

Power line-related mortalities of the Cape Vulture (*Gyps coprotheres*) within the Eastern Cape, South Africa;

Modelling terrain characteristics in hotspot areas using GIS



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***'A Research Report submitted to the Faculty of Science, University of the
Witwatersrand,***

***Johannesburg, in partial fulfilment of the requirements for the degree of Master of
Science.'***

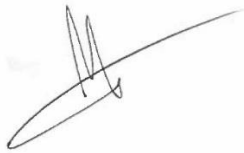
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October 2019

AUTHOR'S DECLARATION

I declare that this Research Report is my own, unaided work. It is being submitted for the Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.



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ABSTRACT

This study examines and correlates basic terrain and topographic characteristics at power line incident hotspots of Cape Vulture (*Gyps coprotheres*) within the Eastern Cape, South Africa. The Cape Vulture (*G. coprotheres*) is a threatened endemic Southern African Vulture. Each year, its population is further threatened by collisions and electrocutions on power line infrastructure that crisscross across South Africa. Each documented collision and electrocution incident is recorded into a national database and recommended mitigation measures are implemented to prevent further loss at these various problematic sites in a reactionary manner. Every day vulture flight patterns overlap the extensive power line network, and yet collisions and electrocutions are only recorded in certain areas.

This study uses the spatial frequency distribution of Cape Vulture power line incident data from the Eastern Cape in South Africa to identify areas of higher frequency, also known as hotspots, across the province. Exploratory Spatial Data Analysis (ESDA) revealed that the majority of the vultures are electrocuted and that the number of birds affected in a single electrocution incident is higher than those affected in a single collision incident. Larger transmission power lines are intrinsically associated with collision incidents and smaller distribution lines with electrocution incidents.

Avian power line risks are a combination of biological, technical and topographical and climatic factors. This study focuses on the GIS modelling of terrain and topographical factors at each collision and electrocution hotspot, which were then compared across hotspots to check for correlation. Unfortunately, distinct terrain characteristics signatures for elevation, slope and aspect and curvatures were not identified but instead displayed similar quantifiable characteristics. Other attributes such as vegetation cover, water, roost and restaurant proximities, line orientation to

wind directions and visibility at each hotspot were more distinct and could be correlated across hotspots. These characteristics were organised into a set of rules that would guide the further development of a predictive model, which can be used to assess the remainder of the Eastern Cape where there is an under-representation of the incident data. It is anticipated that this study's results will be valuable to the Cape Vulture non-governmental organisations (NGO's) and Eskom to inform proactive mitigation action to reduce or avoid further collision and electrocution of these endangered birds.

ACKNOWLEDGEMENTS

Firstly, thank you to the 'Cape Vulture in Crises' [CVC], sponsored through VulPro Lomas Wildlife Protection Trust and DHL Supply Chain, and Kerri Wolter of VulPro for the use of their incident and further auxiliary data for this study.

Thank you to my supervisor Prof Fethi Ahmed, who had the patience to provide assistance and guidance along the way, and it has been such a pleasure working with him.

Thank you to my family for their constant support. My husband Scotty, for his continuous support, patience and encouragement throughout the writing of this thesis. Pushing me to put those extra hours when I was lacking motivation and providing me with the workspace without distraction.

Moreover, finally, a massive special thanks to my mom Kate Webster, who provided invaluable insights and contributions to this work. Her passion for the plight of the Cape Vultures of the Eastern Cape is unmatched. I can only hope the little bit of work I carried out can assist positively in protecting these birds for generations to come.

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LIST OF ABBREVIATIONS AND ACRONYMS

APLIC	Avian Power Line Interaction Committee (USA)
°C	Degrees Centigrade
CIR	Central Incident Register (EWT)
CVC	Cape Vulture in Crises
DEM	Digital Elevation Model
DHL	Worldwide courier, parcel, and express mail services company
EDA	Exploratory Data Analysis
ESDA	Exploratory Spatial Data Analysis
ESKOM	South African electricity public utility
EWT	Endangered Wildlife Trust
GIS	Geographic Information System
GPS	Global Positioning System
IUCN	International Union for Conservation of Nature
km	kilometre
m	metre
mamsl	Meters Above Mean Sea Level
NGO	Non-Governmental Organisation (Non-profit)
SANBI	South African National Biodiversity Institute
SAWS	South African Weather Service
SRTM	Shuttle Radar Topography Mission
USA	United States of America
VulPro	Vulture Conservation Programme
WEP	Wildlife and Energy Programme strategic partnership between EWT and Eskom

1 CHAPTER ONE - INTRODUCTION

1.1 Background to the study

Avian mortality caused by power line infrastructure is a worldwide occurrence and although extensive research, design development, and mitigation have been investigated and implemented; many fatal incidents occur each year, usually incurring significant costs for electricity supply companies across the world (Lehman *et al.*, 2007, Boshoff *et al.*, 2011).

The Cape Vulture (*G. coprotheres*), which is a threatened endemic southern Africa raptor, is particularly vulnerable to negative interactions with power line infrastructure. The species has less than an estimated 3700 breeding pairs left in the wild (Wolter *et al.*, 2014). A decrease in range and numbers has occurred in recent years, and it is now listed as 'Endangered' in the South African Red Data Book and as 'Endangered' globally (IUCN, 2015). A significant contributory factor in the decline of this species is considered to be related to mortality from power lines (through collisions and electrocutions) (Boshoff *et al.*, 2011).

Power line collision incidents occur when the bird cannot see the power line in flight in time to avoid impact (Quinn *et al.*, 2011). This results in often maimed injuries whereby the bird will never be able to fly again or in death, either on impact with the line or ground upon falling after the initial impact. Electrocution of birds occurs when the bird's wings touch a voltage power line together with another voltage line or earth wire on the power line infrastructure, thus causing a high voltage current to flow through the bird. (APLIC, 1994, Lehman *et al.*, 2007). This can occur when the bird is perched on the infrastructure (Lehman *et al.*, 2007) or as a result when wings bridge lines upon collision impact (CVC Field Data).

Eskom generates and distributes the majority of electricity in South Africa, and has an extensive network of transmission and distribution power lines that crisscross the country. Avian mortality via power line electrocution and collisions is important as it can result in significant financial costs for Eskom. Eskom is also compelled to address the issue of avian mortality for ecological, legislative and social-political reasons (Quinn *et al.*, 2011).

To address this, Eskom together with Endangered Wildlife Trust's [EWT] formed a Wildlife and Energy Programme [WEP] strategic partnership, established in 1996 specifically to address power line-wildlife interactions in South Africa (Van Rooyen 2000a). The WEP manages a national spreadsheet database known as the Central Incident Register [CIR], in which mortalities and negative interaction incidents on power line infrastructure are recorded. Eskom uses this CIR to investigate incidents and to implement mitigation measures where necessary, thus aiming to prevent further loss at problematic sites. The mitigation measures mainly include modifying or marking lines to increase visibility and insulating wires and cutting a segment out "gapping" of the earth wire for prevention of electrocution. This method is considered a reactive rather than a proactive approach in reducing the number of deaths due to power lines.

The 'Cape Vulture in Crises' [CVC], sponsored through VulPro Lomas Wildlife Protection Trust and DHL Supply Chain, is a Vulture conservation group within the Eastern Cape, where the frequency of Cape Vulture mortality from power line infrastructure is particularly high (Boshoff *et al.*, 2011). The CVC investigates avian power line interaction incidents within the Eastern Cape and submits this information into the CIR database. The CVC has been active in this area from January 2008 and has investigated 73 incidents (171 birds affected) in the Eastern Cape to

end of December 2017. The CVC has permitted for this information to be used as part of this research.

The Eastern Cape Province is a diverse topographic province. It is characterised by a narrow coastal plain, clad in a subtropical thicket, savanna or forest, which is replaced inland by the escarpment and interior plains (Boshoff *et al.*, 2011). The Cape Vulture is the last surviving vulture species found within the Eastern Cape and although historically was more widespread across the province, now only frequents the eastern and north-eastern parts, which are mountainous and mainly covered by grassland (Boshoff *et al.*, 2009, 2011).

Vulture and other avian species flight patterns overlap the extensive power line network, and yet collisions and electrocutions are only recorded in certain areas. Although the risk posed by power lines is complex and problems are often localised, research has highlighted various factors which contribute to these negative interactions. These include biological (e.g. vision, flight behaviour, age and sex), topographical (e.g. land use, prevailing wind conditions), meteorological (e.g. strong winds, fog) and technical (e.g. power line design, power line grouping) factors (APLIC, 1994; Bevanger, 1994, 1998; Shaw *et al.*, 2010a). Terrain would, therefore, form a significant part of the technical factor, as power lines would have been built to avoid specific topographies, e.g. areas too steep or inaccessible etc. Thus, also influencing the height and orientation of the lines that connect between the power line pylons.

Currently reported negative power line incidents are likely to underestimate true rates because only an unknown fraction of incidents is reported, and of these most are found in areas where human knowledge of the problem is cognizant (Bevanger, 1998). In the Eastern Cape, the majority of reported cases occur in areas used for

commercial agriculture (Boshoff *et al.*, 2009, CVC Field Data). There are little to no reported incidents recorded in the historical homeland areas used more for subsistence farming. These historical homeland areas cover the majority of the Eastern Cape Province. Thus, a large number of incidents are potentially undetected and not reported. To survey the entire Eastern Cape power line network to identify problematic areas would require substantial resources in time, personnel and financial budget. Cost-effective methods are therefore needed to help identify the stretches of power lines that pose the most significant risk to avian species in order to prioritise the deployment of mitigation methods (APLIC, 1994; Quinn *et al.*, 2011).

1.2 Rationale

The focus of this study attempts to understand the terrain and topographic characteristics associated with power lines in areas where there is a higher recorded frequency of Cape Vulture power line incidents in the Eastern Cape. The Cape Vulture prosperity is essential to the health of the environment, and these interactions are a severe threat to the stability of the species population (Boshoff *et al.*, 2011). It is well known that in general avian power line incidents tend to be clustered in certain areas (Quinn *et al.*, 2011). However, incidents are often captured retrospectively and often not systematically (Shaw, 2009), leading to possible over-representation of data in some areas. Although difficult to quantify, Boshoff *et al.*, 2011 estimated as few as 2.6% of Cape Vulture power line mortalities may only be reported. Therefore large areas of the Eastern Cape are not covered, and potential problematic power lines in these areas are then not identified. Risk models are essential proactive methods which can be used to identify these potentially problematic power lines, but the majority of these have been based on the morphological and biological aspects of the birds and often only use real-time data to fit the models retrospectively (Shaw, 2009; Quinn *et al.*, 2011; Smallie, 2012). Terrain and topographical characteristics in these problematic areas are often

not well documented and largely overlooked in research. Power line construction and placement is a function of these terrain and topographical characteristics. Correlation in these characteristics between identified problematics areas can begin to close the gaps in research in recognizing which lines are likely to be more hazardous than others to Cape Vultures. This study will form part of a greater amount of research currently taking place across the world and ultimately assist in the allocation of resources to managing collision and electrocution on existing infrastructure in South Africa and to influence the construction of new infrastructure in South Africa (Lehman *et al.*, 2007).

1.3 Aim and Objectives

This study aims to identify and correlate basic terrain and topographic characteristics at power line interaction hotspots of Cape Vulture (*G. coprotheres*) within the Eastern Cape, South Africa. To achieve this aim and using CVC Eastern Cape field-collected incident data, the objectives of this study were to:

1. Identify Cape Vulture (*G. coprotheres*) power line incident hotspot areas within the Eastern Cape study area and whether these hotspots are affected by the yearly, seasonality and incident type data spread and characteristics.
2. Identify basic terrain characteristics such as elevation height; slope angle and aspect; profile and plan curvature; and associated topographic characteristics such as power line orientation; viewsheds; vegetation type; proximity to water sources and proximity to roosting and breeding sites at each hotspot.
3. Correlate terrain and topographic characteristics at the hotspots to develop a rule set to be used for further research.

1.4 Outline of Research Report

Chapter 1 provides background on the study. It provides the rationale and research objectives of the study, together with the significance and outline of the study.

Chapter 2 focuses on a broad literature overview of the ornithological characteristics of the Cape Vulture morphology, habits, distribution, threats and, habitat. The chapter further explores the different factors that increase the risk of negative avian interactions with power lines. It also highlights similar studies and analysis that has been done to try to address this sort of problems.

Chapter 3 presents the area where the study took place, the sample selection method, and how data was collected. Methods of data analysis are also described.

Chapter 4 examines the results and discussion from the factors that influence the hotspot analysis and the subsequent terrain and topographic analysis at each of these points.

Chapter 5 concludes the study and makes recommendations based on the findings.

2 CHAPTER TWO – LITERATURE REVIEW

2.1 Vultures and Power lines

2.1.1 The Cape Vulture (*Gyps coprotheres*)

The Cape Vulture (*G. coprotheres*) (Mundy *et al.*, 1992) also known as Cape Griffon, is endemic to Southern Africa. It is one of the eight vultures occurring in the area. Its scientific name "*Gyps*" is Greek for a vulture and "*coprotheres*" is derived from the Greek word with "*kopros*" meaning dung or manure and "*thera*" meaning to hunt or capture. It is an 'Old World Vulture' which belongs to the family Accipitridae, that also includes eagles, kites, buzzards and hawks (Mundy *et al.*, 1992; Campbell, 2015).

The Cape Vulture is recognised as a very large (~95cm tall), heavy (average weight 11kgs), pale creamy-buff coloured, long-necked vulture. The Cape vulture has a huge wingspan of 2.55m characterised by black wing feathers (Mundy *et al.*, 1992; Campbell, 2015). The neck skin is mostly devoid of feathers and has a bald-head. The hooked bill is black; the eyes yellow and the surrounding skin pale blue (Mundy *et al.*, 1992; Campbell, 2015). Juvenile birds are darker streaked brown in feather colour with pink neck skin and dark eye (Mundy *et al.*, 1992; Campbell, 2015) (Figure 2-1).

Cape Vultures form large colonies of several hundred birds which roost and build nests on high cliffs (Mundy *et al.*, 1992; Campbell, 2015). The Cape Vulture reaches breeding maturity after 5 years and then pairs up with a mate for life. In March and April, the birds pair up and either re-occupy old sites or build a new nest from grass, plants and sticks. The female lays one egg. The incubation period is 54 days and duties are shared by both parents. By July, most of the birds are caring for recently hatched chicks with one parent remaining on the nest whilst the other parent is out foraging. Around four months from hatching (around mid-summer), the chicks

venture out of the nest to take their first flight, but will regularly return to the nest for feeding before eventually completely fledging (Mundy *et al.*, 1992; Campbell, 2015). Cape Vultures like most vultures are scavenging birds, feeding mostly on the remains of dead animals (Mundy *et al.*, 1992; Campbell, 2015), finding these carcasses exclusively by sight (Martin *et al.*, 2012). They descend in large numbers to feed at carcasses, often together with other vulture and scavenger species, arguing over meat using harsh, grating calls (Mundy *et al.*, 1992; Campbell, 2015). They like to clean themselves after each meal using ponds and pools of water to bathe and preen (Mundy *et al.*, 1992; Campbell, 2015).



Figure 2-1: The Cape Vulture (*G. coprotheres*) with marked wing tag by Kate Webster of CVC (2009)

The Cape Vulture has wide-ranging foraging habits, often wandering widely away from roosting and breeding cliffs (Mundy *et al.*, 1992; Boshoff *et al.*, 2009).

Immature adults tend to range further with apparently random movement in foraging habits (Mundy *et al.*, 1992; Bamford *et al.*, 2007). It forages across a variety

of habitats and will temporarily roost in trees and on electrical transmission pylons in open areas (Mundy *et al.*, 1992). Cape Vultures fly between heights of ~100m and 500m above the ground when foraging, but can reach a flying height of 1500 metres when flying from one roost/breeding colony to the next (pers. Comm. with CVC from tracking data 2016). They generally use thermals to gain height off cliffs before flying further afield. Time spent foraging is dependent on weather conditions, food availability and breeding responsibilities (Mundy *et al.*, 1992).

The distribution of the Cape Vulture is restricted to Southern Africa with main colonies in South Africa, Lesotho and Botswana, occurring from sea-level to around 3100m (in Lesotho Highlands) (Mundy *et al.*, 1992; Bamford *et al.*, 2007). Although occurring in these countries, they are not breeding anymore in Namibia, Zimbabwe and Swaziland (Figure 2-2) (ICUN, 2015). The Cape Vulture is classified 'Endangered' in 2015, with a decreasing population trend according to the International Union for Conservation of Nature (IUCN), with smaller periphery colonies being at the biggest risk (Boshoff *et al.*, 2009, 2011). There is an estimation of about 10 000 individuals' left encompassing less than 4 000 breeding pairs (Boshoff *et al.*, 2007, 2011).

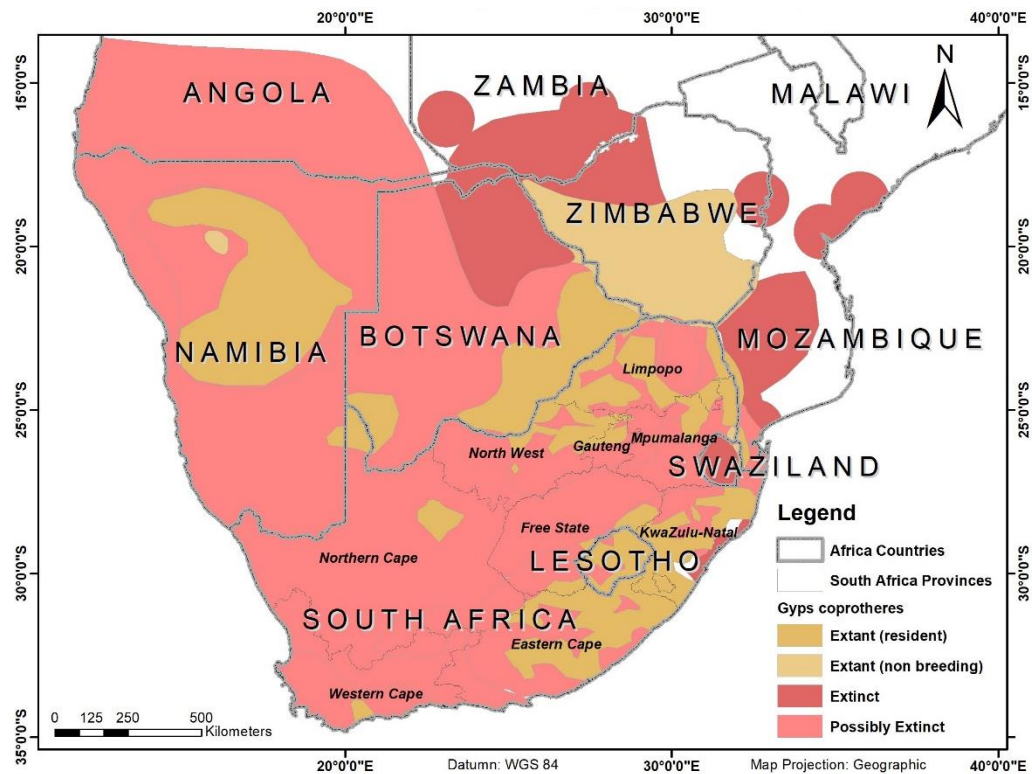


Figure 2-2: The Cape Vulture (*Gyps coprotheres*) distribution (ICUN-2015)

2.1.2 The Importance of Vultures

Vultures and other scavengers play a vital biological role in clearing the land of carcasses. By consuming the remains of dead animals rapidly, vultures prevent these carcasses from becoming hosts to various dangerous pathogens that may spread to wildlife and livestock, thus curbing potential disease outbreaks (Ogada *et al.*, 2016). Vultures consume more carcasses than all the other scavengers put together, thus playing a critical role in nutrient cycling (Ogada *et al.*, 2016). Aerial movements of vultures are also considered to play an essential role in attracting ground-based non-specialist scavengers, thus increasing the rate at which the consumption of decaying carcasses are consumed (Wolter *et al.*, 2014).

2.1.3 The Cape Vulture Threats

The Cape Vulture, like vultures across the world, are facing numerous threats which have resulted in this species' rapidly declining numbers. This has also resulted in a decrease in its distribution range (Boshoff *et al.*, 2007). The various threats identified include: a reduction in the amount of food availability (particularly during the rearing of chicks); inadvertent and advertent poisoning; electrocution and/or collision on electrical infrastructure; loss of foraging habitat due to urban development and bush encroachment; unsustainable harvesting for traditional uses; disturbance of colonies and drowning in farm dams (Mundy *et al.*, 1992; Anderson, 2000; Boshoff *et al.*, 2007; Ogada *et al.*, 2016).

The contamination of their food supply (poisoning) is thought to be the primary threat to these vultures. This includes advertent poisoning, whereby poison left for pests other than vultures (Diekmann and Strachan, 2006) is consumed and fatal to the vultures. Also, unintentional poisoning, through the use of diclofenac, a non-steroidal anti-inflammatory drug in livestock, which is fatal to the Cape Vulture when ingested at livestock carcasses (Wolter *et al.*, 2014). A single poisoning incident can kill in excess of 50 birds, making the species susceptible to sudden local declines (Diekmann and Strachan, 2006). The second most significant threat is hunting for use in traditional health practices, as vultures in southern Africa are caught and consumed for perceived medicinal and psychological benefits (McKean and Botha, 2007). The third most significant threat and the primary threat in the Eastern Cape, which the area of study, is the collision and/or electrocution on electrical infrastructure. These negative interactions have resulted in the high mortality rates, with an estimated minimum of 80 vultures being killed yearly through collisions with power lines in Eastern Cape Province (Van Rooyen, 2000a and b; Boshoff *et al.*, 2011).

2.1.4 Avian Power Line Risks

Avian mortality caused by power line infrastructure is a global occurrence and occurs either through collision and/or electrocution (Loss *et al.*, 2014). Electrical power lines and pylons are spatially extensive networks of linear infrastructure (Quinn *et al.*, 2011). Cape Vulture power line interactions, like other avian power line interactions and mortalities, are not evenly distributed along this infrastructure, but spatially clustered in areas where risk is caused by a combination of interacting factors (Quinn *et al.*, 2011). Bevanger (1994) thoroughly investigated and defined these factors, which include biological, technical and topographical and climatic conditions.

2.1.4.1 *Biological*

The biology of an avian species includes the physical and genetic features that distinguish it from other species. Thus, to some extent, this influences the birds' behaviour in relation to their environment (Kotoane, 2004; Shaw, 2009) and can therefore increase or decrease the risk of its' power line interactions. Physical build, flight behaviour and vision are essential aspects to be considered when evaluating the "collision potential" of an avian species (Bevanger, 1994). Whereas morphology and behaviour impact on an avian species' electrocution risk (Lehman *et al.*, 2007).

Bird species with high wing loading (weight/wing area) and high aspect ratio (wingspan/wing area) have a higher susceptibility to collision with power lines (Bevanger, 1994, 1998; Janss, 2000). The first group have relatively heavy bodies and small wings (e.g., waterfowl - swans, geese, and ducks). The second group of birds includes those species with large, broad wings (low aspect ratio), relatively large body size (moderate wing loading) and long necks (e.g., cranes, storks and vultures) (Bevanger, 1994; Janss, 2000). Both groups have limited ability for rapid reaction to obstacles.

Flight characteristics and behavioural patterns often exacerbate an avian species collision risk. This includes flocking activity or low altitude movement patterns between wetlands and feeding areas in the cranes and waterfowl (Bevanger, 1994; Janss, 2000; Quinn *et al.*, 2011). Avian species active in periods with poor light (e.g. twilight at dawn and dusk) and nocturnal species are also expected to be vulnerable to crashing into artificial obstacles (Bevanger, 1994). Vulture far-ranging flight patterns in search for carrion allows them to cross paths with multiple power lines at various altitudes (Bamford *et al.*, 2007, VulPro GPS tracking data unpublished).

Avian vision has adapted amongst the various species dependent on their needs, accounted by the shape and position of the eye (Martin *et al.*, 2012). Most avian species have eyes on the sides of their heads; this allows for a wide visual field, which assists in detecting predators (Martin and Shaw, 2010). Typical predators or hunters, such as raptors, have eyes on the front of their heads and bifoveal retina (Martin and Shaw, 2010). This is useful for hunting but at the expense of a large blind zone, which may contribute to power line collisions (Martin and Shaw, 2010). Vultures' like raptors eyes have also adapted to seeing great distances when they are searching for food, as they can scan large areas of the ground and maintain their peripheral vision to avoid crashing into vultures flying around them (Martin *et al.*, 2012). Vultures have a blind spot directly in front of them, above and below their heads (Martin *et al.*, 2012).

With electrocution, larger size birds such as raptors, vultures and cranes are more commonly affected, as their wingspan, leg parts and body size allow them to touch and bridge both energised parts (Van Rooyen, 2004; Lehman *et al.*, 2007).

Electrocution generally occurs on power line pylons which are used as nests

(raptors), roosts (vultures) or vantage points for hunting (owls and other raptors) in open areas (Bevanger, 1994; Lehman *et al.*, 2007).

2.1.4.2 Technical

Eskom supplies and distributes the electricity in South Africa through an estimated 350,000 km of power lines. Power line infrastructure design characteristics, arrangement and placement, is a function of demand, date of construction and the voltage the line is carrying. Transmission power lines carry a higher voltage and are generally higher in height than distribution lines, as seen in Figure 2 3 below. These characteristics play a large part in collision risk and electrical risk of avian species.

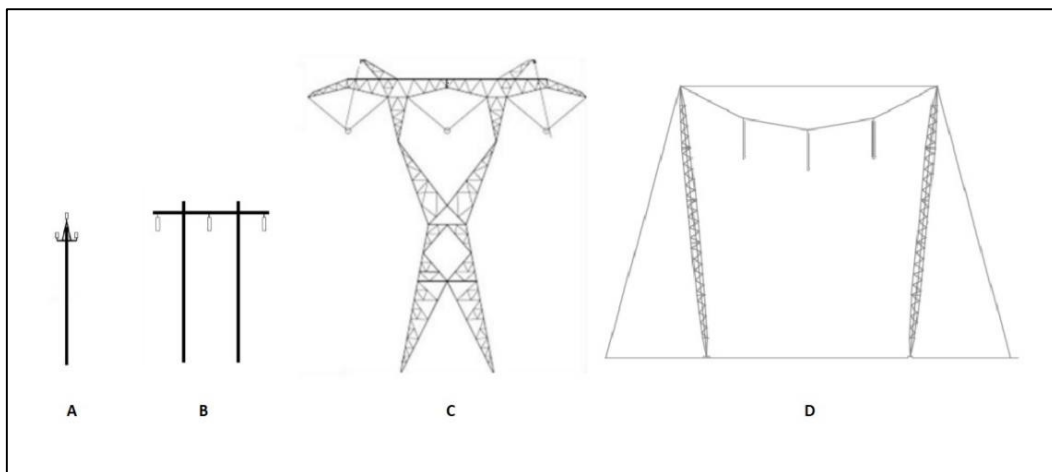


Figure 2-3: Typical configuration of the most common (a and b) distribution lines and the most common (c and d) transmission power lines found within the Eastern Cape. Note: Transmission lines also have overhead earth wires. Modified from Shaw *et al.*, (2010b).

Collision risk is influenced by technical power line characteristics such as the height, diameter, number, and configuration of wires; and the spatial orientation of the power lines (Bevanger, 1994; Quinn *et al.*, 2011). There is generally an increase in avian collision risk with the overhead shield wires, which is the uppermost wire on

most transmission power lines that protect the system from lightning damage (APLIC, 1994). Overhead shield/earth wires are smaller in diameter than the transmission wires and therefore less visible to birds (Bevanger, 1994; Quinn *et al.*, 2011). Observational evidence suggests that birds may change course to avoid the lower phase conductors and then collide with the less visible overhead shield wires (Bevanger, 1994; Crowder, 2000). It is believed that risk can be reduced by grouping similar power lines on a common servitude, or locating them along with other features such as tree lines (Bevanger, 1994). Also, low lines with short span lengths (i.e. the distance between two adjacent pylons) and flat conductor configurations are thought to be the less hazardous (Bevanger, 1994; Jenkins *et al.*, 2010). Electrical design concerns the physical separation between energised and or grounded parts. If this distance is less than that of the head-to-foot or wrist-to-wrist (flesh-to-flesh) distance of a bird, then an electrical current will flow through the bird on contact and cause electrocution (APLIC, 1994; Lehman *et al.*, 2007). Earth-wires on the distribution lines are a particularly high risk to the Cape Vulture (CVC pers. comm., 2016), as the conductors of these lines stick up above the pylon crossbar on which the bird perches.

2.1.4.3 Topographic

Avian species use topographical dips and valleys; linear vegetation breaks, and other features interrupting the visual horizon as directional cues during local flight and migration (Bevanger, 1994; Quinn *et al.*, 2011). Collision risk increases when a power line is near or spans across these flight paths (Quinn *et al.*, 2011). Risk is decreased when power lines are found at or below the height of nearby trees as birds will gain altitude to clear the highly visible tree line, consequently avoiding the power line (APLIC, 1994). This can also be applied to topography and buildings; for example, power lines located near a cliff base or any other tall object have a lower probability of interactions (APLIC, 1994).

The proximity of a power line located directly over or adjacent to an important bird habitat area (e.g. wetlands for wetland birds) together with its orientation to local flight path becomes important as it can affect collision risk (APLIC, 1994). Lines that are located perpendicular to local avian flight patterns are more likely to receive strikes than are lines located parallel (Bevanger, 1994). Vulture's habits as a scavenger species mean that they use a variety of habitats and their flight paths and ranges vary quite extensively (Mundy *et al.*, 1992, Bamford *et al.*, 2007 and CVC pers. comm., 2016).

Power line infrastructure is used more often for nesting, roosting or hunting in areas largely devoid of large natural trees, such as the spatially dominant Grassland and Karoo Biomes in the Eastern Cape (Bevanger, 1994, Boshoff *et al.*, 2007, 2011). Power line infrastructure in forested areas is rarely used for nesting (Bevanger, 1994). The Cape Vulture, in particular, is vulnerable to this risk, as it is known to readily use the various power line pylons as roosts (Figure 2-4) and perches in mostly flat areas as noted in a study by Ledger (1984).



Figure 2-4: Cape Vultures roosting on an Eskom Transmission Power line, Eastern Cape by Kate Webster of CVC (2016).

2.1.4.4 Meteorological

Avian species behavioural patterns are influenced by meteorological conditions, as birds adapt to the different conditions (Bevanger, 1994). The Eastern Cape interior climate is varied, dominated by summer rainfall, with cold winters with occasional snowfalls in the mountainous regions (South African Weather Service, 2018). The prevailing wind conditions are dominated by north-west to westerly winds in winter to the south-east to easterly winds in the summer months (South African Weather Service, 2018).

Collision risk is increased when certain low light weather conditions can impair the ability of birds to detect the presence of power lines in time to take adequate evasive movement and are known to change the general flying height, generally causing birds to fly closer to the ground, at a lower altitude (Bevanger, 1994, APLIC, 1994). This, together with prevailing wind directions, play a significant role in increasing the risk. Lines oriented perpendicular to prevailing wind directions are at a higher risk for collisions as birds generally take off into the wind (APLIC, 1994, Crowder, 2000; Shaw 2009). High winds can also buffet birds into fully visible power lines with which they are quite familiar, but cannot avoid due to the strength of the wind (APLIC, 1994).

Bevanger (1994) does not indicate that meteorological factors significantly influence electrocution risk. However, Lehman *et al.*, (2007) highlighted a study emanating rainy weather which concluded that Golden Eagle wet feathers were 10 times more likely to cause electrocution than any contacts involving dry feathers. However, skin-to-skin contacts were still more dangerous than any contacts involving wet feathers. Inconclusive studies in the USA indicate that wind directions in relation to power lines can also possibly play a role in power line electrocutions (Lehman *et al.*, 2007).

2.2 Modelling risks with GIS

The spatial nature of avian interaction sites with power lines, combined with the general availability of relatively low cost environmental and utility infrastructure spatial data make GIS analysis important in modelling power line risks (Quinn *et al.*, 2011). GIS risk analysis is common in the assessment and establishment of models to predict the likelihood of a given event occurring with a given degree of intensity in a given site. It provides an understanding of the causes and consequences of those risks. This is particularly important in identifying areas prone to natural hazards.

Predictive Risk Models (such as that established in Kotoane, 2004) are complex models which use a number of predictors (variables) as input to formulate predictions and forecast outcomes. The predictors (variables) drive the type of statistical model that would be formulated. This is particularly important in areas which have both identified and unidentified incidences of the phenomenon (Kotoane, 2004, Shaw *et al.*, 2010a). Moreover, although a rule-based model can be locally explicit, often it would not be able to offer universal resolutions (Kotoane, 2004).

In recent years, research on modelling power line risks has increased significantly. Kotoane (2004), Shaw (2009), Quinn (*et al.*, 2011) and Smallie (2012) are amongst numerous authors who have assessed avian power line collisions and electrocutions through GIS statistical methods. Kotoane (2004) and Shaw (2009) focused on species-specific Blue Cranes (*Anthropoides paradisea*) in the Overberg, South Africa, whereas Quinn *et al.* (2011), on a morphologically similar grouping of waterbirds in Atlanta, USA. All these studies developed predictive risk models based on bird habitat, bird mortality risk, and social consequence models. These models were

developed using knowledge of bird morphologies, habits, environmental, power line, and social factors identified in literature reviews of the areas and species.

Kotoane's (2004) rule-based model used Blue Crane characteristics to develop GIS operational questions. Using these questions, Kotoane identified areas of risk by performing the following spatial analysis; overlay analysis; proximity analysis; orientation analysis and visibility analysis. Shaw (2009) tested the efficiency of Kotoane's (2004) model by ground-truthing the study areas and inputting field-collected data into the models to assess the quality of the models. Smallie (2012) did not focus on species-specific or group-specific research but developed a more multi-species risk model based on indices constructed on bird morphologies and behaviour together with a probability and consequence matrix for determining high-risk hotspots across South Africa. All studies identified that further research in all of these areas is needed before GIS may be used to predict where high-risk power lines occur (Shaw, 2009).

Although Boshoff *et al.*, (2011) modelled the potential impact Cape Vulture electrocution power line mortality rate had on the Eastern Cape Vulture population, predictive GIS models primarily focusing on identification of higher risk power lines for Cape Vultures are limited. The vulture's habits as a scavenger species necessitate that although they prefer open vegetation, they use a variety of habitats and their flight ranges can vary quite extensively (Mundy *et al.*, 1992; Bamford *et al.*, 2007; Boshoff *et al.*, 2009). Therefore, the establishment of a model purely based on literature-based bird characteristics and habitat use would be subjective, which have been the focus for most predictive models. Bevanger, 1994; 1998 amongst numerous other authors have indicated that terrain and topographic characteristics are also important contributing factors in power line risk for avian mortality. However, no research has been conducted, where this has been the primary focus.

Due to the unknown nature of the terrain and topographic characteristics that would be associated with power line risk for Cape Vultures, collected field data is used in a more exploratory manner within this research. This is done instead of using the field data to test a pre-defined model. By assessing terrain and topographical characteristics at each hotspot, more accurate rules can be established for further research whereby a predictive terrain model is then developed. This, therefore, can then be used to attempt to identify further hotspot areas not yet identified in the field data.

3 CHAPTER THREE – RESEARCH MATERIALS AND METHODS

3.1 Study Area

The study area focuses on the remaining area of the Eastern Cape where the Cape Vultures are still resident and breeding (Boshoff *et al.*, 2009; ICUN, 2015) and consequently where CVC collected majority of its field data. It also forms part of Eskom's Southern Management region, where Boshoff *et al.*, 2011 identified the highest number of power line-vulture incidents of all regions. It encompasses the north-eastern region of the Eastern Cape Province, South Africa, which covers roughly 67 000 km² centred on an area historically known as the Border Region. It is bounded by the Eastern Cape boundary with the Free State to the north, and a rugged shoreline border with the Indian Ocean to the south (Figure 3-1). The area is characterised by a narrow coastal plain, which becomes a mountainous escarpment inland separated by meandering rivers. The escarpment is dominated by the mountain ranges of Sneeuberge, Stormberge, Winterberge and Drakensberg with the highest point at Ben Macdhui (3001m elevation) in the Southern Drakensberg. The region east from East London and Komani (formerly Queenstown) towards the KwaZulu-Natal border (formerly the Transkei) is characterised by grassland and savanna on rolling hills, interrupted by deep gorges with patches of indigenous forest. The topography of the region provides numerous cliff sites that are suitable for the Cape Vultures to roost or breed on (Boshoff *et al.*, 2009). The region is dominated by Grassland (40% of total area), Nama Karoo (19%) and Savanna (11%) Biomes (Mucina and Rutherford, 2011), which are primarily used in extensive grazing for cattle, goats and sheep for commercial and subsistence farming activities (Boshoff & Vernon 1980). Smaller fragments of land are also cultivated for various crops for animal fodder and human food. The study area contains both high voltage transmission lines (up to 400 kV lines) and low voltage distribution lines.

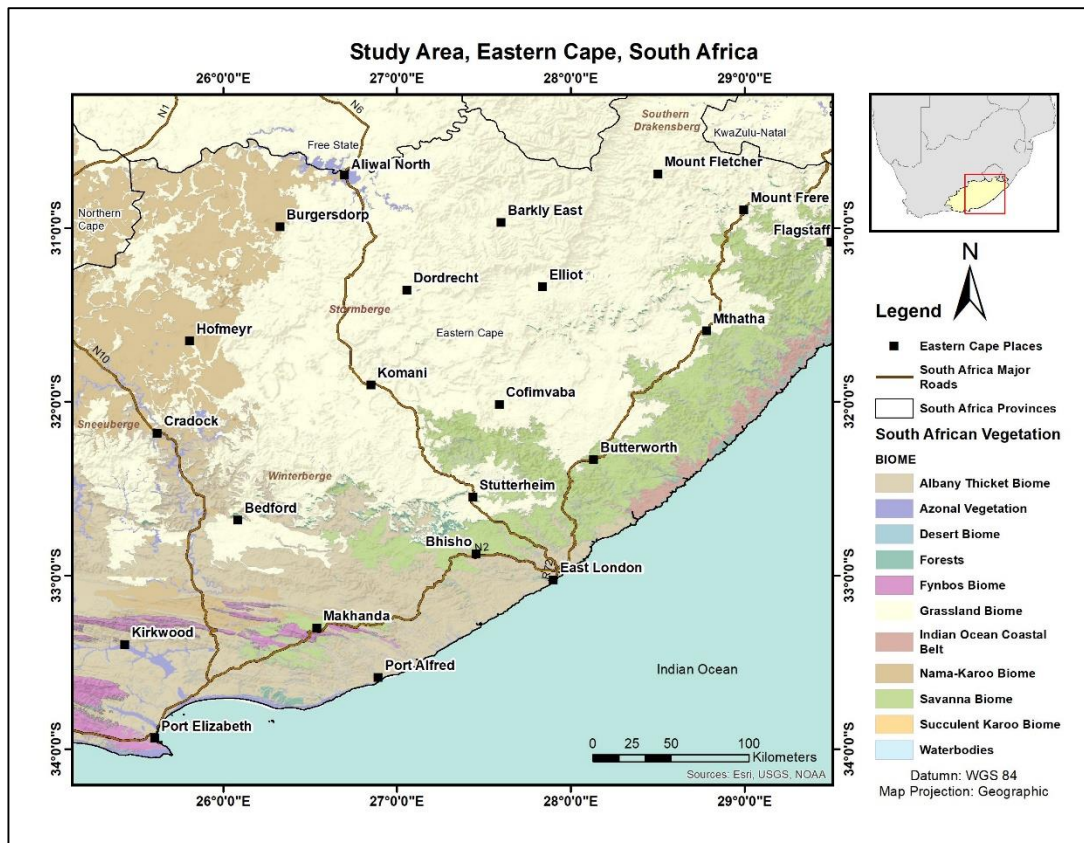


Figure 3-1: Study Area with the ESRI Terrain basemap (Source ESRI, 2016) and Vegetation Biomes (Source SANBI, 2009)

The western portion of the Eastern Cape is generally drier with lower rainfall during winter and/or summer, with frosty winters and hot summers (South African Weather Service, 2018). There is an increase in rainfall and humidity towards the eastern half of the Eastern Cape, becoming more subtropical along the coast (South African Weather Service, 2018). The eastern interior is characterised by summer rainfall and can become very cold in winter, with occasional heavy snowfalls in the mountainous regions (South African Weather Service, 2018). The wind direction data readings from the South African Weather Service stations across the Eastern Cape indicate that the wind direction changes across regions and seasons. In the northern interior, the wind direction slightly changes from a north-north-westerly direction in the winter months to an east-south-easterly to even a westerly closer to the Drakensberg areas in summer months. Whereas along the coastal areas, the wind direction slightly changes from an east-north-easterly

direction in the summer to a west-south-westerly in the winter months (South African Weather Service, 2018).

3.2 Materials

3.2.1 Field Data

3.2.1.1 *Field Data Collection*

All field data was collected and supplied through CVC and VulPro. This was sourced from CVC in 2016 and 2017 and exists in an excel spreadsheet database. Field data was collected from 2008 until December 2017, covering nine years in the Eastern Cape, South Africa. Data was collected primarily based on two methods: reporting and direct observations. Vulture and other avian power line mortalities and injuries are reported by various farmers and concerned public members in the Eastern Cape to the CVC and VulPro, who then undertook an investigation of the incident before recording the incident within their database. This data is collected as and when incidents occur. Data points are also collected through direct observation after a potentially hazardous power line has been identified. A representative from CVC and VulPro would conduct a ground survey along the section of power line deemed hazardous. This would be performed whereby the person would walk under the power lines, searching the area 10m to either side of the outermost conductor to search for vulture and other avian power line mortalities. When a carcass is encountered, photographs and further variables are documented and collected for entry into the database. This is the most accurate method, providing a more precise overview of problematic lines. This sort of data collection is however costly and time-consuming, so consequently, only a few data points are collected in this way. The main variables collected other than location information (Longitude and Latitude) include the date, bird type affected, the number of Vultures affected, the line voltage (KV strength), the type of mortalities/incident and any further comments on contributory factors of incident occurrence.

3.2.1.2 Sample Selection and Sampling Method.

Sample selection for this project includes all collected data points provided by the CVC, which are present within the geographical boundaries of the Eastern Cape. These points include mortality and incidence of all avian incidents with the power lines in this province.

3.2.1.3 Biases and Limitations of the Field Data.

The field data has two inherent main biases due to the data being collected based on reported incidents and/or through observer collection of data based on selected lines for inspection of possible mortalities. The reporting bias would involve the skew in the availability of data, as this sort of data would be more reported in commercial farming areas where awareness of reporting of incidents is higher than within traditional subsistence type farming areas. This results in the skewness of results to a higher percentage in commercial farming to that of traditional subsistence farming. The other type of bias involves observer bias, which arises when the researcher subconsciously influences the data collection, as only a few selected lines were identified to be searched for possible mortalities and others have not. In addition to the two main biases, power line incidents are primarily underestimated generally due to several inherent biases such as habitat bias, search bias, removal or scavenger bias, and crippling bias (APLIC, 1994; Shaw, 2009). Habitat bias refers to the percentage of the power lines which are impossible to search efficiently, either due to very dense vegetation, deep ravines etc. (Bevanger, 1998). Search bias refers to the effectiveness of the observer in locating bird carcasses and is expected to vary with season, the conspicuousness of the decomposing carcasses, and varying experience of observers (APLIC, 1994). Scavenger bias involves birds removed by scavengers (APLIC, 1994; Shaw, 2009). Crippling bias accounts for birds which sustain injuries in power line that are not immediately fatal, enabling them to move well away from the power line, and hence out of the observed area, before

they die (APLIC, 1994; Shaw, 2009). These types of biases should be noted, but are considered minimal to the study, as the aim is to conduct a hotspot analysis on the reported data. Once these hotspots are identified, then terrain and other aspects can be investigated, and outcomes of the study can be applied across areas of no/low reporting followed by ground-truthing of potential problem areas.

3.2.1.4 *Ethical considerations*

The field data and all supported intellectual documentation and information is the property of CVC and VulPro and cannot be distributed, sold or used for commercial purposes to any third party without the prior written consent of CVC and VulPro (Appendix 1).

3.2.2 Additional Data Sources

All GIS data have been acquired from various entities as listed below. This includes the following:

1. Electrical Power line and Infrastructure of the Eastern Cape sourced from an extract from the Eskom's national GIS dataset, December 2017.
2. Assorted biodiversity and vegetation Layers sourced from the South African National Biodiversity Institute (SANBI), December 2017
3. Meteorological data including wind speed and direction sourced from South African Weather Service throughout 2018.
4. SRTM 90m DEM - Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) sourced from South African National Space Agency (SANS), extract out of CIAT – CSI SRTM (Version 4), Jarvis *et al.*, 2008.
5. Cape Vulture restaurant and roosting/breeding sites across the Eastern Cape sourced from VulPro, December 2017.

3.3 Methodology

3.3.1 General

This research study is exploratory and descriptive, and follows a quantitative, mixed research design. A variety of methods were adopted to achieve the objectives of the study. All field data collected by CVC on power line related incidents within the Eastern Cape between and including January 2008 and December 2017 was received from CVC in an excel spreadsheet. This data was compiled into a spatial database, whereby data was cleaned, coordinates checked and plotted. This was followed by the necessary projection conversion of data points and other associated GIS data and clipping of data to the study area. Field data for this study is documented in two ways, 'Incident Reports' and the number of 'Vultures Affected'. Incident Reports relate to the number of reported incidents, whereas the Vultures Affected refers to the actual number of birds affected at each incident. For example, a single reported incident can have multiple affected birds. A total number of 171 Cape Vultures have been documented in 73 incident reports by CVC and included in this research. Although total Incident Reports and Vultures Affected are important, due to the nature of the interaction type, it is essential to distinguish between collision incident types and electrocution incident types. In a spatial context, Incident Reports are considered marked point patterns where the location, but also the stochastic attribute of the number of Vultures Affected at each Incident point is important (O'Sullivan and Unwin, 2010). Areas of where higher frequencies of Incident Reports and Vultures Affected occur can be considered hotspots.

3.3.2 Hotspot Analysis

3.3.2.1 *Exploratory Spatial Data Analysis*

Patterns and statistics of this field data were critically assessed through Exploratory (Spatial) Data Analysis (ESDA) methods to determine any statistical patterns worth noting before hotspot analysis could take place. This was done through an initial descriptive numerical, and graphical exploratory data analysis (EDA) of field data to check the general tendency and spread of the different variables. The spatial clustering

in the data was determined using the Average Nearest Neighbor tool (ESRI, 2011). This was followed by testing for spatial autocorrelation in the data to check the correlation in the distance between incident report points. The differences between transmission and distribution power line incidents; electrocution and collision power line incidents; and yearly and seasonal power line incidents were investigated using chi-squared categorical tests and relative risk and odds ratio tests. This was run through using RStudio (2012) and ArcGIS Spatial Analyst extension (ESRI, 2011).

3.3.2.2 Hotspots

Hotspot analysis was run in a combination of QGIS (2016) and ArcGIS Spatial Analyst extension (ESRI, 2011). Hotspot analysis is classified as a broad set of analyses. However, the relatively limited data and the large spacing between points in this study had to be taken into account when deciding which method to use. This was done by using kernel density analysis. Hotspots or hot spot areas are identified through the frequency distribution of points across space, based on spatial proximity. This is primarily conducted through Kernel Density Estimation (Heatmap Plugin) in QGIS (2016), which is an exploratory method to identify clusters. The estimation assumes event density at any location and counts the number of events in a region. This is called the kernel around the location where the estimate is made. Nearby events are therefore weighted more heavily than further away. Reported incidents are the events, with the number of vultures affected as the weighting. Due to the nature of the data, network kernel density for linear features such as in traffic accidents cannot be applied, as often the incident report is not recorded directly on the line. Literature studies and ESDA analysis results as outlined in Section 4.1.2, guide criteria to be used as rules to determine final hotspots. Five collision hotspots and seven electrocution hotspots were identified and ranked in severity with a lower number indicating a higher severity. Each hotspot is assigned to the closest ~one-kilometre stretch of the power line for electrocution hotspots and ~one and a half kilometre for collision hotspots (within 500 metres of an incident point, spanning from pylon structure to pylon structure). Each power line portion extends at

least 500 metres either side of the incident point, except where the line terminates earlier. Terrain and topographic analysis will be conducted on these power line portions.

3.3.3 Basic Terrain and Topographic Analysis

3.3.3.1 *Introduction*

Terrain primary attributes include slope, aspect and plan and profile curvature. Although traditionally, these attributes are viewed as an important part of hydrological studies, they are essential in the construction of power lines. This, together with cost influences spacing, structure and height of the power lines. Power line pylon spacing and height above the base terrain, therefore, infer its own attributes. In this study, it is important to account for both the terrain base and that of the power line. It is for this reason that the base height of the power line was offset to a constant value of 25m for transmission lines and 5m for distribution lines (the lowest point on the mid-span of power lines). Using the SRTM 90m DEM, basic Terrain and Topographic characteristics at each hotspot power line were determined using a combination of ArcGIS (ESRI, 2011), SAGA (Conrad *et al.*, 2015) and various tools and plugins in QGIS (2016). These included the following:

3.3.3.2 *Elevation analysis*

The elevation of the ground plays a significant role in the height of the power lines. A QGIS plugin 'qProf' (2016) was used to extract elevation values from the DEM pixels that the power line vector file crosses. General statistics for each power line stretch was also generated.

3.3.3.3 *Slope analysis*

A slope can be described by a plane at a tangent to a point on the surface and is made up of two components: Gradient, which is the maximum rate of change of the elevation of the plane (the angle that the plane makes with a horizontal surface) and aspect which is the direction of the plane with respect to some arbitrary zero (north) (De Smith, Goodchild, and Longley, 2007). All hotspot power lines have a slope angle

(gradient) and slope aspect associated with each power line segment. The gradient of the slope is not uniform across the entire power line. Elevation was sampled per pixel for terrain and per pylon for the power lines. The slope was calculated for the segment between these points and the overall mean slope for each line portion is summarised for both collision and electrocution hotspot power lines. This was initially calculated in percentages but converted to degrees for easier reference. A slope is positive if uphill and negative if downhill, but this is dependent on the start together with the directionality of the power line segment. Network directionality in this type of study is not applicable and thus can be considered subjective. It is for this reason that interpretation is derived and assessed on the absolute values of the overall mean slope angles. QGIS Raster Terrain Analysis (2016) was used to calculate aspect analysis outputting a final aspect raster layer with values from 0 to 360 that express the slope direction: starting from North (0°) and continuing clockwise. Aspect values were sampled per pixel for terrain under the power lines using the QGIS plugin 'qProf' (2016). Aspect values were then grouped according to the direction they face (north to north-east, north-east to east, etc.) and the frequency was determined.

3.3.3.4 Curvature analysis

A curvature at a point is generally the inverse of the radius of a circle tangent to the surface at this point in the normal plane. There are two principal curvatures to be investigated, Profile Curvature (rate of change of gradient) and Plan Curvature (rate of change of aspect). Profile Curvature is the index of the surface shape in the direction of the power line, and Plan (Tangential) Curvature is the profile shape in the direction of the contour, at a right angle to the downhill direction (profile curvature). The differential expression for plan curvature is similar to that for profile curvature (De Smith, Goodchild, and Longley, 2007). Small values give a concave surface (bowed) and large values give a convex surface (peaked). SAGA terrain analysis, slope, aspect and curvature tool (2015) was used to generate rasters for both profile and plan curvature attributes. This was calculated using SAGA's Curvature plugin using a 9 parameter 2nd order

polynom (Zevenbergen and Thorne, 1987). Plan Curvature is calculated for each pixel under of the power line, which is essentially the curvature of a contour line at height z and location (x, y) on the power line. A positive value indicates the surface is laterally convex at that pixel. A negative plan indicates the surface is laterally concave at that pixel. A value of zero or very close to zero indicates the surface is linear. The values for the curvature are quantified and assessed for each hotspot power line.

3.3.3.5 Orientation Analysis

The orientation of power lines in relation to perennial wind directions is important as it is a well-known fact that birds land and take off with the wind direction (Bevanger, 1994). Vultures, in particular, need the wind for a better lift due to their biological aspects. Therefore, a wind direction perpendicular to the direction of the line would cause more problems than lines in parallel (Shaw, 2009). Orientation analysis determined the orientation of each power line in relation to the perennial wind direction. A python script in ArcGIS (ESRI, 2011) calculated the angle from the north for each hotspot area line. The perennial wind direction at each hotspot was derived from the South African Weather Service data using the closest weather station to each hotspot. All lines with angles with greater than 45degrees either side of the wind direction orientation were classified as perpendicular and lines less than 45degrees either side of the wind direction, parallel.

3.3.3.6 Visibility analysis

The Eastern Cape has a number of undulating mountainous or hilly areas, which reduces the visibility of power lines to a bird in flight when these lines are backdropped against the dark background of these elevated areas (Kotoane's, 2004), which in turn increases the probability of a collision occurring. Visibility analysis allows us to ascertain which power lines have hills/mountains within a 2500m radius of the hotspot power lines.

The analysis was conducted in QGIS (2016) using visibility analysis plugin in a similar manner to that of Kotoane's (2004). A buffer of 2500m was created along each power line and used to mask the original DEM to speed up processing. Using the power line vertices as input points, and the height in the viewshed tool was set at a constant value of 25m (the lowest point on the mid-span of the transmission power lines). The resultant data layer was an integer grid with values of 0 for invisible areas and 1 for visible areas. The visible pixels were used as a mask to extract the elevation data from the underlying DEM. The result was a raster grid data layer that consists of the elevation of the areas visible to segments of the power line. The height of elevations in the viewed area was compared to the highest elevation value of the power line portion in each hotspot. If values were higher, then a resultant value of 1 was given, and if the values were lower, then a 0 was returned. The resulting grid contains 0 and 1 values. The values of 1 represent all elevations that are higher than the highest power line elevation point (Figure 3-2).

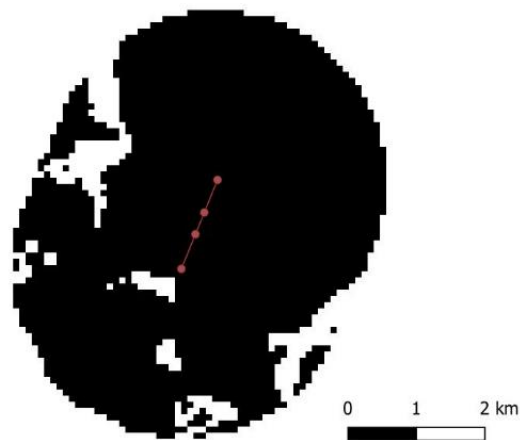


Figure 3-2: Snapshot of a visibility output in Collision Hotspot 2 (Black (invisible)= 0 and White (visible)= 1)

3.3.3.7 *Overlay Analysis*

Vultures tend to prefer foraging in open habitats (Mundy *et al.*, 1992) and use electricity pylons in areas nearly devoid of trees (Bevanger, 1994; Lehman *et al.*, 2007); therefore biomes such as grassland or karoo would be preferred. Each hotspot power line stretch was overlain on the South African National Biodiversity Institute SANBI's (2006) vegetation data (Mucina and Rutherford, 2011) and each biome was recorded.

3.3.3.8 *Proximity analysis*

Vultures can fly long distances in search of food, and these distances and directions are variable. Landowners, in particular abattoirs and cattle feedlots, place deceased domestic animals/unwanted meat unfit for human consumption in an undisturbed area, where vultures and other scavengers can feed. These areas are known as vulture restaurants and provide a constant supply of food in times of food scarcity. The birds, therefore, have starting points (roosts and breeding sites) and destination points (restaurants/feeding sites) which they require water sources along the way. Euclidean distances from the identified hotspot power lines to these points were calculated for the proximal relationships. This was achieved through using VulPro's dataset of Eastern Cape roosting/breeding sites and restaurant sites; and SANBI's National Freshwater Ecosystem Priority Areas Project (NFEPA) dataset (2006) and QGIS MMQGIS Hub distance Plugin (2016, version 2.14.22-Essen). Midpoints were generated for each hotspot power line portion and waterbodies. Distances between points were generated, and each filtered to determine the shortest distances. This was done in conjunction with running different distance buffer zones using QGIS Buffer tool (2016, version 2.14.22-Essen) and determining which points fall within these zones for histogram analysis.

3.3.4 Rule Set for Basic Terrain and Topographic Characteristics

The basic Terrain and Topographic characteristic results for all the above analyses were compared and compiled into a table. Results were deemed conclusive when a characteristic was similar. Inconclusive results were defined where characteristics could be correlated across some hotspots but not the majority of hotspots. Conclusive results were given a higher importance, whereas inconclusive results, were given less of importance levels. The importance levels are important when these results form rules for the future development of a predictive rule-based risk model across the Eastern Cape.

4 CHAPTER FOUR – RESULTS AND DISCUSSION

4.1 Hotspot Analysis

4.1.1 Exploratory Spatial Data Analysis

4.1.1.1 *Overview*

In the Eastern Cape, a total number of 171 Cape Vultures have been documented in 73 incident reports to be negatively affected by power line interactions between and including January 2008 and December 2017. Majority of Vultures affected and incident reports involve power line electrocutions. On average, double the number of birds are affected in an electrocution incident than in a collision incident. The statistical summary of these incidents is provided in Table 4-1 and histogram graphs in Figure 4-1.

Table 4-1: Summary Statistic Table for Incident reports and Vultures affected

	Incident Reports	Total Vultures affected	Average no Vultures per incident report	Std Deviation	Median no Vultures affected per incident report	Min no Vultures affected at incident report	Max no Vultures affected at incident report
Collision	28	37	1.32	1.33	1	1	8
Electrocution	45	134	2.98	2.38	2	1	11
All	73	171	2.34	2.19	1	1	11

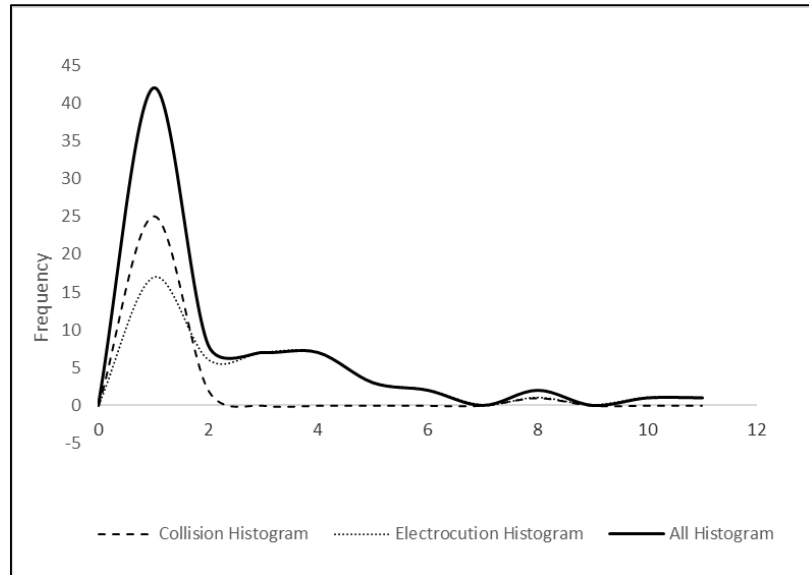


Figure 4-1: Histograms indicating the frequency of Number of Vultures affected in incident reports

The skewed right distributions of the histogram curves indicate that the bulk of the incident reports involve a small number of affected birds, with a few incidents that are much larger than the rest. The collision histogram indicates a unimodal distribution whereby the electrocution histogram indicates a bimodal or even a multimodal distribution, which is also reflected in the All histogram.

Visual representation of the incident reports (Figure 4-2) reveals that the majority are scattered in a non-random spatial point pattern, with points differing between collision incident types and electrocution incident types. Using a nearest neighbour index (ESRI, 2011) based on the average distance from each feature to its nearest neighbouring feature. It tests whether the point pattern from the field data is indeed clustered, by assuming the null hypothesis specifies that the point pattern is randomly distributed.

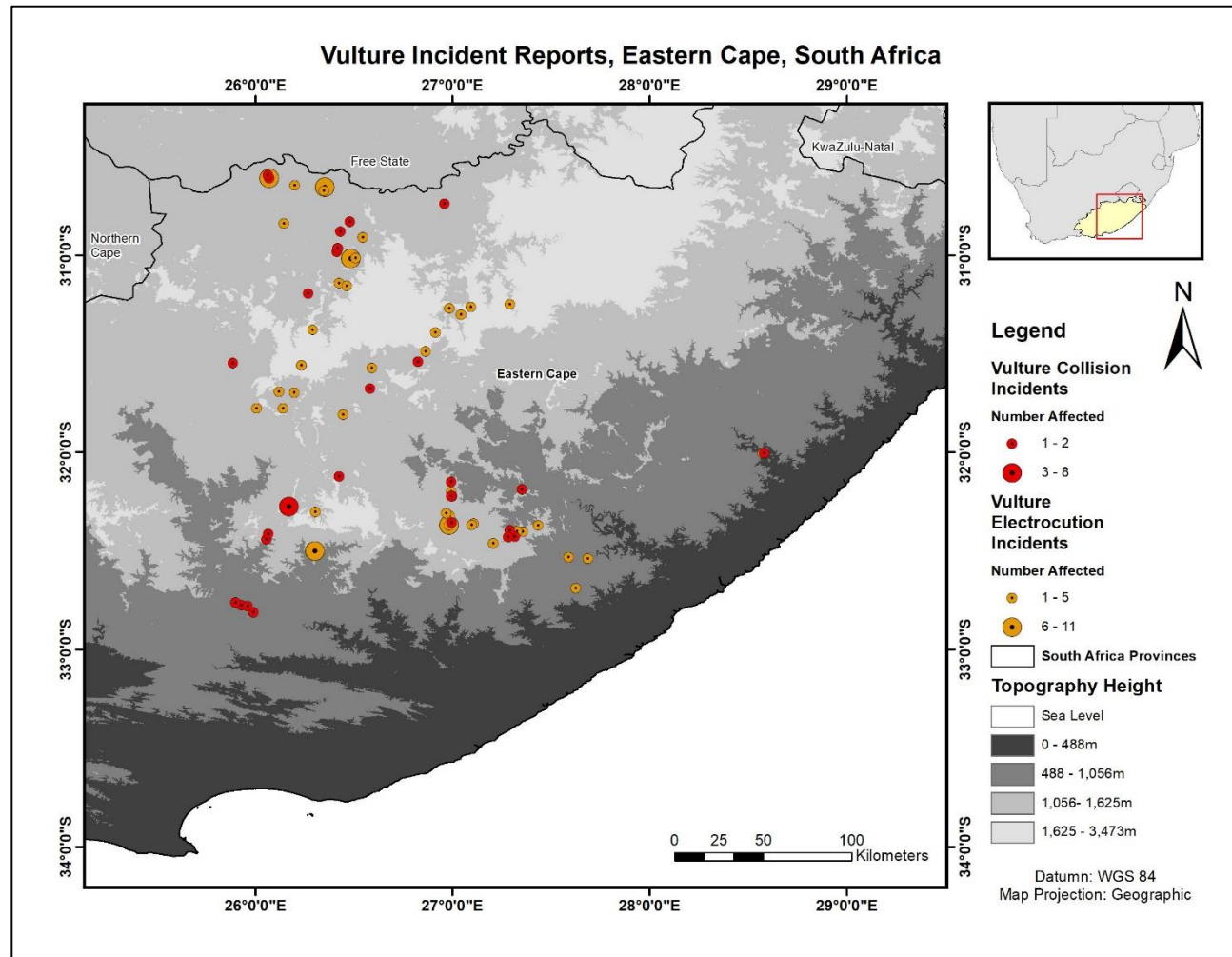


Figure 4-2: Visual representation of Incident Reports

All three analyses rejected the null hypothesis and returned a negative z-scores, which indicates clustering. The z-scores are all strongly negative, indicating there is a less than 1% likelihood that this clustered pattern could be the result of random chance. The nearest neighbour indexes are all below the value of 1, also indicating the pattern exhibits clustering. See Table 4-2.

Table 4-2: Analysis using area sizes for Average Nearest Neighbour calculation

Dataset	Area Size (m) Eastern Cape	p- Value	Z-Value	Nearest Neighbor Index	Accept/ Reject Null hypothesis	Clustered / random/ dispersed pattern
Collision	170331340782	0.00	-5.9572333	0.411516	Reject the Null Hypothesis	Clustered
Electrocution	170331340782	0.00	-8.377786	0.347182	Reject the Null Hypothesis	Clustered
All	170331340782	0.00	-11.239063	0.330495	Reject the Null Hypothesis	Clustered

4.1.1.2 Yearly Profile

There has been a generally steady increase in the overall number of incident reports and Vultures affected (Appendix 2) from the lowest in 2009 (2 Reports and 5 Vultures affected) to the most occur in 2017 (16 Reports and 49 Vultures affected). Although there is a general increase, both Incident Reports and Vultures affected are variable with later years in the study falling below the calculated yearly means (7.3 for Incident Reports and 17.1 for Vultures Affected) of the data (Figure 4-3). There is a nonlinear increase in both electrocution and collision incidents of vultures over the years. Electrocution incidents numbers have always been more per year than those of the collision incidents. As seen in total incidents, there is variability in total numbers, with a rather significant jump in numbers in both collision and electrocution numbers in 2017 (Figure 4-3).

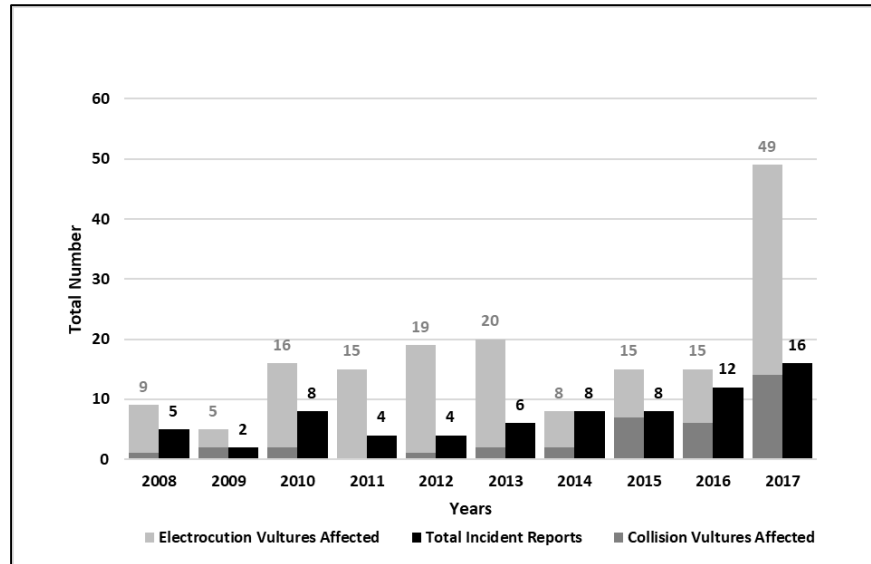


Figure 4-3: Total Number of Incident Reports and Vultures affected per year with Vultures affected stacked per interaction type.

4.1.1.3 Seasonal Profile

Most incident reports and affected birds (Appendix 2) occur in the months of (March, April and May), the South African Autumn Months (82 birds from 26 Incident Reports). This season has both the highest number of electrocution and collision incidents. This is followed by Spring (September, October and November) (34 Birds from 17 Reports). This season has the lowest number of collisions. The lowest incident reports and affected bird numbers being in Summer (December, January and February) (26 Birds from 15 Incident Reports) (Figure 4-4). The Chi-squared test for association failed to reject the null hypothesis of no relationship between the Season and the Incident Type ($X^2 = 1.5035$, $df = 3$, $p\text{-value} = 0.6815$).

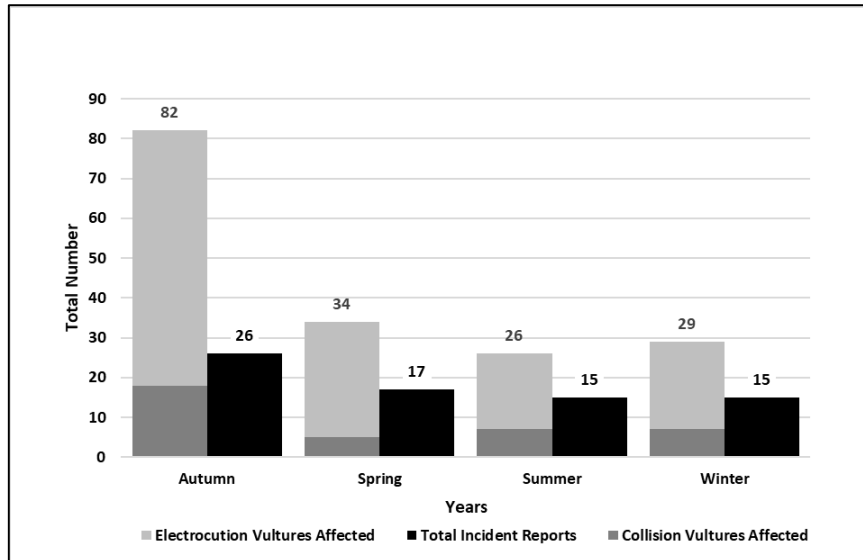


Figure 4-4: Total Number of Incident Reports and Vultures affected per season with Vultures affected stacked per interaction type.

4.1.1.4 Line Type Profile

Most incident reports and affected birds (Appendix 2) occur on distribution lines. Distribution lines interaction incidences (139 Vultures Affected and 52 Incident Reports) more than double the transmission lines interactions (32 Vultures Affected and 21 Incident Reports) (Figure 4-5). A significant number of electrocutions occur on distribution lines versus that occurring on transmission lines, whereas the collisions occur more on Transmission lines.

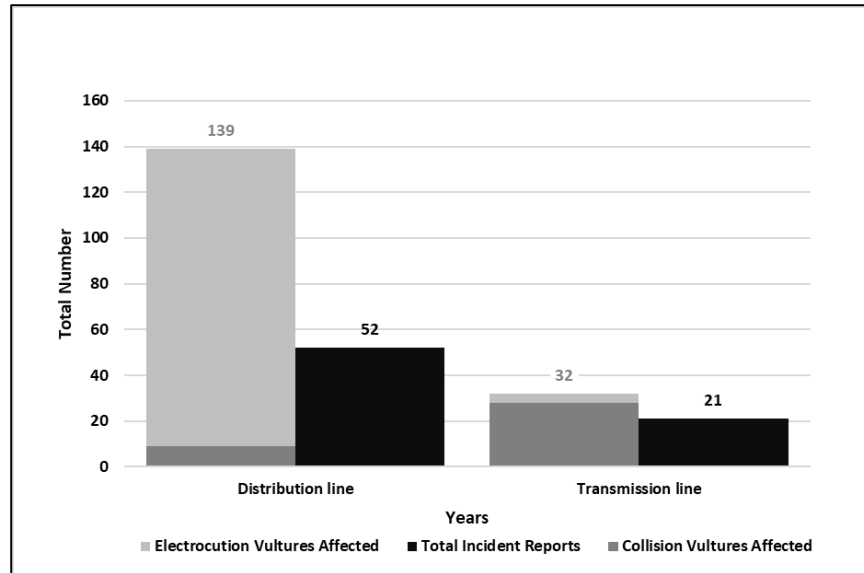


Figure 4-5: Total Number of Incident Reports and Vultures affected per Power Line Type with Vultures affected stacked per interaction type.

Chi-squared test for association revealed that the P-value is very small thus reject the null hypothesis of no association and conclude that there is, in fact, a relationship between Power Line Type and the Incident Type ($\chi^2 = 105.25$, $df = 1$, $p\text{-value} < 0.001$). As there is a relationship between the Power Line Type and the Incident Type, the contingency table was used to calculate the relative risk and odds ratio of the categorical variables.

Relative Risk ratios calculated from the contingency table (Table 4-3) indicated that for Incident types by Transmission Lines, it is 13.51 times more likely to have a collision incident involving a Transmission line than a distribution line. The electrocution risk is significantly less (0.13 times). The Relative Risk for Distribution lines is mirrored with 7.5 times more likelihood of a bird being electrocuted if the line involved is a distribution line. Collision Risk is on distribution lines is insignificant (0.07 times). The odds ratio revealed the odds of a bird getting electrocuted on a distribution line is 101 times more likely than that on a transmission line. Moreover, the odds of a collision occurring more by distribution lines is insignificant.

Table 4-3: Contingency Table for Power Line Type and Power Line Incident Type

Line Type	Collision	Electrocution	All
Distribution line	9	130	139
Transmission line	28	4	32
All	37	134	171

4.1.2 Hotspots

Literature studies and the above ESDA analysis indicate that the nature, average and distribution across years, seasons and line types differ between birds colliding with or being electrocuted on power lines across South Africa. These guide decision-making criteria when selecting hotspots for this study. The criteria are listed as follows:

1. Hotspots are distinguished into collision hotspots and electrocution hotspots
2. The average number of Vultures electrocuted in a single incident is far higher than the average number of birds involved in a collision power line interaction. It is for this reason that the cut-off threshold values for hotspots are higher in electrocution hotspots (2 for Collision and 5 for Electrocution).
3. Although there is a general increase in Incident Reports and Vultures Affected per year for both collision and electrocution power line interactions, it is not systematic and therefore does not affect final hotspot areas.
4. Most Incident Reports and Vultures Affected occur in Autumn months, but there is no association between incident type and season, so will not affect the final hotspot analysis.
5. Most Incident Reports and Vultures Affected involve distribution power lines; however, there is an association between line type and incident type. So, apply the following:
 - a. The risk and odd-ratio indicate that collision hotspots are more likely associated with transmission lines than distribution lines; therefore, only transmission line hotspots will be considered for collision hotspots.

- b. The risk and odd-ratio indicate that electrocution hotspots are more likely associated with distribution lines than transmission lines; therefore, only distribution line hotspots will be considered for electrocution hotspots.

Using the above criteria, five collision hotspots (Figure 4-6) and seven electrocution hotspots (Figure 4-7) were identified and ranked in severity with a lower number indicating a higher severity. The hotspots indicate no observed pattern. Although often found in relatively close proximity to one another, collision and electrocution hotspots are generally found not to overlap. An exception would be where collision hotspot three and electrocution hotspot four, which directly overlap each other. This confirms the fundamental differences between collision and electrocution incidents, as identified above. As such, the study continued to treat them as separate hotspots. However, it must be noted, that where they overlap, conditions favourable for both collision and electrocutions must exist, which makes this area particularly high risk. Majority of the hotspots have multiple incident reports that are further apart; thus, each point is then assigned to a portion of power line. Thus, some hotspots have multiple affected power line portions (Table 4-4 and Appendix 3).

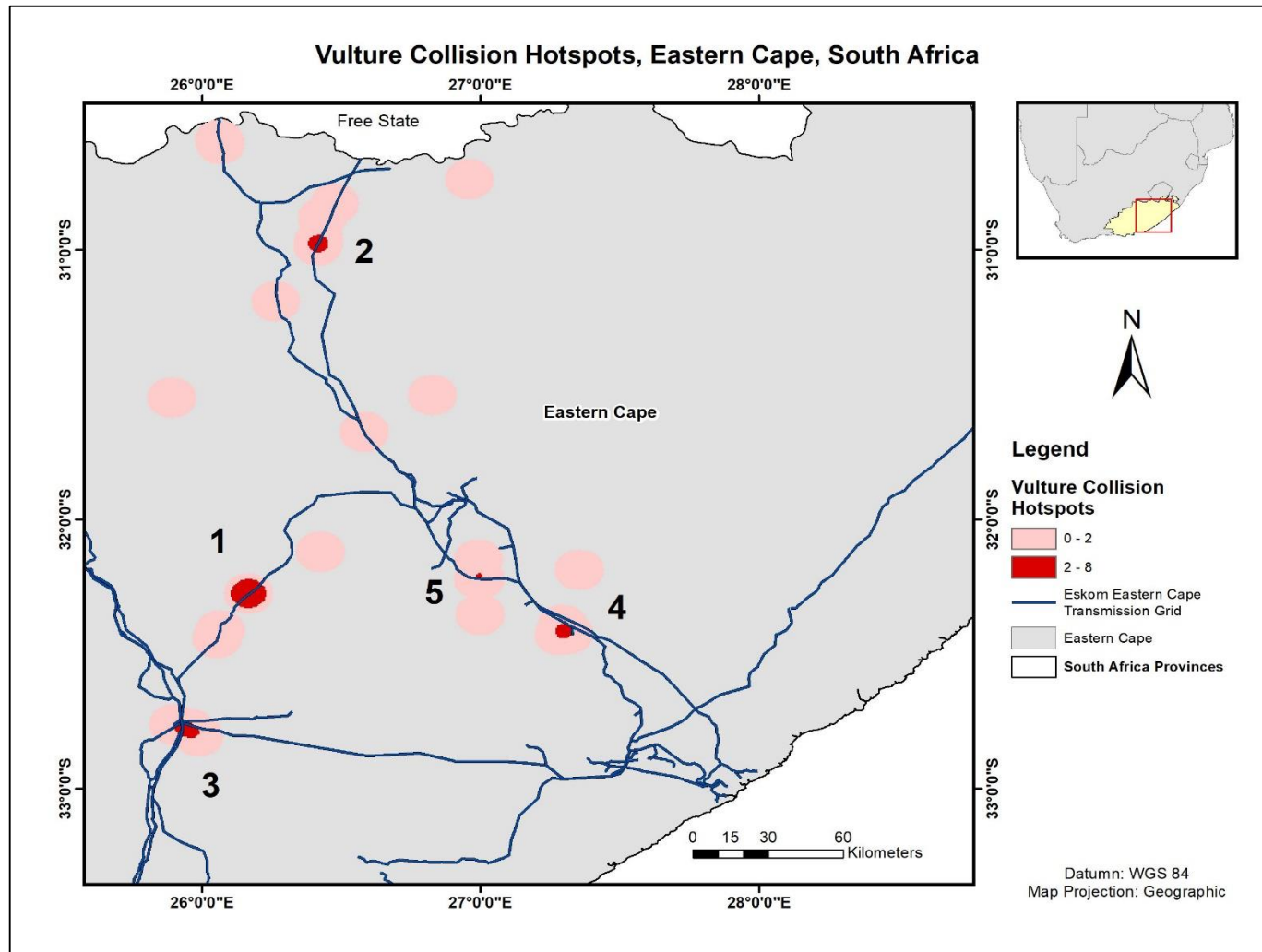


Figure 4-6: Final Collision Hotspots numbered according to areas of highest frequencies to lowest frequencies.

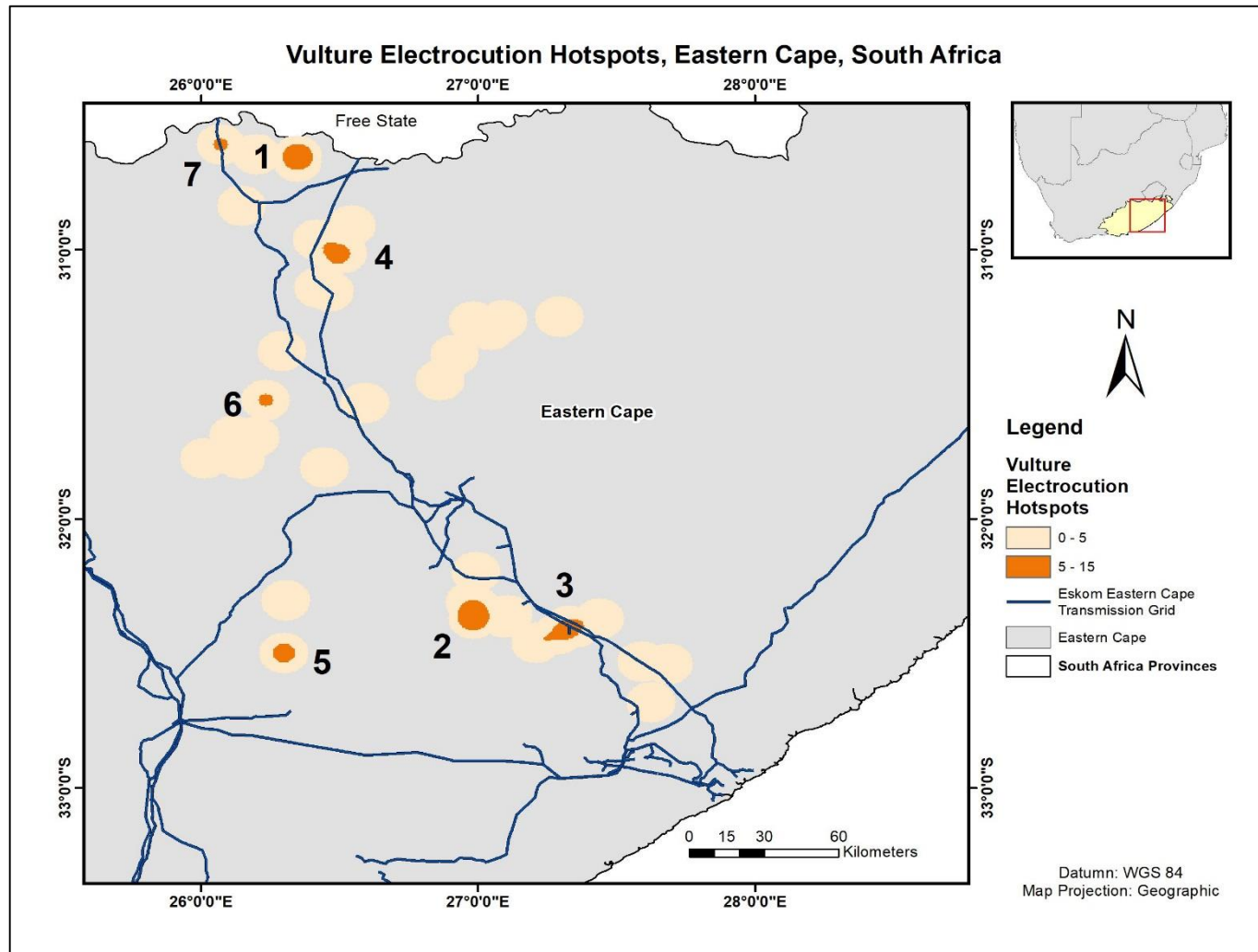


Figure 4-7: Final Electrocuting Hotspots numbered according to areas of highest frequencies to lowest frequencies.

Table 4-4: Hotspot Areas with respective power lines portions

Hotspot Number	Line Number	Line Length (m)
COLLISION		
HOTSPOT1	Line C1.1	1347.27
HOTSPOT2	Line C2.1	1402.74
	Line C3.1	1423.54
HOTSPOT3	Line C3.2	1436.25
	Line C3.3	1823.33
	Line C3.4	1285.26
HOTSPOT4	Line C4.1	1380.12
HOTSPOT5	Line C5.1	1365.54
ELECTROCUTION		
HOTSPOT1	Line E1.1	1317.95
	Line E1.2	1273.81
	Line E2.1	1043.16
HOTSPOT2	Line E2.2	1276.76
	Line E2.3	1012.37
	Line E3.1	1206.64
HOTSPOT3	Line E3.2	1165.23
	Line E3.3	909.467
	Line E4.1	1187.87
HOTSPOT4	Line E4.2	986.894
	Line E5.1	712.804
HOTSPOT6	Line E6.1	1100.19
HOTSPOT7	Line E7.1	903.649

4.2 Basic Terrain and Topographic Spatial analysis

4.2.1 Terrain Spatial Analysis

4.2.1.1 *Elevation*

The elevations above sea level for the power lines of both collision and electrocution hotspots are variable; however, the majority are above 1000m above sea level, the only exception is the power lines in third collision hotspot (Appendix 4). This is likely due to an overlap with the current Cape Vulture distribution areas (as seen in Section 2.1.1 and Figure 2-2) and the elevations found within the range. Collision hotspots have an average elevation change of around 50m between the highest and lowest elevation points on the line. Electrocution

hotspots elevation of power lines is flatter with majority lines having less than 20m elevation change between the highest and lowest elevation points on the line.

4.2.1.2 Slope

4.2.1.2.1 Gradient

The mean gradient change for both power lines and the underlying terrain is relatively small, as all have less than a 7-degree change. Power line gradient and variability is lower than that of terrain gradients, with collision power lines having the lowest gradient mean changes (less than 4-degree change). The gradient change in terrain under collision hotspot power lines have smaller gradient changes (less than 5-degree change) with less variability than the terrain gradient (less than 7-degree change) under the electrocution hotspot power lines.

4.2.1.2.2 Aspect

Aspect varies across power line segments for both collision and electrocution. The collision histogram indicates a unimodal distribution whereby the electrocution histogram indicates a bimodal distribution (Figure 4-8). The majority of collision power lines have north-easterly to south-easterly facing aspects, whereas electrocution hotspot power lines have both easterly facing aspects and westerly to north-westerly facing aspects.

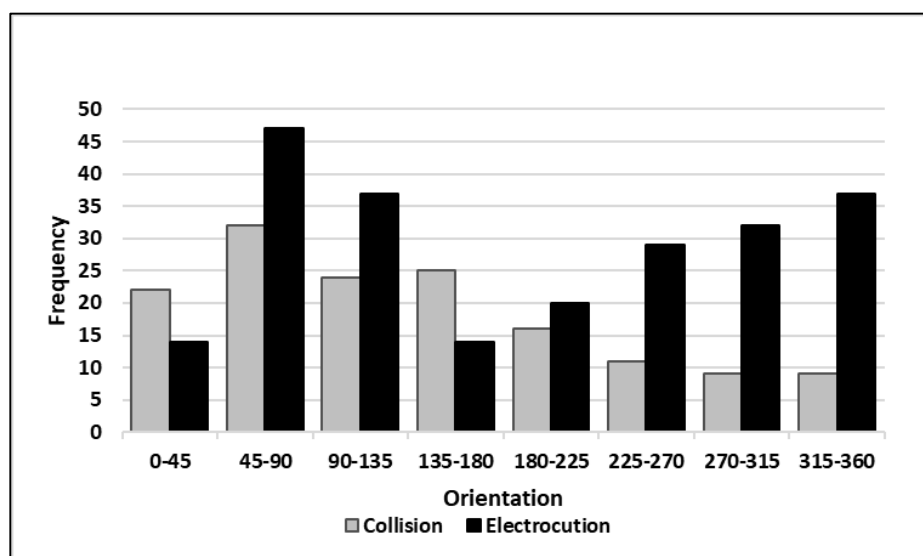


Figure 4-8: Aspect Histogram for Collision and Electrocution power lines

4.2.1.3 Profiles and Plan Curvature

Profile curvature of collision hotspot lines tend to be more convex and planar than concave (Figure 4-9). The terrain profile curvature generally follows the same curvature but is more undulating for profile power lines C2.1, C4.1 and C5.1, which all indicate a convex hill in the middle of the profile. Profile curvature of electrocution hotspot lines is more closely linked to the respective terrain profiles (Figure 4-10). These profiles tend to be more convex and planar than concave, except for profile power line E5.1, which has a very deep concave shape. Profile power lines E2.2, E2.3, E3.1 and E3.3, have a terrain profile which has a slight concave valley to the side of the profile, which the power lines smooth out. Each power line revealed that majority of the collision hotspot lines have laterally convex profiles directly under the line, whereas with electrocution lines equally indicate that they are laterally convex and concave terrain under the line, with Line E7.1 having linear plan curvature under part of the line.

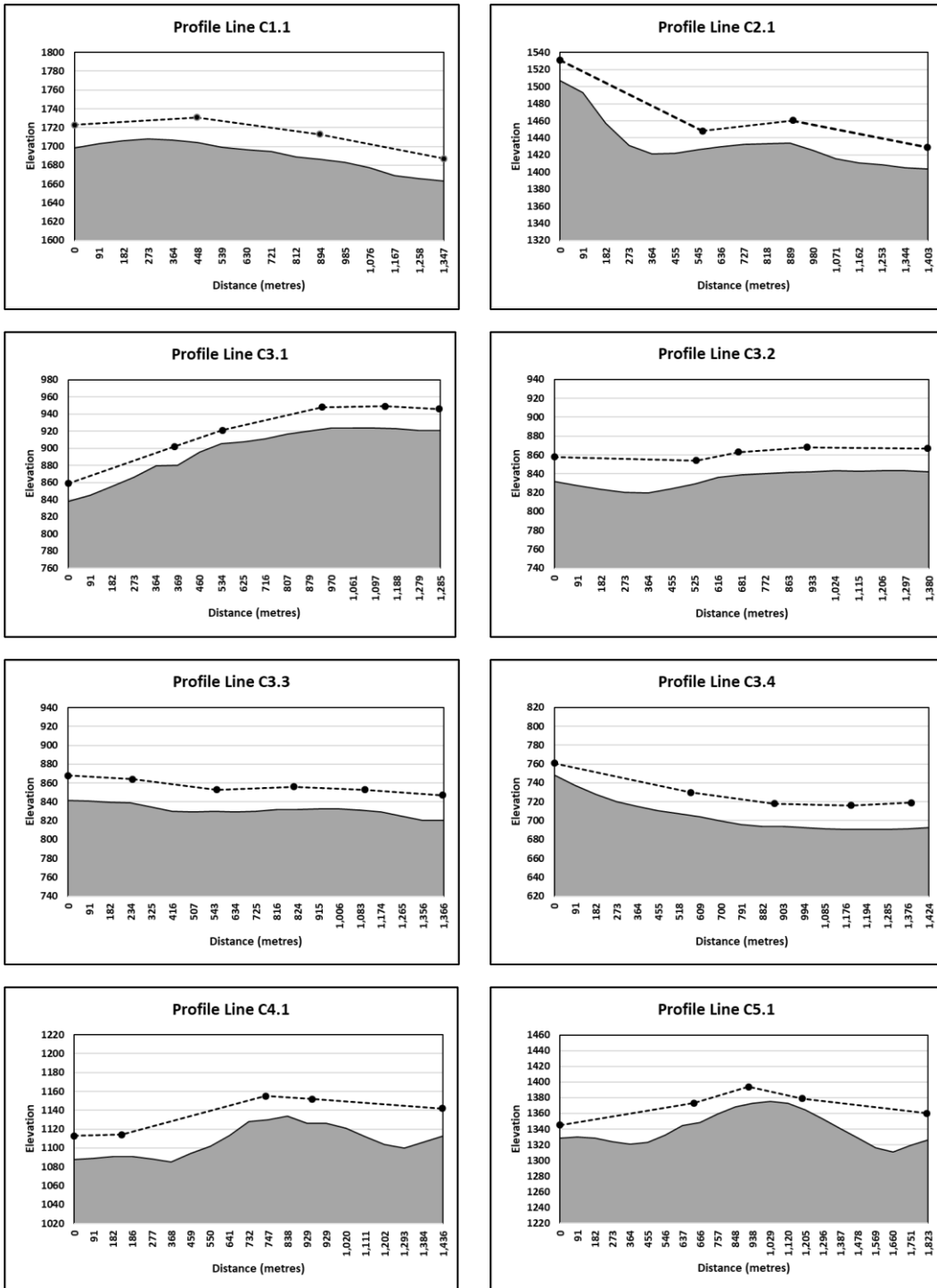


Figure 4-9: Hotspot Collision Profiles (Solid Fill – Terrain Profile and dashed Line – Power Line Profile)

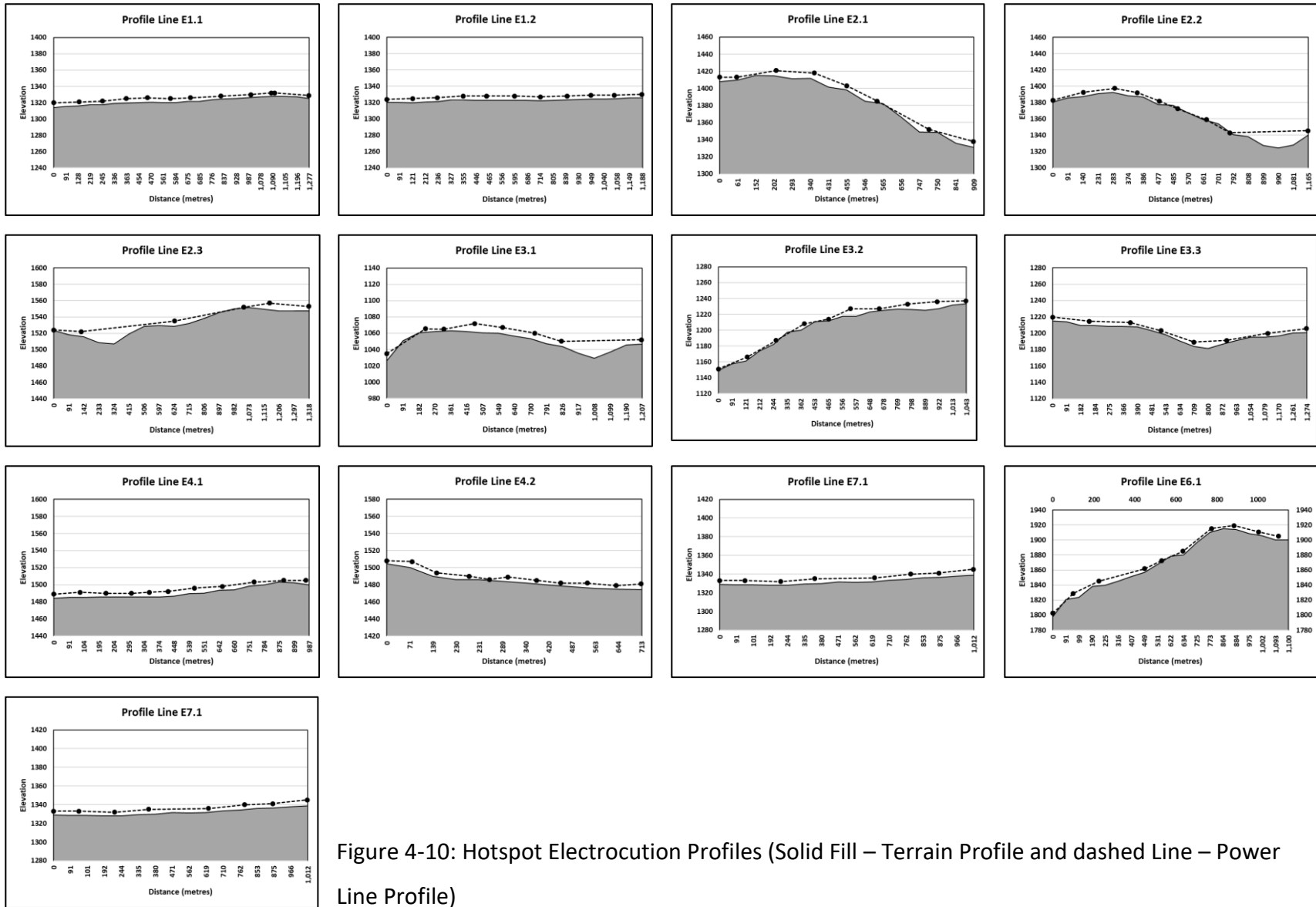


Figure 4-10: Hotspot Electrocutation Profiles (Solid Fill – Terrain Profile and dashed Line – Power Line Profile)

4.2.2 Orientation Analysis

Perennial winds in the hotspot areas range from north-westerlies to south-easterlies. Majority of electrocution hotspot areas power lines are found to be perpendicular to that of the wind direction. It correlates to a study by the Benson (1981) that birds perching on power lines use lines that are perpendicular to perennial winds. This is likely that it is easier to land and take off from the infrastructure with the wind direction. The angle of power lines relative to the prevailing wind was not significant for collision hotspots and is an indication that collisions are likely not as a result of landing and taking off and could be related to strong winds of any direction (Shaw, 2009). It is also important to consider that although perennial wind directions are an important consideration, specific topographies will lend themselves to microclimates, which could alter the wind direction and speed (Shaw, 2009). Summaries are presented in Appendix 4.

4.2.3 Visibility Analysis (Collision Risk)

Wind direction analysis indicated that the orientation of the line does not play a role in determining the collision risk; therefore, all directions from the line are considered important. Majority of the power lines portions have areas of higher elevation in the surrounding 2500m vicinity, thus increasing the obscurity of these lines against the darker backdrop. The elevations are often not isolated and form local ridges or crests, which, when compared with the power line directions, are found to run mostly in parallel with these line portions. Distances to line vary, with some lines running right next to the crest, whereas, some are a further distance away. This is summarised in Appendix 4.

4.2.4 Overlay analysis

All collision and electrocution hotspot areas occur over the open ground of the grassland and/or karoo vegetation biomes. This confirms previous studies that

vultures are most susceptible to roosting in open country and using this country as foraging habitats (Mundy *et al.*, 1992; Boshoff *et al.*, 2011; CVC pers. comm., 2016). This could be related to the overlap of these areas with the diminishing distribution of the Cape Vulture in the Eastern Cape (Boshoff *et al.*, 2011; ICUN 2015). This is summarised in Table in Appendix 4.

4.2.5 Proximity Analysis

4.2.5.1 *Roosting and Breeding Sites*

Distances to the closest two roosts/breeding sites are summarised in the histograms in Figure 4-11 and Appendix 4. This indicates that there is a bimodal distribution for both collision and electrocution hotspots. Majority of the hotspots occur within 15 to 30km away from a roosting or breeding site for both collision and electrocution hotspots and also between 45 to 60km away for electrocution hotspots.

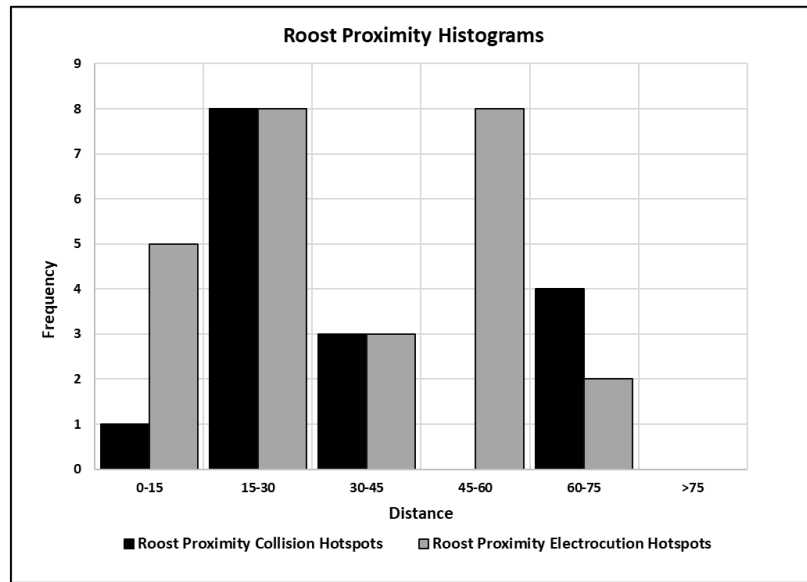
4.2.5.2 *Vulture Feeding Restaurants*

Distances to the nearest restaurants summarised in the histograms in Figure 4-11 and Appendix 4. This indicates that there is a bimodal distribution for electrocution hotspots, whereas there is a unimodal distribution for collision hotspots. Therefore, the majority of the restaurants fall within 15 to 30km for electrocution and over 90km for collision hotspots.

4.2.5.3 *Water Sources*

Vultures require water sources close to their feeding sites as they use these to bath after feeding. Distances to the nearest water source indicated that all sources are found within 3km radius, with the majority found within 1km of the hotspot power lines.

a)



b)

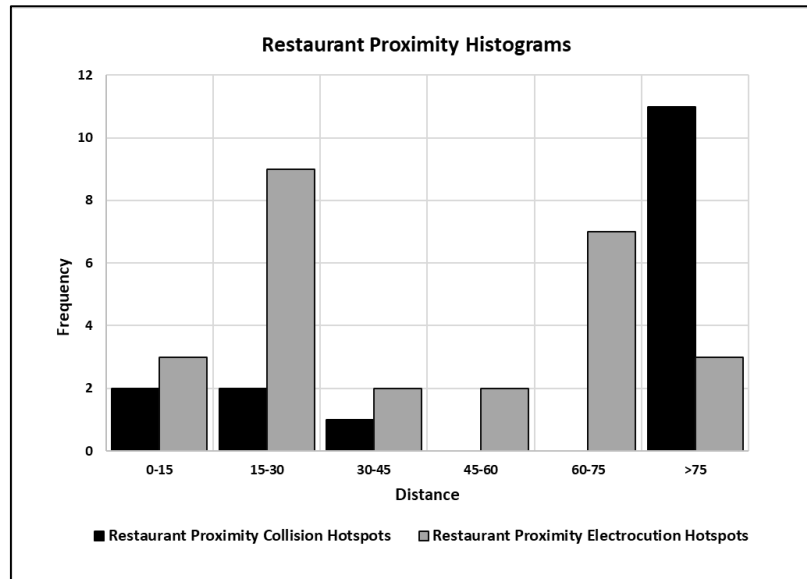


Figure 4-11: a and b): Histograms for Roosting and Restaurant Proximity

4.3 Discussion

The study investigates terrain and topographic characteristics associated with power lines in hotspot areas of Cape Vulture power line incidents in the Eastern Cape. This is achieved initially by an investigation into the field data characteristics, which are used in the identification of areas where there is a higher frequency of incidents.

Exploratory Spatial Data Analysis of the field data confirmed that collision and electrocution incidents are inherently different and the findings of Boshoff *et al.*, 2011, that in the Eastern Cape, the majority of the Cape Vultures are electrocuted. A single electrocution incident generally involves multiple birds, which is indicative that vultures will often perch in numbers on pylons where they move around and interact with each other, adding to the risk of multiple electrocutions (Van Rooyen and Ledger, 1997). The clustering of incident data builds on existing evidence that majority avian collision and electrocution incidents are indeed spatially significant and not random (Quinn *et al.*, 2011). There is a non-linear increase year on year incidents, although alarming cannot translate into a spike in incidents, as this is not systematically collected data. This could be attributed to increased awareness and better reporting, as CVC have indicated that they have put much effort into marketing and communication with the farming communities over the years. Seasonality in incident reports and affected birds are likely attributed to the breeding cycle of the Vultures, as the Winter months, the majority of the birds are nesting (Mundy *et al.*, 1992, Campbell, 2015; CVC pers. comm., 2016) and thus not travelling far from the nest in search for food. Due to the scope of this study, this was not tested and would only be able to be tested using tracking data of the birds. This is in contrast to the end of Summer and Autumn months, where the vegetation is at its thickest, and the abundance food is limited (fewer dead animals), and the majority of the younger vultures have just taken to flight (Mundy *et al.*, 1992, Campbell, 2015; CVC pers. comm., 2016). The relationship identified between Power Line Type and the Incident Type agrees with studies conducted in the USA on Bonelli's Eagle (Loss *et al.*, 2014) which show that electrocution incidents are associated with distribution lines and collision incidents are associated with transmission lines. This is likely due to the technical design of the structures and the height of structures. Transmission lines are higher and thus, more in the path for collision risk (APLIC, 1994). The distribution lines are lower in height, and line

configuration is closer together (APLIC, 1994), and the structures allow for birds to perch; thus, birds are more exposed to live wires which could result in electrocution (APLIC, 1994; Lehman *et al.*, 2007). These identified field data patterns and characteristics were able to guide the identification of both collision and electrocution hotspots across the Eastern Cape, South Africa. The hotspots all occur within the Cape Vulture distribution ranges (ICUN, 2015).

Assessment of the terrain and topographic characteristics at each hotspot revealed that majority hotspot power lines have a relatively small overall elevation and gradient change in both line and terrain slopes. This indicates that vultures are more likely to be found in flat and open areas (Mundy *et al.* 1992). Collision power lines have the lowest gradient changes, as transmission power line infrastructure is often very large. Due to limiting factors in construction (APLIC, 1994), transmission lines can only be built along the most level course through the terrain. This would translate to a lower gradient change, and less distinct concave and convex curvature terrain characteristics. The distance and height of the lines strung between pylons present a smoothing effect on the overall gradient of the line, often eliminating smaller terrain ruggedness presented in profile and plan curvatures. Distribution power line pylon infrastructure is smaller and closer spaced, thus mimic terrain slope variability more (APLIC, 1994). This is indicative of electrocution hotspot power line stretches. Collision power lines mostly have north-easterly to south-easterly facing aspects, whereas electrocution hotspot power lines have both easterly facing aspects and westerly to north-westerly facing aspects. There is no current literature to explain this, but further in-depth analysis is required to explain this phenomenon. Visibility analysis confirms the findings of Kotoane (2004), that visibility of power lines against the backdrop of the surrounding mountains and countryside play an important role in collision risk. If a bird cannot see the line in time to avoid it, it will, therefore, increase the likelihood of colliding with it.

Proximities to roosting and breeding sites are more important for both collision and electrocution hotspots than proximities of restaurants. The Cape Vulture is gregarious and will have a strong 'bond' to colony roosts and breeding areas, not necessarily returning to the same roost every night (Mundy *et al.*, 1992). Therefore, proximity to these sites will be crucial. Boshoff and Minnie (2011) also identified that that proximity within a circular range of 40 km radius (centred on the active breeding colony) realistically identifies the main foraging areas in the grassland-dominated Eastern Cape. Vultures are scavengers, and although they do rely on 'constant' food sources from restaurants, they will feed off any available food source, which can be found almost anywhere (Mundy *et al.*, 1992; Campbell, 2015). Proximity to water is also important, as the majority hotspots occur with 1km of open water bodies (Mundy *et al.*, 1992; Campbell, 2015).

4.3.1 Rule Set for Basic Terrain and Topographic Characteristics

Spatial analysis identified several basic terrains, and topographic characteristics at each hotspot and some of these were able to be correlated and the importance thereof. The data used in this analysis was sufficient enough to distinguish characteristics the study wanted to achieve. These characteristics can outline and form rules that can be applied in predictive modelling for further research in the prediction of power line risk for Cape Vulture in the Eastern Cape. These are outlined in Table 4-5. Thus, a model developed from these rules would only be able to be used within the Eastern Cape for Cape Vultures and would not be able to be applied across southern Africa and for other avian species. Once this model is developed, it would need to be field-checked to determine the effectiveness of these rules and the model.

Table 4-5: Rules for Predictive modelling for Vulture Collision and Electrocution hotspots

Rules	Collision	Electrocution	Priority and Comments
Season susceptibility	Autumn	Autumn	Somewhat Important
Power line Type	Transmission	Distribution	Important
Elevations	Above 1000m	Above 1000m	Somewhat important
Elevation Change	50m over 1500m power line stretch	20m over 1000m power line stretch	Somewhat important
Slope Gradients	less than 4-degree change in terrain gradient over 1500m power line stretch	less than 7-degree change in terrain gradient over 1500m power line stretch	Somewhat important
Slope Aspect	north-easterly to south-easterly	easterly facing aspects and westerly to north-westerly facing aspects	Important
Profiles Curvatures	convex and planar for 1000m power line portions	convex and planar for 1000m power line portions	Somewhat important
Plan Curvature	convex	Not significant	Somewhat important
Wind Direction and Line Orientation	Perpendicular or close to perpendicular	Parallel and Perpendicular	Important
Viewsheds	Parallel Linear Crests to power line portion within 2500m radius Height >Powerline mid-point height of Transmission	Not applicable	Important
Vegetation	Grassland or Karoo Biomes	Grassland or Karoo Biomes	Important
Breeding and Roosting Site Proximity	15 to 30km	15 to 30km	Important
Restaurant Proximity	15 to 30km and 60 to 75km	Over 75km	Not important
Water Proximity	Within 1km	Within 1km	Important

5 CHAPTER 5 - CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study and the field incident data parallel literature studies which document that the Cape Vulture is particularly susceptible to negative interactions with power lines in both collision and electrocution incidents, particularly in the Eastern Cape (Boshoff *et al.*, 2009, 2011 amongst numerous authors). This is related to their physiological features and their wide-ranging foraging habits (Mundy *et al.*, 1992, Bamford *et al.*, 2007., Boshoff *et al.*, 2011) together with different terrain and topographies they transverse.

The Cape Vulture incident data was found to be clustered as with the majority of avian power line interactions (Lehman *et al.*, 2007; Quinn *et al.*, 2011, amongst many other authors). Investigation of the variables that would perhaps influence this clustering indicates that yearly increases could not be considered significant due to the type of data collection whereas seasonality was more important as it coincides with the vultures breeding cycles and the areas and time spent out foraging (Mundy *et al.*, 1992; Campbell, 2015). A significant number of vultures are electrocuted on distribution power lines whereas more vultures collide with transmission lines. These criteria were used to identify the hotspots where the frequency of collision and electrocution incidents were higher than those of the surrounding areas. Thus, the first objective of this study was achieved as vulture power line incident hotspots were indeed identified across the Eastern Cape for both collision and electrocution incidents. These hotspots indicate no observed pattern, but most hotspots have multiple power lines that cross the area. These lines are affiliated to the individual incident reports within the hotspot, which indicates that localised combination of factors in a particular area that prone to be risky is more likely than the power line itself (APLIC, 1994; Bevanger, 1998; Shaw *et al.*, 2010a).

Part of those localising factors in an area are terrain and topographical features. Terrain characteristics play an essential function in the construction of the power line infrastructure (APLIC, 1994). Topographical features are more important in terms of the Cape Vulture habits. Identifying these characteristics at each hotspot was achieved, thus achieving the second objective of the study. Majority terrain characteristics were hard to quantify and correlate across power lines. The elevation is likely to be a function of the likelihood of presence of the areas in which these vultures occur. Slope gradients were generally very gradual, confirming that vultures prefer flatter areas. Aspects and Profile and Plan curvatures indicate that a more substantial variability involves electrocution hotspot power lines. A higher resolution DEM (which is not available) could be used and analysis rerun to determine differences in the results. Viewshed analysis revealed the critical connection between the dark background of higher grounds near the power lines, which increases the likelihood of collisions (Kotoane, 2004). The orientation of power lines in relation to perennial wind directions revealed that birds using the lines to perch (electrocution risk) are more likely to use lines that are perpendicular to the perennial wind direction. Topographic characteristics such as open grassland and karoo vegetation type biomes, the close proximity to water sources, important proximity distances to roosting and breeding sites were more quantifiable. This correlated with literature (Mundy 1992; Boshoff *et al.*, 2009) indicating the importance of these characteristics. Distances to vultures' restaurants were less quantifiable, and it is likely that vultures across the Eastern Cape are getting their food from other sources, typical of a scavenger species (Ogada *et al.*, 2016).

Results from the first two objectives allowed for the third and most important objective of this study to be achieved. Terrain and topographical characteristics

were compared, the importance of each justified and listed as rules that can be used to identify potential risk-prone areas not yet identified

5.2 Recommendations

Most importantly, more data would improve the analyses, and would subsequently minimise over-representation or under-representation of the negative interactions. However, from the findings of this study, a number of recommendations for future investigation and clarification have been identified and could be outlined as follows:

1. All power lines should be inspected at the identified hotspots, and necessary mitigation methods should be applied and reapplied should they become defective. Therefore, long-term monitoring of these areas is necessary to understand the full impacts of the study and the effectiveness of the mitigation methods.
2. A more extensive systematic line sampling should be conducted across the province, in order to ensure that collection biases within the data are overcome, and a larger sample of data can be used in rerunning the analyses. The focal areas for this sampling should be selected on the basis of hotspots, such as those identified in this study.
3. Integration of Cape Vulture GPS tracking data and other sources of data to understand vulture core distributions and the frequency and significance of power line interactions.
4. Wind Farm development should take into account these findings, as these farms if constructed in the identified Collision hotspot areas; then there is a potential for further loss to these birds.

5.3 Value of the Research

The Cape Vulture prosperity is essential to the health of the environment, and the high frequency of power line interactions and mortalities currently being reported is worrying. The extent of these power line interactions remains a severe threat to the stability of the species population (Boshoff *et al.*, 2011). We as custodians of the earth and Eskom have a responsibility to ensure the demise of this species does not happen. This research is valuable as it helps identify gaps in our understanding of these interactions and illustrates that GIS analysis for this type of study can be useful. Areas and rules identified in this study can provide a cost-effective allocation of resources in managing collision and electrocution on existing infrastructure in South Africa and influence the construction of new infrastructure in South Africa.

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Appendix 1: Permission Letter

17 April 2017

Mrs Meagan Bromfield
11 Fynbos
220 Main Avenue
Ferndale
2194

Dear Mrs Bromfield

I hereby give you permission to utilize the data collected by the Cape Vulture in Crises programme together with Vulpro involving power line interactions (collisions and electrocutions).

This work will be utilized for your research studies with your MSc. is GIS and Remote Sensing at the University of Witwatersrand under the title and subtitle;

"Power line-related mortalities of the Cape Vulture (Gyps Coprotheres) within the Eastern Cape, South Africa.

Modelling terrain characteristics in hotspot areas using GIS"

Thank you

Regards



Kate Webster
Cape Vulture in Crises
Sponsored by Vulpro
DHL Supply Chain
Lomas Wildlife Protection Trust

kate@lcom.co.za
045 8394716/
0827025942

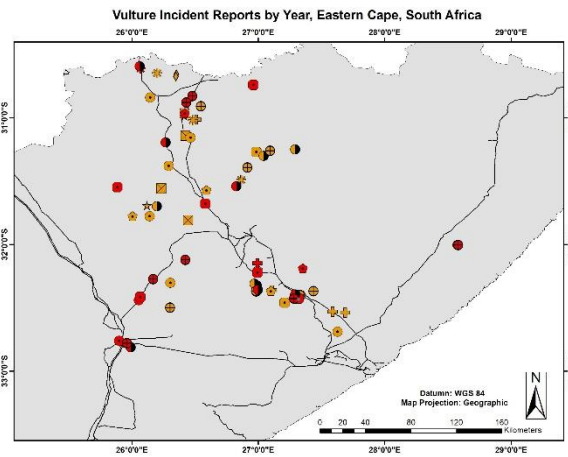


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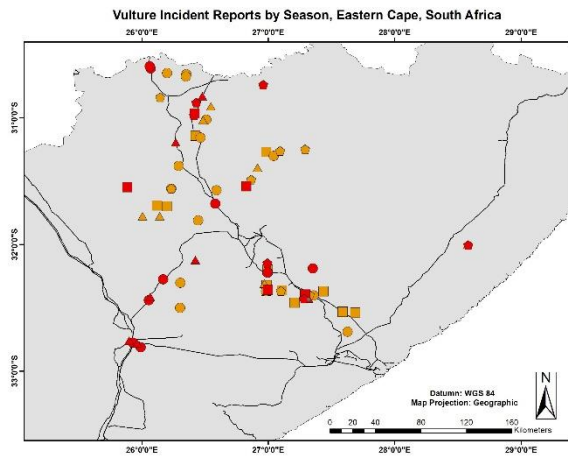


Appendix 2: ESDA Visualisation of distribution of Incident Reports

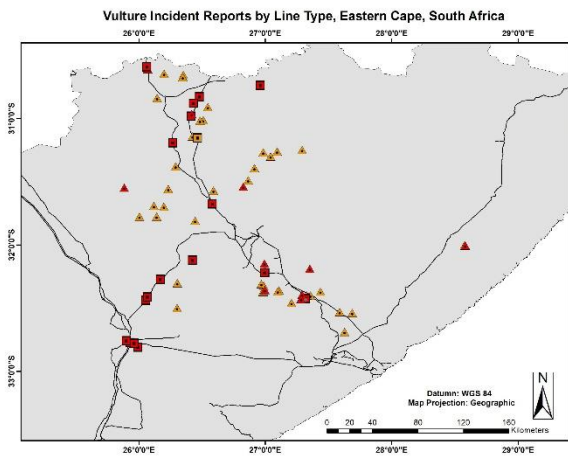
a)



b)



c)

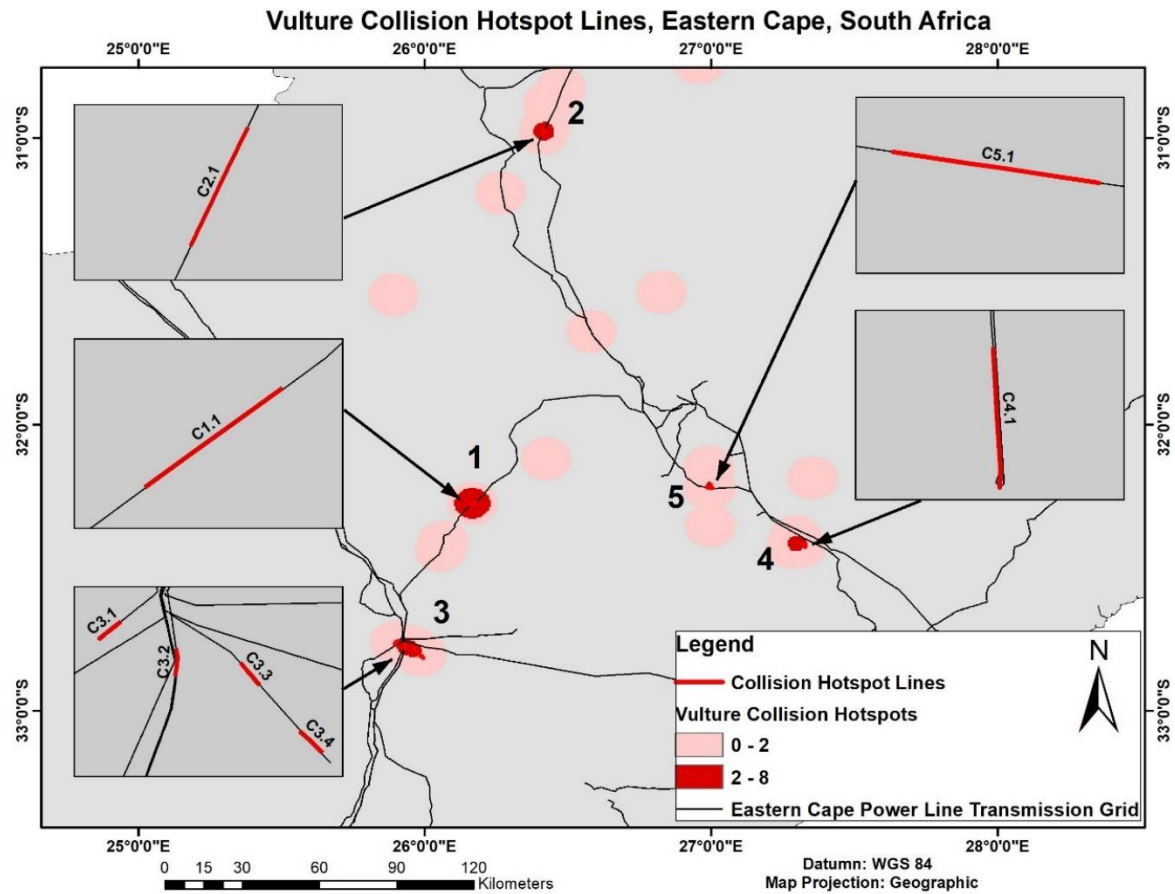


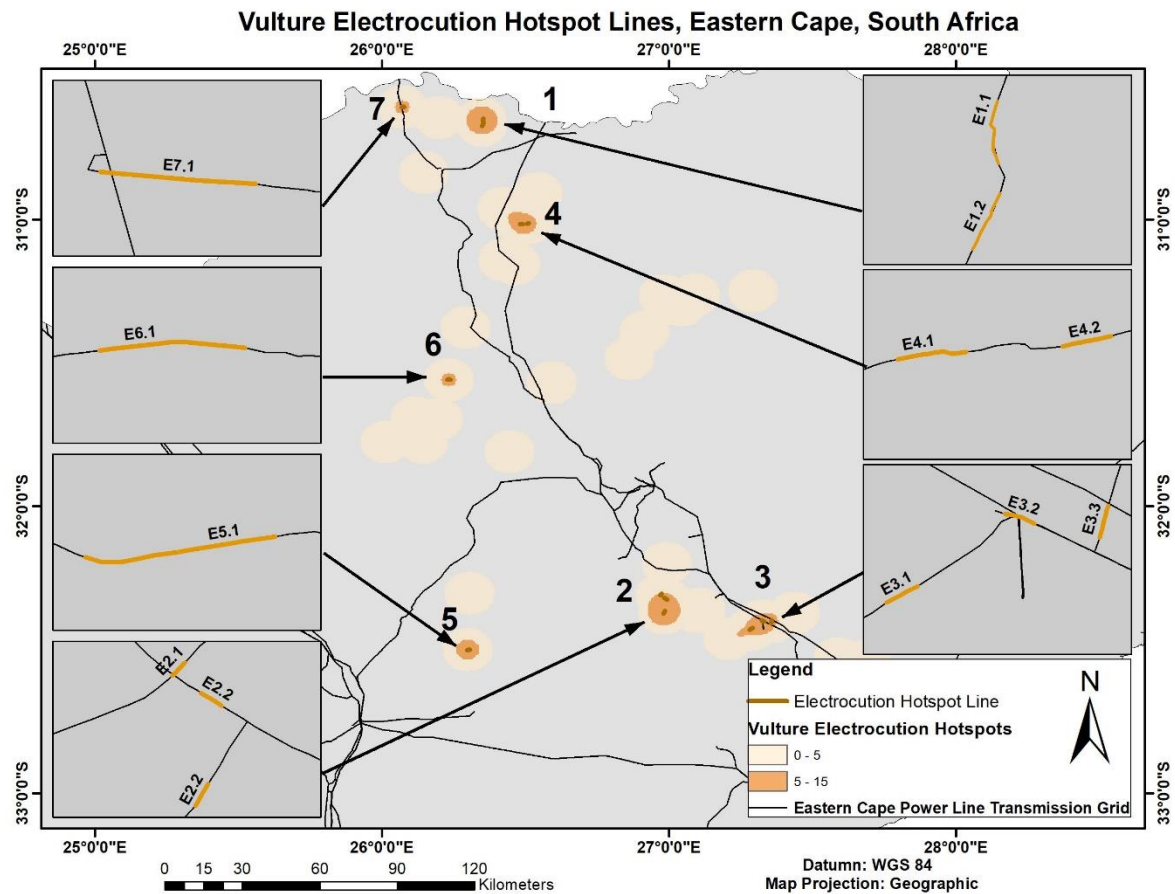
Legend

Eastern Cape Vulture Collision Year	Eastern Cape Vulture Electrocuting Year	Eastern Cape Vulture Collision Season	Eastern Cape Vulture Electrocuting Season	Eastern Cape Vulture Collision Line Type	Eastern Cape Power Line Transmission Grid
2008	2008	Autumn	Autumn	Distribution line	
2009	2009	Spring	Spring	Transmission line	
2010	2010	Summer	Summer		
2012	2011	Winter	Winter		
2013	2012				
2014	2013				
2015	2014				
2016	2015				
2017	2016				
	2017				

Visualisation of a) Yearly distribution of Incident Reports; b) Monthly distribution of Incident Reports and c) Line Type distribution of Incident Reports.

Appendix 3: Hotspot Collision and Electrocution Power Line Portions (a and b)





Appendix 4: Terrain and Topographic Attribute Tables

Table: Elevations

Hotspot Number	Line Number	Line Length (m)	Elevation Min (mamsl)	Elevation Max (mamsl)	Elevation Mean (mamsl)	Diff	Variance	SD
COLLISION								
HOTSPOT1	Line C1.1	1347.27	1663.09	1707.87	1690.61	44.78	213.1	14.6
HOTSPOT2	Line C2.1	1402.74	1403.32	1507.4	1432.67	104.08	773.23	27.81
HOTSPOT3	Line C3.1	1423.54	690.7	748.59	705.02	57.89	287.38	16.95
	Line C3.2	1436.25	1085.51	1133.65	1107.03	48.14	249.82	15.81
	Line C3.3	1823.33	1310.51	1375.48	1340.44	64.97	408.82	20.22
HOTSPOT4	Line C3.4	1285.26	837.89	923.53	897.51	85.64	813.57	28.52
	Line C4.1	1380.12	819.96	843.34	834.78	23.38	72.74	8.53
HOTSPOT5	Line C5.1	1365.54	820.23	841.23	831.5	21	33.55	5.79
ELECTROCUTION								
HOTSPOT1	Line E1.1	1317.95	1506.93	1551.38	1532.64	44.45	212.78	14.59
	Line E1.2	1273.81	1181.63	1214.84	1199.79	33.21	96.02	9.8
HOTSPOT2	Line E2.1	1043.16	1149.12	1233.13	1205.13	84.01	701.16	26.48
	Line E2.2	1276.76	1313.82	1327.6	1321.68	13.78	17.38	4.17
	Line E2.3	1012.37	1327.99	1338.92	1332.04	10.93	12.51	3.54
HOTSPOT3	Line E3.1	1206.64	1026.39	1063.03	1049.4	36.64	133.57	11.56
	Line E3.2	1165.23	1324.25	1392.58	1363.71	68.33	580.16	24.09
	Line E3.3	909.467	1330.83	1414.99	1384.51	84.16	873.47	29.55
HOTSPOT4	Line E4.1	1187.87	1319.84	1325.71	1322.73	5.87	2.79	1.67
	Line E4.2	986.894	1483.95	1503.18	1490.98	19.23	43.7	6.61
HOTSPOT5	Line E5.1	712.804	1474.2	1504.45	1484.51	30.25	86.25	9.29
HOTSPOT6	Line E6.1	1100.19	1797.63	1915.11	1871.14	117.48	1257.68	35.46
HOTSPOT7	Line E7.1	903.649	1022.03	1215.3	1096.83	193.27	3945.81	62.82

Table: Slope Gradients

Line Number	Terrain Profile Gradient					Power line Profile Gradient				
	Overall Absolute Mean Slope Degrees	Overall Slope Mean %	Min of Slope %	Max of Slope %	StdDev of Slope %	Overall Absolute Mean Slope Degrees	Overall Slope Mean %	Min of Slope %	Max of Slope %	StdDev of Slope %
Collision										
C1.1	1.50724	-2.63124	-8.96805	4.919533	3.728825	1.524605	-2.66157	-5.73863	1.785196	3.944494715
C2.1	4.11836	-7.2003	-39.3841	4.26967	12.13258	3.387922	-5.91994	-15.2104	3.487561	9.349520013
C3.1	3.707344	6.479581	-1.78089	16.62578	6.392331	3.417019	5.970904	-1.59151	11.65217	6.204983674
C3.2	0.509203	0.888751	-5.40875	7.628938	3.659941	0.971198	1.695223	-0.76154	5.787409	2.974572771
C3.3	0.757566	-1.32228	-5.51217	1.706651	2.345189	0.857791	-1.49724	-3.56102	1.067198	1.68762614
C3.4	1.987433	-3.47012	-12.5155	2.082599	3.938507	1.30723	-2.28194	-5.98236	1.306962	3.231371117
C4.1	1.252458	2.1863	-10.0933	16.12925	8.404729	0.604862	1.055723	-1.97184	7.3007	4.309865492
C5.1	0.204728	0.35732	-13.5035	13.45809	9.487119	0.46453	0.810776	-5.61714	7.726554	6.210431587
Electrocution										
E1.1	0.530098	0.925222	-2.49765	2.292887	1.098391	0.42064	0.734169	-1.74958	2.548636	1.219256321
E1.2	0.224778	0.392314	-1.36453	2.511728	0.907083	0.287157	0.501188	-0.83801	1.674621	0.706631108
E2.1	5.163421	-9.03634	-19.3336	5.786677	8.588599	4.296348	-7.51263	-17.784	5.644137	8.899008864
E2.2	2.715172	-4.74242	-16.3154	14.87748	8.938507	3.081429	-5.3833	-18.648	6.98812	10.77806215
E2.3	0.669844	1.169152	-8.3187	13.77991	6.097869	0.894883	1.561992	-1.97472	4.741187	3.063093135
E3.1	0.680197	1.187223	-10.1494	26.67323	9.460134	0.009605	0.016763	-7.9447	11.12677	7.008170502
E3.2	4.650216	8.134025	-1.04587	25.95257	6.630301	4.754403	8.317096	0	38.41752	11.99648307
E3.3	0.628975	-1.09781	-72.221	71.22359	24.37074	1.246653	-2.17616	-9.76118	5.799343	5.589682708
E4.1	0.872191	1.522379	-3.51136	4.865576	2.484851	0.871595	1.521337	-0.9995	4.028035	1.608356195
E4.2	2.432795	-4.24858	-15.4976	-0.54397	3.980602	2.066248	-3.60785	-18.9698	5.838848	6.660799265
E5.1	6.819494	-11.9588	-43.412	31.96823	27.786	6.740391	-11.8188	-54.1431	34.72222	33.42487858
E6.1	5.227329	9.148808	-9.19532	31.82913	12.15199	5.146155	9.005966	-10.2051	29.16918	12.8061179
E7.1	0.569686	0.994323	-0.72938	2.118949	0.979156	0.695973	1.214761	-0.70107	2.91439	1.427061474

Table: Terrain Plan Curvature

Line Number	Mean Plan Curvature	Min of Plan Curvature	Max of Plan Curvature	Var of Plan Curvature
Collision				
C1.1	0.002628	-0.00151	0.006646	5.22E-06
C2.1	-6.2E-05	-0.01292	0.010977	3.18E-05
C3.1	0.002093	-0.00285	0.0068	9.76E-06
C3.2	-0.00184	-0.01351	0.005196	2.89E-05
C3.3	0.001409	-0.00559	0.01098	1.72E-05
C3.4	-0.00303	-0.01993	0.005522	4.39E-05
C4.1	-0.00035	-0.01847	0.036815	0.000108
C5.1	0.000536	-0.01225	0.008629	3.41E-05
Electrocution				
E1.1	0.000163	-0.00354	0.00499	5.16E-06
E1.2	0.004157	-0.00768	0.021156	6.54E-05
E2.1	0.003783	-0.00337	0.018027	3.64E-05
E2.2	0.000306	-0.0189	0.011013	3.89E-05
E2.3	0.00408	-0.01483	0.034327	0.000128
E3.1	-0.00019	-0.02493	0.004826	4.9E-05
E3.2	0.000244	-0.0052	0.004716	8.79E-06
E3.3	0.000292	-0.01161	0.009999	2.5E-05
E4.1	-1.1E-05	-0.00712	0.020831	5.3E-05
E4.2	-0.00033	-0.00839	0.004742	1.24E-05
E5.1	-0.00268	-0.01902	0.008318	5.86E-05
E6.1	0.004384	-0.0058	0.053804	0.00026
E7.1	-0.00343	-0.00832	0.003577	1.57E-05

Table: Wind Directions and Power line directions

Hotspot Number	Line Number	Line Direction (Degrees)	Perennial Wind Direction	Perennial Wind Direction (Degrees) (inferred)	Weather Station	Line Orientation to Wind Direction
COLLISION						
HOTSPOT1	Line C1.1	52.8723	NNW-SSE	337.5	Cradock	Perpendicular
HOTSPOT2	Line C2.1	25.5588	NW-SE	315	Jamestown	Perpendicular
	Line C3.1	51.5656	SE-NW	135	Fort Beaufort	Perpendicular
HOTSPOT3	Line C3.2	181.137	SE-NW	135	Fort Beaufort	Perpendicular
	Line C3.3	140.158	SE-NW	135	Fort Beaufort	Parallel
	Line C3.4	132.333	SE-NW	135	Fort Beaufort	Parallel
HOTSPOT4	Line C4.1	356.921	NNW-SSE	337.5	Dohne	Parallel
HOTSPOT5	Line C5.1	98.5571	WNW - ESE	292.5	Queenstown	Parallel
ELECTROCUTION						
HOTSPOT1	Line E1.1	178.99	NNW - SSW	337.5	Aliwal North	Parallel
	Line E1.2	206.153	NNW - SSW	337.5	Aliwal North	Perpendicular
HOTSPOT2	Line E2.1	43.5506	WNW - ESE	292.5	Queenstown	Perpendicular
	Line E2.2	209.125	WNW - ESE	292.5	Queenstown	Perpendicular
	Line E2.3	301.593	WNW - ESE	292.5	Queenstown	Parallel
HOTSPOT3	Line E3.1	61.7164	NNW-SSE	337.5	Dohne	Perpendicular
	Line E3.2	108.044	NNW-SSE	337.5	Dohne	Perpendicular
	Line E3.3	195.382	NNW-SSE	337.5	Dohne	Parallel
HOTSPOT4	Line E4.1	83.7462	NW-SE	315	Jamestown	Perpendicular
	Line E4.2	78.175	NW-SE	315	Jamestown	Perpendicular
HOTSPOT5	Line E5.1	83.8536	SE-NW	135	Fort Beaufort	Perpendicular
HOTSPOT6	Line E6.1	88.9101	NW-SE	315	Jamestown	Perpendicular
HOTSPOT7	Line E7.1	94.3965	NNW - SSW	337.5	Aliwal North	Perpendicular

Table: Viewshed attributes

Visibility Analysis							
Hotspot Number	Line Number	Highest Line Elevation point (mamsl)	Elevation above	Crest1 direction in relation to power line	Crest1t Location in relation to power line	Crest2 direction in relation to power line	Crest2 Location in relation to power line
COLLISION							
HOTSPOT1	Line C1.1	1732.87	Yes	Angled to line	W	Angled to line	E
HOTSPOT2	Line C2.1	1532.40	Yes	Angled to line	SW	Parallel to line	E
	Line C3.1	948.53	No				
HOTSPOT3	Line C3.2	868.34	Yes	Parallel to line	W		
	Line C3.3	866.23	No				
	Line C3.4	773.59	Yes	Parallel to line	N		
HOTSPOT4	Line C4.1	1158.65	Yes	Parallel to line	E	Angled	SW
HOTSPOT5	Line C5.1	1400.48	Yes	Parallel to line	S		

Table: Topographic attributes

		Overlay Analysis	Proximity Analysis				
Hotspot Number	Line Number	Landcover/vegetation	Roost Prox1 (km)	Roost Prox2 (km)	Food Prox1 (km)	Food Prox2 (km)	Water (open water) Prox (km)
COLLISION							
HOTSPOT1	Line C1.1	Karoo Escarpment Grassland	25	30	21	78	1
HOTSPOT2	Line C2.1	Aliwal North Dry Grassland	21	31	79	80	0.5
	Line C3.1	Bedford Dry Grassland	25	69	80	>100	0.5
HOTSPOT3	Line C3.2	Bedford Dry Grassland	25	69	80	>100	1
	Line C3.3	Bedford Dry Grassland	25	67	80	>100	0.5
	Line C3.4	Bedford Dry Grassland	26	67	80	>100	1
HOTSPOT4	Line C4.1	Amathole Montane Dry Grassland	9	34	3	22	1
HOTSPOT5	Line C5.1	Amathole Montane Dry Grassland	30	41	8	32	1
ELECTROCUTION							
HOTSPOT1	Line E1.1	Eastern Upper Karoo	50	56	60	87	0.5
	Line E1.2	Eastern Upper Karoo	50	56	60	87	0.5
	Line E2.1	Karoo Escarpment Grassland	26	47	18	23	1
HOTSPOT2	Line E2.2	Karoo Escarpment Grassland	26	47	20	22	3
	Line E2.3	Amathole Montane Dry Grassland	27	46	18	25	1
	Line E3.1	Amathole Montane Dry Grassland	8	38	4	21	1
HOTSPOT3	Line E3.2	Amathole Montane Dry Grassland	7	36	1	23	1
	Line E3.3	Amathole Montane Dry Grassland	9	32	3	23	1
	Line E4.1	Aliwal North Dry Grassland	13	24	71	73	1
HOTSPOT4	Line E4.2	Aliwal North Dry Grassland	13	22	70	72	1
	Line E5.1	Amathole Montane Dry Grassland	21	25	40	75	3
HOTSPOT6	Line E6.1	Karoo Escarpment Grassland	21	55	65	65	1
HOTSPOT7	Line E7.1	Eastern Upper Karoo	73	75	35	>100	3