



Modelling power-line collision risk for the Blue Crane *Anthropoides paradiseus* in South Africa

JESSICA M. SHAW,^{1*} ANDREW R. JENKINS,¹ JON J. SMALLIE² & PETER G. RYAN¹

¹Percy FitzPatrick Institute, DST/NRF Centre of Excellence, University of Cape Town, Rondebosch 7701, South Africa

²Wildlife & Energy Programme, Endangered Wildlife Trust, Private Bag X11, Parkview 2122, South Africa

The Overberg wheatbelt population of Blue Cranes *Anthropoides paradiseus* in the Western Cape of South Africa is approximately half the global population of this vulnerable species. Blue Cranes are highly susceptible to collisions with overhead power lines, and a spatial model was developed to identify high-risk lines in the Overberg for proactive mitigation. To ground-truth this model, we surveyed 199 km of power lines. Although Blue Cranes were the most commonly killed birds found (54% of all carcasses), the model was unable to predict lines with high collision risk for Blue Cranes. Further Geographic Information System (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. Modelling was limited by a lack of detailed spatial habitat data and recent information on Crane numbers and distributions. We used recent carcass counts to estimate a Blue Crane collision rate, corrected for sample biases, of 0.31/km power line per year (95% CI 0.13–0.59/km/year), which means that approximately 12% (5–23%) of the total Blue Crane population within the Overberg study area is killed annually in power-line collisions. This represents a possibly unsustainable source of mortality. There is urgent need for further research into risk factors and for mitigation measures to be more widely implemented.

Keywords: *Anthropoides paradiseus*, collision mortality, GIS, power line, Western Cape.

Mortality caused by collision or electrocution on power lines is a well-known conservation problem for many bird species, and can be a significant source of unnatural mortality for species with limited distributions or small populations (Avian Power Line Interaction Committee (APLIC) 1994, Bevanger 1998, Janss 2000, Rubolini *et al.* 2005). 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.

The collision risk posed by power lines is often localized 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), particularly affecting birds such as cranes (family Gruidae) that are characterized by high wing loading and a low aspect ratio, resulting in rapid flight and low manoeuvrability (Bevanger 1998).

The Blue Crane *Anthropoides paradiseus* has the most restricted range of all cranes, being near endemic to South Africa (McCann *et al.* 2007). Listed as globally Vulnerable, Blue Cranes have experienced a significant and rapid decline in recent decades, primarily because of habitat loss in their historical grassland strongholds (McCann *et al.* 2001, IUCN 2009). However, conversion of native renosterveld and fynbos vegetation for agriculture in the Overberg region of the Western Cape has provided Blue Cranes with artificial grasslands, enabling their expansion in this area, with numbers increasing dramatically since the late 1960s (Young & Harrison

*Corresponding author.
Email: jessica.shaw@uct.ac.za

2000). Approximately half the total population currently resides in the Western Cape, and the Coordinated Avifaunal Roadcount (CAR) surveys indicate that the population growth is still generally positive (Animal Demography Unit 2002–2008, Young *et al.* 2003, McCann *et al.* 2007). Despite the current 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 may have far-reaching negative effects on this population (Allan 2005, Gbetibouo & Hassan 2005, McCann *et al.* 2007).

In this context, sources of unnatural mortality have the potential to significantly undermine the long-term conservation of this already threatened species. Blue Cranes are prone to collisions with overhead power lines because of their limited aerial manoeuvrability and their habit of flying in flocks, often during low light conditions, while commuting to and from roost sites (Anderson 2002). Power-line collisions are thought to be a significant threat to Blue Cranes in the semi-arid Karoo region of South Africa (McCann *et al.* 2001) but the extent of the problem in the Overberg is unknown. Construction of power lines in the Overberg began in the 1960s, and the grid is still expanding (Eskom unpubl. data).

An accurate estimate of power-line mortality requires dedicated surveys (Bevanger 1999), but systematic searches along power lines are time-consuming and costly to undertake. Mitigation in

South Africa is mainly achieved through line marking, with generally positive results for Blue Cranes in a small trial conducted in the Karoo (Anderson 2002). Currently, lines are marked retrospectively when collisions are reported (van Rooyen & Ledger 1999) but this results in very low levels of mitigation overall. To approach the problem more proactively, a Geographic Information System (GIS) model was developed to identify the low- to medium-voltage distribution power lines posing a high collision risk to Blue Cranes in the Overberg (Kotoane 2003). Based on expert knowledge, rules were developed and integrated into GIS to build a predictive model. Through literature research and discussion with crane experts, proximity to water bodies and congregation sites, absence of natural veld, angle of the line relative to the predominant wind direction and poor visibility of lines against the dark background of higher ground were identified as probable causal factors for collisions. Rules describing these factors were then applied sequentially to available GIS layers of these landscape characteristics (e.g. lines within 500 m of a water body pose a risk), with Figure 1 showing all rules and the increasing risk associated with the addition of more factors. Of the 3515 km of distribution lines considered, 45% were considered to pose some risk to Blue Cranes and thus required mitigation (Fig. 1). However, because of the considerable costs involved in retrospective line marking, action based on the model was suspended until it could be shown to be effective in highlighting problem power lines.

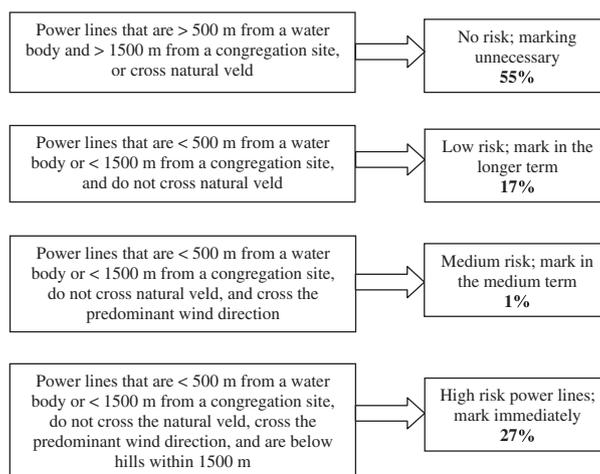


Figure 1. Rules developed to predict Blue Crane collisions with low- to medium-voltage distribution power lines in the Overberg region of the Western Cape (Kotoane 2003), with percentages of the total line shown for each risk category.

This study uses field collision data to assess the validity of the GIS model developed by Kotoane (2003) and aims to further refine this model to explain better the risk posed by power lines in the Overberg region. We provide the first estimate of the scale and biological significance of power-line collisions for Blue Cranes in this region.

METHODS

The study was conducted in the western Overberg, South Africa, in the same area assessed by Kotoane

(2003). Covering 12 848 km² from 19 to 21°E it is bound by mountain ranges to the north and oceans to the south (Fig. 2a). The landscape is characterized by coastal plains and rolling hills, and has been largely developed for agriculture with a predominantly wheat-pasture system (Young *et al.* 2003). Only 15% of fynbos and renosterveld vegetation remains (hereafter ‘natural veld’), primarily as small fragments (Kemper *et al.* 1999). The area contains 815 km of high-voltage transmission lines (213 km of 132- and 400-kV lines, and 602 km of 66-kV lines) and 3856 km of

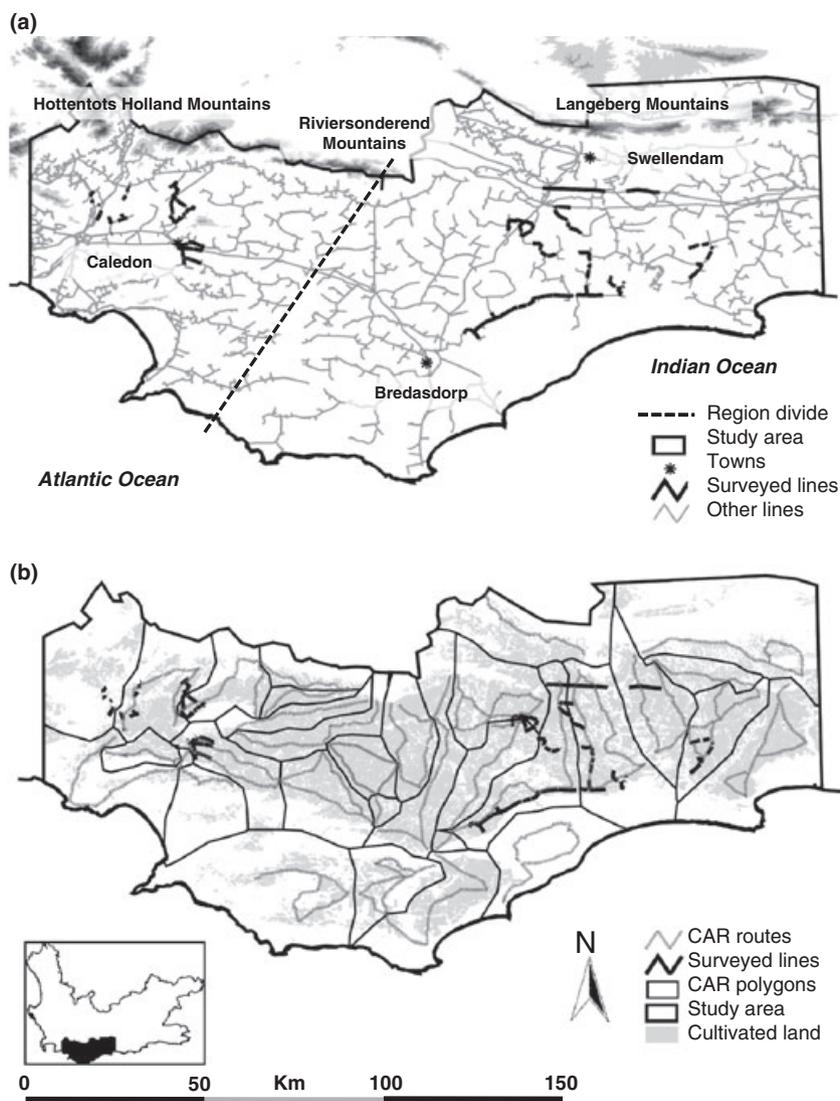


Figure 2. Study area in the Overberg region of the Western Cape, South Africa. (a) Surveyed and all other power lines, with the dividing line arbitrarily separating all power lines into the Caledon and Bredasdorp regions halfway between the groups of surveyed lines. (b) Study area divided into polygons representing the nearest Coordinated Avifaunal Roadcount (CAR) route, with surveyed power lines and cultivated land.

low- to medium-voltage distribution lines (11 and 22 kV).

Fieldwork was conducted from September 2008 to January 2009. Crane mortality was investigated by surveying 44 km of transmission line (66–400 kV) and 155 km of distribution line (11–22 kV) on foot. Lines were selected based on ease of access and to ensure a representative sample of lines of different risk categories as defined in Kotone's (2003) model. Sample lines were centred on Caledon, and between Bredasdorp and Swellendam (hereafter the Caledon and Bredasdorp regions, respectively; Fig. 2a).

To search for collision casualties, one observer walked under the power lines searching the area 15 m to either side of the outermost conductor, as most carcasses are found < 15 m from the line (Bevanger 1999). On one transect, under 400- and 132-kV transmission lines, the total width of the line was too great to see the 15 m either side clearly, so the area under the outermost conductor on one side was searched walking in one direction, with the other side searched on the return leg. Habitat type and live Blue Crane sightings were recorded on all surveys.

When a carcass was found, the line type (voltage), presence and state of any line markers, GPS location, habitat type (following CAR categories (Young *et al.* 2003)) and carcass details were recorded (following Anderson 2002), including distance from the line (outer conductor) and direction relative to the line. Carcasses were scored as fresh (< 1 week old, with soft flesh remains), recent (< 2 months old, with dried flesh remains and numerous feathers), fairly old (< 1 year old, with bones, sinews and possibly some old feathers) and very old (> 1 year, with only bleached bones). All remains were removed for further reference and to prevent double counting during subsequent surveys. Very old or incomplete carcasses were identified using comparative skeletal material. All Blue Crane carcasses found within the search corridor were assumed to have been collision victims. Carcasses of other species were assumed to have died in collisions if they were not likely electrocution or road kill victims, or prey of raptors or corvids.

Spatial data manipulation

ARCVIEW 3.2 and 3.3 (ESRI 1999, 2002) were used to analyse collision risk factors in GIS. Spatial

data were sourced from Eskom (power lines), Department of Land Affairs (roads, 1 : 50 000 maps, National Landcover), CapeNature (CAPE Untransformed Areas), and the Animal Demography Unit, University of Cape Town (CAR routes).

Power lines surveyed were broken into 250-m sections, with the remainder at the end of each line included as a separate section if they were > 150 m long. Data on collision risk factors were then attributed to sections for analysis. Unlike the original model, proximity to congregation sites was excluded because of a lack of recent data on their location. Height of power lines in relation to surrounding hills also was excluded because our data layers showed all lines to be below the height of hills within 1500 m. In addition, distant mountains provide a dark background for lines from a much greater distance, and it is unclear whether lines pose a greater collision risk when on the horizon or against a dark background (K. Shaw & V. Hudson pers. comm.).

Point data (carcasses and live Blue Cranes) were assigned to the nearest power-line section. Data collected on CAR surveys (Animal Demography Unit 2005–2008) were used to develop seasonal indices of Crane density in the Overberg. The average summer and winter densities of Cranes per kilometre of road survey were estimated for each Overberg route, based on up to three summer and three winter counts (July 2005–January 2008). The mean density for each route was taken as the best estimate of Crane density in that immediate area for that season. The study area was then divided into polygons representing the nearest CAR route (Fig. 2b), and Crane densities were assigned to power-line sections within each polygon.

The land-use characteristics of unsurveyed lines were assigned using existing GIS data layers. Cultivated land included improved grassland, temporary cultivated and permanent cultivated land from the National Landcover layer (Fig. 2b), and uncultivated land (i.e. natural veld) was identified from the CAPE Untransformed Areas layer. Roads were split into main roads and secondary roads, and urban areas were clipped from the National Landcover layer. Power-line sections were classified as close to roads or urban areas if they were within 100 and 500 m of these sources of disturbance. The predominant wind directions in the Overberg are southeasterly in summer and northwesterly in

winter (Kotoane 2003). The angle of each power line section was calculated, and sections with angles between 1–90° and 181–270° that run across the prevailing winds were classified as posing a greater risk than lines between 91–180° and 271–360°. Lines were categorized as close to water if they were within 500 m of a water body, including farm dams.

Bias estimation

Four biases tend to underestimate power-line carcass surveys: habitat bias (carcasses missed because of unsearchable habitat), removal or scavenger bias (carcasses removed by scavengers), crippling bias (carcasses of birds not killed outright by the collision but which subsequently die outside of the search area) and search bias (varying carcass recoveries rates of different searchers, search patterns and seasons) (Bevanger 1999).

Habitat bias was estimated by adding the percentage of power lines that could not be searched (e.g. those over deep, thickly vegetated gullies) to two-thirds of the percentage of lines where the visibility was reduced because of the density of natural vegetation and mature crops. This fraction was used as no Blue Crane carcasses were found > 5 m from the line in these habitats (Fig. 3), indicating that the search width should be reduced from 15 to 5 m. This was done separately for the Caledon and Bredasdorp samples because they comprised different proportions of cereal croplands and pastures (Fig. 4), and the biases were combined as an overall weighted average.

A carcass-removal experiment was used to estimate scavenger bias with dead geese and ducks (mainly Egyptian Geese *Alopochen aegyptiacus*), which are commonly hunted during harvest to protect crops. The birds had been shot by a farmer for this reason and were placed in the field within 36 h. They were positioned in four groups of six birds under power lines in separate areas, with each group spread over approximately 800–1000 m of power line to mimic collision hotspots. The carcasses were monitored every day for 5 days, and then a further four times over a period of 5 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 each

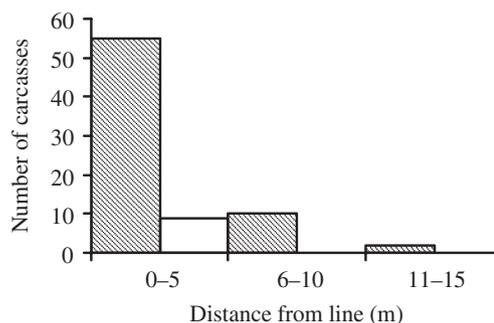


Figure 3. Distance of Blue Crane carcasses from the power line in open habitats, i.e. pasture and stubble (shaded), and closed habitats, i.e. mature cereal and veld (white).

carcass, evidence of scavenging activity and stage of decomposition were recorded (following Savereno *et al.* 1996). As ducks and geese may be more or less palatable than Cranes, three recent Blue Crane collision carcasses were subsequently added to the experiment to gauge similarity between scavenging activity on geese and Cranes.

Crippling bias is extremely difficult to quantify (Bevanger 1999), with figures used in previous studies varying widely, from 0.2 (Bevanger 1995) to 0.74 (Beaulaurier 1981), and averages from other studies frequently applied (Janss & Ferrer 2000, Sundar & Choudhury 2005). We applied the lowest published estimate of 0.2 (Bevanger 1995) as a conservative estimate of crippling bias in this study. Finally, we assumed no search bias in the detection of recent Blue Crane mortalities, as the same observer searched for large, conspicuous carcasses in a single season.

Population impacts

Collision rates for Overberg Blue Cranes were calculated from carcasses judged to be < 1 year old. This judgement was informed by the scavenger experiment carcasses, and was conservative, as carcasses that could not be classified confidently were excluded as > 1 year old. We calculated a collision rate per kilometre for power lines on cultivated and uncultivated land, and then adjusted this figure for the biases described. We compared this with the total population, currently estimated to be approximately 12 000 individuals within the study area. This figure is derived from the National Crane Census count of 2002, adjusted for the trend seen in average summer densities of Blue Cranes on Overberg CAR counts between 2002

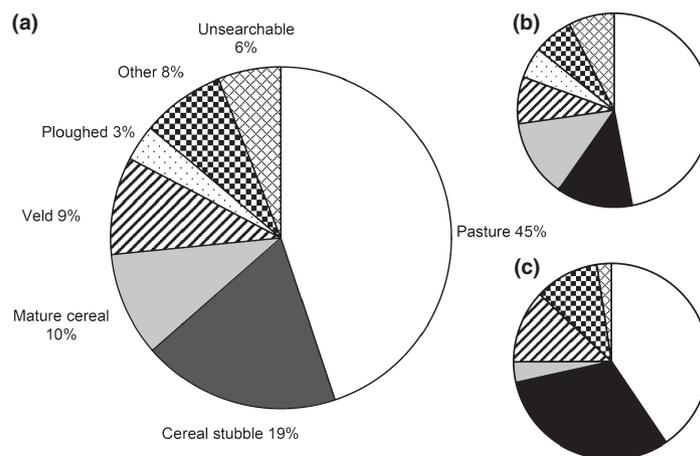


Figure 4. Composition of habitat along power lines surveyed for bird carcasses in the Overberg. (a) Overall habitat, (b) habitat in the Bredasdorp region, (c) habitat in the Caledon region. 'Other' includes low cereal crops, marsh, woodland, fallow fields, canola fields and wasteland, and 'Unsearchable' represents habitat where searching was impossible, e.g. in thickly vegetated gullies.

and 2008 (Animal Demography Unit 2002–2008, K. Shaw unpubl. data).

Statistical analyses

Chi-squared 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 linked to Blue Crane collisions in further modelling, we used 250-m segments of line as the unit of analysis, with the number of Crane collisions per segment as the dependent variable and other factors as independent variables, attributed to segments as described above. Goodness-of-fit tests were performed separately on the independent variables using SPSS 15.0 (SPSS Inc., Chicago, IL, USA, 2006). Significant factors were then analysed using GLMs (generalized linear models) to identify the strongest predictive variables, with 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 ascertain the significance of each explanatory variable, the log-likelihood of the full minimal model including the variable of interest was compared with the log-likelihood of the reduced model excluding it. Finally, numbers of recent Blue Crane carcasses found in each 250-m section of power line were bootstrapped (1000 iterations) to generate 95% confidence intervals for collision rate estimates, treating separately sections found on cultivated and on uncultivated land (as defined by the National Landcover GIS layer).

RESULTS

In total, 199 km of power line were surveyed and 64 Blue Crane carcasses were recovered. Of these, 47 were found on distribution lines and were used to test the validity of Kotoane's (2003) model, and 23 were judged to have been dead for less than a year and were used in the calculation of collision rates. The most numerous of other species found were the carcasses of 18 Denham's Bustards *Neotis denhami*, seven Spur-winged Geese *Plectropterus gambensis* and six White Storks *Ciconia ciconia*, with 18 species (and one unidentified carcass) recovered in total.

The distribution of Blue Crane carcasses per segment of power line did not fit a Poisson distribution ($\chi^2_2 = 18.42$, $P < 0.01$), but could be fitted to a negative binomial distribution ($\chi^2_2 = 4.17$, $P = 0.13$). Blue Crane carcasses were commonly found in collision hotspots, which were characterized by a variety of species and carcass states, with carcasses found on both sides of the line.

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

Testing the model and risk factors

Kotoane's (2003) model did not predict which power lines pose a collision risk to Blue Cranes, with no difference from a null model of equal collision risk, whether comparing lines identified as

Table 1. Number of Blue Crane carcasses found and length of distribution 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
No. of Blue Crane carcasses	20	0	10	17
Blue Crane carcasses/km	0.32	0.00	0.24	0.35

high, low and no risk to Cranes ($\chi^2_2 = 0.86$, $P = 0.65$) or comparing risk and no-risk lines ($\chi^2_1 = 0.48$, $P = 0.49$). The medium-risk category was excluded from the first calculation because so few power lines fell into this category (Table 1).

Proximity to roads, urban areas and water had no apparent impact on collision risk, nor did angle of line relative to prevailing wind conditions, presence of uncultivated land, line marking or sightings of live Blue Cranes. Line voltage, region (Caledon vs. Bredasdorp), CAR Blue Crane density (summer and winter) and presence of cultivated land were significantly linked to collision risk and were analysed further using GLMs. The presence of other bird collision carcasses was also significant ($\chi^2_1 = 4.88$, $P = 0.03$) but was not included in the GLM analysis as it cannot be used to predict collisions at a landscape level.

Region and cultivated land were significant when comparing the log-likelihood of the models with and without these variables (region $\chi^2_1 = 13.81$, $P < 0.01$, cultivated land $\chi^2_1 = 7.92$, $P < 0.01$), but voltage and Crane density were not significant (voltage $\chi^2_1 = 2.40$, $P = 0.30$, summer density $\chi^2_1 = 0.09$, $P = 0.76$, winter density $\chi^2_1 = 0.46$, $P = 0.50$).

Bias estimation

Overall, habitat bias in this fairly open landscape was estimated to be 0.09. Over the 5 months of the scavenger experiment, nine of 24 geese and duck carcasses were removed completely. Of these, five were removed within the first 3 days, one between day 5 and 17, and three between day 60 and 151. Of the remaining carcasses, six were heavily scavenged (carcass dismembered) and six were lightly scavenged (minor movements, carcass still relatively intact) after 5 months. Four car-

casses were moved outside the search corridor, and only three remained untouched at the end of the experiment. All three Blue Cranes were lightly scavenged, although none was removed. From the proportion of goose and duck carcasses removed from the search corridor over 5 months ($n = 13$), a scavenger bias of 0.54 was estimated.

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 $1/(1 - 0.09) \times 1/(1 - 0.54) \times 1/(1 - 0.2) = 2.99$, suggesting that approximately one-third of the estimated Blue Crane collision victims were recovered.

Collision rates

Cultivated land was a significant predictor of Blue Crane collisions, and was used to generate the best estimate collision rates. 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 1837 km on uncultivated land, and the calculated collision rates were extrapolated accordingly (Table 2). Uncorrected total annual losses for the study area were then estimated at 482 (95% CI 202–902) Blue Cranes, or 4% (95% CI 2–8%) of the Overberg population. Corrected for biases, these estimates increase to 1444 (95% CI 604–2703) Cranes, or 12% (95% CI 5–23%) of the Overberg population.

Region was also a significant predictor, but we have low confidence in classifying unsurveyed power lines as the reasons for this effect are unclear. If lines are divided as shown in Figure 2a, the estimation of collision rates based on both land use and region, corrected for biases, gives an annual mortality of 1338 (95% CI 520–2483) Cranes, or 11% (95% CI 4–21%) of the Overberg population. If land use and region are not taken into account, annual mortality is estimated at 1654 (95% CI 935–2590) Cranes, or 14% (95% CI 8–22%) of the Overberg population, corrected for biases.

DISCUSSION

Modelling Blue Crane collisions

The ground survey sampled substantial lengths of power lines of different voltages and configurations

Table 2. Mean collision rates (Blue Cranes/km) and 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.

	Base estimate	Plus habitat bias	Plus scavenger bias	Plus crippling bias
Cultivated land	0.14 (0.07–0.21)	0.15 (0.08–0.23)	0.33 (0.17–0.51)	0.42 (0.22–0.63)
Uncultivated land	0.05 (0.00–0.17)	0.06 (0.00–0.19)	0.13 (0.00–0.41)	0.16 (0.00–0.51)
Overall study area	0.10 (0.04–0.20)	0.11 (0.05–0.22)	0.25 (0.10–0.47)	0.31 (0.13–0.59)

in different habitats, in areas covering much of the CAR population density range, and was therefore a representative dataset with which to test Kotoane's (2003) collision risk model. The lack of correlation between the field data and the model predictions highlights the importance of conducting thorough ground-truthing studies before committing to practical mitigation. Even after expanding the scope of the model to include additional, widely accepted risk factors, it remained ineffective.

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

The difference in collision risk between the two regions of the study, with significantly fewer Blue Cranes killed around Caledon than Bredasdorp, is difficult to interpret. Seasonal Crane density was not a significant predictor of risk in the model, but the data may be too crude spatially to explain this adequately. Both summer (Aucamp 1996) and overall densities in the two sites are similar (Animal Demography Unit 2005–2008), but the distribution of winter flocks may be key. 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) compared with Caledon in the winter (Animal Demography Unit unpubl. data). Collision rates are higher for birds in flocks, as they may panic, or have impeded visibility and limited room to manoeuvre because of the close proximity of other birds (APLIC 1994). In addition, rainfall patterns change across the Overberg (Deacon *et al.* 1992), with cereal cultivation predominant further west, where rainfall is more reli-

able (Kemper *et al.* 2000), potentially attracting the big winter flocks of Cranes to pastures in the east as the preferred winter habitat (Allan 1995).

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, in contrast to the findings of other recent studies (e.g. Heck 2007). This is probably a result of conflict between the microscale at which Crane behaviour is likely to affect collision risk in practice, and the macroscale of the spatial data available to predict the distribution of such behaviour. In addition, other factors probably contribute to collision risk, which are either unmapped for this area or not completely understood, e.g. fog. Recent information on the movements of Blue Cranes and the locations of large roosts is similarly unavailable, but may be very important (Sundar & Choudhury 2005). More temporary factors such as the location of livestock feed-lots may also affect collision risk, as they are an important winter food source (Allan 1995). However, it may be that the numerous factors involved make collisions inherently unpredictable, and if this is so, the use of landscape-level models to direct mitigation is not appropriate. Therefore, we recommend the mitigation of all new lines as standard in the Overberg. We are continuing ground surveys to further investigate collision factors, especially at hot spots, and to further explore potential differences between collisions on transmission and distribution lines. Although no difference was found in this analysis, our sample may have been too small, and practically it is an important factor as the costs of marking transmission lines are much higher than for distribution lines.

Collision rates

Collision rates were estimated 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. We used GIS to extrapolate this rate (Bevanger 1995) because we assumed that the power lines sampled included a representative sample of hot spots and low collision-risk lines.

The overall bias correction factor used in calculating the collision rate was within the range used in other studies, e.g. from 2.5 (Janss & Ferrer 2000) to 14.9 (Bevanger 1995). The scavenger experiment used proxies for Blue Cranes, possibly inflating the scavenge rate because of their smaller size (Bevanger 1995), but this was offset by using the estimate from the 5-month experiment as an annual bias. All three Crane carcasses were scavenged, indicating that they were palatable to scavengers, despite not being as fresh as the geese and ducks. Our final scavenger bias is comparable with those used in other studies (0.4–0.8; Alonso & Alonso 1999, Bevanger 1995), whereas our habitat bias of 0.09 is low relative to other studies (often 0.2–0.3; Bevanger 1995, Alonso & Alonso 1999, Janss & Ferrer 2000).

The overall adjusted mean collision rate of 0.31 Blue Cranes/km/year for the Overberg study area is comparable with that calculated for Sarus Cranes *Grus antigone* in India, at 0.13 cranes/km/year (Sundar & Choudhury 2005). The only other crane-collision rate estimates come from studies on short power-line sections at very high-risk locations, and therefore represent worst case scenarios, e.g. 2.4–5.9 cranes/km/year for Common Cranes *Grus grus* in Spain (Janss & Ferrer 2000), and 1.0 cranes/km/year on distribution lines and 0.7 cranes/km/year on transmission lines for Sandhill Cranes *Grus canadensis* in the USA (Brown *et al.* 1987). These estimates cannot be extrapolated to generate broader regional mortality estimates (Bevanger 1999, Janss & Ferrer 2000).

Consequently, there is a dearth of studies available in which the importance of collision mortality rates is assessed at the population level (Jenkins *et al.* 2010). Our annual Overberg Blue Crane mortality estimate is much higher than those calculated in the few other studies to assess this, mainly because of the extensive network of power lines in the Overberg. Despite recording similar mortality rates per kilometre 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. A Blue Crane population and habitat viability assessment predicted that overall mortality rates must remain below 7.5% for adults for the Western Cape population to persist (McCann *et al.* 2001), and a recent modelling study estimated that adult mortality was 4% for the stable Blue Crane population in the Karoo (Altwegg & Anderson 2009). Therefore, our conservative estimate of 12% (95% CI 5–23%) annual mortality solely attributable to power-line collisions is extremely serious, indicating that collisions alone may be sufficient to limit the Overberg population and, in combination with other mortality factors, could cause the population to decrease. The welfare of Blue Cranes in the Overberg is critical to the persistence of this regionally endemic species. While land use in the region remains favourable, this population 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.

We thank Kevin Shaw and Vicki Hudson at CapeNature for helpful input, and Donella Young and the CAR Project at the Animal Demography Unit for access to data. Mick D'Alton kindly supplied geese for the scavenger experiment, and Bronwyn Botha and De Hoop Nature Reserve provided accommodation during fieldwork. Graham Avery at the Iziko Museums of Cape Town assisted with carcass identification, Penn Lloyd helped with statistics and Nick Lindenberg with GIS analysis. This study was funded by the Wildlife & Energy Programme of the Endangered Wildlife Trust.

REFERENCES

- Allan, D.G. 1995. Habitat selection by Blue Cranes in the Western Cape Province and the Karoo. *S. Afr. J. Wildl. Res.* **25**: 90–97.
- Allan, D.G. 2005. Blue Crane *Anthropoides paradiseus*. In: Hockey, P.A.R., Dean, W.R.J. & Ryan, P.G. (eds) *Roberts Birds of Southern Africa*, 7th edn: 309–311. Cape Town: The Trustees of the John Voelcker Bird Book Fund.
- Alonso, J.A. & Alonso, J.C. 1999. Collision of birds with overhead transmission lines in Spain. In Ferrer, M. & Janss, G.F.E. (eds) *Birds and Power Lines. Collision, Electrocution and Breeding*: 57–82. Madrid: Servicios Informativos Ambientales/Quercus.
- Altwegg, R. & Anderson, M.D. 2009. Rainfall in arid zones: possible effects of climate change on the population ecology of Blue Cranes. *Funct. Ecol.* **23**: 1014–1021.

- Anderson, M.D.** 2002. *Karoo large terrestrial bird powerline project*. Report No 1, Unpublished report to Eskom.
- Animal Demography Unit.** 2002–2008. *Coordinated Avifaunal Roadcounts*, Newsletters 12–24. University of Cape Town, Cape Town.
- Aucamp, E.** 1996. Breeding biology of the Blue Crane in the southern Cape, South Africa. In Beilfuss, R.D., Tarboton, W.R. & Gichuki, N.N. (eds) *Proceedings African Crane & Wetland Training Workshop, 8–15 August 1993*: 389–393. Baraboo, WI: International Crane Foundation.
- Avian Power Line Interaction Committee (APLIC).** 1994. *Mitigating Bird Collisions with Power Lines: The State of the Art in 1994*. Washington, DC: Edison Electrical Institute.
- Beaulaurier, D.L.** 1981. *Mitigation of Bird Collisions with Transmission Lines*. Portland, OR: Bonneville Power Administration.
- Bevanger, K.** 1994. Bird interactions with utility structures: collision and electrocution, causes and mitigating measures. *Ibis* **136**: 412–425.
- Bevanger, K.** 1995. Estimates and population consequences of tetraonid mortality caused by collisions with high tension power lines in Norway. *J. Appl. Ecol.* **32**: 745–753.
- Bevanger, K.** 1998. Biological and conservation aspects of bird mortality caused by electricity power lines: a review. *Biol. Conserv.* **86**: 67–76.
- Bevanger, K.** 1999. Estimating bird mortality caused by collision and electrocution with power lines; a review of methodology. In Ferrer, M. & Janss, G.F.E. (eds) *Birds and Power Lines. Collision, Electrocution and Breeding*: 29–56. Madrid: Servicios Informativos Ambientales/Quercus.
- Brown, W.M., Drewien, R.C. & Bizeau, E.G.** 1987. Mortality of cranes and waterfowl from powerline collisions in the San Luis Valley, Colorado. In Lewis, J.C. (ed.) *Proceedings of the Crane Workshop, 1985*: 128–136. Grand Island, NE: Platte River Whooping Crane Maintenance Trust.
- Deacon, H.J., Jury, M.R. & Ellis, F.** 1992. Selective regime and time. In Cowling, R.M. (ed.) *The Ecology of Fynbos. Nutrients, Fire and Diversity*: 6–22. Cape Town: Oxford University Press.
- Gbetibouo, G.A. & Hassan, R.M.** 2005. Measuring the economic impact of climate change on major South African field crops: a Ricardian approach. *Global Planet. Change* **47**: 143–152.
- Heck, N.** 2007. *A landscape-scale model to predict the risk of bird collisions with electric power transmission lines in Alberta*. MSc thesis, University of Calgary, Calgary.
- IUCN.** 2009. *IUCN Red List of Threatened Species*. Available at <http://www.iucnredlist.org> [accessed July 2009].
- Janss, G.F.E.** 2000. Avian mortality from power lines: a morphological approach of a species-specific mortality. *Biol. Conserv.* **95**: 353–359.
- Janss, G.F.E. & Ferrer, M.** 2000. Common Crane and Great Bustard collision with power lines: collision rate and risk exposure. *Wildl. Soc. Bull.* **28**: 675–680.
- Jenkins, A.R., Smallie, J.J. & Diamond, M.** 2010. South African perspectives on a global search for ways to prevent avian collisions with overhead lines. *Bird Conserv. Int* Doi: 10.1017/S0959270910000122.
- Kemper, J., Cowling, R.M. & Richardson, D.M.** 1999. Fragmentation of South African renosterveld shrublands: effects on plant community structure and conservation implications. *Biol. Conserv.* **90**: 103–111.
- Kemper, J., Cowling, R.M., Richardson, D.M., Forsyth, G.G. & McKelly, D.H.** 2000. Landscape fragmentation in South Coast Renosterveld, South Africa, in relation to rainfall and topography. *Austral Ecol.* **25**: 179–186.
- Kotoane, M.** 2003. *Applying GIS to identify high risk power lines that Blue Cranes (Anthropoides paradiseus) collide with in the Overberg region*. MA thesis, University of Stellenbosch.
- McCann, K., Morrison, K., Byers, A., Miller, P. & Friedmann, Y.** (eds) 2001. *Blue Crane (Anthropoides paradiseus). A Population and Habitat Viability Assessment Workshop, Final Workshop Report*. Apple Valley, MN: Conservation Breeding Specialist Group (SSC/IUCN).
- McCann, K., Theron, L.-J. & Morrison, K.** 2007. Conservation priorities for the Blue Crane (*Anthropoides paradiseus*) in South Africa – the effects of habitat changes on distribution and numbers. *Ostrich* **78**: 205–211.
- van Rooyen, C.S. & Ledger, J.A.** 1999. Birds and utility structures: developments in southern Africa. In Ferrer, M. & Janss, G.F.E. (eds) *Birds and Power Lines. Collision, Electrocution and Breeding*: 205–230. Madrid: Servicios Informativos Ambientales/Quercus.
- Rubolini, D., Gustin, M., Bogliani, G. & Garavaglia, R.** 2005. Birds and powerlines in Italy: an assessment. *Bird Conserv. Int.* **15**: 131–145.
- Savereno, A.J., Savereno, L.A., Boettcher, R. & Haig, S.M.** 1996. Avian behaviour and mortality at power lines in coastal South Carolina. *Wildl. Soc. Bull.* **24**: 636–648.
- Smallwood, K.S.** 2007. Estimating wind turbine-caused bird mortality. *J. Wildl. Manage.* **72**: 215–223.
- Sundar, K.S.G. & Choudhury, B.C.** 2005. Mortality of Sarus Cranes (*Grus antigone*) due to electricity wires in Uttar Pradesh, India. *Environ. Conserv.* **32**: 260–269.
- Young, D.J. & Harrison, J.A.** 2000. Blue Crane monitoring: trends begin to emerge. *Bird Numbers* **9**: 17–20.
- Young, D.J., Harrison, J.A., Navarro, R.A., Anderson, M.D. & Colahan, B.D.** (eds) 2003. *Big Birds on Farms: Mazda CAR Report 1993–2001*. Cape Town: Avian Demography Unit, University of Cape Town.
- Zar, J.H.** 1999. *Biostatistical Analysis*, 4th edn. Englewood Cliffs, NJ: Prentice-Hall.

Received 6 August 2009;
revision accepted 9 May 2010.