitoring in 2012, over 800 breeding pairs (about 2,000 mature individuals) were confirmed (Botha et al. 2012) In addition to the high density of Cape Vultures, the Eastern Cape Province is of high biological importance containing the Pondoland Centre of Plant Endemism, which is one of 34 world biodiversity hotspots (Zukulu et al. 2012).

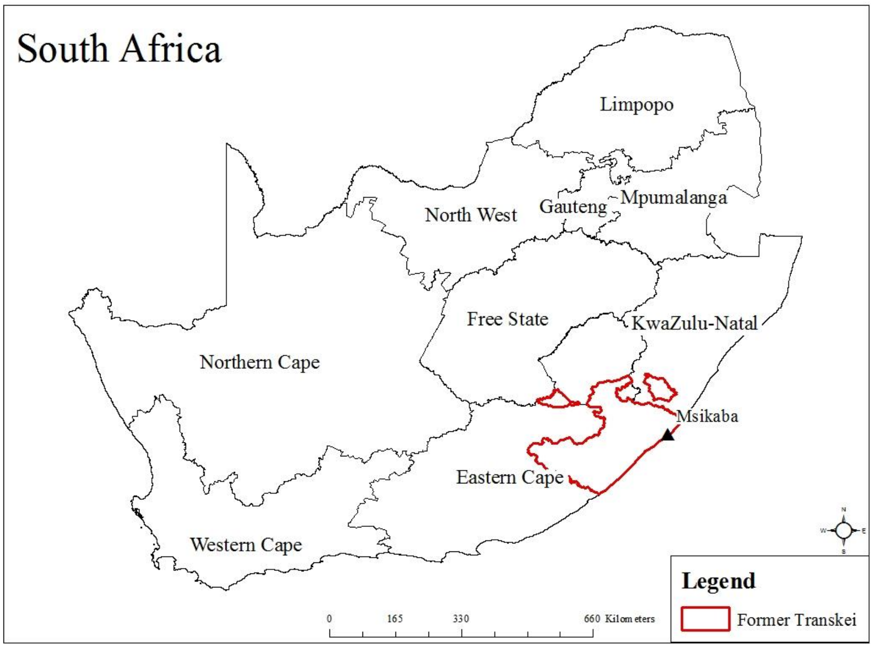

Fig. 1.1 A map of South Africa illustrating the location of the former Transkei homeland.

1.4.1. Msikaba Cape Vulture Colony

The Msikaba Cape Vulture colony (31°18’ S; 29°55’ E 200 m.a.s.l), located on the periphery of the Mkambati Nature Reserve, is one of the largest in the Eastern Cape Province (Boshoff and Minnie 2011), and the closest Cape Vulture colony to the ocean (at 2 km) and is the lowest in the subcontinent. Average rain fall is 1,200 mm and the climate is mild sub-tropical with high humidity (Fisher et al. 2013). The area was always sparsely inhabited, because of poor soils for crops and numerous livestock diseases (Villiers and Costello 2006). Early accounts of shipwrecked sailors that amaXhosa people closer to the ocean were extremely poor and owned few cattle, while those inland were wealthier (Villiers and Costello 2006).

The Msikaba colony is ranked as one of the top conservation priorities for the Cape Vulture in the Eastern Cape Province (Boshoff and Minnie 2011). An initial evaluation in 1983 revealed nesting vultures on cliffs of the Mtentu and Msikaba Rivers. The colony was estimated at 160 pairs, with the majority nesting on the Mtentu River (Piper and Ruddle 1986). However, by 2000, no vultures nested on the Mtentu River (Piper 2008). It is unclear why the vultures shifted from the Mtentu cliff to the Msikaba cliffs, but as mentioned, colonies are not considered closed and not permanently fixed (Borello and Borello 2002). Average number of active nests at the Msikaba Colony between 2000-2010 was 145 (Piper 2008). The maximum number of active nests from 7 years of continuous monitoring (2001-2007) was 171 in 2006, and the minimum number of active nests was 127 in 2005 (Piper 2008). Breeding success ranged from 74 % in 2007 to 85 % in 2004 (Piper 2008). Degree of human impact on the colony was considered relatively low, because the closest tar road is 35 km away (Piper 1994).

1.5 Problem statement and significance of the study

Despite the importance of the Msikaba Cape Vulture colony, no in-depth studies have investigated this distinct colony nor assessed its contribution to Cape Vulture persistence in the Eastern Cape (Piper and Ruddle 1986, Mundy et al. 1992). Furthermore, as Cape Vultures are not confined to protected areas, traditional conservation practices may be ineffective (Phipps et al. 2013b). To fill this gap, knowledge of their behaviours inside and outside of protected areas is needed (Piper and Ruddle 1986). The former Transkei area is unique in the amount of unprotected communal farmland and numerous breeding Cape Vultures, yet relatively few studies have investigated the relationship between communal farmland and the survival of Cape Vultures (Boshoff and Vernon 1980, Vernon and Piper 1991, Vernon 1998).

Consequently, the aims of this study were to identify the foraging range and habitat use of the Cape Vultures from the ecological distinct Msikaba Colony, investigate the surrounding community’s perceptions of the vultures, and describe the cliff characteristics and pair densities that affect nest site selection and breeding success. Furthermore a province wide investigation of factors that influenced Cape Vulture presence and flight height was initiated. All aspects of the project were constructed with the end goal of contributing to the conservation management of the Cape Vulture. By focusing on the Msikaba Cape Vulture colony the, Mkambati Nature Reserve, as part of the Eastern Cape Parks & Tourism Agency, the local conservation authority, can provide some degree of protection to the colony, apply conservation management practices, as well as provide education programs to the public using the results of this study. Identification of Cape Vulture conservation priority areas and needs should be addressed with systematically collected data; result from this study can be used throughout South Africa and possibly across Africa.

1.6 Aims and Objectives

The main aim of the study was to understand the ecology of the Cape Vulture in the Eastern Cape Province with implications for the conservation management of the species.

The study therefore had the following objectives and sub-objectives:

1) To use community perceptions to determine threats to and benefits for Cape Vultures in the communal farmland in the Eastern Cape Province. The sub-objectives were:
    a. To determine livestock ownership trends over the past 10 years across communal farmland areas that differed in the amount of transformed land.
    b. To investigate vulture population trends in communal farmland areas with different proportions of transformed land.
    c. To understand how livestock predators are managed in communal farmland to provide insight into accidental vulture poisoning incidents.
    d. To quantify the type and amount of livestock carcasses available for vultures in communal farmland.
    e. To determine perceptions of vultures by the community members in communal farmland areas including the perceived values of vultures to communities.

2) To determine the foraging range and habitat use of Cape Vultures from the distinct Msikaba Cape Vulture colony in Mkambati Nature Reserve, Eastern Cape Province with implications for conservation management. The sub-objectives were:
    a. To determine seasonal differences (breeding vs. non-breeding season) in foraging ranges of adult vultures captured at the Msikaba Cape Vulture colony.
    b. To identify land use preferences of adult vultures captured at the Msikaba Cape Vulture colony and any seasonal differences.
    c. To recommend sizes for protective buffers around breeding colonies based on activity density estimates.
3) To investigate the effects of cliff characteristics and nesting density on Cape Vulture nest site selection and breeding success
    a. To identify and rank important variables in the breeding ecology of the Cape Vulture at the Msikaba Cape Vulture colony over 13 years.
    b. Characterize ideal nest site locations based on cliff and nest density variables to aim in current breeding colony conservation management strategies and to identify ideal reintroduction sites and conditions.
4) To identify and rank spatial drivers of Cape Vulture presence and flight height in the Eastern Cape Province with implications for wind turbine placement. The sub-objectives were:
    a. To classify movement modes of Cape Vulture movement to quickly locate possible roosting locations.
    b. Using high resolution tracking data to create species distribution models to estimate the probability of Cape Vulture presence and flying at risk height.

c. To provide recommendations of protected buffers around numerous Cape Vulture breeding colonies and roost sites.

1.8 Study Outline

The thesis is comprised of six chapters, of which four are arranged as chapters for publication in relevant international peer-reviewed journals, and thus some repetition in the chapters was unavoidable. The hypotheses and predictions are presented in the respective chapters.

The chapters are arranged in the following outline:

Chapter 2. Identifying anthropogenic threats to Cape Vultures (*Gyps coprotheres*) using community perceptions in communal farmland, Eastern Cape Province, South Africa.

Chapter 3. Foraging range and habitat use of Cape Vultures (*Gyps coprotheres*) in communal farmland in South Africa

Chapter 4. Cliff characteristics and neighbour requirements of an endangered colonial nesting African vulture species

Chapter 5. Threatened at home: Collision risk of endangered vultures to wind turbines is highest at roost sites and breeding colonies.

Chapter 6. The concluding chapter that summarizes the various components of this study.

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CHAPTER 2:

Identifying anthropogenic threats to Cape Vultures *Gyps coprotheres* using community perceptions in communal farmland, Eastern Cape Province, South Africa

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Identifying anthropogenic threats to Cape Vultures *Gyps coprotheres* using community perceptions in communal farmland, Eastern Cape Province, South Africa

MORGAN B. PFEIFFER, JAN A. VENTER and COLLEEN T. DOWNS

Summary

Declines in Old World vulture populations have been linked to anthropogenic pressures. To assess these threats, the social dimensions of vulture conservation must be explored. Prior research in Africa focused on commercial farmers' perceptions of vultures and identified that small stock farmers used poison more than large stock farmers to deter livestock predators. However, the vulnerable Cape Vulture *Gyps coprotheres* breeds throughout communal farmland in the Eastern Cape Province, South Africa. Consequently, community interviews were conducted within the foraging range of the Msikaba Cape Vulture colony, separating regions according to the amount of transformed land. Residents in the least transformed land region perceived the smallest reductions in livestock ownership over the past ten years, while residents of the moderately transformed region perceived the greatest reductions in livestock ownership. Livestock carcasses were reported to be available for vultures at 'informal vulture restaurants'. Arrangement of livestock carcasses was found to be independent of land use; however type of carcass consumed varied. None of the respondents stated they used poison to eliminate livestock predators. More respondents cited illegal poaching of vultures for traditional medicine as a threat, although the majority stated that vultures benefited the community.

Introduction

Human activities have transformed the landscape, displaced species and caused mass extinctions (Alroy 2001, McKee *et al.* 2004), and are one of the most influential factors affecting biodiversity conservation (Jenkins *et al.* 2013). It is important to understand how species persist in human-altered landscapes, to aid in the conservation and management of threatened species (Norris and Harper 2004, Jost Robinson *et al.* 2011). Vultures have interacted with humans for centuries (Mundy *et al.* 1992, Moleón *et al.* 2014). They provide a valuable ecosystem service by consuming carcasses which prevents the spread of disease, recycles nutrients, and provides a waste removal option that is both cost effective and low on carbon emissions (Dupont *et al.* 2012, Ganz *et al.* 2012, Margalida and Colomer 2012, Ogada *et al.* 2012a,b).

Globally, 61% of vulture species are threatened with extinction and are declining mainly due to anthropogenic pressures (Ogada *et al.* 2012a). Asia and Africa have experienced the most dramatic vulture declines in recent years (Pain *et al.* 2008, Virani *et al.* 2011, Ogada *et al.* 2012a). Vulture declines in Asia were linked to diclofenac, a non-steroidal anti-inflammatory drug (NSAID), which is highly toxic to vultures when present in carrion (Oaks *et al.* 2004, Gilbert *et al.* 2006). Declines of African vulture populations are less understood because of the diversity of threats identified (Thiollay 2006, Virani *et al.* 2011, Ogada *et al.* 2012a, Monadjem *et al.* 2013a).

It is vital to understand threats to vultures in terms of land use and local human livelihoods. Previous research in Africa focused on the human dimensions of vulture conservation in commercial farming and protected areas (Boshoff and Currie 1981, Robertson and Boshoff 1986, Brown and Piper 1988, Monadjem and Garcelon 2005, Murn and Anderson 2008, Bamford *et al.* 2009). Relatively few studies have addressed the human dimension in communally owned farmland, despite its prevalence in Africa (Boshoff and Vernon 1980, Vernon 1998, Bamford *et al.* 2007, Virani *et al.* 2011). Furthermore, communal farmland in South Africa is expected to undergo rapid development in terms of electrification, urbanization, and continued human population growth (DEDEAT 2012, Sheehan and Sanderson 2012).

The eastern part (east of 27°E) of the Eastern Cape Province, South Africa includes the communal area formerly known as the Transkei (Boshoff *et al.* 2009). This area was one of the 10 Bantustan homelands created under segregation laws of the former apartheid government of South Africa (Kepe 1997). The dominant livelihood of the amaXhosa people, the ethnic majority, is a combination of subsistence agriculture, local employment, remittances from industrial sectors, and government grants (Kepe 1997, Shackleton *et al.* 2013).

The Cape Vulture *Gyps coprotheres* is endemic to southern Africa and is listed as 'Vulnerable' by the IUCN and in the South African Red Data Book (Anderson 2000, BirdLife International 2012). The global population is about 8,000–10,000 individuals and the regional population of Cape Vultures in the Eastern Cape Province is estimated at 2,000 individuals (Boshoff *et al.* 2009, BirdLife International 2013). It is the most common vulture in the study area, with only the Bearded *Gypaetus barbatus* and Egyptian *Neophron percnopterus* Vultures overlapping rarely (Mundy *et al.* 1992). The majority of active Cape Vulture sites in the Eastern Cape Province are within or near (< 50 km) communal farmland on inaccessible cliffs in river gorges (Piper 2005, Boshoff *et al.* 2009). Carrion is more readily available in communal farming areas where livestock losses are higher than commercial farming areas (Mundy *et al.* 1992, Vernon 1998, Boshoff *et al.* 2009). Furthermore, carcasses contaminated with poison to eliminate livestock predators are scarcer on communal farmland than in commercial farming areas (Brown and Piper 1988, Boshoff *et al.* 2009). It is possible that poison may be too expensive for communal farmers to afford, but other social and cultural factors may influence this practice. However, how communal farmers in the former Transkei manage livestock predators is unknown (Piper and Ruddle 1986).

Illegal poaching of vultures for traditional medicine is thought to be relatively high because of strong cultural traditions and limited access to Western medicine in the former Transkei (Cunningham and Zondi 1991b, Mander *et al.* 2007). Consuming vulture parts, specifically the head/brains, is thought to give the user clairvoyant powers (Cunningham and Zondi 1991b, Mundy *et al.* 1992, Mander *et al.* 2007). The sale of these parts is thought to fluctuate with major sporting events such as the World Cup (Mander *et al.* 2007). Previous studies interviewed traditional healers and vulture part consumers, but little is known of how African people perceive vultures (Beilis and Esterhuizen 2005, Mander *et al.* 2007).

Land use in the former Transkei was relatively unchanged until the elections of 1994, when social grants were provided by the government and less need was placed on subsistence agriculture (Shackleton *et al.* 2013). Since the 1990s, fields have been abandoned and the population has moved toward crowded towns (Vernon 1998, Shackleton *et al.* 2013). Despite land uses changing relatively rapidly in the former Transkei, little is known on how vulture populations have been effected (Vernon 1998, DEDEAT 2012).

Thus the aim of this study was to determine how communal land communities within the foraging range of the Msikaba Cape Vulture colony perceive vultures and the threats to them. Residents of highly transformed areas may not be as closely associated with the residents of low or moderately transformed areas. We expected that vultures in the former Transkei would have access to abundant livestock carcasses because of high livestock mortality, carcasses would be relatively safe from limited use of poison as predator control, and use of vulture parts in traditional medicine would be high because of strong cultural traditions (Brown and Piper 1988, Cunningham and Zondi 1991b, Vernon 1998). Participants in the interviews were identified using two approaches: 1) Attending community events (*n* = 104) and 2) random door-to-door interviews near active Cape Vulture roosts (*n* = 98) (Fig. 1). In general, residents of these rural communities are more comfortable interacting in groups than individually (pers. obs.). Effort was made to engage community members at tribal and municipal meetings, church services, and after-school programmes. Since residents near active roosts are location specific, interviews were done opportunistically in those locations with individuals.

Methods

Study Area

The Msikaba Cape Vulture colony (31°16’S, 29°59’E; 200 m asl) is one of the largest colonies in the former Transkei, and is located in Mkambati Nature Reserve (MNR; Boshoff and Minnie 2011). It is the closest vulture colony to the ocean (2 km) in the world (Mundy *et al.* 1992). MNR is a provincial reserve managed by the Eastern Cape Parks and Tourism Agency (ECPTA) in collaboration with the Mkambati Land Trust (Fig. 1). The majority of the Cape Vulture nests are located on south-west facing cliffs of the Msikaba River gorge inside MNR. During the Cape Vulture breeding season (May–October), a breeding adult vulture’s daily foraging range was calculated as 40–150 km from the colony (Ruxton and Houston 2002, Boshoff and Minnie 2011). Consequently interviews were conducted within this range, which covers an area of 11,310 km^2. The 15 villages surveyed were categorised into three areas: least transformed, moderately transformed, and most transformed (Vernon 1998, Beinart 2009). All but one of the villages (KwaMbimba) were part of the Ngquza Hill municipality. KwaMbimba is part of the Ntabankulu municipality (Fig. 1). According to the 2011 census, the population in the Ngquza Hill municipality was 278,481 and

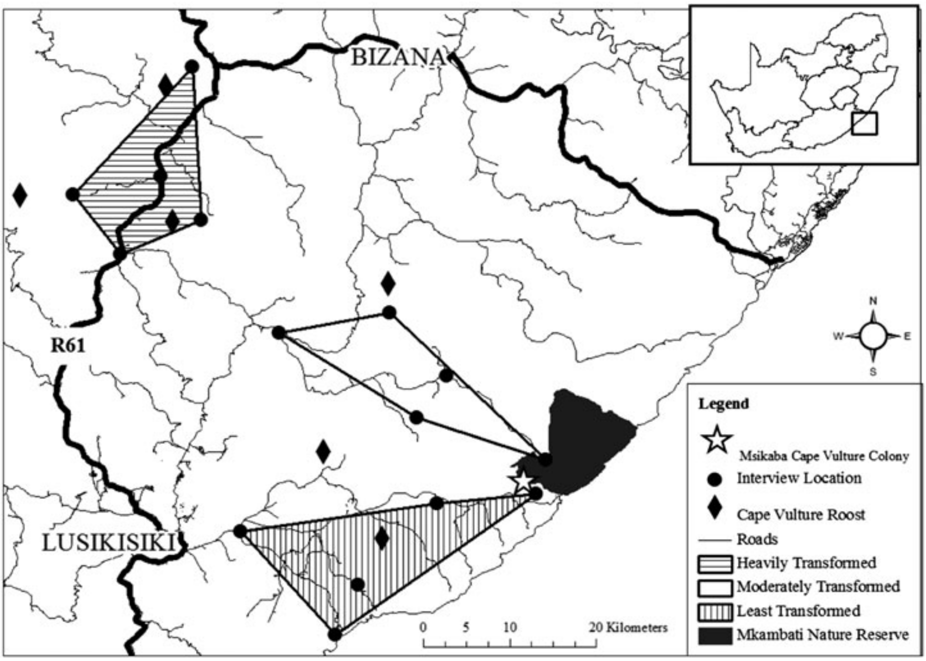

Figure 1. Locations of the 15 communities in which interviews were conducted in the Eastern Cape Province, South Africa. All interview locations were within the foraging range of the Msikaba Cape Vulture colony, which is situated on the southern border of the Mkambati Nature Reserve (MNR).

92% of households were located on tribal land (Statistics South Africa 2011a,b). The population of the Ntabankulu municipality was 123,976 and 95% of households were located on tribal land (Statistics South Africa 2011a,b). The Ngquza Hill and Ntabankulu municipalities have unemployment rates of 52% and 51% respectively, which ranks them as the 9th and 10th (out of 234) municipalities with the highest unemployed populations in South Africa (Statistics South Africa 2011d).

Each region (least transformed, moderately transformed, and most transformed) differed in land cover. Connecting all interview locations with a Minimum Convex Polygon (MCP), there were differences in the amount of natural land cover. The heavily transformed area contained the least natural land (38%). Natural land covered 63% of the communities in the moderately transformed MCP and 81% in the least transformed area. Interestingly, the least transformed area had the smallest percentage of cultivated, degraded and plantation land cover compared to the other two regions, although this was not significant (Fig.1).

Questionnaire survey

A questionnaire covering livestock ownership, carcass management, and perceptions of Cape Vultures was drafted based on Fink (2009); this consisted of mainly open-ended questions (Appendix S1 in the online supplementary material). An estimate of food availability in terms of available carcasses was ascertained by livestock ownership trends in combination with livestock carcass management. Safety of the Cape Vulture's food source was assessed by the extent of poisoned carcasses reported by participants. Perceived trends in the local vulture population were determined by comparing numbers of Cape Vultures observed over a 10-year period.

All interviews were carried out with the participation of the respondents. The survey had University of KwaZulu-Natal (UKZN) ethical clearance, which complies with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008 (Protocol number HSS/0947/012M). The local Traditional Authority gave their permission to conduct the research before entering the communities. Interviews were conducted from June 2012 to January 2013. The three interviewers were isiXhosa speaking undergraduate students from the School of Life Sciences, UKZN. Each interview was conducted in isiXhosa and recorded in English. Photographs of the Cape Vulture were used to aid the respondent's identification of the species. The word for Cape Vulture is different between villages (*idlanga* or *ixhalanga*); effort was made to use the correct colloquial word.

Statistical analyses

Chi-square (χ^2) tests were used to determine differences in residents' responses in relation to land use within the vulture's foraging range. It was expected that there would be significant differences (P-values < 0.05) in the frequency of participants' responses across the natural land cover scale. Residents of least transformed areas were expected to answer differently from residents in more developed areas. Areas with more natural land cover may create a buffer against anthropogenic pressures facing foraging vultures. All statistics were performed in Statistica (StatSoft 2006).

Results

Demographics of respondents

A total of 202 qualitative interviews were conducted with community members within the foraging range of the Msikaba Cape Vulture colony (Table 1). Respondents varied in age with 25 (12%) 14–20 years old, 89 (44%) 21–40 years old, 67 (33%) 41–60 years old and only 21 (10%) older than 60 years. Average number of dependents per household was 5.2 ± 0.33 (SD) people. A total of 110 (54%) respondents were unemployed or earned a living through subsistence farming. The remaining 92 (46%) were employed in other sectors or were studying.

Table 1. Demographics of respondents on livestock management and perceptions of Cape Vultures near the Msikaba Cape Vulture colony in the Eastern Cape Province.

Gender	**Percent**
Male	54
Female	46
Marital status	
Single	53
Married	46
Age Profile	
14-20 years	12
21-40 years	44
41-60 years	33
> 60 years	10
Number of Dependents	
0-1	55
2-5	45
6-10	68
>10	21
Occupation	
Unemployed/subsistence farming	54
Employed and/or studying	45

Livestock ownership trends in relation to Cape Vulture numbers

A total of 123 (65%) participants perceived that local livestock ownership had decreased in the past ten years. Perceptions were dependent on land use (χ^2_8 = 22.27, P = 0.004). Respondents of the moderately transformed communities perceived the greatest reductions in local livestock ownership over the past 10 years while residents of the least transformed communities perceived the smallest reductions in livestock ownership over the same period (Fig. 2).

A similar trend was witnessed with observations of Cape Vultures (Fig. 2). Residents of the moderately transformed areas perceived the greatest reductions in the local Cape Vulture population. In contrast, the least transformed areas perceived the least reductions, but this was not significant (χ^2_8 = 10.37, P = 0.24). In general, the majority of respondents (74%, n = 136) observed that local vulture populations were stable or increasing.

High livestock mortality rates because of tick-borne diseases (gall sickness and red water) were considered the main reason for declines in ownership by 62 (31%) respondents. Changes in

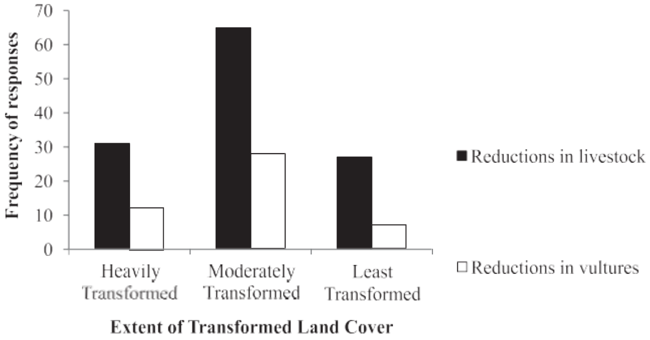

Figure 2. Perceptions of local livestock ownership and vulture population trends by community members in the Eastern Cape Province, South Africa.

livelihoods and traditions were reasons for a decline in livestock ownership by 42 (21%) respondents. Respondents stated that 'youth are not interested in livestock'. Use in business transactions and food security were considered the greatest benefits of owning livestock.

Safety of carcasses for vultures

A total of 114 (56%) respondents stated they had livestock killed by predators, namely black-backed jackal *Canis mesomelas*. However, none of the respondents indicated that they used poisoned carcasses to kill predators. Instead, respondents would rather 'hunt the predator with dogs' and 'fence livestock at night'.

Management of deceased livestock

A total of 105 (52%) respondents had livestock 'naturally/accidentally' die in the last five years. Arrangement of livestock carcasses was found to be random throughout different land uses, as there was no association with dead livestock and extent of transformed land cover ($\chi^2_5 = 1.04$, $P = 0.96$).

Of cattle that died from natural causes, 80 (40%) respondents perceived that the carcass was made available to Cape Vultures by 'throwing it away'. Nineteen (9%) respondents stated that cattle carcasses were specifically left for Cape Vultures. If a horse or a donkey died, 98 (49%) respondents perceived that the carcass was made available to vultures. 26 (13%) respondents stated that horse and donkey carcasses were specifically left for Cape Vultures. Extent of transformed land had no effect on availability of horse or donkey carcasses ($\chi^2_5 = 1.98$, $P = 0.85$) or cattle carcasses ($\chi^2_5 = 4.46$, $P = 0.48$). Throughout all the villages, management of livestock carcasses was found to be a community decision rather than the individual farmer's (pers. obs.).

When questioned about which animals consume livestock carcasses, 166 (82%) respondents mentioned Cape Vultures. One hundred and seventeen (58%) respondents observed vultures feeding on horses, while only 71 (35%) respondents observed vultures feeding on cattle. There was an association between respondents who observed Cape Vultures feeding on cattle or horses carcasses and extent of transformed land ($\chi^2_5 = 12.61$, $P = 0.03$). More cattle carcasses were reported consumed by Cape Vultures in the least transformed areas (Fig. 3). Residents of the heavily transformed land observed the smallest number of cattle carcasses consumed by Cape Vultures. The opposite trend was found with horse carcasses in relation to extent of transformed land cover.

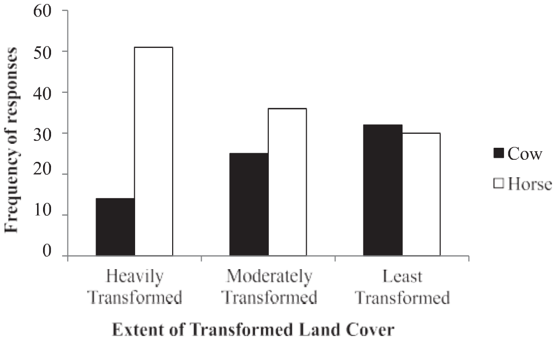

Figure 3. Type of livestock carcasses consumed by Cape Vultures as reported by community members of the Eastern Cape Province, South Africa.

Community perceptions of the Cape Vulture and its threats

One hundred and twenty-nine (64%) respondents were afraid of Cape Vultures because of their aggressive nature while feeding. Sixty-six percent of respondents ($n = 134$) did not know or chose not to answer the targeted questions about threats to vultures. Only 15 (7%) respondents cited poisoning as the cause of a vulture's death or acknowledged a poisoning incident (observation of a dead dog next to a dead horse). Vulture mortalities from electrocution and collision with power lines were cited by < 1% ($n = 2$).

The most cited cause for a vulture's death was illegal poaching for traditional medicine by 62 (31%) respondents. Shooting of vultures was considered the preferred method by 74%, followed by setting traps and using dogs by 3%. None of the respondents mentioned poisoning as a method of obtaining vultures for traditional medicine. Some respondents stated that vultures were difficult to catch. Young boys were found to illegally kill vultures with rocks and slingshots. It was unclear if children were killing vultures for profit. Acknowledgment of illegal poaching of vultures was not found to be dependent on extent of transformed land ($\chi^2_5 = 5.46$, $P = 0.36$).

Despite this pressure, 135 (67%) respondents acknowledged that vultures benefit the local community. Respondents called the vultures their 'free municipality' that are 'good for pointing out dead livestock and tourism'. Positive community perceptions of vultures were not found to be associated with extent of transformed land ($\chi^2 = 3.38$, $P = 0.64$). Although negative views were held by the minority, these respondents stated that vultures 'prevent nutrients from entering the soil, kill livestock, there is no use for them as dogs clean up, and that they are just birds.' Forty-one (20%) respondents thought of nothing when they saw a vulture (Fig. 4).

Discussion

Livestock ownership trends and vulture observations

Our results suggest that livestock ownership in the former Transkei is perceived to have decreased over the past 10 years, coinciding with the conclusions of other studies (Vernon 1998, Shackleton *et al.* 2013). However, this decrease is not thought to be uniform across the landscape (Ainslie 2002, Ntshona and Turner 2002, Hajdu 2009, Vetter and Bond 2012). The current study found that the landscape with the least transformed land cover observed the smallest reductions in livestock ownership over the past 10 years. Since domestic livestock is considered the main food source for Cape Vultures in the former Transkei (Boshoff and Vernon 1980, Vernon 1998), availability of livestock may influence their populations.

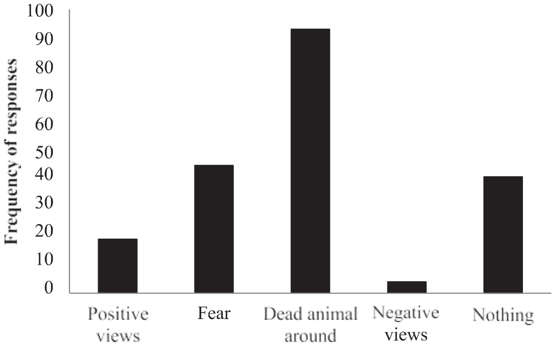

Figure 4. First impressions of Cape Vultures perceived by community members of the Eastern Cape Province, South Africa.

Residents in the moderately transformed area perceived the greatest reductions in livestock ownership. Although land use differed between the heavily and moderately transformed areas, the moderately transformed area had the highest human density of 18.5 homesteads/km^2, as calculated from 2006 aerial photographs. This area may be a remnant of one of the 'betterment' programs in which families were forced into planned developments (Shackleton *et al.* 2013). The presence of the Holy Cross Mission church, one of the largest in the former Transkei, located in this area may have accelerated these programmes (pers. obs.). In these areas, livelihoods have changed from subsistence agriculture to social grants and wage labour which may have decreased the amount of carrion available, in addition to an anthropogenic buffer for foraging vultures (Vernon 1998, Hajdu 2009, Shackleton *et al.* 2013).

Safety of carcasses for vultures

The importance of non-contaminated carcasses for vulture survival has been highlighted in several studies (Chaudhry *et al.* 2012, Prakash *et al.* 2012, Monadjem *et al.* 2013b, Margalida *et al.* 2014). In the current study, it appears that poisoned carcasses are not a common practice in managing predators or obtaining vultures for traditional medicine. Effects of poison on vulture populations can be devastating because they often die in large groups in Africa (Brown and Piper 1988, Mundy *et al.* 1992, Ogada *et al.* 2012a, Beaver 2013) and Europe (Margalida 2012). Although 15 respondents acknowledged seeing a poisoning incident, this was lower than the 36 commercial farmers in the Drakensberg area of South Africa (34%) who used poison (Brown and Piper 1988).

However, due to stricter laws regarding the use of poison in addition to a reduction in small stock farming in the Drakensberg, only 14 (6%) commercial farmers near Lesotho admitted to using poison in a recent study (Hiltunen 2009). The commercial farmers who admitted to using poison responded via a postal survey, a method known to reveal few truthful answers about illegal activities (Hiltunen 2009). Although the exact number of commercial or communal farmers who use poison is difficult to obtain, it is possible that poisoned carcasses are less common in communal land than commercial farming areas.

Management of dead livestock

Tick-borne diseases (gall sickness and red water) were considered the main causes for livestock mortality in the study area. These diseases have caused livestock mortality in the former Transkei for a number of years (Villiers and Costello 2006, Beinart 2009). Although traditional methods exist to treat some of these diseases (Cunningham and Zondi 1991a) most subsistence farmers rely on government supplied services, which have been slack in recent years (Kepe 2002, Beinart 2009, Shackleton *et al.* 2013).

A proportion of livestock that died naturally was perceived to be made available to Cape Vultures. The amount of cattle carcass available out of 9,000 regionally owned cattle (Ainslie 2002) would be 168,480 kg a year in the study area, which can support 337 breeding Cape Vulture pairs, each consuming 500 kg (Mundy *et al.* 1992). This is higher than the previous estimate of 81,000 kg a year for all types of carrion which can support 162 Cape Vulture breeding pairs (Vernon 1998, Ainslie 2002). Although the Msikaba Cape Vulture colony currently only supports 175 breeding pairs , factoring in the neighbouring colonies of Tembukazi (120 pairs) and Ngozi (72), which would overlap with Msikaba's foraging range, the number of breeding pairs adds up to over 350 (Botha *et al.* 2012) .

As most Xhosa communities share meat resources (Ainslie 2002), management of livestock carcasses was found to be a community decision (pers. obs.). Horse meat is not traditionally eaten in South Africa (Katz 2003). Hence horse carcasses were 'thrown away' more than cattle for vultures to feed upon. A common practice with dead livestock was to move it away from homesteads to an open field, or in other terms, an 'informal vulture restaurant' (pers. obs.). In the Ngqwuza

Hill municipality, the majority of residents (74.5%) have their own refuse dump or no rubbish disposal at all (18.4%), which suggests that discarded meat is available to vultures and other scavengers (Statistics South Africa 2011c). Despite the presence of 'informal vulture restaurants', communal livestock carcasses can be considered unpredictable, as there were no trends associated with dead livestock and land use.

Observations of livestock carcasses consumed by Cape Vultures differed among land uses. The least transformed area is traditional communal grazing land used since pre-colonial time by the AmaPondo people (Beinart 2009). Residents from other villages herd their cattle to the least transformed area when conditions are harsh (Beinart 2009). Cattle density is likely higher in the least transformed area because of the extent of communal grazing land. Horses may be more plentiful in transformed areas (for use in organised horse races) and are perhaps hit and killed by cars more frequently, hence more horse carcasses were observed in the heavily transformed area (pers. obs.).

Community perceptions of the Cape Vulture and its threats

In the current study, the majority of respondents (67%) stated that vultures benefited the local community. Vultures were called a 'free municipality' by some respondents, suggesting a beneficial relationship between the communities and the vultures. Negative views of vultures were in the minority, but probably originated from ignorance or fear rather than hatred. This is illustrated by the number of respondents who stated they think of 'nothing' or are 'fearful' when they see a vulture. In contrast, 29 (28%) South African commercial farmers who had negative views of vultures considered the birds to be harmful to their farming operations (Brown and Piper 1988). The majority of respondents in both commercial and communal land perceived that Cape Vulture populations were stable or increasing (Brown and Piper 1988).

Perceived threats to Cape Vultures differed from the previous study (Brown and Piper 1988) in which the majority of commercial farmers cited poisoning, while illegal poaching of vultures was cited more by residents in communal land. Consuming vulture brains is believed to give the user clairvoyant powers in addition to relief from headaches and allergies (Cunningham and Zondi 1991b, Mundy *et al.* 1992, Beilis and Esterhuizen 2005, Mander *et al.* 2007). The total annual sale of vulture parts for traditional medicine in eastern South Africa was estimated at $115,512 (Mander *et al.* 2007).

It is difficult to obtain numbers of illegally killed vultures, but these were estimated at 27 vultures (all species) a year for KwaZulu-Natal, Eastern Cape, and Lesotho (Mander *et al.* 2007). In the current study, the preferred method of obtaining vultures for traditional medicine was the use of firearms, which was much higher than the 41% of vultures harvested by shooting and 35% by poisoning reported by Mander *et al.* (2007). In the current study, none of the respondents mentioned that poison was used to obtain vultures for traditional medicine. As the past study focused on traditional healers and vulture part consumers, the results from this study give a general picture of how African people perceive vultures.

Two participants who resided near a small vulture roost stated they had eaten vulture meat, which has previously only been documented in West Africa with the consumption of Hooded Vultures *Necrosyrtes monachus* (Gbogbo and Awotwe-Pratt 2008). One participant stated that people targeting vultures for traditional medicine were from the neighbouring province, KwaZulu-Natal. The participant mentioned that the 'foreigners' were unsuccessful due to the inaccessible location of the vultures on the cliffs.

The current study confirms that the threats facing African vulture species are diverse. Threats encountered by the Cape Vulture differ between regions in South Africa in terms of land use (communal vs. commercial farming) and ethnic group (Caucasian vs. AmaXhosa farmers). It is important to acknowledge the differences in threats across the landscape in order to develop and build upon management plans for the Cape Vulture. Although the threats are diverse, the underlying themes are transformed landscapes and direct anthropogenic pressures. It will only be through the collaboration of different stakeholders that species will survive.

Management implications

Areas with more natural land cover may create an anthropogenic buffer and carrion for foraging Cape Vultures in the former Transkei. Effort should be made to conserve natural areas and confine development to already transformed regions. Management of livestock carcasses on communal land was found to be a community decision, so educating community leaders about vulture-safe carcasses and the benefits provided by vultures to the community would be an effective conservation measure. The study suggests that illegal poaching may be more prevalent than previously estimated. Education programmes conducted in less transformed regions would be beneficial, as residents of these areas may see vultures more frequently. It is possible to expand on the communities' existing appreciation of vultures and encourage community involvement in the conservation of the Cape Vulture.

Supplementary material

The supplementary material for this article can be found at journals.cambridge.org/bci

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ADDENDUM TO CHAPTER 2

The IUCN status of the Cape Vulture was up listed from ‘vulnerable’ to ‘endangered’ in 2015 (BirdLife International 2015).

BirdLife International. 2015. *Gyps coprotheres*. The IUCN Red List of Threatened Species 2015: e.T22695225A84339218. http://dx.doi.org/10.2305/IUCN.UK.2015-4.RLTS.T22695225A84339218.en.

CHAPTER 3:

Foraging range and habitat use by Cape Vulture *Gyps coprotheres* from the Msikaba colony, Eastern Cape province, South Africa

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Foraging range and habitat use by Cape Vulture Gyps coprotheres from the Msikaba colony, Eastern Cape province, South Africa

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Despite the extent of subsistence farmland in Africa, little is known about endangered species that persist within them. The Cape Vulture (*Gyps coprotheres*) is regionally endangered in southern Africa and at least 20% of the population breeds in the subsistence farmland area previously known as the Transkei in the Eastern Cape province of South Africa. To understand their movement ecology, adult Cape Vultures (n = 9) were captured and fitted with global positioning system/global system for mobile transmitters. Minimum convex polygons (MCPs), and 99% and 50% kernel density estimates (KDEs) were calculated for the breeding and non-breeding seasons of the Cape Vulture. Land use maps were constructed for each 99% KDE and vulture locations were overlaid. During the non-breeding season, ranges were slightly larger (mean [± SE] MCP = 16 887 km^2 ± 366 km^2) than the breeding season (MCP = 14 707 km^2 ± 2155 km^2). Breeding and non-breeding season MCPs overlapped by a total of 92%. Kernel density estimates showed seasonal variability. During the breeding season, Cape Vultures used subsistence farmland, natural woodland and protected areas more than expected. In the non-breeding season, vultures used natural woodland and subsistence farmland more than expected, and protected areas less than expected. In both seasons, human-altered landscapes were used less, except for subsistence farmland.

Conservation implications: These results highlight the importance of subsistence farmland to the survival of the Cape Vulture. Efforts should be made to minimise potential threats to vultures in the core areas outlined, through outreach programmes and mitigation measures. The conservation buffer of 40 km around Cape Vulture breeding colonies should be increased to 50 km.

Introduction

Africa has been inhabited by humans for over 300 000 years (Fisher *et al.* 2013; Sheehan & Sanderson 2012). Within that time, communal grazing of livestock, human-induced fires, depletion of indigenous forests and urbanisation have altered many landscapes (Lawes, Griffiths & Boudreau 2007; Sheehan & Sanderson 2012; Skead 1987; Vetter & Bond 2012). Although heavily human-altered landscapes are often degraded, endangered species can persist in these environments (McKee *et al.* 2004; Phipps *et al.* 2013b).

One opportunistic animal guild that has coexisted with humans for centuries is the vulture (Haas & Mundy 2013; Moleón *et al.* 2014). Vultures perform an important ecosystem service by consuming carcasses. Vultures recycle nutrients, reduce the potential for the spread of infectious diseases, and provide a carbon-neutral waste removal service (Dupont *et al.* 2012; Prakash *et al.* 2003; Ogada *et al.* 2012b). In some cultures, vultures are highly revered and, for example, are used to ritually dispose of human corpses (Haas & Mundy 2013). However, 61% of vulture species worldwide are vulnerable to extinction from a variety of threats (Ogada *et al.* 2012a). Understanding how vultures persist in human-altered landscapes will provide information on where and how to focus conservation efforts on a regional and global scale.

The Cape Vulture (*Gyps coprotheres*), a colonial nesting scavenger, is endemic to southern Africa. It is listed as 'vulnerable' on the Red List of Threatened Species of the International Union for Conservation of Nature and Natural Resources (IUCN) and as 'endangered' in the *Eskom Red Data Book of Birds of South Africa, Lesotho and Swaziland* (BirdLife International 2013).

At least 20% of the global population breeds in the former Bantustan homeland of the Transkei in the Eastern Cape province of South Africa (BirdLife International 2013; Boshoff, Piper & Michael 2009; Piper 1994). This area was created under segregation laws of the former apartheid government of South Africa and is characterised by high human densities and subsistence farmland (Kepe 1997; Shackleton *et al.* 1991; Statistics South Africa 2011). In this area, every resident has access to communal grazing land and livestock numbers are not restricted (Vetter & Bond 2012).

Most of the Cape Vulture breeding colonies in the former Transkei are located in formal protected areas or Important Bird Areas (IBAs) (BirdLife South Africa 2013). Two of the three protected areas, namely Collywobbles Vulture Colony (IBA SA088) and Pondoland Cape Vulture Colonies (IBA SA126), were designated as IBAs specifically to promote the conservation of this threatened species (BirdLife International 2014a; BirdLife International 2014b). However, foraging vultures are rarely confined to protected areas and are thus exposed to numerous threats elsewhere (Bamford *et al.* 2007; Phipps *et al.* 2013a). For example, Cape Vultures are illegally killed for the traditional medicine market and are negatively impacted by power line infrastructure in the Eastern Cape (Boshoff *et al.* 2011; Mander *et al.* 2007). Poisoned carcasses, resulting in mass vulture mortalities, appear to be an infrequent occurrence in subsistence farmland areas, but do occur on commercial farms (Brown & Piper 1988).

A possible benefit to vultures in the former Transkei is the relatively high livestock mortality rates compared to commercial farming areas, which results in an abundance of carrion (Boshoff *et al.* 2009; Vernon 1998). Furthermore, the landscape in the former Transkei contains numerous suitable cliffs on which Cape Vultures roost and breed (Mundy *et al.* 1992; Piper & Ruddle 1986). Despite having knowledge of the potential threats and perceived benefits for Cape Vultures, knowledge of the movement ecology and detailed demographic information of Cape Vultures in this area is lacking.

BirdLife South Africa, the Endangered Wildlife Trust (EWT) and a number of bird specialists recommend 40 km buffers around Cape Vulture breeding colonies as conservation priority areas to prevent mortalities from wind turbines and hazardous power infrastructure development (Boshoff & Minnie 2011; Retief *et al.* 2013). Breeding Cape Vultures of the southern node population are known to forage and move extensively within this range (Boshoff & Minnie 2011; Boshoff, Robertson & Norton 1984; Brown & Piper 1988; Robertson & Boshoff 1986).

Breeding vultures that forage within 40 km of the colony are better able to relieve their partner of parenting duties so that both can forage on the same day (Ruxton & Houston 2002). Vultures that forage in this manner are thought to have higher breeding success because of a higher food delivery rate to the chick (Ruxton & Houston 2002). However, telemetry-based Cape Vulture studies in other regions have indicated that both breeding and non-breeding Cape Vultures forage considerably farther than 40 km from the breeding colony, which may weaken the conservation goals of the colony buffers (Bamford *et al.* 2007; Phipps *et al.* 2013b).

Foraging ranges of vultures may be influenced by the surrounding land uses or presence of vulture feeding sites. Vulture feeding sites (vulture restaurants) provide an uncontaminated, regular supply of carrion for vultures, which aims to prevent mortalities from food shortages and poisonings (Piper, Boshoff & Scott 1999). Most operate on commercial farms in South Africa (EWT and Ezemvelo KwaZulu-Natal [KZN] Wildlife unpublished data). In the Eastern Cape, all active Cape Vulture breeding colonies are in or near subsistence farmland with few vulture feeding sites, but the degree of subsistence farmland use by Cape Vultures remains unknown.

The aim of this study was to document the foraging range and habitat use of adult Cape Vultures in the former Transkei from a colony in the Mkambati Nature Reserve. One intention of the study was to test if 40 km buffers around southern Cape Vulture breeding colonies are adequate for their intended conservation purposes. The size, shape and habitat use in the overall foraging and core areas were investigated and possible seasonal differences quantified. Seasons were separated into either breeding or non-breeding season.

Adult vultures were expected to conduct fewer foraging trips during the early breeding season and incubation (Kendall *et al.* 2014; Spiegel *et al.* 2013). Breeding behaviour may concentrate Cape Vulture movements to areas that maximise the success of foraging trips. These areas would be ideal to identify for conservation planning. Additionally, a small proportion of Cape Vultures may migrate from the eastern part of the Eastern Cape to the west in the non- breeding season (Boshoff *et al.* 2009). If this migration occurs, it would be important to isolate any corridors or flight paths. Vulture movements may be influenced by the availability of resources across the landscape. Therefore, resource selection by the vultures was thought to differ with land use and season (Murn & Anderson 2008; Vernon 1998). The location of the study vulture colony provides a unique opportunity to investigate the vultures' use of subsistence and commercial farmland, as both land uses are present within 100 km of the colony.

Methods

Study area

The entire former Transkei (approximately 27° E – 30° E and 33° S – 30° S) is located in the Eastern Cape and KwaZulu-Natal provinces of South Africa (Boshoff *et al.* 2009). The Indian Ocean coastal belt, savanna and grassland are the three major biomes in the study area (Mucina *et al.* 2006). Ngongoni grass (*Aristida junciformis*) dominates the savanna and grassland biomes, while the Indian Ocean coastal belt supports patches of species-rich sour grasslands (Mucina *et al.* 2006). The dominant herbivores in the study area are domestic livestock (either for subsistence or commercial purposes) and wild ungulates in fenced protected areas (Boshoff & Vernon 1980; Shackleton *et al.* 1991).

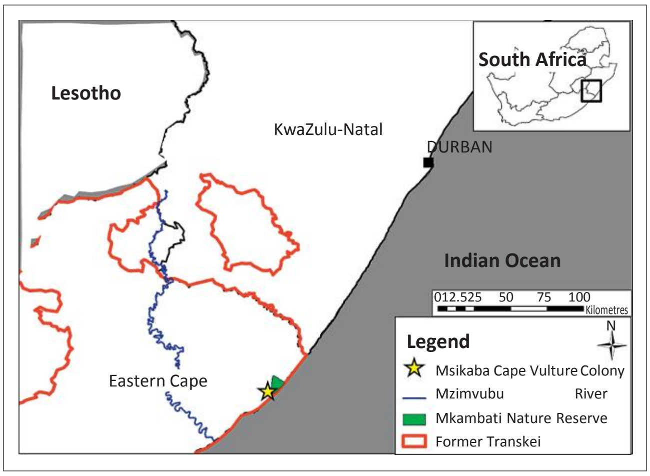


FIGURE 1: Location of the former Transkei, Mkambati Nature Reserve and the Msikaba Cape Vulture breeding colony in the Eastern Cape province of South Africa.

The Msikaba Cape Vulture colony (31°16′ S, 29°59′ E; 200 m a.s.l.; Figure 1) is located on cliffs formed by the Msikaba River in the Mkambati Nature Reserve (Boshoff & Minnie 2011; Piper & Ruddle 1986). At least 170 Cape Vulture pairs breed regularly within the Mkambati Nature Reserve (Botha *et al.* 2012). Vulture breeding activity was first documented at Msikaba in 1984; however, breeding attempts along the Mtentu River, the northern boundary of the Mkambati Nature Reserve, were first documented in the mid-1970s (Piper & Ruddle 1986). Annual rainfall is about 1200 mm and the difference in monthly mean temperature is less than 6 °C along the coast (Shackleton *et al.* 1991).

Cape Vulture captures and marking

A 9 m x 6 m x 3 m wooden-framed walk-in cage trap (Diekmann *et al.* 2004) was constructed at the Cape Vulture feeding site at the Mkambati Nature Reserve. The walls of the cage consisted of wire mesh (100 mm) reinforced with steel cable. Translucent shade cloth (50% opaqueness) was attached to the walls to prevent injuries to the vultures. Construction and baiting of the trap with ungulate carcasses from the Mkambati Nature Reserve commenced at least 7 months before capture attempts.

Each vulture captured was fitted with a unique metal South African Bird Ringing Unit (SAFRING) ring and patagial tags on both wings. Adults (n = 9) were identified by plumage and eye colour (Mundy 1982). Avi-Track (Pietermaritzburg, South Africa) global positioning system (GPS)/global system for mobile (GSM) transmitters were attached as backpacks (n = 3) and pelvic mounts (n = 3) using Teflon® ribbon. Cellular Tracking Technologies (CTT) 1100 GPS/GSM transmitters (Somerset, Pennsylvania, USA) were attached as backpacks (n = 2) and as a pelvic mount (n = 1). The average weights of the Avi-Track and CTT units were 97 g and 136 g respectively, which is less than 1% of the average weight of an adult Cape Vulture (Piper 2005).

Data collection

The Avi-Track transmitters were programmed to record the GPS location of the vulture, direction of travel and speed at least six times a day in 2 h intervals from 06:00 to 18:00. The CTT transmitters were programmed to record the GPS location of the vulture, horizontal dilution of precision, fix quality, direction of travel, speed and altitude every 15 min from sunrise to sunset. For comparison with the Avi-Track units, a subsample of the CTT data was created by using one data point every 2 h for a total of six GPS locations a day. The first and last point of the day (which changed with day length) were used in addition to three points during the day, which were at least 2 h apart.

Data analysis

The vulture transmitter data were entered into ArcGIS 9.3 (ESRI, www.esri.com) and projected to the Universal Transverse Mercator (UTM) (WGS [World Geodetic System] 1984 UTM Zone 35S). To determine if an asymptote was reached during each season, the minimum convex polygons (MCPs) were plotted in relation to the number of GPS locations. Visually, asymptotes were identified and vultures that reached asymptotes were used for further analyses.

Although widely criticised, MCP is the most commonly used home range estimator. It entails drawing the smallest polygon that incorporates all of the animal's locations (Powell 2000). The MCPs (100%) were calculated for each vulture in both breeding and non-breeding seasons and tested for differences. The breeding season data included all fixes from May to October 2013, while the non-breeding season data included fixes from November 2012 to April 2013 (Mundy *et al.* 1992). The mean egg-laying period is May to June, with chicks hatching between July and August. Fledglings can be dependent on their parents until October or November, and even into December (Mundy *et al.* 1992; Piper 1994). The percentage of MCP overlap was calculated for the two seasons.

Since MCPs generally include areas that are not visited by the vulture, kernel density estimates (KDEs) were used to identify high density areas of vultures. In previous studies, 95% KDEs were found to produce numerous fragmented areas; hence 99% KDEs were used (Blundell, Maier & Debevec 2001; Phipps *et al.* 2013b). Fifty percent KDEs were used to identify core areas. Both 99% and 50% KDEs were calculated for the breeding and non-breeding seasons and tested for seasonal differences. All KDEs were calculated using bivariate fixed kernels with a reference bandwidth. Least-squares cross validation calculations for KDEs could not be used because of numerous identical roosting locations. The raster cell size was 1000 m x 1000 m. Both MCP and KDE contours were produced using the Home Range Tools (HRT) extension for ArcGIS (Rodgers *et al.* 2007).

Mann-Whitney tests were used to determine differences in foraging range size (MCP, 99% KDEs, 50% KDEs) and season (breeding vs non-breeding). P-values < 0.05 were read as significant. Statistical analyses were conducted in STATISTICA (StatSoft 2006).

Habitat use and GPS tracking

A land use map was created using the South African National Land Cover Database merged with all the protected areas of South Africa and Lesotho (South African National Botanical Institute [SANBI] 2000; IUCN and United Nations Environment Programme's World Conservation Monitoring Centre [UNEP-WCMC] 2014). The 41 original South African National Land Cover Database land use categories were compressed into six land use classes: urban centres, village communities, natural woody vegetation, tree plantations, commercial farmland and subsistence farmland (Table A1). As the original map did not illustrate livestock grazing land (only cultivated land), land use classes such as 'natural grassland' were separated into commercial or subsistence farmland based on their location to the former political boundaries of the Transkei (Figure A1).

Tree plantations and natural woody vegetation were separated because of the level of human transformation in these areas. To account for urban and suburban sprawl, 2 km buffers were placed around the urban and village layers. The polygon layer was converted into a raster with a cell size of 1800 m. The raster assigned one land use value to each cell, based on the cell centre. Analysis was limited by the resolution of spatial data available, but was compensated appropriately using buffers and the unbiased method of assigning a land use value based on the cell's centre.

The 99% KDEs of pooled Cape Vulture locations from the breeding and non-breeding seasons were clipped to the final categorised land use map, excluding areas that extended into the Indian Ocean, since vultures do not fly above oceans (pers. obs.). For each 99% KDE, areas of all land uses were calculated (km^2). The number of vulture GPS locations within each land use was also calculated. Both procedures were conducted with Hawth's Analysis Tools (Beyer 2004). Habitat use in proportion to availability, considering each land use separately, was tested using the Bonferroni *Z*-statistic in Microsoft Excel (Byers, Steinhorst & Krausman 1984).

In total, 34 Cape Vultures (including 1 recapture) were captured in 2012 and 2013, during the non-breeding season. The GPS locations of birds were highly autocorrelated, with a mean Schoener's index value of 0.10 ± 0.07. This index detected that the individual's GPS locations were not independent of each other, which may result in underestimating home range estimates (Swinhart & Slade 1985). To correct this, all data were rescaled to unit variance using Home Range Tools (Rodgers *et al.* 2007). The reference bandwidth for both seasons across all individuals was 0.34 ± 0.02 for KDEs.

Results

Nine transmitters recorded location data for 277 ± 72 days. Of the vultures fitted with transmitters, five reached an MCP asymptote during the breeding season and four during the non-breeding season (Figure A2). The average number of GPS locations for the breeding and non-breeding seasons were 717 ± 122 ($n = 5$) and 820 ± 123 ($n = 4$) respectively. The number of fixes required for MCPs to become constant varied, but generally, transmitters with fewer than 300 GPS locations were found to be insufficient. Some vultures were tracked for both seasons, while other transmitters were deployed later in the season, or failed. Three transmitters stopped working for unknown reasons (birds were resighted alive) before 300 GPS locations were collected; these data were excluded from the analyses. Two transmitters only collected data for one season (X023 and X022). Of the vultures used for analysis, two (X027 and X023) were confirmed to have successfully raised chicks in 2013. One vulture (X022) was observed at a nesting site arranging nesting material with its partner, but did not breed.

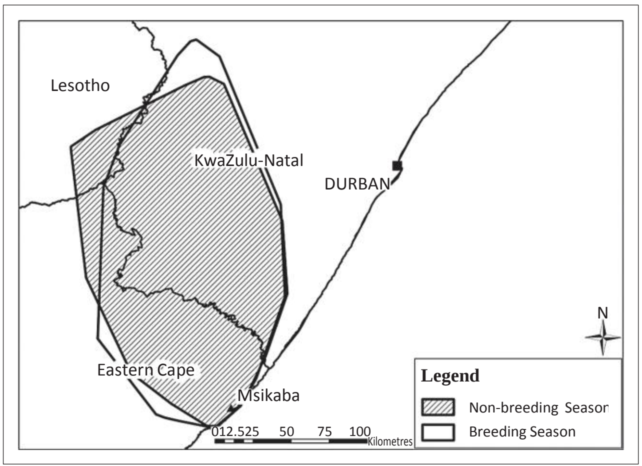


FIGURE 2: The combined minimum convex polygons of adult Cape Vultures (*Gyps coprotheres*) in the breeding ($n = 5$) and non-breeding seasons ($n = 4$) captured at the Msikaba Cape Vulture colony in the Eastern Cape, South Africa.

Foraging ranges

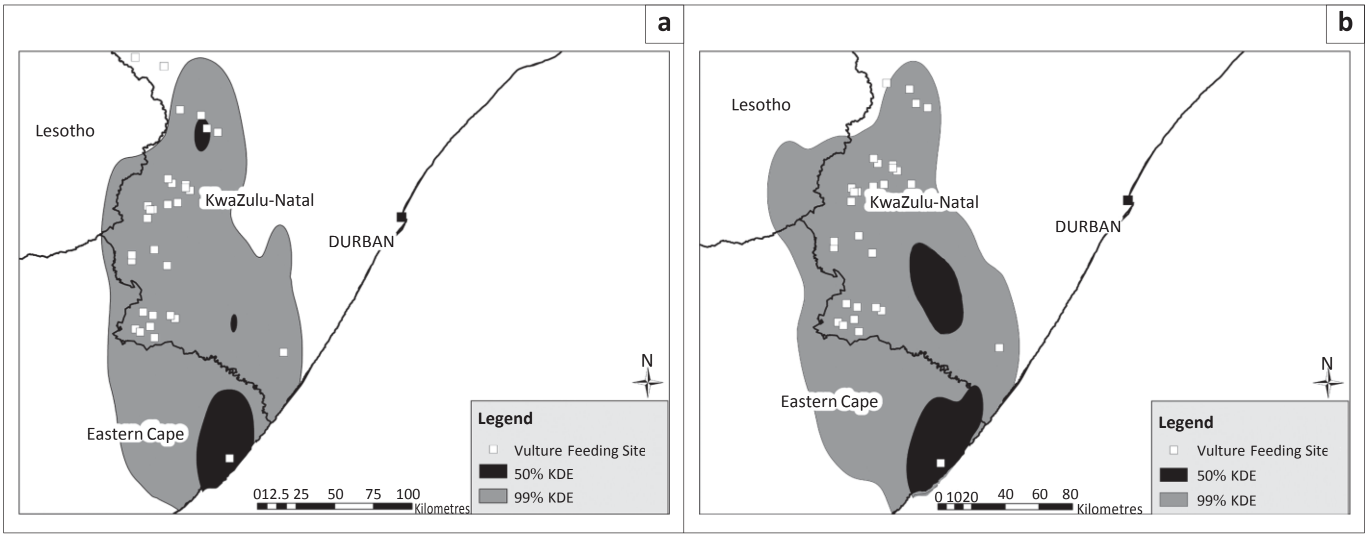
General movements of the Cape Vultures occurred from the breeding colony in the south to the south-western part of the KwaZulu-Natal province. No vultures travelled south of the Mzimvubu River mouth during the tracking period. The pooled breeding season MCP overlapped 92% with the non- breeding season MCP (Figure 2). The mean MCP during the breeding season was 14 707 km^2 ± 2155 km^2 ($n = 5$, median = 13 282 km^2). The mean MCP during the non-breeding season was 16 887 km^2 ± 366 km^2 ($n = 4$, median = 16 602 km^2). There was no significant difference between individual MCPs (Mann–Whitney test, $Z = -0.49$, $P = 0.62$).

Individual 99% KDEs were not significantly larger in the non-breeding season (Mann–Whitney test, $Z = -0.73$, $P = 0.46$), nor were the 50% KDEs (Mann–Whitney test, $Z = -1.71$, $P = 0.09$). When Cape Vulture GPS locations were pooled together, MCPs and 99% KDEs were only slightly larger in the breeding season than the non-breeding season (Table 1). Pooled 50% KDEs were also only slightly larger (908 km^2) in the non-breeding season (Figure 3). Minimum convex polygons and 99% KDEs were similar across the breeding

TABLE 1: Home range estimates for adult Cape Vultures (Gyps coprotheres) captured at Mkambati Nature Reserve, Eastern Cape, South Africa.

ID	Status	Start	End	Days	Fixes BS	NBS	Home Range Estimators (km²)					
							BS MCP	NBS	BS 99%	NBS 99%	BS 50%	NBS 50%
X016	Unknown	26 Nov. 2012	25 May 2013	181	-	753	-	16.395	-	20.186	-	2.785
X033	Unknown	26 Nov. 2012	31 Oct. 2013	340	761	936	8.531	17.947	10.744	27.280	817	3.498
X022	Breeding (Unsuccessful)	17 Mar. 2013	31 Oct. 2013	229	1.046	-	18.811	-	27.014	-	1.863	-
X023	Breeding (Successful)	17 Mar. 2013	31 Oct. 2013	229	716	-	13.282	-	17.457	-	1.298	-
X027	Breeding (Successful)	26 Nov. 2012	31 Oct. 2013	340	525	910	12.598	16.808	20.861	24.947	2.198	2.752
X042	Unknown	26 Nov. 2012	31 Oct. 2013	340	725	681	20.313	16.396	35.307	27.932	6.302	6.327
Mean	-	-	-	277	717	820	14.707	16.887	22.277	25.086	2.496	3.841
SE	-	-	-	-	-	-	2.155	366	4.186	1.755	981	847
Pooled	-	-	-	-	3773	3280	22.640	22.068	26.772	26.003	2.583	3.491

ID, identification; SE, standard deviation; BS, breeding season; NBS, non-breeding season; MCP, minimum convex polygons; KDE, kernel density estimate.



KDE, kernel density estimate.

FIGURE 3: Combined kernel density estimates for adult Cape Vultures (*Gyps coprotheres*) in the (a) breeding (n = 5) and (b) non-breeding season (n = 4) captured at the Msikaba Cape Vulture colony, Eastern Cape, South Africa. Kernel density estimate areas that extended into the Indian Ocean were removed as vultures cannot forage there.

and non-breeding seasons, while the number and size of 50% KDEs differed slightly.

The maximum radius of the 50% KDE around the Msikaba Cape Vulture colony was 46 km during the breeding season. The other two core 50% KDEs during the breeding season had smaller radii (7 km and 11 km) and were located north of the breeding colony (Figure 3). The northernmost 50% KDE during the breeding season was mainly created by one bird (X042), which was not recorded at a breeding site at Msikaba. In the non-breeding season, there were only two core 50% KDEs areas. During the non-breeding season, the maximum radius from the colony to the edge of the 50% KDE was 52 km. The 50% KDE not located around the breeding colony had a radius of 29 km in the non-breeding season.

Habitat use

When vulture locations were pooled, habitats were not selected in proportion to their availability. Habitat selected by vultures differed between the breeding and non-breeding seasons (Table 2; Figure 4). Cape Vultures used subsistence farmland and natural woody vegetation more than expected in both the breeding and non-breeding season (Table 2). Protected areas were used in a greater proportion during the breeding season, while during the non-breeding season protected areas were used less than their availability in the 99% KDEs (Table 2). In both seasons, commercial farmland, plantations, urban centres and villages were used less than their availability in the 99% KDEs of the vultures (Table 2).

Discussion

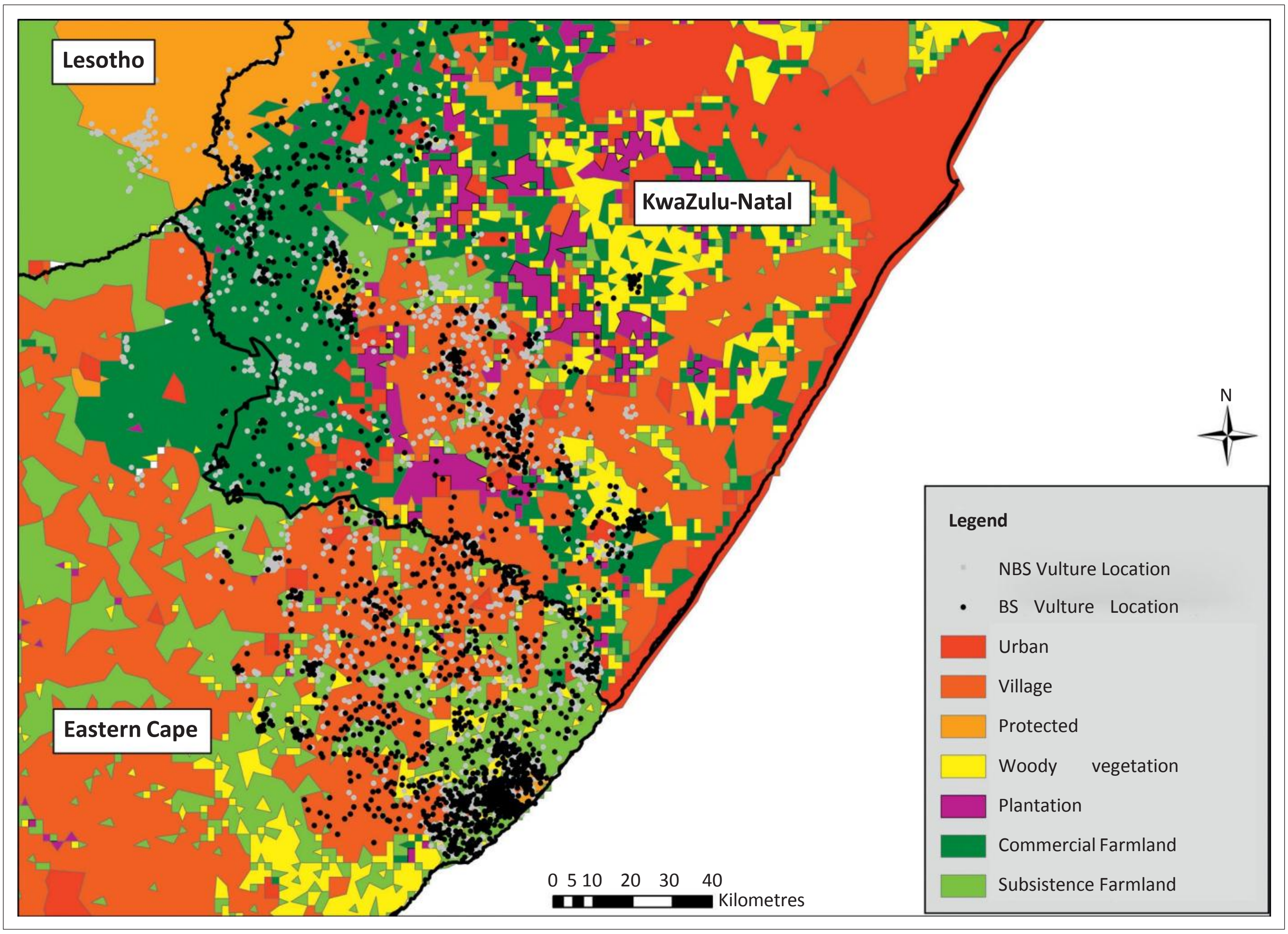
This study highlights the importance of subsistence farmland, rather than commercial farmland, as foraging habitat for Cape Vultures from the Msikaba colony. Although the results presented here are from a small and restructured sample size (n = 9), they illustrate the seasonal foraging and habitat selection patterns of the Cape Vulture in the southern node population.

Adult vultures from the Msikaba colony exhibited a well-defined foraging range. The tagged vultures did not participate in westerly migratory behaviour as previously

TABLE 2: Habitat availability in pooled 99% kernel density estimate based on the reclassified land use map. Bonferroni confidence intervals were used to determine Cape Vulture habitat use in pooled 99%kernel density estimate.

Season	Habitat type	Contribution %	Area (km^2)	P_i	P_{io}	Bonferroni CI	Conclusion
Non-breeding (23 877 km^2)	Commercial Farmland	26	6322	0.147	0.265	$0.131 < P < 0.163$*	Not Preferred
	Subsistence Farmland	17	4077	0.241	0.171	$0.221 < P < 0.260$*	Preferred
	Woody Vegetation	8	1886	0.273	0.079	$0.252 < P < 0.293$*	Preferred
	Plantation	5	1098	0.006	0.046	$0.002 < P < 0.009$*	Not Preferred
	Urban	4	1067	0.018	0.045	$0.012 < P < 0.024$*	Not Preferred
	Village	28	6772	0.226	0.284	$0.207 < P < 0.245$*	Not Preferred
	Protected Area	11	2655	0.09	0.111	$0.077 < P < 0.103$*	Not Preferred
Breeding (24 664 km^2)	Commercial Farmland	28	6977	0.136	0.283	$0.120 < P < 0.151$*	Not Preferred
	Subsistence Farmland	15	3799	0.251	0.154	$0.231 < P < 0.271$*	Preferred
	Woody Vegetation	10	2492	0.286	0.101	$0.265 < P < 0.306$*	Preferred
	Plantation	5	1174	0.004	0.048	$0.001 < P < 0.007$*	Not Preferred
	Urban	5	1318	0.013	0.053	$0.008 < P < 0.018$*	Not Preferred
	Village	27	6552	0.186	0.266	$0.169 < P < 0.204$*	Not Preferred
	Protected Area	10	2352	0.124	0.095	$0.109 < P < 0.139$*	Preferred

Non-breeding season (n = 3269).
Breeding season (n = 3578).
Z, 2.69.
P_i, actual proportion of usage; P_{io}, expected proportion of usage; Bonferroni CI, Bonferroni confidence intervals.
*, a significant difference at $P < 0.05$.



NBS, non-breeding season; BS, breeding season.

FIGURE 4: Cape Vulture (breeding and non-breeding season) locations overlaid on the land use map used for habitat analysis.

reported by Boshoff *et al.* (2009). Foraging ranges calculated as MCPs were found to overlap considerably in the breeding and non-breeding seasons. Other studies have also observed that the distance covered by vultures during the breeding season is similar to the non-breeding season, but foraging trips occurred less frequently in the early breeding season and during incubation (Bamford, Monadjem & Hardy 2007; Kendall *et al.* 2014; Spiegel *et al.* 2013). The 50% core area around the breeding colony was oval shaped and extended towards KwaZulu-Natal with a radius ranging 17 km – 46 km during the breeding season. During the non-breeding season the 50% KDE around the colony increased to a maximum radius of 52 km. The size of the core area around the colony was therefore larger than the proposed 40 km buffer (Boshoff & Minnie 2011).

As the home range represents an area ‘traversed by the individual in its normal activities of food gathering, mating and caring for young’ (Burt 1943), a smaller range may be explained by the abundance of food or suitable roosts in the environment. Formal protected areas were used more than expected during the breeding season, possibly because breeding sites were located in protected areas, not because there was more carrion available. As adult Cape Vultures were captured in the Mkambati Nature Reserve and two vultures were confirmed successful breeders, more time was spent at this locale.

Cape Vultures used formal protected areas less during the non-breeding season, while natural woody vegetation and subsistence farmlands were preferred. Use of natural woody vegetation by the vultures may have been misinterpreted because of the scale of the habitat classifications, as cliffs were not distinguished in the habitat classifications. Vultures did not necessarily use the woody vegetation, but the steep cliffs located above them, as roosting sites. Roost sites in the study area were typically located on isolated cliff faces with indigenous forest at the base (Boshoff & Minnie 2011; pers. obs.).

The two 50% KDEs created during the non-breeding season were both located in subsistence farmland that contains only one formal (registered with EWT or Ezemvelo KZN Wildlife) vulture feeding site, which was located in the Mkambati Nature Reserve. Other studies have found that African vultures use subsistence farmland less (Bamford *et al.* 2007; Bamford *et al.* 2009). This could be explained by different livestock carcass management (burning or burying) or over- harvesting of forest resources, which prevent tree-nesting vulture species from inhabiting these areas (Monadjem & Garcelon 2005). In the former Transkei, carrion may be more readily available because of inadequate animal husbandry and abundant tick-borne diseases (Shackleton *et al.* 2013). Strong cultural traditions may provide another scavenging opportunity for vultures: during traditional ceremonies, local amaXhosa people slaughter and butcher animals, the leftovers of which are discarded for vultures and other scavengers (Pfeiffer pers. obs.).

Commercial farmland areas were used less than expected during both seasons, despite the presence of formal vulture feeding sites. However, the northernmost 50% KDE in the breeding season was located near multiple vulture feeding sites. (One feeding site was located inside the northernmost 50% KDE.) The number of fixes a day in the current study (six a day including roosting locations) may have been insufficient to identify feeding events, which may have resulted in underestimating the use of vulture feeding sites. Furthermore, Cape Vultures can be grounded at roost sites for long periods of time because of adverse soaring conditions. Accordingly, these results may overestimate roosting locations and underestimate feeding events (Monsarrat *et al.* 2013; Spiegel *et al.* 2013). Future research should use higher resolution GPS data in order to identify feeding events and then calculate habitat use.

Conservation implications

The findings presented here highlight the relatively small foraging ranges of adult Cape Vultures from the Msikaba colony and their extensive use of subsistence farmland. Conservation efforts should focus on mitigating threats to vultures in the 50% KDEs, which are mainly located in subsistence farmland. Three local municipalities (Ingquza Hill, Mbizana and Umzimkhulu) were represented in both the breeding and non-breeding season 50% KDEs. On-the- ground conservation projects by provincial staff and relevant non-government organisations should be conducted in these areas. As some Cape Vulture core areas differed between the breeding and non-breeding seasons, other local municipal districts could be targeted based on the time of the year. During the breeding season (May to October), Impendle, uMngeni and Mpofana local municipalities were represented in the 50% KDEs. In the non-breeding season (November – April), Hibiscus Coast, Ezinqoleni, uMuziwabantu and Ubuhlebezwe local municipalities were represented and should be targeted for conservation projects during these months.

Based on these results, it is recommended that buffers around Cape Vulture colonies in the southern node population be increased from 40 km to 50 km. For Cape Vulture roost sites, 40 km buffers appear to be sufficient. In certain areas where this may be in conflict with development, a combination of GPS tracking data and risk assessment modelling should be used to construct conservation priority areas (Katzner *et al.* 2012).

Conclusion

Although vultures are far-ranging foragers that will never be fully secure within protected areas, it is essential to identify and proclaim conservation buffers. Tracking of a small sample of adult Cape Vultures from one colony has successfully identified the main foraging areas of vultures from that colony, and perhaps in the region. These areas can be targeted in focused strategic action plans aimed at avoiding or reducing the mortality of vultures. It will only be with the collaboration of communities, policy makers, conservation organisations and provincial governments that this regionally endangered vulture species will survive.

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Competing interests

The authors declare that they have no financial or personal relationships which may have inappropriately influenced them in writing this article.

Authors' contributions

M.B.P. (University of KwaZulu-Natal) was the project leader. M.B.P., J.A.V. (Department of Biodiversity Conservation) and C.T.D. (University of KwaZulu-Natal) conceived and designed the experiments. M.B.P was responsible for performing the experiments and analysing the data. M.B.P., J.A.V. and C.T.D. wrote the article.

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Appendix 1

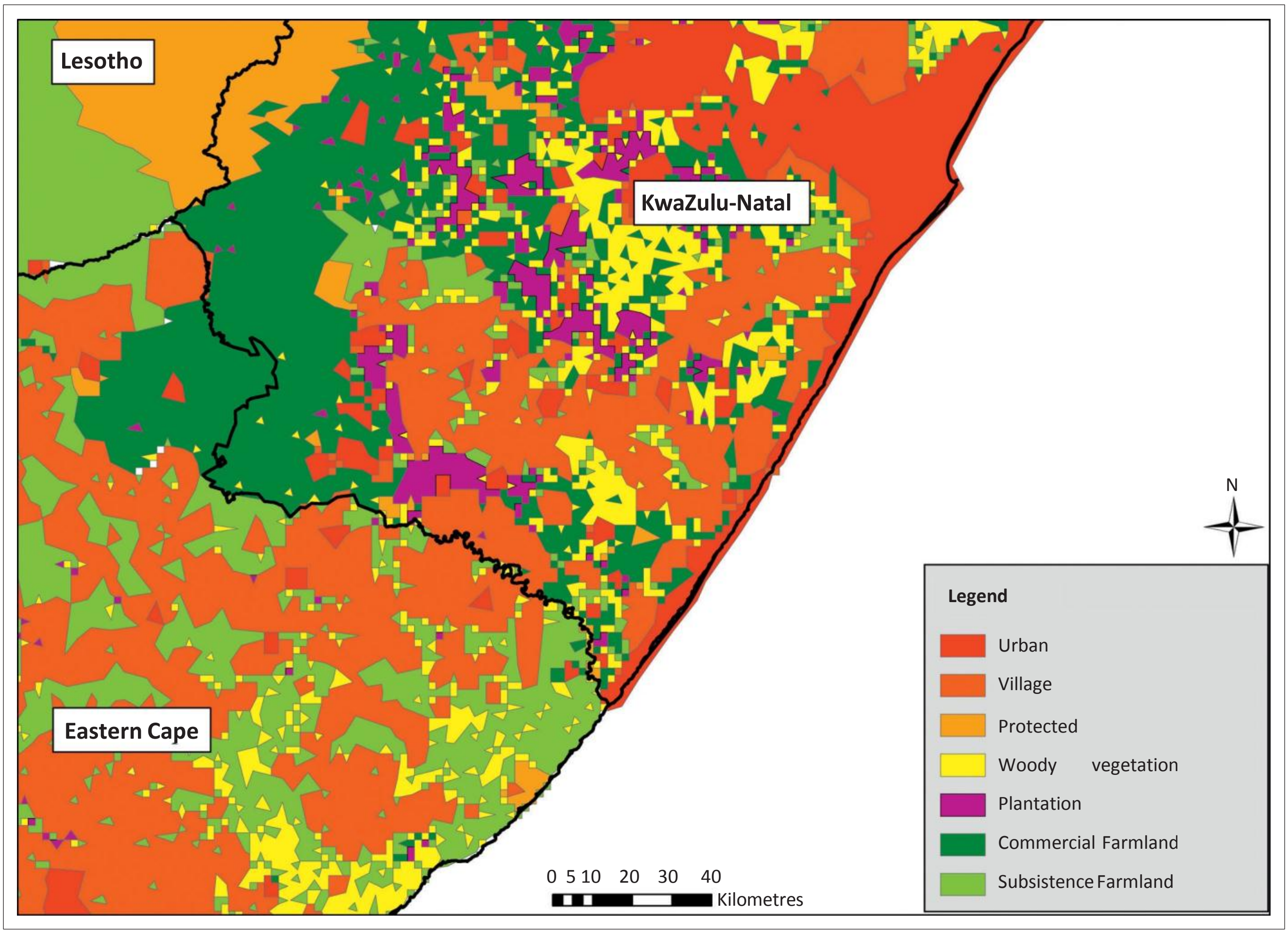
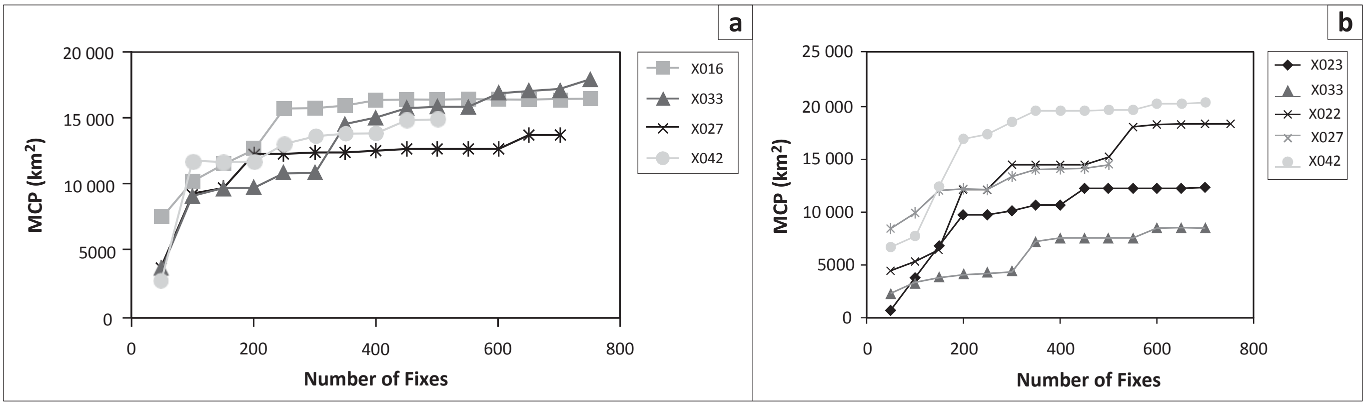


FIGURE A1: Land use map used for habitat analysis detailing the political boundaries of the former Transkei and Lesotho.



MCP, minimum convex polygons.

FIGURE A2: Incremental area analysis of minimum convex polygons of adult Cape Vultures (*Gyps coprotheres*) in relation to number of global positioning system location fixes for (a) the non-breeding season and (b) the breeding season, indicating that foraging range asymptotes were reached during each season.

Table A1 Land use map reclassified categories. Original land use categories were based on the 2000 South African National Land Cover Database (South African National Botanical Institution 2000)

Original Land Use Category	Reclassified Land Use Category
Forest (indigenous)	Woody vegetation
Woodland	Woody vegetation
Thicket, Bushland, Bush Clumps, High Fynbos	Woody vegetation
Shrubland & Low Fynbos	Commercial or Communal Farmland
Natural Grassland	Commercial or Communal Farmland
Planted Grassland	Commercial or Communal Farmland
Forest Plantations (Eucalyptus spp)	Plantation
Forest Plantations (Pine spp)	Plantation
Forest Plantations (Acacia spp)	Plantation
Forest Plantations (Other / mixed spp)	Plantation
Forest Plantations (clearfelled)	Plantation
Waterbodies	Commercial or Communal Farmland
Wetlands	Commercial or Communal Farmland
Bare Rock and Soil (natural)	Commercial or Communal Farmland
Bare Rock and Soil (erosion : dongas / gullies)	Commercial or Communal Farmland
Bare Rock and Soil (erosion : sheet)	Commercial or Communal Farmland
Degraded Forest & Woodland	Woody vegetation
Degraded Thicket, Bushland, etc	Woody vegetation
Degraded Shrubland and Low Fynbos	Commercial or Communal Farmland
Degraded Unimproved (natural) Grassland	Commercial or Communal Farmland
Cultivated, permanent, commercial, irrigated	Commercial Agriculture
Cultivated, permanent, commercial, dryland	Commercial Agriculture
Cultivated, permanent, commercial, sugarcane	Commercial Agriculture
Cultivated, temporary, commercial, irrigated	Commercial Agriculture
Cultivated, temporary, commercial, dryland	Commercial Agriculture
Cultivated, temporary, subsistence, dryland	Communal Farmland
Cultivated, temporary, subsistence, irrigated	Communal Farmland
Urban / Built-up	Urban
Urban / Built-up (rural cluster)	Village
Urban / Built-up (residential, formal suburbs)	Urban
Urban / Built-up (residential, flatland)	Urban
Urban / Built-up (residential, mixed)	Urban
Urban / Built-up (residential, hostels)	Urban
Urban / Built-up (residential, formal township)	Village
Urban / Built-up (residential, informal township)	Urban
Urban / Built-up (informal squatter camp)	Urban
Urban / Built-up (smallholdings…)	Urban
Urban / Built-up, (commercial, mercantile)	Urban
Urban / Built-up, (commercial, education, health, IT)	Urban
Urban / Built-up, (industrial / transport : heavy : light)	Urban
Mines & Quarries (subsurface mining)	Commercial or Communal Farmland

A 2 km buffer was added to urban and village layers. This layer was merged with the formal protected areas of South Africa and Lesotho (International Union for the Conservation of Nature and Natural Resources and United Nations Environment Programme's World Conservation Monitoring Centre 2014). Land use was classified as commercial or subsistence based on its location to the former Transkei political boundaries.

ADDENDUM TO CHAPTER 3

The IUCN status of the Cape Vulture was up listed from ‘vulnerable’ to ‘endangered’ in 2015 (BirdLife International 2015).

BirdLife International. 2015. *Gyps coprotheres*. The IUCN Red List of Threatened Species 2015: e.T22695225A84339218. http://dx.doi.org/10.2305/IUCN.UK.2015-4.RLTS.T22695225A84339218.en.

CHAPTER 4:
Breeding success, cliff characteristics and neighbour requirements of an endangered colonial nesting African vulture species, the Cape Vulture

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Running header: Breeding success and nesting of a Cape Vulture colony

Various hypotheses have been proposed for the advantages of colonial over solitary breeding in birds including group decisions on nest sites, protection from predators, and food resource access especially when food resources are unpredictable and food patch knowledge exchange is beneficial. Irrespective, the breeding success of endangered colonial nesting species is important for their conservation. Many species of *Gyps* vultures form large breeding colonies which are the foci of several conservation efforts. The Cape Vulture (*Gyps coprotheres*) is an endangered species endemic to southern Africa, which has seen a major reduction in population size (≥ 50 % over 48 years). To halt further population declines, conservation practices focus on protecting their breeding colonies. However, there is evidence that vulture breeding colonies are ephemeral and are prone to desertion as a result of human disturbance. Factors that influence the occupancy and breeding success of individual nest sites is not fully understood for any African vulture species. We investigated cliff characteristics and neighbour requirements of the Msikaba Cape Vulture colony, a major breeding colony in the southern node of the population in the Eastern Cape, South Africa together with their nest site occupation and breeding success over 13 years. A total of 1767 breeding attempts were recorded. Nest sites with a higher elevation, smaller ledge depth, higher total productivity, and surrounded by conspecifics were more likely to be selected. The breeding success in a given year was positively influenced by the total productivity of a nest site. Nests in the interior of high density areas had greater breeding success. Over the study period, breeding success was negatively impacted by year, highlighting the effects of a temporal variation or observer bias. Our results identified preferred nest site locations (ledge depths of 1 m, and at a height of 180 m) and their effects on breeding success. High density of nests increased the breeding success, which is an important consideration if declines of reproducing adults continue. This information can be used for planning reintroduction efforts of the endangered Cape Vulture and for their ongoing conservation.

Keywords: breeding success, vulture, nest site occupation, avian colony dynamics

Single species group formation is an evolutionary strategy that has both costs and benefits (Parrish and Edelstein-Keshet 1999, Krause and Ruxton 2002). In birds, flocks are formed for protection against predators, to reduce the cost of flying, and to share information on resources (Krause and Ruxton 2002). Formation of groups by predatory birds is observed when there is an advantage to feeding in groups (Ward and Zahavi 1973). For example, groups of avian insectivores fly through swarms of insects creating a ‘ricochet effect’ in which an insect evades one predator, only to be consumed by an undetected predator (Krause and Ruxton 2002). Various non-mutually exclusive hypotheses have been proposed for colonial breeding in birds including group decisions on nest sites, anti-predation, and food patch knowledge exchange, especially when food resource are unpredictable. Aggregation of breeding birds is believed to occur when food resources are unpredictable and randomly distributed (Ruxton and Houston 2002). Scavenging birds, such as vultures, form breeding colonies and typically forage together. Breeding in a colony may enhance foraging efficiency and thus aid breeding success by increased food provisioning rates (Ward and Zahavi 1973, Krause and Ruxton 2002, Dermody *et al.* 2011). The costs associated with breeding in colonies includes depletion of local resources and competition for optimal nesting sites (Krause and Ruxton 2002, Szostek et al. 2014). Certain individuals may be forced to occupy sub-optimal sites, such as the periphery of the colony and therefore may suffer from increased predation (Forster and Phillips 2009). Although knowledge of optimal nest site characteristics of colonial birds exists for a number of guilds (i.e. water birds and kestrels), links between nest density, cliff characteristics, for *Gyps* vulture breeding success remains unclear (Harris *et al.* 1997, Borello and Borello 2002, Franco *et al.* 2005, Anushiravani *et al.* 2016, Brussee *et al.* 2016).

Vultures are considered to be one of the most threatened guilds at risk of extinction (Ogada *et al.* 2012a). Populations of seven species of African vultures have declined by 80 % over three generations, which is cause for great concern (Ogada *et al.* 2015). Recycling organic material, preventing possible mammalian disease transmission, and providing a free carbon neutral waste removal service are just a few of the economic and ecological services obligate vulture scavengers provide (Dupont *et al.* 2012, Ganz *et al.* 2012, Ogada *et al.* 2012b). In Spain, it was calculated that vultures provide a free sanitation service worth $50 million and prevented 77,344 MT of CO_2 entering the environment per year (Morales-Reyes *et al.* 2015). India spent $34 million on health costs related to surges in feral dog populations with rabies because of vulture declines between 1993 and 2006 (Markandya *et al.* 2008). Such expenses can have catastrophic consequences in developing countries, especially those in Africa (Ogada *et al.* 2015). Causes of the ‘African Vulture Crisis’ includes inadvertent poisoning by poachers, deliberate poisoning and persecution for use of vulture body parts in traditional medicine, and collisions with power-lines (Ogada *et al.* 2012a, Ogada *et al.* 2015). Furthermore, human disturbance at vulture breeding colonies has caused the abandonment of nest sites (Borello and Borello 2002). The colonial breeding nature of some vultures may help with conservation planning and threat mitigation by focusing effort and resources at relatively few breeding locations compared with solitary nesting species.

Gyps vultures can form large (> 1000 pairs) gregarious breeding colonies on cliff formations (Ruxton and Houston 2002, Virani *et al.* 2012, Benson 2015). As a central-place forager, the breeding colony represents the anchor in the foraging ranges of the breeding adults

(Ruxton and Houston 2002, Pfeiffer *et al.* 2015). Unfortunately, in recent years, entire vulture breeding colonies have gone extinct because of human disturbance or reductions in carrion availability (Ogada *et al.* 2015). The southern African endemic Cape Vulture (*Gyps coprotheres*) has seen a drastic range contraction in recent years (Boshoff and Vernon 1980, Borello and Borello 2002, Bamford *et al.* 2007). This species was recently up listed to 'Endangered' on both the Red List of Threatened Species of the International Union for the Conservation of Nature and the South Africa, Lesotho, and Swaziland regional Red Data assessment (BirdLife International 2015, Allan 2015). Although relatively few Cape Vulture breeding colonies have been monitored over three vulture generations (48 years), in the 1960s, vultures bred at 32 known breeding colonies in South Africa (Allan 2015). In 2015, only 11 of these colonies supported breeding pairs which provides evidence of a reduction in the number of mature individuals (Allan 2015). The Cape Vulture has been the focus of numerous multi-agency management plans which aim to prevent further declines of this species (Boshoff and Anderson 2006, Botha *et al.* 2012, Retief *et al.* 2013, Pfeiffer *et al.* 2015). In all of the management plans, protection of breeding colonies, active roosts sites, and the surrounding area is considered to be beneficial to the species (Retief *et al.* 2013, Pfeiffer *et al.* 2015).

Protective areas around vulture breeding colonies and roosts mitigate the proximity of power line infrastructure or wind turbine installations, both which are detrimental to vulture populations (Boshoff *et al.* 2011, Rushworth and Krüger 2014). However, specific knowledge of Cape Vulture nest site selectivity and factors that influence breeding success is lacking. Understanding the use of rock formations by Cape Vultures can help identify ideal breeding sites which could be used in future reintroduction efforts or current conservation planning polices in addition to providing information on nest site factors that my influence breeding success

(Ceballos and Donázar 1989, Sarrazin *et al.* 1996). Cape Vulture pairs will reuse a successful nest site, exhibiting a win-stay, lose-switch strategy (Robertson 1986, Switzer 1997, Borello and Borello 2002, Virani *et al.* 2012). According to this strategy, if a nest site location is not successful, breeding pairs would switch sites to increase their chances of a successful nesting attempt (Switzer 1997). A successful nest site might be the product of an experienced breeding pair or evidence of an optimal nest site. The theory of habitat heterogeneity assumes there are optimal and sub-optimal sites within the breeding colony and therefore may affect the individuals breeding success within the colony (Forster and Phillips 2009, Szostek *et al.* 2014). Consequently, in this study, we attempted to quantify the factors that affect Cape Vulture nest site occupation and breeding success, to provide conservation recommendations. Nests with greater protection from the elements and predators were expected to be optimal sites, which were expected to be higher in elevation to prevent Chacma Baboons (*Papio ursinus*) from raiding nests easily accessible by climbing from below. Optimal nest sites were also expected to have a smaller ledge depth to prevent aerial predator such as corvids and Verreaux's Eagles (*Aquila verreauxii*) from perching and harassing the breeding pair. It was expected that nests with a greater ledge overhang and surrounded by other nests would be selected more than other sites. We expected that factors important to nest site occupation would also be significant in determining the success of the nest.

4.1 Methods

4.1.1 Study site and species

Breeding success at the Msikaba Cape Vulture colony (31° 16' S, 29° 59' E, 200 m a.s.l.; Fig. 4.1) has been monitored consistently with the same monitoring protocol for 13 years and was the study site. The colony is one of the largest Cape Vulture breeding colonies in the southern node of the population and is unique in that it is 2 km from the Indian Ocean and is the lowest colony in elevation (Mundy *et al.* 1992, Boshoff and Minnie 2011). Approximately 170 Cape Vulture pairs breed regularly at the Msikaba Cape Vulture colony, which is located on the cliffs formed by the Msikaba River in the Mkambati Nature Reserve (MNR, Piper and Ruddle 1986, Boshoff and Minnie 2011, Botha *et al.* 2012). Ledges of the colony are made up of Table Mountain sandstone and are south facing (Piper and Ruddle 1986). Annual rainfall at MNR is about 1200 mm and differences in monthly mean temperature are less than 6° C (Shackleton *et al.* 1991). The reserve is surrounded by subsistence agriculture, which may contribute to the persistence of the Cape Vulture in the Eastern Cape Province because of lower poisoning incidences and higher carrion availability (Vernon 1998, Pfeiffer *et al.* 2015).

Fig. 4.1 Location of the Msikaba Cape Vulture breeding colony, Eastern Cape Province, South Africa.

Cape Vultures reach sexual maturity between 5 - 7 years and are considered monogamous (Mundy *et al.* 1992). The breeding season is relatively long lasting from early May to late November (Mundy *et al.* 1992, Pfeiffer *et al.* 2015). During April and May, Cape Vulture pairs gather herbaceous and woody material for their nests, which on average measures 70 cm in diameter and 11 cm thick upon completion (Mundy *et al.* 1992). Peak egg laying occurs around late May or early June and each pair generally has one egg. Incubation lasts 57 days (Robertson 1986). After hatching, the offspring is reliant on the parent for food until late December/January. It is not uncommon for fledglings to frequent the breeding colony until the next breeding season.

Breeding pairs may attempt to breed every year or every other year (Mundy 1982, Mundy *et al.* 1992).

4.1.2 Nest monitoring

Breeding Cape Vultures in MNR were first documented in the mid-1970 on the Mtentu River, which is the reserve's northern boundary. The first counts of Cape Vulture in MNR were conducted in 1983 and 1984 (Piper and Ruddle 1986). In 1984, about 137 nesting sites were recorded, 73 nests on the Mtentu River and 64 on the Msikaba River (Piper and Ruddle 1986). Consistent annual monitoring of the breeding success of the colony was started in 2000 by the late Prof. S. Piper who continued observations until 2008 (Piper 2008). No monitoring occurred in 2009 or 2011. In 2010, MNR field rangers conducted the counts. Between 2012 - 2015, monitoring efforts were coordinated and conducted by the lead author and volunteers. As breeding attempts were made on both the north and south bank of the Msikaba River, observations were made from two vantage points 1) 31° 18' 0" S, 29° 55' 28" E, located inside MNR and 2) 31° 18'16" S, 29° 55' 32" E which is outside of MNR (Fig. 4.1). Observation points were between 200 – 600 m away from nest sites. The colony was classified into 10 different cliff formations based on the geology and distribution of nests. Each cliff formation was photographed and each nest on the formation was given a unique identification number (Benson *et al.* 2007) which were carried over from year to year (Fig. S4.1).

Fig. S4.1 Example of a cliff formation (Mamba) with Cape Vulture nest sites at the Msikaba Cape Vulture breeding colony, Mkambati Nature Reserve, Eastern Cape Province, South Africa.

Monitoring occurred at least three times a year to cover the breeding cycle from incubation to fledging (Borello and Borello 2002, Benson *et. al.* 2007). Only one visit was made during the first year of the surveys in 2000, and therefore breeding success was not calculated for that year and excluded from analysis. Nests (n = 279) were monitored by using binoculars (Bushnell Legend 8 x 42) and spotting scopes (Nikon EDG VR). Occupation of a nest site was confirmed if a well-made tenanted nest was built and/or incubation occurred. This definition meets the criteria of an ‘occupied’ nest (Postupalsky 1974). Observation of a nestling with fully developed primary feathers at the end of the breeding season is the definition of an ‘active’ nest and confirmed a successful breeding attempt (Postupalsky 1974, Benson *et al.* 1990). For standardization, if a nestling was not observed during the last count of a year, but adult(s) were actively brooding over a well-made nest it was also considered a successful breeding attempt. Breeding season outcome decisions were validated by previous monitoring surveys of the given year, and represent the most likely outcome. This method might have inflated the breeding success values, but had no effect on nest site occupation. Although this method does not differentiate between multiple nesting attempts at one site, i.e. early season nest failures with pairs re-attempting to breed, this does not affect the overall productivity of the nest site on a year basis.

4.1.3 Predictor variables

Based on previous research on colonial nesting species and empirical knowledge of the cliff locality and Cape Vulture breeding dynamics, predictor variables were chosen for use in the analysis of their nest site occupation and breeding success (Table S4.1). Cliff measurements of all monitored nest sites were made by a surveyor (G4 Survey (PTY) LTD) using a Leica MS50 Multi Station (a Leica Geosystems product provided by Aciel Geomatics (PTY), LTD, South Africa) in September 2014. Cliff measurements were precise to three decimal places. Height of the nest site was the height between the riverbed and the nest site and included forested and open scree slopes. Ledge depth was calculated from two values: 1) the location of the nest site and 2) the location of the vertical cliff behind the nest site. Overhang was calculated by subtracting the location of the vertical cliff behind the nest site from the closest location to the observer of the overhang above the nest site. The close proximity of some nest sites resulted in the same overhang, ledge depth, and height measurement recorded for those nest sites.

Table S4.1 Cliff and neighbour measurements recorded for nest sites at the Msikaba Cape Vulture colony, Mkambati Nature Reserve, South Africa.

Measure	Definition
Elevation	The height of the nest site measured in metres from the riverbed
Ledge Depth	The difference in metres of two values: 1) the location of the nest site and 2) the location of the vertical cliff behind the nest site
Overhang	The product of subtracting the location of the

	vertical cliff behind the nest site from the closest location to the observer of the overhang above the nest site
Last Year	Whether the nest site was active or not the previous year
Total productivity of the nest site	Percentage of the total breeding success of the nest site over the course of the study
Nests on ledge	Number of other occupied nest sites on the ledge
Direct neighbours	Number of other occupied nests that are direct neighbours of the nest

As nest site numbers did not change during the study period, number of neighbours (occupied nests) on the ledge and number of direct neighbours were calculated by visualizing the activity on the cliff in a given year. Best judgment was used to discern if nests were direct neighbours based on the standard diameter (70 cm) of a Cape Vulture nests and historical photographs (Mundy *et al.* 1992). The total productivity of the nest site (times successful/years of occupation), and if the nest site was used the previous year were determined for each nest site each year of the study.

4.1.4 Data preparation

Data were tested for normality by using a 'quantile-quantile plot' which depicts a proportion of theoretical quantiles against the observed data using the 'stats' package in R (R Core Team 2016). Although cliff overhang and total productivity of the nest site were not normally distributed, it was not enough to warrant a transformation. Additionally, predictor variables of were not required to be normally distributed for the chosen regression models (Grueber et al. 2011). The association between continuous predictor variables were checked using Spearman's correlation coefficients using the 'stats' R package. All continuous predictor variables were not correlated ($r \leq 0.5$). Cliff formations were tested for differences in height, ledge depth, and overhang by a one-way ANOVA using the ‘stats’ R package. Mean values are reported with ± SD.

4.1.5 Regression models

4.1.5.1 Nest site occupation

Nest site occupation in response to the predictor variables was investigated using a generalized linear mixed model (GLMM) with a binominal error term and a logistic link function (1 = a nest site that was occupied, 0 = a nest site that was not occupied) for each nest site between 2001-2015 (McCullagh and Nelder 1989). A global model set was creating using the ‘lmer’ function in the ‘lme4’ package (Bates and Maechler 2009). The predictor variables included: total productivity of the nest site, whether the nest was active the previous year, ledge depth, height, overhang, the number ledge neighbours, and the number of direct neighbours. Whether or not the nest was active the previous year was classified as a categorical variable. We included nest identity as a random term to account for pseudoreplication. The variables were standardized before model analysis using the ‘standardize’ function in the ‘arm’ R package (Gelman and Su 2015). A full submodel set was constructed using the ‘dredge’ function in the ‘MuMIn’ package (Bartoń 2014). We conducted a stepwise regression analysis to determine which variables had a significant correlation with nest site occupation by adding terms that reduced the AIC_c and removing variables that had the least effect. Models were ranked by their AIC_c values, and model averaging was performed with the top models ($\Delta AIC_c \leq 2$). Akaike weights (w_i) were used as an indication of support for each model (Burnham and Anderson 2003).

4.1.5.2 Breeding success

Breeding success was also investigated using a GLMM (1 = successful breeding attempt, 0 = failed breeding attempt). The same predictor variables for the nest site occupation were used in the breeding success model, in addition to year. Year was added as a continuous variable to the breeding success model to investigate annual variation. We included nest identity as a random term to account for pseudoreplication. The variables were standardize before the 'dredge' command. We performed model selection by using AIC ranking methods. All regression models were constructed in R 3.3.0 (R Core Team 2016) using packages MuMIn and effects (Fox *et al.* 2014).

4.2 Results

A total of 279 unique cliff measurements and neighbour information were recorded for Cape Vulture nest sites at the Msikaba Cape Vulture breeding colony over 13 years (2001-2008, 2010, 2012-2015). Out of 3627 observations, 1767 vulture nest occupations were observed over the study period. The mean number of breeding attempts was 136 ± 22.6 per year, and number of breeding pairs increased by about 4 attempts p.a. during the study period (Fig. 4.2). Of the total number of Cape Vulture breeding attempts, the majority (78%, n = 1391) successfully produced a fledgling. Mean number of successful breeding attempts was 107 ± 13.8 p.a. and successful attempts also increased with time by about 2 attempts p.a. (Fig. 4.2). Breeding occurred on all 10 cliff formations of the north bank of the Msikaba River. A one-way ANOVA revealed that cliff formations of possible nest locations differed in regards to height ($F_{(9,269)} = 133$, $p < 0.05$), ledge depth ($F_{(9,269)} = 8.04$, $p < 0.05$), and overhang ($F_{(9,269)} = 18.51$, $p < 0.05$) in the nest occupancy data set. Cliff formations of occupied nest locations also differed in regards to height ($F_{(9,100)} = 62.2$, $p < 0.05$), ledge depth ($F_{(9,100)} = 4.43$, $p < 0.05$), and overhang ($F_{(9,100)} = 9.10$, $p < 0.05$).

Means and standard deviations of the cliff measurements of the nest occupancy data set are presented in Table S4.2. Mean number of active nests on the same ledge was 1.4 ± 2.2 (0-11) and the mean number of direct neighbours was 0.2 ± 0.5 (0-3 ,Table S4.2).

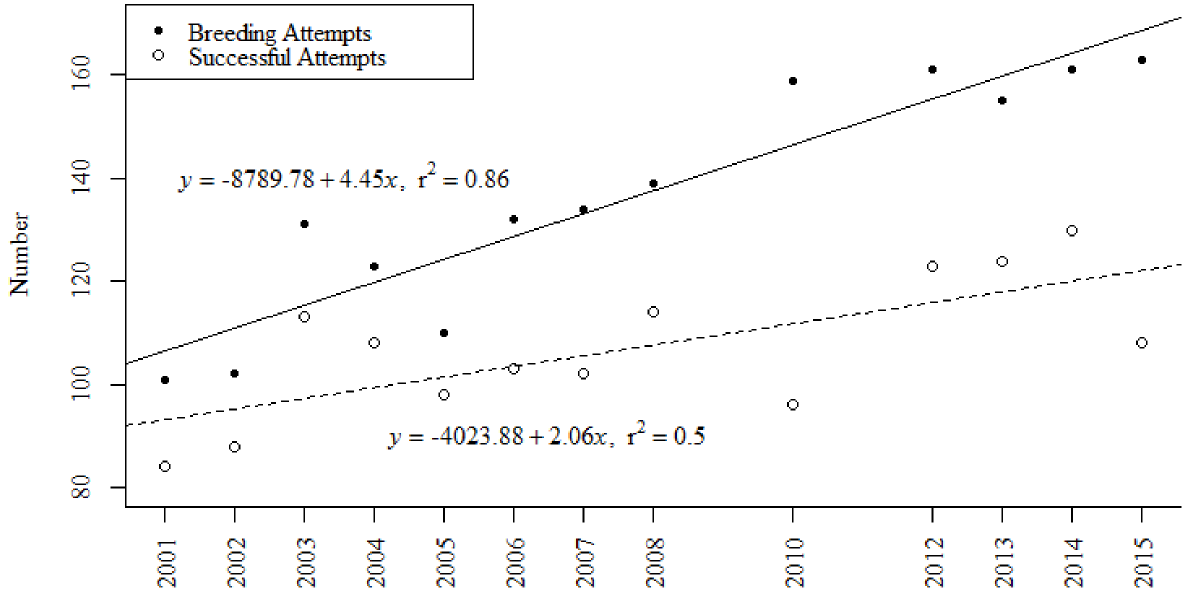


Fig. 4.2 Total number of Cape Vulture (*Gyps coprotheres*) breeding attempts (n = 1767) and successful attempts (n = 1391) at the Msikaba Cape Vulture colony in the Mkambati Nature Reserve, Eastern Cape Province, South Africa. No data were collected in 2009 or 2011.

Table S4.2. Cliff and neighbour breeding pair characteristics of the Msikaba Cape Vulture colony, Mkambati Nature Reserve, South Africa (Means + SD).

Cliff formation	Number of nest sites measured	Ledge depth (m)	Overhang (m)	Elevation (m)	Number of ledge neighbours	Number of direct neighbours
Baboon (1)	17	0.43 - 2.40 (1.15 ± 0.46)	0.37 - 4.63 (1.93 ± 1.39)	99.2 - 121 (109 ± 5.44)	0 - 3	0 - 1

Below Triangle (2)	45	0.53 - 3.65 (1.72 ± 1.00)	0 - 2.93 (1.33 ± 0.75)	117 - 129 (120 ± 2.45)	0 - 9	0 - 2
Black Rock (3)	19	0.42 - 2.05 (1.17 ± 0.42)	0 - 4.07 (1.84 ± 0.94)	134 - 148 (143 ± 3.32)	0 - 3	0 - 1
Buttress (4)	33	0.57 - 3.51 (1.45 ± 0.59)	0.02 - 2.34 (1.44 ± 0.54)	98.4 - 125 (107 ± 8.48)	0 - 3	0 - 2
Joggie's Surprise (5)	21	0.57 - 3.36 (1.30 ± 0.65)	0 - 4.53 (1.42 ± 1.34)	134 - 152 (141 ± 4.06)	0 - 3	0 - 1
Lover's Cave (6)	15	0.30 - 2.99 (1.78 ± 0.81)	0 - 5.05 (1.65 ± 1.18)	120 - 142 (131 ± 5.92)	0 - 2	0 - 1
Mamba (7)	64	0.35 - 4.71 (1.81 ± 1.12)	0 - 6.36 (2.60 ± 1.84)	118 - 166 (142 ± 19.2)	0 - 11	0 - 3
Pyramid (8)	11	0.50 - 2.08 (1.11 ± 0.52)	0.49 - 3.35 (1.79 ± 1.01)	123 - 138 (128 ± 3.76)	0 - 3	0 - 1
Seaview (9)	9	2.09 - 4.03 (3.26 ± 0.84)	3.34 - 10.4 (6.91 ± 2.72)	142 - 142 (142 ± 0.14)	0 - 8	0 - 1
Top Triangle (10)	45	0.45 - 1.97 (1.20 ± 0.39)	0 - 4.59 (1.43 ± 0.94)	165 - 187 (176 ± 4.80)	0 - 4	0 - 2
Totals	**279**	**0.35 - 4.71 (1.55 ± 0.90)**	**0.00 - 10.4 (1.94 ± 1.66)**	**98.4 - 187 (137 ± 23.8)**	**0 - 11 (1.4 ± 2.2)**	**0 - 3 (0.2 ± 0.5)**

4.2.1 Nest site occupation

Out of 128 total models, two had a $\Delta AIC_c < 2$, with a collective *wi* of 1.00 (Table 4.1). The top rated models showed that Cape Vulture nest site occupation was best explained by all the predictor variables (Table 4.2). Nest site occupation increased as height increased, but decreased as ledge depth increased (Fig. 4.3). Number of ledge neighbours and direct neighbours positively influenced nest site occupation. If a nest site was active the previous year, the chances it would be selected again as a nest site were greater. As total productivity of a nest site increased, the occupation of the nest site was higher (Fig. 4.3).

Table 4.1 Results from the top GLMs ($\Delta AIC_c < 2$) for factors influencing Cape Vulture (n = 3627, observations from 2000 to 2015) nest site occupation at the Msikaba colony. Model parameters: Height (height of nest site), Depth (ledge depth), Productivity (total productivity of the nest site), Direct Neighbours (number of direct neighbours), Neighbours (number of ledge neighbours), Previously Active (if the nest was active the previous year), Overhang (ledge depth of the overhang of the nest site).

Models	**df**	**logLik**	**AIC_c**	**ΔAIC_c**	***wi***
Height + Depth + Productivity + Direct Neighbours + Neighbours + Previously Active	**8**	**-1779**	**3574**	**0.00**	**0.71**
Height + Depth + Productivity + Direct Neighbours + Neighbours + Previously Active + Overhang	**9**	**-1779**	**3576**	**1.75**	**0.29**
Height + Depth + Productivity + Neighbours + Previously Active + Overhang	8	-1793	3602	28.3	0.00
Height + Depth + Productivity + Neighbours + Previously Active	7	-1794	3603	28.6	0.00

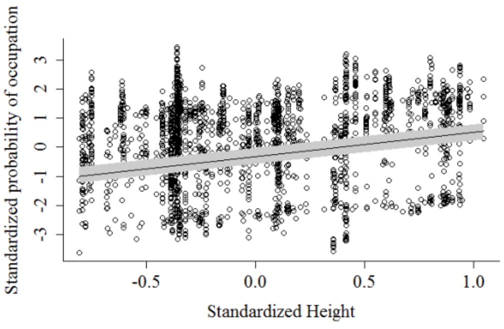
df –Degrees of freedom, logLik – Model’s loglikelihood value, *wi* – Akaike weight

Table 4.2 Model-averaged coefficients for predicting Cape Vulture nest site occupation (n = 3627) at the Msikaba colony. Model parameters: Height (height of nest site), Depth (ledge depth), Productivity (total productivity of the nest site), Direct Neighbours (number of direct neighbours), Neighbours (number of ledge neighbours), Previously Active (if the nest was active the previous year), Overhang (ledge depth of the overhang of the nest site); RI = relative importance of the variable.

					Confidence intervals		
Parameter	**Estimate***	**SE**	**Adjusted SE**	**z**	**2.5%**	**97.5%**	**RI**
(Intercept)	0.65	0.07	0.07	9.29	0.51	0.78	-
Previously Active = No †	-1.42	0.09	0.09	16.3	-1.59	-1.25	1.00
Height	0.58	0.09	0.09	6.47	0.40	0.75	“
Depth	-0.70	0.10	0.10	6.93	-0.89	-0.50	“
Neighbours	0.57	0.10	0.10	5.83	0.38	0.76	“
Direct Neighbours	0.52	0.10	0.10	5.28	0.33	0.72	“
Productivity	1.98	0.11	0.11	18.4	1.77	2.19	“
Overhang	0.02	0.06	0.06	0.26	-0.14	0.25	0.29

* Effect sizes have been standardized on two SD following Gelman (2008).

† Previously Active = Yes for the preceding year was the reference category.


Standardized probability of occupation
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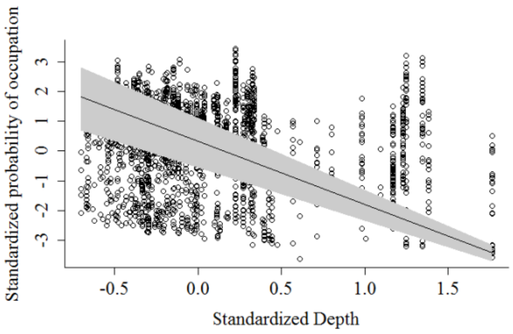
-2
-1
0
1
2
3
-0.5
0.0
0.5
1.0
Standardized Height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1
2
3
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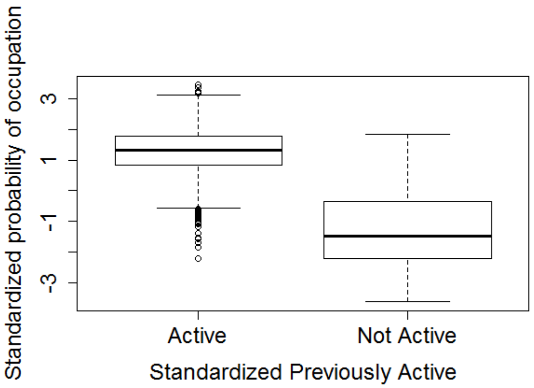
0.0
0.5
1.0
1.5
Standardized Depth


Standardized probability of occupation
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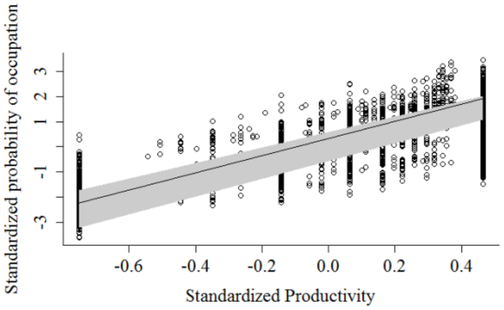
-1
1
3
Active
Not Active
Standardized Previously Active


Standardized probability of occupation
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2
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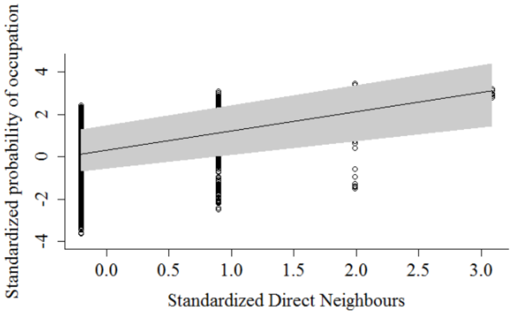
-0.4
-0.2
0.0
0.2
0.4
Standardized Productivity


Standardized probability of occupation
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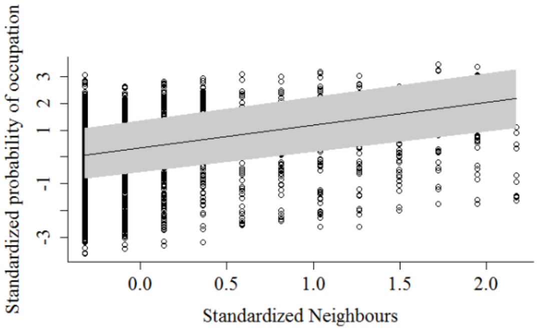
0
2
4
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Standardized Direct Neighbours


Standardized probability of occupation
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2
3
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0.5
1.0
1.5
2.0
Standardized Neighbours

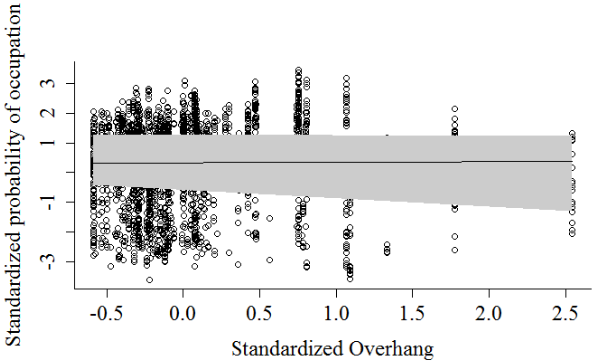

Standardized probability of occupation
-3
-1
1
2
3
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
Standardized Overhang

Fig. 4.3 Model-averaged estimates (± 95 % confident intervals) of top variables from the GLMM showing the probability of nest occupation (n = 3627) based on cliff characteristics and neighbour requirements at the Msikaba Cape Vulture colony, Mkambati Nature Reserve, Eastern Cape Province, South Africa.

4.2.2 Breeding success

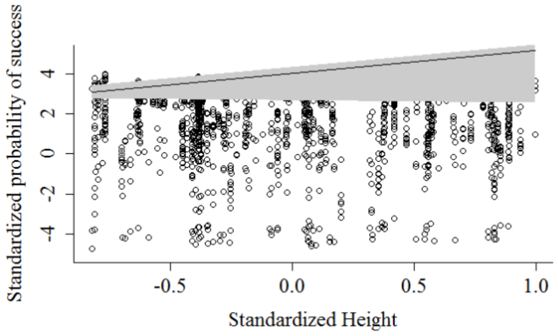
In regards to Cape Vulture breeding success 8 models, out of 256, resulted in $\Delta AIC_c < 2$, with a collective *wi* of 0.39 (Table 4.3). Year and total productivity of the nest site were represented in all top models. The total productivity of the nest site had a positive effect on the probability that the site would be successful (Fig. 4.4). If the nest site was used in the previous year, the chances of the site being productive increased. The number of direct neighbours was very important (relative importance = 1.00) in determining if a nest would be successful or not (Table 4.4). As the number of direct neighbours increased, so did the breeding success (Fig. 4.4). Years also was very important and showed a declining probability of breeding success as time advanced in the study period (relative importance = 1.00, Table 4.4). Nests that were located on a higher cliff ledge had a higher breeding success. Ledge depth and overhang had very little effect on breeding success (relative importance < 0.10).

Table 4.3 Results from the top GLMs ($\Delta AIC_c < 2$) for factors influencing Cape Vulture (n = 1767 observations from 2000 to 2015) breeding success at the Msikaba colony. Model parameters: Height (height of nest site), Depth (ledge depth), Productivity (total productivity of the nest site), Direct Neighbours (number of direct neighbours), Neighbours (number of ledge neighbours), Previously Active (if the nest was active the previous year), Overhang (ledge depth of the overhang of the nest site), and Year.

Models	df	logLik	AIC_c	ΔAIC_c	*wi*
Height + Productivity + Direct Neighbours + Previously Active + Year	**7**	**-580**	**1174**	**0.00**	**0.08**
Productivity + Direct Neighbours + Previously Active + Year	**6**	**-581**	**1175**	**0.33**	**0.07**
Height + Productivity + Previously Active + Year	**6**	**-582**	**1175**	**0.98**	**0.05**
Productivity + Previously Active + Year	**5**	**-583**	**1176**	**1.30**	**0.04**
Height + Productivity + Direct Neighbours + Year	**6**	**-582**	**1176**	**1.39**	**0.04**

Height + Productivity + Direct Neighbours + Neighbours + Previously Active + Year	**8**	**-580**	**1176**	**1.65**	**0.04**
Height + Productivity + Direct Neighbours + Previously Active + Year + Overhang	**8**	**-580**	**1176**	**1.77**	**0.03**
Height + Depth + Productivity + Direct Neighbours + Previously Active + Year	**8**	**-580**	**1176**	**1.97**	**0.03**
Height + Productivity + Neighbours + Previously Active + Year	7	-581	1177	2.09	0.03
Height + Productivity + Previously Active + Year + Overhang	7	-581	1177	2.09	0.03

df –Degrees of freedom, logLik – Model’s loglikelihood value, *wi* – Akaike weight


Standardized probability of success
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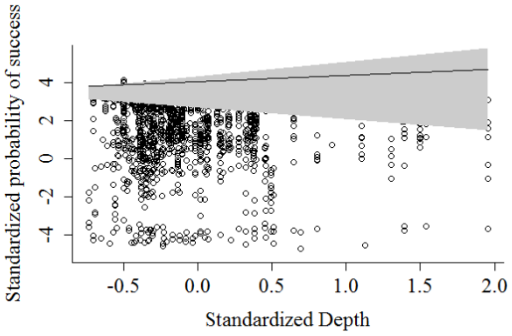
-2
0
2
4
-0.5
0.0
0.5
1.0
Standardized Height


Standardized probability of success
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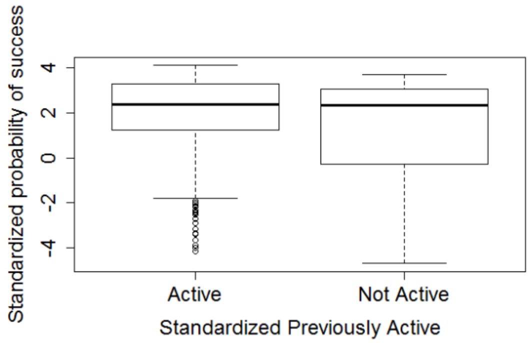
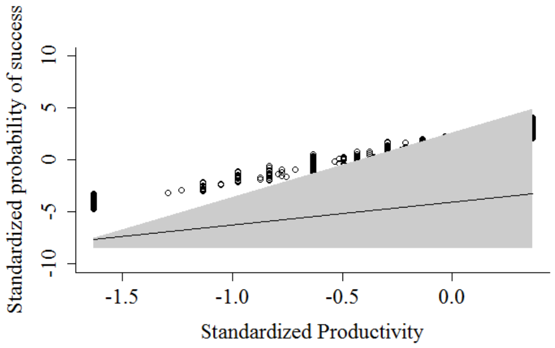
-2
0
2
4
-0.5
0.0
0.5
1.0
1.5
2.0
Standardized Depth


Standardized probability of success
-4
-2
0
2
4
Active
Not Active
Standardized Previously Active


Standardized probability of success
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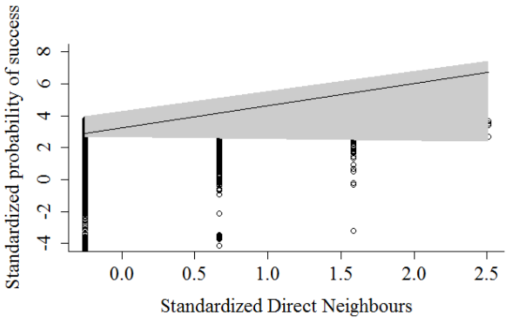
-5
0
5
10
-1.5
-1.0
-0.5
0.0
Standardized Productivity


Standardized probability of success
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-2
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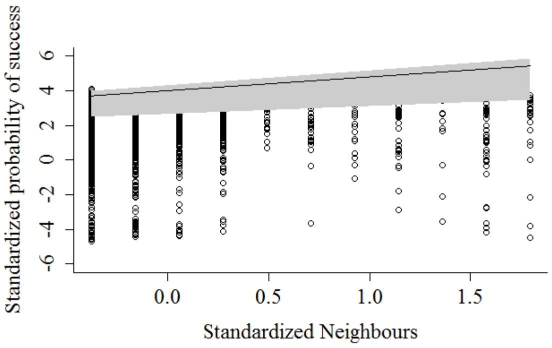
2
4
6
8
0.0
0.5
1.0
1.5
2.0
2.5
Standardized Direct Neighbours


Standardized probability of success
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-4
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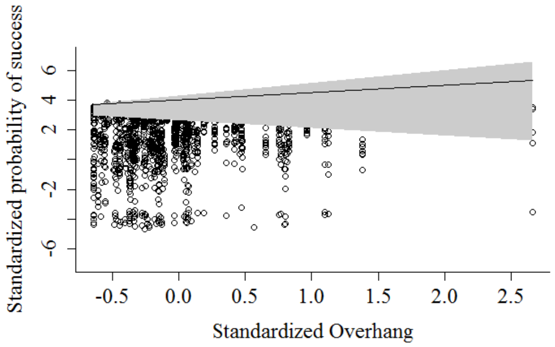
0
2
4
6
0.0
0.5
1.0
1.5
Standardized Neighbours


Standardized probability of success
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2
4
6
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
Standardized Overhang

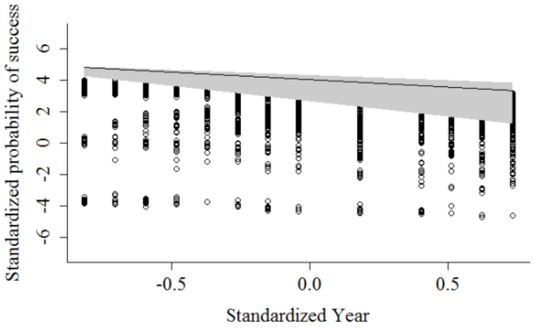
Standardized probability of success
-6
-4
-2
0
2
4
6
-0.5
0.0
0.5
Standardized Year

Fig. 4.4 Model-averaged estimates (± 95 % confident intervals) of top variables from the generalized linear model showing the probability of a nest being successful (n = 1767) based on cliff characteristics and neighbour requirements at the Msikaba Cape Vulture colony, Mkambati Nature Reserve, Eastern Cape Province, South Africa. No data were collected in 2009 or 2011.

Table 4.4 Model-averaged coefficients (with shrinkage) for predicting Cape Vulture breeding success (n = 1767) at the Msikaba colony. Model parameters: Height (height of nest site), Depth (ledge depth), Productivity (total productivity of the nest site), Direct Neighbours (number of direct neighbours), Neighbours (number of ledge neighbours), Previously Active (if the nest was active the previous year), Overhang (ledge depth of the overhang of the nest site), and Year.

					Confidence intervals		
Parameter	**Estimate***	**SE**	**Adjusted SE**	**z**	**2.5%**	**97.5%**	**RI**
(Intercept)	1.92	0.12	0.12	15.4	1.67	2.16	-
Previously Active = No †	-0.31	0.20	0.20	1.56	-0.68	-0.00	0.89
Height	0.18	0.17	0.17	1.01	-0.06	0.56	0.71
Depth	0.00	0.05	0.05	0.06	-0.30	0.37	0.08
Neighbours	0.00	0.06	0.06	0.16	-0.23	0.43	0.09
Direct Neighbours	0.22	0.19	0.19	1.12	-0.05	0.63	0.76
Productivity	3.53	0.21	0.21	16.6	3.11	3.94	1.00
Year	-0.66	0.17	0.17	3.98	-0.98	-0.33	1.00
Overhang	0.00	0.06	0.06	0.13	-0.26	0.43	0.09

* Effect sizes have been standardized on two SD following Gelman (2008).

† Previously Active = Yes for the preceding year was the reference category.

4.3 Discussion

Nest site occupancy and breeding success of the Msikaba Cape Vulture colony were influenced by both cliff characteristics and nest density. Our results supported our predictions, that nest sites were influenced by height, ledge depth, overhang, and proximity of nest sites. The Cape Vultures were occupying nest sites that had greater protection from the elements and predators and were located near conspecifics, supporting the anti-predatory hypothesis for colonial breeding. The physical cliff characteristics were less important in determining breeding success, but proximity of nests was relatively important.

Evidence was also found that supported the ‘win-stay, lose-switch’ nest site occupation strategy in the Cape Vulture. The positive relationship between years of occupation and breeding success has been observed at other Cape Vulture colonies (Vernon *et al.* 1984, Borello and Borello 2002) and other *Gyps* vulture species (Fernandez *et al.* 1998). However, without tagged individuals it is difficult to discern if the sites are optimal or if the birds are experienced. Preliminary analysis suggests that there are optimal sites. As part of another study, 35 individuals were captured from the Msikaba Cape Vulture colony in 2012 and 2013 (Pfeiffer *et al.* 2015). All individuals were given a unique patagial tag alpha-numerical number that could be viewed by an observer when the vultures were on the breeding cliffs. Out of 14 tagged vultures which were observed to have bred more than one year at the colony, only 2 (14 %) switched nest sites. One of the marked vulture pairs failed and then switched nests sites, while the other vulture was successful at both the new and old nest site. The new nest sites were located on the same cliff formation as the old nest site, suggesting loyalty to familiar surroundings or beneficial information-sharing neighbours supporting both the anti-predatory and food resource hypotheses.

Proximity of neighbouring nests measured as number of direct neighbours was important for predicting breeding success. However, only 75 out of 1767 breeding attempts had two or more direct neighbours and these nests were located only on four cliff formations. This suggests that the Cape Vulture has higher breeding success when nesting in high density areas with conspecifics. Again this supports the anti-predatory hypothesis. Although the horizontal space on the ledges at the Msikaba colony was restricted and could only facilitate up to three direct neighbours, nests on the interior had the highest breeding success. This is similar to the sea level colonies of albatross, where there was a higher breeding success in the interior of the colony, where predation from skuas and petrels was lower (Forster and Phillips 2009). It is possible that Cape Vulture colonies need to maintain a certain density in order to successfully defend against predators. If Cape Vultures continue to decline, smaller breeding colonies may experience declines in breeding success and then abandonment. These desertions would cause range contractions and concentrate breeding attempts at only the biggest colonies. Few large breeding colonies would increase vulnerability to threats. A single mass poisoning incident near one of these remnant breeding colonies could further increase the likelihood of extinction (Ogada *et al.* 2015). Even small scale fatalities from power line infrastructure, persecution, and wind farm collisions would be amplified if large numbers of vultures are concentrated in one area. Furthermore, large breeding colonies would increase competition for food resources and contribute to greater foraging ranges exposing vultures to numerous threats (Corman *et al.* 2016). Reducing the number of breeding colonies may also constrict gene flow and produce a genetic bottleneck, which could further accelerate the decline of the species (Bonnell and Selander 1974).

Of the physical cliff characteristics, ledge overhang was not very significant in either model. The presence of an overhang/rocky shelter had no effect on the breeding success of *Gyps* vultures in Spain (Fernandez *et al.* 1998). Furthermore, the majority (72 % or n = 169) visible occupied nests on the main face of the Colleywobbles Cape Vulture colony did not have an overhang (Vernon and Piper 1991). Since Cape Vultures breed during the dry season, overhanging ledges above the nests sites might not be needed to protect against the elements, furthermore a large overhang might prohibit manoeuvrability. As predicted, smaller ledge depths and higher elevations of nest sites were selected. Similarly, most of the nests at Colleywobbles had two cliff walls surrounding the nest (48 % or n = 113) and a ledge depth (44 % or n = 104) that allowed vultures to land only on one side of the nest (Vernon and Piper 1991). Ledges that were approximately 1.0 m and nest sites at 180 m a.s.l. were selected with a higher probability. The cliff formation that had the greatest ledge depths (‘Seaview’, mean = 3.26 ± 0.84 m) was selected highest in 2002 (n = 9), but by 2015, occupation of the cliff dropped dramatically (n = 1). During this period, occupation of other cliff formations increased. It is possible that the first few years of consistent monitoring observed the colonization of the cliffs of the Msikaba River, where vultures concentrated until they found more ideal nest sites. These results highlight the adaptability of the species to relocate to new nesting locations; an important trait if breeding colonies are disturbed.

Breeding success of Cape Vultures was influenced by year, which highlights the effects of seasonal variation and observer bias. After the main observer’s death in 2009, monitoring duties fluctuated with different parties, which could contribute to the negative trend observed. Alternatively, variation in the availability of food resources and changes in seasonal weather patterns could have caused the differences observed with time. With climate change scenarios there are increased drought periods and increased extreme temperature incidences, which is another possibility for the trends observed (Easterling *et al.* 2000). Although the number of breeding attempts and successful breeding attempts increased during the study period, the overall breeding success of the colony has decreased which is a concern. An increase in the number of inexperienced pairs could be an additional possible explanation for this trend (Mundy *et al.* 1992).

Our study provides support that the endangered Cape Vulture occupies nest sites based on cliff characteristics, neighbour requirements, and uses the win-stay, lose-switch strategy. As Cape Vultures are long lived, generally living over 20 years, the data set represents a relatively short period of the vulture’s biology. Continuation of breeding success monitoring at the Msikaba Cape Vulture colony will strengthen the current data set and can be used to further investigate the observed trends. Methods used in the current study can be applied to other Cape Vulture breeding colonies and results can be compared to gain a clearer picture of Cape Vulture nest site occupancy and their effects on breeding success. Current conservation planning strategies include placing no-go buffers around Cape Vulture breeding colonies and roost sites to prevent wind turbine development and hazardous power line construction from occurring in order to prevent vulture fatalities (Retief 2013). Due to the remote locations of breeding colonies in areas that are logistically impossible to survey on the ground, it is highly likely that some breeding colonies have not been documented or protected. Desktop studies can identify potential survey areas that have ledges that are at least 1.0 m deep, cliffs and screes that are at least 180 m tall, and the preferred aspect, which is opposite of the prevailing wind during the vulture breeding season (Brown and Piper 1988). If the current Cape Vulture population declines continue to occur, reintroduction efforts may have to be considered and our results can be used to reassess the nesting suitability of historical breeding colonies before re-establishing breeding colonies.

4.4 Acknowledgments

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CHAPTER 5:

Threatened at home: Collision risk of endangered vultures to wind turbines is highest at roost sites and breeding colonies

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5.1 ABSTRACT

An increase in global energy consumption has created a demand for renewable energy, particularly in developing countries. Investment in these resources can aid in a country's goals to reduce carbon emissions. Some renewable energy installations such as wind turbines can have severe impacts on wildlife populations, especially threatened species. Of particular concern are endangered raptor species, which are known to experience detrimental impacts from collisions with wind turbine blades. Collisions are strongly linked to flight height patterns, yet are not well-understood for many raptor species. Our aim was to investigate how factors such as topography, wind speed, distance from conservation priority sites (roost sites, breeding colonies, and supplementary feeding sites) influence the flight behaviour of the endangered Cape Vulture (*Gyps coprotheres*). To investigate these relationships, we used high resolution tracking data from the Eastern Cape Province, South Africa, where wind farms are proposed. Locations recorded from GPS transmitters fitted on vultures were used to identify roost sites using a change point state-space model. Two predictive models were created; 1) a species distribution model to determine the probability of vultures flying in the study area and 2) a distribution model to estimate the probability of vultures flying at risk height. Distance from roost site was considered the most important predictor variable. Probability values increased exponentially closer to breeding colonies and roost sites. The models created can refine conservation buffers around priority sites. Our results can be used as a tool in environmental risk planning for proposed wind farms.

Keywords: conservation, state-space model, risk assessment, movement ecology, vulture

5.2 Introduction

The rate at which wind turbines have been installed has increased globally in the past few decades (Saidur *et al.* 2011). As wind energy does not generate greenhouse gases nor radioactive waste and uses less water than other energy production methods, there is an international demand to increase the amount of this ‘green’ energy (Leung and Yang 2012). This demand caused wind power to be the fastest-growing source of electric power generation globally (USEIA 2011). However, wind turbines can have undesirable impacts on the landscape and wildlife (Leung and Yang 2012). Numerous fatalities have been recorded at wind turbine sites across a wide range of taxa either directly (e.g. collision) with birds (Barrios and Rodríguez 2004, De Lucas et al. 2008b, Smallwood and Thelander 2008, Carrete et al. 2012, de Lucas et al. 2012, Loss et al. 2013) or indirectly (e.g. barotrauma, an injury caused by a change in air pressure) in bats (Kunz et al. 2007, Arnett et al. 2008, Doty and Martin 2013, Bennett and Hale 2014). The causes of raptor fatalities range from low visibility, creation of foraging and perching areas and placement of turbines in areas which raptors exhibit lower flight heights, however much remains unclear (Smallwood et al. 2009, Katzner et al. 2012, Martin et al. 2012). Although a number of mitigation strategies have been developed (de Lucas et al. 2012, Bennett and Hale 2014), the most widely proven method to prevent wildlife mortalities is placement of wind turbines in areas where risks to biodiversity are lowest (Marques *et al.* 2014). Predicting low risk areas has been determined for a number of species at the pre-construction phase with species distribution models (SDMs,(Belaire et al. 2014, Reid et al. 2015, Vasilakis et al. 2016). There is an urgent need to guide wind energy development with systematically produced maps of high risk areas for already sensitive species before irreversible declines, and possibly extinctions, occur (Rushworth and Krüger 2014, Vasilakis et al. 2016).

Old World vulture species are particularly susceptible to wind turbine collision because of their difficulty in detecting the hazardous blades (Martin *et al.* 2012). Moreover, these vulture species are already threatened from multiple anthropogenic threats (Ogada et al. 2012, Ogada et al. 2015). Irreversible damage to vulture populations could lead to the loss of ecosystem services, such as carcass disposal and nutrient recycling (Sekercioglu 2006). The loss of these services was estimated to release 77 344 metric tons of CO_2 into the environment and cost around $50 million in insurance payments in Spain per year (Morales-Reyes et al. 2015). Research regarding wind energy installations and its impact on the environment in Africa is limited (Doty and Martin 2013, Rushworth and Krüger 2014, Reid et al. 2015). This lack of knowledge, plus the notion that environmental impact assessments in sub-Saharan Africa are weak, can further accelerate the potential damages to wildlife and ecosystem services (Kakonge 2006).

Flight patterns of raptors are known to be influenced by social cues, soaring conditions, temporal variables, food resources, distance to nest sites, and topographical features (Avery et al. 2011, Carrete et al. 2012, Spiegel et al. 2013, Cortés-Avizanda et al. 2014, Kane et al. 2014, Reid et al. 2015). To identify high risk areas for wind turbine sensitive species, spatially important variables can be incorporated into a SDM to produce maps that can be used for wind energy installation (Katzner et al. 2012, Reid et al. 2015). For example, raptors use ridgetops and slopes more than expected and fly lower over these topographical features than others (Katzner et al. 2012, Miller et al. 2014, Rushworth and Krüger 2014). Raptors fly slower and lower when exposed to high cross winds (Spaar and Bruderer 1996, Shamoun-Baranes et al. 2003).

Of particular significance for management purposes is estimating and verifying the size of buffers placed around conservation priority areas such as roost sites and breeding colonies by investigating the effects these sites have on the vultures' flight patterns. The justification of buffer sizes (20 km for roosts and 40 km for breeding colonies) has previously been based on empirical information, such as the energy budget of breeding vulture pairs, movement data from a single Cape Vulture and observations at different distances from breeding colonies (Ruxton and Houston 2002, Boshoff and Minnie 2011, Retief et al. 2013). As this evidence is biased to breeding colonies, more information is needed to justify the extent of buffers around roost sites. Vulture roosts are used during both day and night as sleeping localities, areas to exchange social information, and resting places until flying conditions are ideal (Mundy et al. 1992, Dermody et al. 2011). Identification of roost sites without telemetry data is difficult, due to the extent of the vulture's foraging area, number of sites used and infrequency of use (Phipps et al. 2013). Using tracking data with a high GPS fix frequency (every 15 min.) may help in identifying roost sites (Beyer et al. 2013).

We studied the flight behaviour of Cape Vultures in order to; a) rank the significant factors that influence the Cape Vulture's above ground level (AGL) height and use this information to b) create SDMs to identify low collision risk areas for the Cape Vulture in the Eastern Cape Province of South Africa. We predicted that ridges/slopes, high wind speeds, and proximity to feeding sites, breeding colonies, and roost sites would increase the probability of vultures flying at risk height. The final SDMs of collision probabilities would help identify areas of suitable and sustainable wind energy installation with the least impact on Cape Vulture populations.

5.3 Materials and methods

5.3.1 Study Area

The Eastern Cape Province of South Africa is an area that is suitable for wind energy development (upwards of 20 wind energy facilities proposed, Fig 1), because of a high average wind speed, rolling topography, and access to the necessary support infrastructure (Smallie 2013, 2014, WASA 2014). The major biomes in the study area are the Indian Ocean coastal belt, savanna and grassland (Mucina *et al.* 2006). The study area contains a number of large-bodied grassland specialist birds such as bustards, korhaans, storks, and cranes. Raptors that are of conservation concern include the Southern African critically endangered Bearded Vulture (*Gypaetus barbatus*) population , the Cape Vulture, Verreaux's (*Aquila verreauxii*) and Martial (*Polemaetus bellicosus*) eagles, and migratory harriers and buzzards (Smallie 2013, 2014).

5.3.2 Focal Species

The Cape Vulture is a large bodied bird (average weight = 9 kg), is heavily reliant on thermals, ranges widely, is a central placed forager during the breeding season, and may even participate in partial migrations (Mundy et al. 1992, Boshoff et al. 2009a, Herrera-Alsina et al. 2013, Pfeiffer et al. 2015). Additionally, conservation priority areas such as breeding colonies for the Cape Vulture are relatively easy to identify because of the gregarious nature of the species.

Recently, the Cape Vulture has been up-listed to Endangered because 50 % of the population has declined over three generations (Allan 2015). The total Cape Vulture population is estimated at 4700 pairs (9400 mature individuals), which breed communally on cliff faces (Mundy et al. 1992, Allan 2015). The species is endemic to southern Africa, ranging from South Africa to Angola and Mozambique; the smallest distribution of any Old World vulture species (Mundy *et al.* 1992). The Eastern Cape Province supports about 2000 Cape Vultures, which is approximately 20 % of the global population (Boshoff *et al.* 2009b). There are 20 known Cape Vulture breeding colonies found within the study area, the largest being Colleywobbles Important Bird and Biodiversity Area (IBA), which can annually contain upwards of 200 breeding pairs (Boshoff and Vernon 1980, Boshoff and Minnie 2011).

5.3.3 Vulture Captures and GPS Deployment

To avoid a spatially clumped data set, we used birds from four distinct locations. Overall, nine Cape Vultures were equipped with Global Positioning System (GPS) transmitters between 2012 and 2015 (Table 5.1). Eight vultures were captured using walk-in cage traps: three at Mkambati Nature Reserve (31° 18' S, 29° 55' E) in the north-eastern part of the Eastern Cape Province, three at Oribi Gorge Nature Reserve (30° 39' S, 30° 15' E) in the southern part of the KwaZulu-Natal Province, and two at Elliot in the Eastern Cape Province midlands (31° 21' S, 27° 51' E). A ninth Cape Vulture was rehabilitated following an acute poisoning incident and released in the Maloti-Drakensberg Park in the KwaZulu-Natal Province (29° 23' S, 29° 40' E). Vulture captures were approved by the ethics committee of the University of KwaZulu-Natal and executed under Threatened or Protected Species (TOPS) permits granted by the Department of Environmental Affairs (TOPS Permit Numbers: 05052, 27273). The transmitters were fitted to Cape Vultures using backpack and pelvic harnesses made from Teflon Ribbon (Bally Ribbon Mills, Bally, Pennsylvania, U.S.A.). All harnesses contained a ‘weak link’; a loop of Teflon sewn together with perishable cotton thread (Fig. S5.1). Over time, the weak link deteriorates and the harness and transmitter fall off unaided (Krüger *et al.* 2014). Three different transmitter types were used (Microwave Telemetry Inc. Maryland U.S.A., e-obs digital telemetry, Gruenwald, Germany, and Cellular Tracking Technologies (CTT), Somerset, PA, U.S.A.), varying in the number of location fixes per day. All transmitters recorded altitude with a vertical error of less than or equal to 22.5 m (Lanzone et al. 2012, Microwave Telemetry Inc. 2015). Data were acquired either by satellite download (Microwave Telemetry), base station (e-obs) or transmitted on the GSM network (CTT).

Table 5.1 Information on the nine individual Cape Vultures (*Gyps coprotheres*) with GPS transmitters used for analysis.

Vulture ID	Age	GPS transmitter type	Time Period Monitored	Capture location	Total presence points	1 hour Sub set	Total Flying Points	Flying points at risk height	Flying points above risk height
N103	Juvenile	e-obs	01/04/2015 – 30/06/2015	Oribi Gorge NR, KZN	457	160	14	5	9
N110	Juvenile	e-obs	01/03/2013 - 31/05/2014	Oribi Gorge NR, KZN	27,773	3,090	276	66	210
N134	Juvenile	e-obs	01/03/2013 – 31/10/2013	Oribi Gorge NR, KZN	39,474	1,529	23	8	15
N157	Adult	Microwave	04/09/2013 – 11/05/2014	Rehabilitated, Maloti Drakensberg Park, KZN	2,352	2,352	342	127	215
O31	Adult	CTT	01/05/2015 – 30/07/2015	Elliott, EC	7,405	595	60	33	27
O32	Adult	CTT	30/04/2015 – 03/06/2015	Elliott, EC	5,732	197	39	11	28
X023	Adult	CTT	01/04/2013 – 31/01/2015	Mkambati NR, EC	10,404	2,998	1,753	485	1,268
X027	Adult	CTT	03/12/2012 – 19/12/2013	Mkambati NR, EC	11,187	2,654	573	233	340
X042	Adult	CTT	01/12/2012 –	Mkambati NR,	9,346	2,519	451	153	298

			16/03/2014	EC					
Totals					114,130	16,094	3,531	1,121	2,410
Means					12,681	1,788	392	125	268

Minimum and maximum flying points are in bold. NR = Nature Reserve, EC= Eastern Cape Province, KZN = KwaZulu-Natal Province.

Fig. S5.1 Detail of the weak link of the GPS transmitter harness. Teflon® is sewn together using dental floss or cotton thread.

5.3.4 Spatial Data

To investigate the factors that may influence Cape Vulture AGL flight, predictor variables were chosen based on the ecology of the species (Table S5.1). Predictor variables were topography, wind speed, distance from nearest breeding colony, supplementary feeding station, and roost site. Topography was obtained from ten landforms calculated from 10 m x 10 m digital elevation models (DEMs) using the Jenness topographic index (Jenness 2006, Rushworth and Krüger 2014), which was reduced to four categories: 1) ridges, 2) midslopes, 3) plains, and 4) valleys (Table S5.2). The topography dataset was resampled to obtain the same extent and cell size as the other predictor variables using the nearest neighbour algorithm in ArcGIS. Average wind speed (ms^{-1}) was collected on a 250 m x 250 m grid by the Wind Atlas of South Africa (WASA 2014). Wind speed information was only available for part of the Eastern Cape Province. Cape Vulture breeding colonies were identified from Boshoff and Minnie (2011) and verified during the 2014 Cape Vulture breeding season. The Euclidean (straight-line) distance from nearest breeding colony was calculated. Distance from nearest vulture feeding site was calculated from the registry of sites for the Eastern Cape and KwaZulu-Natal Provinces (EWT and Ezemvelo KZN Wildlife unpublished data).

Table S5.1 Grid size and data sources for the predictor variables of the risk assessment models for Cape Vultures (*Gyps coprotheres*) in the Eastern Cape Province, South Africa.

Predictor variable	Grid size	Data source
Average wind speed (ms^{-1})	250 m x 250 m	Wind Atlas of South Africa (WASA)
Distance from nearest vulture feeding site (km)	250 m x 250 m	EWT and Ezemvelo KZN Wildlife unpublished database
Distance from nearest Cape Vulture breeding colony (km)	250 m x 250 m	EWT and Ezemvelo KZN Wildlife unpublished database
Distance from nearest Cape Vulture roost site (km)	250 m x 250 m	Created
Topography	250 m x 250 m	Reclassified using Jenness topographic index

Table S5.2 Topography reclassification for the topography predictor variable for use in species distribution models for the Cape Vulture (*Gyps coprotheres*) in the Eastern Cape Province, South Africa.

Original classification	Reclassification	Landform type
1	4	Canyons, deeply incised streams
2	2	Midslope drainages, shallow valleys
3	1	Upland drainages, headwaters
4	4	U-shaped valleys
5	3	Plains
6	2	Open slopes
7	1	Upper slopes, mesa
8	1	Local ridges, hills in valleys
9	2	Midslope ridges, small hills in plains
10	1	Mountain tops, high ridges

Identification of roost sites required an in depth analysis of the movement data. Using only stationary points to identify roosts could result in bias because the transmitters may fail to record the early morning or evening stationary points. Instead, vulture roosts were identified using a change point state-space model in a cluster analysis setting (Lebret *et al.* 2015). This model uses the animal's orientation and normal velocity between consecutive points to distinguish two different types of movement modes (encamped and exploratory) from GPS data (Morales et al. 2004, Beyer et al. 2013).

During the breeding season, adult vultures will alternate with their partner for foraging trips, which may last a few days to two weeks (Ruxton and Houston 2002). To ensure that both the foraging trips and movements associated with nest and chick rearing duties were included, movements were divided into months for each individual.

All tracking data were filtered for technical errors. GPS locations located in erroneous UTM zones or had a poor fix quality (HDOP > 10 or type of fix < 3) were removed. All date and time duplicates were also removed. Distances travelled between consecutive points (step lengths) and turning angles were calculated using the adehabitatLT. Step lengths and turning angles between consecutive points were found to be related with individual/transmitter frequency (step length (Kruskal-Wallis $H_{(9)} = 19\ 164$, $p < 0.05$) and relative angle (Kruskal-Wallis $H_{(9)} = 20$, $p = 0.02$)), therefore all GPS location data were reduced to 1-hour intervals to match the lowest fix frequency setting. The population was treated equally by standardizing to the lowest fix frequency. After sub-setting, a total of 16 094 points remained from the nine individuals. Both the encamped and exploratory movement modes were identified for all vultures in each month (Morales *et al.* 2004). The exploratory movement mode had long distances (mean = 1.36 km) between consecutive points. In the encamped movement mode, the vultures moved shorter distances (mean = 0.001 km) between consecutive points. Although mean turning angles were similar (around 0°) between the two movement modes, the spread differed and the mean step lengths were drastically different. Relative turning angles, as calculated with the adehabitatLT package, were converted from radians to degrees and plotted using Oriana (Kovach 2011, Calenge 2013).

An active vulture roost was identified by at least two consecutive encamped movement modes less than 1 km from each other as the last points of the day or the first points of the next day for an individual bird. Roosts that were within 5 km from each other were considered the same roost for management planning purposes, and one centre point was used located between these sites. Cape Vultures are known to use the entire length of cliffs for roosting and breeding, and in general cliff faces were not longer than 5 km (Brown and Piper 1988). The Euclidean distance from nearest roost was calculated on a 250 m x 250 m grid using the nearest neighbour assignment of ESRI's Resample tool.

5.3.5 Data Processing

The precision of the DEMs affects the AGL vertical error (Katzner et al. 2012). The highest resolution publically available digital DEMs for South Africa are 30 m x 30 m. To reduce the vertical error encountered, DEMs of a smaller grid size of 10 m x 10 m were created for the study area (Zhang and Montgomery 1994). We used 1:50 000 topographical maps of South Africa with 20 m contour vector data, spot height elevations and river vector data. Contour, height and river data for each quarter degree cell were merged in ArcGIS v.9.3.1 using the ESRI Spatial Analyst's Topo to Raster tool (ESRI 2009).

The error of the 10 m x 10 m DEM was determined by comparing randomly selected known spot height elevations (n = 5237 or 23 %) from the 1:50 000 topographical maps used to create the DEM to the values from the created DEM (Barringer and Lilburne 1997). Absolute values of the difference between the spot heights and DEM values were then used to calculate the RMS Error which was ± 13 m for the 10 m x 10 m DEM. For the current study, the total vertical error was considered to be ± 45.5 m (22.5 m GPS + 10 m interpolation + 13 m RMS Error) (Katzner et al. 2012, Lanzone et al. 2012). Cape Vulture AGL flights of less than 46.0 m were removed to account for the vertical error (Katzner et al. 2012). By removing AGL flights less than 46.0 m, there is a bias towards higher flights but this was considered negligible because the AGL risk area for wind turbine collision is relatively small (Katzner et al. 2012).

The 1-hour tracking data set was filtered to include points above 46.0 m and were located in areas where average wind speed information was available (n = 5271). Flight points were categorized by both speed and flight height. AGL flights were calculated by subtracting the elevation value from the 10 m x 10 m DEM from the GPS altitude reading. GPS points with an instantaneous speed greater than 1.5 ms^{-1} (n =2137), or less than 1.5 ms^{-1} with an AGL of over 100 m were considered flight points (n =1394,(Duerr et al. 2012, Phipps et al. 2013). GPS locations with a speed less than 1.5 ms^{-1} and were under 100 m

AGL were removed (n = 1179), leaving a total of 3531 GPS locations were used as presence records (Fig. S5.2).

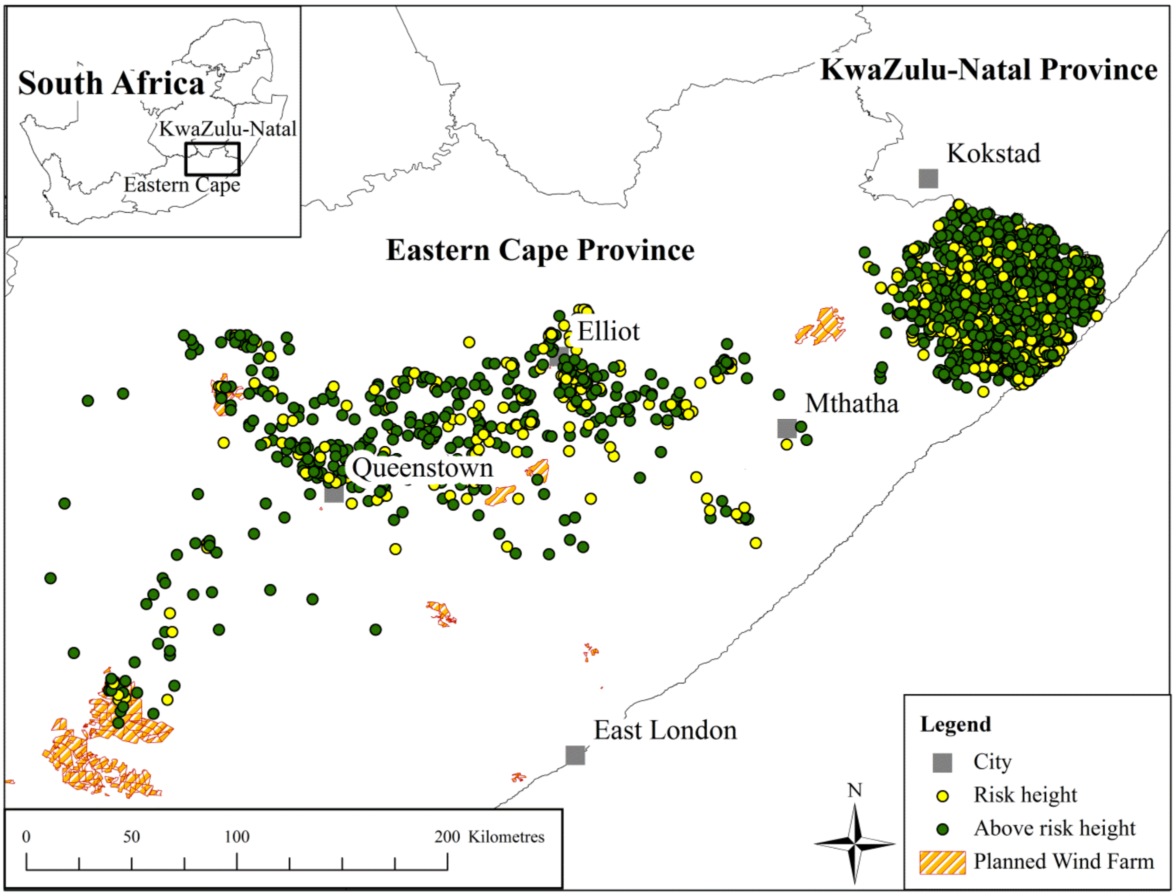


Fig. S5.2 Flying GPS locations of the nine Cape Vultures in the Eastern Cape Province, South Africa. 1,121 flying points at risk height and 2,410 flying points above risk height were used in the creation of the risk flying height and flying distribution model.

All variables were checked for correlation using Spearman's correlation coefficient. Distance from nearest breeding colony and distance from nearest feeding site were highly correlated ($\rho_{10\ 619}$) = 0.79, $p < 0.00$). Distance from nearest feeding site was excluded from the analysis rather than distance from nearest colony because one of the objectives was to assess the spatial influence of breeding colonies to justify buffer sizes. Correlation tests were carried out using R (R Core Team and contributors worldwide 2014).

5.3.6 Cape Vulture Species Distribution Models

Two species distribution models were created to model the probability of Cape Vultures flying in the study area and flying at risk of collision. The first species distribution model was created to determine the probability of Cape Vultures flying in the study area based on the predictor variables. All flying GPS locations of the 1-hour data set, were considered presence points for the presence training model (n =3531) and coded as ‘True’. Although some SDMs can be produced with only presence data, we generated pseudo-absence points to create a more robust model (Reid et al. 2015). Pseudo-absence points were created by randomly selecting GPS locations within 50 km of presence points (n =10 593, 9763 after removed) and were coded as ‘False’. Three times as many points were chosen for the background points based on Wakefield et al. and Reid et al. (2011, 2015). The presence and pseudo-absence points were used to test the fit of different SDM methods by creating training and testing data sets. Evaluation of the SDMs was conducted by dividing the presence data into five random groups using the dismo package in R (Hijmans *et al.* 2013). The model was fitted to four of these random groups (training data) and the fifth was used as test data to predict the distribution. Models were evaluated using presence (n = 706) and background (n = 1819) test data which were randomly selected using the k-fold partitioning (Hijmans *et al.* 2013). Area under the receive curves (AUCs) were used to evaluate the model performance based on the accuracy of predicting the location of the test data. The machine learning random forest SDM method produced the best results for predicting the presence of Cape Vultures. The model was used to predict the probability of a Cape Vulture flying in the study area based on the predictor variables on a 250 m x 250 m grid. The probability map was then projected and displayed in ArcGIS using a colour coded scheme to distinguish between the probability values.

A second species distribution model was produced to estimate the probability of Cape Vultures flying at risk height based on the predictor variables. The presence values from the GPS locations were coded as ‘True’ or ‘False’ based on whether the vultures were flying within risk height of the wind turbine blades. In South Africa, the rotor swept zone is considered to be between 55 m - 185 m (Smallie 2013, 2014). Presence points (n = 1121) for the training data set were locations where the bird was flying at risk height (< 185 m) and were coded as ‘True’. Absence points (n = 2410) for the training data set were GPS locations where the bird was flying above 185 m and were coded as ‘False’. To evaluate the model, testing data sets were created for presence (n = 224) and absence (n =482) points. The model was evaluated by dividing the presence data into five random groups as outlined for the presence SDM (Hijmans *et al.* 2013). AUCs were used to evaluate the SDM. The generalized linear model (GLM) SDM method performed the best. The GLM SDM was used to predict the probability of Cape Vultures flying at risk height based on the predictor variables on a 250 m x 250 m grid across the study area. The probability map was then projected and displayed in ArcGIS using a colour coded scheme to emphasise the differences in probability values across the landscape.

5.3.7 Buffer Size Recommendations

Conservation buffers are often used in environmental risk planning because it is a practical way for engineers and planners to visualize risk, which can be invisible from a biological perspective, especially with a far ranging forager (Pfeiffer et al. 2015). In order to justify the extent of conservation buffers around conservation priority areas, the probability of Cape Vultures flying at risk height and the probability of vultures flying in the area were plotted in relation to distance from roost site and breeding colony. Trend lines with the highest R^2 value were applied to each probability data set (Cameron and Windmeijer 1997). Where the trend lines intersected, indicates a realistic value where risk would be either acceptably low or unacceptably high. From this a recommended value (in kilometres) for buffer size based on roost site or breeding colony was ascertained.

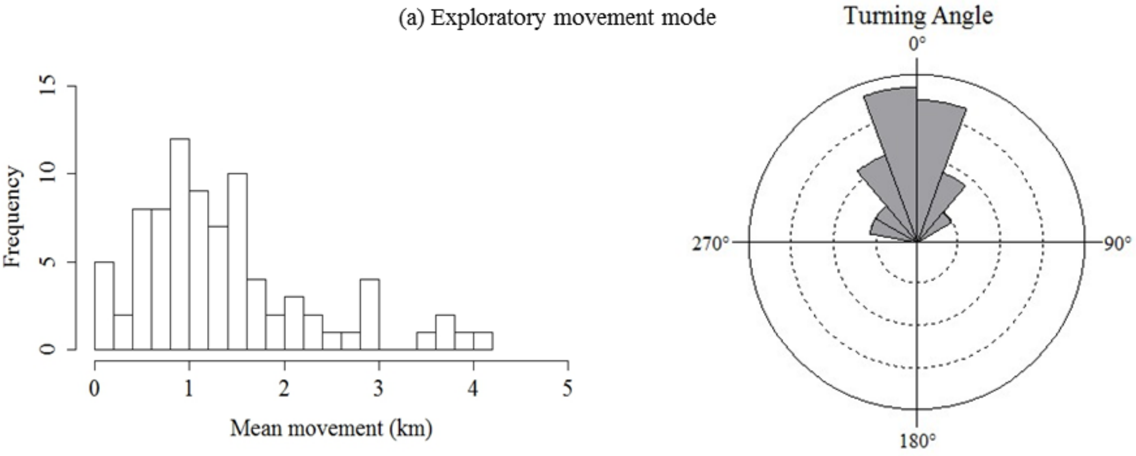
Data analysis was carried out in R ver. 3.1.2 with the following packages: adehabitatLT ver. 0.3.17, Rmixmod ver. 2.0.2, statistical ver. 3.1.2, randomForest ver. 4.6-10, and dismo ver. 1.0-12 (Calenge 2013, Hijmans et al. 2013, Breiman and Cutler 2014, R Core Team and contributors worldwide 2014, Lebret et al. 2015).

5.4 Results

Between 2012 and 2015, the nine Cape Vultures equipped with GPS transmitters provided 114 130 fixes covering an area of 52 576 km^2 within the Eastern Cape Province. Maximum speed calculated was 90.5 kmh^{-1} and maximum flight height recorded was 2205 m above ground level. Using 1 – 2 clusters for the monthly change point state-space model provided the best results (likelihood = -2276,

Fig. 5.1). A total of 159 active roost sites were identified between 2012 and 2015 using the behavioural states identified with the state-space model.

(a) Exploratory movement mode



(b) Encamped movement mode

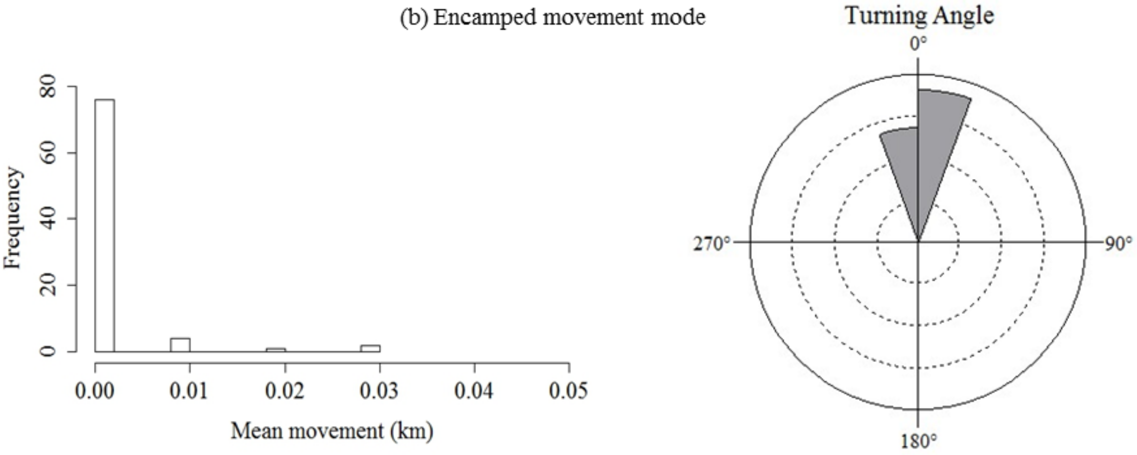


Fig. 5.1 Cape Vulture movement mode classifiers. Frequency distributions of the mean (a) exploratory movement mode and (b) encamped movement mode from all GPS locations of nine Cape Vultures. Mean movement is distance travelled between consecutive points in 1 hour intervals.

Two SDMs were created to rank the spatial predictor variables in regards to the probability of vultures flying in the area and flying at risk height. Using the flying GPS locations and random background points within 50 km of GPS locations, a SDM using the random forest method produced the best results. The model provided the best performance with a value of 0.951 for AUC (Fig. 5.2). Each variable was ranked by the mean decrease in accuracy (Fig. S5.3 Table S5.3). Distance from nearest roost was considered the strongest predictor (mean decrease in accuracy = 77.0), followed by average wind speed (mean decrease in accuracy = 73.6). As the distance from nearest roost site or breeding colony increased, the probability of a Cape Vulture flying in the area decreased (Fig. S5.4). Average wind speed was the second ranked predictor variable. As wind speed increased, there was an increase in the probability that vultures would be present. Topography was considered the least important predictor variable (Fig. S5.4). It was found that the vultures were more likely to fly above ridges and midslopes and less likely to fly over valleys and plains (Fig. S5.4).

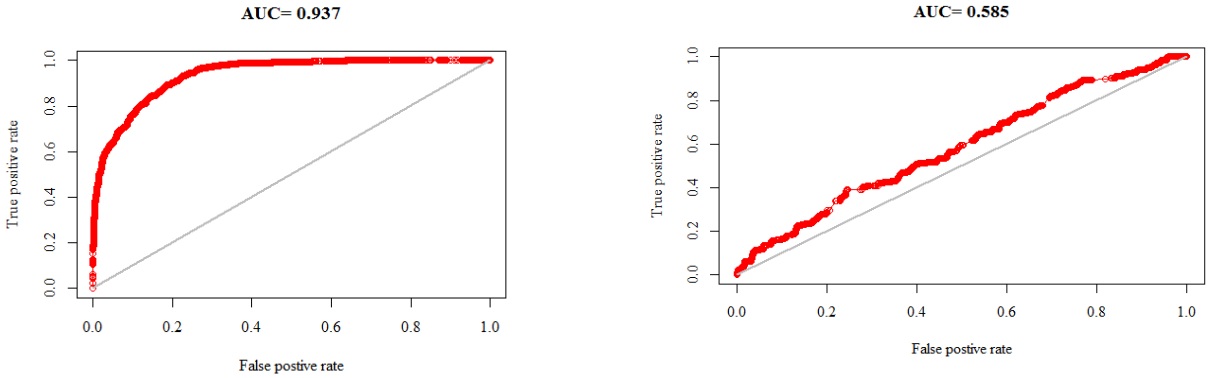


Fig. 5.2 Model evaluations for the species distribution model and the risk flying height model for the Cape Vulture in the Eastern Cape Province, South Africa. (a) Area under the curve (AUC) as a model evaluation for the Cape Vulture flying distribution model for the study area in the Eastern Cape Province. (b) Area under the curve (AUC) as indicator of model performance for the risk flying height model. The risk was identified as the probability of Cape Vultures flying at a height in which they may collide with wind turbine blades.

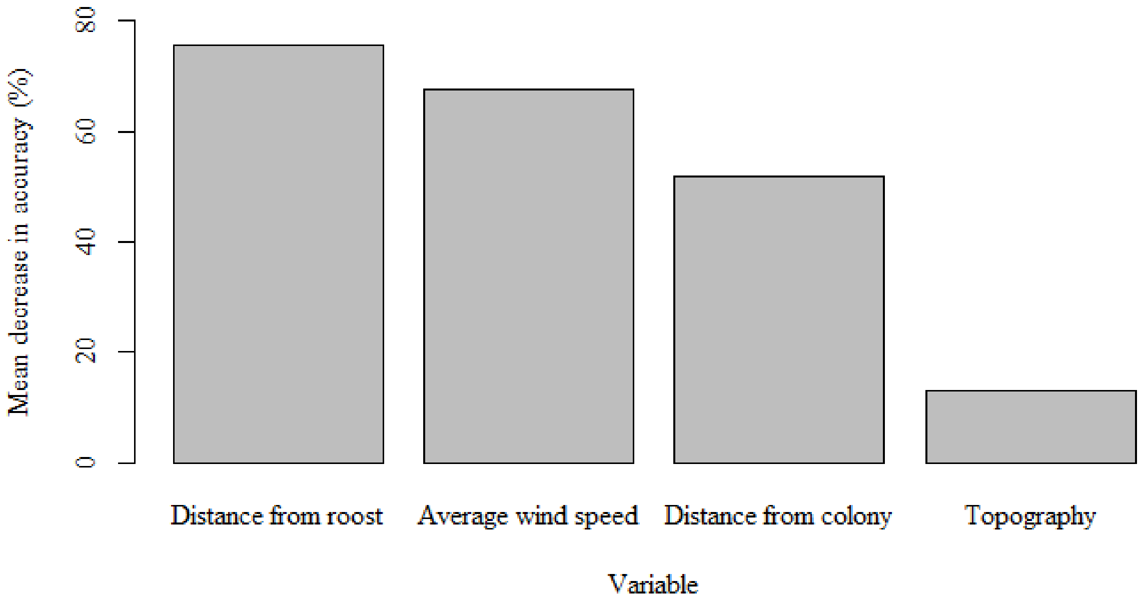


Fig. S5.3 Variable importance plot for the flying distribution model for the Cape Vulture in the Eastern Cape Province, South Africa. Predictor variables ranked in order of their importance. The model predicted where Cape Vultures were more likely to fly based on the predictor variables.

Table S5.3 Variable importance mean square error and node purity values for the flying species distribution model of Cape Vultures for the Eastern Cape Province, South Africa.

Predictor variable	% Mean decrease in accuracy	% Node purity
Distance from nearest breeding colony (km)	59.88	401.32
Distance from nearest roost site (km)	73.04	528.98
Average wind speed (ms^{-1})	69.44	139.32
Topography	30.31	19.24

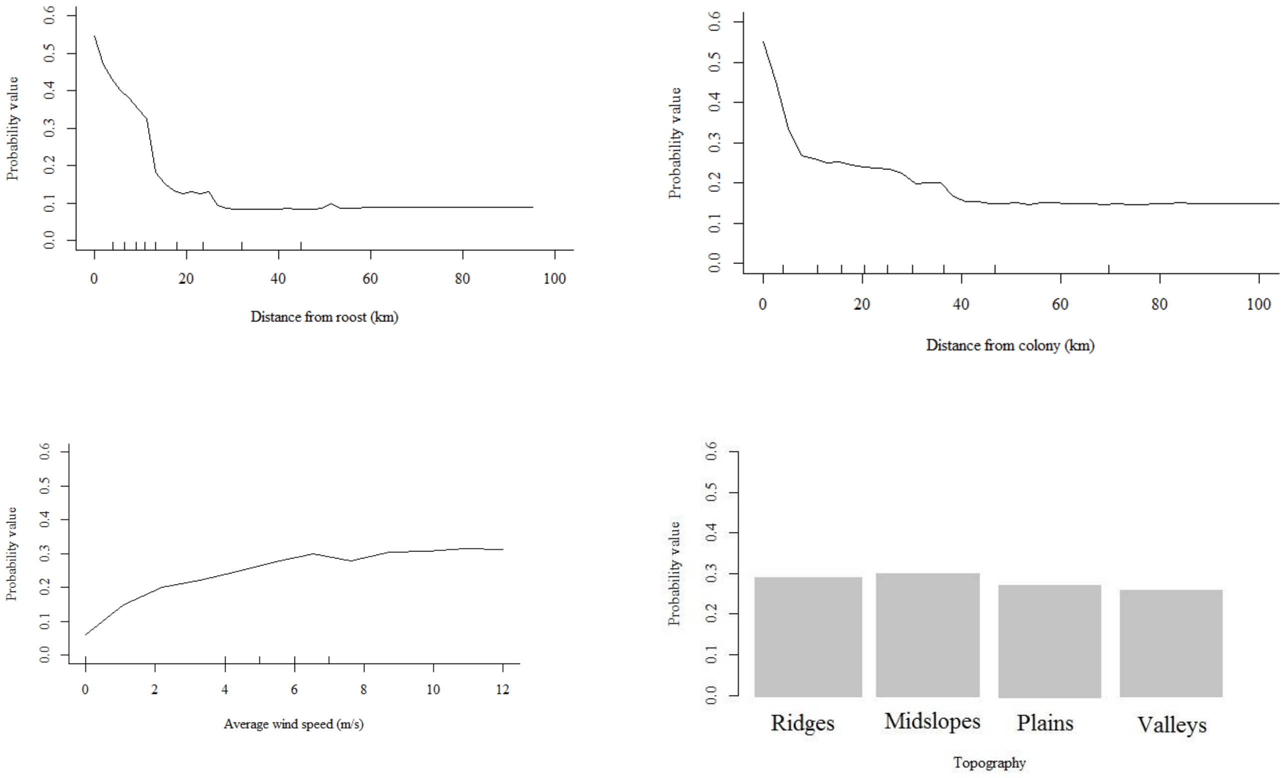


Fig. S5.4 Predictor variable effects plots for the flying species distribution model for Cape Vultures in the Eastern Cape Province, South Africa. Probability that Cape Vultures would be flying based on (a) distance from nearest roost site, (b) distance from nearest breeding colony, (c) average wind speed and (d) topography.

The second SDM identified relationships between the predictor variables and the probability that Cape Vultures would fly at risk height (< 185 m). The GLM method performed the best with a value of 0.614 for AUC (Fig. 5.2). All continuous variables were considered to be strong predictors of determining flight height (Table 5.2). Only one of the topography categories (valleys) was considered a strong predictor ($p < 0.01$). As distance from nearest roost site and breeding colony increased, the probability that vultures would fly at risk height decreased by 3.59 and 1.79 respectively (Table 5.2, Fig.

S5.5). As the average wind speed increased, the probability that vultures would fly at risk height increased by 0.16 (Table 5.2). If a vulture flew over a valley, the probability that it would be flying at risk height decreased by 0.19.

Table 5.2 Variable importance for the risk flight height species distribution model of Cape Vultures (*Gyps coprotheres*) for the Eastern Cape Province, South Africa.

Coefficients	**Estimate**	**SE**	***Z* value**	***P***
Distance from nearest breeding colony (km)	-1.79	0.36	-5.01	< 0.01
Distance from nearest roost site (km)	-3.59	0.89	-4.06	< 0.01
Average wind speed (ms^{-1})	0.17	0.04	4.69	< 0.01
Midslopes	-0.13	0.29	-0.46	0.65
Plains	-0.60	0.81	-0.75	0.45
Valleys	-0.26	0.09	-2.74	< 0.01

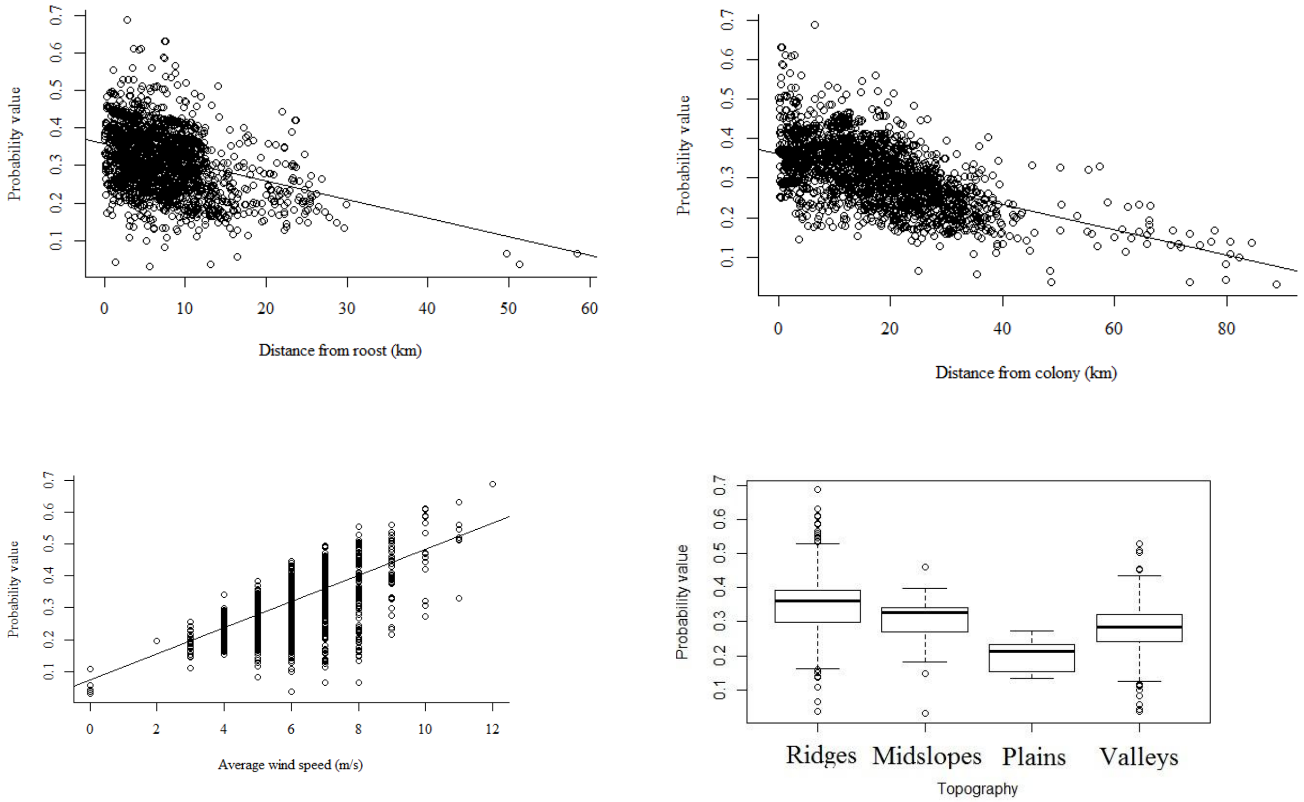


Fig. S5.5 Predictor variable effects plots for the risk height species distribution model for Cape Vultures in the Eastern Cape Province, South Africa. Probability that Cape Vultures would fly at risk height based on (a) distance from nearest roost site, (b) distance from nearest breeding colony, (c) average wind speed and (d) topography.

Two maps were produced that displayed the probability of vultures flying in the area (Fig. S5.6), and the probability of Cape Vultures flying at risk height (Fig. 5.3). The trend lines with the highest R^2 values intersected at around 14 km for the distance from roost site variable in the probability outcome plots (Fig. S5.7). For distance from nearest breeding colony, the trend lines intersected at 16 km (Fig. S5.7).

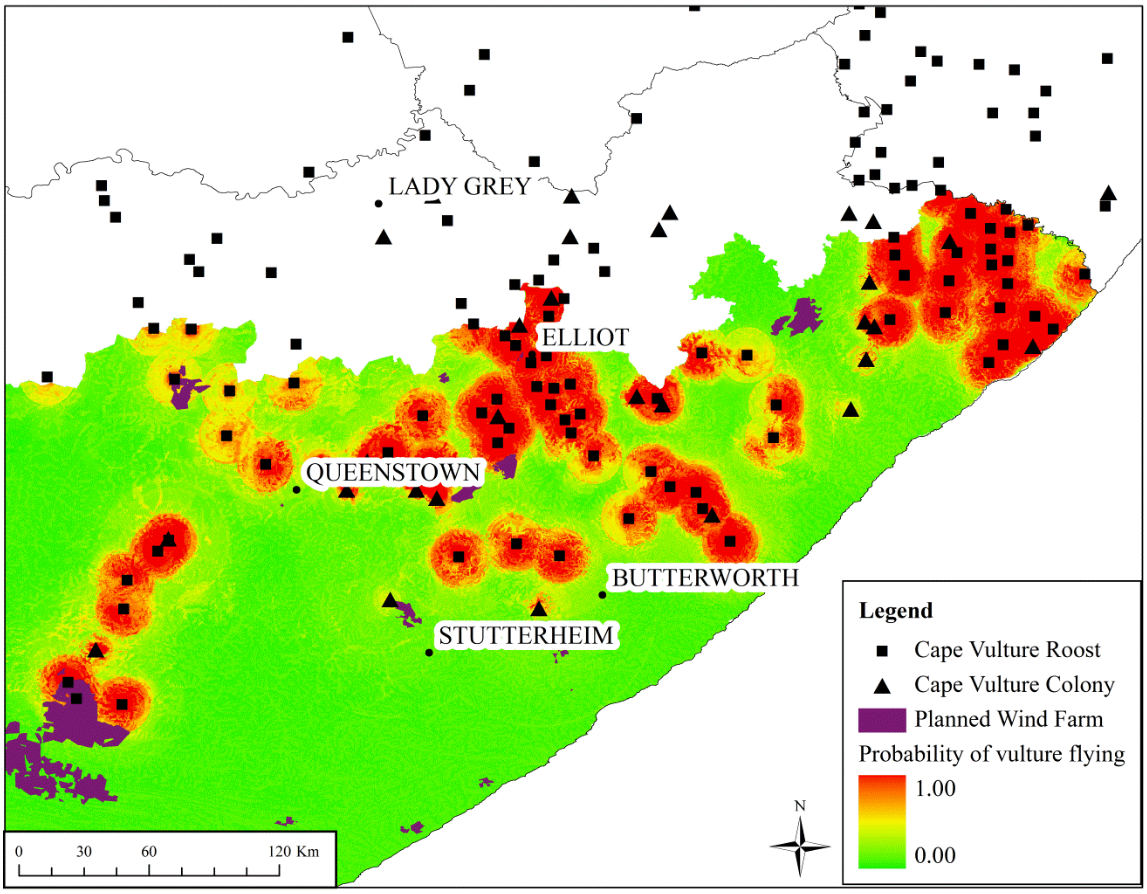


Fig. S5.6 Risk flying height and species distribution maps for the Cape Vulture in the Eastern Cape Province, South Africa. The machine learning species distribution model was used to predict the probability of tagged vultures flying in the area based on the spatial predictor variables (distance from nearest roost site, distance from nearest breeding colony, average wind speed and topography).

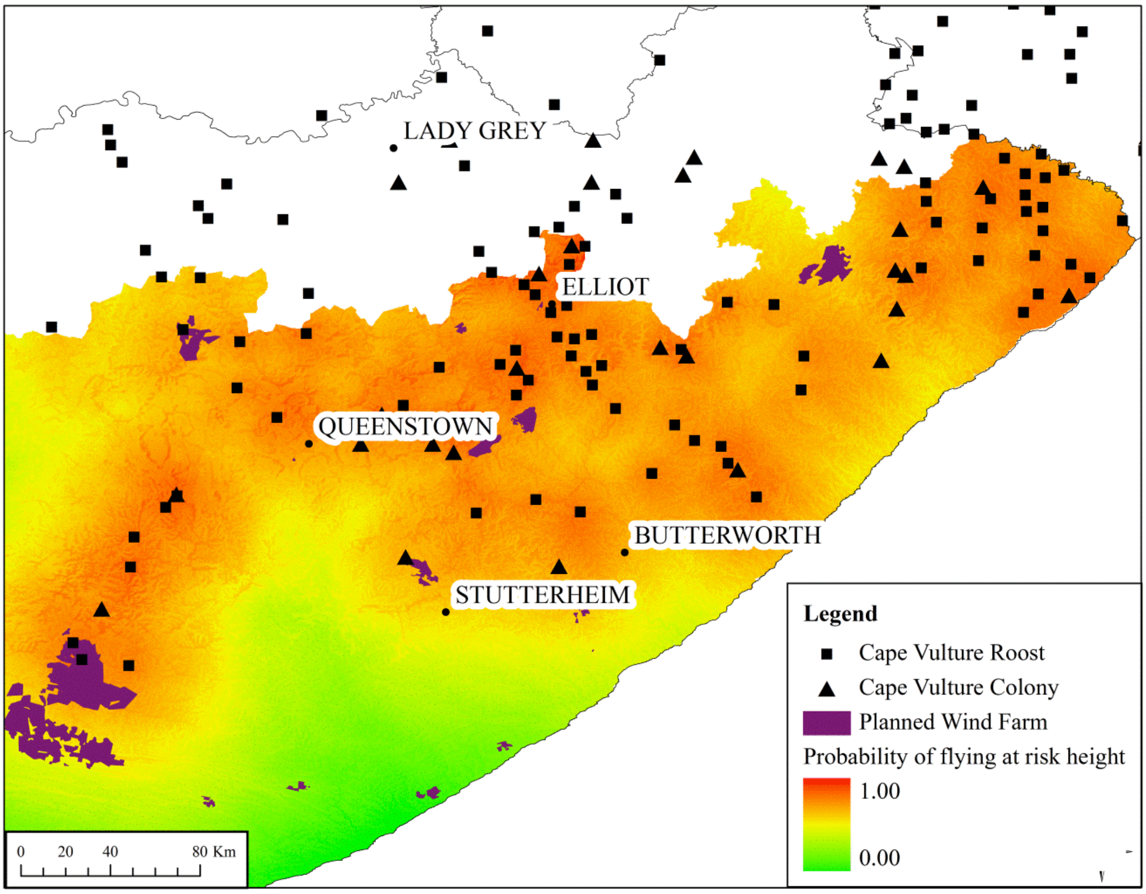


Fig. 5.3 Risk flying height map for the Cape Vulture in the Eastern Cape Province, South Africa. The regression species distribution model displaying the probability of vultures flying at risk height based on the spatial predictor variables. Probability results were not reported for the northern part of the Eastern Cape Province because no data on average wind speed was available.

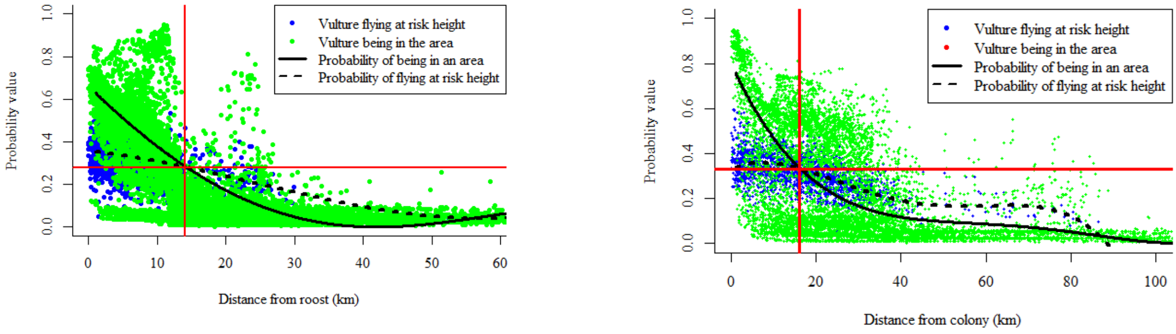


Fig. S5.7 Probability plots to determine the buffer size around Cape Vulture (a) roost sites and (b) breeding colonies. The probability outcomes of the two SDMs were plotted in relation to distance from roost site. Non-linear trend lines were added to each data set based on the best R^2 value. At the intersection of the trendlines, a recommendation for buffer size is given. For roosts sites the recommendation is 14 km and for breeding colonies it is 16 km.

5.5 Discussion

Spatial variables that influenced Cape Vulture AGL flight height were identified and ranked using two SDMs. Distance from nearest roost site was considered the strongest predictor variable. A state-space model was used to identify Cape Vulture roost sites with high resolution tracking data, and highlighted a number of conservation priority sites for this species that were previously unknown. The predicted probability values from the SDMs are useful for identifying vulture/wind turbine conflict areas based on the spatial variables across the study area. Our results can be used in environmental planning to assess the risk a proposed wind turbine development may have on the endangered Cape Vulture.

Our results are similar to other studies which have shown that as distance to a nest site or roost site increased, the collision risk decreased (Carrete et al. 2012, Reid et al. 2015). It was found that Cape Vultures were more likely to fly at risk height over ridges and slopes, which supports the findings of Rushworth and Krüger (2014). A strong positive relationship was found between average wind speed and the probability of flying at risk height. As higher wind speeds make high thermal soaring difficult, vultures could have a higher risk of collision with wind turbine blades because of their lower flight height (Barrios and Rodríguez 2004).

Multiple studies have highlighted that behaviour is a significant variable that should be considered in pre-construction monitoring and post-construction mitigation efforts of wind turbine installation (Barrios and Rodríguez 2004, de Lucas et al. 2008a, Smallwood et al. 2009, Carrete et al. 2012, de Lucas et al. 2012). As roost sites were identified using behavioural data collected from GPS transmitters, our results emphasise the use of behavioural data to supplement spatial variables. Although the mean step lengths corresponded with the definitions of the encamped and exploratory movement modes, turning angles did not adhere to these classifications (Morales *et al.* 2004). Turning angles were more varied with the exploratory movement mode and the turning angles of the encamped movement mode were less variable. This deviation may occur because of the differences in the mechanics of movement between land and aerial animals. A land mammal generally faces the direction it would like to go, whereas soaring raptors rely on circling in thermals to gain altitude and then gliding to the next thermal (Duriez *et al.* 2014). Cape Vultures with transmitters circling in these thermals may have recorded a variety of turning angles with large step lengths.

Supplementary vulture feeding sites are a conservation tool that can be implemented by public and private land managers (Cortés-Avizanda et al. 2016). However, distance from nearest feeding sites was found to be correlated with distance from nearest breeding colony and not used in analysis. The majority of the colonies in the study area are located in communal farmland (Boshoff *et al.* 2009b) and all of the registered vulture restaurants are located in commercial farming areas or protected areas (EWT and Ezemvelo KZN Wildlife unpublished data). It has been found that 'informal' vulture restaurants are present in subsistence farmland; however their locations have not been documented (Pfeiffer *et al.* 2014). The inclusion of distance from nearest feeding site in the adult Bearded Vulture risk height predictive model was not highly significant (Reid *et al.* 2015). There was a relationship observed with non-adults, who had a higher chance of flying at risk height within 100 km of a restaurant (Reid *et al.* 2015). Therefore the absence of this variable may not have affected the results of the adult vultures, but could have influenced the juvenile flight behaviour.

The risk flight height SDM did not perform as well as the presence SDM, this might be due to the small sample size or other local factors (e.g. micro-variation in wind patterns) that were not included in analysis. Although age does effect movement patterns of vultures, in the current study, Cape Vultures of different ages were treated equally due to our small sample size (Mundy et al. 1992). By using vultures from different cohorts, we allowed for a population level risk assessment exercise that outweighed any seasonal migration movements (Boshoff et al. 2009a). During the study, our sample size was further reduced as the majority (55% or n = 5) of the tagged Cape Vultures died. Causes of death were from collisions or electrocutions with power line infrastructure and suspected poisonings. This further emphasizes the need to reduce any negative impacts proposed wind energy installations would have on this already endangered species.

A potential strategy to mitigate impacts of wind energy on vultures is to create conservation buffers around colonies and roosts (Boshoff and Minnie 2011, Retief et al. 2013, Pfeiffer et al. 2015).

The suggested buffer sizes from the current study (14 km for roosts and 16 km for breeding colonies) is smaller than what was found in previous research were adult vultures from the Mkambati Nature Reserve used 50 km around the breeding colony in a higher proportion (Pfeiffer *et al.* 2015). The current study however looked at multiple breeding colonies of various sizes with vultures of different ages. There is evidence from other species that birds from larger colonies forage greater areas than birds from smaller colonies (Corman *et al.* 2016). As Cape Vulture conservation sites are widespread, regional differences are to be expected and using a one-size fits all buffer assumes a homogenous landscape. All significant variables (including temporal and behavioural) that influence raptor flight height should be included in the environmental planning process in addition to our results.

5.6 Conclusion

The probability of Cape Vultures flying at risk of collision with wind turbine blades and being in the area was significantly influenced by distance to nearest breeding colony and roost site. The probability plots identified buffer sizes of 14 km for roosts and about 16 km for breeding colonies. Since roost sites were only identified in areas where tracking data exists, future research is needed to predict roost sites based on suitable roost site characteristics. A model can be created based on spatial predictor variables that identify roost locations. The use of radar will provide a reliable validation by obtaining accurate flight height information, which will help in the successful application of the created SDMs into management plans (Becker 2016). Now that SDMs have been created to estimate collision probabilities at a landscape scale for the Cape Vulture, a colonial species, it can be adjusted to solitary breeding and foraging conservation priority species at the local scale. Pre-construction surveys of potential wind farm sites should make use of telemetry and radar data not only on vultures, but other priority species in an intense local evaluation that investigates the potential losses to all biodiversity and consequentially their ecosystem services. It is only with systematic research and collaboration that the end goal of sustainable renewable energy development in Africa will occur.

5.7 Acknowledgments

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Competing interests: None.

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CHAPTER 6:

Conclusion

6.1 Introduction

Within this chapter, the main research findings are summarized and discussed in relation to the research aims and objectives. Overall management recommendations and directions for future research are presented.

Human population growth and increased energy demands are major threats to the biodiversity essential for effective ecosystem functions (Cincotta et al. 2000, Hansen et al. 2004, McKee et al. 2004). Avian scavengers, specifically vultures, are the most threatened group of birds (Ogada et al. 2012a). Their population declines can have detrimental impacts on the carrion cycle, which is essential for nutrient recycling and potentially minimizing the spread of disease (Beasley et al. 2012, Ogada et al. 2012b). In the absence of vultures, India spent $34 billion on health costs related to high densities of feral dog (*Canis lupus familiaris*) populations (Markandya et al. 2008). Using company sanitation services to dispose of livestock carcasses in Spain was not only expensive, but added thousands of tons of the greenhouse gas CO_2 into the environment per year (Morales-Reyes et al. 2015). It is imperative to halt vulture population declines before such expenses and consequences become common place. In order to create and develop useful mitigation strategies to combat vulture population declines, background information is needed to fill knowledge gaps. This dissertation provides a holistic approach to the conservation and understanding of the Cape Vulture (*Gyps coprotheres*) in an area which was traditionally under researched.

The former Transkei area of the Eastern Cape Province, South Africa, contains about 20% of the global population of the Cape Vulture (Boshoff et al. 2011). However, research in this area was mainly descriptive and called for more in-depth research of this endangered vulture in a non-western agricultural environment (Piper and Ruddle 1986, Boshoff et al. 2009a, Boshoff and Minnie 2011, Boshoff et al. 2011). As the Cape Vulture is relatively common in the subsistence farmland areas of the

Eastern Cape Province, understanding how it persists and survives will help safe guard the species. This study used a holistic approach that included investigations into trends and perceptions of livestock ownership and the role of vultures in subsistence farmland, vulture foraging ranges and habitat use, breeding ecology, and the drivers of vulture flight height and presence. All investigations were theory driven and analyzed using appropriate and innovative methods. Each chapter of this thesis provides new aspects on the ecology of the species and provides management recommendations that can be implemented to prevent further declines.

6.2 Research Findings

Four separate research objectives were created to address issues of Cape Vulture conservation and ecology:

The former Transkei subsistence farmland area of the Eastern Cape Province has a high human density and the persistence of the Cape Vulture is dependent on domestic livestock (Vernon 1998). The attitude of commercial farmers towards vultures has been investigated, and poisoning and persecution were found to be the major threats in these areas (Brown and Piper 1988, Hiltunen 2009). Vulture parts are used in the traditional medicine industry, which was thoroughly examined in order to estimate profits and sales (Mander et al. 2007, Whiting et al. 2011). However, these studies focused on traditional healers and dealers of vulture parts, perceptions of people who live in subsistence land amongst the vultures was lacking. By interviewing community members residing around the Msikaba Cape Vulture colony, we found that the majority of people held positive views of vultures because of the perceived benefits (e.g. cleaner) of vultures (Chapter 2). Type of carcass consumed by vultures was depended on location and management of livestock carcasses was found to be a community made decision (Chapter 2). Poaching for traditional medicine was perceived to be the greatest threat to vultures in the area (Chapter 2). Declines in vulture populations were observed in the more transformed areas, while no change in the population was observed in the least transformed area (Chapter 2).

The second objective was to use movement data to investigate the Cape Vulture's use of subsistence farmland and the degree of movements around the breeding colony. This study was the first to provide evidence with unbiased GPS tracking data that adult Cape Vultures preferred subsistence farmland and did not prefer commercial agriculture (Chapter 3). GPS location data suggests that breeding vultures use an asymmetrical area around the breeding colony with a maximum radius of 52 km (Chapter 3). Although the sample size was relatively small, evidence was provided that Cape Vultures have similar total foraging ranges during the breeding and non-breeding seasons, although use was concentrated in different areas (Chapter 3). Foraging ranges of these individuals were much smaller than vultures from the northern node of the population (Chapter 3)(Bamford et al. 2007, Phipps et al. 2013).

The third objective of the research was to explore physical cliff characteristics and density effects on nest site selection and breeding success. Breeding success was monitored for over 15 years at the Msikaba Cape Vulture colony, yet no in-depth study has investigated the breeding dynamics of this unique coastal colony (Piper and Ruddle 1986). Use of the Msikaba River gorge has not been uniform, with the majority of the breeding vultures moving upriver (Chapter 4). Physical measurements of the cliff formations and nest density provided insight into factors that influenced nest site selection and breeding success (Chapter 4). Elevation, ledge depth, and proximity of nests were significant variables in nest site selection, whereas overhang above the nest site was not very important (Chapter 4). Breeding success was highly variable depending on year, and density of nests influenced the breeding outcome (Chapter 4). Nests that were surrounded by more nests had higher breeding success, suggesting that this nesting strategy helps prevent predation (Chapter 4). As vulture populations continue to decline, they may surpass a critical threshold of breeding pairs that mitigates predation events (Chapter 4). This could lead to a further retraction of the species' range to only the largest breeding colonies.

The fourth research objective was to identify and rank the drivers of Cape Vulture flight height and then create risk assessment maps for use in wind energy installation. Blades from wind turbines can be potential hazards for birds and bats (Smallwood and Thelander 2008, Rydell et al. 2016). In South

Africa, wind energy installations are increasing and are a likely major threat to vulture species (Smallie 2013, Rushworth and Krüger 2014, Smallie 2014). Foraging range data presented in this study illustrates that buffers around colonies and roosts would not fully protect this far-ranging species (Chapter 3 and 5). Knowledge on the drivers of Cape Vulture flight height and predicting risk across the landscape would help sustainably develop wind energy. Risk assessment modeling was used to identify areas for future wind energy development in the Eastern Cape Province. Topography, wind speed, and distance from nest and roost influenced flight height of Cape Vulture (Chapter 5). Food availability is known to influence flight height of other vulture species, however distance from vulture restaurant had to be excluded from the current study because of correlation (Spiegel et al. 2013). Of the two predictive models created, the vulture presence probability model performed better than the model attempting to predict flight height (Chapter 5). Two risk assessment maps were created for each predictive model (Chapter 5). Although all factors should be considered, these results suggest buffer sizes for breeding colonies and roost sites that can be applied.

6.3 Discussion and Recommendations

Human population growth and the impact that has on the environment is one of the top threats to biodiversity (Cincotta et al. 2000, Hansen et al. 2004, McKee et al. 2004). With increased habitat fragmentation and urban/suburban sprawl, wildlife populations have adapted to human modified landscapes (Adams 1994) or have undergone population declines (McKinney 2002). Conversion of natural habitats into agricultural systems has also increased to supply the global food demand and can have negative impacts on biodiversity if not developed sustainably (Green et al. 2005). Not all agricultural systems rely on homogenous land use commonly seen in developed countries; subsistence agriculture seen in developing countries may actually provide benefits to biodiversity, specifically bird species (Mulwa et al. 2012). However, biodiversity research in and around subsistence agriculture communities is limited (Martin et al. 2012b). This can severely limit the applications of ecological research in human-modified landscapes, which makes up 75% of the Earth’s land surface (Martin et al.

2012b). The research presented in this thesis does not present research focused entirely on pristine protected areas, but attempted to quantify the complex relationships between the endangered Cape Vulture and a heavily human modified landscape and then produce solid management guidelines.

The results from the investigation into the foraging range and habitat use of adult vultures captured at Msikaba Cape Vulture colony emphasizes that conservation management plans need to extend across provincial boundaries. In order for Ezemvelo KZN Wildlife to achieve their goal of ‘conserving the indigenous biodiversity of KwaZulu-Natal for future generations’ conservation efforts for the Cape Vulture must address population threats in the Eastern Cape and Lesotho in addition to the province of KwaZulu-Natal. Managers and NGOs should facilitate workshops and focus groups specific to the southern node population of the Cape Vulture to address regional trends and threat patterns. Management of the critically endangered Bearded Vulture (*Gypaetus barbatus*) already spans this area (Kruger et al. 2014), but more attention is needed in the resource scarce Eastern Cape Province (Boshoff et al. 2009a, Hiltunen 2009). Community-based-conservation in Africa is essential for endangered wildlife to persist, and community inclusion with Cape Vulture management decisions will help secure the future of the species (Hackel 1999). Seasonal movement patterns identified can be used to target anthropogenic threats at certain times in areas where the vultures concentrate, thus using conservation resources and time of agency/NGO personnel effectively. Since these foraging ranges are much smaller than those found elsewhere in Africa, effective mitigation might be easier to enforce. The kernel density estimates for home ranges of Cape Vultures can be used as preliminary recommendations for protective buffers around colonies. Impendle, uMngeni and Mpofana local municipalities in the Eastern Cape and KwaZulu-Natal Provinces should be the focus of Cape Vulture conservation efforts from May to October. From November to April, the Hibiscus Coast, Ezinqoleni, uMuziwabantu and Ubuhlebezwe local municipalities should be targeted. Conservation efforts can include providing safe supplementary food, educational days with members of the public, monitoring of roosts and feeding sites, reporting fatalities from power line infrastructure, and as general patrol areas for conservation officers to enforce environmental laws.

Africa, especially South Africa, has a troubled history of excluding native people from protected areas which alienated them from management decisions (Hackel 1999). Western values of conservation may differ from those living in subsistence farmland, who may perceive livestock predators as detrimental to their livelihood and must be exterminated (Akama 1996, Kideghesho et al. 2007). Our interview results revealed that locals in subsistence farmland held positive views of Cape Vultures and understood their role in the carrion cycle. As very few environmental education programs on vultures are conducted in the area, it suggests this appreciation is inherent in the amaXhosa community. This appreciation might be influenced by the importance of rural livelihoods found in this community. However, with the increase of urban sprawl and economic pressures these livelihoods may be threated (Shackleton et al. 2013). The continued human population growth may consume the least transformed areas of the study area resulting in Cape Vulture habitat loss and shifting cultural attitudes. Tapping into the inherent appreciation for Cape Vultures before further developments occur could positively impact decision outcomes for vulture and rural livelihood conservation. Working with the inherent appreciation and community leaders, education programs can target subsistence farmland areas to reduce Cape Vulture fatalities from traditional medicine. Since vulture observations were decreasing in the transformed areas, programs can focus on the least transformed areas, which may also be harboring other endangered species, like plants endemic to the Maputaland-Pondoland-Albany region of endemism (Perera et al. 2011). Employing local people in monitoring breeding colonies and power line structures for fatalities create jobs in a low-income area, contribute to long-term databases, and identify dangerous power lines to be mitigated.

Wind energy is a powerful resource, but one that very few people want in ‘their backyard’ (Wolsink 2007). Renewable energy development has the potential to create jobs; this factor coupled with weak environmental assessments had made the subsistence farmland areas of the Eastern Cape Province ideal for wind energy companies (Kakonge 2006, Wei et al. 2010, Smallie 2014). Wildlife fatalities from collisions has been recorded across taxa, and although some evidence exists of raptors learning to avoid the dangerous blades (Johnston et al. 2014, Cabrera-Cruz and Villegas-Patraca 2016), *Gyps* vulture species are still considered to be particularly susceptible to fatal collisions (Carrete et al. 2012, Martin et al. 2012a, Rushworth and Krüger 2014). Our results highlight the complexity of predicting flight height of Cape Vultures, and suggest that vulture presence is easier to predict. Therefore, mitigation strategies for wind energy should focus on placing wind turbines in low vulture activity areas, which we have highlighted in terms of the predictor variables measured. Wind energy development should not only consider distance from roost site or breeding colonies, but wind speed, topography, and other important factors not investigated in this study.

Another factor to consider when planning conservations strategies for the Cape Vulture, is that breeding colonies can be ephemeral, responding to human disturbance and beneficial environmental conditions (Borello and Borello 2002, Boshoff 2012, Botha and Kruger 2012). Understanding the drivers of these changes will help produce adaptive management strategies to ensure that breeding colonies are protected from threats. The results from the cliff characteristics and nest density chapter provide evidence that Cape Vultures participate in the ‘win-stay, lose-switch’ breeding strategy and select sites that provide protection from predators (Szostek et al. 2014). Critical densities at breeding colonies influence breeding success; therefore management agencies should estimate and maintain critical densities at breeding colonies. Conservation effort should be directed to breeding colonies which do not met these critical densities on the periphery of the range of the Cape Vulture, because they would be the first to experience decreased breeding success because of low nest density. Specifically in the Eastern Cape, the breeding colonies located west of 27° E are generally smaller and not formally protected, and ideal candidates for intense management to prevent declines (Boshoff and Vernon 1980, Boshoff et al. 2009b). In attempts to reintroduce breeding pairs into a historic location, enough pairs should be released to create the critical densities needed for breeding success. Releasing more vultures at one time might increase the overall survivability of rehabilitated Cape Vultures (Monadjem et al. 2013).

6.4 Future Work

A number of questions have been answered with the results of this study, yet it also raised some questions that would benefit from further research:

We have established that adult Cape Vultures captured from one breeding colony foraged in a relatively small area compared to other regions in the species' range (Bamford et al. 2007, Phipps et al. 2013). As a smaller area should be easier to enforce conservation laws and mitigate negative power infrastructure, the study area represents a good location to test different management plans. In the short term, effort should focus on why the foraging ranges are so small so those conditions can be replicated in other areas. Specific research questions are:

1. What type of carrion is consumed by vultures and are there seasonal differences? Where are these carcasses located in terms of land use, human disturbance, and topography? Screening the already compiled GPS location data for day stops can provide insight into possible feeding events. These locations can be checked on the ground, and then characterized by observations and discussions with land owners.

Community members around the Msikaba Cape Vulture colony generally held positive views of the vultures and may even provide favorable foraging opportunities because of their husbandry techniques and predator animal control. Further research questions can explore the following:

1. What are the characteristics of an 'informal vulture feeding site', where are they located and when do vultures visit these sites? Characterize the type of subsistence farmland present in the former Transkei, in terms of human density, crop and livestock diversity and densities, rangeland management, density and abundance of livestock predators, income and education levels. This information can be used to compare subsistence farmland in different regions and identify key factors that are beneficial to the Cape Vulture's persistence in the former Transkei.

The risk assessment maps created are a good tool for preliminary planning regarding wind energy in the Eastern Cape Province. However, many more research questions should be addressed including:

1. Confirming the locations of roost sites identified using the transmitter data, then characterizing landscape and anthropogenic factors that influence the presence of roosts. Can this information be used to create a roost probability map? Are roosts used uniformly and if not can roost use be predicted? To what extent are Cape Vultures using man-made structures in the southern population node? The current sample size was relatively small and biased towards adult vultures, extending the sample size to include first year Cape Vultures will provide insight into age differences in regards to risk of collision with wind turbine blades and power line infrastructure.

The breeding ecology of Cape Vulture is intriguing because of its colonial nature. This behaviour helps identify breeding colonies which are conservation priority areas that can be safe guarded to prevent disturbance to large numbers of breeding pairs. However, how vultures use cliffs and distribute themselves was lacking, and our research provided some answers. Other research questions could address:

1. How does aspect, slope and temperature effect nest site selection and breeding success? How do these results compare to other breeding colonies of Cape Vultures across their range? Besides increased predator protection, do vultures from high nest density areas have higher foraging success? Do Cape Vultures come back to the breeding colony they were hatched at to breed? And if so, would it be near the nest they were hatched from?

6.5 Concluding Remarks

This dissertation provides explanations for the persistence of the endangered Cape Vulture in subsistence farmland; an area of high human population density and transformed landscapes. The results presented here illustrate the connection Cape Vultures have with different land uses and local livelihoods. It provides insight into the movement ecology of the Cape Vulture in an effort to determine high collision risk areas between wind turbine blades and vultures. Furthermore, it fills gaps on the breeding ecology of the Cape Vulture, which is important in all conservation planning for the species. By investigating the connection between the ecology, biology, and human dimensions of people and vultures, knowledge has been gained that will guide Cape Vulture management practices throughout its range.

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Appendix A: Sample Interview

A. Age?
B. Gender?
    B.i. Are you married?
    B.ii. How many people do you support?
C. Occupation?
D. What village are you from?

Livestock Questions

1. Do you:
    a. Own animals   b. Care for them
    c. Use to have them   d. Other
2. What livestock do you have? 2.a. And how many of each?
3. Do you own more livestock now, 10 years ago, or is it the same?
If they had livestock 10 years ago,
4. What livestock did you have 10 years ago? 4.a. And how many of each?
5. What are the benefits of owning animals?

Other Livestock Questions

6. Are there more people who own livestock now than 10 years ago or is it the same?
6.a. How many more or less farmers are there? And why?
7. What has made your livestock ill in the last year?
8. What diseases have killed livestock since you have lived here?
9. What medicine have your given your livestock and how often?
10. If you have horses, do you give your horses anything to improve their performance?
11. How often do you dip your livestock?
12. What type of predators have killed your livestock?
13. How do you protect against predation of your livestock? Does anyone use poison?
14. Have your livestock died naturally in the last five years?
15. How did your livestock die?
16. What do you do with cows that naturally died?
17. What do you do with horses and donkeys that naturally died?
18. What animals eat the dead livestock?
19. Are there ever dead birds near the dead livestock? 19.a. What type of birds?

Vulture Questions

20. What do you think when you see a vulture (show picture)?
22. Are there any beliefs (good and bad) about vultures in this area?
21. Do vultures scare you? 21.a Why?
23. Where do you see vultures?
24. How many do you normally see?
25. What do you see them eat?
26. Have you ever found a dead vulture?
27. Do you see more vultures now, 10 years ago or is it the same? 27.a. If there is a difference, why are there more/less vultures?
28. How do you think vultures die?
29. Are vultures something that benefits the community? 29.a. Why?