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Mortality of sarus cranes (*Grus antigone*) due to electricity wires in Uttar Pradesh, India

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SUMMARY

Although overhead electrical wires are known to have caused severe declines of bird populations, there are no studies in India that address this danger, even for endangered species. Rates of mortality, factors affecting mortality and population effects of electrical wires on the globally endangered sarus crane (*Grus antigone*) were assessed for breeding and non-breeding cranes in Etawah and Mainpuri districts, Uttar Pradesh, India. Non-breeding cranes were most susceptible to wires and, within territories, mortalities were higher for pre-dispersed young. Similar proportions of non-breeding and breeding cranes were killed, together accounting for nearly 1% of the total sarus crane population annually. Supply wires accounted for the majority of sarus crane deaths, and only non-breeding cranes were killed by both supply and high-tension power lines. Non-breeding crane deaths at roost sites were correlated with numbers of roosting birds and numbers of wires at each site. Over 40% of 251 known sarus crane territories had at least one overhead wire posing a risk to breeding adults and pre-dispersed young. A risk index for wires over territories of cranes was computed; mortality was not affected by increasing the number and therefore risk posed by wires. Most crane deaths in territories occurred as a result of wires at edges of territories. Wires around roosting sites, territoriality and age of sarus cranes appear to be the most important factors affecting their mortality due to wires. Mitigation measures will be most effective around roost sites and for wires that border territories of breeding pairs.

Keywords: collision, electricity wires, electrocution, mortality rate, sarus crane, Uttar Pradesh

INTRODUCTION

Mortality related to power lines is known to affect migratory and non-migratory bird species (Hendersen *et al.* 1996; Bevanger 1998; Janss 2001; Rubolinie *et al.* 2001). Recent development and expansion of power grids in many countries is proving to be a major conservation problem to many threatened and endangered species (Crivelli *et al.* 1988; Allan 1996; Davis 1998; Donázar *et al.* 2002). Studies have attempted to understand power line related bird mortality and/or collision risk with respect to morphology (Bevanger 1998; Janss 2000), behaviour (flight frequency: Rusz *et al.* 1986; attraction to lighted structures: Ogden 1996), breeding status, age and wind speed (Henderson *et al.* 1996), and power line design and placement (Ferrer *et al.* 1991; McCann & Wilkins 1995; Janss & Ferrer 1998). Most studies have focused on single species, usually those of conservation concern or those that cause significant economic losses. These have documented rates of mortality (Tacha *et al.* 1979; Bevanger 1995; Henderson *et al.* 1996; Janss & Ferrer 2000; Donázar *et al.* 2002; Bevanger & Brøseth 2004), ways to reduce mortality (Morkill & Anderson 1993; Alonso *et al.* 1994; Brown & Drewien 1995; Janss & Ferrer 1998; Bevanger & Brøseth 2001) and methods to minimize electrical outages (Janss 1998). Few studies have paid attention to ecological characteristics of species (Henderson *et al.* 1996) and fewer still to the consequences at the population level due to wire-related mortality (Bevanger 1995).

Gruiformes, particularly cranes, are at high risk of mortality due to electrical wires (Bevanger 1998), and at least three of the 15 extant species experience mortalities at rates that are of concern to endangered species and local populations (US Fish & Wildlife Service 1994; McCann & Wilkins 1995; Allan 1996; Meine & Archibald 1996; Davis 1998; McCann & van Rooyen 2002; Wassenich 2003). There is little empirical information on the extent of mortality of most species of cranes (Brown & Drewien 1995) and long-term information on consequences to crane populations is rare (Masatomi 1991). Previous studies on crane mortality due to electricity wires have indicated that a variety of factors can affect such mortality, including age (Brown *et al.* 1987; Ward & Anderson 1992; Morkill & Anderson 1993; Brown & Drewien 1995), terrain (Brown *et al.* 1987), season (Faanes & Johnson 1992) and the type of wire (McCann & Wilkins 1995; Ward & Anderson 1992).

In India, the sarus crane (*Grus antigone*) is the only resident crane species and is globally threatened (BirdLife International 2001). Etawah and Mainpuri districts in Uttar

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Pradesh have the highest estimated population of this species (Archibald *et al.* 2003; Sundar 2005) with known instances of mortality due to electrical wires (Sundar & Choudhury 2001). While habitat destruction is known to be an important factor for decline in sarus crane populations, the contribution of mortality due to electrical wires to this important population has not been studied. Wire-related mortality is known from many areas in India and Nepal (C.K. Borad, S. Javid, B.M. Parasharya & R. Suwal, unpublished data 2003), but has not received specific attention.

In areas with year-long water supply, breeding sarus crane pairs defend perennial, well-defined territories and non-breeders live in mobile flocks roosting in large wetlands (K.S.G. Sundar, personal observation 1999–2002). Young cranes stay with parents on their natal territories until the next breeding season when they disperse or are chased away and join non-breeding flocks (K.S.G. Sundar, personal observation 1999–2002). Non-breeding cranes can comprise more than 50% of the population but information on their foraging range is not known (Sundar & Choudhury 2003; Sundar 2005). Breeding territorial adult cranes and pre-dispersed young are therefore only exposed to wires that border or are directly over the territory, while non-breeders are exposed to all the wires in their foraging and dispersal range. In this study, we attempted to determine the role of season, rainfall, breeding status, gender and age on sarus crane mortality due to electricity wires. We also aimed to determine the importance of electricity wire-related deaths at the population level and the potential risk of overhead wires to breeding sarus cranes. We provide a summary of crane mortality events across the globe to illustrate the seriousness of the problem to these taxa.

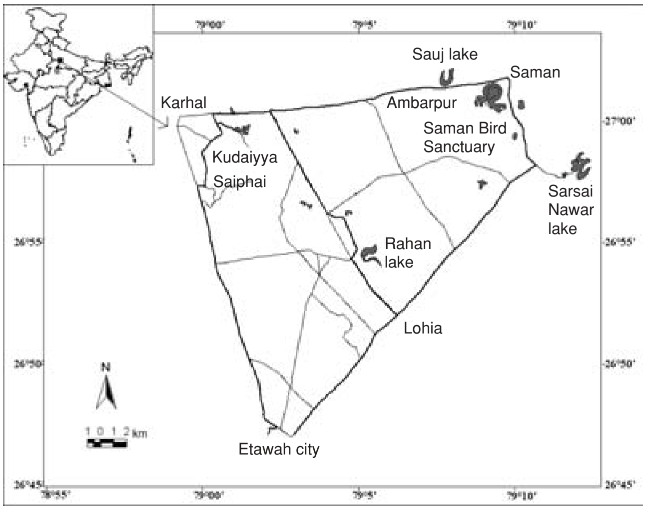

Figure 1 Outline map of the study area, showing the roads (lines) and wetlands (shaded areas) used to monitor territorial and non-breeding sarus cranes.

METHODS

Study area

Detailed fieldwork was carried out on an area of *c.* 50 km^2, encompassing the towns of Etawah, Karhal, Saman and Lohia on the border of Etawah and Mainpuri districts in the state of Uttar Pradesh, India (Fig. 1). This region of flat terrain comprises the western fringe of the Gangetic flood plains. The landscape is a mosaic of natural wetlands, crop fields, irrigation canals, and human habitation and associated structures, with trees thinly dispersed over the landscape. Uttar Pradesh has one of the highest densities of humans in the country with 500–700 people km^{-2}, most of whom are farmers (Anon. 2001). The principal crops are rice (*Oryza sativa*) in the monsoon and wheat (*Triticum aestivum*) in the winter. Three seasons could be differentiated: summer (March to June), monsoon (July to October) and winter (November to February). Most of the precipitation to the area was during the monsoon with an annual average rainfall (1990–2001) of 882 mm, and temperature varied between 1°C and > 45°C (District Magistrate's Office, Etawah, India, personal communication 2002). Morning and evening fog occurred for nearly two months in winter. Rainfall was measured at Etawah town and, during the study period, was higher than the average for the decade (2000: 2519 mm; 2001: 2394 mm). Further details on the study area can be found in Sundar (2004, 2005).

Field methods

Field observations were carried out between January 1999 and June 2002. We used plumage characteristics to recognize three broad age classes of cranes, namely juvenile (< 5 months of age), sub-adult (> 5 months, still in natal territory) and adult (including dispersed birds older than five months). Ages of young cranes in territories were known because they were monitored after hatching. We ascertained the gender of injured adult cranes during unison calling behaviour; the males called with opened wings and females with closed wings (Archibald 1976). To assess the effect of rainfall on mortality rates, we recorded daily rainfall using a rain gauge at Etawah city. Reason for mortality was assessed as collision if there were no obvious burn marks but the bird had fatal injuries, and as electrocution if they had burn marks. It was not possible to determine from the carcasses whether birds had first collided with wires and were electrocuted later.

Power lines

Two kinds of power lines were differentiated during the study. Supply wires consisted of two parallel wires made of steel-reinforced aluminium wires of 52.21–103.6 mm^2 at a height of 5.8 m from the ground carrying 200–400 V electricity (referred to as supply wires throughout the paper). High-tension power lines consisted of three sets of parallel wires and a top earth wire of 207 mm^2 steel-reinforced aluminium, with the lowest set 6.1 m from the ground and the terminating ground wire 10–12 m from the ground, and carried 11 000–13 500 V electricity (District Magistrate's office, Etawah, India, personal communication 2000; referred to as power lines throughout the paper). Wires broken and outages caused by crane collisions/electrocutions were documented whenever encountered.

Biases in mortality data

We followed Janss and Ferrer (2000) to correct for four kinds of biases in data on collision victims: (1) detection bias, (2) habitat bias, (3) removal bias and (4) crippling bias. For detection and habitat bias we used a value of 0.2, since sarus cranes are very large birds and the area monitored was largely open. We did not apply a removal bias since such a bias for birds >5 kg is unknown. Also, observations on fresh kills showed that while carcasses were frequently scavenged immediately after the death, signs of death (for example feathers and pelvic bones) remained for over a month at the site of the incident. A value of 0.5 was used as crippling bias. Values for bias used here are an average of values calculated in previous studies (see Janss & Ferrer 2000).

Estimating rate of mortality

To correct for losses, we followed Bevanger (1995), i.e. the inverse of one minus the bias, B $(1/(1-B_x))$. The total correction factor was a product of all correction factors, namely 1/(1-detection or habitat bias) × 1/(1-crippling bias) $= 1/(1-0.2) \times 1/(1-0.5) = 2.5$. The estimate of total mortality therefore was $2.5 \times$ the annual rate of mortality. Due to differing interactions with power lines of breeding and non-breeding cranes (see above), the rate of mortality was calculated separately depending on the breeding status of the cranes using methods described below.

Non-breeding sarus cranes

Mortality was investigated by regularly monitoring cranes along a road transect of 160 km, which covered five wetlands that were permanent roosting areas of *c.* 900 sarus cranes. Three of these wetlands (Kudaiyya, Sauj and Ambarpur; Fig. 1) had differing numbers of electricity wires over or adjacent to the wetland. Crane numbers in individual wetlands and feeding areas varied with human disturbance and season. Annually however, breeding cranes in the area experienced similar recruitment rates each year (K.S.G. Sundar & B.C. Choudhury, unpublished information 1999–2002), and annual rates of dispersal were assumed to be similar. Along the road, 108 km of wires were monitored, of which 85 km were supply wires, 15 km power lines and eight km were both. The road was surveyed on a motor bike with an additional observer driven at 25–40 km hr^{-1} an average of three times a week; the area below wires 50 m on either side was monitored and all kills encountered below wires were tabulated. Fresh carcasses were dissected to determine gender, scrutinized to determine cause of death (electrocution indicated by burn marks, collision indicated by injuries/fractures) and the type of wire that caused mortality noted whenever possible. Previous studies have demonstrated that the number of collisions of birds has no relation to the flight frequency over power lines (Rusz *et al.* 1986) and we did not quantify flight frequency. Crane deaths at roost sites were classified as breeding or non-breeding birds after careful scrutiny of known breeding pairs at the sites. Annual R for non-breeding cranes was calculated as the number of cranes dying per km of wire using the following formula:

$$R_n = \frac{\text{Number of birds killed}}{\text{Length of electricity wire monitored (km)}} \times 2.5 \qquad (1)$$

where 2.5 is the correction factor.

The calculated value was doubled for 2002 because fieldwork was conducted for only six months. Proportion of deaths from the total population was calculated from the total number of birds in all five wetlands. All congregations in the area were not enumerated and there was considerable movement of flocks between sites; proportions therefore are likely to be higher estimates.

Breeding sarus cranes

A total of 251 territorial pairs were located by presence of nests, chicks and territorial behaviour, and identified by number of chicks, location and physical markings. Extent of each territory was not determined very exactly during this study, which prevented calculation of the length of wires over each territory. These were monitored for one, two or three breeding seasons. For the 1999–2000 breeding season, observations began in December 1999 when most young had not fledged yet and constituted a complete breeding season. Each identified territory was visited at least twice a week, and when cranes were missing the area below wires and the rest of the territory was searched to confirm mortality. If the carcass or signs of death were not discovered, the young were considered to have dispersed. Since territory size did not exceed 50 ha and breeding adults were perennially territorial in the region (K.S.G. Sundar & B.C. Choudhury, unpublished information 1999–2002), crippling and deaths of adults and young could be reliably confirmed. At each carcass, cause of death (electrocution or collision), gender and age were determined as best as possible. Colour-banded cranes observed after they were dispersed were counted as non-breeding cranes. Since all mortality and injury events could be reliably observed a correction factor was not required for territories, and annual R was calculated as the number of birds killed per territory using the formula:

$$R_b = \frac{\text{Number of birds killed}}{\text{Number of territories monitored}} \qquad (2)$$

Proportion of deaths from the total population in territories was calculated considering number of territorial pairs and total number of fledged young known from these territories.

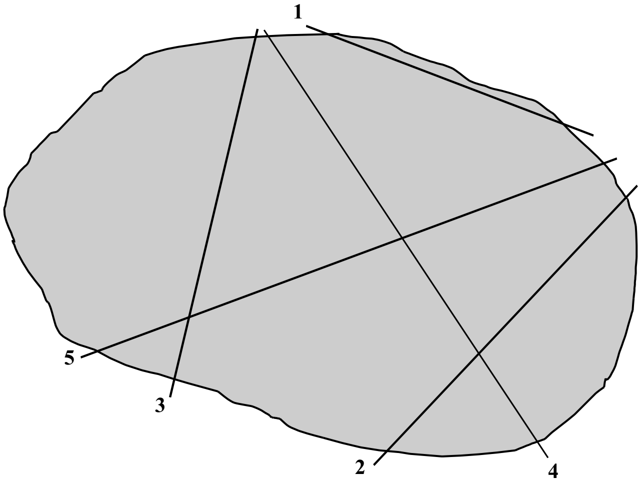

Figure 2 Criteria used to assign weights to wires towards calculation of the risk index (R_I) for sarus crane territories in Uttar Pradesh, India. The shaded polygon represents a hypothetical territory with electricity wires running overhead (lines), and numbers indicate weights assigned to each. See text for a detailed description of the calculation of R_I.

Risk of mortality to cranes in territories

For cranes in territories, we assessed the potential risk posed by wires running over the territory. The extents of territories were ascertained by observations of territorial interactions (unison calling) of identified pairs. At least 35 interactions on the edge of territories of each pair spread across a full year were used to determine territories. For each territory, number of wires (supply and power) and their position relative to the territory (Fig. 2) were determined. Wires were weighted according to their position over the territory. These weights were 5 where the wire divided the territory into approximately two halves, 4 where the wire divided the territory into one-third and two-thirds, 3 where the wire divided the territory into one-quarter and three-quarters, 2 where wire divided the territory into one-fifth and four-fifths, and 1 where wire was at the border of the territory (Fig. 2). A wire that divided the territory into two equal halves had the longest segment that cranes could fly into, and therefore was assumed to afford the greatest risk. Since cranes maintained perennial territories, we assumed that flight activity was distributed equally across the entire territory. Total risk that wires posed to cranes in territories was calculated as a risk index (R_I) using the formula for weighted average (Sokal & Rohlf 1995):

$$R_I = Y_w = \frac{\sum_{i=I}^{n} w_i Y_i}{\sum_{i=I}^{n} w_i} \qquad (3)$$

where Y_w = weighted average, Y_i = weights assigned to different wires, and w_i = frequency of wires.

Cranes in territories did not fly as high as non-territorial cranes (K.S.G. Sundar, personal observation 1998–2002). Power lines were nearly twice as high as supply wires and posed a smaller risk to territorial cranes. While calculating R_I, we assumed that power lines posed half the risk of supply wires. For territories that had both kinds of wires running overhead, risk was calculated separately for supply wires and power lines, halved for power lines, and added to the risk calculated for supply wires to obtain total R_I values.

Data analyses

R_n and R_b have different scales of measurement and are not directly comparable. However, the proportion of cranes killed each year calculated for cranes of differing breeding status was comparable. All data were checked for normality prior to analyses (Kolmogorov-Smirnov one-sample test of normality), and parametric tests were used only for normally distributed data. Effect of season and site were calculated using χ^2 goodness-of-fit tests. A Fisher's exact test was used to determine if cause of death (collision/electrocution) varied by the kind of wire. Spearman's rank correlation (r_s) was used to determine effect of number of wires and cranes in roost sites on number of deaths. All statistical tests were carried out using S-PLUS® 2000 (MathSoft 1998–1999).

RESULTS

Mortality and injury

A total of 35 dead and eight sarus cranes injured by wires were recorded. Most dead cranes were adults ($n = 30$, 86%), and most of these were non-breeding birds ($n = 27$, 77%). Supply wires caused most of the mortality (97%), while power lines caused most of the injuries (75%). Most injured cranes suffered broken wings (87.5%) and one territorial male crane suffered a fractured leg. Reason for death could not be determined for 11 cranes (31.4%), and an equal number died due to collision and electrocution ($n = 12$, 34.3% each). All cranes injured or killed by power lines were non-breeding cranes.

Rates of mortality

More non-breeding cranes died each year compared to cranes in territories (Table 1), and rates of mortality did not differ significantly between years irrespective of breeding status (χ^2 tests, $p > 0.5$; Table 1). On average, >1% each of the total population of non-breeding and territorial cranes was killed by electrical wires annually, though proportions of cranes dying in territories had a greater annual variation. More than 0.6% of the total population of cranes was killed each year (Table 1).

Factors affecting mortality

Gender could be ascertained for eight dead cranes and most of these (75%) were female. Of the eight injured cranes, one was a breeding adult and the rest were non-breeders. Gender

Table 1 Rates of mortality (R_n and R_b; see text for details) and proportion of the population of sarus cranes killed by electricity wires in Uttar Pradesh, India.

Year	*Non-breeders*			*In territories*			*Entire population: % total killed*
	No. dead	*% total population*	R_n	*No. dead*	*% total population*	R_b	
2000	8	0.89	0.185	4	2.72	0.074	0.71
2001	15	1.67	0.347	2	0.4	0.01	0.83
2002	5	0.56	0.232	1	0.17	0.004	0.28
Mean	9.33	1.04	0.255	2.33	1.1	0.03	0.61
SD		0.57	0.08		1.41	0.04	0.29

Table 2 Mortality of non-breeding sarus cranes due to electricity wires in Uttar Pradesh, India in relation to roosting and non-roosting areas (NA = not assessed).

Areas		*No. cranes killed*				*No. wires monitored (supply, power lines)*
		2000	*2001*	*2002*	*Total*	
Roosting areas	Ambarpur	2	3	0	5	1, 3
	Kudaiyya	3	4	4	11	4, 1
	Sauj	0	1	0	1	1, 0
Non-roosting areas		3	7	1	11	NA

could be ascertained for seven injured birds, and most were males (71%). Season did not affect number of deaths of either territorial ($\chi^2 = 1.0$, $df = 2$, $p = 0.61$) or non-breeding cranes ($\chi^2 = 1.36$, $df = 2$, $p = 0.51$) for the pooled data (see Table 1). For cranes in territories, there were insufficient data to explore differences due to season or rainfall. Of the eight cranes that died in territories, five (62.5%) were young birds. Of the five pre-dispersed young birds killed, two were juveniles and three were sub-adults, and gender was indeterminable.

Non-breeding cranes were killed to a greater extent than cranes in territories (91% of all deaths). For non-breeding cranes, neither total rainfall ($r_s = 0.22$, $p > 0.1$) nor number of rainy days ($r_s = 0.34$, $p > 0.1$) correlated to the number of cranes killed in a particular season. Most deaths of non-breeding cranes were beside roost sites (61%), but numbers of dead birds were not significantly different from those found away from these sites ($\chi^2 = 0.9$, $df = 1$, $p = 0.34$). Numbers of cranes dead at each roosting site pooled for the three years were not significantly different (one-sample t-test, $t = 1.61$, $df = 4$, $p = 0.18$; see Table 2). Number of deaths alongside roost sites was significantly correlated with maximum counts of birds ($r_s = 0.976$, $p < 0.01$) and numbers of wires at each site ($r_s = 0.874$, $p < 0.05$; see Table 2). Cause of death was only a result of collision for power lines while reason for mortality by supply wires was mostly electrocution (63%). Cause of death varied significantly with the kind of wire (Fisher's exact test, $p = 0.04$).

Risk of mortality to breeding cranes

Of the 251 territories monitored, complete information on either the extent of territories or the number and positions of wires overhead could not be reliably collected for five territories. More than 40% of the territories had at least one wire overhead (Table 3). Only eight deaths caused by wires were recorded and supply wires were responsible for all of them. Deaths were due to wires of rank one ($n = 5$, 62.5%), two ($n = 1$, 12.5%) and three ($n = 2$, 25%). All wires of rank one that caused crane deaths were along roads. All three adults were killed by wires of rank one. Mortality occurred only in one year within territories monitored for multiple years, and the maximum number of mortalities in a single territory was two birds which died the same day (one adult and one sub-adult).

Table 3 Summary statistics of territories of breeding pairs of sarus cranes with electricity wires running overhead in Uttar Pradesh, India.

Type of wire	*No. of territories (%)*
No information	5 (1.99)
Without wires	139 (55.38)
Supply wires only	64 (25.5.)
Power lines only	20 (7.97)
Supply + power lines	23 (9.16)

Table 4 Summary statistics of wires of different ranks over territories of sarus cranes in Uttar Pradesh, India (see Fig. 2 for the ranking system).

Rank of wire	*No. of wires*		
	Supply wires	*Power lines*	*Total (%)*
5	29	10	39 (23.21)
4	25	4	29 (17.26)
3	18	10	28 (16.67)
2	14	8	22 (13.1)
1	34	16	50 (29.76)

We counted a total of 168 wires over sarus crane territories, and numbers of wires of different ranks varied significantly (one sample t-test, $t = 6.82$, $df = 4$, $p = 0.002$) with wires of ranks one and five dominating (Table 4). The maximum number of wires over any territory was five (mean ± SD no. of wires/territory $= 0.67 \pm 0.96$). The maximum R_I

value was 7.17 (mean ± SD = 1.28 ± 1.83), and R_I values were strongly correlated with the number of wires above each territory ($r_s = 0.786$, $p < 0.01$). R_I values of territories with crane mortality did not differ significantly with values of territories without mortality (Wilcoxon's rank-sum test, $Z = 1.05$, $p = 0.13$).

Damage to electricity wires

No power line was damaged by crane strikes, but six supply wires were broken. One supply wire bordering a roosting site, Kudaiyya, was broken thrice, and one bordering another roosting site, Ambarpur, was broken twice by non-breeding cranes. A territorial adult caused the other cut wire. At least three additional power outages could be ascribed to crane strikes.

DISCUSSION

Rates of mortality and population consequences

Numbers of sarus cranes dying, irrespective of breeding status, were similar and overall nearly 1% of the total population died because of wires each year. This is significant considering that this proportion is used to identify important bird areas for water birds (Birdlife International 2001). Consequences of mortality due to wires at the population level for cranes are very variable being as high as 39% for the endangered whooping crane (*G. americana*, Brown *et al.* 1987) and as low as 0.6–2.0% for common crane (*G. grus*, Janss & Ferrer 2000). Studies on other bird species also show that deaths due to wires can vary highly from being very significant (mute swan *Cygnus olor*, 30% of the resident population killed in two months, Beer & Ogilvie 1972; capercaille *Tetrao urogailus*, 90% of the annual hunting harvest, Bevanger 1995; black grouse *T. tetrix*, 40% of the annual hunting harvest, Bevanger 1995) to being low (willow ptarmigan *Lagopus lagopus*, 9% of the annual hunting harvest, Bevanger 1995; great bustard *Otis tarda*, 1.6–4%, Janss & Ferrer 2000). Sarus cranes killed due to wires were on the lower end of the range.

Wire-related mortality was the sole cause of mortality for fledged young and adult sarus cranes in territories during this study, and was the most important reason for non-breeding cranes (67% of 52 deaths during the study; K.S.G. Sundar & B.C. Choudhury, unpublished information 1998–2002). Other crane species are also similarly affected by wires, including the sandhill (*G. canadensis*, 67.5% of all deaths, Pogson & Lindstedt 1988) and wattled cranes (73% of all deaths, McCann & Wilkins 1995). The frequency of wire-related deaths of sarus cranes in other areas may be smaller because there are fewer cranes, but consequences at the population level may be far more serious because of the removal of the few breeding individuals and require urgent evaluation. Globally, there has been an increased awareness of the dangers of wires to cranes and the past decade has seen a considerable increase in focus on the issue. Considerable numbers of crane deaths due to wires have been documented for 10 of the 15 crane species (Appendix 1). Electricity wires are clearly one of the most important factors with respect to mortality in these taxa and require focused conservation attention.

Factors affecting mortality

In territories, more young cranes died due to wires. However, low sample sizes prevented statistical analyses. A similar pattern is available for sandhill cranes from many areas (Brown *et al.* 1987, 48% of cranes killed were juveniles while only 9.9% in the population were juveniles; Ward & Anderson 1992, 62% of birds killed; Morkill & Anderson 1993, ratio of juveniles to adults killed = 24:76, in population = 12:88; Brown & Drewien 1995, 30% of cranes killed were juveniles while only 4.7% of the population were juveniles) and whooping cranes (Brown *et al.* 1987, 100% of killed and injured birds were juveniles/sub-adults). On average, non-breeding sarus cranes constituted 51% of the total population in the study area (K.S.G. Sundar, unpublished information 2000–2002), and were killed to a much greater extent than cranes in territories. Mortality in some bird species, particularly Anatids, is known to vary with gender (Anderson 1978), but was not different in sandhill cranes (50:50, $n = 58$, Morkill & Anderson 1993) or sarus cranes (this study).

Other factors that are known to affect mortality of birds due to wires are terrain, vegetation, weather, wind, temperature and season (Brown *et al.* 1987; Faanes & Johnson 1992; Brown 1993; Bevanger 1998). The terrain in the study area was uniformly flat with little variation in natural vegetation, and areas around roosts had similar land-use practices. These factors therefore do not seem to be of importance to wire-related mortality of sarus cranes, and the number of deaths was similar across seasons.

Number of wires affected rate of mortality at roost sites for non-breeding sarus cranes, but not within territories. For sarus cranes in territories, the position of the wire relative to the territory was more important. Rates of mortality were affected due to overhead wire frequency, particularly level of the wire, in ptarmigans (*Lagopus* spp., Bevanger & Brøseth 2001), and abundance of birds (sandhill cranes, Faanes & Johnson 1992; ptarmigan, Bevanger & Brøseth 2004).

Supply wires killed more sarus cranes, as has also been reported for two crane species from South Africa (grey crowned = 86%, wattled = 79% of kills, McCann & Wilkins 1995), but high-tension power lines killed more blue (87% of kills, McCann & Wilkins 1995) and sandhill cranes (four times the mortality due to supply wires, Ward & Anderson 1992). Ward and Anderson (1992) discussed reasons for these differing rates of mortality; differing heights, thickness of wires and distance between wires of supply and power lines are thought to be responsible. In Uttar Pradesh, power line wires were too far apart for wings of cranes to make contact with more than one wire and none died due to electrocution, while supply wires were much closer, causing more deaths by electrocution.

Nine of the fifteen species of cranes are known to migrate and, of the other six, few subspecies carry out long-distance or regional migrations during the dry season (Meine & Archibald 1996; Allan 1996). But during the breeding season, all of them have a non-breeding population comprising of younger birds and a breeding population with territorial birds (Meine & Archibald 1996; Allan 1996). For migratory taxa, mortality during migration is most important (US Fish and Wildlife Service 1994; Brown & Drewien 1995; Wassenich 2003) and there is no published information on the risk of wires and the rates of mortality during the breeding season. Conservation effort for the sarus crane with regard to wire-related mortality would be more efficiently spent on non-breeding birds, except in areas with low densities where a few crane deaths may exterminate entire breeding populations.

Behavioural issues

Some prominent behavioural reasons responsible for deaths in territories were:

- Fewer adult cranes died than younger birds in territories, and adults were clearly aware of the presence of electricity wires. Adults often called out to young in flight to help avoid collision with wires. Many adults in territories had signs of injury, and few were injured during the study indicating that 'learning' is an important component of avoiding wires.
- Aggression at edge of territories was regular between territorial birds, and most adult deaths were due to wires of rank one at the edge of territories.
- Parental bond killed additional birds; parent birds remained around carcasses of young, sometimes causing more deaths. Removal of dead cranes from below wires is necessary to avoid more deaths.
- Cranes in territories needed to contend with far fewer wires than non-breeding cranes, and were probably more practiced at avoiding individual wires due to long periods of residence in the same area. However, non-breeding cranes may not stay in an area long enough to completely 'map' all the wires and have to contend with a much greater area.
- Non-breeding cranes are forced to fly higher to avoid territorial pairs that chased conspecifics flying low over their territories, and therefore were also affected by power lines.
- Non-breeding birds often consisted of birds which apparently did not have wires over their natal territories. Non-familiarity and lack of awareness of the presence of the threat of wires may be leading to more bird deaths.

Other authors have also pointed out that young cranes may lack familiarity with areas and be less agile, causing deaths of more juveniles (Brown *et al.* 1987). In flocks, Brown *et al.* (1987) reported that 71% of cranes adjusted flight height and speed near wires, indicating awareness.

Flushing by humans is known to be a major cause of mortality in other species of cranes (Brown *et al.* 1987; Morkill & Anderson 1993) and, for blue cranes at least, predators appear to have learnt that flushing cranes results in mortality (A. Burke, personal communication 2003). In this study, human disturbance was common, as nearly all cranes lived on private or communal lands. Non-breeding cranes were often disturbed as their roost sites were used for grazing and other purposes. Cranes were also frequently chased from fields, and flushing could be responsible for many deaths each year.

Methodological issues

Most studies that document electricity wire related mortality obtain rates of mortality as number of birds dying per unit length of wire (Alonso *et al.* 1994; Bevanger 1995; Janss & Ferrer 1998; Donázar *et al.* 2002), as was carried out for non-breeding cranes in this study. Very few studies have addressed the problem of electricity wire related bird mortality taking into account the life-history of the species studied (Henderson *et al.* 1996) and none used multiple methods. Our field method for breeding territorial cranes would be very useful to document and mitigate electricity wire related mortality for other species during the breeding season. This method is, however, in need of verification to determine if position of wires is indeed the most important factor and to consider inclusion of other factors, such as proximity of wires to principal feeding area and location of wires relative to regular bird movement within territories to form a more complete risk index.

Our observations were made along the roadside, which was also the orientation of most supply wires, and this may have inflated R_I values and rates of mortality for territorial cranes. Territorial crane pairs were distributed almost as a continuous blanket in the landscape, and pairs frequently used roads as the edge of their territories (K.S.G. Sundar, personal observation 1998–2002). It would therefore be relevant to study cranes alongside roads since cranes elsewhere have reduced risk of wire-related mortality.

Conservation issues

While farmers and officials in the power sector are aware of collision events, there has been little done to either study the extent of power outages, or rate of mortality of cranes in this region or elsewhere in India. Most new power lines and supply wires are erected over governmental lands and in the study area large wetlands and saline wastelands were used. These were prime roost areas and may impact the population to a considerable extent as the number of wires increases, also causing considerably more wire damages and power outages. The Etawah-Mainpuri area has remained largely rural and unchanged in terms of land use for decades. Electrification is new to the rural villages of the two districts; in

1965–1966, none of the villages in Etawah district had electricity and, in 1996–1997, 1046 villages (22%) were connected with electricity wires (UPGOV [Uttar Pradesh Government] 2000). Proper planning to prevent endangering cranes and wires is required and is easily possible.

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Appendix 1 Events of mortality of cranes due to electricity wires worldwide. Mortality records for unmarked wires are provided when studies were experimental. Counts are from differing lengths of wire and are not to be compared directly. Information for subspecies has been combined in areas with more than one subspecies. [1]Values in parenthesis indicate number of localities when data is from more than one locality.

Crane species	*Study area*	*Study period*	*No. birds killed*[1]	*Source*
Grey-crowned *B. regulorum*	South Africa	1990–1995	16 (6)	McCann and Wilkins (1995)
	Midlands, South Africa	1994–1995	5	McCann and Wilkins (1995)
	South Africa	1996–2002	77 (47)	McCann and van Rooyen (2002)
Blue *A. paradisea*	South Africa	1987–1995	148 (16)	McCann and Wilkins (1995)
	Midlands, South Africa	1994–1995	5	McCann and Wilkins (1995)
	South Africa	1996–2002	313 (98)	McCann and van Rooyen (2002)
Wattled *G. carunculatus*	South Africa	1984–1994	23 (11)	McCann and Wilkins (1995)
	Midlands, South Africa	1994–1995	14	McCann and Wilkins (1995)
	South Africa	1996–2002	6 (4)	McCann and van Rooyen (2002)
Sandhill *G. canadensis*	Central North Dakota, USA	1980–1982	62 (4)	Faanes and Johnson (1992)
	Colorado, USA	1983–1984	78	Brown *et al.* (1987)
	California, USA	1983–1988	27	Pogson and Lindstedt (1981)
	Nebraska, USA	1986–1987	135	Ward and Anderson (1992)
	Florida, USA	1988–1990	81	Morkill and Anderson (1993)
Sarus *G. antigone*	Uttar Pradesh, India	1998	3 (2)	Sundar and Choudhury (2001)
	Uttar Pradesh, India	2000–2002	35	This study
Brolga *G. rubicundus*	Victoria, Australia	1965–1981	1	White (1987)
	Victoria and Darlington, Australia	1985–1986	2	Goldstraw and du Guesclin (1991)
White-naped *G. vipio*	Amur region, Russia	1995	1	S.M. Smirenski, personal communication 2003
	Amur region, Russia	2000	1	Smirenski *et al.* (2000)
Eurasian *G. grus*	Federal Republic of Germany	1975–1982	8	Neumann (1987)
	Extremadura, Spain	1989–1990	5	Alonso *et al.* (1994)
	Extremadura, Spain	1992–1995	25	Janss and Ferrer (2000)
Whooping *G. americana*	Texas, USA	1950–1987	5	Lewis *et al.* (1992)
	Colorado, USA	1983–1984	3	Brown *et al.* (1987)
	USA	1956–1987	15	US Fish & Wildlife Service (1994)
Red-crowned *G. japonensis*	Hokkaido, Japan	1952–1986	144	Masatomi (1991)
	Korea	1973–1974	1	Kyu and Oesting (1981)