The End of the Line for South Africa's National Bird? Modelling Power Line Collision Risk for the Blue Crane

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ABSTRACT

The Overberg wheatbelt population of the Blue Crane (*Anthropoides paradiseus*) comprises approximately half the global population of this Red-listed species. Blue Cranes are highly susceptible to collisions with overhead power lines, and a spatial risk model was developed to identify high risk lines in the Overberg for proactive mitigation. In this study, I surveyed 199 km of power lines to ground-truth the model before it is widely implemented. Unfortunately, the model was shown to be completely ineffective at predicting collision risk for Blue Cranes. Further GIS modelling was undertaken to test a wider range of landscape and power line variables, but only the presence or absence of cultivated land could usefully identify lines posing a collision risk. Currently, the lack of detailed spatial data and recent Blue Crane demographic information mean that GIS models cannot be used to adequately describe the complex collision problem. On the ground survey, Blue Cranes were the most commonly killed birds found (54% of all carcasses). I used recent carcasses to estimate a Blue Crane collision rate of 0.25 $km^{-1}.yr^{-1}$ (95% CI 0.10-0.46 $km^{-1}.yr^{-1}$), corrected for biases, which means that approximately 10% (95% CI 4-18%) of the total Blue Crane population within the Overberg study area is killed annually in power line collisions. While crude, this estimate is extremely high and represents a possibly unsustainable source of unnatural mortality for the Blue Crane. There is urgent need for further research into risk factors and for mitigation measures to be more widely implemented. In addition to Blue Cranes, carcasses of at least 19 other bird species were recovered (including 5 Red-listed or locally endemic taxa), highlighting the wider impacts of power line-induced mortality in the Overberg. After Blue Cranes, Denham's Bustards (*Neotis denhami*) were the most numerous species found with a corrected collision rate of 0.06 $km^{-1}.yr^{-1}$ (95% CI 0.01-0.12 $km^{-1}.yr^{-1}$), some 30% (95% CI 6-59%) of the total Overberg population. Such a high level of unnatural mortality is of serious concern for this threatened species.

1. Introduction

Mortality caused by collision or electrocution on power lines is a well known conservation problem for many bird species worldwide (Janss, 2000; Rubolini et al., 2005), and while unlikely to impact thriving populations, can be a biologically significant source of unnatural mortality for those with limited distributions or small populations (APLIC, 1994; Bevanger, 1998; Mañosa and Real, 2001). As more bird species become vulnerable because of habitat loss and other factors, the expansion of power distribution networks increases the severity of power line mortality. In southern Africa, collisions with power lines may already have a significant impact on several threatened species (van Rooyen and Ledger, 1999).

In order to monitor and mitigate the impact of power lines on birds in South Africa, the national electricity supplier Eskom formed a strategic partnership with the Endangered Wildlife Trust in 1996 (van Rooyen and Ledger, 1999). While collisions can only be eliminated by burying lines, marking lines to increase visibility remains the most practical method of reducing collisions with existing power lines (APLIC, 1994; Alonso and Alonso, 1999; Rubolini et al., 2005). Most collisions occur with the earthwire, which is usually placed above the thicker and more conspicuous conductors (Alonso and Alonso, 1999). In South Africa, a variety of marking devices are used, but uncertainty remains about which is best as they vary in effectiveness between species and in different conditions (van Rooyen and Ledger, 1999; Anderson, 2002).

The collision risk posed by power lines is complex and problems are often localised. Collisions frequently occur where 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 interact (APLIC, 1994; Bevanger, 1994). Collision mortality is species-specific (Janss, 2000), with frequently affected species often characterised by a high wing loading and low aspect ratio, resulting in rapid flight and low manoeuvrability, restricting their ability to avoid unexpected obstacles (Bevanger, 1998). With such characteristics, the cranes (family Gruidae) fall into this high collision risk definition (Bevanger, 1998). Cranes act as important flagship species for wetland and grassland conservation, yet are one of the most threatened bird families worldwide (Beilfuss et al., 2007).

The Blue Crane (*Anthropoides paradiseus*) has the most restricted range of all cranes, being near endemic to South Africa where it is the national bird (McCann et al., 2007). The species has experienced a significant and rapid decline in recent decades, primarily because of habitat loss in its historical grassland strongholds (McCann et al., 2001), and is therefore listed as globally Vulnerable (BirdLife International, 2008a). Three distinct populations of Blue Crane are recognised in South Africa, centred in the Eastern Grasslands, the central Karoo, and the Overberg/Swartland region of the Western Cape (McCann et al., 2007). While the Eastern Grassland population has been decreasing and the Karoo population stable, conversion of renosterveld and fynbos ('natural veld') for agriculture in the Overberg has provided Blue Cranes with 'artificial grasslands', enabling their expansion in this region. Approximately 12 000 cranes, representing roughly half of the national population, are now resident in the cereal croplands of the Western Cape (McCann et al., 2007). This population is therefore crucial to the persistence of the species. However, despite the favourable conditions in the Overberg, the Blue Crane remains in a precarious position because of heavy reliance on cereal crops and sheep pastures. Potential market or climate driven changes in farming practices, such as an increase in the cultivation of unfavourable crops such as canola, or broad-scale intensification of agriculture leading to a decrease in the availability of pastures, are likely to have far-reaching negative effects on the Blue Crane population in this region (Leeuwner et al., 2003; Allan, 2005a; Gbetibouo and Hassan, 2005).

In this context, any sources of regular, unnatural mortality, such as power line collisions (and possibly including poisoning, drowning of young in water troughs, predation by dogs, fence entanglement, and taking of young for food and pets (Allan, 2005a)) has the potential to significantly undermine the long-term conservation of this already threatened species. Unfortunately, as large, seasonally gregarious birds, Blue Cranes are particularly prone to collisions with overhead power lines, because of their limited manoeuvrability, and their habit of flying in flocks and during low light conditions (Anderson and Piper, 2007). Such collisions are thought to be a significant threat to Blue Cranes in the Karoo (McCann et al., 2001), but the extent of the problem in the Overberg is unknown. The Central Incident Register (CIR) (Eskom-EWT, 2008), which collates all reported wildlife mortalities on Eskom power infrastructure, includes over 750 Blue Crane collisions accumulated over 12 years, of which approximately 260 occurred in the Overberg. This suggests that collisions may be a significant limiting factor for Overberg cranes, the effects of which will only worsen with the ongoing expansion of the power grid.

Opportunistically compiled registers of avian power line collisions are likely to underestimate true mortality rates, because only an unknown fraction of casualties are located incidentally, and of these most are found in areas of high human traffic, with only an unknown fraction ever reported (Bevanger, 1999). Substantial resources in time and effort are required to obtain comprehensive mortality data stemming from systematic searches, and so perceived problematic lines in South Africa, identified largely in terms of data on the CIR, are presently marked on a reactive basis (van Rooyen and Ledger, 1999). In an effort to start working more proactively, a GIS model was developed to identify low voltage distribution power lines posing a high collision risk to Blue Cranes in the Overberg (Kotoane, 2003). This model was designed to reduce preventable crane collision mortalities, and to raise the efficacy of line marking throughout the Overberg, using fine scale habitat data to avoid over-generalisation of this complex problem. It used expert knowledge of Blue Crane biology and habitat use to develop rules based on topographic features and known crane congregation sites (Fig. 1). Of the 3515 km of distribution lines considered, 956 km (approximately 27%) were identified as the highest risk that should be marked immediately, and 1589 km (approximately 45%) were considered to pose some risk to Blue Cranes and thus requiring mitigation (Fig. 1). However, because of the considerable costs involved in retrospective line marking, implementation of the model has been suspended until it has been adequately ground-truthed and shown to be effective in highlighting problem power lines.

In the present study, field data were gathered on the distribution of Blue Crane collisions on power lines in the Overberg to (i) assess the validity of the GIS model developed by Kotoane (2003), (ii) further refine this model to better explain the collision risk posed by power lines in this region, by considering a wider range of variables, and (iii) provide a first estimate of the scale and biological significance of the Blue Crane power line collision problem in the Overberg.

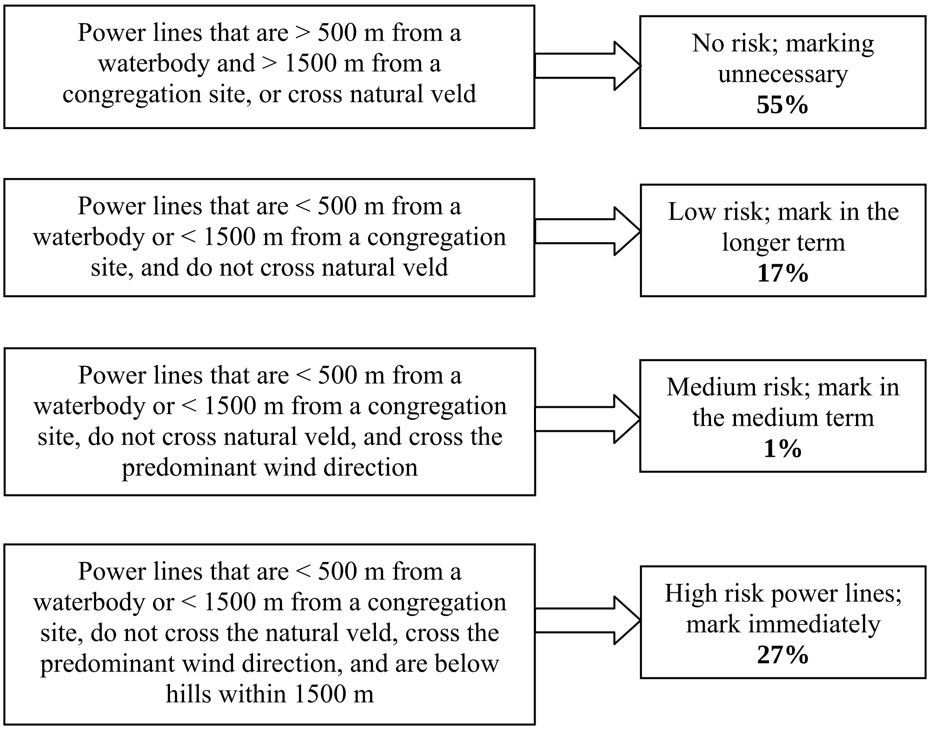

Figure 1. Rules developed to predict Blue Crane collisions with low voltage distribution power lines in the Overberg region of the Western Cape (Kotoane, 2003), with percentages of the total line shown for each risk category. Due to the very low coverage of medium risk lines, this category was excluded from the analysis.

2. Methods

2.1 Study area

The study was conducted in the Overberg region of the Western Cape, South Africa. For ease of comparison, the study area was the same as that defined by Kotoane (2003), which covers 12 848 km^2 and is centred on the magisterial districts of Caledon, Bredasdorp, Hermanus, Swellendam and Heidelberg (Fig. 2). It extends from 19° E to 21° E, and is bounded by the Hottentots Holland, Riviersonderend and Langeberg Mountains to the north, and the Atlantic and Indian Oceans to the south. The study area contains 815 km of high voltage transmission lines (602 km of 66 kV lines, and 213 km of 132 kV and 400 kV lines) and 3856 km of low voltage distribution lines (11 kV and 22 kV).

The Overberg landscape is characterised by coastal plains and rolling hills, and was historically vegetated by fynbos and renosterveld. The region has undergone extensive agricultural transformation over the past century, leaving approximately 15% of the original renosterveld, primarily as small fragments (Kemper et al., 1999). Currently, much of the region operates a wheatland-pasture system, in which dryland pastures are sown with a cereal crop to provide grazing for sheep, cattle and ostriches in the following season. To a lesser extent, canola is grown, and there are some vineyards and orchards (Leeuwner et al., 2003). The Overberg wheatbelt is listed as an Important Bird Area (Barnes, 1998).

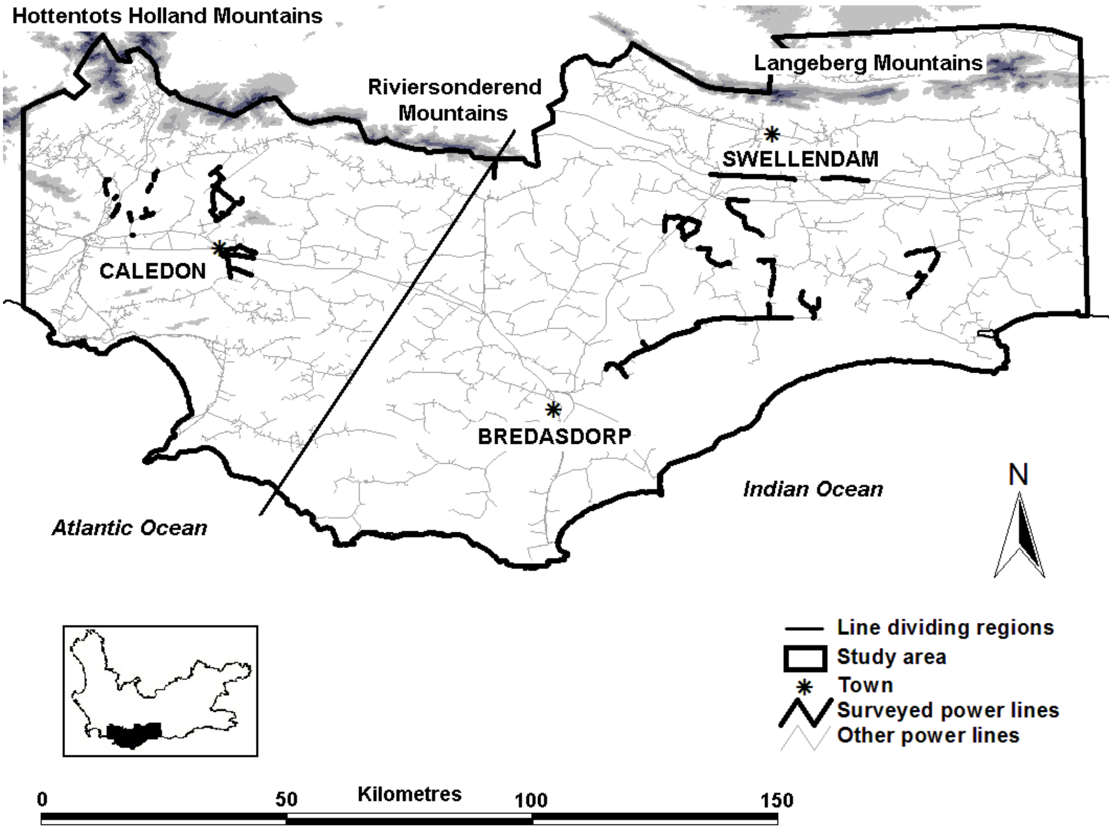

Figure 2. Study area in the Overberg region of the Western Cape, showing surveyed and all other power lines. The dividing line separates the power lines surveyed into the Caledon and Bredasdorp regions.

2.2 Field methods

2.2.1 Ground survey

Field work was conducted between September 2008 and January 2009. Crane mortality was investigated by surveying approximately 44 km of transmission line (66-400 kV) and 155 km of distribution line (11-22 kV) on foot. These lines were centred around Caledon, and between Bredasdorp and Swellendam (hereafter referred to as the Caledon and Bredasdorp regions (Fig. 2)), with surveys in both regions conducted throughout the field work period. I selected lines based primarily on ease of access, but also to ensure a representative sample of lines of different risk categories as defined in Kotoane's (2003) model. On all transects, a Garmin GPS 60 was used to record the location of all live Blue Crane sightings, all carcasses, the presence/absence of any line marking devices, and to record habitat by taking a waypoint every time this changed. The type and practical condition of the devices used on all marked lines was also recorded.

To search for collision casualties, I walked straight along under the power lines, searching the area 15 m to either side of the outermost conductor. Under 400 kV and 132 kV transmission lines the total width of the line was too great to clearly see the 15 m either side on one transect, so the area under the outermost conductor on one side was searched walking in one direction, and the area under the outermost conductor on the other side was searched on the return leg. While other studies have covered areas from 5-10 m (Bevanger and Brøseth, 2004) up to 50 m (Sundar and Choudhury, 2005) either side of surveyed lines, given that most carcasses are found well within the 15 m mark (Bevanger, 1999), 15 m was selected as a practical and adequate search width for this study. Because time in the field was limited, and because Overberg power lines often run adjacent and parallel to fences, the recommended zig-zag search pattern (APLIC, 1994) was not used.

When a carcass was encountered, I took photographs and collected data on the line, location and carcass, expanding on the data categories used by Anderson (2002). I recorded the date and time, habitat type, line voltage, and GPS coordinates. Carcasses were identified to species where possible. I recorded the state of the carcass: fresh (within a week old, with soft flesh remains and fresh feathers), recent (within two months old, with dried flesh remains and numerous feathers still present), fairly old (within a year old, with dry bones and possibly some old feathers remaining) and very old (older than one year, with bleached bones, no flesh or feathers), and whether or not the carcass was ringed. I also noted the side of the line on which the carcass lay (compass direction relative to the line), the distance of the carcass from the outer conductor, and the position of the carcass along the span, in categories of 'midspan' (central $^{1}/_{5}$ of the span), 'in-between' (adjacent $^{2}/_{5}$ of the span) and 'close to pylon' (remaining $^{2}/_{5}$ adjacent to the pylons). In most cases it was not possible to age or sex carcasses in the field. All remains were removed to prevent double counting and for further reference. Where necessary, very old or incomplete carcasses were later identified using comparative skeletal material at the Iziko Museums of Cape Town. Unless clearly indicated otherwise (e.g. chicks fallen from nests), all bird carcasses found within the search corridor were assumed to have been either collision or electrocution victims.

Lines where I encountered 'collision hotspots' (several crane carcasses within a short length of power line) during the first survey (conducted between September and December 2008), were surveyed a second time in January 2009 to try to assess collision rates in these areas (approximately 7.3 km).

2.2.2 Aerial survey

In addition to the ground survey, I conducted an aerial survey in a Bellanca 8GCBC Scout aircraft on 9 October 2008. I was the primary observer on this flight, although the pilot served as an additional observer whenever possible. We flew at a height of 15-30 m, at approximately 160 km/hr, to one side of the line. We covered approximately 70 km of 11/22 kV lines, 181 km of 66 kV lines and 31 km of 400 kV lines. Habitat, GPS location, distance from line and position along span was recorded for all carcasses seen from the air.

2.2.3 Scavenger removal experiment

In order to estimate the effect of scavengers on the number of carcasses found, I conducted a carcass removal experiment using 24 dead geese and ducks (20 Egyptian Geese (*Alopochen aegyptiacus*), 3 South African Shelducks (*Tadorna cana*) and 1 Yellow-billed Duck (*Anas undulata*)). The birds had been shot and had their stomachs removed, and were placed in the field within 36 hours. They were artificially positioned in four groups of six birds under power lines in separate areas, to mimic collision hotspots (each group was spread over approximately 800–1000 m of power line). I monitored the carcasses every day for five days, and then a further three times over a period of two months. Monitoring was more intensive at the start of the experiment because carcasses are most likely to be removed by vertebrate scavengers before they fill with maggots and/or mummify (Smallwood, 2007). Presence or absence of the carcass, details of scavenging activity and stage of decomposition was recorded on each monitoring occasion (following Savereno et al., 1996). As ducks and geese may be more or less palatable than Blue Cranes, three recent Blue Crane collision carcasses were subsequently added to the experiment to gauge similarity between scavenging activity on the different species.

Over the two months of the experiment, 6 of 24 carcasses were removed completely. Of these, 5 were removed within the first three days, and the sixth between day 5 and day 17. Of the remaining carcasses, 7 were lightly scavenged (minor movements, carcass still relatively intact) and 7 were heavily scavenged (carcass dismembered) after two months. Only 4 of the remaining carcasses were untouched by the end of the experiment. One carcass was moved approximately 240 m from its original position, and three others moved more than 30 m, putting these carcasses outside of the search corridor. All three Blue Cranes were lightly scavenged, although none were removed. Aside from people, potential scavengers seen during fieldwork included White-necked Ravens (*Corvus albicollis*), Pied Crows (*Corvus albus*), domestic cats (*Felis catus*) and dogs (*Canis lupus familiaris*), Cape foxes (*Vulpes chama*), bat-eared foxes (*Otocyon megalotis*), Cape porcupines (*Hystrix africaeaustralis*) and yellow mongooses (*Cynictis penicillata*).

2.3 Analytical methods

2.3.1 Spatial data manipulation

To analyse collision risk factors, I used the Geographic Information Systems (GIS) ArcView 3.2 and 3.3 (Environmental Systems Research Institute, 1999; Environmental Systems Research Institute, 2002). I used spatial data from a number of sources (Appendix 1), and several GIS extensions (Appendix 2). Layers were reprojected into an Albers Equal-Area Conic projection (Appendix 3) when necessary for distance and area calculations.

I developed a shapefile of power lines surveyed from the original Eskom power line layers. These surveyed lines were broken into 250 m sections, and the remainder at the end of each line included as a separate section only if it exceeded 150 m in length. I then attributed data on the various collision risk factors (APLIC, 1994) to these sections for further analysis. Unlike the original model, proximity to congregation sites was excluded from the analysis because of a lack of recent data on the location of these sites. Height of power lines in relation to surrounding hills was also excluded, because following Kotoane's (2003) methods, my data layers showed all lines to be below the height of hills within 1500 m. In addition, high mountains such as the Langeberg range near Swellendam provide a dark background for lines from a much greater distance than 1500 m, and it is unclear whether lines pose a greater collision risk when on the horizon or against a dark background (K. Shaw and V. Hudson, pers. comm.).

Point data from waypoints (Blue Crane carcasses, other carcasses and live Blue Crane sightings from line surveys) were assigned to the nearest power line section. I used data collected on Coordinated Avifaunal Roadcounts (CAR) (Animal Demography Unit, 2005-2008) to develop an index of Blue Crane population density in the Overberg. I calculated the average density of Blue Cranes (all age classes combined per kilometre) for each Overberg route, separately for each of up to 6 half-yearly counts (July 2005–January 2008) because the routes sometimes varied in distance between counts. I then took the mean of these averages for the final density value per route. Two routes were excluded because of deficiencies in the data available for the relevant time frame. The study area was then divided into polygons representing the nearest CAR route (Fig. 3), and population densities were assigned to the power line sections within each polygon.

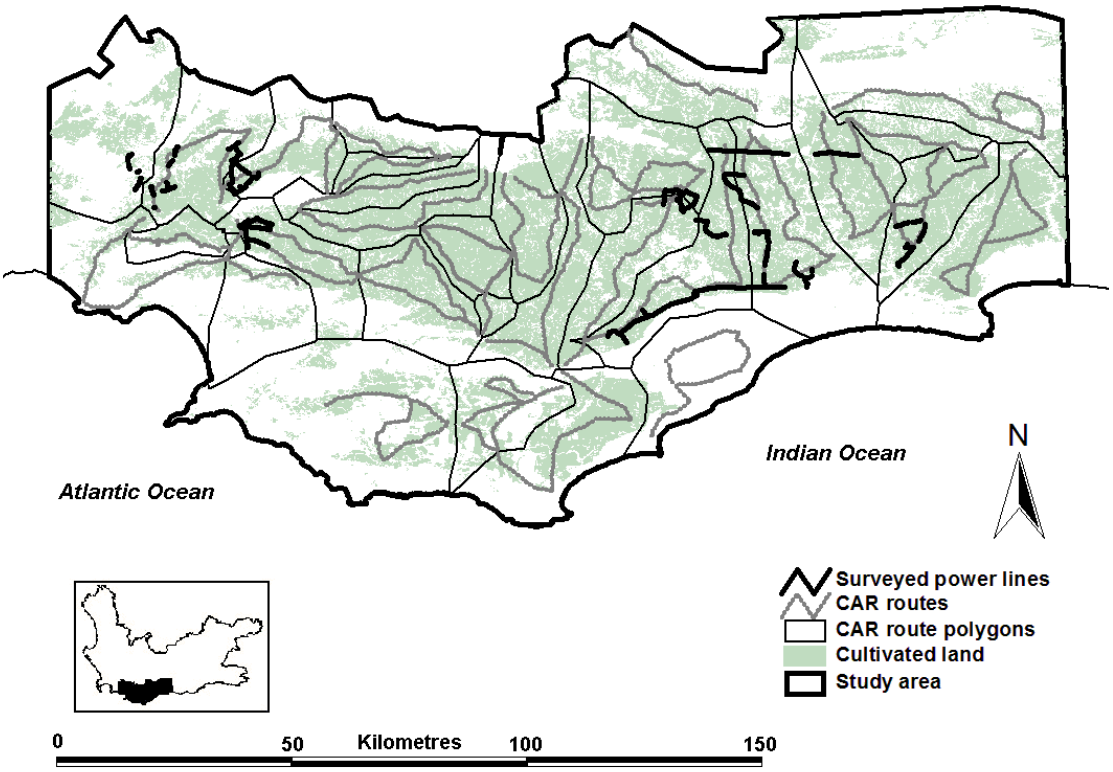

Figure 3. Study area divided into polygons representing the nearest Coordinated Avifaunal Roadcount (CAR) route, with surveyed power lines and cultivated land.

The National Landcover layer was clipped to create a cultivated land layer, represented by the improved grassland, temporary cultivated and permanent cultivated land categories (Fig. 3). All power line sections with their centre in cultivated land were considered to be on cultivated land, and all others to be on uncultivated land. Similarly, the CAPE Untransformed Areas layer was used to classify all power line sections with their centre in veld as on veld, and all others to be on off veld. To assess the accuracy of the cultivated land layer, I systematically compared 20% of the line sections (n=153) with the habitat data collected in the field. I categorised a section as cultivated if at least 50% was under cultivation. The National Landcover layer classified 84% of sections correctly when compared with the field data, and thus was assumed to be reasonably accurate for further analysis.

I split the roads layer into main roads (main, major, freeway and through route categories) and secondary roads (secondary and road categories), and clipped urban areas from the National Landcover layer. I categorised power line sections as close to roads or urban areas if they were within 100 m and 500 m of these sources of disturbance. The predominant wind directions in the Overberg are south-easterly in the summer and north-westerly in the winter (Kotoane, 2003). I calculated the angle of each power line section, and classified all sections with angles between 1-90° and 181-270° as posing a greater risk than lines between 91-180° and 271-360°, because these run approximately perpendicular to the predominant wind direction. Power lines were categorised as close to water if they were within 500 m of any waterbody, including farm dams, on a waterbodies layer developed from the 1:50 000 maps. Power lines were categorised as close to open water if they were within 500 m of waterbodies that did not fall in veld, urban and forested areas, as Blue Cranes prefer to roost in open waterbodies (Allan, 2005a). I manually categorised all power line sections as marked or not according to my field observations and waypoints.

2.3.2 Bias estimation

Four inherent and site-specific methodological biases tend to result in underestimation in power line carcass surveys: habitat bias, search bias, removal or scavenger bias, and crippling bias (APLIC, 1994). In this study, these biases mainly affect the calculation of collision mortality rates, as the ground truthing of Kotoane's (2003) model uses relative, rather than absolute numbers of collision victims, and biases are assumed to be constant.

Habitat bias refers to the percentage of the power line corridor which was impossible to search efficiently (Bevanger, 1999). The landscape in the Overberg is very open, but habitat bias arises from the density of vegetation in natural veld, and in mature cereal, canola and fallow fields. In these 'closed' habitats, the effective search width when walking in a straight line is reduced to approximately 5 m, as demonstrated by the fact that no Blue Crane carcasses were found further than 5 m from the line in these habitats (Fig. 4). In a few extreme cases, short sections of line were completely unsearchable e.g. deep, thickly vegetated gullies.

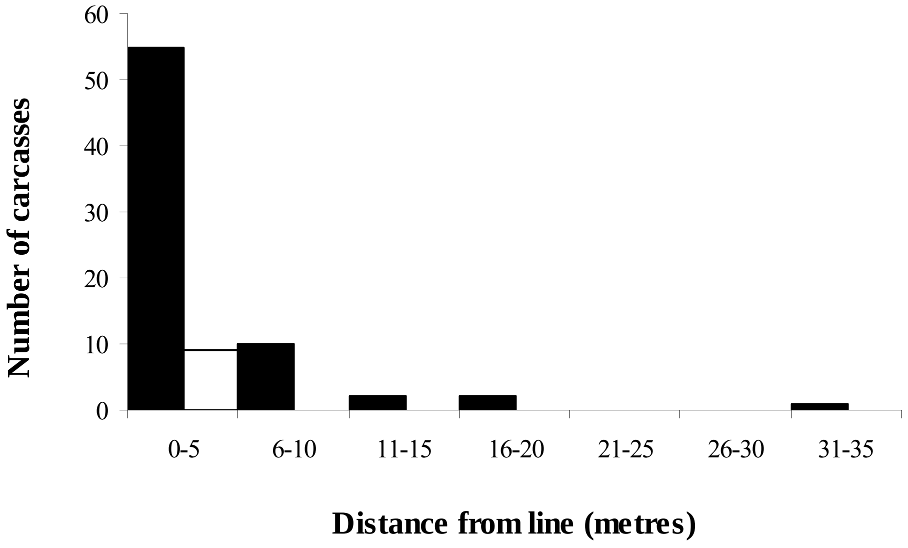

Figure 4. Distance of Blue Crane carcasses from the power line in open habitats i.e. pasture and stubble (black) and closed habitats i.e. mature cereal and veld (white).

To calculate the habitat bias, the habitats crossed in the Caledon and Bredasdorp samples were analysed separately (Fig. 5). For each, the total percentage of habitat with dense vegetation was calculated and multiplied by 0.66, because 0.66 of the search width of 15 m was unsearchable. These percentages were then adjusted for the fact that 81% of the Blue Cranes colliding with power lines were found within 5 m of the line (Fig. 4) (Bevanger, 1999), and then added to the percentage of totally unsearchable habitat. The habitat biases calculated for Caledon and Bredasdorp were then averaged, weighted by the amount of line surveyed in each, giving an overall habitat bias of 0.09. This is lower than the habitat bias in most other studies, which is often between 0.20 and 0.30 (Bevanger, 1995; Alonso and Alonso, 1999; Janss and Ferrer, 2000).

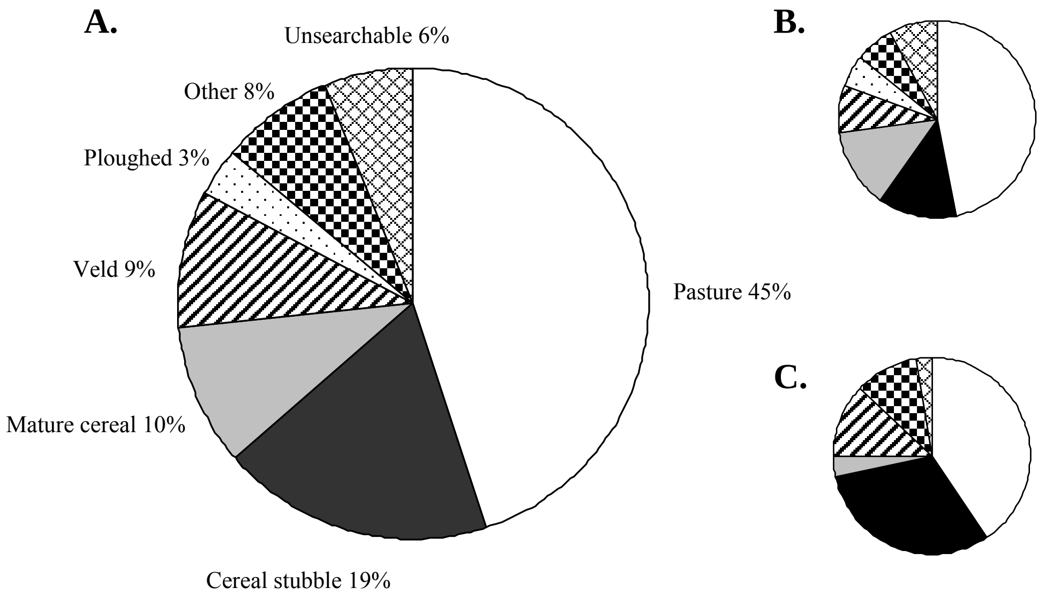

Figure 5. Composition of habitat along power lines surveyed for bird carcasses in the Overberg. A represents overall habitat, B represents the habitat in the Bredasdorp region and C represents the habitat in the Caledon region. 'Other' includes low cereal crops, marsh, woodland, fallow fields, canola fields and wasteland, and 'Unsearchable' represents habitat where searching was impossible, e.g. in thickly vegetated gullies.

Search bias refers to the effectiveness of the fieldworker in locating carcasses, and is expected to vary with season, conspicuousness of different sized carcasses, and varying experience of searchers (APLIC, 1994). In this study I have assumed no search bias in the detection of recent Blue Crane mortalities, as I was searching alone for large and obvious carcasses in a single season. In addition, only 3 Blue Cranes were found further than 15 m from the power line (Fig. 4), suggesting that 15 m was an appropriate search width.

Scavenger bias corrects for collision victims removed by scavengers (APLIC, 1994). I used the results of the scavenger removal experiment to calculate the scavenger bias as 0.42, from the proportion of goose and duck carcasses removed from the search corridor over two months (n=10). While my quantitative scavenger removal experiment used geese and ducks as surrogates, the resulting scavenger bias can reasonably be applied to Blue Cranes. The scavenge rate is expected to be higher for the surrogates than Blue Cranes because of size (Bevanger, 1995), but this is balanced by the fact that the experiment only ran for two months and the value calculated was used as a yearly estimate. All three Blue Crane carcasses were scavenged, indicating that they were palatable to scavengers, despite not being as fresh as the geese and ducks. In addition, it is known that farm labourers harvest carcasses (van Rooyen and Ledger, 1999; discussion with farmers), CapeNature staff collect carcasses for documentation, and I encountered one farmer who explained that he removes dead Blue Cranes from under power lines along roads on his land, preferring them not to rot in view. Finally, my scavenger bias is comparable with that used in other studies, e.g. 0.43 used by Alonso and Alonso (1999), and 0.5-0.8 by Bevanger (1995).

Crippling bias accounts for birds which sustain injuries in power line collisions that are not immediately fatal, enabling them to move well away from the power line, and hence out of the surveyed area, before they die. This bias is extremely difficult to quantify, and can only be assessed with any accuracy in appropriate tracking studies, or by direct observations of power line collisions (Bevanger, 1999). Figures used in previous studies vary widely, from 0.20 (Bevanger, 1995) to 0.74 (Beaulaurier, 1981) and averages from other studies are frequently applied (Janss and Ferrer, 2000; Sundar and Choudhury, 2005). I have applied a conservative crippling bias of 0.20, using Bevanger's (1995) estimate for Capercaillie (*Tetrao urogallus*) in Norway. This is supported by local field knowledge (V. Hudson, pers. comm.) and a study by Savererno et al. (1996) that calculated a crippling bias of 0.26 from observed collisions, mainly of waders and gulls, with power lines in South Carolina, U.S.A..

2.3.3 Collision rate

Collision rates are normally calculated by regular dead bird surveys of short sections of power line, sometimes combined with bird flight monitoring studies (APLIC, 1994; Bevanger, 1998), but these approaches were discounted for this study by time constraints. In addition, no further Blue Crane collision casualties were found on the second survey of collision hotspots. Therefore, a collision rate for the Overberg was calculated from the Blue Crane carcasses found on the first survey that I could be certain were <1 year old (e.g. body largely intact, most feathers present, on top of vegetation). This judgement was informed by the observed decomposition rate of scavenger experiment carcasses, and is conservative, as any carcasses that I could not confidently classify were discarded from the collision rate analysis. I calculated a collision rate per kilometre for power lines on cultivated and uncultivated land, and then adjusted this figure for the biases described, before comparing it to the total population.

The most recent and reliable population estimate for Blue Cranes in the Overberg comes from the National Crane Census 2002 (McCann et al., 2007). To gain a current population estimate, I first summed the populations counted within the boundaries of the Overberg study area in 2002 (from unpublished National Crane Census 2002 data). I then fitted a regression line to the average summer densities of Blue Cranes per 100 km seen on the Overberg CAR routes from 2002 to 2008 (Fig. 6) (Animal Demography Unit, unpublished data), and adjusted the 2002 population estimate accordingly. Summer densities were used as the cranes are more evenly spread over the landscape during the breeding season, resulting in less variability between counts and more reliable population trends (Shaw, 2003). The CAR counts suggest a population increase of 30% since 2002, so I estimated a current population of approximately 12 000 individuals in the study area in 2008.

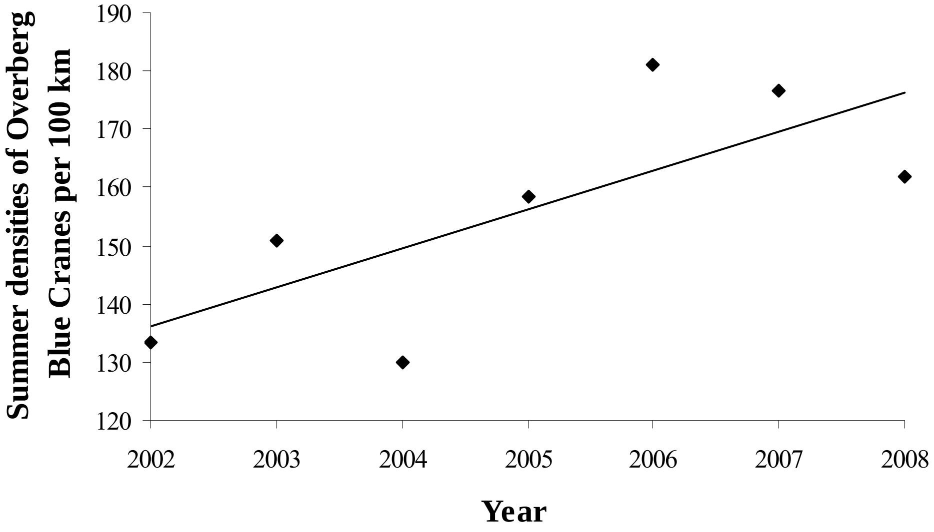

Figure 6. Average summer densities of Blue Cranes counted in the Overberg region of the Western Cape on Coordinated Avifaunal Roadcounts (Animal Demography Unit, unpublished data), with regression line ($y = 6.705x - 13287$, $r^2 = 0.55$, P=0.058).

As the second most numerous collision victim (Tables 1 and 2), and itself a Red-listed species of considerable conservation concern (Barnes, 2000), a collision rate was also calculated for Denham's Bustard (*Neotis denhami*). The mean winter population in the southern Cape (which is broadly similar to my study area) was estimated to be 956 birds (95% CI 464-1447) in 2002 (Allan, 2002). This mean figure was used for the population in 2008, because unlike Blue Cranes, no significant population trends could be ascertained from the CAR densities for Denham's Bustard. As Denham's Bustards are large birds, the biases calculated for Blue Cranes are equally applicable and were subsequently applied to collision rates as they were for the cranes. The number of Denham's Bustard carcasses found was too low to test for landscape predictors of collisions, and so a single collision rate was calculated for the whole study area.

2.4 Statistical analysis

Chi-square goodness of fit tests were used to test the efficiency of Kotoane's (2003) model in predicting power lines posing a high collision risk (Zar, 1999). To identify factors which were related to the presence or absence of Blue Crane collisions, chi-square goodness of fit tests were performed separately on the variables attributed on the 250 m segments of surveyed power lines, using SPSS 15.0 for Windows (SPSS Inc., 2006). Yates' Correction for Continuity was made for all chi-square goodness of fit tests with one degree of freedom (Zar, 1999).

Significant factors were then analysed using GLMs (Generalised Linear Models) to identify the strongest predictive variables, using the software R 2.4.1 (R Development Core Team, 2008). A negative binomial modelling approach was taken, as the distribution of Blue Crane carcasses was overdispersed (Zar, 1999). To find the best model, a strategy of backward-elimination of non-significant explanatory variables was used. To ascertain the significance of each explanatory variable, the log-likelihood of the full minimal model including the variable of interest was compared to the log-likelihood of the reduced model excluding it. Akaike's Information Criterion (AIC) was used to assess model support (Quinn and Keough, 2002). Finally, to generate 95% confidence intervals for the collision rate estimation, the numbers of recent Blue Crane carcasses found in each 250 m section of power line were bootstrapped (1000 iterations), treating sections found on cultivated and uncultivated land (as defined by the National Landcover GIS layer) separately.

3. Results

3.1 Aerial survey

Unfortunately, the speed of the aircraft, and the decomposed nature of most carcasses meant that few collision victims could be identified from the air. For a 13.7 km stretch of 400 kV power line that was walked within 2 weeks of the aerial survey, only 25% of the large bird carcasses which were still relatively intact, with feathers, were seen from the air (Table 1). Therefore, only data from the ground survey were included in subsequent analyses.

Table 1. Comparison of ground and aerial surveys in recovery efficiency of recent carcasses of large birds for a 13.7 km stretch of 400 kV power line near Swellendam.

	Ground survey	**Aerial survey**
Blue Crane	9	1
Denham's Bustard	2	1
Egyptian Goose	1	0
Unknown	0	1
Total	**12**	**3**

3.2 Ground survey

In total, I surveyed 199 km of power line on foot, and found 147 bird casualties of 19 species (Table 2). This total includes carcasses found on the second survey to collision hotspots, but excludes possible road kills, and small birds found close to pylons which could have been food items of perching corvids and raptors. Species that commonly perch on pylons and were found close to the pylon, such as Helmeted Guineafowl (*Numida meleagris*) and Egyptian Geese, were assumed to be electrocution victims. The remaining 132 birds are assumed to have been collision victims.

Table 2. Number of collision and electrocution carcasses of all species found during ground power line surveys.

Common name	**Scientific name**	**Number of collisions**	**Number of electrocutions**
Blue Crane	*Anthropoides paradiseus*	79	0
Denham's Bustard	*Neotis denhami*	17	0
White Stork	*Ciconia ciconia*	10	1
Spur-winged Goose	*Plectropterus gambensis*	7	1
Helmeted Guineafowl	*Numida meleagris*	3	4
Egyptian Goose	*Alopochen aegyptiaca*	2	4
Hadeda Ibis	*Bostrychia hagedash*	2	1
Southern Black Korhaan	*Eupodotis afra*	2	0
Black-headed Heron	*Ardea melanocephala*	1	1
African Spoonbill	*Platalea alba*	1	0
Barn Owl	*Tyto alba*	1	0
Lanner Falcon	*Falco biarmicus*	1	0
Cape Spurfowl	*Pternistis capensis*	1	0
Grey-winged Francolin	*Scleroptila africanus*	1	0
Rock Dove	*Columba livia*	1	0
Capped Wheatear	*Oenanthe pileata*	1	0
Red-capped Lark	*Calandrella cinerea*	1	0
Cape Crow	*Corvus capensis*	0	2
Sacred Ibis	*Threskiornis aethiopicus*	0	1
Unidentified korhaan/bustard		1	0
Total		**132**	**15**

Altogether, 79 Blue Crane carcasses (54% of all carcasses) were recovered. Of these, 15 were found outside the search corridor, or were very old carcasses missed on the first survey but discovered on the second, and are excluded from subsequent analyses. Of the remaining 64 cranes carcasses, 23 were judged to have been dead for less than a year and were used in the calculation of collision rates, and 47 were found on distribution lines and were used to test the validity of Kotoane's (2003) model. Of the 17 Denham's Bustard carcasses found, 5 were estimated to have been dead for less than a year, and were used to calculate a collision rate for this species. I also found the carcasses of 11 White Storks, 6 of which were fresh and were found during the second survey of collision hotspots.

The distribution of Blue Crane carcasses did not fit a Poisson distribution (χ^2=18.42, df=2, P<0.01), but could be fitted to a negative binomial distribution (χ^2=4.17, df=2, P=0.13). The carcasses were clumped as they were commonly found in collision hotspots, which were characterised by a variety of species and carcasses states, with carcasses found on both sides of the line. For example, the worst hotspot I encountered was a 1.6 km stretch of 400 kV line near Swellendam. On the first survey (October 2008) I found the carcasses of 11 Blue Cranes (ranging in state from recent to very old) and 1 Denham's Bustard, and on the second (January 2009) found 2 Hadeda Ibises, 1 African Spoonbill and 3 White Storks.

The position of carcasses along the span was not random (Blue Cranes χ^2=29.77, df=2, P<0.01, other species χ^2=22.78, df=2, P<0.01), with the midspan of the power line disproportionally killing more birds (Fig. 7). This demonstrates that most birds are killed away from the pylon, and the pattern is similar for Blue Cranes and other species (Fig. 7).

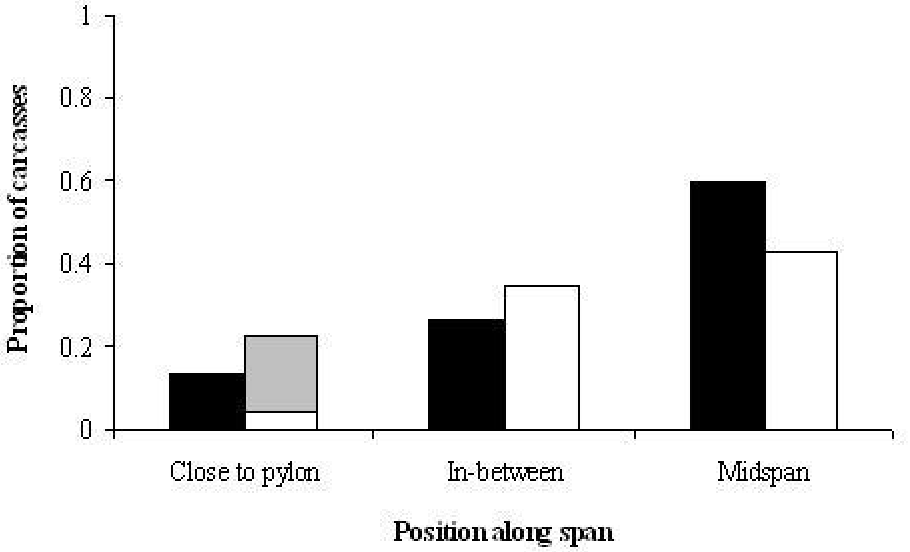

Figure 7. Proportion of carcasses found in each span section, weighted to adjust for length of spans. Blue Cranes (black) and all other species (white) found along power line spans, with assumed electrocutions (grey).

Of the 199 km of surveyed lines, 12.3 km (6.1%) were marked. The marking devices were defective on just over half (6.7 km) of these lines, primarily because of broken moving parts, and markers moving along the line.

3.3 Testing the model and risk factors

Kotoane's (2003) model did not predict which power lines pose a collision risk to Blue Cranes. Comparing lines identified as high, low and no risk to cranes, and then comparing risk and no risk lines showed that Kotoane's model was not significantly different from a null model of equal collision risk (χ^2=0.86, df=2, *P*=0.65, χ^2=0.48, df=1, *P*=0.49). The medium risk category was excluded because so few power lines fell into this category (Table 3).

Table 3. Number of Blue Crane carcasses found and length of power line surveyed for each of the risk types as described in Kotoane's model (2003).

	High	**Medium**	**Low**	**No risk**
Total length of lines in study area (km)	955.6	33.3	600.3	1925.8
Length of lines surveyed (km)	63.2	1.9	41.1	48.3
Number of Blue Crane carcasses	20	0	10	17
Blue Crane carcasses.km^{-1}	0.32	0.00	0.24	0.35

Chi-square tests to determine the predictive value of factors to identify high risk lines were not significant for proximity to roads, urban areas and water, angle of line relative to prevailing wind conditions, presence of natural veld, line marking or sightings of live Blue Cranes. Line voltage, region (Caledon vs. Bredasdorp samples), CAR Blue Crane density (categorised) and presence of cultivated land were all significant, and were analysed further using GLMs. The presence of other bird collision carcasses was also significant (χ^2=4.88, df=1, *P*=0.03), but was not included in the GLM analysis.

The cultivated land and region model best describe the data (Table 4) Region and cultivated land were also significant when comparing the log-likelihood of the models with and without these variables (region χ^2=13.81, df=1, P<0.01, cultivated land χ^2=7.92, df=1, P<0.01), but voltage and crane density were not significant (voltage χ^2=2.40, df=1, P=0.30, density χ^2=0.18, df=1, P=0.66).

Table 4. Best-fit Generalised Linear Models developed to predict the probability of Blue Crane power line collisions. Variables are presence of cultivated land, region (Caledon and Bredasdorp), voltage (11/22kV, 66kV and 132/400kV) and crane density (averaged CAR count densities over 3 years).

Model	**AIC**
Cultivated Land and Region	414.82
Cultivated Land, Region and Voltage	416.41
Cultivated Land, Region and Density	416.63
Region	420.74
Cultivated Land	426.63

3.4 Collision rates

Both cultivated land and region were significant predictors of Blue Crane collisions, but the extrapolated collision rates are based only on cultivated land. This is because the reasons for the region effect are not clear, and therefore the unsurveyed power lines could not be categorised to either region with confidence.

I extrapolated the calculated collision rates (Table 5) to estimate total annual losses for the study area (Table 6). In the study area, there are 4608 km of power line, excluding lines in urban areas. Of these, 2771 km are on cultivated land, and 1827 km are on uncultivated land, and total Blue Crane losses were calculated accordingly.

The overall bias correction factor was calculated as the product of the inverse of one minus each bias factor (1/1-B_i) (Bevanger, 1995). As the search bias was assumed to be zero, the factor calculation for this study was (1/1-0.09) x (1/1-0.42) x (1/1-0.2) = 2.35, suggesting that less than half of the estimated Blue Crane collision victims were recovered.

Table 5. Mean collision rates (birds. km^{-1} (with bootstrapped 95% confidence intervals)) for cultivated land, uncultivated land, and the overall Overberg study area. Rates were adjusted for biases in a stepwise fashion i.e. habitat bias is the base estimate adjusted for habitat bias, and scavenger bias is the base estimate adjusted for habitat and scavenger biases. See text for bias estimation.

	Base estimate	**Plus habitat bias**	**Plus scavenger bias**	**Plus crippling bias**
Blue Crane				
Cultivated land	**0.14**	**0.15**	**0.26**	**0.33**
	(0.07 - 0.21)	(0.08 - 0.23)	(0.14 - 0.40)	(0.17 - 0.50)
Uncultivated land	**0.05**	**0.06**	**0.10**	**0.13**
	(0.00 - 0.17)	(0.00 - 0.19)	(0.00 - 0.32)	(0.00 - 0.40)
Overall study area	**0.10**	**0.11**	**0.20**	**0.25**
	(0.04 - 0.20)	(0.05 - 0.22)	(0.08 - 0.37)	(0.10 - 0.46)
Denham's Bustard				
Overall study area	**0.03**	**0.03**	**0.05**	**0.06**
	(0.01 - 0.05)	(0.01 - 0.06)	(0.01 - 0.10)	(0.01 - 0.12)

Table 6. Estimated total annual losses of Blue Cranes and Denham's Bustards in the Overberg study area due to power line collisions, expressed as the total number of individuals killed, and as a percentage of the total population. Figures calculated using the mean collision rates with and without bias corrections (with bootstrapped 95% confidence intervals).

	Number killed. yr^{-1}	**Percentage of the population killed. yr^{-1}**
Blue Crane		
Uncorrected	**482**	**4.02%**
	(202 - 902)	(1.68- 7.52%)
Corrected	**1135**	**9.46%**
	(475 - 2124)	(3.96 - 17.70%)
Denhams's Bustard		
Uncorrected	**120**	**12.55%**
	(24 - 240)	(2.51- 25.10%)
Corrected	**283**	**29.56%**
	(57 - 565)	(5.91 – 59.11%)

4. Discussion

4.1 Modelling collision risk

The ground survey sampled substantial lengths of power lines of different voltages in different habitats, and in areas covering much of the CAR population density range, and was therefore a representative data set with which to test the collision risk model. Unfortunately, the field data found little support for Kotoane's (2003) model, highlighting the importance of thorough ground-truthing studies.

A useful result from the model analysis is that there is similarity between the location of the carcasses of Blue Cranes and other birds, supporting the notion that collision hotspots are at least as much a function of line placement and design, as they are of species specific biology. This indicates that mitigation measures implemented for Blue Cranes may benefit other species in some areas, perhaps because some areas act as general flyways due to e.g. topography (Bevanger, 1994).

I expanded on the variables included in the risk model to see if any other factors could predict the Blue Crane collision risk, but several widely accepted risk factors (APLIC, 1994) could not. As grassland birds, cranes avoid natural veld (Allan, 1995), and power lines crossing such areas were therefore expected to pose a lesser risk. However, no such effect was found, which may be explained by more subtle habitat use characteristics. While Blue Cranes broadly rely on transformed agricultural land, they still commute over veld, and may use fragments as escape cover (Bidwell, 2004). Power lines running perpendicular to the prevailing wind were expected to pose a higher risk, as cranes are heavy birds and use wind to aid take-off and landing (Meine and Archibald, 1996). Perpendicular lines are therefore more likely to cross the flight path of cranes at low levels, and cranes are also more likely to be blown into these lines in high winds (Bevanger, 1994). However, angle of power lines in relation to the prevailing wind was not significant. It may be that strong winds of any direction are a more important risk factor (Brown and Drewien, 1995), especially as extreme wind conditions are common all along the coastal plains of the Western Cape (Deacon et al., 1992). There was also no effect of average population density, as was also found in a study of White Storks in Spain (Garrido and Fernández-Cruz, 2003). Voltage was insignificant, implying that transmission lines pose a similar risk to distribution lines. This finding is supported by a study based on three different line voltages in Spain (Janss and Ferrer, 1998), but contrasts with the Karoo, where transmission lines are responsible for the majority of large terrestrial bird casualties (Anderson and Piper, 2007). Finally, lines in close proximity to roads and urban areas were expected to show reduced mortality, as cranes avoid sources of anthropogenic disturbance (Bidwell, 2004). However, there was no evidence for this, despite the possible bias caused by the increase in carcass removal expected in these areas, because of increased visibility.

That some factors were not statistically significant in this assessment may not necessarily mean that they are unimportant, but rather that such a broad-scale analysis was too crude to demonstrate their effects. For example, there was no effect of proximity to water. Dams in the Overberg are ubiquitous, and only those that are shallow and open enough, with a gradual gradient down to the water are suitable for roosting (V. Hudson, pers. comm.). Unfortunately, there are no spatial waterbody depth data currently available for the Overberg, and so it is not possible to identify suitable dams using GIS.

The GLM analysis identified cultivated land and region as the significant factors influencing power line collision risk. Lines that cross cultivated land pose a higher risk, as expected, as this is the preferred habitat of Blue Cranes in the Overberg (Allan, 2005a). However, there are 2771 km of such lines in the study area (59% of all lines), and basing a proactive marking strategy on this factor alone may be prohibitively expensive.

The much lower collision rate around Caledon than Bredasdorp is difficult to interpret. More lines in the Caledon area are marked, but generally these did not form part of my sample. Crane density was not a significant predictor in the model, but while the overall densities in the two sites were similar, the seasonal distribution of Blue Cranes may be having an effect. Densities on routes close to surveyed lines appears to be higher in Bredasdorp in the summer and Caledon in the winter (Animal Demography Unit, 2005-2008), but there is a great deal of variation between routes and years, and this seasonal difference contradicts field knowledge and satellite tracking results that show some Caledon cranes moving to Bredasdorp in the winter (McCann and Shaw, 1998; K. Shaw, pers. comm.). In addition, a study of breeding Blue Cranes on sites near Bredasdorp and Caledon concluded that there was no significant difference between the density of pairs in the two regions during the breeding season (Aucamp, 1996), implying that summer densities should be similar, as the proportion of flocks is small (Shaw, 2003).

The distribution of winter flocks may be a key factor behind the regional difference. The CAR data between 2005 and 2008 show that Bredasdorp has a higher proportion of flocks, and a greater number of large flocks (50+ birds) than Caledon in the winter (Animal Demography Unit, unpublished data). Collision rates are higher for birds in flocks, as they may panic, or lack visibility and room for manoeuvre because of the close proximity of other birds (APLIC, 1994). Of the Blue Crane carcasses I found in Bredasdorp, 40% were classed as 'fairly old', and therefore could have died in the previous winter. Climatic variation leading to differing land use patterns may also contribute to the region effect. Rainfall patterns change across the Overberg, with winter rainfall in the west, and a bimodal spring-autumn regime towards the east (Deacon et al., 1992). Cereal cultivation relies on reliable rainfall, and is therefore less predominant further east (Kemper et al., 2000), and so the big winter flocks of cranes may move to pastures in the east as the preferred winter habitat (Allan, 1995). Overall, I think that subtle, spatial differences in land use, weather conditions, and crane flocking behaviour probably contribute to the regional effect. Further work to locate large roost sites and clarify seasonal movements within the Overberg crane population is vital to explain this effect more conclusively.

In summary, GIS modelling using currently available data layers cannot be used as a tool to identify power lines posing a high collision risk to Blue Cranes in the Overberg. This contradicts the findings of other recent studies (e.g. Heck, 2007), and may simply reflect the crudity of the spatial data used in this analysis, which effectively precludes identification of the site-specific factors which together make lines high risk. In addition, there are many more environmental and behavioural factors that contribute to collision risk, which are either unmapped for this area, or not completely understood. For example, foggy conditions reduce visibility and may increase collisions (APLIC, 1994; Bevanger, 1994), but the spatial data to assess this are not available. Recent information on the movements of Blue Cranes and the locations of large roosts are similarly unavailable, but may be very important (Sundar and Choudhury, 2005). More temporary factors such as the location of livestock feedbins may also affect collision risk, as they can represent an important winter food source (Allan, 1995; V. Hudson, pers. comm.).

4.2 Collision rates

I calculated a collision rate by extrapolating from the number of recent carcasses found, which is a crude approximation of the true rate. However, compared with regular surveys and flight monitoring studies, this method has the advantage of sampling a much wider selection of power lines, and avoiding seasonal biases. I was able to use GIS to extrapolate this rate (Bevanger, 1995), because I assume that the substantial length of power line sampled included a representative sample of hotspots and low collision risk lines. It was not surprising that I did not find new carcasses on my second survey of re-sampled hotspots, as these sections were short and there were less than two summer months between surveys. As discussed above, collision rates may be higher in winter when the birds congregate in large flocks.

The overall adjusted mean collision rate of 0.25 Blue Cranes.km^{-1}.yr^{-1} for the Overberg study area is within the range calculated in other crane collision studies. For example, the mortality rate of Sarus Cranes (*Grus antigone*) in India is 0.13 cranes.km^{-1}.yr^{-1} (Sundar and Choudhury, 2005), and for Common Cranes (*Grus grus*) in Spain it is 2.4–5.9 collisions.km^{-1}.yr^{-1}, where birds are only present during winter (Janss and Ferrer, 2000). Rates of 1.0 collisions.km^{-1}.yr^{-1} on distribution lines, and 0.7 collisions.km^{-1}.yr^{-1} on transmission lines can be estimated for Sandhill Cranes (*Grus canadensis*) in Colorado, U.S.A. (Brown et al., 1987). However, these last two studies were conducted on short power line sections at very high risk locations e.g. 7.3 km in Spain, and therefore represent worst case scenarios. Such studies cannot be extrapolated to generate broader regional mortality estimates (Bevanger, 1999; Janss and Ferrer, 2000), of which very few exist.

There is also a dearth of studies available in which the importance of collision mortality rates is assessed at the population level (Negro, 1999). A recent PHVA conducted for the Blue Crane predicted that overall mortality rates must remain below 10% for juveniles, and 7.5% for adults for the population in the Western Cape to persist (McCann et al., 2001). Therefore, my estimate of 9.5% (95% CI 4.0-17.7%) annual mortality attributable to power line collisions is extremely serious, indicating that collisions alone may be sufficient to limit the Overberg Blue Crane population, and combined with other mortality factors could even cause the population to decrease.

My annual Blue Crane mortality estimate for the Overberg is much higher than other studies, mainly because of the much greater integration of the Overberg crane population with a more extensive and complex network of power lines. Despite recording comparable mortality rates per km of power line, Sundar and Choudhury (2005) estimated that just under 1% of the Sarus Crane population in their study were killed on power lines annually, and Janss and Ferrer (2000) estimated that 0.6–2.0% of a wintering Common Crane population die annually. Further work on the ageing of carcasses found in this study will provide useful insights into the population level effects of Overberg collisions. For example, several studies suggest that juvenile cranes are more susceptible to power line collisions than adults (Brown et al., 1987; Sundar and Choudhury, 2005).

4.3 Impact of power lines on other species

Large terrestrial birds were most heavily affected by power line collisions in this Overberg study (Table 2), which is consistent with similar work done in other parts of the world (Janss, 2000). Of the other species found, the numbers of Denham's Bustard and White Stork carcasses are of the greatest conservation significance. Denham's Bustard is listed as Near Threatened (BirdLife International, 2008b), and its annual mortality rate at 30% is potentially even more worrying than that estimated for Blue Cranes. However, it is a very rough first estimate, with 95% confidence intervals of 6-59%. Nevertheless, even at the lower end it is higher than the 0.9-3.6% annual collision mortality calculated for the Great Bustard (*Otis tarda*) in Spain (Janss and Ferrer, 2000). In South Africa, bustards are known to be susceptible to power line collisions (van Rooyen and Ledger, 1999), with Ludwig's Bustard (*Neotis ludwigii*) comprising 45% of all carcasses recovered along transmission lines in the Karoo (Anderson, 2002). There is clearly urgent need for more research into power line mortality suffered by Denham's Bustard. As for the Blue Crane, this is especially urgent in the Overberg region, which may represent an important area for this threatened species as it declines across the rest of its range (Allan, 2005b).

Over half of White Stork carcasses were found fresh on the second survey to collision hotspots in January, when the density of storks in the Overberg was noticeably higher, suggesting that the migratory population had arrived between the surveys. This high seasonal toll supports findings that utility structures cause significant mortality to this migrant species (van Rooyen and Ledger, 1999). A study in Spain estimated that 1% of the population during post-breeding migration, and 5-7% of the population during winter die on power lines (Garrido and Fernández-Cruz, 2003), indicating that power lines may pose a general threat to White Storks across its range. While the species is not currently considered threatened, this threat may become more significant in light of population and breeding range declines (Anderson, 2005).

5. Conclusion

The welfare of Blue Cranes in the Overberg is critical to the persistence of this regionally endemic species, and the high frequency of power line collision mortalities recorded during this study is of grave concern. While land use in the region remains favourable, the Overberg cranes may be able to absorb such losses, but in the face of climatic and market driven land use changes, the extent of unmitigated power lines remains a serious threat to the stability of the population. Other species, especially Denham's Bustard and the White Stork, also suffer substantial losses to power lines.

It is not currently possible to build a useful spatial risk model, due to crude and outdated spatial data, a lack of adequate Blue Crane demographic and distributional data, and an incomplete understanding of the combination of risk factors which interact at collision hotspots. Further research in all of these areas is needed before GIS may be used to predict where high risk power lines occur. Unfortunately, this means that there is currently no ready means with which to direct a comprehensive, proactive line marking strategy. This study demonstrates the importance of ground-truthing studies in ensuring such strategies have a solid scientific background.

In terms of mitigation, I therefore recommend that all identified hotspots be marked, and re-marked should marking devices become defective. A long term monitoring programme of sample power lines in the Overberg should be implemented, in order to gain crucial information on seasonal collision rates. In general, line marking should be much more widely applied, especially on cultivated land in the Bredasdorp area. This should be informed by more extensive line surveying, which could probably be done by relatively unskilled workers, and by discussion with landowners, which would highlight as yet unknown collision hotspots. Concentrating on these areas may be more efficient than implementing a large-scale mitigation scheme (Rubolini et al., 2005). Finally, the central three-fifths of the span caused the majority of casualties of both Blue Cranes and other species, being less visible than the line close to pylons, supporting findings in North Dakota, U.S.A. (Faanes, 1987) and in the Karoo (Anderson, 2002). This has implications for mitigation, suggesting that marking just the central part of each span may be adequate (Anderson, 2002).

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Appendix 1. Sources of GIS data used in the study.

Layer	**Source**	**Notes**
1:50 000 maps of the Overberg region	Department of Land Affairs, various years	Raster images and shapefiles of 1:50 000 topographical maps, including waterbodies
Power lines	Eskom, 2008	All transmission and distribution power lines
Land use	National Landcover, 2005	
SRTM 90m DEM	NASA, 1990	
CAPE Untransformed Areas	CapeNature, 2001	Natural veld untransformed by urbanisation, cultivation, plantations or high density aliens
Roads	Department of Land Affairs, unknown date	All major and minor roads
CAR Routes	Animal Demography Unit, University of Cape Town, 2008	

Appendix 2. GIS extensions used in the study (additional to standard ESRI extensions provided with ArcView 3.x).

Extension	**Author**	**Source**
Coordinates Tool Box Ext 1.0.	Arun Saraf 2001	www.support.esri.com, accessed January 2009
Distance and Azimuth Tools v1.6	Jeff Jenness 2005	www.support.esri.com, accessed January 2009
DNRGarmin v5.4.1	Minnesota Department of Natural Resources 2001	www.dnr.state.mn.us, accessed September 2008
Edit Tools v3.6	Ianko Tchoukanski 2006	www.support.esri.com, accessed January 2009
SantiTools	Santiago Mancebo 2001	www.support.esri.com, accessed January 2009

Appendix 3. Parameters used to reproject data to an Albers Equal-Area Conic projection.

- Central Meridian: 24
- Reference Latitude: 0
- Standard Parallel 1: -18
- Standard Parallel 2: -32
- False Easting: 0
- False Northing: 0
- Spheroid: WGS 84

DECLARATION

1. I know that plagiarism is wrong. Plagiarism is to use another's work and to pretend that it is one's own. This includes copying phrases and sentences from another's writing, and inserting these into one's own work.
2. I have used a standard convention for citation and referencing. Each significant contribution to, and quotation in, this Report from the work, or works, of other people has been attributed, and has been cited and referenced. Where exact wording is used, this is placed in quotation marks, and the page number is included in the citation.
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