# A POWER LINE RISK ASSESSMENT FOR SELECTED SOUTH AFRICAN BIRDS OF CONSERVATION CONCERN

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## DECLARATION

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

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(Signature of candidate)

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## ABSTRACT

A selection of southern African bird species were modelled in terms of the probability of these species colliding with or being electrocuted on overhead power lines in South Africa, based on morphological and behavioral factors. Species were included in the model on the basis of internationally recognized vulnerability to these interactions at the family level. The collision model performed poorly when tested against the actual reported mortalities for species contained in the Eskom-EWT Strategic Partnership Central Incident Register CIR)(chi-square of goodness of fit) at the individual species, family and within family levels. The electrocution model performed slightly better at the family, and within family level. Both collision and electrocution models performed better for the physically larger species (and families) and for those species with higher modelled probability of collision or electrocution. As the product of random carcass detection and reporting, the CIR data are biased in various ways. Testing the models against the CIR is therefore equally important for highlighting inadequacies in the CIR, as in the model. A number of new species have emerged as being of high collision (including most importantly African Pygmy Goose, Southern Ground Hornbill, Black-bellied Bustard, Yellow-throated Sandgrouse, Caspian Tern, Hooded Vulture, Bateleur, African Marsh Harrier, Black Harrier, Pink-backed Pelican and Yellow-billed Stork) or electrocution (Southern Bald Ibis) probability in theoretical terms, and will require further investigation to determine their actual probability of interaction. By mapping the combined distributions of those species with high probabilities of collision and/or electrocution mortality, a number of priority high risk geographic areas emerge around the country.

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# 1. INTRODUCTION

Above ground electrical infrastructure constitutes an important interface between man and birds. Because of its vertical prominence in the landscape, the opportunity for interaction between electrical infrastructure and birds is significant (Van Rooyen, 2004). Typical direct interactions with conservation implications include collision of birds with overhead cables, and electrocution of birds perching on infrastructure, both of which normally result in bird mortality (Van Rooyen, 2004).

Collision refers to the scenario whereby birds collide with the cables whilst in flight (Van Rooyen, 2004). This occurs because the cables are not visible enough, and the birds are unable to adjust their flight at the last minute when they see the cables. A collision victim is usually killed by the impact with the cable, or the subsequent impact with the ground. Although on smaller power lines the bird may cause a short circuit and be electrocuted by touching two conductors on impact, this is not the case on larger power lines and is not the primary cause of death. Bird species believed to be most vulnerable to collision are: the larger, slow flying, mostly terrestrial species such as cranes and bustards; the fast flying species such as waterfowl; and predatory species which are distracted whilst in rapid pursuit of their prey, such as falcons (Jenkins, Smallie & Diamond, 2010).

A bird electrocution occurs when a bird that is perched on an electrical pole bridges the gap between a live and a grounded component, or two live components (Van Rooyen, 2004), thereby causing a short circuit. The bird is killed instantly by internal burning associated with the live current passing through its body. The species most vulnerable to electrocution are the larger birds, as body size is critical in determining the likelihood of bridging the gaps between live or live and grounded components. Vultures, large eagles and other perching birds are particularly vulnerable (Van Rooyen, 2004; Bevanger 1998).

In response to the threat posed by these interactions to South African avifauna, a strategic partnership was initiated in 1996 between Eskom and the Endangered Wildlife Trust (EWT), one of South Africa's largest conservation non-governmental organizations. The Eskom-EWT Strategic Partnership strives to address the above interactions through work on both the existing electrical infrastructure across SA, and through input into the planning of new infrastructure. Due to the rapid progression of our understanding of these issues in the past 13 years, and the rapid expansion of Eskom's infrastructure – most efforts by the Partnership have been on an *ad hoc* basis. Whilst already contributing significantly to both bird conservation and the sustainability of Eskom's business, the Partnership could benefit from employing a more strategic approach to resource allocation. A consolidation of our knowledge of collision and electrocution, and the species concerned, is seen as an extremely useful management tool. Much of the Partnership's efforts to date have been guided by the actual mortality data contained in the Central Incident Register (CIR), the product of incidental detection and reporting of interactions. There are a number of obvious biases in this data, which raise questions around their reliability in determining Partnership efforts. There is therefore a need to return to basic principles in determining which species are likely to be vulnerable to the interactions and hence worthy of priority.

This study aims to develop and test a model to characterize the probability of South African bird species colliding with or being electrocuted on overhead electrical infrastructure.

The objectives of the study are as follows:

1. To identify a representative list of bird species deemed likely to be negatively affected by collision or electrocution, based on existing literature.
2. To characterize these bird species in terms of their probability of interacting with power lines through collision and electrocution, based on morphological and behavioural characteristics.
3. To test the modelled species collision and electrocution probability scores against the actual species mortality data contained in the Eskom-EWT Central Incident Register.
4. To consolidate this information into a map of the probability of collision and electrocution, and a final collision and electrocution risk map (using conservation status as a measure of severity) across South Africa.
5. To test the predicted spatial distribution of each interaction for each species against the actual data contained within the Eskom-EWT Central Incident Register.

It could be argued that in order to achieve Objective 1, Objective 2 needs to already have been achieved. This study is however not conducted in a vacuum of knowledge in this field, and therefore makes use of extensive pre-existing knowledge in this field. The order in which Objectives 1 and 2 are achieved is therefore not of critical importance.

The management application of the above information includes:

1. To inform and influence construction of new infrastructure in South Africa.
2. To inform our allocation of resources to managing collision and electrocution on existing infrastructure in South Africa.
3. To inform our approach to, and prioritization of bird species conservation in this sector.
4. To identify gaps in our knowledge and understanding of these interactions, so that these areas can be improved upon in the near future.

## 2. LITERATURE REVIEW

*Bird collision and electrocution*

Factors contributing towards bird collisions with overhead lines and other infrastructure include: line height and cable configuration; topography; weather conditions; land use; proximity of foraging, roosting and breeding resources; species size and mass, maneuverability, speed of flight, altitude of flight, flocking behaviour, migratory behaviour, age, sex, time and regularity of flight, experience of area, wing loading, visual acuity, display behaviours, duration in flight, predatory behaviour, length of limbs, provisioning behavior; and often complex interactions between these factors (Brown, 1992; APLIC, 1994; Bevanger, 1994; Hunting, 2002; Crowder & Rhodes, 2001; Rubolini, Gustin, Bogliani & Garavaglia, 2005; Drewitt & Langston, 2008). Recently Jenkins, Smallie and Diamond (2010) reviewed international work on bird collision ranging in publication date over 15 years. This review revealed that the relevant factors, species, consequences and mitigation measures are very similar across this range of work, suggesting at least partial consensus on our international understanding of bird collision. These authors also present a useful summary of recent literature which lists families implicated in collisions internationally in eight papers (Brown, 1992; APLIC, 1994; Bevanger, 1994; Bevanger, 1998; Hunting, 2002; Crowder & Rhodes, 2001; Rubolini *et al.*, 2005; & Drewitt & Langston, 2008).The contributing factors identified by these previous studies were based largely on analysis of mortality records and theoretical postulation of the relevant factors. Little data conclusively supporting the importance of most of the above factors exist, therefore the model developed by the current study is predominantly theoretical. An exception to this is the factor of wing loading. Rayner (1988) used Principal Components Analysis to separate flying birds into six categories of wing loading, which when examined against actual mortality victims proved to be a relatively good predictor of collision risk, with the exception of gulls. Recent literature agrees on the importance of wing loading in determining a species ability to take evasive action (Jenkins *et al.*, 2010). Wing loading is the ratio of mass to wing area, high wing loading making for less maneuverability. Very little data exists on wing area, wing span and wing loading for bird species in South Africa (Mendelsohn, Kemp, Biggs, Biggs & Brown, 1989), this data being particularly difficult and laborious to measure consistently.

This study incorporates only the species related factors, which can be loosely grouped into those contributing to: the birds' exposure to overhead lines (mostly a function of behavioral factors); and the species susceptibility to overhead lines (mostly a function of morphological factors) (Jenkins *et al.*, 2010). The behavioral factors most relevant are those that relate to the frequency or duration with which a species will fly horizontally at power line height, thereby 'exposed' to the likelihood of collision (Jenkins *et al.,* 2010). Susceptibility is the ability to see and avoid the overhead line timeously and is determined by morphological factors such as the structure of the eye, and visual acuity (Bevanger 1994, Drewitt &

Langston, 2008), physical size, weight and wing structure which influence the ability to avoid collision once the power line is seen (Brown 1992; Bevanger, 1994; Rubolini *et al.,* 2005). Not much is known about visual acuity amongst bird species and its relevance to collision, making incorporation of this factor beyond the scope of this study. However, important differences between bird species are believed to exist. Raptors are believed to have poor peripheral vision in spite of good binocular vision (Bevanger, 1998), and certain game birds have poorly developed fovea (Bevanger, 1994, 1998), making these species groups vulnerable to collision with power lines. An initial study of the visual acuity of several collision vulnerable South African species has recently been conducted in SA (Martin & Shaw, 2010), and is the first of its kind internationally. This study has shown that visual acuity can differ significantly between three relevant families of birds, the cranes, storks and bustards, and that frontal visual acuity (most relevant to power line collisions) in these species may be relatively poor when compared to peripheral acuity. It appears from this work that visual acuity in collision vulnerable bird species may play a far greater role in determining the species' susceptibility to collision than previously understood.

In the case of electrocution, similar factors are relevant. A species' susceptibility depends primarily on morphological factors such as its physical size, critical dimensions being wing span and 'tip of toe to tip of beak' (van Rooyen, 2004). A species exposure is determined by behavioral factors such as whether it migrates or moves extensively within the country, it's preference for perching or roosting on open perches, and whether it is solitary or gregarious.

### *Resource allocation*

Conservationists globally face the ongoing problem that the cost of saving biodiversity (both financial and human) far exceeds the available resources (Mace, Possingham & Leader-Williams*,* 2006). It has been estimated that in the late 20th century only US$6 billion (James, Gaston & Balmford, 1999) was spent per year on biodiversity conservation globally, whilst the ecosystem services provided to humankind by that biodiversity exceeds US$33 trillion per year. Even if these figures are hugely incorrect, there is clearly a serious imbalance compared to the business sector which spends approximately 10% of its capital asset value per year on maintaining those assets (Mace *et al.,* 2006). On top of this gross underinvestment is the factor of often poor management or governance of these funds by the conservation sector (Mace *et al.*, 2006). In response to these problems the conservation sector is starting to develop methods for ensuring a more targeted approach to conservation (Johnson, 1995; Kershaw, Mace & Williams*,* 1995; Olson & Dinerstein, 1998; Myers, Mittermeier, Mittermeier, da Fonseca & Kent, 2000; Possingham, Andelman, Noon, Trombulak & Pulliam*,* 2001). This study is no different. Financial resources are always a limiting factor in determining the impact of the Eskom-EWT Strategic Partnership, prompting the current study in an attempt to allocate resources as carefully as possible.

### *Single species conservation*

The current study focuses on the direct threats of electrical infrastructure to individual bird species and hence does not entertain the option of an ecosystem approach. Single species approaches typically make use of one or other of keystone, umbrella, flagship or indicator species defined below by Mace *et al. (*2006). A keystone species is disproportionately important for the functioning of its ecosystem. Loss of the species would therefore have a significant ecological impact. Umbrella species have such demanding habitat requirements that if we conserve them, we will inevitably conserve a host of other species with lesser requirements. Flagship species are chosen more for their ability to raise awareness and support, and are often the more charismatic species. Indicator species are used to show either community composition or environmental change. The above description applies better to conservation of habitat for a species than addressing direct threats such as the current study. However, it provides useful insight nonetheless, with perhaps the most useful of the four types for the current study being the concept of 'umbrella species'. The concept of an umbrella species is particularly relevant to bird electrocution. If electrical infrastructure is designed with sufficient clearances to safeguard the larger species, the smaller ones will also inevitably benefit. This concept is expanded on later in this study.

### *Use of indices*

Indices measure, simplify and communicate the complexity of a system (Farell & Hart, 1998). Indices help set standards, and allow monitoring and comparison (various authors in Barnett, Lambert & Fry, 2008), and are also (importantly for the current study) used to allocate mitigating resources (Barnett *et al.*, 2008). Indices typically involve the combination of several sub indicators through an aggregation process which can hide deficiencies in each sub indicator, so the mathematics of aggregation is important (Bossel, 1999). For the purpose of aggregation, different types of data need to be reduced to a standard unit, most commonly a score between 0 and 1 or a multiple point scale of 1 to 5 for example (Bossel, 1999). A suggestion has been made that by multiplying sub indicators it ensures that poor performance in any one is reflected in the final index, which can be problematic (Sagar & Najam, 1998). The weighting of indicators is also often contentious and difficult to achieve, although can be used to reflect expert opinion and judgement. The current study uses a scale of 1 to 4, specifically so that there is no middle score, which would provide the scorer with an easy option if undecided. Aggregation can take the form of addition, averaging or multiplication of factors but invariably is a subjective process (Barnett *et al.,* 2008; and Vincent, 2004). This often creates a 'conflict' between the weight or authority given to an index, and its often subjective construction (Barnett *et al.*, 2008). The current study is a particularly good example of this. Ultimately conservation planning decisions will be made on the outcomes of the aggregation of scores which have little formal basis. In an attempt to increase my confidence in the scores, I obtained expert input from several ornithologists as suggested as critical by Barnett *et al.*, 2008).

*Risk assessment*

The process followed in the current risk assessment is very similar to that followed by Allan (2006) in the context of bird strike risk assessment at airports. Allan used a simple probability (likelihood) x severity (consequence) matrix, where probability was the risk of a species being struck by an aircraft, and severity was the risk of damage to the aircraft. The current study uses probability (derived from exposure and susceptibility) and severity as determined by the conservation status of the species, severity being greater for more threatened species. In addition to Allans' simple matrix, the current study takes into account spatial elements using species distribution data.

As with Allans' study (2006), the purpose of the current study is to determine the best possible allocation of resources to managing the interactions for maximum effect. Allan (2006) refers to this as 'action thresholds', a term which was adopted later in this study. The thresholds will need to be determined based on a number of factors, essentially deciding 'what to save first' (Mace *et al.*, 2006). A common approach is to aim efforts at those species most at risk of extinction (or most threatened). Unfortunately for many threatened species, there could be no known management interventions or the interventions could be risky or expensive, meaning that return on investment is low (Possingham, Andelman, Burgman, Medellin, Master & Keith, 2002). However, extinction risk and conservation priority are not necessarily the same thing (Mace & Lande, 1991). Extinction risk is only one of a host of factors used to set conservation priority and is really an expression of how urgently the species requires attention, and how much time remains to intervene as managers (Mace *et al.*, 2006). Mace *et al.* (2006) present a number of classes used to set priorities for single species conservation approaches: importance, feasibility, biological value, economic value, urgency and chances of success. Interestingly as conservationists we generally only consider factors under the 'biological' heading above, ignoring the other equally important factors such as economic and social (Mace *et al.*, 2006). The current study sets action thresholds for species primarily on the basis of the final confidence in their modelled probability scores.

# 3 METHODS

## 3.1 Overview

A set of species, representative of relevant families was identified, and these species were assigned collision and electrocution probability scores based on the probability of them interacting with power lines (derived from a combination of indices of relative exposure and susceptibility, as per Jenkins *et al.* 2010). These probability scores were then tested against actual mortality data contained in the Central Incident Register (CIR). The data in the CIR are the product of the detection and reporting of bird carcasses under power lines, by the public, landowners and Eskom staff. Once an 'incident' has been reported to Eskom-EWT, a field investigator is dispatched to the site, and a standard field investigation form completed. Since the initial detection of carcasses is by chance, the data are not systematically obtained. Collision and electrocution probability scores were then combined with the quarter degree square presence or absence data for the species (using Southern African Bird Atlas Project data – Harrison *et al.,* 1997) to produce a spatial representation of the probability of either collision or electrocution across South Africa. In order to map collision or electrocution risk the above scores were then weighted with the species conservation status (or severity of interaction) (Barnes, 2000). For the purpose of this study, risk is defined as the consequence of the interaction occurring. In conservation terms, the consequence (or risk) of a mortality of a threatened species is far greater than that of a common species. Conservation resources would be more readily allocated to high risk (or consequence) areas of the country.

## 3.2 Collision

*Species selection*

Selection of species to use for this model was based on those families cited in previous studies, adapted for local relevance. Several families not relevant to South African circumstances were discarded (Albatrosses-Diomedeidae, Flycatchers-Monarchidae, Warblers-Cisticolidae, Thrushes-Muscicapidae, Swans-Anatidae, Condors-Cathartidae, Hummingbirds-Trochilidae, & Tanagers-Thraupidae), and several added based on the authors' experience (Typical hornbills-Bucerotidae, Ground-hornbills-Bucorvidae, Swifts-Apodidae, Sandgrouse-Pteroclidae, Secretarybird-Sagitariidae, Ibises & spoonbills-Threskiornithidae). In the larger families a sample of species was selected that covered the range of body size (from morphological data in Hockey *et al.,* 2005) within the family.

*Susceptibility: Morphological analysis*

Wing loading was selected as being the key morphological characteristic to incorporate into this study. In order to circumvent the lack of wing area data for southern African bird species, a crude index of wing loading was calculated using species body mass and wing length using data contained in Hockey *et al.* (2005). In total, of the 152 species, 26 species had mass data available for only one sex, in these cases the same data was used for both sexes. Fourteen species only had wing length data for 1 sex, and so the same data was then used for both sexes. One species, the Bald Ibis, had no mass data available in Hockey *et al.* (2005). Since data for relatively good surrogates in the form of similar ibises existed, no effort was made to find data for this species in other sources. Final wing loading scores were converted to an index of 1 to 4, to facilitate combination with the behavioral scores. This conversion was done as follows: The median wing loading score across all species was used to divide the species into two data sets, A (those species with scores above the median) and B (those species with scores below the median). The median of sets A and B were then used to divide the data again into sub-sets Aa (those above the median of A), Ab (those below the median of A), and Ba and Bb (those above and below the median of B respectively). Scores were the assigned as follows: Aa = 1; Ab = 2; Ba = 3; Bb = 4. In order to test the validity of the crude wing loading estimates I compared my wing loading scores for 30 raptors and owls with those obtained by Mendelsohn *et al.* (1989), who present the best source of wing dimension data for diurnal and nocturnal African raptors (58 to 66 species), and the only wing loading data available for southern African birds. In addition I tested the relationship between wing length and wing area using the raw data from Mendelsohn *et al.* (1989) (shown in Appendix 3), in order to determine whether the relationship between these two dimensions is constant across the 30 relevant species.

### *Exposure: Behavioral analysis*

Literature on bird collisions around the world (Brown, 1992; APLIC, 1994; Bevanger, 1994; Hunting, 2002; Crowder & Rhodes, 2001; Rubolini *et al.*, 2005; Drewitt & Langston, 2008) was consulted in order to determine relevant factors that could be incorporated into this model. The ten behavioral factors (eight identified initially, and a further two added on the basis of experts' input as described elsewhere in this report) contributing most to this and most easily scored for the selected species were decided to be: migration, movement, flight frequency; flight length; flight height; flight speed; focus during flight; flocking behaviour; visibility during flight (what the bird sees); and openness of habitat. Theoretically species which: spend more months of a year in South Africa; move around in new unfamiliar areas of SA; fly more often; fly for longer; fly at typical power line height; fly faster; are distracted whilst in flight; flock together; fly when it is darker; and fly in more open habitat (hence vertical intrusion such as power lines are more prominent, and the common species are less evolved for flying amongst vertical obstructions), will be at greater risk of collision. For each of the selected species (Table 1), scores were assigned subjectively for each of the ten variables, where 1 represents low exposure and 4 high, using my own ornithological knowledge supplemented with thorough reading of the species accounts in Hockey *et al.* (2005). These scores were circulated (in the format shown in Appendix 2) to a panel of six respected South African ornithologists for comment and input (see Appendix 4 for full list). Once scores were finalized, the median of all scores for each species was used as the overall behavioral score for these species. It is hoped that by using the median method, the challenges (Barnett *et al.,* 2008; and Vincent, 2004) associated with aggregating the scores through other means can be avoided.

### *Testing of the model*

Overall collision probability for a species was then determined as the median of the behavioral and morphological scores for the species. These final species probability scores were then tested against actual collision mortality data contained in the Eskom-EWT Central Incident Register (CIR) (Table 2). The CIR is a database of reported bird mortalities on Eskom infrastructure from 1996 to the present. Records are the result of chance detection of mortalities, not structured line searches. To facilitate comparison, the CIR data were converted to scores of 1 to 4 as above under 3.2. Where a species was present in the model but did not have reported collisions in the CIR, it was assigned a score of zero. Modelled species collision probability scores were then tested against the actual collision probability scores using a Chi-square test. This testing was done at various levels: individual species scores; the family level (calculated as the median of species scores within each family); and within those families for which sufficient species were represented in the CIR data.

### *Mapping of collision probability*

Collision probability was then mapped for all modelled species, using Southern African Bird Atlas Project presence-absence data (Harrison *et al.*, 1997), in order to show the spatial distribution of the relevant species. In order to obtain a collision probability score for each quarter degree square, the collision probability scores for all species present in that square were summed. This process was then repeated for those species with collision probability scores of 3 and 4 only.

### *Mapping of risk*

The collision probability scores for those species with scores of 3 and 4 were then weighted with the conservation status (Barnes, 2000). For each species, the collision probability score was multiplied (since the two scores are on different scales) by the species conservations status score in order to obtain a species collision risk score.  Scores for conservation status were assigned to species as follows: 6 for ‘Critically endangered’; 5 for ‘Endangered’; 4 for ‘Vulnerable’; 3 for ‘Near-threatened’; 2 for protected internationally under the ‘Convention on the Conservation of Migratory Species of Wild Animals’ or the ‘Bonn Convention’ (United Nations Environment Programme, 1983); and 1 for species not Red Listed. The collision risk score for each quarter degree square was obtained by summing the collision risk scores of the species present in that square. This was then displayed as a map of true collision risk priority in SA (after the risk matrix by Allan (2006)).

In each mapping step the degree of clustering (i.e. areas of similar values) of either high or low values in the study area was measured. A spatial clustering technique developed by Getis and Ord (1992), the “Hotspot analysis (Getis-Ord General G)” function in ArcGIS 9.2, was used for this purpose. When using this tool, the null hypothesis states "there is no spatial clustering of the values". A Z score is calculated to help determine if the index or P value is significant, and is a measure of standard deviation. The p-value is the probability of false rejection of the null hypothesis. When the Z score is large (or small) enough such that it falls outside of the desired significance, the null hypothesis can be rejected. If the null hypothesis is rejected the sign of the Z score becomes important. If the value is positive, it means that high values are clustered together. If the value is negative, it means that low values are clustered together (Getis & Ord, 1992. A Z score near zero indicates no apparent clustering within the study area. A positive Z score indicates clustering of high values. It is important to note that the Z score is not absolute, meaning that the degree of clustering between the different Figures 2 to 7 cannot be compared.

### 3.3 Electrocution

*Species selection*

Species were selected for the electrocution analysis based on the literature cited in Table 1. In addition to the identified families, Phasianidae (gamebirds), Numididae (guineafowl), Bucerotidae (hornbills), Bucorvidae (ground hornbills), Gruidae (cranes – the Crowned Crane is the only tree roosting crane worldwide, and hence vulnerable to electrocution), Sagitariidae (Secretarybird), Phalacrocoracidae (cormorants), Threskiornithidae (ibises, spoonbills), and Pelicanidae (pelicans) were all included based on the authors knowledge and experience in South Africa over a ten year period of working in this field.

*Susceptibility: Morphological analysis*

Average body length and wing length data were obtained for each species from Hockey *et al.* (2005). Due to the paucity of data on wing span, wing length was used as an index of the wing span of a bird. In order to determine species wing length scores from the actual data, the median wing length was used as above under 3.2. For each species, the median of these two scores, height and wing span was taken as the final morphological score for the species.

*Exposure: Behavioral analysis*

Five ‘behavioral’ factors were taken into account: migration, movement, perching likelihood, roosting likelihood and gregarious nature. Theoretically, migratory species spend only half the year in SA and hence are less exposed to electrocution risk here, nomadic species would spend more time in unfamiliar territory (and hence interacting with unfamiliar infrastructure) therefore placing them at greater risk, species which perch or roost more often and for longer duration would be at more risk, more gregarious species would be at greater risk through the increased chance of multiple birds bridging the relevant gaps between hardware on a pylon. A final species behavioral score was calculated as the median of these five scores for each species.

A final electrocution probability score for each species was obtained using the median of the species' morphological and behavioral scores.

*Testing of the model*

The modelled species electrocution probability scores were tested against the actual CIR data in the same manner as for collision.

*Mapping of electrocution probability*

Electrocution probability was mapped in the same manner as for collision.

*Mapping of electrocution risk*

Electrocution risk was mapped in the same manner as for collision.

# 4. RESULTS

## 4.1 Collision

*Species selection*
In total, this model considered 34 families (shown in Table 1) comprising 152 species, displayed in Appendix 2.

*Exposure: Morphological analysis*
The raw data for the full species set and final wing loading scores can be seen in Appendix 2. The hypothesis that the crude wing loading index would not differ significantly from that calculated by Mendelsohn *et al.* (1989) for the 30 raptor species for which he had data, was tested using chi-square. The hypothesis was rejected at the 95% confidence level (chi = 16.93, n=30, d.f.=29). Examination of the relationship between wing area and wing length (ratio of wing area:wing length) revealed variation even within the raptors, the lowest value being 1.7 for Pygmy Falcon and the highest 11.9 for Cape Vulture. This ratio increased proportionally to mass.

*Susceptibility: Behavioral analysis*
Responses on my subjective scoring of the ten behavioral factors were received from four of the six ornithologists, ranging from brief comment to thorough amendments of species scores in the case of one expert. In summary, comments included questions about: the overall project and validity of methods; the assumptions underlying the various factors, and the lack of supporting data for these factors; the intraspecific variation in all of the factors; the low scores assigned to large terrestrial species for flight speed (which is in fact not as slow as it appears, otherwise these heavy birds would not sustain flight); the independence of the factors; and the basis for selection of the species. In most cases these comments have either resulted in amended scores, or explanation in the methodology of this report. Opinions on the best way to approach this subjective scoring exercise varied from a single recorder/scorer approach being best (for consistency), to an approach ‘spreading the blame across as many recorders/scorers as possible’ being the best. The one comprehensive response to the actual species scores suggested different scores (by one point only) in 205 (17%) cases out of a total of 1 216 scores for collision (152 species x 8 factors) and suggested two new factors, migration and movement. One hundred and twelve (55%) of the suggested changes were decreased scores for a specific factor. The factor most changed was speed of flight (38 changes), and least changed was visibility (13 changes). All suggested changes were accepted. The final scores for all morphological and behavioral factors are presented in Appendix 2.

Table 1. List of families cited by recent literature as affected by collision and electrocution with overhead wires, and several additional taxa decided by the author to be important for this study.

| **Bird families** | **Citing authors - collision** | **This study – 2010 - collision** | **Citing authors – electrocution** | **This study 2010 - electrocution** |
|---|---|---|---|---|
| Phasianidae & Numididae - Gamebirds, Quails, Pheasants | Bevanger 1998, Hunting 2002, Brown 1992 | 7 species | Added based on local knowledge | 2 species |
| Anatidae & Dendrocygnidae – Waterfowl | Brown 1992, Bevanger 1998, Hunting 2002, Rubolini *et al.* 2005, Drewitt & Langston 2008 | 9 species | Rubolini *et al.* 2005 | 9 species |
| Picidae - Woodpeckers | Hunting 2002 | 4 species | | |
| Bucerotidae - Typical hornbills | Added based on local knowledge | 3 species | Added based on local knowledge | 3 species |
| Bucorvidae - Ground-hornbills | Added based on local knowledge | 1 species | Added based on local knowledge | 1 species |
| Apodidae – Swifts | Added based on local knowledge | 5 species | | |
| Tytonidae & Strigidae - Owls | Hunting 2002 | 5 species | Haas 1980, Rubolini *et al*. 2005 | 5 species |
| Columbidae – Pigeons | Bevanger 1998, Hunting 2002, Drewitt & Langston 2008 | 5 species | Haas 1980 | 5 species |
| Otididae – Bustards | Bevanger 1998, Hunting 2002, Rubolini *et al.*. 2005, Drewitt & Langston 2008 | 7 species | | |
| Gruidae – Cranes | Brown 1992, Bevanger 1998, Hunting 2002, Rubolini *et al.* 2005, Drewitt & Langston 2008 | 3 species | Added based on local knowledge | 1 species |
| Rallidae – Rails | Bevanger 1998, Hunting 2002, Drewitt & Langston 2008 | 9 species | | |
| Pteroclidae - Sandgrouse | Added based on local knowledge | 2 species | | |
| Scolopacidae - Sandpipers | Bevanger 1998, Hunting 2002 | 3 species | | |
| Recurvirostridae - Waders - Stilts, Avocets | Rubolini *et al.* 2005 | 2 species | | |

| **Bird families** | **Citing authors - collision** | **This study – 2010 - collision** | **Citing authors – electrocution** | **This study 2010 - electrocution** |
|---|---|---|---|---|
| Charadriidae – Plovers | Bevanger 1998, Hunting 2002, Drewitt & Langston 2008 | 5 species | | |
| Laridae - Gulls, Terns | Bevanger 1998, Hunting 2002, Rubolini *et al.* 2005 | 4 species | Haas 1980 | 4 species |
| Accipitridae - Vultures, Eagles, Hawks | Hunting 2002 | 24 species | Haas 1980, Janss 2000, Rubolini *et al*. 2005 | 14 species |
| Sagitariidae - Secretarybird | Added based on local knowledge | 1 species | Added based on local knowledge | 1 species |
| Falconidae – Falcons | Hunting 2002, Drewitt & Langston 2008 | 4 species | Haas 1980, Janss 2000, Rubolini *et al*. 2005 | 4 species |
| Podicipedidae - Grebes | Bevanger 1998, Hunting 2002 | 2 species | | |
| Phalacrocoracidae - Cormorants | Bevanger 1998, Hunting 2002 | 3 species | Added based on local knowledge | 3 species |
| Ardeidae – Herons | Brown 1992, Rubolini *et al.* 2005, Drewitt & Langston 2008 | 9 species | Rubolini *et al*. 2005 | 9 species |
| Phoenicopteridae - Flamingos | Hunting 2002 | 2 species | | |
| Threskiornithidae - Ibises, spoonbills | Added based on local knowledge | 5 species | Added based on local knowledge | 5 species |
| Pelecanidae – Pelicans | Brown 1992, Hunting 2002 | 2 species | Added based on local knowledge | 2 species |
| Ciconidae – Storks | Hunting 2002 | 5 species | Haas 1980, Janss 2000 | 5 species |
| Diomedeidae - Albatrosses | Hunting 2002 | Excluded due to habitat | | |
| Monarchidae, Muscicapidae – Flycatchers | Hunting 2002 | X | | |
| Corvidae – Crows | Hunting 2002 | 3 species | Added based on local knowledge | 3 species |
| Hirundinidae - Swallows | Hunting 2002 | 6 species | | |

| **Bird families** | **Citing authors - collision** | **This study – 2010 - collision** | **Citing authors – electrocution** | **This study 2010 - electrocution** |
|---|---|---|---|---|
| Cisticolidae – Warblers | Bevanger 1998, Hunting 2002 | X | | |
| Alaudidae – Larks | Bevanger 1998, Hunting 2002 | 5 species | | |
| Muscicapidae - Thrushes | Bevanger 1998, Hunting 2002 | X | Haas 1980 | 2 species |
| Sturnidae – Starlings | Bevanger 1998, Hunting 2002 | 4 species | Haas 1980 | 4 species |
| Passeridae – Sparrows | Hunting 2002 | 3 species | | |
| Anatidae - Swans | Brown 1992 | Do not occur in SA | | |
| Cathartidae - Condors | Brown 1992, Hunting 2002 | Do not occur in SA | | |
| Trochilidae - Hummingbirds | Hunting 2002 | Do not occur in SA | | |
| Thraupidae - Tanagers | Hunting 2002 | Do not occur in SA | | |
| Lanidae – Shrikes | | | Haas 1980, | 4 species |
| Passerines in general | | | Rubolini *et al.* 2005 | |
| | | *34 families, 152 species* | | *22 families, 94 species* |

*Testing of the model*

Table 2 presents the actual number of collisions reported to the Eskom-EWT Strategic Partnership during the period August 1996 to July 2009, as well as the assigned species probability scores on a scale of 1 to 4. The CIR had a total of 2 044 recorded individual bird collisions. Of these, 74 unidentified birds (nearly 4%) and 2 racing pigeons were excluded. This left 1 968 mortalities, spread over 73 species, or 26 families, compared to 152 modelled species, spread over 34 families. Fifty-four of the modelled species are represented in the CIR data, and the CIR had 18 species not represented in the model. On a family basis 24 of the modelled families were represented by species in the CIR, sometimes with different species but from the same family. Of the additional species in the CIR, 17 of 18 were contained in families represented in the model, the exception being the Cape Parrot (Pssitacidae).

Table 2. The actual reported mortality data and corresponding scores for 73 species that collided with and 59 species that were electrocuted on power lines, from the Central Incident Register (Eskom-EWT, August 1996 to July 2009).

| **Family** | **Species** | **# Reported collisions** | **Colli-sion score** | **# Reported electrocut-ions** | **Electr-ocution score** |
|---|---|---|---|---|---|
| Phasianidae | Swainson's Spurfowl | 1 | 1 | 0 | |
| | Common Quail | 2 | 1 | 0 | |
| Numididae | Helmeted Guineafowl | 2 | 2 | 28 | 4 |
| Dendrocygnidae | White-faced Duck | 2 | 2 | 0 | |
| Anatidae | African Black Duck | 1 | 1 | 0 | |
| | Cape Shoveller | 1 | 1 | 0 | |
| | South African Shelduck | 4 | 3 | 0 | |
| | Yellow-billed Duck | 10 | 4 | 0 | |
| | Spur-winged Goose | 32 | 4 | 8 | 3 |
| | Egyptian Goose | 33 | 4 | 37 | 4 |
| Bucorvidae | Southern Ground Hornbill | | | 4 | 2 |
| Psittacidae | Cape Parrot | 1 | 1 | 0 | |
| Tytonidae | Barn Owl | 1 | 1 | 21 | 4 |
| Strigidae | Marsh Owl | 1 | 1 | 4 | 2 |
| | Spotted Eagle Owl | 2 | 1 | 67 | 4 |
| | Verreaux's Eagle Owl | 0 | | 7 | 3 |
| | Cape Eagle Owl | 0 | | 8 | 3 |
| | White-faced Scops Owl | 0 | | 1 | 1 |
| Columbidae | Laughing Dove | 1 | 1 | 0 | |
| | Speckled Pigeon | 11 | 4 | 7 | 3 |
| Otidae | Northern Black Korhaan | 3 | 3 | 0 | |
| | Blue Korhaan | 4 | 3 | 0 | |
| | Karoo Korhaan | 4 | 3 | 0 | |
| | Denham's Bustard | 22 | 4 | 0 | |
| | Kori Bustard | 54 | 4 | 1 | n/a |
| | Ludwig's Bustard | 235 | 4 | 2 | n/a |
| Gruidae | Wattled Crane | 9 | 3 | 0 | |
| | Grey Crowned Crane | 147 | 4 | 25 | 4 |
| | Blue Crane | 771 | 4 | 0 | |

| **Family** | **Species** | **# Reported collisions** | **Colli-sion score** | **# Reported electrocut-ions** | **Electr-ocution score** |
|---|---|---|---|---|---|
| Rallidae | Corncrake | 1 | 1 | 0 | |
| | Red-knobbed Coot | 1 | 1 | 0 | |
| | Spotted Crake | 1 | 1 | 0 | |
| | White-winged Flufftail | 1 | 1 | 0 | |
| Scolopacidae | African Snipe | 1 | 1 | 0 | |
| Charadriidae | Crowned Lapwing | 1 | 1 | 0 | |
| | Kittlitz's Plover | 1 | 1 | 0 | |
| Laridae | Swift Tern | 1 | 1 | 0 | |
| Accipitridae | African Crowned Eagle | 1 | 1 | 6 | 2 |
| | African Hawk Eagle | 1 | 1 | 0 | |
| | Black Sparrowhawk | 1 | 1 | 0 | |
| | Black-chested Snake Eagle | 1 | 1 | 9 | 3 |
| | Montagu's Harrier | 1 | 1 | 0 | |
| | Southern Pale Chanting Goshawk | 1 | 1 | 9 | 3 |
| | Steppe Buzzard | 1 | 1 | 11 | 3 |
| | Lappet-faced Vulture | 2 | 2 | 47 | 4 |
| | Tawny Eagle | 2 | 2 | 2 | 1 |
| | Bearded Vulture | 4 | 3 | 0 | |
| | Jackal Buzzard | 4 | 3 | 26 | 4 |
| | African Fish Eagle | 5 | | 31 | 4 |
| | Martial Eagle | 6 | 3 | 49 | 4 |
| | African White-backed Vulture | 12 | 4 | 174 | 4 |
| | Verreaux's Eagle | 15 | 4 | 36 | 1 |
| | Cape Vulture | 59 | 4 | 320 | 4 |
| | African Goshawk | 0 | | 1 | 1 |
| | African Harrier Hawk | 0 | | 1 | 1 |
| | Forest Buzzard | 0 | | 1 | 1 |
| | Black-shouldered Kite | 0 | | 4 | 2 |
| | Brown Snake Eagle | 0 | | 4 | 2 |
| | Long-crested Eagle | 0 | | 9 | 3 |
| | European Honey-Buzzard | 0 | | 4 | 2 |
| Sagitariidae | Secretarybird | 46 | 4 | 0 | |
| Falconidae | Lanner Falcon | 1 | 1 | 4 | 2 |
| | Lesser Kestrel | 1 | 1 | 1 | 1 |
| | Peregrine Falcon | 1 | 1 | 2 | 1 |
| | Greater Kestrel | 2 | 2 | 3 | 2 |
| | Rock Kestrel | 0 | | 2 | 1 |
| | Amur Falcon | 0 | | 5 | 2 |
| Phalacrocoracidae | White-breasted Cormorant | 1 | 1 | 1 | 1 |
| Ardeidae | Grey Heron | 1 | 2 | 4 | 1 |
| | Goliath Heron | 2 | 1 | 1 | 2 |
| | Cattle Egret | 7 | 3 | 11 | 3 |
| | Black-headed Heron | 17 | 4 | 27 | 4 |
| | Purple Heron | 0 | | 1 | 1 |
| Scopidae | Hamerkop | 1 | 1 | 1 | 1 |
| Phoenicopteridae | Lesser Flamingo | 63 | 4 | 0 | |
| | Greater Flamingo | 84 | 4 | 0 | |
| Threskiornithidae | Glossy Ibis | 2 | 2 | 0 | |

| Family | Species | # Reported collisions | Collision score | # Reported electrocutions | Electrocution score |
|---|---|---|---|---|---|
| | African Spoonbill | 2 | 2 | 0 | |
| | Southern Bald Ibis | 3 | 3 | 2 | 1 |
| | Hadeda Ibis | 7 | 3 | 68 | 4 |
| | African Sacred Ibis | 22 | 4 | 6 | 2 |
| Pelicanidae | White Pelican | 15 | 4 | 0 | |
| Ciconidae | Marabou Stork | 2 | 2 | 7 | 3 |
| | Abdim's Stork | 4 | 3 | 0 | |
| | White Stork | 204 | 4 | 17 | 3 |
| | Black Stork | 0 | | 1 | 1 |
| Corvidae | Pied Crow | 1 | 1 | 16 | 3 |
| | White-necked Raven | 0 | | 2 | 1 |
| | Cape Crow | 0 | | 19 | 3 |
| Sturnidae | Wattled Starling | 1 | 1 | 0 | |
| | Pied Starling | 0 | | 1 | 1 |
| | Red-winged Starling | 0 | | 1 | 1 |
| Ploceidae | Masked Weaver | 0 | | 1 | 1 |
| | Red-billed Buffalo-Weaver | 0 | | 1 | 1 |
| | | 1968 | | 1169 | |

Figures 1a and b show the distribution of the probability scores for both the model and the CIR, for collision and electrocution. In both cases, the model appears to show a bell shaped distribution, whilst the CIR shows greater frequency for the probability scores of 1 and 4 than for scores of 2 and 3.

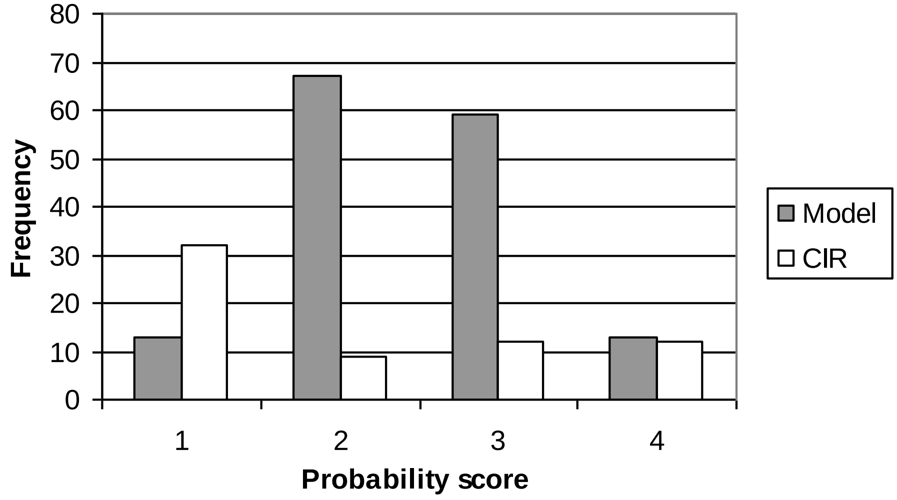

**Figure 1a**

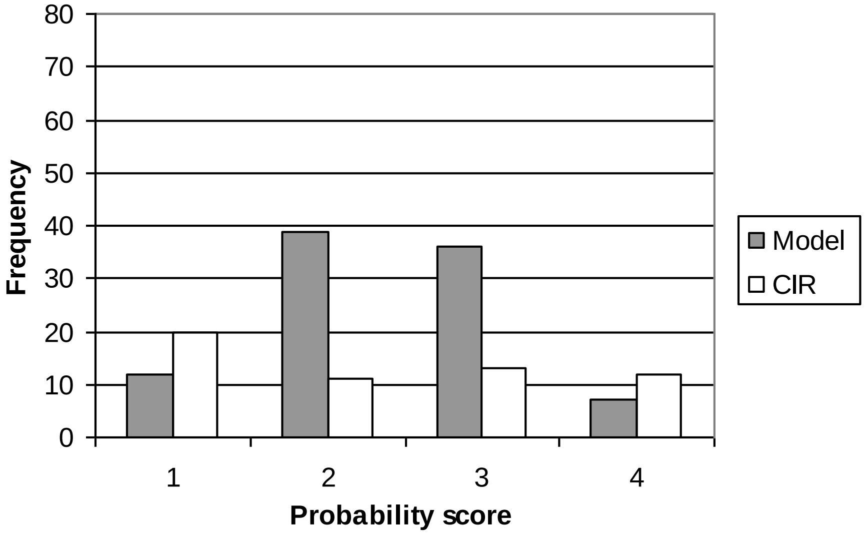

**Figure 1b**

Figure 1a and b. Frequency of probability scores and Central Incident Register scores (both consisting of scores of 1 to 4) for both the collision (Figure 1a) and electrocution (Figure 1b) models.

The hypothesis that the modelled collision probability scores would not differ significantly from scores derived from the actual CIR data was tested using a chi square test at several levels: the individual species scores; the family level (calculated as the median of species scores within each family); and within those families for which sufficient species were represented in the CIR data (Table 3).

Table 3. Outputs of a goodness of fit test between collision probability scores and actual Central Incident Register scores, including chi-square values, p-values and result of testing.

| **Test** | **Model** | **CIR** | **chi square value** | **Critical P value AT 95%** | **Result** |
|---|---|---|---|---|---|
| *Individual species* | 152 model species | 55 species in model, remainder assigned scores of zero | 214.48 (n=152, d.f. = 151) | Approx 168.28 for df = 200 | Reject at 95% level |
|  | 54 matching species | 54 matching species | 113.25 (n=54, d.f. = 53) | Approx 37.29 | Reject at all levels |
|  | 33 species with 3 or higher score | 33 matching species | 9.11 (n=30, d.f.=29) | Approx 17.71 | Accept at 95% level |
| *Family level* | 35 family scores | 35 family scores | 46.3 (n=35, d.f. = 34) | Approx 21.70 | Reject at all levels |
| *Within family* |  |  |  |  |  |
|  | Anatidae 8 species | 5 species + 3 zero scores | 9.88 (n=8, d.f.= 7) | 2.17 | Reject at all levels |
|  | Otididae 7 species | 5 species + 2 zero scores | 6.57 (n=7, d.f. = 6) | 1.64 | Reject at all levels |
|  | Gruidae 3 species | 3 species | 0.21 (n=3, d.f.=2) | 0.103 at 95%, 0.211 at 90% | Accept at 90% |
|  | Accipitridae, Sagittariidae & Falconidae collectively 35 species | 15 species + 20 zero scores | 41.25 (n=35, d.f.=34) | Approx 21.70 | Reject at all levels |
|  | Threskiornithidae 5 species | 5 species | 0.78 (n=5, d.f.=4) | 0.711 at 95%, 1.06 at 90% | Accept at 90% |
|  | Ciconidae 5 species | 3 species + 2 zero scores | 3.35 (n=5, d.f. =4) | 0.711 | Reject at all levels |

At the individual species level, the hypothesis of no difference between expected and observed probability scores was rejected, the chi square statistics being significantly higher than the critical value for both 95% and 90% (Table 3). Examination of the individual species chi square figures revealed that almost all the species with the highest contribution to chi were those that were not represented in the CIR at all, and hence assigned a score of 0. In order to investigate further, the test was run again using only the 54 species for which there was a match between model and CIR. At this level the hypothesis was also rejected. I then tested the 30 species with scores of 3 and above, that had matching species in the CIR against each other and this was accepted. At the family level, family collision probability scores for 35 families were tested against 35 families using median values, and the hypothesis was again rejected.

Examination of the family chi square contributions revealed that in general the larger bodied families contributed less, i.e. the model performed better for these species. This was tested by calculating the correlation coefficient for family mean mass and its chi square statistic, resulting in $r = -0.55$ ($p < 0.05$, $n=34$). This means that the higher the mean mass of a family, the lower the chi square value and therefore more likelihood of significance. In addition it appears that there may be a relationship between chi square and family probability score. This was again tested using correlation coefficient which was -0.46, ($p < 0.05$, $n = 34$) showing a relatively strong negative correlation between family probability score and family chi square, i.e when probability score is higher, chi square is lower. The families (six) for which sufficient species were contained in the CIR were compared. Although all were rejected at the 95% level (details in Table 3), Gruidae (cranes) and Threskiornithidae (ibises and spoonbill) were accepted at the 90% level. This is important later in this study in determining ‘action thresholds’ as these will be based on the species with higher probability scores.

*Mapping of collision probability*

Figure 2 shows the distribution of the 152 modelled species across SA, using presence-absence data from Harrison *et al.* (1997). Key areas that emerge are: the Lowveld (defined as the Kruger National Park and surrounds), Gauteng and western Mpumalanga, the western parts of KwaZulu-Natal; and parts of the Western Cape.

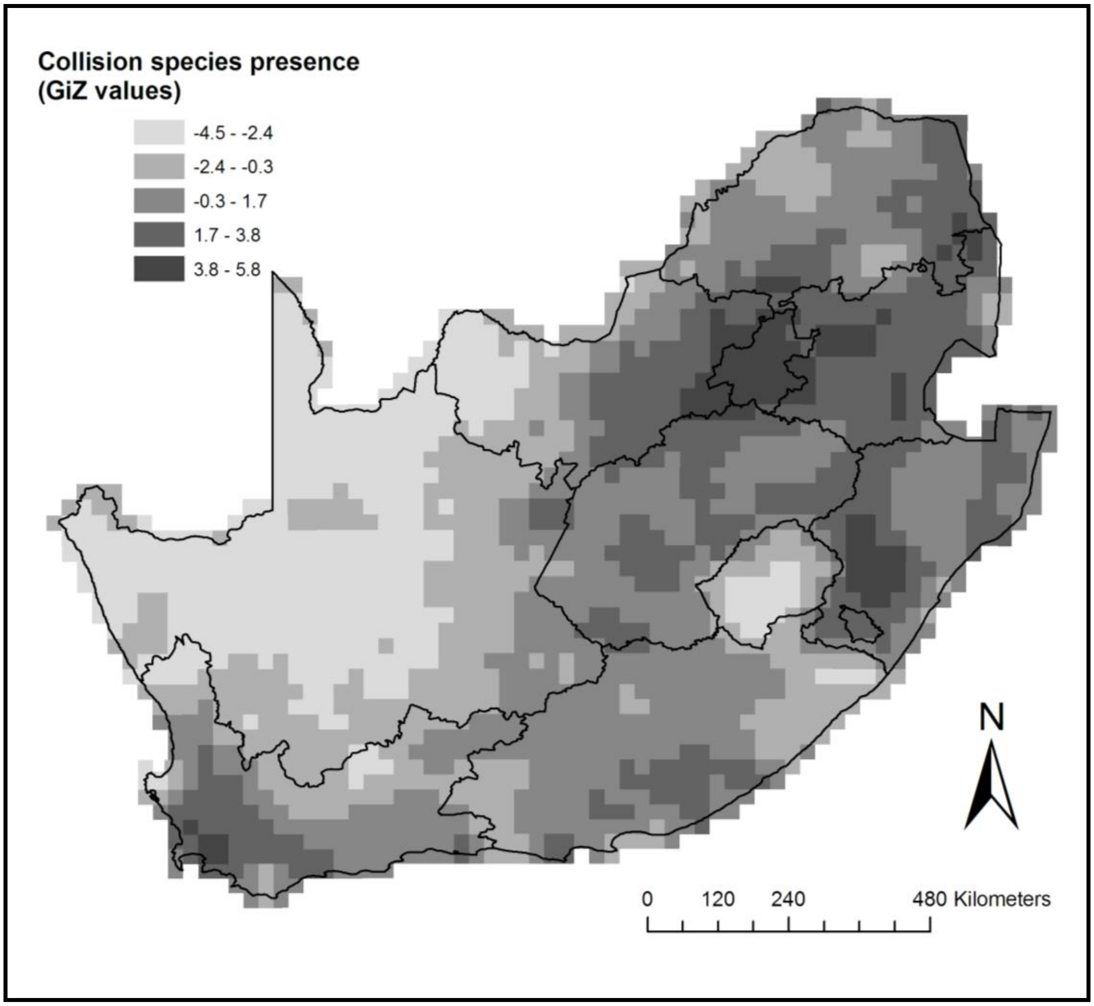

Figure 2. Hotspot analysis (Getis-Ord Gi) for the presence of the 152 collision modelled species. The displayed scores are the GiZ values, high values indicating high degree of clustering and low values indicating a low degree of clustering. Original species presence data are from Harrison *et al.* (1997).

The action threshold (after Allan 2006) was decided to be a collision probability score of 3 or above since, as discussed elsewhere in this report, the model performed far better for species with these higher probability scores, so our confidence in these species being priority species is higher. All those species above this threshold are shown in Figure 3. The results of testing the model above also reveal greater accuracy for the higher collision probability species, which would add to our confidence in using the species with 3 and 4 for action. The results of Figure 3 differ from those of Figure 2 mostly in that the lowveld (defined as the Kruger National Park and surrounds) area is no longer as important.

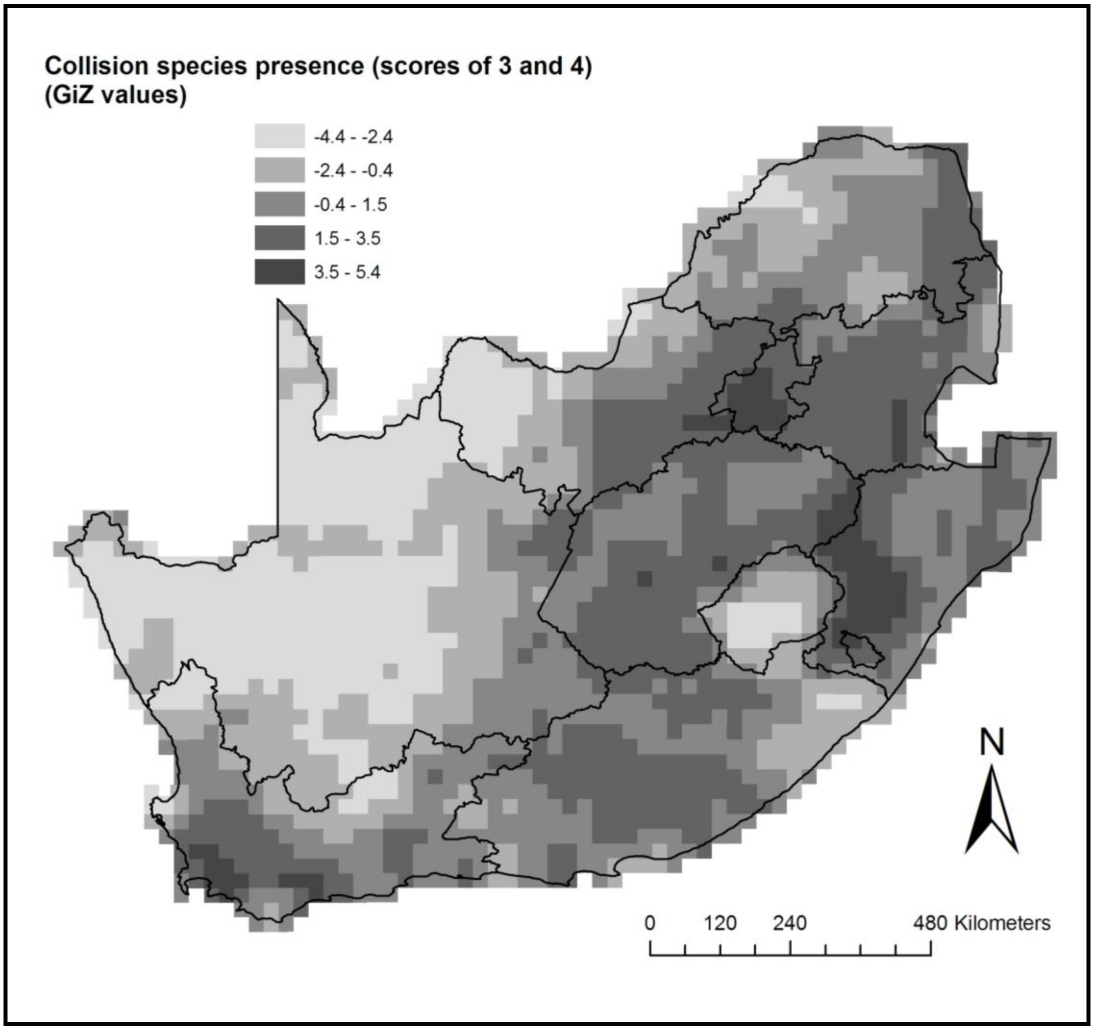

Figure 3. Hotspot analysis (Getis-Ord Gi) for the presence of the 72 collision modelled species with collision probability scores of 3 and 4. The displayed scores are the GiZ values, high values indicating high degree of clustering and low values indicating a low degree of clustering. Original species presence data are from Harrison *et al. (*1997).

Collision probability was then weighted by conservation status for these species in order to map final collision risk in Figure 4. The results of Figure 4 are that the western KwaZulu-Natal emerges as the most important area.

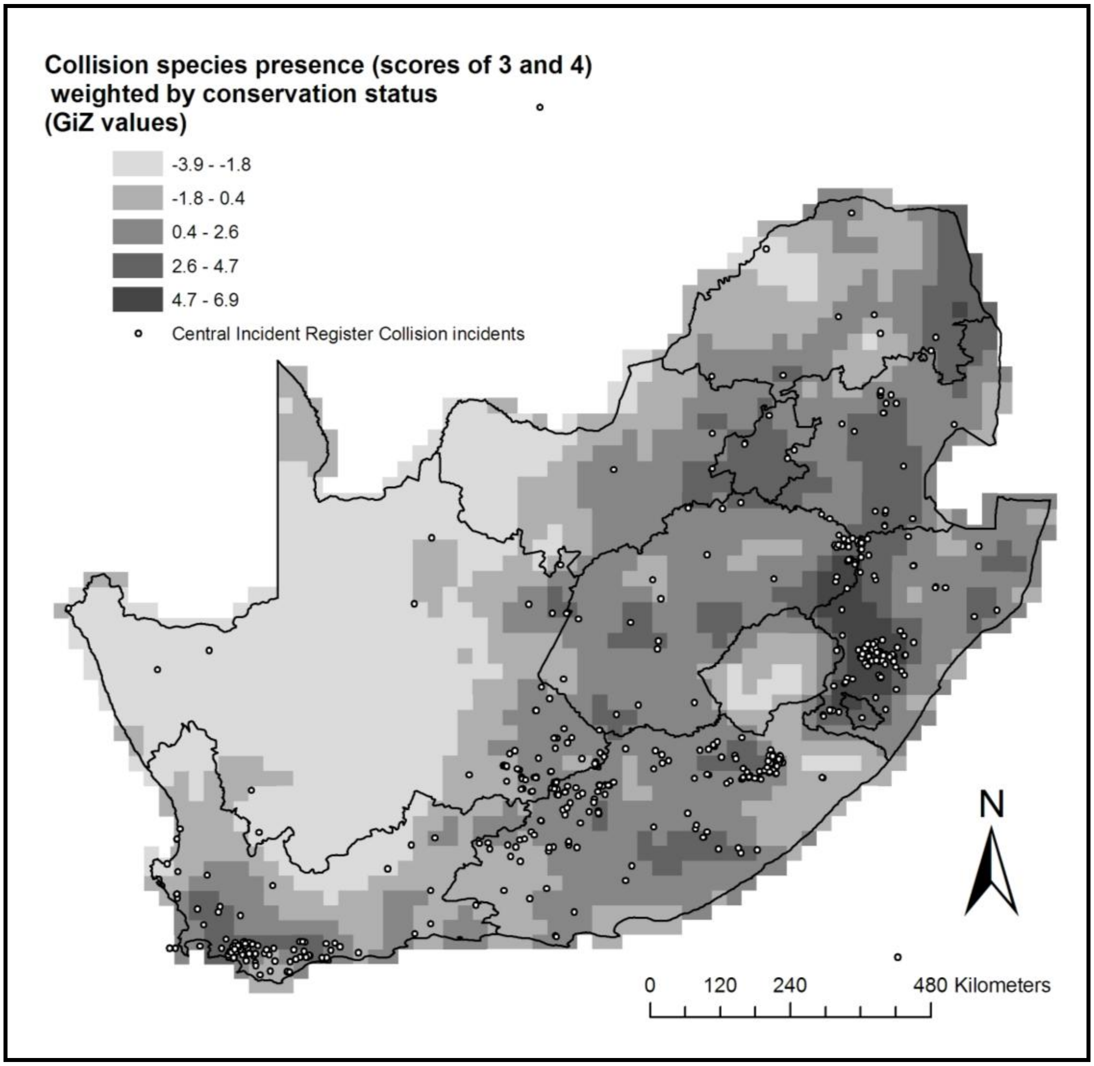

Figure 4. Hotspot analysis (Getis-Ord Gi) for the presence of the 72 collision modeled species with collision probability scores of 3 and 4, weighted by their conservation status. The displayed scores are the GiZ values, high values indicating high degree of clustering and low values indicating a low degree of clustering. Original species presence data are from Harrison *et al.* (1997). The Central Incident Register collision incidents are overlaid on this map.

The CIR collision incidents were plotted on Figure 4 in order to ascertain visually the degree of overlap between these locations and the expected high probability collision areas of the country. Since the models' performance was poor it was not deemed necessary to formally test the model spatially. Figure 4 shows a relatively good correspondence of the reported mortalities (CIR) in the high probability areas, particularly in the western KwaZulu-Natal and Western Cape areas.

## 4.2 Electrocution

*Species selection*

In total, 94 species from 22 families were considered (see Table 1).

*Exposure: Morphological analysis*

For 17 of the 94 species, wing length data were only available for one sex, prompting the application of the available data across both sexes. The raw morphological data can be seen in Appendix 3.

*Susceptibility: Behavioral analysis*

Although the same experts commented on both the collision and electrocution models, fewer comments were received from experts on the subjective scores assigned for electrocution than collision, presumably due to the perceived simplicity of the electrocution problem. Comprehensive input was received from one ornithologist, who suggested changing 13 (5%) of 258 scores, with the majority of these (9) being changes to 'perch likelihood' scores. All suggested changes were of one point only, and all were accepted. The full set of assigned scores can be seen in Appendix 3.

*Testing of the model*

Table 2 presents the actual number of electrocutions reported to the Eskom-EWT Strategic Partnership during the period August 1996 to July 2009, as well as the assigned species probability scores on a scale of 1 to 4. The CIR contained a total of 1 271 bird electrocutions, 98 of which were unknown species, excluded from further analysis. Two Ludwig's Bustard and 1 Kori Bustard were excluded from analysis as it is believed that these were erroneous records. This left a total of 1 170 bird electrocutions, spread across 58 species or 17 families. Thirty-eight of these species matched those in the model. At the family level, 15 families matched, sometimes with differing species therein. The CIR contained an additional 21 species across 2 families.

Testing the 94 modelled species (22 families) against the CIR (assigning zeros for those species missing from the CIR) resulted in a rejection of the hypothesis that expected and observed electrocution probability scores would not differ significantly (see Table 4 for full details). Testing the 38 species in the model against the 38 matching species in the CIR resulted in a rejection of the null hypothesis of no difference at the 95% level.

Testing of those matching species with modelled probability scores of 3 and above, showed a good fit, the hypothesis being accepted at the 95% level. Testing at the family level, i.e. 22 families versus 22 families, showed a poor goodness of fit. Five families were tested against each other (Strigidae, Accipitridae, Sagitariidae & Falconidae collectively, Ardeidae, Threskiornithidae and Corvidae), and in all cases the null hypothesis was not rejected.

Table 4. Outputs of goodness of fit testing between expected and observed electrocution probability scores.

| **Test** | **Model** | **CIR** | **Chi square value** | **Critical value 95%** | **Result** |
|---|---|---|---|---|---|
| *Individual species* | 94 model species | 38 recorded species + 56 species assigned zeros | 124.34 (n= 94, d.f. = 93) | Approx 71.77 | Rejected |
| | 38 matching model species | 38 matching species | 16.84 (n=38, d.f.=37) | Approx 24.10 | Accepted at 95% level |
| | 27 species of the above 38 with scores of 3 and above | 27 species | 9.92 (n=27, d.f. = 26) | 15.38 | Accepted at 95% level |
| *Family level* | 22 families | 22 families | 22.6 (n=22, d.f.=21) | 11.59 | Rejected |
| *Within family* | Strigidae 4 species | 2 matching, 2 zeros | 2.52 n=4, d.f. -=3 | 0.352 | Rejected |
| | Accipitridae, Sagitaridae, Falconidae 29 species | 15 matching species, 14 zeros | 36.46 n=29, d.f. = 28 | 16.93 | Rejected |
| | Ardeidae 9 species | 4 match, 5 zeros | 11.54 n= 9, d.f.=8 | 2.73 | Rejected |
| | Threskiornithidae 5 species | 3 match, 2 zeros | 7.44 n=5, d.f. = 4 | 0.711 | Rejected |
| | Corvidae 3 species | 3 match | 1.14 n=3, d.f. = 2 | 0.103 | Rejected |

*Mapping of electrocution probability*

Figure 5 shows the spatial distribution of the 94 modelled electrocution species across SA. Key areas that emerge are the lowveld (defined as the Kruger National Park and surrounds), parts of Mpumalanga, Gauteng and surrounds, western KwaZulu-Natal, and parts of the Western Cape.

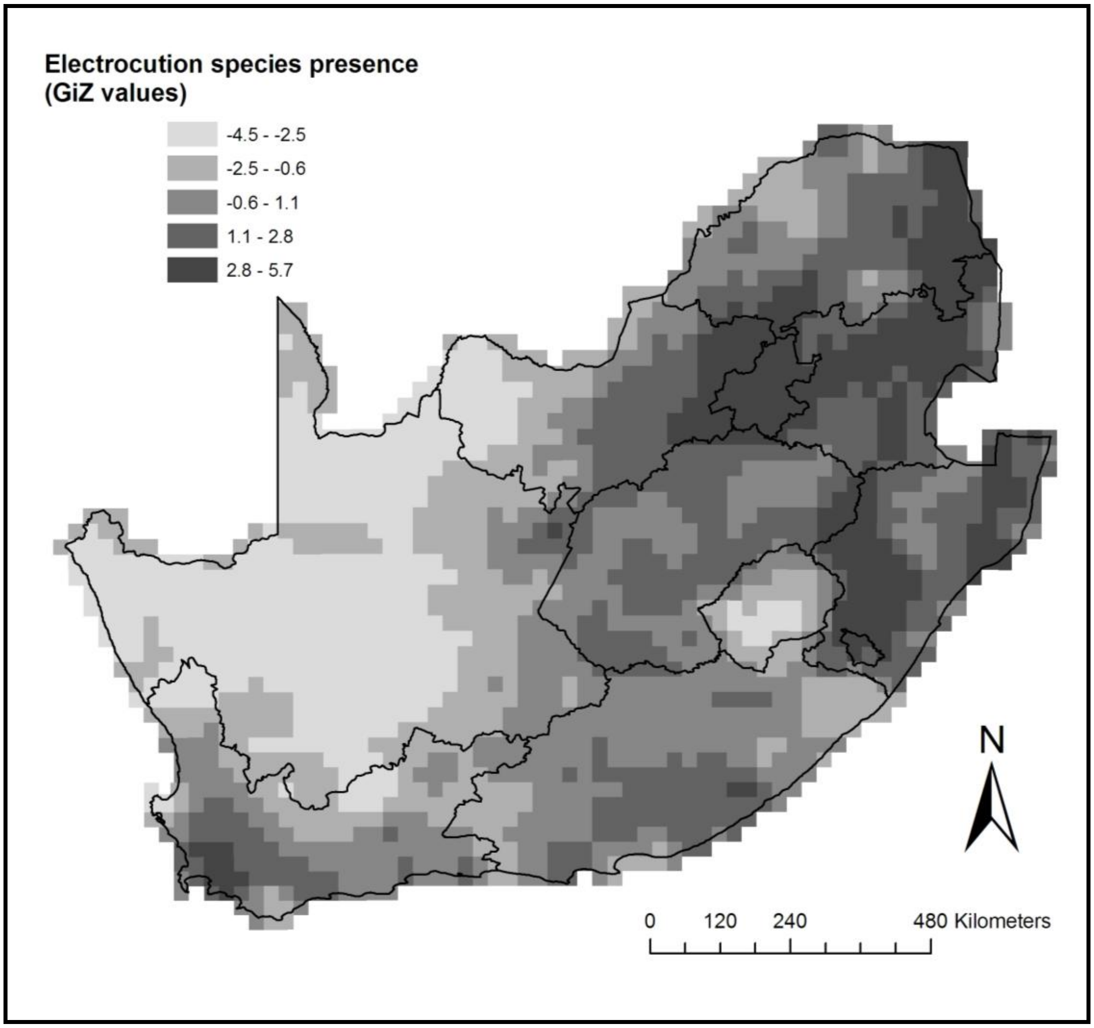

Figure 5. Hotspot analysis (Getis-Ord Gi) for the presence of the 94 electrocution modeled species. The displayed scores are the GiZ values, high values indicating high degree of clustering and low values indicating a low degree of clustering. Original species presence data are from Harrison *et al.* (1997).

Since the model performed better for those species with electrocution probability scores of 3 or 4, these species were then mapped in Figure 6. The major difference between the results of Figure 6 and Figure 5 are that the lowveld (defined as the Kruger National Park and surrounds) and western KwaZulu-Natal areas emerge as more important than previously.

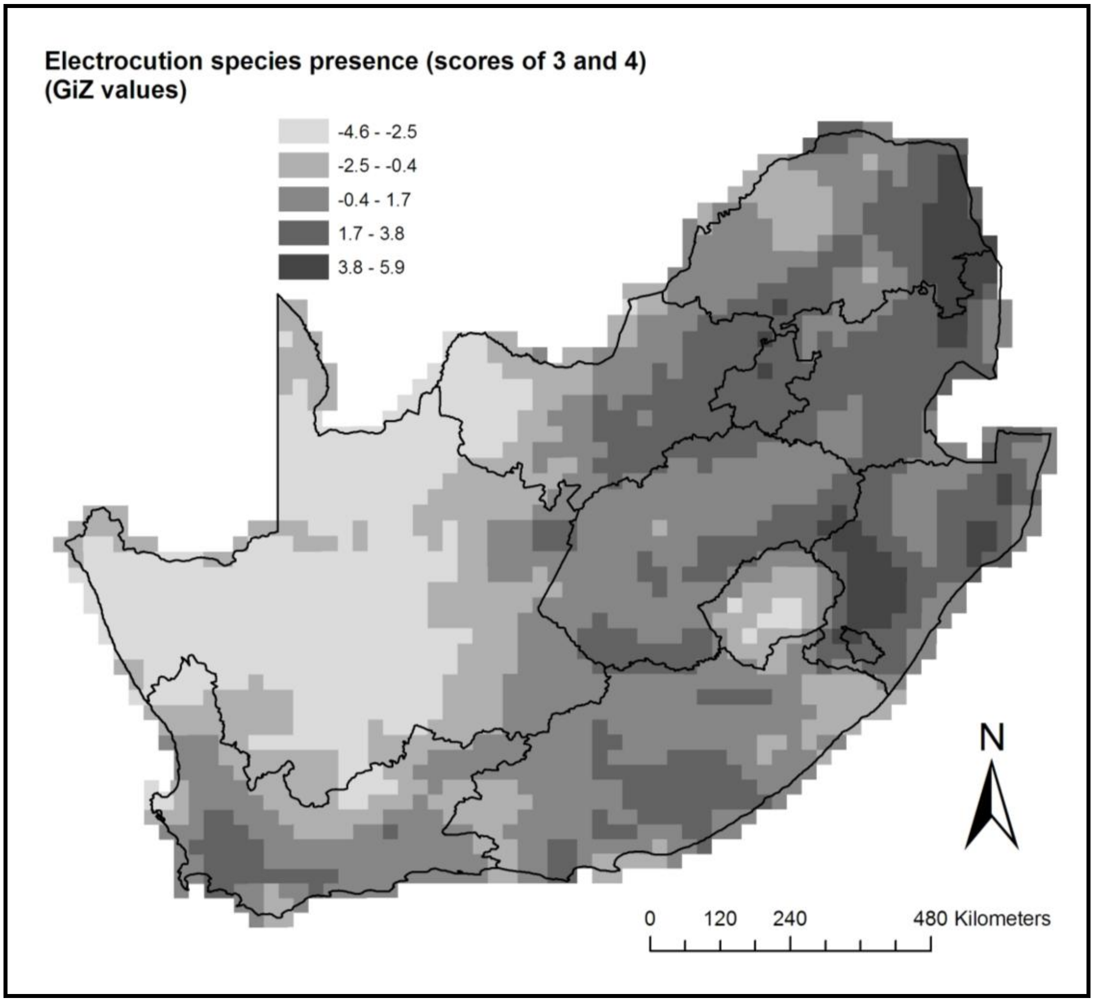

Figure 6. Hotspot analysis (Getis-Ord Gi) for the presence of the 43 electrocution modelled species with electrocution probability scores of 3 and 4. The displayed scores are the GiZ values, high values indicating high degree of clustering and low values indicating a low degree of clustering.  Original species presence data are from Harrison *et al. (*1997).

The probability scores of the species were then weighted with conservation status scores in order to map final electrocution risk across SA (Figure 7). In this map, the lowveld area (defined as the Kruger National Park and surrounds) emerges as even more important than the rest of the country, whilst the western KwaZulu-Natal area remains reasonably important.

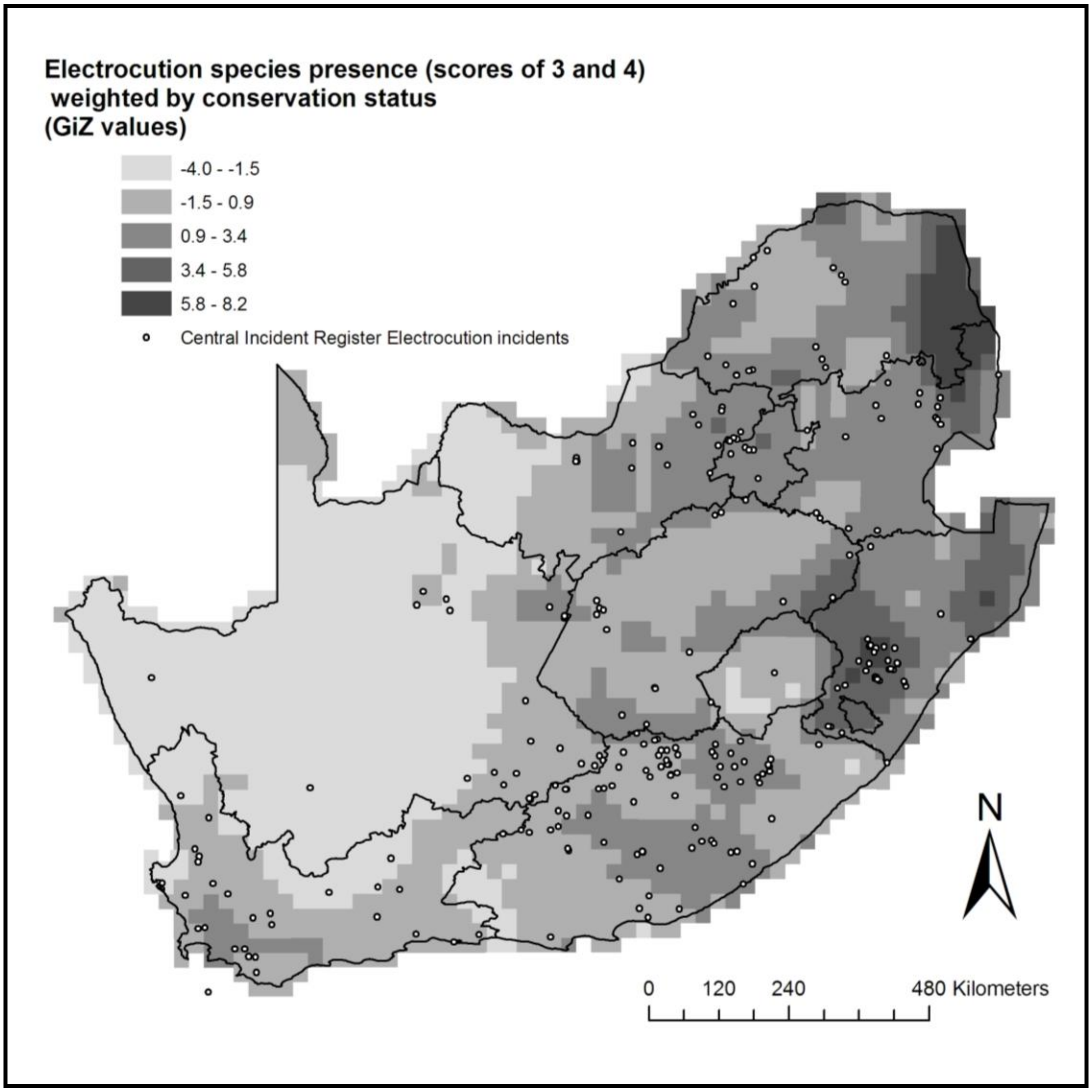

Figure 7. Hotspot analysis (Getis-Ord Gi) for the presence of the 43 electrocution modelled species with electrocution probability scores of 3 and 4, weighted by their conservation status. The displayed scores are the GiZ values, high values indicating high degree of clustering and low values indicating a low degree of clustering. Original species presence data are from Harrison *et al. (*1997). The Central Incident Register electrocution incidents are overlaid on this map.

## 5. DISCUSSION

*Identification of representative list of species and probability scoring*
The first objective of this study, to identify a representative sample of species for the purpose of developing a collision and an electrocution model, was achieved. The samples of collision and electrocution species used for this study have widened our analysis considerably as compared to the CIR data, an additional eleven collision and one electrocution species being identified as particularly important. Many of the international studies which list relevant families made use of mortality data acquired through incidental detection and not systematic line searching. This challenge is also faced by the South African data (CIR) and knowledge. The wide diversity of reference studies from several continents and varying conditions has at least partially assisted in widening our focus in South Africa. Families identified as important by the model can now be examined more thoroughly. The families with the highest collision probability scores and of greatest conservation concern are the bustards (Otididae), cranes (Gruidae), flamingos (Phoenicopteridae), pelicans (Pelicanidae), and storks (Ciconidae). This corresponds well with our current understanding. In particular Shaw *et al.* (2010a and b) found that Blue Cranes lose approximately 12.5% of their Overberg population to power line collisions annually. Most of the above identified species have high body mass, corresponding with the findings of Janss (2000) and Bevanger (1998). A number of species considered in the model have not previously been recorded as collision or electrocution victims in the CIR. These species modelled probability scores therefore differed significantly from the actual data in the CIR. Of particular concern amongst these are the species that are already Red Listed (Barnes, 2000). In the case of collision, these species include African Pygmy Goose, Southern Ground Hornbill, Black-bellied Bustard, Yellow-throated Sandgrouse, Caspian Tern, Hooded Vulture, Bateleur, African Marsh Harrier, Black Harrier, Pink-backed Pelican and Yellow-billed Stork) The low incidence of collisions for these species in the CIR can be attributed to a combination of factors including, low overall population numbers, distribution confined to protected areas with few power lines, and aquatic habitat eliminating the chance of carcass detection. Efforts are now required to investigate these species further to establish whether they do in fact collide with power lines. In particular, systematic line sampling within key distribution ranges of these families will be important in order to identify species that are falling victim to collision or electrocution. Most importantly this study has questioned the assumption to date that mortalities of these species are not occurring.

The families with the highest electrocution probability scores and of conservation concern are the ground hornbills (Bucorvidae), cranes (Grey-crowned) (Gruidae), raptors (in particular the vultures and eagles), pelicans (Pelicanidae) and storks (Ciconidae). Cape Vulture electrocutions in particular have been well documented in recent work in the Eastern Cape, by Boshoff *et al.* (in prep.). In the case of the raptors and White Stork, this corresponds well with our anecdotal knowledge. However, the Southern Ground Hornbill, Grey Crowned Cranes and pelicans are not species for which we have extensive electrocution experience and further investigation will be required.

Two species stand out as having electrocution probability scores differing significantly from the CIR data. The Barn Owl has significantly more recorded electrocutions than expected by the model. This is perhaps due to its propensity for perching or nesting on electrical transformer boxes, where clearances between live phases are far smaller than on the majority of pole structures, thereby resulting in numerous recorded electrocutions despite its relatively small size. The Southern Bald Ibis has a much higher expected electrocution probability score than the actual data. Southern Bald Ibis have been observed perching and roosting on transmission power lines regularly (although these lines are too large to represent any electrocution risk), and it was thought that this represented a general propensity for perching on poles. However, it is possible that the birds do not readily perch on the smaller distribution lines which pose electrocution risk.

This studies’ approach ignores the presence and characteristics of power line infrastructure with which to interact. Species which occur predominantly in areas with low power line density, or high availability of natural perching substrate, would not have as much opportunity to interact with power lines. However, it must be remembered that this study aims at informing the construction of new infrastructure as much as the management of existing infrastructure.

*Susceptibility – morphological factors*

The morphological data used for both collision and electrocution models were in some cases available for only one sex, or did not distinguish between the sexes. The models therefore did not distinguish between sexes, using mean measurements where data existed for both sexes, and applying data from one sex to the other where missing. However, for some species, relevant differences in behaviour and morphology exist between the sexes, which could result in varying collision or electrocution exposure and susceptibility. These differences are considered important future study topics for priority species which exhibit significant dimorphism and are identified as significant by this study, an example of which is Ludwig’s Bustard.

The index of wing loading used for the collision model is crude for two reasons: the relationship between wing length and wing area is unknown, and is not likely to be consistent across taxa; and wing length is not an adequate surrogate for wing span, wingspan being the distance from tip to tip, thus including the body itself as well as the extent of the wing from the carpal joint to wing’s junction with the body. This is borne out by the poor comparison of my index against real wing loading for the 30 raptor species calculated by Mendelsohn *et al.* (1989). It must be said that the raptors are particularly diverse in size, the difference between smallest and largest species in the family being a factor of 141 times (61g - Pygmy Falcon) and (8600g - Cape Vulture). The next most diverse family used in my analysis is Ardeidae, with a factor of 30 between Goliath Heron

(4 330g) and Dwarf Bittern (142g). Further examination of the relationship between wing area and wing length revealed variation even within the raptors, the lowest value being 1.7 for Pygmy Falcon and the highest 11.9 for Cape Vulture. This ratio increases proportionally to mass. Since there is such large variation within one family, i.e. raptors, one would expect even greater interfamily variation, thus making our crude wing loading index of questionable validity. This study highlights the inadequacy of available surrogate measures for wing area and the data gap facing future attempts to examine wing loading across species. More comprehensive morphological data collection for southern African bird species, in particular for wing area is extremely important in future. This study did not check the availability of such data in the SAFRING data base (South African Bird Ringing Unit) and it is recommended that this be conducted as soon as possible in future. Since understanding and quantifying the behavioural factors relevant to collision (as discussed below) is so difficult, the acquisition of reliable wing loading data is even more important. Species interest groups, captive facilities, and investigators of collision and electrocution mortality incidents (since fresh carcasses can be measured) have an important role to play in this regard. This study has not contributed to our understanding of the relationship between wing loading and collision probability. In particular a better understanding of the allometric relationship between various bird morphometric measurements needs to be achieved. The above data gaps will need to be filled before we can examine this relationship further for South African species.

Electrocution susceptibility scoring is based on a more complete understanding of the relevant factors. Larger birds have higher probability of electrocution, unlike with collision where higher wing loading *may* mean higher collision probability. The analysis for electrocution is therefore believed to be simpler and more robust.

### *Exposure – behavioural factors*

Several studies have agreed on the importance of the behavioural factors that I analysed in determining a species' collision probability (Brown, 1992; APLIC, 1994; Bevanger, 1994; Hunting, 2002; Crowder & Rhodes, 2001; Rubolini, *et al.,* 2005; Drewitt & Langston, 2008). However, it appears that no attempt has been made to acquire data on these factors, perhaps due to the difficulties involved. My scoring of these factors is undeniably subjective, but may represent the first attempt to quantify these factors. One of the experts consulted for this portion of the study (Dr Andre Boshoff, pers. comm.) correctly questioned the validity of subjective scoring of these factors. Each of the factors could be argued to be important in opposing ways. For example a species which seldom flies could be less exposed to collision, but when it does fly it could be far more susceptible to collision since it is a poor flier. This becomes more problematic as factors interact, as clearly these ten behavioral factors are not entirely independent. For example, species which usually fly over open habitat may evolve towards flying lower than those that generally fly over dense habitat. Since this study did not collect data on these factors, its contribution towards understanding them is limited. Due to their complexity, it is not clear to what extent future study can or should attempt to isolate and obtain data on these factors. Perhaps the overall combination of factors is most important in determining a species probability of collision. A priority would seem to be the collection of more representative frequency data on actual collisions (more statistically robust than the current CIR, a full discussion of the CIR is later in this report) in order to allow future testing of factors. Also, for those factors and species for which it is possible, actual data on these ten factors are needed. One such factor is that of flight height. Research into typical height of flight for the priority collision species (such as cranes and bustards) should now be undertaken, and related to typical power line cable height in the relevant areas. Remote sensing techniques may be able to contribute significantly to data collection for such factors. Radar ornithology has evolved considerably in recent years (various authors including Kelly, McLaughlin & Smith, 2007; Walls, Pendlebury, Budgey, Brookes & Thompson, 2009), and could be used to obtain accurate flight speed, height and frequency data for certain situations. This should be investigated further. In addition to the ten factors integral to this study, recent research has illustrated that avian visual acuity differs significantly between species, and is linked to the species evolution and how it uses vision (Martin & Shaw, 2010).

The electrocution model also subjectively scored behavioral factors. However due to fewer and better understood factors (5 for electrocution c.f. 10 for collision), this scoring was significantly simpler. However, assumptions remain, for example it is assumed that Cape Vultures are more vulnerable to electrocution because of their gregarious nature, but apart from one observed incident in which multiple birds were electrocuted, there exists little evidence for this. Further research into perching behaviour should be conducted, perhaps using captive birds in a rehabilitation centre, and video technology.

*Behavioural and morphological factors*

The independence of these two types of factors for any given species is questionable. For example, birds that utilize dense habitat would evolve short and perhaps ultimately lower wing loading. This study did not make use of real data for these factors, and also lacked a reliable mortality data set against which model outputs could be tested. It is recommended that once these two areas have been improved upon, a formal testing of these factors is conducted, perhaps using a technique such as principal components analysis.

*Performance of the model*

The third objective, that of testing the models' performance has been conducted, albeit with an admittedly flawed data set against which to test.

The collision model performed poorly at most levels when tested against the CIR data. Firstly, there is a deliberate mismatch between the number of modelled species (152 species, 34 families), and those in the CIR (73 species, 26 families). Many of the species represented in the model and not the CIR, such as members of the Ardeidae, Anatidae and Phalacrocoracidae are extremely unlikely to be detected as collision victims due to their habitat, and the likelihood of collision victims falling into water. Testing only the matching species again revealed low confidence in the model. The model was not significantly different from the CIR when testing only those species with a collision probability score of 3 and above, indicating that the model performs better for high collision risk species. This may be due to a better baseline understanding of the higher collision risk species, and hence more accurate scoring of the various factors. The model also performed better for physically larger species, again due to any or a combination of the following: the model is more accurate for larger species; the CIR is biased towards detection of larger species.

The electrocution risk model also performed poorly initially when tested against the CIR (or vice versa, as discussed elsewhere in this report). Once again the model deliberately contained more species (94 species, 22 families) than the CIR (58 species, 17 families). However, testing only the matching 38 species resulted in an acceptance of the model. This shows that the ability of the model to predict a species electrocution probability is good. Species accounting for large contributions to the chi statistic include the Barn Owl, Jackal Buzzard both of which exhibit higher observed than expected values, and Tawny Eagle (lower observed that expected). (Table 4) The White-breasted Cormorant, Southern Bald Ibis, and White-necked Raven showed lower observed than expected scores. The model again performed well for the species with electrocution probability scores of 3 and above. Nearly all variation between model and CIR was as a result of the model predicting higher risk.

*Central Incident Register*

The CIR data are the product of incidental detection and reporting of collisions and electrocutions by various sources and not systematic line searching. A number of significant biases therefore exist in this data. This is a worldwide challenge according to Drewitt and Langston (2008) who state that reported bird mortalities through collision with different infrastructure around the world, reflect more closely the distribution of observer effort, than actual collision frequency. Some of these biases include: size of bird – larger carcasses being more easily detected; plumage colour – conspicuous colours being more easily detected; species conservation status – threatened species being more readily reported than common species; habitat type – it being easier to detect carcasses in more open habitat; geographic bias – where full time field staff are present detection and reporting are increased. The poor performance of the model should therefore not be interpreted entirely as a flaw in the model but rather as a function of the flawed CIR data. Effort is now required to gain a better sample of collision and electrocution data, through regular systematic sampling. This is an element that is lacking in the field of bird collision and electrocution internationally and is identified as a future need by one of the most recent reviews of bird collision (Jenkins *et al*., 2010). This presents an opportunity for Eskom-EWT to lead in this respect, if the correct data collection processes can be implemented. The correct process would be to identify sufficient (in terms of statistical power) sample sections of power line across South Africa, representing a range of vegetation types and habitats. These sample lines should then be patrolled at an acceptable frequency to allow the thorough investigation of collision and electrocution on these lines, and make inferences about the broader power line network. Further, all future conservation effort (and testing of this studies' model) should be guided by data arising from these systematic efforts, and not by the CIR. It is recognized that even systematic line sampling suffers from data challenges, such as detection, habitat, and scavenger biases and these should be carefully considered.

*Mapping of probability*

The fourth objective of this study was to develop a map of the probability of collision and electrocution in South Africa. This has been achieved and displayed in several steps. In the case of both collision and distribution, the mapping of only those species with probability scores of 3 and 4, and the weighting for species conservation status has resulted in a consolidation of and fewer priority areas in South Africa. In the case of collision, the emergence of western KwaZulu-Natal as a top priority is not surprising, given the high abundances of threatened species such as the three crane species, Denham's Bustard, Cape Vulture and various others. The other areas of slightly less importance are the Western Cape, parts of Gauteng and Mpumalanga, and parts of the Eastern Cape. This is in line with what we know about collision in South Africa, except that parts of the Karoo and Namaqualand are emerging as significant collision hotspots through the work of Jessica Shaw (pers. comm., 2010). This may perhaps be explained by the fact that these areas are home to relatively few collision prone species, the Ludwig's and Kori Bustard, and Blue Crane, whilst other areas of the country have higher species diversity. On the electrocution map, key areas to emerge after weighting for conservation status are the lowveld (defined as the Kruger National Park and surrounds), and again the western KwaZulu-Natal. The reason for this is the abundance of various large raptors and vultures in the lowveld, and the Cape Vulture (which received the highest possible electrocution probability score) in the western KwaZulu-Natal area. The lowveld may also emerge as important based on the protected status of the Kruger National Park, thereby serving as a refuge for various large threatened bird species. Interesting, the Eastern Cape, the subject of excellent research into Cape Vulture electrocution by Boshoff *et al*. (in prep.) has not emerged as highly important, possibly again due to the absence of significant abundance of any other electrocution prone species. The Kimberley area also shows as secondary importance, probably due to the abundance of African White-backed Vulture, the subject of previous research into electrocution (Van Rooyen *et al*., 2006). Looking at both interactions, the western KwaZulu-Natal and to a lesser extent the lowveld emerge as key areas for future conservation attention.

Given that several areas known to be collision and electrocution hotspots in South Africa have not emerged as topmost priority in the risk maps, it will be important to look further than the highest priority areas and consider the second and third priority levels for future action. Further, it may be argued that the use of presence absence data rather than actual species abundance has masked certain key areas with locally high abundance of key species.

The hot spot analysis first documented by Getis and Ord (1992) has proven an extremely useful tool in highlighting aggregations within the spatial data, so that the description of these hot spots is not simply a subjective visual exercise.

### *Spatial testing of model*

The fifth and final study objective was to test the model spatially. Due to the overall relatively poor performance of the model when tested against the CIR, it was not believed to be beneficial to test the model spatially. Overlaying the collision and electrocution data from the CIR on the maps of collision and electrocution risk did however show a good correlation. Although I considered testing the quarter degree square score for collision and electrocution probability against the plotted CIR data, two problems with this approach emerged: The analysis would include numerous quarter degree squares with zero scores for CIR data, making comparison difficult; and a relatively low proportion of the CIR incidents had associated geographic coordinates (48% for electrocution and 72% for collision). In addition, the purpose of this study is as much to plan future power line network as to work on the current network. Since the Eskom network is set to approximately double in the next few decades, at least half of the value of this study will be for providing input into network not yet built.

### *Single species conservation*

Five families emerge as important for collision due to their high modeled collision probability. For simplicity, indicator species can be selected for each family, based on their ability to represent the family in terms of conservation priority, geographic distribution, and most importantly conservation action. As far as possible, duplication of conservation effort between families should also be avoided. For example, Denham’s Bustard and Blue Crane occur in more or less the same part of the country and the same habitat. The selected collision indicator species for priority attention are therefore be as follows: Blue Crane; Ludwig’s Bustard; Lesser Flamingo; White Stork, and Great White Pelican. The value of these species as indicators can be tested using the IndVal method by Dufrene and Legendre (1997). This method establishes a percentile that gives a measurement of the species as an indicator.

In terms of electrocution, the two most important families that could be used as indicator species appear to be the vultures and eagles, as these families show high electrocution probability and are physically the largest species. The indicator species chosen for electrocution would therefore be the Cape Vulture and Martial Eagle. Geographically, the eagle covers most of the arid western parts, and the vulture the eastern parts of South Africa. These are both species associated with vegetation types dominated by low vegetation (interspersed with trees in the case particularly of the eagle), where natural perch availability is lower and likelihood of these species perching on power lines greater. Both species therefore represent important ‘umbrella’ species (Mace *et al.* 2006), which are used to protect other species with similar habitat requirements. The umbrella concept can be interpreted from a technical perspective in the case of electrocutions. As the most gregarious and largest species, vultures represent the worst case scenario for electrocution. Network made safe for vultures is therefore also safe for most other species. A species action planning approach can now be taken by the Eskom-EWT Strategic Partnership.

### *Use of indices*

The subjectivity of the behavioral factors used in this study has been discussed adequately above. However one advantage of the methodology of this study was that indices were not aggregated through multiplication or addition (described as being problematic as it hides multiplies any problems in the data (Sagar & Najam, 1998). Medians and means were used in order to counter this possible problem.

### *Resource allocation/action thresholds*

Since resources (time, staff capacity, and finances) are limiting factors, the entire power line network in South Africa cannot be systematically and regularly searched for collision victims. Our conservation efforts therefore need to be based on theoretical predictions. This study has provided some basis for these predictions, and the resources of the Eskom-EWT Strategic Partnership can now be allocated towards the highest priority activities in accordance with better governance of available funds (Mace *et al.*, 2006). In addition, this study has provided a defendable rationale for the selection of priority species and actions,.

### *Species conservation status*

The “Red Data book of Birds of South Africa, Lesotho and Swaziland” edited by Barnes in 2000 is the only recognized national classification system currently available. The publication is however quite dated, and will be updated in 2011 according to BirdLife South Africa, who have acquired funding for this purpose (Anderson pers. comm.). This study used conservation status as a measure of severity of the consequence when the probability realises. Severity in this case is understood as a measure of how serious the implications are for the species population, those species with more threatened conservation status being less able to afford to lose individuals. It could be questioned whether all collision and electrocution events are equally severe for the individual bird. Experience in South Africa has shown that the vast majority of electrocution victims are killed at the site, injuries being uncommon. Collision victims are generally also killed at the site, either by the impact with the cable or the impact with the ground when they fall. Those birds which escape with injuries (often to the legs) are believed unlikely to survive very long, as feeding and escaping predators becomes near impossible. These birds are believed less likely to breed successfully and are hence effectively lost to the population.

## 6. CONCLUSION & RECOMMENDATIONS

In response to the findings of this study a number of recommendations have been developed. As is the case with much applied research, this study has raised a number of questions, and identified a number of areas requiring future research. In no particular order, these are as follows:

1. Several key species have been predicted to have a high probability of collision or electrocution by the model that were not previously believed to be highly vulnerable to these interactions. Focused attention must now be given to these species, through systematic line sampling in their core distributions, to establish whether they do in fact interact significantly with power lines.

2. In order to counter the various biases within the data in the Central Incident Register, extensive systematic line sampling should be conducted (bearing in mind the data challenges and biases mentioned elsewhere in this report). Three such projects exist already, in the Karoo, Overberg and high altitude grasslands. Similar projects need to be established in the remaining biomes and in representative areas around the country. Whilst the CIR remains a useful management tool, future conservation planning should rather be based on the results of systematic line sampling. The focal areas for this sampling should be selected on the basis of risk maps such as those contained in this study, preferably after refinement to address shortcomings identified by this study and incorporate more current bird distribution data as they becomes available.

3. It is believed that many species exhibit either behavioral or morphological differences between males and females. These differences may render the sexes more or less at risk of interaction with power lines. It is recommended that for the top priority species, sex specific mortality rates be established as a matter of priority.

4. Many of the behavioral factors considered for the collision model are not well understood and difficult to quantify. However, several are more easily quantified, and this should be done as soon as possible. An example is flight height. Whilst birds obviously by necessity fly at different heights, it may be possible to establish the height at which the priority species spend most of their flying time and relate this to the height at which power lines are built.

5. The difficulties associated with quantifying the behavioral factors in this study in some respects highlight the importance of having good data and understanding of the morphological factors. The most obviously lacking data in this regard appears to be that of wing area, which facilitates the calculation of wing loading.

It is recommended that for the top priority species, relevant conservation groups and individuals be identified and requested to begin the (challenging) collection of data on wing area through suitable dead birds, ringing exercises, and museum collections.

6. Although this study has provided a coarse scale map of where the priority areas are for interaction of birds with power lines, much finer scale mapping is required, making use of different sources of data. For example for many of the Red Listed species such as cranes, reliable data on roost sites, breeding sites and preferred foraging areas for flocks exist. Effort should also be invested in determining just how much power line network exists in these species ranges, and how much future network is likely to be built as this will also determine priority. More formal methods of determining priority areas of the country based on GIS data should also be developed. New data such as the Southern African Bird Atlas Project 2 are becoming available, and is at the pentad level rather than the quarter degree square as was the case with the SABAP 1. In addition, the effects of climate change on species distribution, and hence priority areas of the country need to be investigated.

7. The proportion of incidents in the CIR with geographic coordinates recorded needs to be improved. Although the CIR was started in 1996, when Global Positioning Systems (GPS) were relatively rare, this has changed and increased access to GPS means there is little excuse for not collecting coordinates for point data. Recent changes to the CIR database and means of entering data make it compulsory to enter coordinates.

8. Whilst a good general understanding of the species most at risk of interactions existed prior to this study, modelling the species has provided useful confirmation of what we know. Several families emerge as being top priority. It is recommended that species action plans now be compiled for these species in order to provide guidance to future actions for both Eskom and EWT.

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Appendix 1:  List of species' common and scientific names and Roberts numbers.

| **Roberts #** | **Common Name** | **Scientific Name** |
|---|---|---|
| 6 | Great Crested Grebe | *Podiceps cristatus* |
| 8 | Little Grebe | *Tachybaptus ruficollis* |
| 49 | White Pelican | *Pelecanus onocrotalus* |
| 50 | Pink-backed Pelican | *Pelecanus rufescens* |
| 55 | White-breasted Cormorant | *Phalacrocorax carbo* |
| 58 | Reed Cormorant | *Phalacrocorax africanus* |
| 60 | Darter | *Anhinga melanogaster* |
| 63 | Black-headed Heron | *Ardea melanocephala* |
| 64 | Goliath Heron | *Ardea goliath* |
| 65 | Purple Heron | *Ardea purpurea* |
| 66 | Great White Heron | *Egretta alba* |
| 67 | Little Egret | *Egretta garzetta* |
| 71 | Cattle Egret | *Bubulcus ibis* |
| 74 | Green-backed Heron | *Butorides striatus* |
| 77 | White-backed Night Heron | *Gorsachius leuconotus* |
| 79 | Dwarf Bittern | *Ixobrychus sturmii* |
| 83 | White Stork | *Ciconia ciconia* |
| 85 | Abdim's Stork | *Ciconia abdimii* |
| 87 | African Openbill | *Anastomus lamelligerus* |
| 89 | Marabou Stork | *Leptoptilos crumeniferus* |
| 90 | Yellow-billed Stork | *Mycteria ibis* |
| 91 | African Sacred Ibis | *Threskiornis aethiopicus* |
| 92 | Southern Bald Ibis | *Geronticus calvus* |
| 93 | Glossy Ibis | *Plegadis falcinellus* |
| 94 | Hadeda Ibis | *Bostrychia hagedash* |
| 95 | African Spoonbill | *Platalea alba* |
| 96 | Greater Flamingo | *Phoenicopterus ruber* |
| 97 | Lesser Flamingo | *Phoeniconaias minor* |
| 99 | White-faced Duck | *Dendrocygna viduata* |
| 102 | Egyptian Goose | *Alopochen aegyptiacus* |
| 103 | South African Shelduck | *Tadorna cana* |
| 104 | Yellow-billed Duck | *Anas undulata* |
| 107 | Hottentot Teal | *Anas hottentota* |
| 108 | Red-billed Teal | *Anas erythrorhyncha* |
| 112 | Cape Shoveller | *Anas smithii* |
| 114 | Pygmy Goose | *Nettapus auritus* |
| 116 | Spur-winged Goose | *Plectropterus gambensis* |
| 118 | Secretarybird | *Sagittarius serpentarius* |
| 119 | Bearded Vulture | *Gypaetus barbatus* |
| 121 | Hooded Vulture | *Necrosyrtes monachus* |
| 122 | Cape Vulture | *Gyps coprotheres* |
| 124 | Lappet-faced Vulture | *Torgos tracheliotus* |
| 126 | Yellow-billed/Black Kite | *Milvus migrans* |
| 127 | Black-shouldered Kite | *Elanus caeruleus* |
| 131 | Verreaux's Eagle | *Aquila verreauxii* |
| 132 | Tawny Eagle | *Aquila rapax* |
| 136 | Booted Eagle | *Hieraaetus pennatus* |
| 137 | African Hawk Eagle | *Hieraaetus spilogaster* |

|  |  |  |
|---|---|---|
| 139 | Long-crested Eagle | *Lophaetus occipitalis* |
| 140 | Martial Eagle | *Polemaetus bellicosus* |
| 142 | Brown Snake Eagle | *Circaetus cinereus* |
| 146 | Bateleur | *Terathopius ecaudatus* |
| 148 | African Fish Eagle | *Haliaeetus vocifer* |
| 152 | Jackal Buzzard | *Buteo rufofuscus* |
| 154 | Lizard Buzzard | *Kaupifalco monogrammicus* |
| 157 | Little Sparrowhawk | *Accipiter minullus* |
| 158 | Black Sparrowhawk | *Accipiter melanoleucus* |
| 160 | African Goshawk | *Accipiter tachiro* |
| 162 | Southern Pale Chanting Goshawk | *Melierax canorus* |
| 165 | African Marsh Harrier | *Circus ranivorus* |
| 168 | Black Harrier | *Circus maurus* |
| 170 | Osprey | *Pandion haliaetus* |
| 171 | Peregrine Falcon | *Falco peregrinus* |
| 172 | Lanner Falcon | *Falco biarmicus* |
| 183 | Lesser Kestrel | *Falco naumanni* |
| 186 | Pygmy Falcon | *Polihierax semitorquatus* |
| 188 | Coqui Francolin | *Francolinus coqui* |
| 190 | Greywing Francolin | *Francolinus africanus* |
| 195 | Cape Spurfowl | *Francolinus capensis* |
| 196 | Natal Spurfowl | *Francolinus natalensis* |
| 200 | Common Quail | *Coturnix coturnix* |
| 203 | Helmeted Guineafowl | *Numida meleagris* |
| 204 | Crested Guineafowl | *Guttera pucherani* |
| 207 | Wattled Crane | *Bugeranus carunculatus* |
| 208 | Blue Crane | *Anthropoides paradiseus* |
| 209 | Grey Crowned Crane | *Balearica regulorum* |
| 210 | African Rail | *Rallus caerulescens* |
| 213 | Black Crake | *Amaurornis flavirostris* |
| 215 | Baillon's Crake | *Porzana pusilla* |
| 217 | Red-chested Flufftail | *Sarothrura rufa* |
| 222 | White-winged Flufftail | *Sarothrura ayresi* |
| 223 | African Purple Swamphen | *Porphyrio porphyrio* |
| 226 | Common Moorhen | *Gallinula chloropus* |
| 227 | Lesser Moorhen | *Gallinula angulata* |
| 228 | Red-knobbed Coot | *Fulica cristata* |
| 230 | Kori Bustard | *Ardeotis kori* |
| 231 | Denham's Bustard | *Neotis denhami* |
| 232 | Ludwig's Bustard | *Neotis ludwigii* |
| 234 | Blue Korhaan | *Eupodotis caerulescens* |
| 237 | Red-crested Korhaan | *Eupodotis ruficrista* |
| 238 | Black-bellied Bustard | *Eupodotis melanogaster* |
| 239 | Northern Black Korhaan | *Eupodotis afra* |
| 248 | Kittlitz's Plover | *Charadrius pecuarius* |
| 249 | Three-banded Plover | *Charadrius tricollaris* |
| 255 | Crowned Plover | *Vanellus coronatus* |
| 258 | Blacksmith Plover | *Vanellus armatus* |
| 260 | Wattled Plover | *Vanellus senegallus* |
| 264 | Common Sandpiper | *Actitis hypoleucos* |

| | | |
|---|---|---|
| 266 | Wood Sandpiper | *Tringa glareola* |
| 269 | Marsh Sandpiper | *Tringa stagnatilis* |
| 294 | Pied Avocet | *Recurvirostra avosetta* |
| 295 | Black-winged Stilt | *Himantopus himantopus* |
| 315 | Grey-headed Gull | *Larus cirrocephalus* |
| 322 | Caspian Tern | *Hydroprogne caspia* |
| 338 | Whiskered tern | *Chlidonias hybridus* |
| 339 | White-winged Tern | *Chlidonias leucopterus* |
| 344 | Namaqua Sandgrouse | *Pterocles namaqua* |
| 346 | Yellow-throated Sandgrouse | *Pterocles gutturalis* |
| 349 | Speckled Pigeon | *Columba guinea* |
| 354 | Cape Turtle Dove | *Streptopelia capicola* |
| 355 | Laughing Dove | *Streptopelia senegalensis* |
| 356 | Namaqua Dove | *Oena capensis* |
| 358 | Emerald-spotted Wood Dove | *Turtur chalcospilos* |
| 392 | Barn Owl | *Tyto alba* |
| 395 | Marsh Owl | *Asio capensis* |
| 396 | African Scops Owl | *Otus senegalensis* |
| 398 | Pearl-spotted Owlet | *Glaucidium perlatum* |
| 402 | Verreaux’s Eagle Owl | *Bubo lacteus* |
| 417 | Little Swift | *Apus affinis* |
| 418 | Alpine Swift | *Apus melba* |
| 421 | Palm Swift | *Cypsiurus parvus* |
| 422 | Mottled Spinetail | *Telacanthura ussheri* |
| 423 | B\326Hm's Spinetail | *Neafrapus boehmi* |
| 455 | Trumpeter Hornbill | *Bycanistes bucinator* |
| 458 | Red-billed Hornbill | *Tockus erythrorhynchus* |
| 460 | Crowned Hornbill | *Tockus alboterminatus* |
| 463 | Southern Ground Hornbill | *Bucorvus leadbeateri* |
| 480 | Ground Woodpecker | *Geocolaptes olivaceus* |
| 486 | Cardinal Woodpecker | *Dendropicos fuscescens* |
| 487 | Bearded Woodpecker | *Thripias namaquus* |
| 489 | Red-throated Wryneck | *Jynx ruficollis* |
| 500 | Cape Long-billed Lark | *Mirafra curvirostris* |
| 502 | Karoo Lark | *Mirafra albescens* |
| 504 | Red Lark | *Mirafra burra* |
| 507 | Red-capped Lark | *Calandrella cinerea* |
| 508 | Pink-billed Lark | *Spizocorys conirostris* |
| 518 | Barn Swallow | *Hirundo rustica* |
| 521 | Blue Swallow | *Hirundo atrocaerulea* |
| 523 | Pearl-breasted Swallow | *Hirundo dimidiata* |
| 524 | Red-breasted Swallow | *Hirundo semirufa* |
| 533 | Brown-throated Martin | *Riparia paludicola* |
| 534 | Banded Martin | *Riparia cincta* |
| 547 | Cape Crow | *Corvus capensis* |
| 548 | Pied Crow | *Corvus albus* |
| 550 | White-necked Raven | *Corvus albicollis* |
| 577 | Olive Thrush | *Turdus olivaceus* |
| 581 | Cape Rock Thrush | *Monticola rupestris* |

|  |  |  |
|---|---|---|
| 731 | Lesser Grey Shrike | *Lanius minor* |
| 732 | Common Fiscal | *Lanius collaris* |
| 759 | Pied Starling | *Spreo bicolor* |
| 761 | Violet-backed Starling | *Cinnyricinclus leucogaster* |
| 762 | Burchell's Starling | *Lamprotornis australis* |
| 764 | Glossy Starling | *Lamprotornis nitens* |
| 801 | House Sparrow | *Passer domesticus* |
| 802 | Great Sparrow | *Passer motitensis* |
| 803 | Cape Sparrow | *Passer melanurus* |

**Appendix 2.** All morphological data and behavioral scores for the 152 modeled collision species.

| Family | Common name | Male Wing (cm) | Female Wing (cm) | Male Mass (g) | Female Mass (g) | Morphological score | Migration | Movement | Flight frequency | Flight length | Flight height | Flight speed | Distraction during flight | Visibility during Flight | Flocking | Openness of habitat | Behavioral score | Final collision probability score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Phasianidae | Coqui Francolin | 134.2 | 134.2 | 254.7 | 231.6 | 3 | 4 | 1 | 1 | 1 | 1 | 3 | 1 | 2 | 2 | 2 | 1.5 | 2 |
| | Grey-winged Francolin | 159 | 156 | 424.3 | 359 | 3 | 4 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 2 | 4 | 1.0 | 2 |
| | Cape Spurfowl | 220.4 | 202.1 | 977 | 767 | 4 | 4 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 2 | 3 | 1.0 | 3 |
| | Natal Spurfowl | 173.4 | 158.4 | 501 | 390 | 3 | 4 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 2 | 2 | 1.0 | 2 |
| | Common Quail | 104 | 105 | 90 | 103 | 2 | 1 | 1 | 2 | 1 | 1 | 4 | 1 | 2 | 1 | 4 | 1.0 | 2 |
| Numididae | Crested Guineafowl | 268 | 261 | 1149 | 1149 | 4 | 4 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 2 | 1 | 1.0 | 3 |
| | Helmeted Guineafowl | 270 | 260 | 1380 | 1500 | 4 | 4 | 1 | 2 | 1 | 1 | 3 | 1 | 1 | 3 | 3 | 1.5 | 3 |
| Dendrocygnidae | White-faced Duck | 232.9 | 230.1 | 699 | 704 | 3 | 4 | 1 | 3 | 3 | 3 | 3 | 1 | 2 | 2 | 3 | 3.0 | 3 |
| Anatidae | SA Shelduck | 355.8 | 362.2 | 1360 | 1120 | 3 | 4 | 4 | 3 | 3 | 3 | 3 | 1 | 3 | 2 | 3 | 3.0 | 3 |
| | Egyptian Goose | 405.4 | 369.3 | 2350 | 1870 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 1 | 2 | 3 | 3 | 3.0 | 4 |
| | Spur-winged Goose | 518 | 448 | 5090 | 3550 | 4 | 4 | 1 | 3 | 3 | 3 | 3 | 1 | 2 | 3 | 3 | 3.0 | 4 |
| | African Pygmy Goose | 157.4 | 157.4 | 262 | 262 | 3 | 4 | 1 | 2 | 2 | 2 | 3 | 1 | 2 | 1 | 3 | 2.0 | 3 |
| | Red-billed Teal | 226 | 218 | 593 | 544 | 3 | 4 | 1 | 2 | 2 | 3 | 3 | 1 | 2 | 2 | 3 | 2.0 | 3 |
| | Hottentot Teal | 149 | 142 | 228 | 255.5 | 3 | 4 | 1 | 2 | 2 | 3 | 3 | 1 | 2 | 2 | 3 | 2.0 | 3 |
| | Cape Shoveler | 238.1 | 226.4 | 688.3 | 597.8 | 3 | 4 | 1 | 3 | 3 | 3 | 3 | 1 | 2 | 2 | 3 | 3.0 | 3 |
| | Yellow-billed Duck | 583 | 535 | 965 | 823 | 2 | 4 | 1 | 3 | 3 | 3 | 3 | 1 | 2 | 2 | 3 | 3.0 | 3 |
| Picidae | Cardinal Woodpecker | 93 | 92 | 33 | 29 | 1 | 4 | 1 | 2 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1.0 | 1 |
| | Ground Woodpecker | 129 | 129 | 119 | 115 | 2 | 4 | 1 | 2 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1.0 | 2 |
| | Bearded Woodpecker | 130 | 129 | 87 | 78 | 2 | 4 | 1 | 2 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1.0 | 2 |
| | Red-throated Wryneck | 94 | 91 | 54 | 50 | 1 | 4 | 1 | 2 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1.0 | 1 |
| Bucerotidae | Red-billed Hornbill | 188 | 177 | 150 | 128 | 2 | 4 | 1 | 3 | 2 | 3 | 1 | 1 | 1 | 1 | 2 | 1.5 | 2 |
| | Crowned Hornbill | 255 | 234 | 244 | 205 | 2 | 4 | 1 | 3 | 2 | 3 | 1 | 1 | 1 | 1 | 2 | 1.5 | 2 |
| | Trumpeter Hornbill | 288 | 263 | 721 | 567 | 3 | 4 | 1 | 3 | 2 | 3 | 1 | 1 | 1 | 1 | 2 | 1.5 | 2 |
| Bucorvidae | Southern Ground Hornbill | 560 | 528 | 4190 | 3340 | 4 | 4 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 3 | 1.5 | 3 |
| Apodidae | Mottled Spinetail | 146 | 147 | 32.9 | 34.5 | 1 | 4 | 1 | 4 | 2 | 2 | 3 | 3 | 2 | 1 | 3 | 2.5 | 2 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bohm's Spinetail | 117 | 117 | 13.5 | 13.6 | 1 | 4 | 1 | 4 | 2 | 2 | 3 | 3 | 2 | 1 | 3 | 2.5 | 2 |
| | Little Swift | 133 | 135 | 24.5 | 25 | 1 | 4 | 1 | 4 | 2 | 2 | 3 | 3 | 2 | 1 | 3 | 2.5 | 2 |
| | Alpine Swift | 210.8 | 209 | 77 | 77 | 1 | 4 | 1 | 4 | 2 | 2 | 3 | 3 | 2 | 1 | 3 | 2.5 | 2 |
| | African Palm Swift | 135.4 | 132.3 | 15 | 14.2 | 1 | 4 | 1 | 4 | 2 | 2 | 3 | 3 | 2 | 1 | 3 | 2.5 | 2 |
| Tytonidae | Barn Owl | 293 | 294 | 410 | 366 | 2 | 4 | 1 | 3 | 2 | 3 | 1 | 3 | 4 | 1 | 2 | 2.5 | 2 |
| Strigidae | African Scops Owl | 127 | 130 | 65 | 65 | 1 | 4 | 1 | 3 | 1 | 2 | 1 | 2 | 4 | 1 | 2 | 2.0 | 2 |
| | Verreaux's Eagle Owl | 448 | 465 | 1720 | 2370 | 4 | 4 | 1 | 3 | 2 | 3 | 1 | 3 | 4 | 1 | 2 | 2.5 | 3 |
| | Pearl-spotted Owlet | 105 | 107 | 67 | 98 | 2 | 4 | 1 | 3 | 1 | 2 | 1 | 2 | 4 | 1 | 2 | 2.0 | 2 |
| | Marsh Owl | 296 | 288 | 313 | 313 | 2 | 4 | 3 | 3 | 2 | 2 | 1 | 3 | 4 | 1 | 4 | 3.0 | 3 |
| Columbidae | Speckled Pigeon | 232 | 227 | 348 | 358 | 2 | 4 | 1 | 3 | 2 | 3 | 3 | 1 | 1 | 3 | 3 | 3.0 | 3 |
| | Laughing Dove | 138.7 | 134.2 | 100.5 | 97 | 2 | 4 | 1 | 2 | 2 | 3 | 3 | 1 | 1 | 1 | 2 | 2.0 | 2 |
| | Cape Turtle Dove | 160.5 | 163 | 135.8 | 124.8 | 2 | 4 | 1 | 2 | 2 | 3 | 3 | 1 | 1 | 2 | 2 | 2.0 | 2 |
| | Emerald-spotted Wood Dove | 112.9 | 109.9 | 65 | 61 | 1 | 4 | 1 | 2 | 1 | 2 | 3 | 1 | 1 | 1 | 2 | 1.5 | 1 |
| | Namaqua Dove | 107.5 | 104.6 | 40.4 | 39.3 | 1 | 4 | 4 | 2 | 3 | 2 | 3 | 1 | 1 | 2 | 3 | 2.5 | 2 |
| Otididae | Denham's Bustard | 558 | 459 | 8640 | 4100 | 4 | 4 | 1 | 3 | 2 | 3 | 2 | 1 | 2 | 2 | 4 | 2.0 | 3 |
| | Ludwig's Bustard | 551 | 465 | 4360 | 2470 | 4 | 4 | 4 | 4 | 3 | 3 | 2 | 1 | 2 | 3 | 4 | 3.0 | 4 |
| | Kori Bustard | 758 | 616 | 12400 | 5700 | 4 | 4 | 1 | 1 | 2 | 3 | 1 | 1 | 2 | 1 | 3 | 1.5 | 3 |
| | Red-crested Korhaan | 267 | 255 | 682 | 667 | 3 | 4 | 1 | 2 | 1 | 3 | 3 | 2 | 2 | 1 | 2 | 2.0 | 3 |
| | Northern Black Korhaan | 281 | 272 | 768 | 710 | 3 | 4 | 1 | 2 | 1 | 3 | 3 | 2 | 2 | 1 | 3 | 2.0 | 3 |
| | Blue Korhaan | 336 | 331 | 1420 | 1200 | 4 | 4 | 1 | 2 | 1 | 3 | 3 | 1 | 2 | 2 | 4 | 2.0 | 3 |
| | Black-bellied Bustard | 365 | 340 | 2350 | 1200 | 4 | 4 | 1 | 2 | 1 | 3 | 3 | 2 | 2 | 1 | 3 | 2.0 | 3 |
| Gruidae | Grey Crowned Crane | 560.7 | 523 | 3775 | 3775 | 4 | 4 | 1 | 4 | 3 | 3 | 2 | 1 | 3 | 4 | 4 | 3.0 | 4 |
| | Blue Crane | 572.1 | 550.3 | 5090 | 4650 | 4 | 4 | 1 | 4 | 3 | 3 | 2 | 1 | 3 | 4 | 4 | 3.0 | 4 |
| | Wattled Crane | 669.7 | 634.1 | 8970 | 8290 | 4 | 4 | 1 | 3 | 3 | 3 | 2 | 1 | 3 | 2 | 4 | 3.0 | 4 |
| Rallidae | Red-chested Flufftail | 76.5 | 76.6 | 38.8 | 35.9 | 1 | 4 | 4 | 1 | 1 | 2 | 2 | 1 | 3 | 1 | 2 | 2.0 | 2 |
| | White-winged Flufftail | 76.3 | 76.9 | 31.8 | 31.8 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 3 | 1 | 2 | 2.0 | 2 |
| | African Rail | 122 | 115 | 179.6 | 145.6 | 2 | 4 | 4 | 1 | 1 | 2 | 2 | 1 | 3 | 1 | 2 | 2.0 | 2 |
| | Black Crake | 106.4 | 101.6 | 98 | 90 | 2 | 4 | 4 | 1 | 1 | 2 | 2 | 1 | 3 | 1 | 2 | 2.0 | 2 |
| | Baillon's Crake | 84.9 | 83.7 | 29.1 | 44.5 | 1 | 4 | 4 | 1 | 1 | 2 | 2 | 1 | 3 | 1 | 2 | 2.0 | 2 |
| | African Purple Swamphen | 251 | 243 | 636 | 556 | 3 | 4 | 1 | 1 | 1 | 2 | 1 | 1 | 3 | 1 | 2 | 1.0 | 2 |
| | Common Moorhen | 163 | 161 | 247 | 247 | 2 | 4 | 1 | 1 | 1 | 2 | 1 | 1 | 3 | 1 | 3 | 1.0 | 2 |
| | Lesser Moorhen | 137 | 132 | 153 | 109.5 | 2 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 3 | 1 | 2 | 1.5 | 2 |
| | Red-knobbed Coot | 227 | 217 | 737 | 737 | 3 | 4 | 1 | 1 | 1 | 1 | 2 | 1 | 3 | 2 | 3 | 1.5 | 2 |
| Pteroclidae | Namaqua Sandgrouse | 170 | 165 | 185 | 176 | 2 | 4 | 4 | 3 | 3 | 2 | 3 | 2 | 2 | 4 | 4 | 3.0 | 3 |
| | Yellow-throated Sandgrouse | 215 | 210 | 353 | 347 | 3 | 4 | 4 | 3 | 3 | 2 | 3 | 2 | 2 | 3 | 4 | 3.0 | 3 |
| Scolopacidae | Common Sandpiper | 112.5 | 112.5 | 46.5 | 46.5 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 3 | 2.0 | 2 |
| | Wood Sandpiper | 125.5 | 125.5 | 60.4 | 60.4 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 3 | 2.0 | 2 |
| | Marsh Sandpiper | 138.8 | 138.8 | 66.7 | 66.7 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 3 | 2.0 | 2 |
| Recurvirostridae | Black-winged Stilt | 232 | 170.9 | 167.4 | 162.5 | 2 | 4 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 4 | 2.0 | 2 |
| | Pied Avocet | 218.7 | 216.2 | 322.5 | 322.5 | 2 | 4 | 4 | 3 | 2 | 2 | 2 | 2 | 1 | 3 | 3 | 2.5 | 2 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Charadriidae | Kittlitz's Plover | 104.6 | 104.6 | 35.7 | 35.7 | 1 | 4 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 4 | 1.0 | 1 |
| | Three-banded Plover | 111.4 | 111.4 | 33.1 | 33.1 | 1 | 4 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 4 | 1.0 | 1 |
| | Blacksmith Lapwing | 214 | 208 | 169 | 162 | 2 | 4 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 4 | 1.0 | 2 |
| | African Wattled Lapwing | 236 | 237 | 258 | 250 | 2 | 4 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 3 | 1.0 | 2 |
| | Crowned Lapwing | 202 | 194 | 203 | 187 | 2 | 4 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 4 | 1.0 | 2 |
| Laridae | Caspian Tern | 411 | 411 | 690 | 690 | 3 | 4 | 1 | 3 | 2 | 3 | 1 | 2 | 2 | 2 | 4 | 2.0 | 3 |
| | Whiskered Tern | 235 | 232 | 92.5 | 107 | 1 | 4 | 1 | 3 | 2 | 2 | 1 | 2 | 2 | 2 | 4 | 2.0 | 2 |
| | White-winged Tern | 208.8 | 208.8 | 54.1 | 54.1 | 1 | 1 | 1 | 3 | 3 | 2 | 1 | 2 | 2 | 2 | 4 | 2.0 | 2 |
| | Grey-headed Gull | 318 | 309 | 280 | 280 | 2 | 4 | 1 | 3 | 2 | 2 | 1 | 2 | 1 | 3 | 4 | 2.0 | 2 |
| Accipitridae | Osprey | 469 | 495 | 1400 | 1570 | 3 | 1 | 1 | 3 | 3 | 3 | 1 | 3 | 2 | 1 | 4 | 2.5 | 3 |
| | Black-shouldered Kite | 268.7 | 267.9 | 237 | 258.5 | 2 | 4 | 1 | 3 | 2 | 3 | 1 | 3 | 2 | 1 | 3 | 2.5 | 2 |
| | Black Kite | 442 | 464 | 807 | 850 | 3 | 1 | 1 | 4 | 3 | 3 | 1 | 3 | 2 | 2 | 3 | 2.5 | 3 |
| | African Fish Eagle | 539 | 570 | 2250 | 3400 | 4 | 4 | 1 | 3 | 3 | 3 | 1 | 3 | 2 | 1 | 3 | 3.0 | 4 |
| | Bearded Vulture | 752.5 | 766.8 | 5760 | 5760 | 4 | 4 | 1 | 4 | 4 | 3 | 3 | 3 | 2 | 1 | 4 | 3.0 | 4 |
| | Hooded Vulture | 523 | 523 | 2120 | 2120 | 4 | 4 | 1 | 4 | 4 | 3 | 1 | 3 | 2 | 2 | 2 | 2.5 | 3 |
| | Cape Vulture | 713 | 713 | 8600 | 8600 | 4 | 4 | 1 | 4 | 4 | 3 | 1 | 3 | 2 | 3 | 4 | 3.0 | 4 |
| | Lappet-faced Vulture | 763 | 763 | 6700 | 6700 | 4 | 4 | 1 | 4 | 4 | 3 | 1 | 3 | 2 | 2 | 2 | 2.5 | 3 |
| | Bateleur | 531 | 538 | 2240 | 2240 | 4 | 4 | 1 | 4 | 4 | 3 | 2 | 2 | 2 | 1 | 2 | 2.0 | 3 |
| | Brown Snake Eagle | 528 | 529 | 2050 | 2050 | 4 | 4 | 1 | 3 | 3 | 3 | 2 | 2 | 2 | 1 | 2 | 2.0 | 3 |
| | African Marsh Harrier | 366.5 | 377.6 | 431 | 570 | 2 | 4 | 1 | 4 | 2 | 2 | 1 | 4 | 2 | 1 | 4 | 2.0 | 2 |
| | Black Harrier | 357 | 371.8 | 375 | 555 | 2 | 4 | 3 | 4 | 3 | 2 | 1 | 4 | 2 | 1 | 4 | 3.0 | 3 |
| | Lizzard Buzzard | 218 | 233 | 242.8 | 303.6 | 2 | 4 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 2.0 | 2 |
| | Southern Pale-chanting Goshawk | 354 | 380 | 741 | 903 | 3 | 4 | 1 | 2 | 2 | 3 | 2 | 1 | 1 | 1 | 4 | 2.0 | 3 |
| | African Goshawk | 204 | 248 | 221 | 358 | 2 | 4 | 1 | 2 | 2 | 3 | 2 | 4 | 1 | 1 | 1 | 2.0 | 2 |
| | Little Sparrowhawk | 141 | 160 | 74 | 106 | 1 | 4 | 1 | 2 | 1 | 2 | 2 | 4 | 1 | 1 | 1 | 1.5 | 1 |
| | Black Sparrowhawk | 287 | 340 | 543 | 908 | 3 | 4 | 1 | 2 | 2 | 2 | 2 | 4 | 1 | 1 | 1 | 2.0 | 3 |
| | Jackal Buzzard | 419 | 444 | 970 | 1360 | 3 | 4 | 1 | 3 | 3 | 3 | 1 | 3 | 1 | 1 | 3 | 3.0 | 3 |
| | Tawny Eagle | 521 | 543 | 1910 | 1970 | 3 | 4 | 1 | 3 | 3 | 3 | 1 | 3 | 1 | 1 | 3 | 3.0 | 3 |
| | Verreaux's Eagle | 604 | 631 | 3700 | 4500 | 4 | 4 | 1 | 3 | 3 | 3 | 3 | 3 | 2 | 1 | 3 | 3.0 | 4 |
| | African Hawk Eagle | 422 | 435 | 1250 | 1580 | 3 | 4 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 2 | 2.0 | 3 |
| | Booted Eagle | 381 | 381 | 709 | 975 | 3 | 2 | 1 | 2 | 3 | 3 | 2 | 2 | 1 | 1 | 3 | 2.0 | 3 |
| | Martial Eagle | 607 | 647 | 3310 | 4700 | 4 | 4 | 1 | 3 | 3 | 3 | 1 | 3 | 1 | 1 | 3 | 3.0 | 4 |
| | Long-crested Eagle | 385 | 394 | 1065 | 1065 | 3 | 4 | 1 | 3 | 3 | 3 | 1 | 3 | 1 | 1 | 2 | 2.5 | 3 |
| Sagittariidae | Secretarybird | 650 | 635 | 3810 | 3410 | 4 | 4 | 1 | 2 | 3 | 3 | 1 | 1 | 1 | 1 | 4 | 1.5 | 3 |
| Falconidae | Pygmy Falcon | 119 | 115 | 61 | 60 | 1 | 4 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 1.5 | 1 |
| | Lesser Kestrel | 237 | 237 | 140 | 153 | 2 | 1 | 1 | 3 | 3 | 3 | 2 | 3 | 2 | 3 | 4 | 3.0 | 3 |
| | Lanner Falcon | 315 | 314 | 506 | 726 | 3 | 4 | 1 | 3 | 3 | 3 | 3 | 3 | 2 | 1 | 4 | 3.0 | 3 |
| | Peregrine Falcon | 284 | 277 | 528 | 771 | 3 | 2 | 1 | 3 | 3 | 3 | 3 | 3 | 2 | 1 | 4 | 3.0 | 3 |
| Podicipedidae | Little Grebe | 98 | 98 | 146 | 146 | 2 | 4 | 4 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 4 | 2.0 | 2 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Great-crested Grebe | 176.3 | 176.3 | 61 | 61 | 1 | 4 | 4 | 1 | 1 | 1 | 3 | 1 | 2 | 1 | 4 | 1.5 | 1 |
| Phalacrocoracidae | White-breasted Cormorant | 337 | 317 | 3120 | 2950 | 4 | 4 | 1 | 3 | 2 | 3 | 2 | 1 | 2 | 2 | 3 | 2.0 | 3 |
| | Reed Cormorant | 212 | 207 | 585 | 525 | 3 | 4 | 1 | 3 | 2 | 3 | 2 | 1 | 2 | 2 | 3 | 2.0 | 3 |
| | African Darter | 349 | 344 | 1485 | 1530 | 4 | 4 | 1 | 3 | 2 | 2 | 2 | 1 | 2 | 1 | 3 | 2.0 | 3 |
| Ardeidae | Little Egret | 280 | 272 | 532 | 510 | 3 | 4 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 4 | 1.5 | 2 |
| | Great Egret | 383 | 383 | 1110 | 1110 | 3 | 4 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 4 | 1.5 | 2 |
| | Black-headed Heron | 401 | 401 | 1480 | 1400 | 3 | 4 | 1 | 3 | 2 | 3 | 1 | 1 | 1 | 1 | 3 | 1.5 | 2 |
| | Goliath Heron | 591 | 575 | 4330 | 4330 | 4 | 4 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 3 | 1.5 | 3 |
| | Purple Heron | 371 | 355 | 917.5 | 830 | 3 | 4 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 1.5 | 2 |
| | Cattle Egret | 253 | 248 | 379 | 368 | 2 | 4 | 1 | 3 | 2 | 3 | 1 | 1 | 1 | 3 | 4 | 2.5 | 2 |
| | Green-backed Heron | 178.4 | 178.4 | 214 | 214 | 2 | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 1.0 | 2 |
| | White-backed Night Heron | 267 | 267 | 440 | 440 | 3 | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 2 | 1.0 | 2 |
| | Dwarf Bittern | 162 | 162 | 142 | 142 | 2 | 1 | 1 | 3 | 3 | 1 | 1 | 1 | 1 | 1 | 2 | 1.0 | 2 |
| Phoenicopteridae | Greater Flamingo | 419.8 | 395 | 2860 | 2570 | 4 | 4 | 4 | 3 | 4 | 3 | 2 | 1 | 3 | 4 | 4 | 3.5 | 4 |
| | Lesser Flamingo | 358.6 | 329.3 | 1830 | 1260 | 4 | 4 | 4 | 3 | 4 | 3 | 2 | 1 | 3 | 4 | 4 | 3.5 | 4 |
| Threskiornithidae | Hadeda Ibis | 353 | 353 | 1420 | 1270 | 4 | 4 | 1 | 4 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 2.0 | 3 |
| | African Sacred Ibis | 378 | 363 | 1620 | 1380 | 4 | 4 | 1 | 3 | 2 | 3 | 1 | 1 | 1 | 3 | 4 | 2.5 | 3 |
| | Glossy Ibis | 297 | 273 | 660 | 605 | 3 | 4 | 1 | 3 | 2 | 2 | 1 | 1 | 1 | 2 | 4 | 2.0 | 3 |
| | Southern Bald Ibis | 386 | 386 | 800 | 800 | 3 | 4 | 1 | 3 | 3 | 2 | 1 | 1 | 1 | 4 | 4 | 2.5 | 3 |
| | African Spoonbill | 384 | 384 | 1450 | 1660 | 4 | 4 | 4 | 2 | 3 | 3 | 2 | 1 | 1 | 2 | 4 | 2.5 | 3 |
| Pelecanidae | Pink-backed Pelican | 605 | 560 | 5970 | 4920 | 4 | 4 | 1 | 2 | 4 | 3 | 1 | 1 | 1 | 2 | 4 | 2.0 | 3 |
| | Great White Pelican | 702 | 620 | 11450 | 7590 | 4 | 4 | 1 | 2 | 4 | 3 | 1 | 1 | 1 | 3 | 4 | 2.5 | 3 |
| Ciconidae | Marabou Stork | 745 | 678 | 7100 | 5700 | 4 | 4 | 1 | 3 | 3 | 3 | 2 | 1 | 1 | 2 | 3 | 2.5 | 3 |
| | African Openbill | 400 | 400 | 1240 | 970 | 3 | 4 | 1 | 2 | 3 | 3 | 2 | 1 | 1 | 3 | 3 | 2.5 | 3 |
| | Yellow-billed Stork | 482 | 482 | 2000 | 2000 | 4 | 4 | 1 | 3 | 3 | 3 | 2 | 1 | 1 | 2 | 3 | 2.5 | 3 |
| | Abdim's Stork | 438 | 435 | 1300 | 1300 | 3 | 1 | 1 | 4 | 3 | 3 | 2 | 1 | 1 | 4 | 4 | 2.5 | 3 |
| | White Stork | 577 | 558 | 3570 | 3330 | 4 | 1 | 1 | 4 | 3 | 3 | 2 | 1 | 1 | 4 | 4 | 2.5 | 3 |
| Corvidae | Cape Crow | 330 | 321 | 537 | 537 | 3 | 4 | 1 | 3 | 2 | 2 | 1 | 1 | 2 | 2 | 3 | 2.0 | 3 |
| | Pied Crow | 356 | 356 | 550 | 519 | 2 | 4 | 1 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 3 | 2.0 | 2 |
| | White-necked Raven | 403 | 403 | 762 | 762 | 3 | 4 | 1 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 3 | 2.0 | 3 |
| Hirundinidae | Brown-throated Martin | 102.8 | 102.8 | 11.5 | 11.5 | 1 | 4 | 1 | 4 | 2 | 3 | 3 | 3 | 2 | 1 | 3 | 3.0 | 2 |
| | Banded Martin | 129 | 127.5 | 28.1 | 28.1 | 1 | 1 | 1 | 4 | 3 | 3 | 3 | 3 | 2 | 1 | 3 | 3.0 | 2 |
| | Barn Swallow | 123.5 | 121.3 | 20.4 | 20.1 | 1 | 1 | 1 | 4 | 3 | 3 | 3 | 3 | 2 | 1 | 3 | 3.0 | 2 |
| | Blue Swallow | 113.4 | 107.4 | 13.1 | 13 | 1 | 1 | 1 | 4 | 3 | 2 | 3 | 3 | 2 | 1 | 4 | 2.5 | 2 |
| | Pearl-breasted Swallow | 100.7 | 100.7 | 11.8 | 11.8 | 1 | 1 | 1 | 4 | 3 | 2 | 3 | 3 | 2 | 1 | 3 | 2.5 | 2 |
| | Red-breasted Swallow | 133.2 | 129.8 | 31.5 | 30.3 | 1 | 1 | 1 | 4 | 3 | 3 | 3 | 3 | 2 | 1 | 3 | 3.0 | 2 |
| Alaudidae | Cape Long-billed Lark | 112 | 98 | 61 | 61 | 1 | 4 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 4 | 1.0 | 1 |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pink-billed Lark | 76.1 | 72.5 | 14 | 14.6 | 1 | 4 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 4 | 1.0 | 1 |
| | Red Lark | 106 | 98 | 40.3 | 33.7 | 1 | 4 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 4 | 1.0 | 1 |
| | Karoo Lark | 93 | 88 | 30.4 | 27.2 | 1 | 4 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 3 | 1.0 | 1 |
| | Red-capped Lark | 95 | 89.5 | 24.1 | 23.1 | 1 | 4 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 4 | 1.5 | 1 |
| Sturnidae | Burchell's Starling | 182 | 167 | 127 | 117 | 2 | 4 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2.0 | 2 |
| | Violet-backed Starling | 108 | 100 | 44.4 | 44.7 | 1 | 1 | 1 | 3 | 2 | 2 | 3 | 1 | 1 | 3 | 2 | 2.0 | 2 |
| | Pied Starling | 154 | 150 | 105 | 102 | 2 | 4 | 1 | 3 | 2 | 3 | 2 | 1 | 1 | 3 | 2 | 2.0 | 2 |
| | Cape Glossy Starling | 134 | 128 | 85 | 80 | 2 | 4 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2.0 | 2 |
| Passeridae | Cape Sparrow | 78.8 | 75.1 | 29.6 | 29.4 | 1 | 4 | 1 | 3 | 2 | 2 | 2 | 1 | 1 | 3 | 2 | 2.0 | 2 |
| | House Sparrow | 76.2 | 73.8 | 25.4 | 26.2 | 1 | 4 | 1 | 3 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2.0 | 2 |
| | Great Sparrow | 84 | 81 | 32.1 | 31.6 | 1 | 4 | 1 | 3 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2.0 | 2 |

**Appendix 3.** All morphological data and behavioral scores for the 94 modeled electrocution species.

| Family | Common name | Mean height (cm) | Height score | Male Wing (cm) | Female Wing (cm) | Wing score | Morphological score | Migration | Movement | Perch likelihood | Gregarious nature | Roost likelihood | Behavioral score | Final elect probability score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Numididae | Crested Guineafowl | 50 | 2 | 268 | 261 | 2 | 2 | 4 | 1 | 1 | 2 | 2 | 2 | 2 |
| | Helmeted Guineafowl | 55.5 | 3 | 270 | 260 | 2 | 2.5 | 4 | 1 | 3 | 4 | 4 | 4 | 3 |
| Dendrocygnidae | White-faced Duck | 47 | 2 | 233 | 230.1 | 2 | 2 | 4 | 1 | 2 | 3 | 1 | 2 | 2 |
| Anatidae | SA Shelduck | 62.5 | 3 | 356 | 362.2 | 3 | 3 | 4 | 4 | 1 | 2 | 1 | 2 | 3 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Egyptian Goose | 67.5 | 3 | 405 | 369.3 | 3 | 3 | 4 | 4 | 3 | 2 | 3 | 3 | 3 |
| | Spurwinged Goose | 98 | 4 | 518 | 448 | 4 | 4 | 4 | 1 | 2 | 2 | 2 | 2 | 3 |
| | African Pygmy Goose | 33 | 1 | 157 | 157.4 | 1 | 1 | 4 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Red-billed Teal | 45.5 | 2 | 226 | 218 | 1 | 1.5 | 4 | 1 | 1 | 2 | 1 | 1 | 1 |
| | Hottentot Teal | 34.5 | 2 | 149 | 142 | 1 | 1.5 | 4 | 1 | 1 | 2 | 1 | 1 | 1 |
| | Cape Shoveller | 53 | 3 | 238 | 226.4 | 2 | 2.5 | 4 | 1 | 1 | 2 | 1 | 1 | 2 |
| | Yellow-billed Duck | 57 | 3 | 583 | 535 | 4 | 3.5 | 4 | 1 | 1 | 2 | 1 | 1 | 2 |
| Bucerotidae | Red-billed Hornbill | 40 | 2 | 188 | 177 | 1 | 1.5 | 4 | 1 | 3 | 2 | 2 | 2 | 2 |
| | Crowned Hornbill | 52 | 2 | 255 | 234 | 2 | 2 | 4 | 1 | 2 | 3 | 2 | 2 | 2 |
| | Trumpeter Hornbill | 57.5 | 3 | 288 | 263 | 2 | 2.5 | 4 | 1 | 2 | 3 | 2 | 2 | 2 |
| Bucorvidae | Southern Ground Hornbill | 110 | 4 | 560 | 528 | 4 | 4 | 4 | 1 | 1 | 3 | 2 | 2 | 3 |
| Tytonidae | Barn Owl | 31.5 | 1 | 293 | 294 | 2 | 1.5 | 4 | 1 | 2 | 1 | 2 | 2 | 2 |
| Strigidae | African Scops Owl | 16 | 1 | 127 | 130 | 1 | 1 | 4 | 1 | 1 | 1 | 2 | 1 | 1 |
| | Verreaux's Eagle Owl | 59.5 | 3 | 448 | 465 | 4 | 3.5 | 4 | 1 | 2 | 1 | 2 | 2 | 3 |
| | Pearl-spotted Owlet | 19 | 1 | 105 | 107 | 1 | 1 | 4 | 1 | 2 | 1 | 2 | 2 | 2 |
| | Marsh Owl | 36.5 | 2 | 296 | 288 | 2 | 2 | 4 | 3 | 1 | 2 | 1 | 2 | 2 |
| Columbidae | Speckled Pigeon | 33 | 1 | 232 | 227 | 2 | 1.5 | 4 | 1 | 2 | 3 | 3 | 3 | 2 |
| | Laughing Dove | 25 | 1 | 139 | 134.2 | 1 | 1 | 4 | 1 | 2 | 2 | 2 | 2 | 2 |
| | Cape Turtle Dove | 27 | 1 | 161 | 163 | 1 | 1 | 4 | 1 | 2 | 2 | 2 | 2 | 2 |
| | Emerald-spotted Wood Dove | 19.5 | 1 | 113 | 109.9 | 1 | 1 | 4 | 1 | 2 | 1 | 2 | 2 | 2 |
| | Namaqua Dove | 25.5 | 1 | 108 | 104.6 | 1 | 1 | 4 | 4 | 2 | 1 | 2 | 2 | 2 |
| Gruidae | Grey-crowned Crane | 105 | 4 | 561 | 523 | 4 | 4 | 4 | 1 | 1 | 3 | 3 | 3 | 4 |
| Laridae | Caspian Tern | 50.5 | 2 | 411 | 411 | 3 | 2.5 | 4 | 1 | 1 | 3 | 1 | 1 | 2 |
| | Whiskered Tern | 23 | 1 | 235 | 232 | 2 | 1.5 | 4 | 1 | 1 | 3 | 1 | 1 | 1 |
| | White-winged Tern | 21 | 1 | 209 | 208.8 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 1 |
| | Grey-headed Gull | 42 | 2 | 318 | 309 | 2 | 2 | 4 | 1 | 1 | 3 | 1 | 1 | 2 |
| Accipitridae | Osprey | 59 | 3 | 469 | 495 | 4 | 3.5 | 1 | 1 | 3 | 1 | 3 | 1 | 2 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Black-shouldered Kite | 30 | 1 | 269 | 267.9 | 2 | 1.5 | 4 | 1 | 3 | 3 | 3 | 3 | 2 |
| | Black Kite | 55 | 3 | 442 | 464 | 4 | 3.5 | 1 | 1 | 2 | 3 | 3 | 2 | 3 |
| | African Fish Eagle | 68 | 3 | 539 | 570 | 4 | 3.5 | 4 | 1 | 3 | 1 | 2 | 2 | 3 |
| | Bearded Vulture | 110 | 4 | 753 | 766.8 | 4 | 4 | 4 | 1 | 1 | 1 | 1 | 1 | 3 |
| | Hooded Vulture | 70 | 3 | 523 | 523 | 4 | 3.5 | 4 | 1 | 3 | 1 | 3 | 3 | 3 |
| | Cape Vulture | 110 | 4 | 713 | 713 | 4 | 4 | 4 | 1 | 4 | 4 | 4 | 4 | 4 |
| | Lappet-faced Vulture | 101.5 | 4 | 763 | 763 | 4 | 4 | 4 | 1 | 3 | 2 | 3 | 3 | 4 |
| | Bateleur | 57.5 | 3 | 531 | 538 | 4 | 3.5 | 4 | 1 | 3 | 1 | 2 | 2 | 3 |
| | Brown Snake-eagle | 73.5 | 3 | 528 | 529 | 4 | 3.5 | 4 | 1 | 3 | 1 | 2 | 2 | 3 |
| | African Marsh Harrier | 46.5 | 2 | 367 | 377.6 | 3 | 2.5 | 4 | 1 | 1 | 1 | 1 | 1 | 2 |
| | Black Harrier | 50.5 | 2 | 357 | 371.8 | 3 | 2.5 | 4 | 3 | 1 | 1 | 1 | 1 | 2 |
| | Lizzard Buzzard | 36 | 2 | 218 | 233 | 2 | 2 | 4 | 1 | 2 | 1 | 2 | 2 | 2 |
| | Southern Pale-chanting Goshawk | 54.5 | 3 | 354 | 380 | 3 | 3 | 4 | 1 | 4 | 1 | 2 | 2 | 3 |
| | African Goshawk | 38 | 2 | 204 | 248 | 2 | 2 | 4 | 1 | 1 | 1 | 1 | 1 | 2 |
| | Little Sparrowhawk | 25 | 1 | 141 | 160 | 1 | 1 | 4 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Black Sparrowhawk | 52 | 2 | 287 | 340 | 2 | 2 | 4 | 1 | 2 | 1 | 1 | 1 | 2 |
| | Jackal Buzzard | 49.5 | 2 | 419 | 444 | 3 | 2.5 | 4 | 1 | 4 | 1 | 2 | 2 | 2 |
| | Tawny Eagle | 71 | 3 | 521 | 543 | 4 | 3.5 | 4 | 1 | 3 | 1 | 2 | 2 | 3 |
| | Verreaux's Eagle | 88 | 4 | 604 | 631 | 4 | 4 | 4 | 1 | 2 | 1 | 1 | 1 | 3 |
| | African Hawk-eagle | 62.5 | 3 | 422 | 435 | 3 | 3 | 4 | 1 | 3 | 1 | 2 | 2 | 3 |
| | Booted Eagle | 50 | 2 | 381 | 381 | 3 | 2.5 | 2 | 1 | 2 | 1 | 2 | 2 | 2 |
| | Martial Eagle | 80.5 | 4 | 607 | 647 | 4 | 4 | 4 | 1 | 3 | 1 | 3 | 3 | 4 |
| | Long-crested Eagle | 55.5 | 3 | 385 | 394 | 3 | 3 | 4 | 1 | 3 | 1 | 2 | 2 | 3 |
| Sagittariidae | Secretarybird | 137.5 | 4 | 650 | 635 | 4 | 4 | 4 | 1 | 1 | 1 | 1 | 1 | 3 |
| Falconidae | Pygmy Falcon | 20 | 1 | 119 | 115 | 1 | 1 | 4 | 1 | 3 | 2 | 3 | 3 | 2 |
| | Lesser Kestrel | 29 | 1 | 237 | 237 | 2 | 1.5 | 1 | 1 | 3 | 3 | 3 | 3 | 2 |
| | Lanner Falcon | 42 | 2 | 315 | 314 | 2 | 2 | 4 | 1 | 2 | 1 | 1 | 1 | 2 |
| | Peregrine Falcon | 38.5 | 2 | 284 | 277 | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 2 |
| Phalacrocoracidae | White-breasted Cormorant | 90 | 4 | 337 | 317 | 3 | 3.5 | 4 | 1 | 2 | 2 | 3 | 2 | 3 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Reed Cormorant | 55 | 3 | 212 | 207 | 1 | 2 | 4 | 1 | 1 | 1 | 2 | 1 | 2 |
| | African Darter | 90 | 4 | 349 | 344 | 3 | 3.5 | 4 | 1 | 2 | 1 | 2 | 2 | 3 |
| Ardeidae | Little Egret | 64 | 3 | 280 | 272 | 2 | 2.5 | 4 | 1 | 2 | 3 | 4 | 3 | 3 |
| | Great Egret | 95 | 4 | 383 | 383 | 3 | 3.5 | 4 | 1 | 1 | 2 | 3 | 2 | 3 |
| | Black-headed Heron | 92 | 4 | 401 | 401 | 3 | 3.5 | 4 | 1 | 2 | 3 | 4 | 3 | 3 |
| | Goliath Heron | 142.5 | 4 | 591 | 575 | 4 | 4 | 4 | 1 | 1 | 1 | 1 | 1 | 3 |
| | Purple Heron | 84.5 | 4 | 371 | 355 | 3 | 3.5 | 4 | 1 | 1 | 2 | 1 | 1 | 2 |
| | Cattle Egret | 54 | 3 | 253 | 248 | 2 | 2.5 | 4 | 1 | 2 | 4 | 3 | 3 | 3 |
| | Green-backed Heron | 41 | 2 | 178 | 178.4 | 1 | 1.5 | 4 | 1 | 1 | 2 | 2 | 2 | 2 |
| | White-backed Night Heron | 52.5 | 2 | 267 | 267 | 2 | 2 | 4 | 1 | 1 | 1 | 1 | 1 | 2 |
| | Dwarf Bittern | 25 | 1 | 162 | 162 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Threskiornithidae | Hadeda Ibis | 76 | 4 | 353 | 353 | 3 | 3.5 | 4 | 1 | 3 | 3 | 4 | 3 | 3 |
| | African Sacred Ibis | 82 | 4 | 378 | 363 | 3 | 3.5 | 4 | 1 | 3 | 3 | 4 | 3 | 3 |
| | Glossy Ibis | 57.5 | 3 | 297 | 273 | 2 | 2.5 | 4 | 1 | 2 | 2 | 4 | 2 | 2 |
| | Southern Bald Ibis | 75.5 | 3 | 386 | 386 | 3 | 3 | 4 | 1 | 2 | 4 | 4 | 4 | 4 |
| | African Spoonbill | 82.5 | 4 | 384 | 384 | 3 | 3.5 | 4 | 4 | 2 | 2 | 2 | 2 | 3 |
| Pelicanidae | Pink-backed Pelican | 127.5 | 4 | 605 | 560 | 4 | 4 | 4 | 1 | 3 | 2 | 3 | 3 | 4 |
| | Great White Pelican | 159 | 4 | 702 | 620 | 4 | 4 | 4 | 1 | 2 | 3 | 2 | 2 | 3 |
| Ciconidae | Marabou Stork | 150 | 4 | 745 | 678 | 4 | 4 | 4 | 1 | 2 | 3 | 3 | 3 | 4 |
| | African Openbill | 57.5 | 3 | 400 | 400 | 3 | 3 | 4 | 1 | 2 | 3 | 3 | 3 | 3 |
| | Yellow-billed Stork | 97 | 4 | 482 | 482 | 4 | 4 | 4 | 1 | 1 | 3 | 2 | 2 | 3 |
| | Abdim's Stork | 78.5 | 4 | 438 | 435 | 3 | 3.5 | 1 | 1 | 2 | 3 | 3 | 2 | 3 |
| | White Stork | 112.5 | 4 | 577 | 558 | 4 | 4 | 1 | 1 | 2 | 3 | 2 | 2 | 3 |
| Corvidae | Cape Crow | 50 | 2 | 330 | 321 | 2 | 2 | 4 | 1 | 4 | 4 | 3 | 4 | 3 |
| | Pied Crow | 49 | 2 | 356 | 356 | 3 | 2.5 | 4 | 1 | 4 | 3 | 3 | 3 | 3 |
| | White-necked Raven | 52 | 2 | 403 | 403 | 3 | 2.5 | 4 | 1 | 4 | 2 | 3 | 3 | 3 |
| Laniidae | Common Fiscal | 22 | 1 | 98.9 | 98.9 | 1 | 1 | 4 | 1 | 3 | 2 | 2 | 2 | 2 |
| | Lesser Grey Shrike | 21 | 1 | 120 | 118 | 1 | 1 | 1 | 1 | 3 | 2 | 2 | 2 | 2 |
| Musciapidae | Cape Rock Thrush | 21.5 | 1 | 113 | 109 | 1 | 1 | 4 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Olive Thrush | 24 | 1 | 116 | 111.5 | 1 | 1 | 4 | 1 | 1 | 1 | 1 | 1 | 1 |
| Sturnidae | Burchell's Starling | 30 | 1 | 182 | 167 | 1 | 1 | 4 | 1 | 1 | 3 | 1 | 1 | 1 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Violet-backed Starling | 18 | 1 | 108 | 100 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 |
| Pied Starling | 25 | 1 | 154 | 150 | 1 | 1 | 4 | 1 | 2 | 3 | 3 | 3 | 2 |
| Cape Glossy Starling | 25 | 1 | 134 | 128 | 1 | 1 | 4 | 1 | 2 | 1 | 2 | 2 | 2 |

## Appendix 4. List of those experts who provided comment on subjective scoring of bird collision factors.

Dr Andre Boshoff – Centre for African Conservation Ecology, Nelson Mandeal Metropolitan University.

Dr Alan C Kemp – Honorary Research Associate, Percy FitzPatrick Institute, University of Cape Town

Dr Peter Ryan – Associate Professor, Percy FitzPatrick Institute, University of Cape Town.

Dr Warwick Tarboton – private ornithologist.