Collisions & Biases: Estimating The Impact of Low-Voltage Distribution Lines on the Ludwig's Bustard (*Neotis ludwigii*)

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ABSTRACT

Bird collision mortality associated with power lines is a global conservation challenge. The Ludwig's Bustard (*Neotis ludwigii*) population is probably declining throughout its range as a result of collisions with power lines. Collision estimates derived from periodic carcass counts along power lines are likely to be underestimates because of two main bias factors: scavenger and search bias. In this study 44 Egyptian geese (*Alopochen aegyptiacus*) and Spurwing geese (*Plectropterus gambensis*) were used as surrogates to explore the levels of the bias by conducting a scavenger trial (90 day period) and three search trials (conducted after 24 hours, 48 and 90 days). Scavengers had detected 88% and removed 11% of carcasses after the first week, and only 14% of carcasses were removed by the end of the 90-day trial period. On average, observers located 70% of carcasses across the three trials with no clear pattern in detection rate over time. Scavenger bias and search bias for this site in the Karoo were calculated at 0.14 and 0.30 respectively. Five low-voltage distribution power line transects (approximately 99 km) were surveyed in the Namakwa District, South Africa, to calculate a crude collision rate for Ludwig's Bustard. A total of 22 Ludwig's Bustard carcasses were located and used to estimate an unadjusted collision rate of 0.27 $km^{-1}.y^{-1}$ (95% CI 0.03-0.29 $km^{-1}. y^{-1}$). This collision rate extrapolated across the 63,000 km of distribution lines crossing the bustard's range represents an annual mortality of 13,000 individuals. The bias adjusted collision rate estimate increased to 0.45 $km^{-1}.y^{-1}$ (95% CI 0.04-0.48 $km^{-1}.y^{-1}$), which suggests 22,000 individuals are killed annually. The combined mortality of low-voltage and high-voltage lines could be in the order of 32 000 individuals annually. Implementation of existing mitigation devices and research into additional measures are necessary to prevent further decreases of this endangered species.

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CHAPTER 1

The Science of Monitoring Power Line Collisions

Review of Bias Correction Factors

Collision estimates derived from carcass counts beneath wind farms, along power line transects, or indeed any other form of collision point are susceptible to several biases (Bevanger 1999, Smallwood 2007), which have the potential to significantly underestimate the real mortality rate (Smallwood 2007, Arnett et al. 2008, Ponce et al. 2010). The only way to accurately determine mortality rates along power lines is to monitor them continually to observe every collision victim and its outcome (Ponce et al. 2010). The inability to do this over a sufficiently large enough area introduces several potential sources of error (Bevanger 1999). Mortality estimates derived from counting carcasses along power line corridors should be adjusted to account for carcasses removed by scavengers (scavenger bias), carcasses missed due to observer error (search bias - e.g. observer fatigue or inexperience), carcasses missed due to unsearchable habitat (habitat bias) and carcasses missed due to collision victims moving out of the search corridor before dying (crippling bias). A review of several studies and their correction factors is presented in Table 1.1.

Table 1.1 Summary of selected studies presenting bias correction factors associated with periodic surveys for collision victims on power lines and related infrastructure

Authors & Locality	Target Species	Surrogate Species	Structure (No./Length)	Habitat	Season & Duration	Sample Size & Density	No. Observers & Search Width	Calculated Bias Factors
Bevanger (1995) Norway	Multiple Tetranoid	?	Power Lines	Subalpine	?	?	?	0.2-0.4 (Search Bias)* 0.5-0.8 (Scavenger Bias)* 0.2-0.3 (Habitat Bias)* 0.2-0.3 (Crippling Bias)*
Savereno et al. (1996) USA	Multiple	Mallard Ducks (*Anas platyrhyncos*)	Power Lines (1.2 km)	Saltmarsh	- 2 months	11 Mallard Ducks 9.17 birds/km^{-1}	4 45 m	0.27 (Search Bias) 0.27 (Scavenger Bias) 0.74 (Crippling Bias)
Janss & Ferrer (2000) Spain	Great Bustard (*Otis tarda*) Common Crane (*Grus grus*)	?	Power Lines	Cereal Cultivation	All seasons	?	?	0.20 (Search+Habitat Bias)∝ 0.50 (Crippling Bias)ℵ
Sundar & Choudhury (2005) India	Sarus Crane (*Grus antigone*)	?	Power Lines	Wetlands & Croplands	All seasons	?	?	0.20 (Search+Habitat Bias)θ 0.50 (Crippling Bias)θ

* Estimates based on author's judgement, observations and work from unpublished investigations

∝ Estimate chosen by authors after reviewing estimates by Renssen (1975), Bealaurier (1981), Hartman et al. (1993), Hugie et al. (1993), Pearson (1993) & Bevanger (1995)

ℵ Estimate derived from averaging estimates from Renssen (1975), Bealaurier (1981) and Bevanger (1995)

θ Estimates derived from Janss & Ferrer (2000)

Table 1.1 Continued

Authors & Locality	Target Species	Surrogate Species	Structure (No./Length)	Habitat	Season & Duration	Sample Size & Density	No. Observers & Search Width	Calculated Bias Factors
Flint et al. (2010) Alaska	Waterfowl & Shorebirds	Northern Pintails (92%)	Communication Towers & Field Transects	Tundra	Fall, Winter & Summer 6 days	565 10 birds/km^{-1}	?	0.6 (Scavenger Bias)σ
Ponce et al. (2010) Spain	Multiple Farmland & Steppe Birds	Multiple	Power Lines (14 km)	Cereal Cultivation	All seasons 1 month	522 5 birds/km^{-1}	4 50 m	0.47 (Search Bias)κ 0.72 (Scavenger Bias)κ
Shaw et al. (2010) South Africa	Blue Crane (*Anthropoides paradiseus*)	Multiple	Power Lines (3.2-4 km)	Wheatbelt	Spring 2 months	24 6-7.5 birds/km^{-1}	1 30 m	0.09 (Habitat Bias) 0.54 (Scavenger Bias) 0.20 (Crippling Bias)ϕ
Smallwood et al. (2010) USA	Multiple	Multiple	Wind Turbine (20)	Grassland	All seasons 21 days	- 1-5 birds/km^{-1}		0.73 (Scavenger Bias)
Stevens et al. (2011) USA	Greater Sage Grouse (*Centrocercus urophasianus*)	Ring-necked Pheasant (*Phasianus colchicus*)	Fence (54.6 km)	Sagebrush Steppe	Winter 1 month	100 1.8 birds/km^{-1}	2 30 m	0.47 (Search Bias) 0.75 (Scavenger Bias)

σ Daily scavenger bias rate

κ Figures are estimates across four different carcass sizes (very small, small, medium, large). Search bias for large carcasses was 0.28 and scavenger bias for large carcasses was 0.43.

ϕ Derived from Bevanger (1995)

Scavenger Bias

Scavenger trials have been conducted most notably in studies of the effects of pesticide toxicity on bird mortality (see review in Prosser et al. 2008). Scavenger trials provide a useful means to estimate carcass removal rates and thus inform the frequency to conduct surveys so as not to miss the majority of collision victims (Smallwood 2007). In spite of their importance, scavenger trials are often ignored because of their time-consuming nature and complexity (Jenkins et al. 2011). Stevens et al. (2011) noted that where trials have been conducted, several studies do not provide clear and concise descriptions of their methodology and others are handicapped by small sample sizes (e.g. Savareno et al. 1996, Table 1.1). It is clear from Table 1.1 that applying estimates from other studies (e.g. Bevanger 1995) is dangerous given considerable variance in bias estimates. Several site-specific factors affect scavenger bias and carcass removal trials.

Estimates of carcass persistence in carcass removal experiments are hugely variable (24-98% persistence after 24 hours, Prosser et al. 2008). Numerous factors may account for local differences in scavenger detection and removal rates. One of the most obvious is temporal and spatial variation in scavenger abundance/density and activity (Bevanger et al. 1994, Prosser et al. 2008, Flint et al. 2010). Flint et al. (2010) reported lower carcass persistence rates in autumn than either summer or winter most likely because of seasonal differences in scavenger density and food availability. It thus may be misleading to extrapolate results from a single season (Arnett et al. 2008), especially in strongly seasonal environments, and results should be interpreted cautiously.

The diversity of scavengers also might play an important role in carcass persistence (Flint et al. 2010). If scavengers are predominantly mammalian, carcass removal rates are expected to be higher than when scavengers are predominantly avian (especially with larger carcasses). The manner in which scavengers detect a carcass may also be important. Prosser et al. (2008) suggested that the cryptic plumage of quail *Coturnix japonica* (in relation to their study site) would present a tougher challenge to scavengers dependent on visual cues (e.g. avian species) than those using olfactory stimuli (e.g. mammals).

Bevanger et al. (1994) reported the presence of Red Fox (*Vulpes vulpes*) tracks beneath overhead transmission lines continuing for several km. Similarly, Northern Ravens (*Corvus corax*) and Pied Crows (*C. albus*) are thought to supplement their diet by patrolling roads looking for carrion (Kristan et al. 2004, Hockey et al. 2005). Scavenger habituation to anthropogenic structures seems a reasonable conclusion given that often these structures represent collision hotspots in an otherwise uniform landscape (Arnett et al. 2008). Flint et al. (2010) tested this assumption but found no differences between scavenging rates at tower structures (radio and satellite) and randomly selected field transects. They concluded that despite a lack of pattern in their results, carcass persistence in relation to distance from tower structures should receive more attention.

Scavenger persistence trials may be influenced by the choice and treatment of carcasses (Smallwood 2007). Several studies have investigated the role of carcass size in persistence trials (e.g. Morrison 2002, Smallwood 2007, Flint et al. 2010, Ponce et al. 2010), and carcass size has been the most important factor in some trials (Smallwood 2007). Carcass removal rates tend to increase with decreasing carcass size (Ponce et al. 2010) and smaller carcasses experienced the highest initial disappearance rates (Prosser et al. 2008). The largest carcass removed gives a rough measure of the types of scavengers within the study area, because only larger scavengers will be able to remove large carcasses.

In terms of treatment of carcasses prior to placement, Bumann & Stauffer (2002) proposed that carcasses with exposed viscera presented stronger olfactory cues to scavengers. Most scavenger trials are conducted with frozen carcasses, which may differ in olfactory stimuli compared to fresh carcasses (Smallwood 2007). Ponce et al. (2010) placed carcasses in the field with a large cut to their ventral side to simulate collisions with power lines. However, no studies appear to have compared whether intact carcasses are removed at a different rate to manipulated carcasses. In addition carcasses are commonly placed beneath anthropogenic structures intact whereas collision victims with wind turbines for example may have been dismembered, which then allows a greater number of scavengers to partake in removal of the carcass (Smallwood 2007).

Carcass density has produced variable results in different studies. For example, Prosser et al. (2008) found no difference between removal rates of carcasses placed at random in a field at either high (20 carcasses per 5 ha) or low densities (2 carcasses per 5 ha). Similarly, Ponce et al. (2010) found no differences between removal rates when carcasses were placed beneath power lines at densities of 20 carcasses km^{-1} or 5 carcasses km^{-1}. One might expect more carcasses to be removed from a high-density site because scavengers may develop a search image (Prosser et al. 2008) and be attracted to the site (e.g. Bevanger et al. 1994). On the other hand too many carcasses may result in lower removal rates because of 'scavenger swamping' (Smallwood 2007, Smallwood et al. 2010). Smallwood et al. (2010) criticized high-density carcass trials for producing biased removal estimates. Smallwood et al.

showed that in trials with low carcass densities (1-5 carcasses per wind turbine instead of 10 or 20) removal rates for all birds were 67% higher than rates derived through high carcass density trials. Several species even recorded removal rates up to three times greater (Smallwood et al. 2010), illustrating the importance of accounting for carcass density as a possible confounding variable.

Carcass Surrogates

It is common practice to use surrogate species in scavenger removal trials (e.g. Gehring et al. 2009, Shaw et al. 2010, Table 1.1), often because the species of interest has an assigned protected status (e.g. Stevens et al. 2011) or because they are difficult to collect in large numbers required for trials (Smallwood 2007). Using surrogates to calculate scavenger bias is clearly problematic because of the uncertainty regarding the suitability of the surrogate (Smallwood 2007). Surrogates may be more or less palatable, detectable or removable by scavengers and (Smallwood 2007). Surrogates should be matched as closely as possible to the main species of concern (e.g. size and plumage colouration) and the resultant scavenger bias estimates should be treated cautiously.

Scavenger Bias Conclusions

Scavenger removal trials also may be influenced by environmental factors such as geographic heterogeneity (Kostecke et al. 2001, Flint et al. 2010), or vegetation height and cover (Smallwood 2007; Arnett et al. 2008). Flint et al. (2010) found strong support for geographic variation in carcass removal trials among transects. Vegetation cover and height are likely to influence carcass detection by scavengers, especially those dependent on visual cues (Smallwood 2007). This set of explanatory factors affecting scavenger trials is by no means exhaustive but it illustrates that results from scavenger removal trials cannot be generalized with any confidence and should ideally be treated as species, size, season and site-specific estimates (Arnett et al. 2008).

Search Bias

The second main source of bias affecting estimates of avian power line mortalities is the detectability of carcasses or other remains by field workers (Bevanger 1999). Field workers are unlikely to find all carcasses and thus detection trials play an important role in accurate collision rate estimation. Detectability trials frequently accompany studies quantifying avian collisions, but like scavenging trials they have received a fair amount of criticism because many studies have not investigated the various factors that influence detectability (Stevens et al. 2011).

Ponce et al. (2010) found that only carcass size and observer experience significantly influenced carcass detectability in a farmland area of central Spain. Osborn et al. (2000) only found carcass size to be important, with over 90% of large carcasses found compared to fewer than 70% of small carcasses. Vegetation type and cover can also influence the detection of carcasses (Tobin & Dolbeer 1990, Bevanger 1999, Smallwood 2007, Arnett et al. 2008) as can weather conditions (e.g. snow, Bevanger 1999).

Ponce et al. (2010) noted that personal motivation and search effort should also not be overlooked, despite them being difficult to account for or measure. During power line surveys observers may not detect carcasses for several km at a time, which may affect their concentration. Conversely, as a result of time constraints and lack of study sites the density of carcasses in search trials is often several times greater than naturally expected, which is likely to increase observer awareness (Smallwood 2007). Added to this is increased effort simply because the observer knows they are being tested. Together it suggests that search trials are likely to overestimate carcass detection rates.

The concerns regarding the use of surrogates in scavenger trials also apply to search trials. Stevens et al. (2011) for example, used female Ring-necked Pheasant carcasses as surrogates for Greater Sage-Grouse because of size and plumage similarities. Stevens et al. (2011) were unaware of any studies that investigated whether small differences in plumage colouration influenced detectability. Until such time the use of surrogates is likely to remain common practice and results should thus be interpreted cautiously.

Habitat Bias

Habitat bias is closely related to search bias (Bevanger 1999). Power lines are likely to cross heterogeneous landscapes, some of which may be more or less searchable (e.g. rivers or deep gullies). Habitat bias is associated with unsearchable sections of power lines and reduced search widths. This bias correction factor can be both site and season specific (e.g. heavy snowfall) and collision estimates that require a large habitat bias correction are unlikely to be robust (Bevanger 1999).

Crippling Bias

Crippling bias represents the final source of potential bias in power line collision surveys. Smallwood et al. (2010), for example, spotted a Golden Eagle (*Aquila chrysaetos*) with a broken wing over 400 m from the nearest wind turbine. Bevanger (1995) estimated a conservative value of 0.20 for Capercaillie (*Tetrao urogallus*) in Norway while Beaulaurier (1981) and Savereno et al. (1996) both estimated a figure of 0.74 after many hours observing a power line transect and watching what happened to collision victims (Table 1.1). This source of bias is the most difficult to quantify because it can only be accurately measured through direct observation or telemetry (Bevanger 1999). Studies that consider it an important correction factor (e.g. through direct observation of many collisions) typically apply estimates from other publications (e.g. Janss & Ferrer 2000, Sundar & Choudhury 2005, Shaw et al. 2010).

Review of Avian Power Line Collisions

Anthropogenic structures (e.g. power lines, wind turbines and communication towers) are responsible for killing and injuring huge numbers of birds annually (Klem, 1990, Bevanger 1995, Erickson et al. 2005, Drewitt & Langston 2008). The impacts of high-tension lines have been apparent since 1876 when Coues reported 100 carcasses (predominantly Horned Larks [*Eremophila alpestris*]) beneath a 4.8 km stretch of telegraph wire in the United States. In spite of early reports of mortalities associated with power lines (e.g. Faanes [1987] estimated 125 mortalities $km^{-1}.y^{-1}$ for a 9.6 km section of power line in North Dakota) it is only in very recent times that an understanding of their far reaching effects around the globe has emerged (Table 1.2).

Power lines cause avian mortalities through electrocution (i.e. if a bird comes into contact with two phase conductors or an earth wire and a phase conductor) and through direct collision (often with the earth wire) (Bevanger 1994). Avian electrocutions cost energy suppliers billions of dollars in lost revenue and repairs, and thus extensive efforts have been made to understand how the electrocution problem can be mitigated (e.g. Janss & Ferrer 2001, Manosa 2001, Lehman et al. 2007). Power line collision mortality, on the other hand, has proven to be a more complex matter. This may be due in large part to the limited damage collisions caused to infrastructure in comparison to electrocutions. Nevertheless, now that it has been recognized that collisions pose the greatest threat to the persistence of several endangered species, especially those with small populations and restricted ranges, it is a topic in need of timely research and intervention (Manville 2009). A review by Manville (1999) reported that over 350 species worldwide have fallen victim to collisions with power lines and other electricity structures.

Until recently, avian mortality on power lines was considered to be negligible at the population level (Faanes 1987, Bevanger 1994), but it is now thought to have the potential to trigger local or national declines of some species (Drewitt & Langston 2008). In the last few decades a comprehensive body of literature has arisen documenting the impacts of power lines on avian species (e.g. Crivelli et a. 1988, Bevanger 1995, Janss & Ferrer 2000, Rubolini et al. 2005, Martin et al. 2007, Rollan et al. 2010, Shaw et al. 2010, Raab et al. 2011). The work conducted by Bevanger (1995) is one of the most frequently cited studies regarding avian losses to power line collisions. Bevanger estimated that close to 100,000 grouse were killed annually in Norway in collisions with high-voltage power lines. This estimate represented up to 90% of the annual hunting harvest of grouse species (Bevanger 1995). When the additive effects of hunting (both legal and illegal), habitat destruction and other harmful anthropogenic practices are considered it is clear that the power line collision problem has evolved into a global conservation challenge (Bevanger & Broseth 2004, Rubolini et al. 2005, Jenkins et al. 2010).

Table 1.2 Review of selected field studies providing collision rates (mortalities km^{-1}. year^{-1})

Authors	Species	Locality	Habitat	Voltage & Length	No. Sites	Casualties	Mortality Rate & % of Population	Season & Duration	Search Frequency/ Interval
Faanes (1987)	Multiple	North Dakota USA	Prairie	12/230/400 kV 9.6 km†	7	633	125 km^{-1}. y^{-1} ?	Spring & Fall 1980-1982	Twice Weekly
Savereno et al. (1996)	Multiple	South Carolina USA	Saltmarsh	115 kV 1.2 km	1	28	76-344 km^{-1}. y^{-1} ?	All seasons 1991-1994	Twice Weekly
Janss & Ferrer (2000)	Common Crane	Extremadura Spain	Cereal Cultivation	400 kV 3.5 km	1		7-17 km^{-1}. y^{-1}* 1.5-6% yr^{-1}	All seasons 1992-1995	Average 1.35 months
	Great Bustard	‘’	‘’	132 kV 3.8 km	1	23	1-4 km^{-1}. y^{-1}* 0.9-3.6% yr^{-1}	‘’	1.15 months
Anderson (2002) ∝	Ludwig’s Bustard	Eastern Karoo South Africa	Karoo Shrubland	132 kV 10 km	1	17	1.95 km^{-1}. y^{-1}ϕ ?	All seasons 1997-1998	Monthly
	Blue Cranes	‘’	‘’	‘’	‘’	29	3.15 km^{-1}. y^{-1}ϕ ?	‘’	‘’
Bevanger & Broseth (2004)	Multiple (Ptarmigan)	Buskerud Norway	Subalpine	22/66/300 kV 11 km	4	279	5.3 km^{-1}. y^{-1} ?	All seasons 1989-1995	Average ϕ 6.3 days

† Total length spread over the number sites mentioned

* Collision estimates adjusted with bias correction factors

ϕ Not provided by authors but calculated from data

∝ Study involved in testing mitigation devices. Only pre-marking data was used for this table.

Table 1.2 Continued

Authors	Species	Locality	Habitat	Voltage & Length	No. Sites	Casualties	Mortality Rate & % of Population	Season & Duration	Search Frequency/ Interval
Sundar & Choudhury (2005)	Sarus Cranes	Uttar Pradesh India	Wetlands & Croplands	0.2-0.4/11-13.5 kV 160 km	?	12	0.13 km^{-1}. y^{-1}* 1% yr^{-1}	All seasons 1999-2002	Thrice Weekly
Shaw et al. (2010)	Blue Crane	Overberg South Africa	Wheatbelt	11-22/66-400 kV 199 km	?	23	0.31 km^{-1}. y^{-1}* 12% yr^{-1}	Spring 2008-2009	3 Months
	Denham's Bustard (*Neotis denhami*)	‘’	‘’	‘’	?	5	0.06 km^{-1}. y^{-1}* 30% yr^{-1}	‘’	‘’
Garcia-del-Rey & Rodriguez-Lorenzo (2011)	Houbara Bustard (*Chlamydotis undulata fuertaventura*)	Fuerteventura & Lanzarote Canary Islands	Semi-arid Steppes	? (Transmission) 366 km	2	66	0.36 km^{-1}. y^{-1}ϕ 6.6-11.5% yr^{-1}	Spring & Autumn 2008	3 months
Jenkins et al. (2011)	Ludwig's Bustard	Karoo South Africa	Karoo Shrubland	400 kV 338 km	6	109	0.63 km^{-1}. y^{-1}* 11-15% yr^{-1}	All seasons 2008-2009	Average 3.8 months

* Collision estimates adjusted with bias correction factors

ϕ Not provided by authors but calculated from data

A Biological Handicap

Biologists have gained a greater understanding of how biological characteristics (e.g. behaviour & morphology) of species interact with environmental (e.g. meteorology & topography) and anthropogenic factors (e.g. power line structure, height and positioning) to increase the likelihood of collisions (Bevanger 1994, Janss 2000, Drewitt & Langston 2008). Jenkins et al. (2010) summarised collision risk as the interaction between 'exposure to collision risk' (e.g. flying at the height of power lines) and 'inherent susceptibility to collision' (e.g. the visual capacity to detect power lines and the physical capacity to avoid collisions). This 'susceptibility to collision' appears to hold the key to species-specific mortality on power lines (Janss 2000). Species with high wing loadings and low aspect ratios, such as bustards (Otididae), cranes (Gruidae), storks (Ciconiidae) and pelicans (Pelecanidae), are characterized by rapid flight and limited maneuverability, which makes these species frequent power line victims (Bevanger 1998, Janss 2000).

Recent work by Martin & Shaw (2010) showed that bustards have relatively small binocular visual fields and large blind spot areas. Pitching their heads downwards by only 25° during flight (such as might occur when searching for foraging areas) renders them effectively blind in the direction of travel. This structural constraint further increases their likelihood of colliding with power lines.

Mitigation in Light of an Expanding Threat

Erickson et al. (2005) estimated that in the United States alone, high-tension power lines were responsible for approximately 130-174 million avian mortalities annually. Total avian mortalities in the USA could be an order of magnitude larger, however, given that the impact of the extensive distribution line network has not been estimated (Erickson et al. 2005). Currently there are some 65 million km of medium-high voltage power lines in use across the globe (Jenkins et al. 2010). Global estimates of bird mortalities as a result of this power line network (including distribution lines) are in the range of one billion annually (Hunting 2002). These estimates should, however, be viewed with caution, given the gross extrapolation from comparatively few studies.

The global power line network, both distribution lines (typically 2.4 kV – 60 kV) and transmission lines (typically >69 kV – APLIC 2006) is currently expanding at 5% annually (Jenkins et al. 2010). The greatest concern for conservationists is that, given this increase, avian collision mortality is set to escalate in the future unless effective mitigation measures are introduced. Prevention of future collision mortalities is only possible if new power lines are buried, re-routed or not built at all (Drewitt & Langston 2008, Raab et al. 2011). However, it is unlikely that any of these solutions will be seriously considered on a large scale (but see Raab et al. 2012). The placement of power lines is often reduced to simple economic calculation (Anderson 2002). The real challenge is to identify methods to reduce avian mortalities on the existing line network.

Testing and identifying devices that will mitigate collisions with power lines has become a hot topic (Barrientos et al. 2011). Jenkins et al. (2010) reviewed a number of studies that employed different mitigation strategies (e.g. line-marking devices and removal of earth wires) and found that all reduced collisions by 50-60%. Barrientos et al. (2011) conducted a meta-analysis on the effectiveness of line-marking devices and found that collision mortality was 78% lower on marked lines. A study by Anderson (2002) however, suggested that line-marking devices were ineffective in reducing Ludwig's Bustard mortalities and several other studies have also produced inconclusive results (e.g. Janss & Ferrer 2000). It is important to note that the behaviour and morphology of a target species may contribute just as much to the success of line marking devices as the visibility and density of devices, so it is difficult to extrapolate these results species (Barrientos et al. 2011).

The South African Perspective

At present, in South Africa, there are approximately 350,000 km of power lines (www.eskom.co.za). This network is set to increase extensively as a result of Eskom, South Africa's energy supplier, injecting huge sums of money into increasing its capacity. This expansion is likely to have an adverse impact on South Africa's birds. Since 1996, Eskom and the Endangered Wildlife Trust (EWT) have worked together to establish the scale of the collision problem. Since 1996, over 700 Blue Cranes collisions have been recorded as well as over 200 Ludwig's Bustard, 200 White Storks *Ciconia ciconia* and 100 Grey Crowned Cranes *Balearica regulorum* (Eskom/EWT Strategic Partnership 2008). These figures are not derived from repeatable and structured power line surveys and thus provide only an indication of the scale of the problem (Jenkins et al. 2010, Shaw et al. 2010). Shaw et al. (2010) estimated that only 2.6% of mortalities are reported to the partnerships Central Incident Register (CIR), which stresses the need for intensive and representative power line surveys.

In spite of numerous incidental collision reports (Eskom/EWT Strategic Partnership 2008) it is somewhat surprising, given the size of the power grid, that there are only a handful of publications and reports quantifying avian power line mortalities in South Africa. A recent power line survey (11 kV to 400 kV) conducted in the Overberg region of the Western Cape estimated that Blue Cranes had a collision rate of 0.31 mortalities $km^{-1}.y^{-1}$ which extrapolates to some 12% of the total Blue Crane population in the Overberg region (Shaw et al. 2010). The collision rate of Denham's Bustard was estimated at 0.06 mortalities $km^{-1}.y^{-1}$, which extrapolated to 30% of the Overberg population annually (Shaw et al. 2010). In total, 18 bird species were recorded as collision victims (Shaw et al. 2010) which is a cause for concern given that eight of the ten most frequent collision species in South Africa are red-listed (Barnes 2000).

The Ludwig's Bustard

The Ludwig's Bustard is one of the high-profile species that is currently thought to be declining as a result of power line mortality (Anderson 2002, Jenkins et al. 2011). Jenkins et al. (2011) documented collision rates for Ludwig's Bustards across its South African range (Fig. 1.1). A collision rate of 0.63 mortalities $km^{-1}.y^{-1}$ was estimated for transmission lines, which implies that 11-15% of the total population (last estimated at 56,000-81,000; Allan 1994) could be killed annually on high-voltage power lines (>132 kV in Jenkins et al. 2011). This probably under estimates the scale of the problem given that estimates were not adjusted for bias factors and that no estimates are currently available for mortalities on low-voltage power lines or telephone lines (Jenkins et al. 2011). This suggests that the collision rate could be similar to the 1-3 mortalities $km^{-1}.y^{-1}$ estimated for Ludwig's Bustards in the eastern Nama Karoo by Anderson (2002).

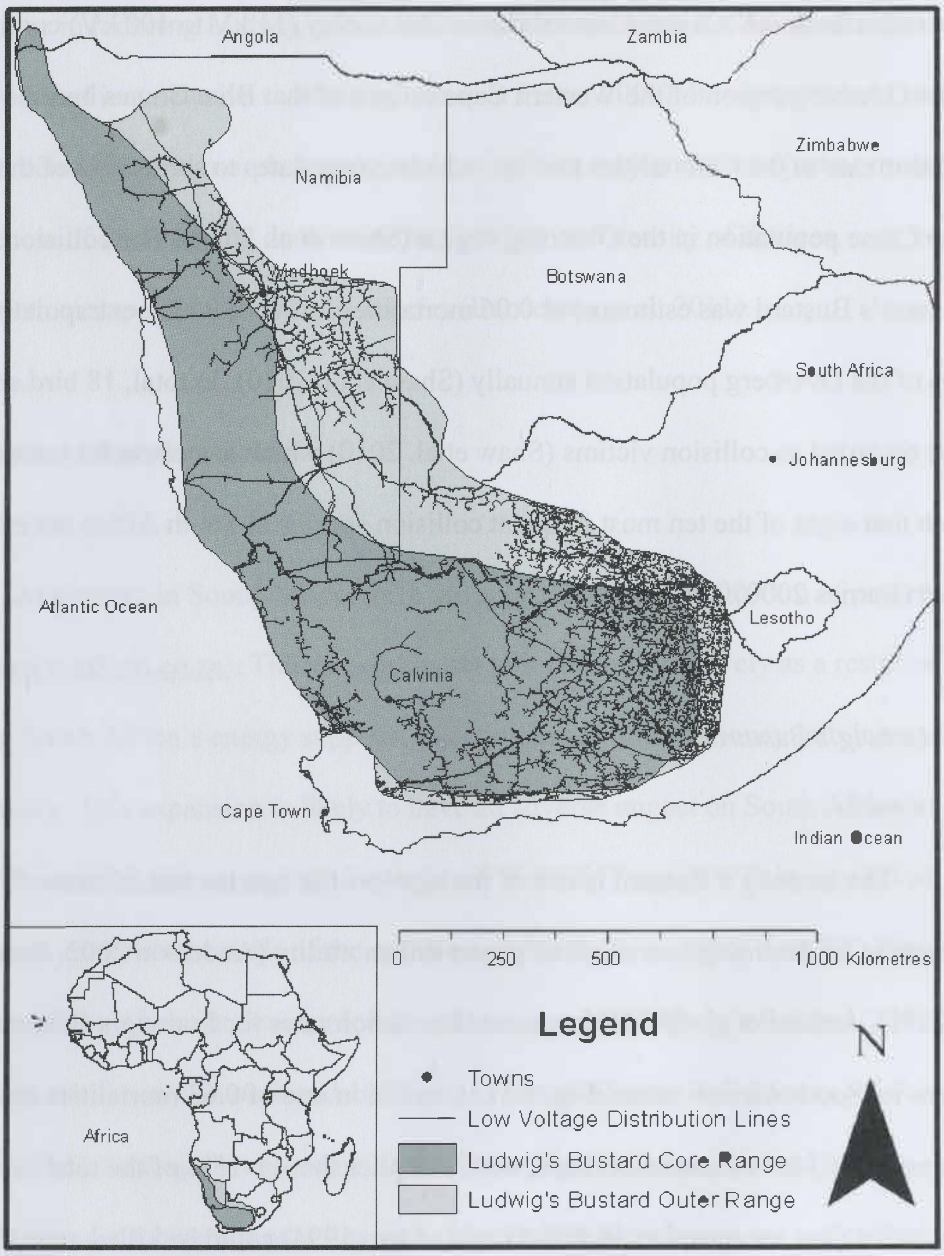

Figure 1.1 The approximate range of the Ludwig's Bustard (two tone shading represents core and peripheral areas based on atlas reporting data, Allan 1997) and low-voltage distribution lines (<132 kV) that cross this range.

Ludwig's Bustard was recently listed as Endangered (Birdlife International 2011). It fits the description of a susceptible collision victim, being a large, heavy-bodied, fast-flying species. Furthermore, it undertakes both long distance seasonal migrations, following increased productivity caused by rains, as well as short daily flights around dawn and dusk (during poor light conditions) to and from roosting sites on hilltops to feeding sites on adjacent plains (Allan 2005). This behaviour, in addition to visual constraints (Martin & Shaw 2010) are likely increase their inherent susceptibility to collision.

In Europe, listed as Vulnerable (http://www.iucnredlist.org/apps/redlist/-search, 2012), the Great Bustard faces an equally severe challenge from high-voltage power lines (e.g. Janss & Ferrer 2000, Raab et al. 2011), which now represent the greatest source of accidental mortality for this species (e.g. Martin et al. 2007). Martin et al. (2007) showed that over 50% of radio-tagged Great Bustards in Spain died as a result of power line collisions in their second year of life. Garcia-del-Rey & Rodriguez-Lorenzo (2011) reported that more than 10% of the Canary Island Houbara Bustard population (estimated at 1000 individuals) died in a single year from power line collisions (Table 1.2).

Aims of the Study

A population viability analysis (PVA) conducted for the MacQueen's Bustard *Chlamydotis macqueenii* in Kazakhstan showed that an annual mortality rate exceeding 7.2% of the adult population would lead to eventual extinction (Combreau et al. 2001). If this estimate is used as a guideline, the current decline of the Ludwig's Bustard estimated by Jenkins et al. (2011) is of concern and this species is likely in need of swift and effective conservation action. The estimate by Jenkins et al. (2011) provides an incomplete picture because it has not been adjusted for bias estimates specific to the Karoo. In addition to the 17,000 km of high-voltage power lines intersecting the Ludwig's Bustard range there is a significant low-voltage distribution line network whose effects are unlikely to be negligible (Fig. 1.1). This investigation estimates detection and scavenger bias in the Karoo to address these limitations in order to improve the accuracy of the estimated collision rate. I provide an estimate for Ludwig's Bustard collision rates on the extensive distribution line network. In addition, I use the bias estimates to update the figures presented by Jenkins et al. (2011) to evaluate the overall impact of power lines on Ludwig's Bustard.

CHAPTER 2

Estimating bias correction factors

2.1 Introduction

Bird collision rate estimates derived from periodic carcass counts along power line transects or other anthropogenic structures underestimate the actual numbers of birds killed because of two main bias factors (Bevanger 1999, Smallwood 2007; Chapter 1). Scavenger bias refers to carcasses that are absent during surveys and remain unaccounted for because they have been removed by scavengers (Bevanger 1999). Search bias refers to the proportion of carcasses that are not spotted by observers during surveys. Investigations that do not correct for these biases are strictly underestimates. The most accurate way of estimating these bias rates is by conducting scavenger and search trials with experimental carcasses. In spite of their importance, such trials are rarely conducted due to their time-consuming nature and complexity (Jenkins et al. 2011). Little work has been conducted underneath power lines in spite of the scale of the collision problem (Ponce et al. 2010, Chapter 1).

The results from scavenger and search bias experiments are hugely variable and are affected by a number of factors (Chapter 1). Carcass removal rates during trials are dependent upon carcass density (Smallwood et al. 2010), carcass size (Flint et al. 2010, Ponce et al. 2010), seasonal predator abundance and activity (Prosser et al. 2008), scavenger territoriality (Prosser et al. 2008), possible predator habituation to anthropogenic structures (Flint et al. 2010), geographic heterogeneity (Flint et al. 2010), vegetation type (Kostecke et al. 2001) and weather conditions (Bevanger

1999). Carcass detection trials by observers are also affected by carcass size (Ponce et al. 2010), vegetation type and height (Arnett et al. 2008, Stevens et al. 2011), weather conditions (Bevanger 1999) and experience and motivation of the observer (Gehring et al. 2009, Ponce et al. 2010). This is by no means an exhaustive list but it serves to illustrate that the results from these trials can be highly specific to a species, habitat or season (Arnett et al. 2008).

Scavenger bias is arguably the most important source of bias in regions such as the Succulent Karoo where there are a large number of different small to medium sized mammalian predators (Appendix 1) (Jenkins et al. 2011). In this chapter I present correction factors for scavenger and search bias at one site in the Hantam Karoo. I also investigate the factors that affect detection rates by observers in relation to carcass location and age.

2.2 Study Area & Methods

The study was conducted near Calvinia (31°28′S 19°46′E) in the Namakwa District, located in the southwest region of the Northern Cape, South Africa (Fig. 2.1). Calvinia is located in the succulent Karoo, an arid region that is characterized by flat to slightly undulating terrain of low shrub and rocky outcrops with occasional flat-topped hills (Mucina & Rutherford 2006). The average rainfall for Calvinia is 170 mm annually while the average temperature is 16.8°C (Mucina & Rutherford 2006). Livestock farming for wool (Merino sheep) and mutton production (Dorper sheep) are the main sources of income for landowners in this region (Anderson 2002).

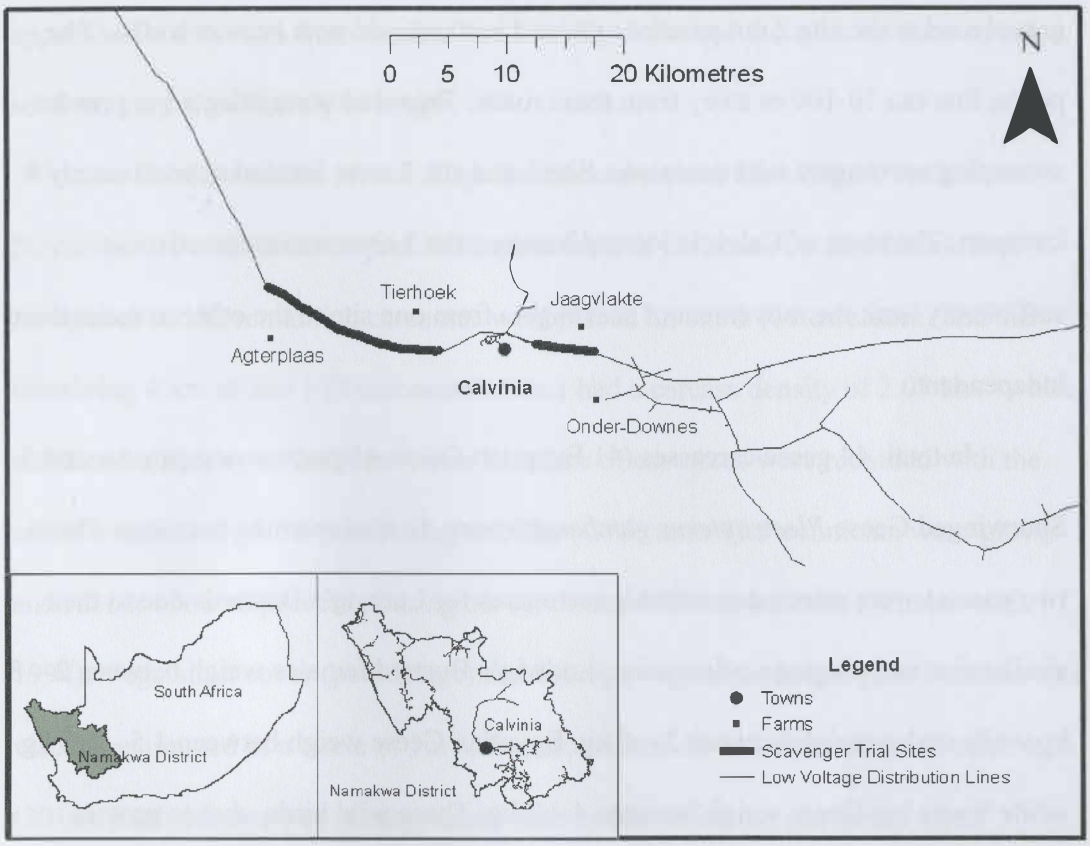

Figure 2.1 The study area in the Namakwa district of the Northern Cape, South Africa. Lines show electricity distribution lines, with bold segments around Calvinia showing the two sections of line used for the scavenger bias study.

Experimental Design: Scavenger Bias

In order to estimate the scavenger removal rate of large bird carcasses a scavenger removal trial was conducted from November 2011 to February 2012. A 66 kV line (Appendix 2) was selected for this trial due to its close proximity to an accessible road, which was essential for the placement of carcasses. A 14 km section was selected east of Calvinia situated on the private land of Tierhoek and Agterplaas (hereafter site 1) and a 5.75 km section was selected to the west on the private land of

Jaagvlakte and Onder-Downes (site 2, Fig. 2.1). Site 1 ran parallel to a low traffic gravel road while site 2 ran parallel to a hard surface road with heavier traffic. The power line ran 50-100 m away from these roads. Two sites were selected to prevent swamping scavengers with carcasses. Site 1 and site 2 were located approximately 8 km apart. The town of Calvinia located between the 2 sites was assumed to sufficiently limit the movement of scavengers from one site to the other to make them independent.

In total, 44 geese carcasses (41 Egyptian Geese *Alopochen aegyptiacus* and 3 Spurwinged Geese *Plectropterus gambensis*) were divided over the two sites. These two species were selected as suitable surrogates for Ludwig's Bustards due to their similar size and plumage colouration. Ludwig's Bustard females weigh between 2 – 3 kg while males weigh between 3 – 6 kg. Egyptian Geese weigh between 1.5 – 2.5 kg while Spurwing Geese weigh between 4 – 7 kg. These wild birds, shot to protect crops during harvest times, were favoured over farmed birds (known to have a characteristic smell) in order to avoid influencing carcass removal rate (Bevanger 1999, Prosser et al. 2008).

The geese were shot, placed in cold storage to prevent the onset of decomposition and deployed in the field within 96 hours. Microsoft Excel was used to randomly generate locations (i.e. power line pylon number, distance from the power line [maximum 15m], side of line and location along the span (e.g. close to pylon, in-between or midspan – Appendix 3) for the carcasses along each section.

Ludwig's Bustard data from previous power line surveys in the Karoo (Unpublished data, J. Shaw) were compiled to determine distribution of carcasses found beneath power lines (i.e. distance from line and location along span). These data were then used to calibrate the random location generator to produce locations for the geese that resembled the 'natural' distribution. A field technician paced out the approximate distances from the line and visually estimated the span sections as pylon sections vary significantly in length.

A field technician placed 22 geese carcasses on 10 km of site 1 on 2 November (time constraints prevented placement of carcasses on all 14 km). On 3 November the 22 remaining carcasses were placed on site 2 (15 carcasses) and the remaining 4 km of site 1 (7 carcasses). Site 1 had a carcass density of 2.07 km^{-1} while site 2 had a density of 2.61 km^{-1}. The locations of carcasses were recorded with the aid of a handheld global positioning satellite (GPS) unit. The technician wore gloves and rubber boots to prevent tainting the carcasses with human scent (Whelan et al. 1994). Vegetation cover (percentage) and average vegetation height (centimetres) was visually estimated in a circle of 3m radius around the carcass according to Ponce et al. (2010). Each carcass was photographed with an identification number to allow comparison between its initial and subsequent appearances.

Carcasses were revisited daily at the start of the trial (i.e. days 1-7) and then on selected days (day 14, 21, 28, 48 and 90) because the majority of disappearances occur soon after placement or collisions (e.g. Smallwood 2007, Prosser et al. 2008). During each visit the presence or absence of carcasses, degree of scavenging intensity (light, medium or heavy), distance moved (m) and evidence of scavengers (e.g. tracks or scat) were recorded. Scavenging intensity was recorded as light (several feathers removed and carcass relatively intact), moderate (less than half of the carcass flesh consumed) and heavy (carcass dismembered or more than half of the flesh consumed). A carcass was considered absent if fewer than five feathers were located, because it is not uncommon for feathers to be lost during moulting or fighting, and thus several feathers cannot reliably represent a power line collision casualty (Bevanger 1999).

When a carcass was not found, a 10 m radius circle was walked around the initial location with the observer searching for any signs (e.g. feathers or drag marks). If the carcass was not located, the search distance was increased to 20 m. If a carcass trail was spotted, it was followed to its conclusion, as would have been normal practice during power line surveys. New locations of moved carcasses were recorded with a GPS unit to calculate the distance moved, vegetation measurements were taken and their persistence at the new site monitored.

In addition to carcasses, 20 feather piles were placed, with respective densities of 0.79 km^{-1} at site 1 and 1.5 km^{-1} at site 2. The purpose of putting out feather piles was to determine whether there was a difference between feather pile and carcass detection and to investigate how long feather piles would persist for, before no longer reliably representing a collision victim (i.e. until less than 5 feather remained). Feather piles consisted of 15 Ludwig's Bustard feathers (a combination of small breast feathers and larger wing feathers derived from carcasses found by J. Shaw during previous power line transects) and were placed at randomly selected sites using the same protocol used for carcasses. Feather piles were placed in the field on the same day as carcasses and revisited on the same survey days as carcasses. The number of feathers remaining within a 10 m-radius circle was recorded to provide an indication of feather pile persistence.

Search Bias

The search bias investigation was conducted, firstly, to shed light on the detection efficiency of observers and secondly to test whether observer experience played a part in detection efficiency. Detection trials were conducted on 3 separate occasions to determine the impact of carcass deterioration on detection by observers. The first detection trial took place 24 hours after the placement of carcasses and feather piles, with the second and third trials taking place 48 and 90 days after initial placement.

Observers conducting the search trials were considered either experienced or naïve. Naïve observers took part in all 3 trials. Experienced observers only took part in the first (24 hours after placement) and third (90 days after placement) trials. The effect of observer experience was investigated because it has the potential to significantly affect collision rate estimates, especially when estimates are based on large-scale extrapolation from relatively few carcass counts. The definition of experience was adopted from Ponce et al. (2010) i.e. number of km walked under power lines before the present study.

Observers walked at a steady pace (approximately 4 km h^{-1}) searching directly under the power line and recorded the location of any carcasses and feather piles detected. The recommended zig-zag pattern (APLIC 1994) was not used because of time constraints. The second observer followed once the first had disappeared from sight (approximately 30 minutes). Immediately after completion of the trial any carcasses or feather piles undetected by both observers were visited by a field technician not involved in the searches to determine whether they had been missed or were absent altogether. Photographs were taken of each carcass to monitor deterioration throughout the length of the experiment.

Analytical Methods

All data analysis was conducted in R 2.4.1 (R Development Core Team 2008). All analysis used a GLM in a Binary response (i.e. carcass found vs not found) with logit link function to analyse differences between the detection rates of observers. This was repeated for feather pile detection.

Data were analysed to determine whether there was a difference between detection rates of fresh carcasses (trial 1) and carcasses exposed to scavengers and the elements (trials 2 & 3). Detection of geese carcasses was converted into 'successes' and 'failures' according to how many observers detected each carcass (i.e. if both observers detected the same carcass then it was classified as two successes: zero failures).

To establish the factors that influenced carcass detection by observers (and removal by scavengers). For the first trial I included vegetation cover, vegetation height and carcass distance from the line as factors. For the second and third trials, in addition to the three factors mentioned above, I also included maximum vegetation height, spread of the carcass (high, medium & low) and visibility of the carcass (see Appendix 4 for explanatory variables and their abbreviations). To investigate the importance of each explanatory variable I used the corrected Akaike's Information Criterion (AICc) to select the best model from a collection of models with different explanatory variables.

Corrected AIC was preferred to the normal AIC because AICc performs better when sample sizes are small relative to the number of parameters (n/K<40, Burnham & Anderson 2004). AIC does, however, converge to AIC as sample size increases (Burnham & Anderson 2004). Corrected AIC was computed as follows

$$\mathrm{AICc} = -2\log\big(L(\theta)\big) + 2K + \frac{2K\,(K+1)}{n-K-1}$$

where $\log(L(\theta))$ is the log-likelihood at its maximum numerical value and K is the number of parameters in the model (Burnham & Anderson 2004).

The models with the lowest AICc values are the best-fit (Burnham & Anderson 2004). AICc values are not interpretable by themselves, so subtracting the model with the lowest AICc from the AICc values of all other models provided value with which to rank the models:

$$\Delta_i\mathrm{AICc} = \mathrm{AICc}_i - \mathrm{minAICc}$$

The best model (lowest AICc) receives a $\Delta = 0$. Subsequent models are considered to provide as good a fit to the data as the minimum model if $\Delta_i < 2$.

Akaike weights (w_i) were also calculated, which present the likelihood of the model with reference to the data (Burnham & Anderson 2004). In this way different models can be compared to each other providing strength for a particular model. The weights were normalized so they add up to one:

$$Wi = \frac{\exp\left(-\frac{\Delta i}{2}\right)}{\sum \exp\left(-\frac{-\Delta r}{2}\right)}$$

Overall Bias Correction Factor

To correct for losses (e.g. through scavenger activity and observer error) we calculated an overall correction factor. The scavenger bias value is derived simply by calculating the proportion of carcasses completely removed by scavengers from the total number of carcasses put out. Similarly the search bias factor is calculated by simply taking the proportion of carcasses missed by an observer (or averaged across several observers).

I used Bevanger's (1995) formula to calculate the overall bias correction (OBC) factor. The overall correction factor is a product of all the bias factors (subtracted from the inverse of one) i.e. $\frac{1}{1-habitat\ bias}$ x $\frac{1}{1-search\ bias}$ x $\frac{1}{1-scavenger\ bias}$x $\frac{1}{1-crippling\ bias}$. The overall correction factor is then multiplied with the annual baseline mortality rate (R_{baseline}) to produce bias adjusted mortality estimates ($R_{corrected}$):

$$Rcorrected = \frac{\text{Number of birds killed}}{\text{Length of power line monitored (km)}} \text{ X OBC Factor}$$

2.3 Results

Scavenger Bias

After 1 day, scavengers had detected 25% of carcasses. Detection exceeded 50% by day three and increased steadily up to 88% after seven days (Fig. 2.2). On day 28, 93% (n = 41) of carcasses had been detected which means only 3 carcasses were judged to have remained undetected for the full trial period.

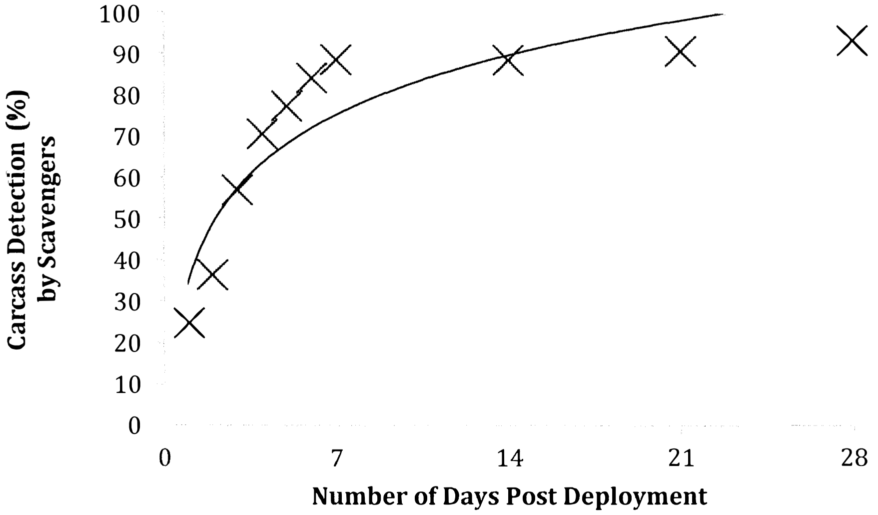

Figure 2.2 Cumulative percentage of carcass detection by scavengers on survey dates. The curve represents the best logarithmic model to fit the detection data ($y = 21.116\ln(x) + 34.097$)

In total 61% of the geese were moved by scavengers at some stage during the initial 28-day monitoring period. Of those that were moved, 92% of their total distance moved occurred in the first week following placement. The maximum distance a single carcass was moved was 83 m.

Another interesting observation from this study that may have affected carcass detection rates was the final location of carcasses. During the initial random placement of carcasses, five carcasses (11%) ended up directly underneath the power line. On day 90, 29% (n =11) of the remaining carcasses were found directly beneath the power line. It appears that scavengers actively moved carcasses to the Eskom track beneath power lines.

Six carcasses (14%) were removed completely during the trial period (Fig. 2.3). None disappeared during the first day, but 3 carcasses were removed by day 2 and by day 3 an additional two carcasses disappeared. The final carcass disappeared between day 14 and day 21. The other 38 carcasses remained in the study area until day 90. Given the small number of carcasses removed none of the predictor variables (vegetation cover, average vegetation height and carcass distance from the line) could explain carcass removal.

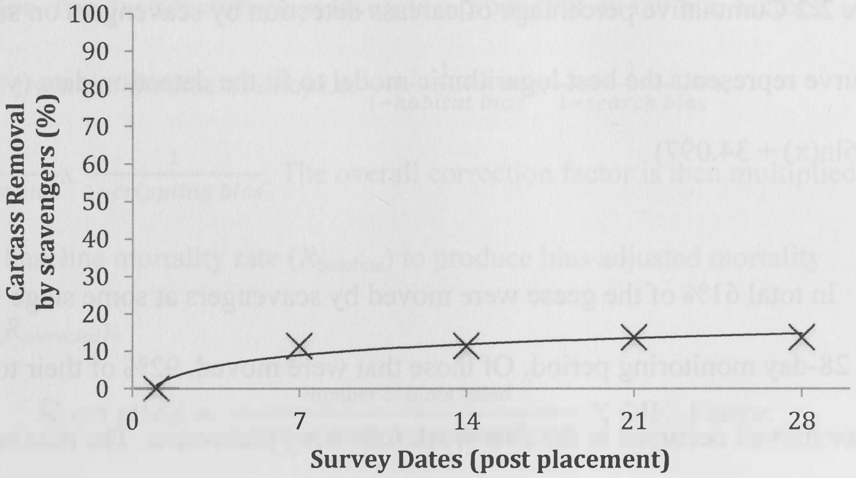

Figure 2.3 Cumulative percentage of carcass removal by scavengers on survey dates. The curve represents the best logarithmic model to fit the detection data ($y = 4.1511\ln(x) + 0.8993$)

It was not possible to statistically compare differences, in removal rates by scavengers, between Spurwing Geese (n = 3) and Egyptian Geese (n = 41) to determine whether scavengers favoured one species in particular. None of the larger

Spurwing Geese carcasses were removed by the end of the scavenger trial and only two of the three carcasses had been scavenged (two lightly scavenged, 1 undetected).

Search Bias

Carcass detection was relatively consistent throughout the 90-day monitoring period with little difference over time (Fig. 2.4). The greatest proportion of carcasses (75%) was found after day 1 with no significant difference between detection rates of the experienced and naïve observer (*P*=0.63). The overall detection dropped significantly to 61% during the second detection trial after 48 days (*P*=0.0485) when both observers were naïve (no significant difference between observers; *P*>0.05). During the final detection trial after 90 days overall detection rates increased to 74%, again without a statistically significant difference between experienced and naïve observers (*P*=0.12).

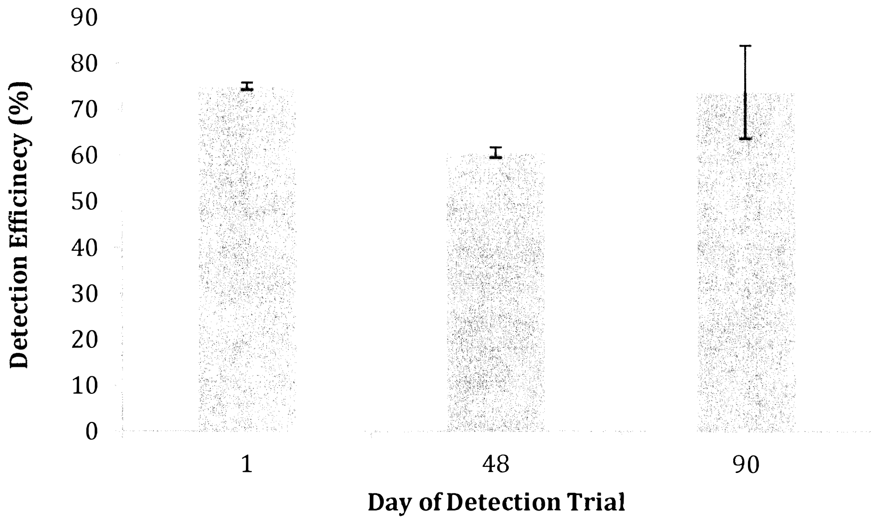

Figure 2.4 Carcass detection efficiency across three search trials (trial 1 & 3 conducted by an experienced and naïve observer, trial 2 conducted by 2 naïve observers).

There was no significant difference between carcass detection of the first and third trials (*P*=0.847) nor was their a difference between the second and third trials but this was border line (*P*=0.086) Within trials there was no effect of experience on carcass detection rates nor was there any significance overall between experienced and naïve observers (*P*=0.154 – calculated using data from trial 1 & 3). Experienced observers did however locate more carcasses than naïve observers during the first and third trials. On average experienced observers located 79% of carcasses whereas naïve observers located 69% of carcasses. Figure 2.5 presents two examples of carcass deterioration over time.

Figure 2.5 Photographic timeline of carcass deterioration on days 1, 7, 48 & 90. Carcass A illustrates slower scavenging while Carcass B illustrates rapid scavenging.

Feather pile detection dropped off sharply after 24 hours (first detection trial) (Fig. 2.6). Detection rates averaged 63% after day 1 and subsequently decreased to 18% and 5% respectively after 48 and 90 days. There was no significant effect of experience on feather pile detection during any of the trials. Detection rate differences between carcasses and feather piles were only analysed for day 1 (subsequent trials had few feather piles). During the first trial significantly less feather piles (63%), compared to carcasses (75%), were detected (*P*=0.014).

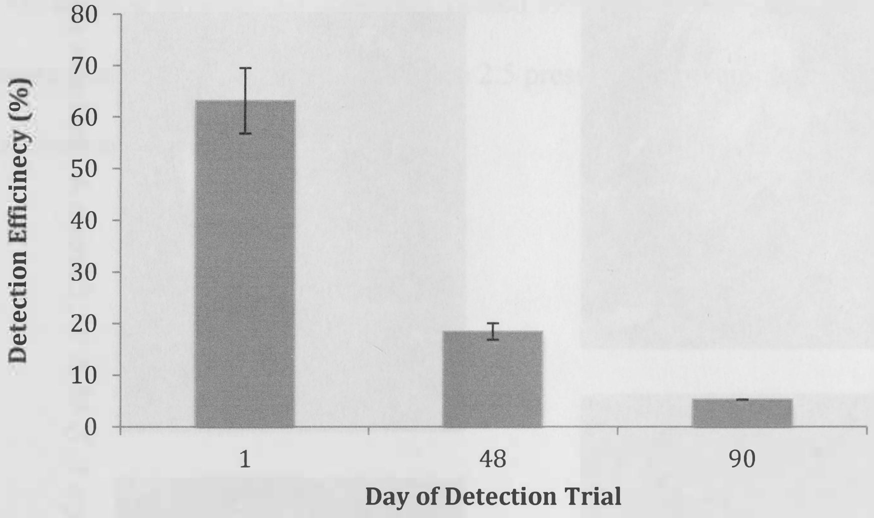

Figure 2.6 Feather pile detection efficiency across three search trials

The results from the univariate GLM analyses for factors affecting carcass and feather pile detectability are presented in Table 2.1. During the first trial carcass detection was significantly influenced by vegetation height (i.e. higher detection with lower vegetation height). Both vegetation cover and height significantly influenced feather pile detection during the first trial (analysis not conducted on subsequent feather pile detection due to small sample size).

Table 2.1 Results of the generalized linear model (univariate analyses) showing all significant and non-significant variables affecting carcass and feather pile detectability per trial.

Trial	Object	Variable	*P*	Estimate
1	Carcasses	**Height**	**0.033**	-0.063
		Cover	0.144	-0.024
		Distance	0.329	-0.090
	Feather Pile	**Distance**	**0.004**	-0.607
		Cover	**0.023**	-0.065
		Height	0.123	0.056
2	Carcasses	**Visibility**	**0.001**	-1.064
		Spread	**0.005**	-1.023
		Distance	**0.005**	-0.228
		Height	**0.008**	-0.089
		Max Height	**0.039**	-0.008
		Cover	0.137	-0.028
3	Carcasses	**Visibility**	**0.017**	-0.778
		Distance	**0.037**	-0.136
		Spread	0.081	-0.681
		Height	0.197	-0.039
		Cover	0.830	0.004
		Max Height	0.886	-0.001

Carcass detection in the second trial was affected by 5 of the 6 explanatory variables. Visibility of the carcass, spread of the carcass, distance of the carcass from the power line and average vegetation height were all highly significant factors. In the third trial only carcass visibility and carcass distance from the power line were significant factors. Multivariate analyses were conducted to produce a set of candidate models that best explained carcass detection by observers. The results from the GLMs are presented in Table 2.2.

Eight candidate models (including the null model) were produced for both carcass and feather pile detection by observers. As may have been expected from the univariate analyses the top 3 models all included average vegetation height. It is interesting to note that the top 3 models only performed slightly better than the null model. The model with all 3 explanatory variables performed best for feather pile detection and by far outperformed the null model.

For trial 2, 3 models received a ΔAICc < 2 with the best performing model containing all highly significant explanatory variables from the univariate analyses. The null model performed poorly. Finally in trial 3, the best-fit model only contained the visibility of the carcass. In total 5 models performed equally well and were only slightly better than the null model as a fit for the data.

Table 2.2 Summary of the best model selection by the generalized linear model (multivariate analyses), ranked according to ΔAICc, for carcass and feather pile detection by observers per trial (only the null model and models with a ΔAICc < 2 are presented below)

Model	AICc	ΔAICc	w_i[a]	K[b]	L[c]
Trial 1:Carcasses					
Vheight	81.24	**0**	0.322	2	1
Vheight$^+$Distance	82.12	**0.88**	0.208	3	0.645
Vcover$^+$Vheight	82.45	**1.21**	0.176	3	0.547
Null Model	84.43	3.19	0.065	1	0.203
Trial 1:Feather Piles					
Vcover$^+$Vheight$^+$ Distance	27.69	**0**	0.660	4	1
Vcover$^+$Vheight	29.60	**1.91**	0.254	3	0.385
Null Model	46.69	19.0	<0.01	1	<0.01
Trial 2:Carcasses					
Vheight$^+$Vmax$^+$Distance$^+$Visibility$^+$Cspread	72.47	**0**	0.666	6	1
Vheight$^+$Cspread$^+$Distance	72.82	**0.35**	0.552	4	0.837
Vheight$^+$Vmax$^+$Distance$^+$Visibility$^+$Cspread$^+$Vcover	74.14	**1.67**	0.286	7	0.434
Null Model	90.10	17.9	<0.01	1	<0.01
Trial 3:Carcasses					
Visibility	69.50	**0**	0.660	2	1
Distance	70.04	**0.54**	0.503	2	0.762
Visibility$^+$Cspread	70.19	**0.69**	0.467	3	0.708
Distance$^+$Cspread	70.20	**0.70**	0.465	3	0.704
Visibility$^+$Distance	70.98	**1.48**	0.314	3	0.476
Null Model	73.08	3.58	0.110	1	0.167

[a] Model weight

[b] Number of parameters

[c] Model likelihood as calculated by w_i/w_{top}. The model with the best ΔAICc, i.e. 0 was considered w_{top}

Overall Bias Correction Factor

The scavenger bias value for the Hantam Karoo was calculated at 0.14. This figure was derived from taking the number of carcasses completely removed as a proportion from those put out (6 out of 44 disappeared). The search bias value was calculated as 0.30. This value was derived by averaging the proportion of carcasses missed by both naïve and experienced observers (6 individuals over 3 trials) during detection trials.

Bevanger's (1995) formula was used to calculate the overall bias correction factor with which to multiply the baseline annual mortality rate to produce bias factor adjusted mortality estimates. Crippling and habitat bias were not included in the calculation. The following calculation was made:

$$\mathrm{OBC} = \frac{1}{1-habitat\ bias} \times \frac{1}{1-search\ bias} \times \frac{1}{1-scavenger\ bias} \times \frac{1}{1-crippling\ bias}$$

$$\mathrm{OBC} = \frac{1}{1-0.30} \times \frac{1}{1-0.14}$$

$$\mathrm{OBC} = 1.66$$

2.4 **Discussion**

Scavenger Bias

Scavenger bias correction factors play a crucial role in calculating accurate collision rates (Smallwood 2007). Collision rates that are not adjusted for this source of bias are likely to be underestimates (smallwood 2007). In this study Fgyptian and

Spurwing geese were used as surrogates for Ludwig's Bustards, to calculate a first estimate for scavenger bias in the Hantam Karoo.

Carcass disappearance rates are a function of carcass size. Ponce et al. (2010) reported that over 40% of large carcasses (Common Pheasants *Phasianus colchicus*) were removed after 28 days while small and very small carcass had experienced losses between 85-93% respectively. Flint et al. (2010), similar to my study, also used geese in scavenger trials as surrogates for 'large carcasses' and found that they persisted longer than smaller carcasses. In this study only 14% of carcasses were completely removed which is surprisingly low given that the Karoo is home to numerous small-medium sized mammalian predators as well as some large predators (Jenkins et al. 2011; Appendix 1). Conversations with farmers revealed that some believed they lost 30% of lambs to scavengers, mainly the Black-backed Jackals (*Canis mesomelas*). This suggests that predators capable of removing geese-sized carcass are certainly present in the study area but it is also possible that farmers actively control their populations.

Smallwood et al. (2010) showed the importance of carcass density in influencing carcass removal rates by scavengers. The authors argued that carcass removal trials place too many carcasses at unrealistic densities, which may result in scavenger swamping. In this study the density of carcasses was just over 2 km^{-1}. This density was thought to be a reasonable density given that Anderson (2002) found a mean density of 2.16 bustards km^{-1} (range = 0.3 – 5.4 km^{-1}) during several clearing and monitoring periods underneath high-voltage power lines in the Karoo. The density in this study was however lower than several other studies (e.g. Flint et al. 2010, Ponce et al. 2010).

Another possible explanation for the low removal rate is that geese are an inappropriate surrogate species for the Karoo habitat. Egyptian Geese weigh similar to a female Ludwig's Bustard, while Spurwing Geese weigh similar to a male Ludwig's Bustard. It is thus unlikely that weight affected removal rates. It also seems unlikely that the plumage characteristics of both Egyptian Geese and Spurwing Geese have affected carcass detection and thus removal rates. Scavengers detected most carcasses (93%) within a week and only 3 remained, apparently, undetected for the full duration of the study. This compares well with the study by Ponce et al. (2010) who showed that 94% of carcasses were detected after 7 days.

Palatability of geese carcasses is also unlikely to have influenced disappearance rates because most carcasses were heavily scavenged. It seems that most scavengers consume carcasses where they are found.

Search Bias

Carcass detectability by observers of fresh carcasses (trial 1) was influenced by average vegetation height surrounding the carcass, with observers more likely to locate carcasses where the average vegetation height was lower. This result is supported by several studies (e.g. Philibert et al. 1993, Stevens et al. 2011). Fresh carcasses present a large obvious target thus the higher the surrounding vegetation the less likely its detection. During the second trial carcasses had deteriorated significantly (e.g. dismembered and discoloured; Fig. 2.5). Average vegetation height as well as maximum vegetation height, distance of the carcass from the line and how spread out the carcass was all influenced detection. Carcasses that were spread over a larger area presented more signs for the observer and the closer the carcass was to the centre of the search corridor the more likely an observer would detect it.

This pattern was also expected for the third detection trial but surprisingly only visibility of the carcass and distance of the carcass from the power line influenced detection significantly. After 90 days carcasses had deteriorated to bleached bones and pieces of wings. The fact that observers were only presented with bleached bones may explain the non-significant difference between detection rates of the first and third trial. One possible explanation as to why carcass deterioration did not result in lower detection rates is that bleached bones in the Karoo habitat may present an equally visible stimulus as large, fresh carcasses. The implication of this is that a power line search frequency of three months may still be appropriate to detect the majority of carcasses in the Karoo habitat. Another observation is that carcasses deteriorate very fast (Fig. 2.5), which has implications for the ageing of collision victims.

In this study carcasses found during power line surveys were classified according to the description provided by Anderson (2002). Carcasses from the removal trial that had been in the field for 7-12 weeks appeared as if they may have been 6 months to a year old. The approximate ageing of carcasses plays a crucial role in calculating accurate collision rates. The results from this carcass removal trial suggest observers are likely to overestimate the age of bird remains and thus omit them from periodic collision rate calculations making the assumption that they were missed during previous surveys.

Another interesting point for discussion is that 29% of carcasses were found directly underneath the power line on the Eskom track, during the third trial when initially only 11% of carcasses were located there after random placement (90 days previously). Scavengers may have moved carcasses to the Eskom track because it represents a slightly more exposed and vegetation free area from where scavengers may better monitor their surroundings.

Carcasses were easier to locate than feather piles. Stevens et al. (2011) showed that observers only located 2% of feather piles and in excess of 50% of carcasses 24 hours after placement. The results from this study echo the results by Stevens et al. (2011) although it was closer overall with 75% of carcasses and 63% of feather piles located 24 hours after placement respectively. Feather pile detection declined sharply because almost all feather piles had been removed by the wind after 90 days, which shows that feather evidence persists poorly for an extended period of time. Vegetation cover heavily influenced feather pile detection, during the first trial. I do not know of any other studies that have investigated what variables affect feather pile detection but this result implies that where vegetation cover is higher the current power line survey method detects only a small proportion of collision victims (but only if all that remains is a feather pile). Observers found individual feathers but as these cannot represent a collision with any certainty (Ponce et al. 2010) it suggests that a three-month search interval is too long (especially if carcasses are removed rapidly and all that remains is a feather pile).

In spite of the importance of search trials in estimating observer efficiency, which in turn is necessary to correct power line surveys, very few studies have looked into the influence of observer experience. A recent study by Ponce et al. (2010) showed that carcass detection increased with observer experience (defined as the number of km of power line surveyed) up to a ceiling. In their study a completely naïve observer only located 25% of carcasses during a trial whereas three other observers, who had each walked in excess of 600 km previously found 65% on average (57-70%). Ponce et al. (2010) did, however, caution the extrapolation of their results due to their small sample size of observers.

In this study six different observers were used (2 experienced; 4 naïve). The definition of experience was adopted from Ponce et al. (2010) i.e. number of km walked under power lines before the present study. Overall, once data were pooled from both naïve and both experienced observers (during trial 1 & 3) there was no significant influence of experience on detection (P=0.154). This result does however not take away from the need for trained personnel to conduct power line surveys in the Karoo because on each occasion experienced observers did locate more carcasses (10%). The difference may not be significant but if extrapolation takes place on a large scale, even small differences such as 10% may seriously affect estimates or correction factors.

Overall Bias Correction Factor

In this study the overall correction factor applied was 1.66. I chose not to include habitat bias because no sections in the study site had any unsearchable habitat. In other studies estimates of 0.09 (Shaw et al. 2010) and 0.20-0.30 (Bevanger 1995, Janss & Ferrer 2000) have been applied. In favour of calculating an accurate and conservative bias correction factor, habitat bias was neglected but this may have resulted in underestimating the overall correction factor slightly.

Crippling bias is the most difficult of the bias factors to estimate. Savereno et al. (1996) observed 25 of 34 collision victims flying out of the search corridor (74%) making the assumption that all of these eventually died. Janss & Ferrer (2000) extracted an average of 0.50 from the literature. In light of the absence of data and observational accounts to base an estimate on, I did not apply a crippling bias correction factor. It is important to note however that given the collision problem for Ludwig's Bustards it seems plausible that some bustards will come to ground outside the search corridor. The overall correction factor will thus be an underestimate.

The search bias estimate of 0.30 is an average from detection trials of fresh and deteriorated carcasses. This is important because power line surveys in this study were conducted on a three-monthly frequency, so a wide range of carcass ages are encountered. The estimate for this study falls within the range suggested by Bevanger (0.2-0.4; 1995) and is similar to that of Savereno et al. (1996). My estimate is, however, most similar to that of Ponce et al. (2010) who showed that across four observers search bias for large carcasses was 0.28.

The scavenger bias estimate of 0.14 is relatively low when compared to other studies (Table 1.1). The scavenger bias trial conducted by Shaw et al. (2010) in the Overberg Wheatbelt reported a scavenger bias of 0.42 and only took place 400 km to the south of Calvinia. The estimate in my study is encouraging for the justification of using power line surveys to estimate the number of casualties from collisions. My estimate, however, is based on a relatively small carcass sample size, conducted during a single season and on two sites located in close proximity to a town and running parallel to a road system (one major & one minor). Carcass removal rates may be higher further away from human settlement and activity. It is also important to consider predator management by different landowners. Conversations with farmers revealed that some actively tried to control the number of predators by putting out traps while others did not.

The overall correction factor of 1.66 calculated in this study is lower than estimates calculated for other large birds. Janss and & Ferrer (2000) applied an overall correction factor of 2.5 for great bustards (*Otis tarda*) and common cranes (*Grus grus*) in Spain. Shaw et al. (2010) calculated an overall correction factor of 2.99 for blue cranes (*Anthropoides paradiseus*), which suggests only a third of collision victims are actually accounted for. The scavenger bias estimate in my study should be treated as a first estimate for Ludwig's Bustards and should not be viewed as the norm for the entire Karoo or range of the Ludwig's Bustard.

CHAPTER 3

Ludwig's Bustard Collision Rates on Low-Voltage Distribution Lines

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3.1 Introduction

Bird mortality from collisions with power lines is a serious conservation challenge worldwide (Rubolini et al. 2005, Chapter 1). Collision mortality varies greatly among species (Janss 2000). Species characterized by high wing loadings and low aspect ratios (e.g. bustards & cranes) are especially susceptible because they have limited maneuverability in flight (Janss 2000). In addition, species with relatively small visual fields when flying are also likely collision victims (Martine & Shaw 2010). These physical characteristics interact with environmental factors (e.g. weather), behavioural factors (e.g. nomadism) and anthropogenic factors (e.g. power line height) to create an unpredictable and complex challenge for conservationists (Drewitt & Langston 2008).

In South Africa power lines are also implicated in avifaunal mortalities (e.g. Shaw et al. 2010). Barnes (2000) reported that eight of the top ten collision victims were Red Listed species. Power lines are also thought to be responsible for large annual losses of Ludwig's Bustard, which may ultimately lead to a population decline (Anderson 2002, Jenkins et al. 2011). Anderson (2002) estimated a collision rate of 1.95 km^{-}1.y^{-1} on transmission lines (132-400 kV) on the eastern Nama Karoo whereas Jenkins et al. (2011) reported a lower collision rate of 0.63 km^{-}1.y^{-1} on transmission lines throughout the Karoo. The latter study concluded that approximately 11-15% of the population died annually (Jenkins et al. 2011). As a result Ludwig's Bustard was up-listed to Endangered on the IUCN Red List (http://www.iucnredlist.org/apps/redlist/ 2010) and its conservation status is unlikely to improve given the expected expansion of Eskom's power grid and the current ineffectiveness of line marking devices (Jenkins et al. 2010). Studies to date have focused on the impacts of high-voltage transmission lines (≥132 kV, e.g. Anderson 2002). However, the length of South Africa's low-voltage distribution line network is several times greater than the high-voltage network. This concerning because the Eskom/EWT partnership (2008) reported that approximately 50% of Ludwig's Bustard collisions recorded since 1996 have been on distribution lines. In this Chapter I present a first estimate of Ludwig's Bustard collision rates on low-voltage distribution lines, with and without bias correction factors calculated in Chapter 2.

3.2 Study Area & Methods

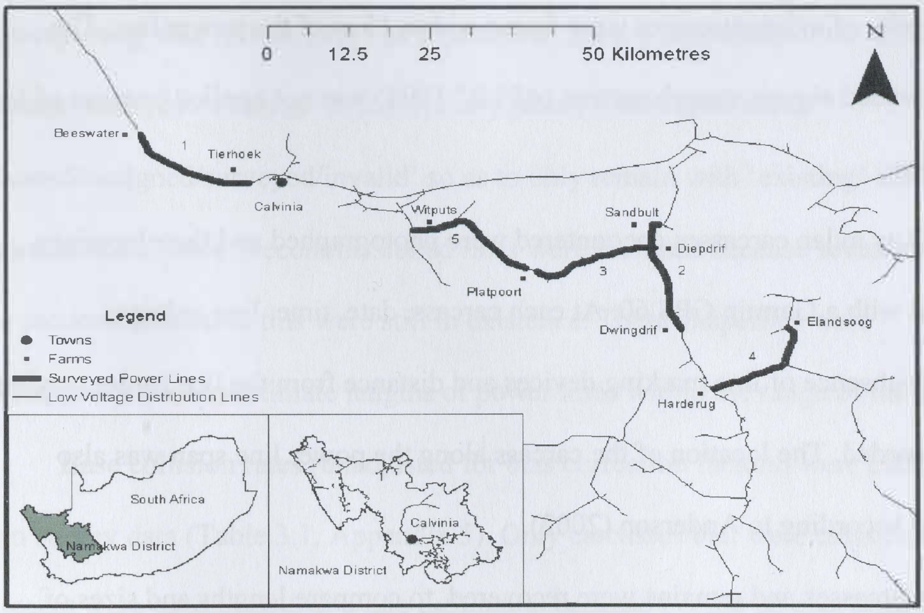

Figure 3.1 The study area around Calvinia in the Namakwa District of the Northern Cape, South Africa. Lines show electricity distribution lines with bold segments showing the five power line transects surveyed in the study.

The study was conducted in the Namakwa District around the town of Calvinia (Fig. 3.1). Fieldwork was conducted between September 2011 (survey 1) and December 2011 (survey 2). Five sections of low-voltage power lines were surveyed on foot, each ranging from 17-21 km long, for a total of 99 km (Fig.3.1). These representative sections were all situated within 80 km from Calvinia. Power line sections were selected based primarily on travel distance and land access permission. Two of the 20 km sections (sections 2 & 3 on Fig. 3.1) had been surveyed two months prior to the current survey while the remaining three sections had not been surveyed previously.

Field workers walked at a steady pace directly under the power lines, actively searching the area roughly 15 m either side of the line. Bevanger & Broseth (2004) used a search width of 5-10 m while other studies searched up to 50 m either side (Sundar & Choudhury 2005, Ponce et al. 2010). The most appropriate search width is entirely dependent on vegetation type and height but Bevanger (1999) reported that the majority of avian carcasses were found within 15 m of the power line. The recommended zig-zag search pattern (APLIC 1994) was not applied because of time constraints.

Any avian carcasses encountered were photographed and their locations recorded with a Garmin GPS 60. At each carcass, date, time, line voltage, presence/absence of line marking devices and distance from the line (outer conductor) were recorded. The location of the carcass along the power line span was also recorded according to Anderson (2002).

Carcasses and remains were recovered, to compare lengths and sizes of selected bones (where possible) with skeletal specimens at the University of Cape Town, for species identification and sexing. All remains were cleared to prevent double counting on subsequent surveys. Where carcasses could not be removed (e.g. carcasses stuck in a gulley or too heavy to carry) they were marked clearly with spray paint or dragged out of the search corridor. Carcasses were classified into four states according to Anderson (2002; Fresh ≤1 week old, Recent ≤ 2 months, Fairly Old ≤ 12 months, Very Old ≥ 12 months). All carcasses and remains located were assumed to be collision victims unless the species was known to be susceptible to electrocutions (e.g. crows found under pylons).

Pearson's Chi-squared Goodness-of-fit tests were conducted to analyse the sex ratio of Ludwig's Bustard carcasses and to determine whether their location along the power line span was random.

I used ArcGIS 9.3.1 (Geographical Information System) software with several GIS extensions. Data were derived from several sources and data layers were projected in an Albers Equal-Area Conic projection to calculate distances. ArcGIS was used to create a shapefile of the Ludwig's Bustard core and outer ranges using atlas-reporting data (Allan 1997) as a guideline. Eskom shapefiles of the distribution network were first 'cleaned' to remove any power lines classified as 'planned/designed/surveyed/invalid' so as to only remain with 'existing' and '(de) commissioned' lines. Decommissioned lines were included because several power line sections labeled as this were still in existence. These shapefiles were subsequently used to estimate lengths of power lines within the range of the species.

Base collision rates (unadjusted for bias correction factors) were estimated from survey data (Table 3.1, Appendix 5). Only carcasses that were classified as fresh or recent were used in collision rate estimation because I could be confident that those carcasses found in December had occurred in the 3-month sampling period (September – December). This was repeated for carcasses initially found during the

September survey to account for the period July to September. Fairly old and very old carcasses were not included in the analysis because it is impossible to know how long they had been there and they could simply have been missed from one survey to the next. This method probably underestimated the collision rate. A collision rate per 3-month interval was calculated for each survey and then averaged, before extrapolating for the duration of a year. Estimates were subsequently adjusted for scavenger and search bias in a stepwise fashion (Table 3.2). The scavenger bias correction factor was calculated as 1.16 (1/1-0.14) while the search bias correction factor was calculated as 1.43 (1/1-0.3).

To calculate 95% confidence intervals for the collision rate estimation, the number of fresh and recent Ludwig's Bustard carcasses found on each km was bootstrapped (1,000 iterations). To calculate the proportion of population killed annually, I averaged the upper and lower estimate of the population in the late 1980s and used that as the current population size (Allan 1994) i.e. (56,000 + 81,000)/2 = 68,500.

To calculate the annual mortality of Ludwig's Bustards the total length of power lines in the core range was multiplied by the annual mortality rate. Collision rates in the outer range of the Ludwig's Bustard were assumed to be half the rate in the core range (following Jenkins et al. 2011). These figures were added together to provide the overall number of birds killed.

3.3 Results

Most bird collision carcasses found during both surveys were Ludwig's Bustards (79% - Table 3.1). The crow and raven carcasses recovered were assumed to be electrocution victims as they were found directly beneath pylon structures and are known to sit upon pylons. Unidentified bustards accounted for 11% of collision victims and were not included in the collision rate estimation in favour of a conservative estimate.

Table 3.1 Number of collision and electrocution carcasses of all species found during both power line surveys

Common Name	**Scientific Name**	**Collisions**	**Electrocutions**
Ludwig's Bustard	*Neotis ludwigii*	22	0
Karoo Korhaan	*Eupodotis vigorsii*	2	0
Spur-winged Goose	*Plectropterus gambensis*	1	0
Cape Crow	*Corvus capensis*	0	3
White-necked Raven	*Corvus albicollis*	0	1
Unidentified Bustards	*N. ludwigii/Ardeotis kori*	3	0
Total		**28**	**4**

Ludwig's Bustard Collisions

Most collisions occurred in the midspan section (Appendix 3) (χ^2=9.8, df=2, P<0.05) (Fig. 3.2). Over 95% of Ludwig's Bustard carcasses were found within 5 m either side of the power line (Fig. 3.3). Most (91%) of the 22 Ludwig's Bustard carcasses could be sexed. Carcasses were predominantly male (65%) but this was not significantly different from a 1:1 sex ratio (χ^2 = 1.8, df = 1, P = 0.18), possibly due to a small sample size.

The base collision rate from the two surveys was calculated at 0.27 $km^{-1}.y^{-1}$ (Table 3.2). Approximately 63,000 km of low-voltage distribution lines are found within the range of the Ludwig's Bustard, of which 54% is found within the core range (Appendix 6). Most of this extensive network is found within South Africa (79%). Simple extrapolation of uncorrected collision rates suggests that in the order of 13,000 (1,500 – 14,200) Ludwig's Bustards die annually through collision with power lines, which accounts for approximately 19% of the population. The adjusted collision rate of 0.45 $km^{-1}.y^{-1}$ results in an annual mortality of 22,000 (2,000 – 23,500) individuals or 32% of the population.

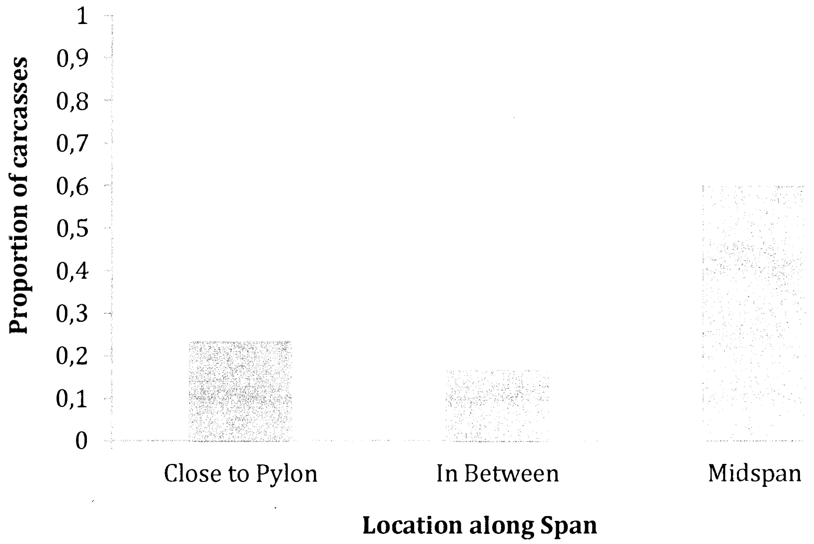

Figure 3.2 Proportion of Ludwig's Bustard carcasses found beneath different sections of the power line span (weighted to adjust for lengths of sections).

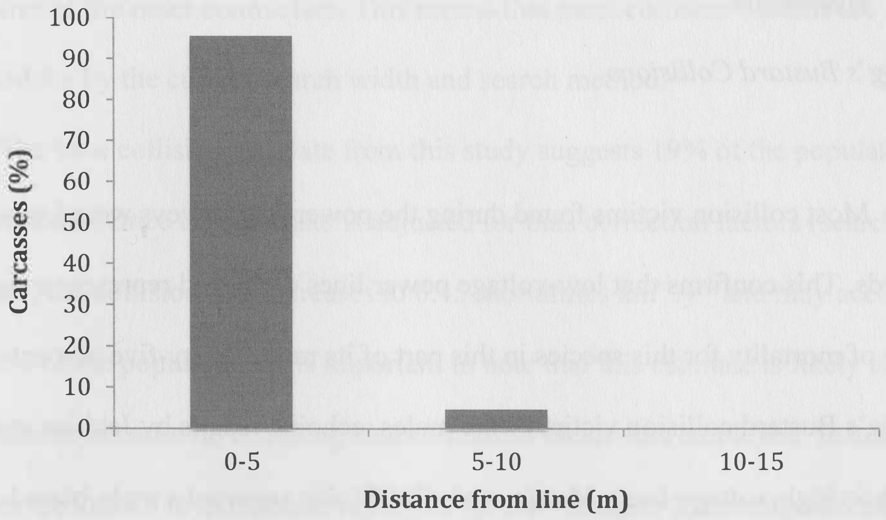

Figure 3.3 Perpendicular distances of Ludwig's Bustard carcasses from the outer cable of the power line.

Table 3.2 Mean collision rates (mortalities. km^{-1}.y^{-1} (with bootstrapped 95% confidence intervals) for Ludwig's Bustard. Search and scavenger bias correction factors were introduced in a stepwise fashion i.e. scavenger bias is the base collision rate adjusted for scavenger bias (see Appendix 7 for calculation).

	Base Estimate	Plus Scavenger Bias	Plus Search Bias
Collision Rate	**0.27**	**0.31**	**0.45**
	(0.03 – 0.29)	(0.03 – 0.34)	(0.04 – 0.48)

3.4 Discussion

Ludwig's Bustard Collisions

Most collision victims found during the power line surveys were Ludwig's Bustards. This confirms that low-voltage power lines do indeed represent a significant source of mortality for this species in this part of its range. Sixty-five percent of Ludwig's Bustard collision victims were males, echoing results by Jenkins et al. (2011) on high-voltage lines. Martin et al. (2007) also reported a male-biased mortality in the Great Bustard as a result of hunting and power line collisions.

Jenkins et al. (2011) discussed that this skewed mortality ratio was likely due to the males being heavier and thus less maneuverable to avoid collisions. A different explanation the same authors proposed was that fewer females were located because their carcasses weigh less and can thus be more easily removed by scavengers. This study used larger and heavier Spurwing geese as a surrogate for male Ludwig's Bustards and smaller, lighter Egyptian geese as surrogates for female Ludwig's Bustards. All 6 carcasses removed during the scavenger trial (Chapter 2) were Egyptian geese but this is not enough to support the idea that smaller female Ludwig's Bustards are more removable because of other confounding variables such as differences in olfactory and visual stimuli.

This study demonstrated that Ludwig's Bustards, like many collision victims, are significantly more susceptible to collisions with the midspan region of power lines (e.g. Anderson 2002, Shaw et al. 2010). It would be erroneous to conclude this was a ubiquitous pattern but it may hint at a testable hypothesis for the effectiveness of line-marking devices. Beneath power lines all but one of the carcasses was located within five metres of the outer conductors. This means that most collision victims are accounted for by the current search width and search method.

The base collision estimate from this study suggests 19% of the population is killed annually. Once this estimate is adjusted for bias correction factors (search & scavenger) the collision rate increases to 0.45 mortalities $km^{-1}.y^{-1}$ and may account for up to 32% of the population. It is important to note that this estimate is likely to be an underestimate because no crippling bias correction factor was employed. In addition, carcasses are known to deteriorate rapidly (Fig. 2.4 - Chapter 2) turning into bleached bones. This study omitted all Ludwig's Bustard carcasses that could not confidently be classified as fresh or recent. It is thus highly likely that I have underestimated the number of collision victims.

These results point to several possible sources of error. The first likely explanation being that the initial population estimate of Ludwig's Bustards conducted in the late eighties (Allan 1994) was a considerable underestimate. If these mortality estimates are accurate the population must have been an order of magnitude larger to sustain such heavy losses for several decades. It is also impossible to speculate on the effect of these losses on the population because little is known about the demographic parameters of Ludwig's Bustards e.g. age of first reproduction (Jenkins et al. 2011). Martin et al. (2007) reported a mortality rate of 0.70 and 0.10 for radio-tagged juvenile Great Bustards in their first and second year in Spain. If these survival estimates are at all comparable to Ludwig's Bustards then my collision rates are a cause for concern.

Another possibility is that the collision rate calculated in this study is a significant overestimate. In this study a collision rate derived from approximately 100 km is extrapolated for over 63,000 km. Large-scale extrapolation from a relatively small power line sample size is not uncommon (Table 1.2). However, the obvious risk involved in such practice is that the selected study site may not be representative of the range as a whole. The study site around Calvinia may have a particularly high density of bustards or power lines crossing roosting habitat for example.

Calvinia is located firmly in the core range of the Ludwig's Bustard (Fig. 1.1). The densest region of the distribution line network however, is in the east of the species' range with a huge proportion located in the outer range and towards the edges of the species' range. It is highly likely that extrapolating the collision estimate from a single site in the core of the species' range has inflated the total number of casualties. Replication studies must be conducted in the east of the species' range to reveal whether collision rates are comparable to the 0.27 $km^{-1}.y^{-1}$.

It is also important to account for the possible effect of seasonality on the collision estimates of Ludwig's Bustards (Jenkins et al. 2011). Allan (1997) reported that Ludwig's Bustards migrated into the succulent Karoo during winter and spring in response to increased productivity from rainfall. It is possible that collision rates may be lower in the succulent Karoo during summer months when Ludwig's Bustards have moved east. It may thus be problematic to extrapolate an annual collision rate when I have only collected data for a single season but without further surveys it is difficult to say how much error is involved. Without repeating these surveys in subsequent seasons it will remain only a matter of speculation. In this study I followed Jenkins et al. (2011) by applying a 50% collision rate in the outer range of the species. This is an arbitrary figure and currently there are no data available to test the accuracy of this assumption. Given the scale of extrapolation used in this study it is possible that much error could be attributed to this point. The results presented in this report are a best estimate but they should be interpreted cautiously because of the reasons discussed above.

CHAPTER 4

Study Review and Synthesis

4.1 Synthesis & Future Research

The Ludwig's Bustard is highly susceptible to collisions with power lines. The base collision rate calculated for the distribution line network is approximately half the unadjusted collision rate calculated for Ludwig's Bustards on high-voltage transmission lines (Jenkins et al. 2011). Jenkins et al. (2011) calculated a collision rate of 0.63 $km^{-1}.y^{-1}$ which equated to approximately 8,600 casualties annually. In spite of the estimate for the distribution lines being considerably less, the sheer size of the distribution line network means that its impact is likely to be greater.

Jenkins et al. (2011) used the population estimates from the late eighties (Allan 1994) to estimate that 11-15% of the population was killed annually on high-voltage lines. Their estimate was however, not adjusted with bias correction factors. Only the scavenger bias correction factor, calculated in my study, can reasonably be applied to their estimate (they conducted surveys by car thus the search bias correction factor is not applicable). Once the transmission line collision rate estimate is adjusted for scavenger bias it suggests roughly 10,000 individuals are killed annually. Combining the adjusted estimates for both these studies suggests in the order of 32,000 individuals are killed annually (40-57% of the population).

I would caution the interpretation of these results, especially those derived from the distribution line network. As discussed in Chapter 3, the distribution line network estimate is derived from a single site (located in the core range) during a single season. Given the extent of the distribution network towards the edge of the species' range this estimate could be significantly inflated. However, the estimate calculated by Jenkins et al. was conducted on six sites throughout the Karoo region, increasing the robustness of their mean estimate of 0.66 mortalities $km^{-1}.yr^{-}$ (range = 0.20 – 1.81 mortalities $km^{-1}.yr^{-1}$). Despite questions about their accuracy these results do provide an indication of the scale of the collision problem for this species.

A population viability analysis (PVA) conducted for the MacQueen's Bustard in Kazakhstan showed that an annual mortality rate exceeding 7.2% of the adult population would lead to eventual extinction (Combreau et al. 2001). Jenkins et al. (2011) cautiously proposed an annual mortality ceiling of 16% for the Ludwig's Bustard. If the bias adjusted estimate from Jenkins et al. is taken to be accurate and is combined with even a fraction of the mortality rate estimated in my study this annual mortality ceiling is exceeded. The losses that the Ludwig's Bustard population is currently experiencing are almost certainly unsustainable.

If current trends are set to continue the Ludwig's Bustard is unlikely to persist. It is the mortality on the distribution line network that conservationists and Eskom will need to address if they are to stem these huge annual losses. With 79% of the low-voltage power line network currently existing in the South African range of the Ludwig's Bustard it is crucial that Eskom plays a leading role in testing possible mitigation devices.

The accuracy, severity and implications of these results for the Ludwig's Bustard are dependent on several factors. Arguably the most important of these is the current population size of the species. It is difficult to speculate on what effect these losses are currently having on the species because there are no up-to-date estimates and this should be a priority. Understanding the individual characteristics of each collision victim (e.g. male vs. female; adult vs. juvenile) is also important to understand what collision rate the population can reasonably sustain and what effect a potentially skewed sex ratio will have.

Surveys need to be replicated at sites in the core and outer ranges of the Ludwig's Bustard in order to compare the collision rates on larger spatial scale and to determine whether collision rates are indeed significantly lower in the outer ranges. In addition, carcass removal trials (with different carcass densities) need to be conducted wherever collision rates are estimated to gauge removal rates over the same spatial scale.

The discussion of mitigation devices on low-voltage power lines was beyond the scope of this study but data from this study provide the opportunity for another testable hypothesis. The midspan region of power lines kills most Ludwig's Bustards (Anderson 2002, this study) thus a future study could look at simply placing line-marking devices on the midspan section to determine whether the distribution of victims under power line spans changes.

4.2 Complications with the study

Carcass removal experiments are a crucial component of any study trying to estimate accurate collision rates. At the same time, they are hard to set up properly without introducing additional biases. Several studies have argued that the presence and thus scent of humans when placing a carcass may serve to attract or deter scavengers from an area (Flint et al. 2010, Ponce et al. 2010). The same can be true of daily or frequent carcass visits during the carcass-monitoring period. This could assist scavengers in locating carcasses and thus accelerate carcass detection and removal rates. Conversely, predators may be wary of visiting areas where humans have been, especially in areas where humans place traps to control predator populations.

It proved too difficult to secure two continuous and easily accesible10 km sections for the carcass removal trial. This would have made comparisons between the sites interesting. The presence of a relatively heavy traffic road on scavenger activity is also not known. Stevens et al. (2011) found that carcass removal rates were lower near roads but due to large confidence intervals they did not draw any conclusions. In addition, both sites were located within four km of Calvinia, which may also have acted as a scavenger deterrent or attractant.

Estimates from search trials are likely to be more accurate if they reflect the 'normal' density of carcasses to avoid observer effects. During power line surveys sometimes only a single carcass was found over a 10 km stretch. When an observer is aware that he/she could be locating up to 22 carcasses per 10 km they are likely to increase their search effort, in spite of efforts not to do so.

Another important variable is the type of land and predator management by landowners in the Karoo, which may either attract or deter predators. It is undesirable to extrapolate the results from several farms to the entire range of the Ludwig's Bustard because the local effects may be quite significant. Identifying the main types of scavengers active in the Karoo was beyond the scope of this study but should be relatively easy with the use of camera traps. Understanding the main scavenger species (i.e. density, home range size, territorial behaviour) however, will help to understand the carcass removal rates.

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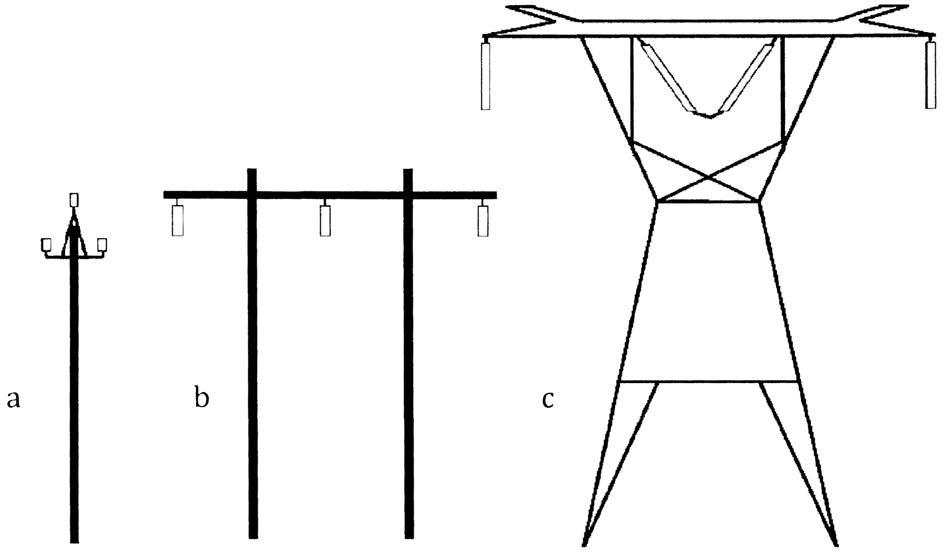
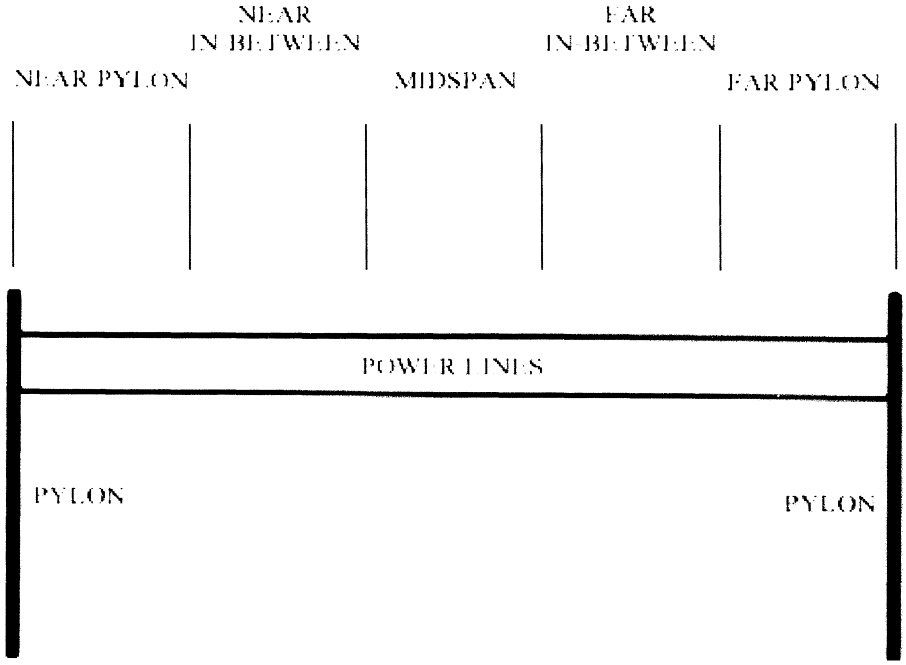
Appendix 1. Potential scavengers in the Karoo region

Common Name	Scientific Name
Caracal	*Caracal caracal*
Leopard	*Panthera pardus*
Cape Fox	*Vulpes chama*
Black-backed Jackal	*Canis mesomelas*
Domestic Dog	*Canis lupus familiaris*
African Wildcat	*Felis silvestris lybica*
Domestic Cat	*Felis catus*
Small spotted Genet	*Genetta genetta*
Meerkat	*Suricata suricatta*
Honey Badger	*Mellivora capensis*
Cape Porcupine	*Hystrix africaeaustralis*
Yellow Mongoose	*Cynictis penicillata*
Small Grey Mongoose	*Galerella pulverulenta*
Chacma Baboon	*Papio cynocephalus ursinus*
Humans	*Homo sapiens*
Cape Crow	*Corvus capensis*
Pied Crow	*Corvus albus*
White-necked Raven	*Corvus albicollis*
Pale Chanting Goshawk	*Melierax canorus*
Verreau's Eagle	*Aquila verreauxii*

Appendix 2. Typical configuration of (a) 11/22 kV and (b) 66 kV lines (both distribution lines) and (c) 132/400 kV transmission lines in South Africa (Not to scale). (Derived from Shaw et al. 2010)



Appendix 3. A typical power line section split into 5 separate sections by observers to judge where a carcass was found.



Appendix 4. Explanatory variables included in the GLM analysis to explain carcass and feather pile detection by observers during search trials

Factor	Notes	Abbreviation
Vegetation Cover	As a percentage, in a 3 m radius circle around the carcass	Vcover
Vegetation Height	Average height in a 3 m radius circle around the carcass	Vheight
Maximum Vegetation Height	Maximum height in a 3 m radius circle around the carcass	Vmax
Carcass distance from the line	Distance from outer conductor (Distance = 0 if under power line)	Distance
Spread of the carcass	Including bones and feathers classified as Low/Medium/High	Spread
Visibility	A measure of obstructions in the line of sight of the carcass classified as Poor/Moderate/Good	Visibility

Appendix 5. Ludwig's Bustard carcass data from two surveys of 99 km of distribution lines around Calvinia in 2011.

Site	Distance (km)	September				December			
		Fresh	Recent	Fairly Old	Very Old	Fresh	Recent	Fairly Old	Very Old
Tierhoek-Beeswater	17.4	-	-	-	-	-	1	-	-
Harderug-Elandsoog	21.0	-	1	1	3	1	2	-	-
Sandbult-Dwingdrif	21.2	-	-	3	-	-	-	-	-
Diepdrif-Platpoort	20.3	-	3	-	-	-	-	1	-
Platpoort-Witputs	19.1	1	1	-	1	-	2	-	1
Total	**99**	**1**	**5**	**4**	**4**	**1**	**5**	**1**	**1**

Appendix 6. Lengths (km) of existing distribution lines within the range of the Ludwig's Bustard

Country	Power line (kV)	Range	Total length (km)	
South Africa	≤ 33	Core	29 087	
		Outer	17 895	
	50 – 88	Core	1 755	
		Outer	995	
		Total	49 734	(79%)
Namibia	≤ 33	Core	2 648	
		Outer	8 895	
	50 – 88	Core	884	
		Outer	344	
		Total	13 620	(21%)
South Africa + Namibia		**Total**	63 354	

Appendix 7. Crude collision rates (birds $km^{-1}.yr^{-1}$) for Ludwig's Bustards at five sites along low voltage distribution lines around Calvinia, in the Karoo, South Africa.

Site (length)	Sampling Interval	Bustards Killed	Rate Birds $km^{-1}. yr^{-1}$
Sandbult-Dwingdrif (21.15 km)	April – July 2011 (3 months)	1	0.19
	July – September 2011 (2.07 months)	0	0
	September – December 2011 (2.73 months)	0	0
Diepdrif-Platpoort (20.34 km)	April – July 2011 (3 months)	1	0.2
	July – September 2011 (2.07 months)	3	0.87
	September – December 2011 (2.73 months)	0	0
Platpoort-Witputs (19.09 km)	June – September 2011 (3 months)	2	0.42
	September – December 2011 (2.73 months)	2	0.46
Harderug-Elandsoog (20.99 km)	June – September 2011 (3 months)	1	0.19
	September – December 2011 (2.73 months)	3	0.63
Tierhoek-Beeswater (17.40 km)	June – September 2011 (3 months)	0	0
	September – December 2011 (2.73 months)	1	0.26
All Lines (98.97 km)		**14**	**0.27**