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The impact of power line-related mortality on the Cape Vulture *Gyps coprotheres* in a part of its range, with an emphasis on electrocution

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Summary

The global population of the Cape Vulture *Gyps coprotheres*, a threatened southern African endemic, is known to be impacted by electrocutions and collisions on power line infrastructure, but to date this impact has not been estimated or quantified. Using data in a national database from the period prior to our study, conducted in the Eastern Cape Province of South Africa, we estimated a mean annual mortality rate from power line-related mortality of around 14 vultures per year. After applying an adjusted rate based on the results of a landowner survey, this estimate increased to around 80 vultures per year (i.e. a 5.7 fold increase). For a number of reasons, the estimated mean annual mortality rate is considered to under-represent the true situation, and must therefore be considered a minimum value. A simple model was constructed and run to investigate the potential impact of the mortality rate from electrocution on the study population. It distinguishes between vulture subpopulations in areas of high and low electrocution threat, and a migratory subpopulation that moves between these two areas. The model, simulated over 50 years and applying a constant theoretical maximum annual growth rate of 2%, indicates positive growth of the population in those areas where the electrocution threat from power lines is low, whereas the population in those areas where this threat is high is predicted to crash to extinction, from electrocution mortality alone, within a 20–35 year period. The regional population is predicted to show positive growth over the 50 year period. However, for a number of reasons that relate to the nature of certain parameters used in the model, the simulations must be considered to be conservative, at best. In addition, other unnatural mortality factors (notably inadvertent poisoning, drowning in high-walled farm reservoirs, harvesting for the traditional medicine trade, local food shortage), which are additive to power line-related mortality have not been taken into account. Management recommendations aimed at obtaining an improved estimate of the mean annual mortality rate from power lines, and at ameliorating the impact of electrocutions on the regional Cape Vulture population, are briefly mentioned. These address the former by documenting ways to improve the quantity and quality of the field data, and the latter by identifying areas where urgnt action needs to be taken to reduce or avoid the electrocution of vultures, by mitigating extant 'unsafe' power line infrastructure, and by ensuring that that only 'safe' infrastructure is used for new power lines.

Introduction

A number of studies on a variety of avian taxa have demonstrated a demographic impact from power line-related mortality (e.g. Crivelli *et al.* 1987, Ferrer and Hiraldo 1992, Bevanger 1995, Mañosa and Real 2001, Sergio *et al.* 2004, Rubolini *et al.* 2005, González *et al.* 2007, Margalida *et al.* 2008, Raab *et al.* 2010, Rollan *et al.* 2010, Shaw *et al.* 2010a,b). Raptor mortality caused by power line infrastructure is a global phenomenon and despite extensive research, design development, and mitigation, numerous fatal incidents occur each year, usually incurring significant costs for electricity generation and supply utilities (Lehman *et al.* 2007). In South Africa, at least 14 raptor species (including vultures and owls) are known to be killed on power line infrastructure, with two vulture species – Cape Vulture *Gyps coprotheres* and African White-backed Vulture *G. africanus* – being prominent in this category (Markus 1972, Ledger and Annegarn 1981, Boshoff and Basson 1993, Ledger *et al.* 1993, Kruger 1999, Van Rooyen and Ledger 1999, Kruger and Van Rooyen 2000, Lehman *et al.* 2007, Jenkins *et al.* 2010). The Cape Vulture, which is endemic to southern Africa, has undergone a decline in range and numbers and is now listed as 'Vulnerable' in the South African Red Data Book (Anderson 2000) and as 'Vulnerable' globally (IUCN 2010). Mortality from power lines (through electrocutions and collisions) is widely considered to be an important, but unquantified, contributory factor in the decline of this species (Mundy *et al.* 1992, Kruger 1999, Anderson 2000, Van Rooyen 2004, Boshoff and Anderson 2006, Jenkins *et al.* 2010). An Old World congener, the Eurasian Griffon *G. fulvus*, has also been shown to be impacted by electrocution on power lines in Spain (Ferrer *et al.* 1991).

Although mortality of Cape Vultures on power lines has been occurring in South Africa as far back as 1948 at least (Van Rooyen and Piper 1997), the first published account was of electrocutions in the then Western Transvaal (now North West) Province (Markus 1972). From 1996, when data on avian mortalities caused by power line infrastructure (electrocutions and collisions) in South Africa started to be formally recorded (Van Rooyen and Ledger 1999) until 2008, the second highest proportion (19.6%; n = 754) of known power line incidents, and the second highest proportion (20%; n = 1,850) of known mortalities of bird species listed in South Africa's Red Data Book (Barnes 2000), refer to the Cape Vulture (Central Incident Register [CIR], Wildlife and Energy Programme [WEP] of the Endangered Wildlife Trust [EWT], Johannesburg). The CIR is a spreadsheet database that contains records of wildlife-power line incidents in South Africa. The WEP incorporates the Eskom-Endangered Wildlife Trust Strategic Partnership, which was established in 1996 specifically to address power line-wildlife issues in South Africa (Van Rooyen 2000a). Eskom is a company that generates and distributes over 95% of the electricity in South Africa, through an extensive network of transmission and distribution lines. Although there are biases inherent in the CIR data (see later), they nonetheless indicate that Cape Vultures are highly prone to being killed on power line infrastructure.

To what extent the data in the CIR can be used to estimate a realistic Cape Vulture mortality rate from power lines (e.g. number of birds killed per year per area or region) is not known; this aspect forms a key component of the present study. Nationally, the actual number of mortalities is likely to be much higher than is presently known, as the majority of the power line-related mortalities are considered to go unreported (Kruger 1999, C van Rooyen, WEP, pers. comm. November 2005). As far back as the 1980s, researchers were aware that vulture mortalities from power lines were being underestimated, especially owing to loss of information by Eskom (Ledger and Annegarn 1981). This problem is not unique to South Africa; in Israel, where data were not regularly collected, the mortality of the Eurasian Griffon from electrocution was "undoubtedly" higher than indicated by the available information (Leshem 1985).

Unless a realistic mortality rate from power lines can be estimated, it will be difficult to predict the potential impact of this unnatural mortality factor on the Cape Vulture population. This paper describes an attempt to (a) estimate a mean annual mortality rate from electrocution on, and collision with, power line infrastructure, for the Cape Vulture in a part of its global range (the study area), and (b) to model the potential impact of the estimated mortality rate from electrocution on the demography of the species in this area. Since neither (a) nor (b) require it, a distinction between the different types (= designs) of power line infrastructure that can and do kill Cape Vultures is not made in this study.

Finally, management recommendations to improve the quality of the data used to estimate the said mortality rate, and to reduce vulture mortality from power lines, are briefly listed.

Study area

Eskom operates according to six management regions, and the incidence of Cape Vulture mortality from power line infrastructure is, according to data from a 13-year period (1996-2008), particularly high in the Southern Region, with 37% of known power line-vulture incidents; this far exceeds the next highest value, 18%, for each of the Northern and Eastern regions (n = 148) (CIR, WEP-EWT). Furthermore, the Southern Region has 44% (n = 370) of all known mortalities over the same period. This far exceeds the value (19%) for the next highest Eskom Region, namely North West. In addition, the highest mean number of Cape Vultures killed per incident, (3 birds/incident), refers to the Southern Region. These calculations are based on the assumption that vultures killed by power lines, through electrocution or collision, have an equal chance of being discovered and reported in each Eskom Region. Consequently, our study was conducted in the 169,000 km^2 Eastern Cape Province, one of South Africa's nine provinces and one that incorporates most of Eskom's Southern Region.

The Eastern Cape Province exhibits high biotic and topographic diversity. It is characterised by a broad coastal plain, clad in subtropical thicket, savanna or forest, which is replaced in the hinterland by a high escarpment and interior plain. The eastern and north-eastern parts, which are covered mainly by grassland, are mountainous while the western and north-western parts are dominated by a flat or rolling plain, clad in arid dwarf shrubland, with hills and mountains in places. The Cape Vulture is the most common and widespread vulture species in the Eastern Cape (Harrison *et al.* 1997).

The study area and the localities of sightings of Cape Vultures during the 2000-2008 period, and of roost and breeding sites that were active during 2004-2007, are shown in Figure 1.

Methods

a) Distribution pattern of known power line-vulture incidents

The sites of all known vulture-power line incidents from the 1970s to 2008 (electrocutions and collisions) in the Eastern Cape, for which geographic coordinates are available or can be reliably estimated, were obtained from early EWT records, from the literature (Boshoff and Vernon 1980), from the CIR, and from the present study. These sites were plotted on a map to establish their spatial distribution pattern, especially in relation to the potential threat provided by areas where 'unsafe' power lines predominate – see (b) below. A single 'incident' refers to mortality or mortalities on one type of infrastructure (pole/tower/conductor), or along a specific section of power line, over a very limited period (day or successive days).

b) Power line threat areas

All Eskom power line infrastructure has, to a greater or lesser degree, the potential to kill Cape Vultures through collisions (Jenkins *et al.* 2010) but only certain design types have the potential to electrocute them (Kruger 1999, Van Rooyen and Ledger 1999, Van Rooyen 2000a, Van Rooyen 2004). Consequently, and for the purposes of our population model – see (e) below – a spatial analysis was conducted to identify areas of relative threat to the vultures from electrocution on 'unsafe' power line infrastructure. This was achieved by creating two 'electrocution threat' areas: high electrocution threat (HET) area (i.e. area with a relatively high incidence of 'unsafe' power lines) and low electrocution threat (LET) area (area with a relatively low incidence of 'unsafe' power lines). In the context of this study, 'unsafe' power lines are those that have infrastructure (of various designs) that is known to electrocute vultures; these lines are mainly part of low- to medium-voltage rural distribution networks that were erected in Eastern Cape and elsewhere in the 1970s and 1980s (Kruger 1999, Van Rooyen and Ledger 1999). 'Safe' power lines were erected mainly in the 1990s and 2000s and comprise infrastructure that does not

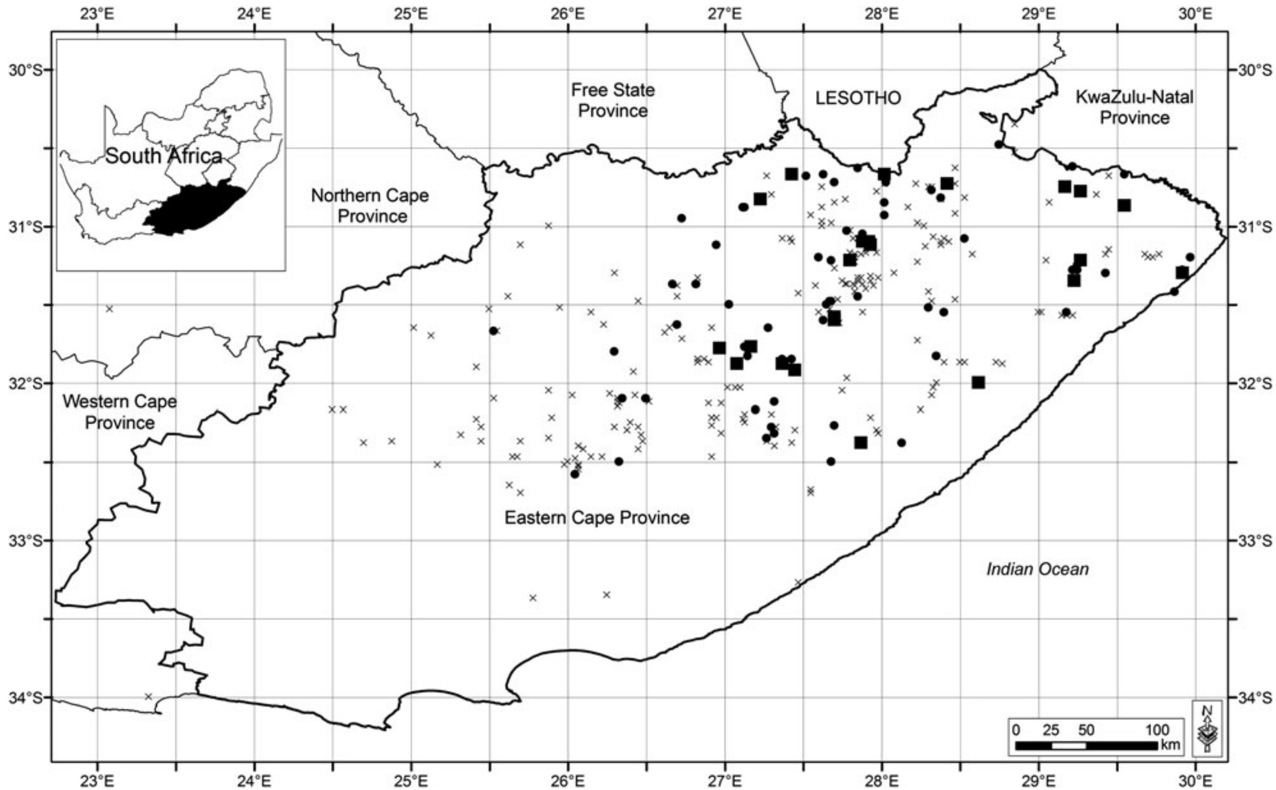

Figure 1. The Eastern Cape Province of South Africa, which forms the study area. The localities of Cape Vulture *Gyps coprotheres* roosts (●) and breeding sites (■) that were active during the post-1999 (mainly 2004–2007) period, and of sightings (×) of vultures at and away from these active sites during the 2000–2008 period, are shown. Sightings away from the active sites were made on an opportunistic basis. Source: Boshoff *et al.* (2009a), this study.

electrocute vultures (C van Rooyen, WEP, pers. comm. November 2005). The required information on power line status was obtained from Eskom through the WEP-EWT. In the absence of supporting data and information, it is assumed that the risk of vultures colliding with power line infrastructure is not significantly influenced by the type of infrastructure (various types/designs are used for transmission and distribution networks in South Africa). It is therefore further assumed that there is no marked difference in the vulture collision risk between power lines in the HET and LET areas.

Eighty-four percent of all Cape Vulture mortality records for the study area in the CIR relate to electrocutions, and 16% to collisions ($n = 163$) (CIR, WEP-EWT). Two factors are considered to play a role here. Firstly, since collisions do not normally cause line faults, they are not followed up by field investigators and reported, and secondly the HET area comprises freehold, commercial farming land where landowners generally have a high degree of awareness of activities on their properties and have access to a good communications network to report vulture mortality incidents to Eskom or to the WEP-EWT. On the other hand, the LET areas comprise communal, subsistence farming land where farmers have a lesser degree of awareness of what is taking place on the land, and who do not have easy access to a good communications network to report incidents. Thus, the absence of records of power line-related vulture deaths from the LET areas is considered to reflect a combination of (i) the low incidence of 'unsafe' or potentially 'unsafe' power lines (which can electrocute vultures), and (ii) the non-reporting of deaths from collisions (which are undoubtedly occurring in these areas). Despite these possible sources of bias against finding carcasses resulting from collisions, we expect that electrocutions, especially in the HET area, will have a marked impact on the Cape Vulture population in the Eastern Cape.

c) Mortality rate derived from extant data

A key parameter in estimating a mean annual mortality rate from power line-related incidents is the 'incident reporting level', the basis of which is formed by the data and information on power line-vulture incidents (resulting in vulture mortality) that are currently registered in the CIR. The records captured in the CIR are obtained from two main sources. Firstly, from Eskom staff involved in regular line patrols and line fault investigations; this information is processed via a number of standard in-house Eskom procedures, prior to it being captured in the CIR. Secondly, from opportunistic reports of power line-related mortality incidents received from the public, including landowners who have power lines traversing their properties.

The records in the CIR for the period 1996-2008 and for Eskom's Southern Region provide data and information on the number and localities of known power line-Cape Vulture incidents, the number of vultures killed per incident, the date on which the incident was entered into the CIR, the total number of vultures killed (all incidents), the mean number of vultures killed per known incident, the minimum and maximum number of vultures killed per incident, the mean number of incidents per year, and the mean number of vultures killed per year in known incidents. The number of recorded incidents, over the 13-year period referred to earlier, provide an initial incident reporting level, i.e. prior to the landowner survey (see (d) below). It is emphasised that since the CIR was only established in 1996, the incident records from the 1970–1995 period (see above) could not be used for the exercise described here.

Factors considered to affect the quality of the CIR data were established by means of personal (face-to-face) or telephone interviews conducted with Eskom and WEP-EWT personnel, and with the sample of landowners selected to establish the mortality rate from extrapolated data (see below).

d) Mortality rate derived from extrapolated data

Data and information from an independent source were used to assess the quality of the data in the CIR and to provide an adjusted incident reporting level. To achieve this, personal or telephone interviews were conducted during September 2008 with a sample of landowners (commercial stock farmers) in 12 commercial stock farming districts: Aliwal North (8 landowners), Barkly East (10), Burgersdorp (8), Cathcart (24), Dordrecht (10), Elliot (8), Lady Grey (8), Molteno (8), Queenstown (8), Sterkstroom (8), Stutterheim (8), and Tarkastad (16) (n = 124). These districts were selected on a post-hoc basis, as they fall within the general area where power line-vulture incidents have been recorded since the 1970s.

Three pertinent questions were put to landowners selected for the survey: (i) "Are you aware of one or more power line-related incidents involving the deaths of vultures on your property, in the past 13 years (1996-2008)?" (ii) "If any incidents occurred, were they reported by you to Eskom or to the WEP-EWT?" (iii) "If vultures have been killed by power lines on your property, would you necessarily have knowledge of every incident?"

To compare geographic co-ordinates, the CIR was then checked to establish which, and how many, of the incidents reported during the 2008 landowner survey had been captured in the CIR. The resulting value (a proportion, derived from the number of incidents recorded during the 2008 landowner survey vs the number of these incidents that were listed in the CIR prior to the landowner survey) was used to provide an adjusted incident reporting level and, ultimately, through extrapolation of the pre-landowner survey CIR data, a revised estimated annual mortality rate.

e) Potential impact of electrocution on the population

In order to assess the potential impact of electrocutions on the Cape Vulture population in the Eastern Cape, we developed a spatially and temporally explicit population model (Dunning *et al.* 1995) that incorporates electrocution as a stand-alone mortality factor that influences the population over time. The model ignores all other mortality factors (including collisions) and therefore its predictions can be viewed as being conservative.

The overall Cape Vulture population in the Eastern Cape is estimated at ~2,000 individuals, comprised of a minimum 630 breeding pairs (Boshoff *et al.* 2009a). Based on the geographical location of breeding colonies, we assume that currently this population comprises two subpopulations, namely those that live and forage mainly in the HET area and in the LET areas (see the outcome of (b) above, including Figure 2). The larger subpopulation, occupying the LET areas, consists of ~1,680 vultures (84% of breeding pairs, c.530), while the smaller subpopulation, occupying the HET area, consists of ~320 individuals (16% of breeding pairs, c.100). During the non-breeding season in the austral spring-summer (August–October), at least ~250 birds migrate into the so-called East Cape Midlands (roughly the Cradock, Tarkastad and northern Bedford and Adelaide districts; Figure 3) in the HET area (Boshoff *et al.* 2009b). Based on information in Boshoff *et al.* (2009a,b), it is assumed that these birds originate from, and return to, the LET areas (possibly including Lesotho) to the east and north-east during the austral summer-autumn (January–March), resulting in a concentration of migrant birds in the HET area during November and December. Migrant birds could, therefore, remain in the HET area for anywhere between four and eight months during the non-breeding season, depending on when they leave and return to the LET areas.

Our model separates the two subpopulations described above with respect to power line electrocution. In addition to these two subpopulations, we include a third, migratory, segment of the population that moves between the two subpopulations. The migratory segment is treated as part of the LET area subpopulation when present in these areas, as minimal electrocution-related mortality is recorded in this region. While the migratory birds are in the HET area, they and the resident birds are exposed to the risk of electrocution on 'unsafe' power lines. There is no evidence to suggest that any of the migratory vultures remain in the HET area following their movement into that area, and therefore we model separately each segment (resident and migratory) in the HET area. To generate population estimates for the HET area, we combine the migratory and resident components while the former is in this area. The combination of the populations in the HET and LET areas represents the vulture population trend for the entire study area over time.

Since 84% of all Cape Vulture deaths related to power lines are due to electrocution (see above), we estimate the number of vulture deaths in our study area resulting from electrocution as $d_{elec} = 0.84^* d_{max}$ where d_{max} is the estimated number of vultures dying from power line-related incident (i.e. actual numbers reported, corrected by landowner interviews including both electrocution and collisions, see Results). We assume that monthly mortality ($m_{monthly}$) remains constant throughout the year, such that the population in the HET area will decline at $m_{monthly}$ each month resulting in d_{elec} dead vultures in a twelve month period. However, in order to obtain $m_{monthly}$, an estimate of the number of vultures in the HET area during the year is required. At the start of the austral year (July) the resident population in the HET area numbers around 320 individuals, and this subpopulation declines throughout the year as a result of electrocution until the end of the austral year (June). In addition, migratory vultures bolster the HET area subpopulation; such that the size of the HET area subpopulation is a function of the arrival and departure dates of the migrant vultures. Between August and October, about 250 migrant birds arrive in the HET area and similarly their numbers decline as a result of power line electrocution before the surviving migratory vultures leave the HET area, between January and March. To simplify the arrival and departure of the migrant sub-population in the HET area we assume that the migrant vultures are in the HET area for a minimum of four months (= short occupancy, October–January) or a maximum of eight months (= long occupancy, August–March). By combining the number of resident and migratory vultures in the HET, and assuming a constant rate of decline over a twelve month period, we estimate $m_{monthly}$ for both the short and long occupancy periods that results in d_{elec} dead vultures by the end of the twelve month period. We convert $m_{monthly}$ to an annual survival rate using $(1\text{-}m_{monthly})^t$ where t is the number of months spent in the HET (HET residents = 12 months, short occupancy migrants = 4 months, long occupancy migrants = 8 months). Finally, we assume that the estimated annual mortality rate from power line electrocutions remains relatively constant from year to year (i.e. no major mitigation programme to make extant 'unsafe' power lines 'safe' is implemented, and no new 'unsafe' infrastructure is erected).

The Cape Vulture has an expected theoretical maximum per capita rate of increase of around 2% per annum (Piper 1994: 411). We use this rate of increase as a conservative population growth rate for each year, with the core breeding season occurring between May and October, during the austral winter, in both the HET and LET areas. We iterate the model on a monthly time step, corresponding to an austral year starting in July and ending in June, to account for the movement by the migratory segment of the population, occurring at different times of the year. During each month we simulate an initial movement of vultures from the LET areas to the HET area (the timing will vary depending on whether we assume a long or short occupancy period), apply $m_{monthly}$ to both the resident population in the HET area and the migratory population in the HET (when applicable), simulate the movement of vultures back to the LET areas (again the timing will vary depending on whether we assume a long or short occupancy period), and allow the population to grow at the theoretical maximum growth rate.

We simulate the model for 50 years and assess the population size of the LET area, HET area and Eastern Cape in January of each year. January corresponds to a period when the migratory subpopulation is in the HET region (for both short and long occupancy).

Results

a) Distribution pattern of known power line mortality incidents

The sites of known power line-vulture incidents in the Eastern Cape Province for the 1970s–2008 period exhibit a distinctive spatial pattern, i.e. they are confined to a certain area and are not scattered throughout the study area (Figure 2 and (b) below).

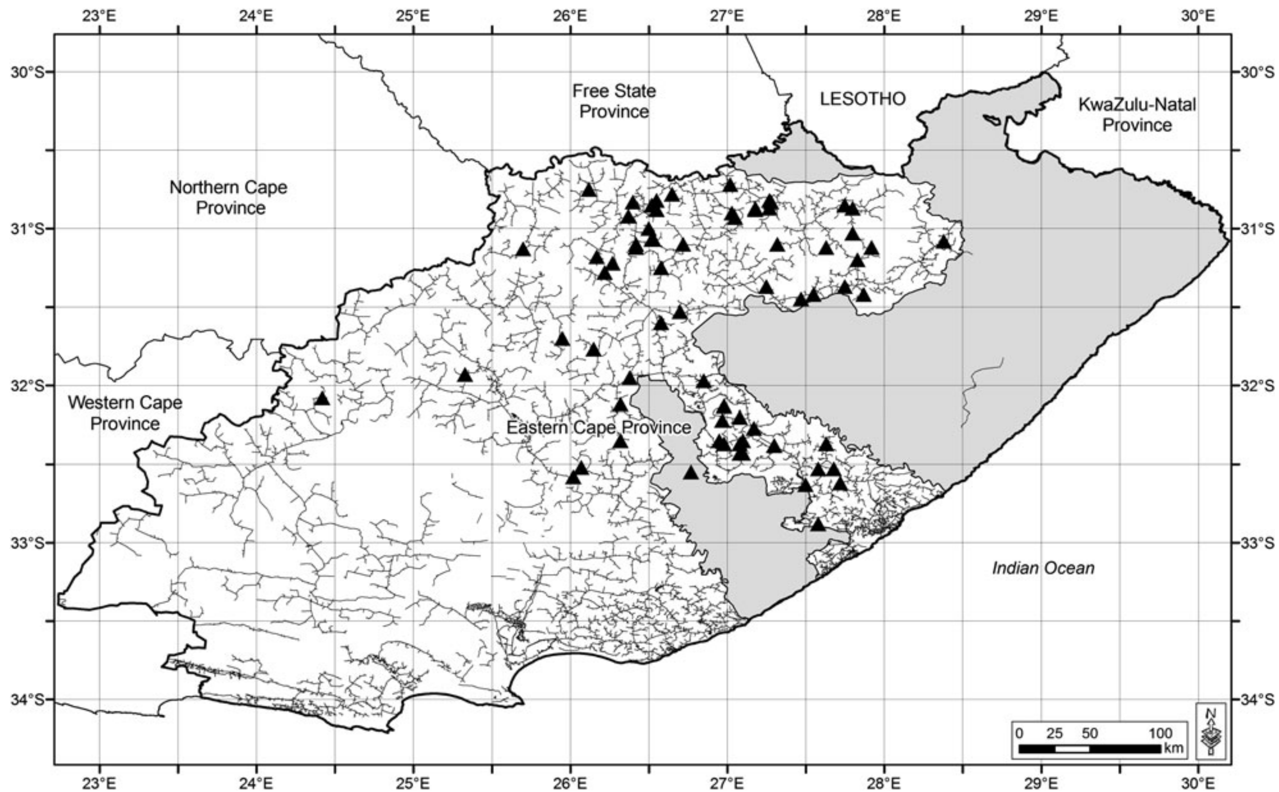

Figure 2. The study area, showing (a) the sites (▲) of known power line-Cape Vulture incidents (electrocutions and collisions) in the 1970s–2008 period, (b) power lines (—) that are 'unsafe' or potentially 'unsafe' (i.e. that comprise infrastructure that is known to electrocute Cape Vultures), and (c) high electrocution threat (HET) (unshaded) and low electrocution threat (shaded) areas, to the east of 25°S30'E. Sources of data: CIR (WEP-EWT), Eskom and this study.

b) Power line threat areas

Eskom's power line network extends throughout the study area but only those lines that comprise infrastructure that is, from an electrocution point of view, 'unsafe', or potentially 'unsafe', for the vultures are mapped in Figure 2. Based on the criteria mentioned in section (b) of Methods, and comparing the spatial outputs showing the power line-vulture incident sites and the location of 'unsafe' or potentially 'unsafe' power lines, it was possible to broadly delineate areas of high (HET) and low (LET) electrocution threat, respectively (Figure 2). Given that relatively few sightings of Cape Vultures are made in the region to the west of 25°30′E (Figure 1), the HET and LET areas that are relevant to this study lie to the east of this line of longitude. All sites bar one, of vultures killed on power line infrastructure in the study area, for the 1970s–2008 period, fall within the HET area (Figure 2).

c) Mortality rate derived from extant data

Mortality data derived from Cape Vulture records from the study area for the period 1996–2008 that were registered in the CIR prior to the landowner survey, indicate an estimated mean mortality rate of 13.92 (say 14) birds killed per year, with a mean of 5.08 (say 5) incidents occurring per year (calculated from data in Table 1).

The values in Table 1 for the total number of known incidents, and for the total number of vultures killed in all incidents, are somewhat higher than those given in the Introduction, this owing to a post-hoc adjustment of one incident that had been captured in the CIR prior to the landowner survey (see (d) below); this refers to multiple incidents, over a period of time, at one particular site. Consequently, the mean number of vultures killed per incident in Table 1 (= 2.74) is slightly higher than the mean value for South Africa (= 2.5, as calculated from extant data in the CIR).

The interviews with WEP-EWT and Eskom personnel revealed that, overall, the record in the CIR is incomplete, for the following reasons: Not all fields are completed in some incident data rows in the spreadsheet database (e.g. number of birds killed per incident, geographic co-ordinates); standard in-house reporting procedures are not always diligently carried out by Eskom personnel; incidents are obtained on a reactive basis (as opposed to a proactive one); carcass removal rates from below power line infrastructure by mammalian scavengers (especially jackals)

Table 1. Cape Vulture power line-related mortality statistics over 13 years (1996–2008), from entries in the Central Incident Register curated by the Wildlife and Energy Programme (WEP) of the Endangered Wildlife Trust (EWT), Johannesburg (see text).

Year	No. known incidents	No. birds killed/known incident	Total no. birds killed
1996	1	3	3
1997	4	2, 1, 1, 3	7
1998	6	1, 1, 4, 1, 3, 5	15
1999	1	3	3
2000	3	2, 3, 3	8
2001	6	1, 2, 2, 6, 5, 3	19
2002	4	9, 12, 3, 2	26
2003	6	1, 3, 1, 1, 1, 3	10
2004	7	4, 1, 1, 2, 1, 2, 3	14
2005	3	3, 6, 1	10
2006	12	3, 1, 1, 2, 2, 1, 1, 1, 1, 1, 2, 3,	19
2007	3	2, 3, 1	6
2008	10	17, 5, 2, 2, 1, 2, 1, 9, 1, 1	41
	Total = 66	Mean = 2.74 (SD = 2.8)	Total = 181

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are not known (removal of carcasses by scavengers is known to negatively affect bird mortality estimates based on carcass counts below power lines (Bevanger 1999, Ponce *et al.* 2010)); power line-vulture interactions (especially collisions) that do not cause line faults (and result in follow-up investigations) are not normally recorded by Eskom maintenance crews; not all incidents (electrocutions or collisions) known to landowners are reported by them to Eskom or the WEP-EWT (see (d) below for evidence of this from the present study); in those parts of the study area where communal tenure and subsistence agriculture prevails, a number of factors (e.g. lack of awareness, rugged terrain, poor communications network) reduce the chances of vultures killed by power lines being reported to the WEP-EWT or to Eskom.

d) Mortality rate derived from extrapolated data

Of the 124 landowners interviewed, 23 (18.5%) reported that one or more power line-vulture incidents had occurred on their properties during the period in question (Figure 3). When the data from the landowner interviews were compared with those in the CIR (relating to the period prior to the landowner survey), it was found that of the 23 properties from which incidents had been reported by the landowners interviewed, only four (17%) were registered in the CIR. In other words, 83% of the incidents reported by the landowners during the interviews had not been captured in the CIR. Thus, by extrapolating an incident reporting level of 17% to one of 100%, and by taking a mean of five incidents occurring each year (Table 1), it can be projected that around 29 incidents occur in a year. Further, if around 2.7 vultures are killed per incident (Table 1) then it can be projected that around 78 vultures are killed each year in power line incidents in the Eastern Cape; this represents some 3.9% of the entire vulture population (of about 2,000 birds, see Boshoff *et al.* 2009a) in this region.

Alternatively, taking an incident reporting level of 17% and a mean of 14 vultures killed by power lines each year (Table 1), it is estimated that around 82 vultures (4.1% of the population) are killed in each year. Based on these data, applied as an adjustment to the data in the CIR, a more realistic estimated mean annual mortality rate of Cape Vultures from power lines in the Eastern Cape Province may be in the region of 80 birds (78-80-82), or 4% of the population, i.e. 5.7 times the rate estimated from the CIR data.

It is emphasised that the adjusted estimated mean annual mortality rate is considered to under-represent the true situation and must therefore be regarded as a minimum figure. The reasons for this are as follows: The limitations of the data that existed for the CIR prior to this study (see (c) above); the landowners interviewed had not conducted regular, systematic searches for vulture carcasses under power lines traversing their properties; although some landowners stated that more than one incident had occurred during the period under consideration, multiple incidents per property were taken as one incident per property for the calculation of the adjusted rate; not all incidents (electrocutions or collisions) known to landowners are reported by them to Eskom or the WEP-EWT (23 of the 124 landowners interviewed reported power line-vulture incidents on their properties, since 1995, but only 6 (26%) of these had been reported by them to Eskom or the WEP-EWT); not all incidents have the potential to be reported to Eskom or the WEP-EWT by landowners – 11% of 105 landowners interviewed about this issue stated that they would not necessarily be aware of the existence of vulture carcasses under power line infrastructure on their properties.

e) Potential impact of electrocution on the vulture population

Based on the estimated mortality rate of 80 vultures per year (see Results above), d_{elec} equals 67 vultures. This then translates into $m_{monthly}$ of 1.22% and 1.487% per month for the long and short occupancy scenarios respectively. Thus, if migratory vultures spend long periods in the HET area, yearly survival estimates for the HET area subpopulation and migratory subpopulation

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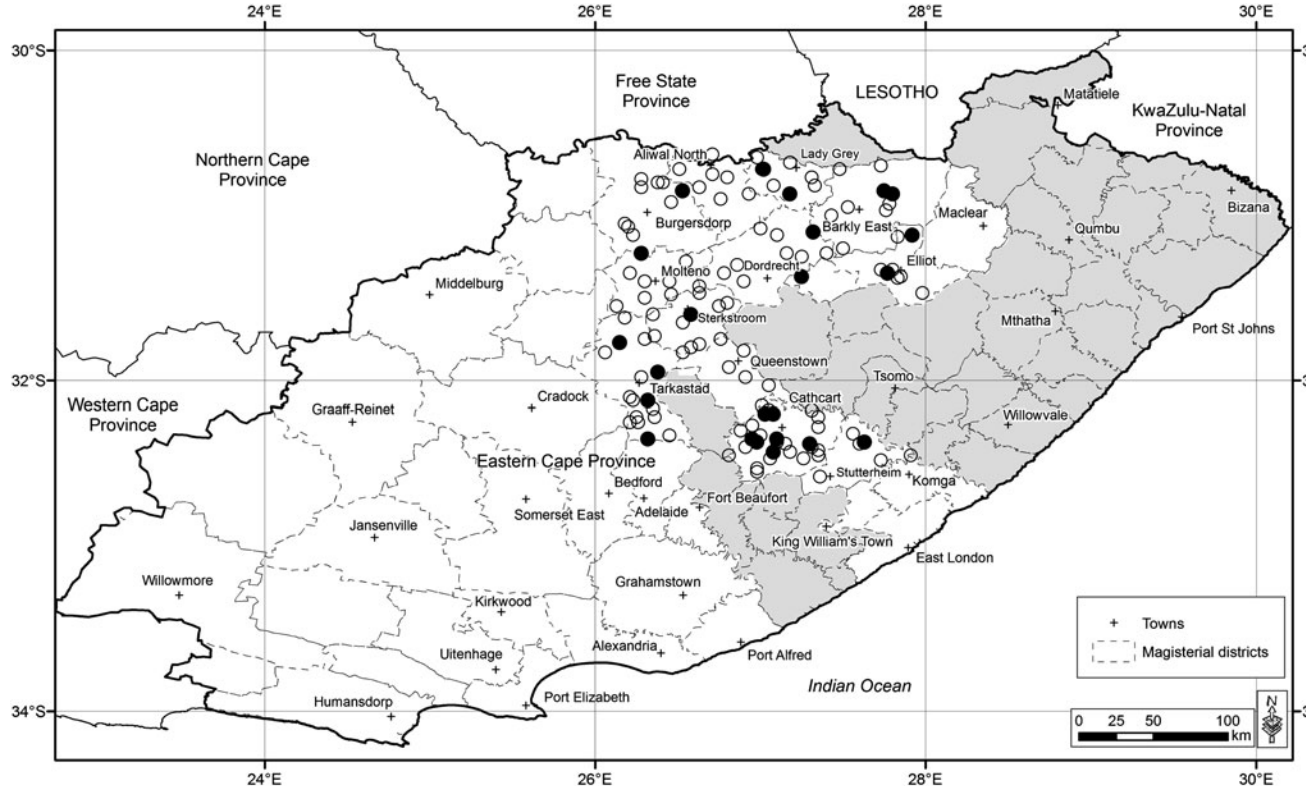

Figure 3. The localities of commercial stock farms in the Eastern Cape Province whose owners participated in the landowner survey (see text). ● = Farms where vulture-power line incidents were reported during the landowner survey; ○ = farms where no vulture-power line incidents were reported during the land-owner survey. Shading denotes LET (low electrocution threat) areas to the east of 25°S30′E.

are 0.86 and 0.91, respectively. Assuming that the migratory sub-population spends a short length of time in the HET area, yearly survival rates for the HET area and migratory sub-populations are now 0.84 and 0.89, respectively. Therefore, if migratory vultures are spending long periods of time in the HET area, their presence is dampening the estimated impact that power line electrocution is currently having on the local population in the HET area.

Assuming a constant rate of increase of 2%, the resident vulture subpopulation in the LET areas, which is not constrained by any electrocution-related mortality, shows a characteristic increase in population size over time (Figure 4A). However, assuming the above mentioned mortality rates, with no evidence that migratory vultures will remain in the East Cape Midlands area of the HET area, the resident subpopulation in the HET area is destined to decrease to localised extinction (Figure 4B). Overall the population in the Eastern Cape, in the absence of additional mortality and assuming a constant 2% population increase per year, shows a positive growth rate (Figure 4C), with the migratory subpopulation re-colonising the HET area each year and providing a seasonal presence of vultures in the HET area that increases with an increasing LET population (Figure 4D). However, reducing the growth rate to 0.6% and 1.3% per annum for the short and long occupancy scenarios, respectively, results in a population decline across the entire Eastern Cape region (results not shown), stressing the importance of initiating conservation actions to limit the impacts of various other mortality factors not included in the model presented.

Discussion

A common approach in attempts to estimate bird mortality rates from power lines involves a search for bird carcasses below power lines, on a prospective and systematic basis, or on a reactive and non-systematic basis (Lehman *et al.* 2007). The latter is essentially the approach that has been followed by Eskom, in association with the WEP-EWT. This has resulted in the data and information in the CIR, the most comprehensive database in South Africa on wildlife (including the Cape Vulture) mortality from power lines, deriving mainly from retrospective sampling,

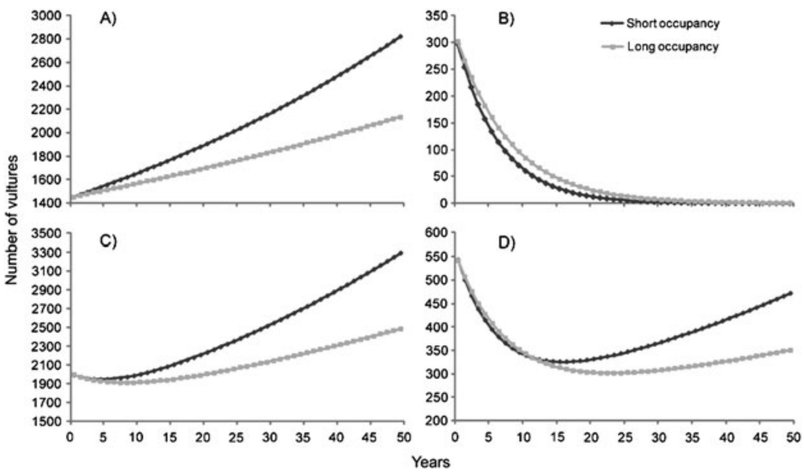

Figure 4 Simulated population trends (based on monthly time step iterations, and for two occupancy scenarios – see text) for the Cape Vulture over the next 50 years in the different parts of the study area: A) resident subpopulation in the low electrocution threat (LET) areas, B) resident subpopulation in the high electrocution threat (HET) area, C) population in the entire study area, and D) population in the high electrocution threat (HET) area (migratory component and resident component combined).

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e.g. chance encounters, intermittent reports from landowners, and some line fault investigation and line patrol reports. Consequently, the information in the CIR is considered to be incomplete and therefore to under-represent the true situation (Kruger 1999, Van Rooyen and Ledger 1999). The findings of our study (see (c) under Results) lend strong support to this view. In a survey of mortality of Blue Cranes *Anthropoides paradiseus* and Denham's Bustards *Neotis denhami*, caused by power lines in the Overberg region of South Africa, a comparison with mortality rates from the CIR led to an estimate of only 2.6% of power line mortalities being reported (Shaw *et al.* 2010b), thereby emphasising the loss of information in the CIR data, even for large-bodied (and therefore conspicuous) birds.

Although the findings of the landowner survey component of our study were used to adjust the estimated mean annual mortality rate obtained from data and information obtained from the CIR (in the pre-landowner survey period), they are also incomplete (for the reasons listed in (d) under Results) and therefore under-represent the true situation. Thus, even though the adjusted rate is an improvement, it is still not an accurate reflection of this parameter, and must be viewed as a minimum value. Consequently, given that the mean annual mortality used in the population model is clearly an underestimate, and because we used a conservative annual growth rate in the design of the model (see (e) in Methods), the outcomes of the simulations must be regarded as conservative, at best.

Even though the vultures are potentially killed by collisions with power line infrastructure in all parts of the study area, our population simulations suggest that 'unsafe' power lines, which can cause electrocutions, have a major detrimental impact on the Cape Vulture population in the study area. More specifically, the impact that electrocution has on this bird in the HET area is potentially severe and should drive that resident population to very low numbers, if not eradicate it from the region as a resident species. As previously mentioned, we have no evidence to suggest that migratory vultures will remain in the East Cape Midlands region of the HET area once the resident population is reduced to low numbers (see (e) under both Methods and Results). However, if this is the case, the drain on the population in the LET areas may be greater, resulting in a greater overall population decline in the province. In this regard, it could be said that the LET areas, which hold or are very close to most of the currently active major breeding sites (Figures 1 and 2; Boshoff *et al.* 2009a) are acting as a 'source' of vultures, whereas the HET area, which has relatively few large breeding sites, is acting as a 'sink' (*sensu* Pulliam 1988).

The survival rates of juvenile and immature Cape Vultures are low (Piper 1994, Piper *et al.* 1999). Available data indicate that mortality from electrocution is making a significant contribution to these low rates; ring recoveries of 51 electrocuted birds in the period 1948–1996 show that 21 (41%) were 0–6 months old, 20 (39%) were 6 months–3 years old, and 10 (20%) were older than three years (Van Rooyen and Piper 1997). This, together with the fact that the predictions of our model are conservative, emphasises the negative impact of electrocution on the conservation of this species.

Our study indicates that a proactive approach (in this case personal interviews with landowners) to obtain data and information on the incidence of power line-related incidents involving vultures, provides better results (enhanced information gain) than does a passive and reactive approach. Support for this comes from a study of the African White-backed Vulture *Gyps africanus* in the Kimberley area of the Northern Cape Province of South Africa, where rates of power line mortality established during an intensive landowner survey (Murn 2001) were significantly higher than the nationally reported figures (Van Rooyen 2000b).

All the landowners surveyed during our study were very familiar with the Cape Vulture in the field and they revealed a remarkably high degree of awareness of its conservation plight (a result of campaigns conducted over the years by the conservation agency of the provincial government and national conservation NGOs). In addition, because of the constant threat of fly-borne disease emanating from dead animals, stock farmers generally maintain (through their staff) a high degree of awareness of dead animals on their properties; they are not specifically searched for but those that are encountered are usually reported to the farmer (AB unpubl. data). Consequently, we contend that the vulture information obtained from the landowner survey, as reported and analysed in this paper, is an acceptable reflection of the true situation.

The Bearded Vulture *Gypaetus barbatus* also occurs in the far north-eastern parts of the study area but power line-related mortality incidents involving this species seemingly comprise a very small proportion of all power line-related vulture deaths; as of 2008, only one power line mortality incident was known, compared to the 148 incidents involving Cape Vultures (CIR, WEP-EWT). In addition, the landowners in this region appear to know the difference between the two species (AB unpubl. data). It is therefore considered highly unlikely that incorrect identification is a significant factor in the Cape Vulture analysis.

Criticism might be generated by our focus on a Cape Vulture population delineated by the borders of a political region (the Eastern Cape Province). This population is not an isolated one, as it forms, together with contiguous populations in neighbouring KwaZulu-Natal Province and the country of Lesotho, the southernmost of two main nodes of occurrence for the species in its global range (Piper 1994, Mundy *et al.* 1997). However, despite the fact that some movement (emigration and immigration) of birds between populations in the three political areas can be expected to occur, the numbers involved are considered to be very low (see Piper 1994), and are therefore considered unlikely to substantially influence the outcome of the demographic model. The overall decline (in range and numbers) of the Cape Vulture population in the Eastern Cape Province is certainly corroborated by the findings of other studies (Boshoff and Vernon 1980, Boshoff *et al.* 2009a).

Our results confirm the potentially highly negative impact of power lines (and particularly 'unsafe' ones) on the regional and global population of the threatened Cape Vulture, and they highlight the urgent need for Eskom to plan and implement appropriate actions to ameliorate or remove this impact. In this regard, some key management recommendations are briefly listed later.

It is emphasised that our study considers only a single unnatural factor, power lines, which was possible since it is additive (*sensu* Lehman *et al.* 2007) to, and not dependent on, the wide range of other unnatural factors that are known to be operating, notably deliberate and inadvertent poisoning, drowning in high-walled farm reservoirs, harvesting for traditional medicines, shortage of calcium in the diet, and possible effects of agro-chemicals (Boshoff and Vernon 1980, Anderson 2000, Boshoff and Anderson 2006, Mander *et al.* 2007). Our current regional population increases if annual population growth is greater than 0.6% and 1.3% per annum for the short and long occupancy scenarios, respectively. If these other mortality factors, together with mortality resulting from collisions with power line infrastructure, had to be factored into the model, thereby reducing the possibility that a 2% population increase is possible, the prospects for the continued presence of the entire population will be reduced.

It follows that the implications of power line-related mortality for the regional and global conservation of the species must be considered to be very conservative. In addition, the situation is not static and new power lines are regularly being constructed, as part of the South African government's economic development programme; these lines will further increase the risk of collision-related vulture mortality, which we do not take into account in our model, and of electrocutions if 'unsafe' structures are erected. A new threat to the vultures in the study area is the current proliferation of plans to establish wind-energy facilities, with some wind turbines having already been erected.

Management recommendations

The outcomes of our study enable us to make a number of management recommendations, aimed at improving the quality and usefulness of the data and information in the CIR, and any subsequent estimation of a mean annual mortality rate for Cape Vultures from power lines. In order to achieve this it is recommended that (a) a proactive approach be adopted through the design and implementation of a regular and systematic sampling scheme for selected sections of power line, (b) the input fields in the CIR be modified to cater for relevant data (e.g. multiple mortalities over time at a single site), and checks carried out to ensure that all data/information fields on the field forms and in the spreadsheet are completed, for each investigated incident, (c) compliance by Eskom personnel with standard in-house incident reporting and data/information recording protocols is significantly improved, (d) regular training courses, to improve the bird-identification skills of Eskom field personnel, are held, (e) the discovery and reporting of incidents to Eskom or the WEP-EWT by landowners is actively and regularly promoted, and (f) appropriate research to determine vulture carcass removal rates by mammalian scavengers, in major habitats and agriculture zones, is conducted.

Another benefit of our study is the identification of areas within the Eastern Cape Province where urgent action needs to be taken by Eskom to reduce or avoid the electrocution of vultures, by (a) mitigating extant 'unsafe' infrastructure, and (b) ensuring that that only 'safe' infrastructure is used for new power lines.

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