SOSC-43

Effectiveness of Avian Collision Averters in Preventing Migratory Bird Mortality from Powerline Strikes in the Central Platte River, Nebraska

2008 - 2009 Final Report

30 September 2009

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EXECUTIVE SUMMARY

Collisions with powerlines cause substantial mortality among many species of birds, but such losses may be reduced by installing devices that make powerline wires conspicuous. During 5 March-18 April 2008 and 3 March-13 April 2009, we investigated mortality of sandhill cranes (*Grus canadensis*) stemming from collisions with two 69-kilovolt (kV) powerline arrays at a major night roost of the species on the Platte River in Buffalo County, south central Nebraska. Static wires of each powerline were equipped with FireFly™ bird diverters (FireFly Diverters LLC, Grantsville, Utah). We searched for carcasses of cranes at sandbars, islands, and shallow water areas between riverbanks below each powerline three times weekly and attempted to account for detectability biases. An estimated 50-93 sandhill cranes were killed by the two powerlines in 2008 and 37-70 were killed in 2009. These estimates were one-half to one-third of that reported in a previous study at the site, before FireFlys were installed. Using binoculars and night-vision scopes, we observed 101 and 117 collisions by sandhill cranes at one of the powerlines in 2008 and 2009, as the cranes returned to their roost from about 0.5 hours before sunset until about 2 hours after sunset. Most collisions occurred when flocks of more than 1000 cranes suddenly flushed from their roost within 0.5 km of the powerline after dusk. There appeared to be no relationship between collision incidence and weather or light conditions. About one-half of cranes that collided fell immediately to the ground, either dead or crippled. Another 29% continued to fly after striking wires, but their flight was hampered. About 65% of observed collisions involved static wires. We also observed reactions of 474 flocks of sandhill cranes to the powerline in 2009. Cranes reacted more quickly to avoid the powerline than they did to powerlines not equipped with diverters or to powerlines equipped with 30-cm yellow aviation balls as diverters in a previous study in south central Nebraska, and did so mainly by gradually climbing in flight. Individual wires on the powerline we observed also were instrumented in 2009 with bird strike indicators (BSIs), a new electronic technology to detect bird collisions. Collision incidents we observed and those indicated by BSIs were highly correlated. Diel records from BSIs indicated one-half of collisions by birds occurred during evening; nearly all the rest were distributed across remaining night hours. Our results might suggest FireFlys reduce the likelihood that a sandhill crane will collide with powerlines at Rowe, but more rigorous experimental design incorporating replication is needed to reliably assess and provide broader inferences on effectiveness of FireFlys in decreasing mortality of cranes and other bird species at powerlines. BSIs should be further evaluated and incorporated into such assessments.

INTRODUCTION

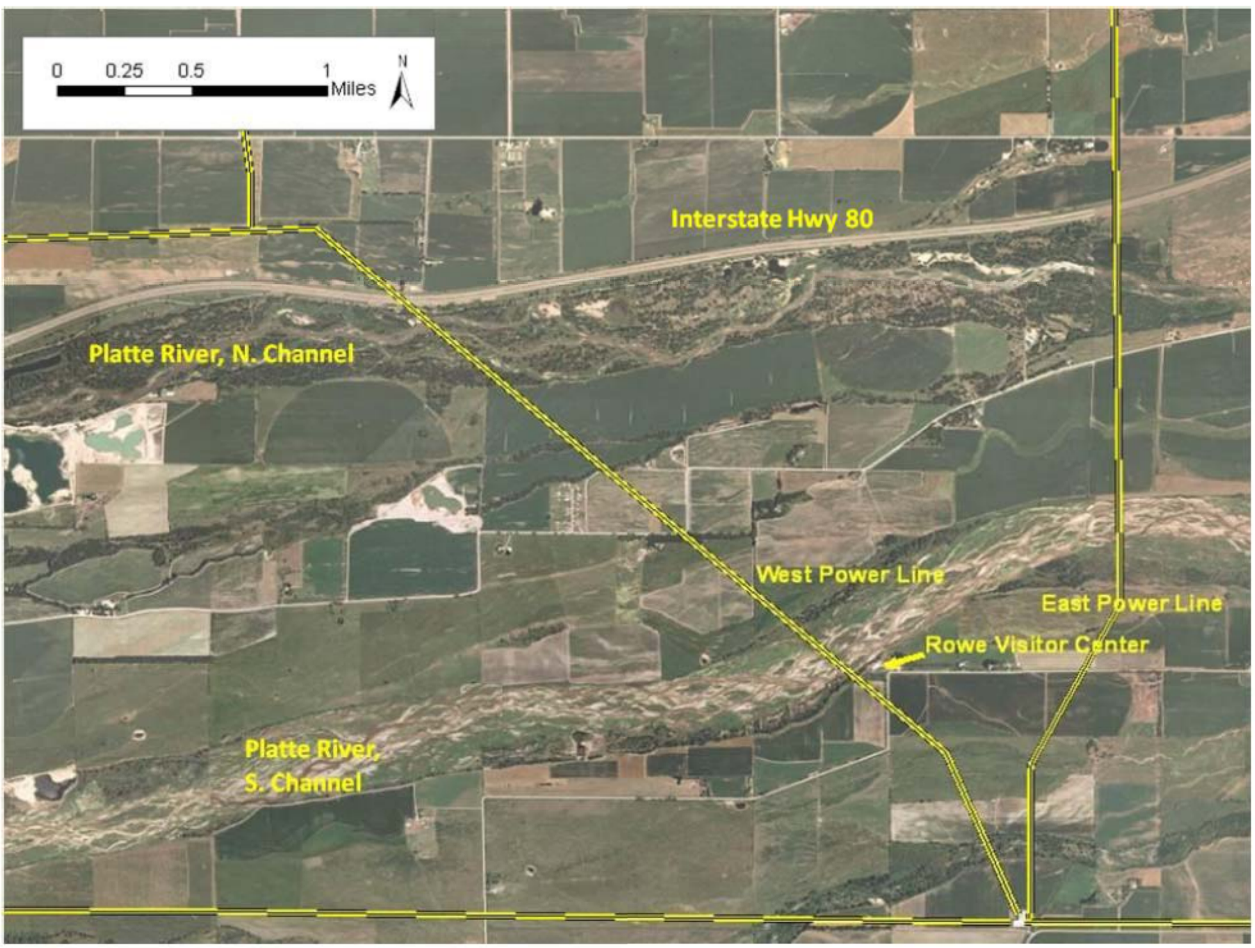
Many species of birds experience substantial mortality through collision and electrocution at powerlines (Bevanger 1994, Morkill and Anderson 1991, Avian Power Line Interaction Committee 1994, Lehman 2001). In North America, sandhill cranes (*Grus canadensis*) and whooping cranes (*G. americana*) seem particularly vulnerable to collisions with powerlines due to their large size and poor maneuverability in flight (Stehn and Wassenich 2008). The broad valley of the Platte River in central Nebraska poses great risk for such collisions (Ward et al. 1987). Roughly 500,000 sandhill cranes stage in the area for about 6 weeks during their spring migration, roosting at night on the river's sandbars and shallow waters. During spring 2006, Wright et al. (2009) recorded 61 carcasses of sandhill cranes during twice weekly searches below two 69-kV powerline arrays, where the powerlines cross the river at the National Audubon Society's Lillian Rowe Sanctuary (hereafter, "Rowe"). In 2007, they searched more intensively and accounted for several potential detectability biases; an estimated 165 to 219 sandhill cranes were killed by colliding with the powerlines (Wright et al. 2009).

During spring 2008 and spring 2009, we expanded the work at Rowe by Wright et al. (2009) after FireFly™ devices (FireFly Diverters LLC, Grantsville, Utah) had been placed on the powerlines to avert birds. Our objectives were: 1) quantify mortality of sandhill cranes, whooping cranes, and other species of birds at the two powerlines after FireFly diverters had been installed; 2) describe the nature and context of collisions by sandhill cranes with one of the FireFly-equipped powerlines at Rowe as the cranes returned to their night roost during evenings; and 3) document behavioral reactions of flocks of sandhill cranes to a powerline equipped with FireFlys and compare the reactions to those of cranes to powerlines equipped and to powerlines not equipped with diverter devices in a previous study in the Platte River valley. During spring 2008, we also sought to document evidence of bird mortality at two other powerlines over the Platte River in south-central Nebraska, one of which was equipped with FireFlys.

STUDY AREA AND METHODS

Physical features of the study site and powerlines at Rowe are detailed in Wright et al. (2009) and summarized here. Rowe is in Buffalo and Kearney counties in south central

Nebraska. A major roost site for spring migrant cranes, the sanctuary follows the Platte River's south channel. The 250- to 500-m (about 275 to 600 yards) wide channel is braided with sandbars and islands and bordered by grassy meadows and cropland. Water flows vary daily on the river in spring; most water is less than 0.5 m (20 inches) deep. Sandhill cranes and whooping cranes roost in the area mainly during late February through mid-April and mid-March through late April, respectively. The cranes usually leave night roosts on the river 1 to 2 hours after sunrise to feed in the surrounding landscape and return to roosts mainly during the last hour of daylight.



Two 69-kV powerlines cross the Platte River at the National Audubon Society's Lillian Rowe Sanctuary in Buffalo County, south central Nebraska. During spring 2008 and 2009, over-river spans of each were the focus of intensive study of powerline collisions by sandhill cranes that roost on the river. The area also is used by whooping cranes.

Two 69-kV powerline arrays stretch across the Platte River within the sanctuary, one about 0.1 km (about 100 yards) west of Rowe's visitor center and the other about 1.8 km (about 1.1 miles) east. Each array has two nonelectrified "static" wires suspended about 15 m (50 feet) above the ground and three transmission "conductor" wires about 5 m (17 feet) below these, all supported by wood, H-frame pole structures (powerlines of 69 kV or greater commonly are called transmission lines, while smaller arrays commonly are called distribution lines). The western powerline includes a support structure amid the river channel. The eastern powerline has a support structure on either river bank, but none in the river channel. Bank-to-bank spans of the western and eastern powerlines are 301 m (about 1000 feet) and 283 m (about 935 feet), respectively.

The over-river span of each powerline was equipped with a spinning model of the FireFly on its static wires in September 2007. The FireFly's main component is an acrylic plastic tag that measures 9 x 15 cm (3.5 x 6 inches), is 3 mm (0.13 inches) thick, and is covered with yellow and orange reflective tape and photo-reactive coatings that luminesce up to 8 to 10 hours after sunset. FireFlys were attached at 12-m (40-foot) intervals on each static wire by means of

During spring 2008 and 2009, static wires of both powerlines at Rowe were marked with "FireFly" devices (FireFly Diverters LLC, Grantsville, Utah) in an attempt to make powerlines more conspicuous to birds and thus reduce collisions by birds with the wires.

spring-loaded clamps. Attachment points alternated between wires such that a FireFly occurred on one or the other line every 6 m (20 feet). FireFlys were suspended by swivels so they would spin in any wind. By winter 2009, about one-third of the FireFlys broke, typically at the swivel, and fell from the powerlines; these were replaced by a non-spinning model just before migrant cranes began to arrive in the area in February 2009.

Estimate of Mortality Based on Carcasses Below Powerlines

We searched for carcasses on foot within 60 m (200 feet) of the powerlines between riverbanks every Monday, Wednesday, and Friday, using techniques described for 2007 surveys in Wright et al. (2009). All bird remains were removed from quadrats just before initial surveys were conducted each year. To locate crane carcasses in a quadrat, one searcher walked slowly (3-4 km/hour [about 2 mph]) in a zig-zag pattern down one-half of the quadrat then back on the other half. Searches lasted 0.5-1.5 hour/powerline. During each search, carcass type and description (i.e., extent scavenged) were recorded. We marked legs and distal wings of each carcass with orange paint to avoid recounting the carcass on subsequent surveys. Legs and wings were marked because they persisted longer than other body parts.

When a crane carcass was discovered, its distal legs and wings were painted orange to avoid *recounting on subsequent surveys.*

We estimated carcass detection rates by attempting to account for carcasses removed by scavengers, overlooked by observers, or swept downstream by water (Wright et al. 2009; Table 1). We used a blind assessment approach in which one of us placed one to three complete, intact sandhill crane carcasses within each quadrat 1.5-4 hours after a search on randomly selected days. Placed carcasses were uniquely but inconspicuously marked by a combination of broken or removed remiges and broken phalanges or tarsi. We recorded the location of each placed carcass via Geographic Positioning System receiver (GPS; Garmin eTrex, Garmin International, Olathe, Kansas; accuracy $\pm$ 5 m, North American Datum 1983). We also noted distance and direction from natural markers. Carcasses were placed subjectively to simulate a typical pattern of distribution based on observations in 2006 and 2007 (Wright et al. 2009), and observers had no knowledge of carcass placements. Within 1.5-4 hours after each carcass search, GDW (2008) or SMM (2009) made a verification visit to placed carcasses. If remains of a given carcass persisted, it was noted whether signs of scavenging were evident and whether it had been marked with paint (i.e., discovered by the observer that day).

To estimate the number of carcasses swept downstream prior to detection, we calculated the proportion of the width of the channel at each powerline array covered by deep water, i.e., the mean depth needed to float complete carcasses of sandhill cranes downstream (12.5 cm [5 inches]; Wright et al. 2009). We used a laser level and a GPS to determine widths of channel segments that equaled or exceeded this depth at the highest and lowest flow levels observed during our survey period. We multiplied the inverse of the proportion of channel covered by deep water by the number of estimated mortalities corrected for both carcass detection rates and scavenger removal rates (Wright et al. 2009; see Table 1 in RESULTS, page 12). We used measurements from 2008 for both years because maximum and minimum widths of deep water were similar.

Direct Observation of Collisions and Behavioral Reactions of Cranes

During 5 March-14 April 2008 and 3 March-13 April 2009, we observed the eastern powerline at Rowe from a blind placed on the south bank of the river about 60 m (200 feet) to the side (west) of the powerline. We observed the powerline each evening, defined as about 0.5 hours before until 2 hours after sunset (i.e., roughly 1800-2100 hrs). In 2008 we also observed

Some crane carcasses likely were swept downstream, away from powerlines, before being detected by investigators. Following methods in a recent study at Rowe (Wright et al. 2009), this potential bias was estimated by measuring the proportion of the river channel with water deep enough for carcasses to float, both at maximum and minimum flows for the season.

the powerline from about 1 hour before until 2 hours after sunrise, but discontinued these observations after noting cranes left the roost after sunrise and readily detected and avoided powerlines. Similarly, on seven nights in March 2008 we monitored crane flight activity at the powerline between evening and dawn. Noting no major activity by cranes during this sample of night-long periods, we focused on evenings.

Observations were of birds flying upstream or downstream, between riverbanks, below to just above the level of the powerline. We used 10 x 50X binoculars to observe cranes until darkness limited visibility, then switched to using 3x or 5x, Generation III night-vision scopes. We recorded time of collisions, flock size, and weather and light conditions. We categorized fate of each bird that collided with the powerline as either 1) collision or other contact evident but subsequent flight unaltered i.e., normal; 2) collision followed by obviously hampered flight (such birds often were losing height as they left our field of view); 3) collision followed immediately by loss of flight although alive while falling, typically evidenced by wing flapping; or 4) collision followed immediately by a motionless fall to the ground, i.e., appearing dead. When uncertain whether a collision occurred, we recorded "possible strike" but did not include such records in data summaries. In 2009, we also tried to identify which wire was struck.

Sandhill cranes at Rowe's eastern powerline were observed from blinds each evening from early March through mid-April in 2008 and 2009.

Bird strike indicators (BSIs; EDM International, Fort Collins, Colorado) were attached to wires of the eastern powerline at Rowe in 2009. A relatively new technology, the BSI is an impulse-based, vibration sensing tool that, when mounted on a powerline wire, records bird collisions as unique signatures. A BSI was attached to each static and each transmission wire, roughly: 1) 90-95 m north, 2) 180-185 m north, and 3) 90 m south of the H-frame support structure on the south bank of the river. Thus, a total of 15 BSIs were used. BSIs were distributed at intervals of about one-third of the powerline span to maximize their sensitivity to vibrations caused by bird collisions. Records of collisions were transmitted to a computer base station at Rowe headquarters. To validate BSI records of collisions, we compared the timing and total number of collisions of birds that we observed directly to those recorded by BSIs during each evening observation period. We used correlation to assess the strength of the relationship between the two sources of data then used BSI records to explore the incidence of collisions by birds during each 24-hour diel period.

Bird Strike Indicators (EDM International, Inc., Ft. Collins, Colorado) were mounted on wires of the eastern powerline at Rowe during spring 2009 to record collisions by birds especially during hours when the powerline was not being directly observed.

We categorized behavioral reactions of flocks of sandhill cranes to the eastern powerline at Rowe during 2009, using the same approach as Morkill and Anderson (1991): 1) no reaction, 2) gradual climb, 3) flare i.e., suddenly increased altitude as cranes flapped quickly to rise above the powerline, and 4) reverse path. Using a focal sampling approach (Altmann 1974), we selected the first flock approaching less than 10 m above the powerline in each 5-minute interval every evening. A flock was defined as one or more cranes physically independent (more than roughly 30 m [100 feet]) from other cranes. We categorized flocks as either small (groups of 1-3 individuals) or large (4-20 individuals), similar to Morkill and Anderson (1991). We divided the evening data into two temporal subsets: 1) early evening (i.e., about 15 minutes before until 45 minutes after sunset) and 2) late evening (more than 45 minutes after sunset). Reactions of cranes by flock size and time were compared by using chi-square tests of independence. We also used chi-square tests to compare proportions of reaction categories in our study to those of sandhill cranes reported by Morkill and Anderson (1991), who measured reactions to powerlines not equipped with diverter devices and to powerlines marked with 30-cm (12-inch) diameter, yellow aviation balls as diverter devices. However, our late evening data were not used for the comparisons because Morkill and Anderson (1991) observed cranes only during daylight. Comparison to data in Morkill and Anderson (1991) was one of few, limited options to gauge the influence of FireFlys, because we were unable to directly compare effects of FireFlys by simultaneously assessing crane behavior at unmarked but otherwise equivalent (i.e., “control”) powerlines during our study.

We used similar methods between 2008 and 2009 except we added a second blind and observer on the north bank of the river in 2009 to try to discern which wire a given bird collided with. In 2009 we also sampled the level of local abundance of cranes in relation to time of evening by counting the number of cranes passing through the bank-to-bank river corridor during a 30-second interval every 5 minutes.

Simple correlation was used to assess relationships in 2009 between 1) local abundance of sandhill cranes and the number of collisions we directly observed, and 2) the number of collisions by birds recorded by BSIs and the number of collisions by sandhill cranes we directly observed during the same time each evening. We considered $P < 0.05$ to indicate statistical significance for chi-square tests and correlation results.

Evidence of Bird Mortality at Other Roost Sites

During spring 2008, we also searched for carcasses of birds beneath spans of two other powerlines that crossed the Platte River in south-central Nebraska. The Speidel powerline was a 35-kV distribution line that crossed the river's south channel about 8 km (5 miles) east-southeast of Kearney in Buffalo County. To restore open roosting habitat for cranes and other species of birds, roughly 20 ha (about 50 acres) of trees and other vegetation had been removed from the area during late winter 2008. The powerline lacked devices to alert birds and minimize collisions. The Shelton powerline was a 35-kV distribution line about 5 km (3 miles) west of the Shelton interchange on U.S. Interstate highway 80 in Kearney County. FireFlys had been placed on its static wires in late winter 2008. Together with collaborators, we used methods outlined in Wright et al. (2009) to search three times weekly for bird carcasses beneath the Speidel and Shelton powerlines within respective river channels (n = 20 search visits at each). We did not, however, attempt to correct for biases in detectability of carcasses at the two powerlines.

RESULTS

Mortality Based on Carcasses

We found 47 carcasses of sandhill cranes and none of whooping cranes beneath powerlines at Rowe (Table 2). Forty-two (89.4%) carcasses were beneath the eastern powerline. We also found 13 carcasses of seven other species of birds beneath powerlines at Rowe, all but one of which were waterfowl (Anseriformes). Based on crane carcasses detected during searches and corrections for related biases, we estimate 50-93 and 37-70 sandhill cranes were killed by colliding with powerlines at Rowe in spring 2008 and 2009 (Table 1).

Table 1. Assessment of detection bias and estimate of total mortality of sandhill cranes at two 69-kVpowerlines over a night roost of the cranes on the Platte River at the Lillian Rowe Sanctuary in south central Nebraska, based on carcasses found below the powerlines, 17 March-14 April 2008 and 3 March-13 April 2009 (follows Wright et al. 2009).

Carcass origin	2008	2009	Source[a]
Assessment of detection bias on area of channel not covered by deep water [b]			
Placed carcasses	20	17	A
Removed by scavengers before observer's search	1	1	
Present for observer's search	19	16	
Present for search but undetected by observer	6	3	
subtotal: removed plus present-undetected	7	4	B
Proportion detected ([A-B]/A)	0.65	0.76	C
Detected by observer, death attributed to collision	25	22	D
Estimate: killed by collision but not falling into deep water (D / C)	38.5	28.9	E
Percentage of bank-to-bank channel covered by deep water [c]			
Minimum	22.7		F
Maximum	58.8		G
Estimate: total mortality attributed to powerlines			
Minimum (E/[1.00-F])	49.8	37.4	
Maximum (E/[1.00-G])	93.4	70.1	

[a] Used for subsequent calculations, following Wright et al. (2009).

[b] Water depth $\geq$ 12.5 cm

[c] Percentage estimate based conservatively on highest and lowest values recorded between the two powerline spans in 2008. Minimum and maximum water levels and channel configuration

appeared similar in 2009.

Table 2. Number and identity of carcasses of birds detected beneath two 69-kVpowerlines[a] over the Platte River at the National Audubon Society's Lillian Rowe Sanctuary in Buffalo County, south central Nebraska, during 5 March to 18 April 2008 and 3 March to 13 April 2009.

	Sandhill crane		Duck[b]		Goose[c]		Passerine species[d]	
Powerline	2008	2009	2008	2009	2008	2009	2008	2009
Western	0	5	1	0	2	2	0	0
Eastern	25	17	2	3	1	1	0	1

[a] Three searches were conducted on foot weekly on the ground within 60 m of each powerline, from riverbank to riverbank.

[b] Mallard (*Anas platyrhynchos*), gadwall, (*A. strepera*), northern pintail (*A. discors*), green-winged teal (*A. crecca*).

[c] Snow goose (*Chen caerulescens*) and Canada goose (*Branta canadensis*).

[d] Song sparrow (*Melospiza melodia*).

No bird carcasses were detected beneath the Speidel powerline and 13 carcasses of nine species of birds were found under the Shelton powerline, including three sandhill cranes (2008 only; Table 3). Lack of bird tracks on sandbars within 100-150 m (about 325-500 feet) of the powerline at Speidel indicated cranes and other flocking species of birds were not roosting in the area. Based on tracks, cranes at Shelton probably roosted at least 140 m (> 460 feet) east of the powerline in early spring, but roosted closer later in spring as their abundance in the area increased. In all, 74 carcasses of at least 12 species of birds were recorded at the four powerlines surveyed in this study, including a common merganser (*Mergus merganser*) that, while in flight, wedged its bill into a spiral vibration damper on the eastern powerline at Rowe in late February 2009.

Table 3. Carcasses of birds detected beneath two 35-kV powerline spans over the Platte River in Buffalo and Kearney Counties, south central Nebraska, during 5 March to 18 April 2008. [a]

Powerline	Sandhill crane	Duck[b]	Goose[c]	Passerine species[d]
Speidel	0	0	0	0
Shelton	3	1	3	6

[a] Three searches were conducted on foot weekly on the ground within 60 m of each powerline, from riverbank to riverbank.

[b] Green-winged teal.

[c] Snow goose and Canada goose.

[d] Cedar waxwing (*Bombycilla cedrorum*), Lincoln's sparrow (*Melospiza lincolnii*), song sparrow, dark-eyed junco (*Junco hyemalis*), unidentified sparrow (Emberizidae), and red-winged blackbird (*Agelaius phoeniceus*).

Direct Observations of Birds at Rowe's Eastern Powerline

In 2008, we did not witness collisions by birds with the eastern powerline at Rowe through 16 March, during which time observations were restricted to daylight hours. Thereafter, we used night-vision equipment and observed collisions by 101 individual sandhill cranes with the powerline during late evening (Table 4). Two-thirds of these collisions resulted in individual cranes falling to the ground within 60 m of the powerline. Nearly half of those that fell to the ground appeared to be killed instantly when they collided with wires of the powerline. Most other cranes that collided with the powerline exhibited hampered flight after collision. In 2009, we observed 117 collisions by sandhill cranes (Table 4). Outcomes of collisions differed markedly from 2008 (X^2 = 1247, df = 3, P < 0.001). For example, the percentage of collisions resulting in unaltered flight was nearly four times greater in 2009 than in 2008. We observed no collisions by other species of birds, except an unknown species from a mixed-species flock of sandhill cranes and Canada geese collided with the powerline in 2008.

We could identify which wires – static or transmission – were struck by cranes in 71 (60.7%) of 117 collisions observed in 2009. Static wires were struck in 46 (64.8%) of the 71 collisions. We often were unable to identify wires involved in collisions when large flocks (> 100 individuals) of cranes passed through the powerline array, obscuring our view of specific wires. Nearly all sandhill cranes that approached the powerline at or below line height flew up and over the static wires, although some (probably < 1%) flew between static and transmission wires and, on rare occasions, one to several cranes flew below the transmission wires.

Collisions we observed by sandhill cranes with the eastern powerline at Rowe during evening occurred 24-105 minutes after sunset (i.e., from dusk into nightfall) in 2008 and 29-155 minutes after sunset in 2009. Illumination by moonlight or extent of cloud cover did not seem to markedly affect the birds' abilities to detect and avoid the powerline. For example, in 2008 the percentage of collisions that occurred on bright, moonlit nights (14.8%) approached the percentage of such nights of observation (25.0%); in 2009, 53.8% of collisions were recorded on cloudless nights. There also was no obvious relationship between collision incidence and

Table 4. Outcome of physical contact by flighted sandhill cranes with the eastern powerline over a night roosting area for the cranes on the Platte River at Audubon's Lillian Rowe Sanctuary in south central Nebraska, as determined by direct observation from about 0.5 hours before sunset until 2 hours after sunset, 17 March to 14 April 2008 and 3 March to 13 April 2009.

	2008	2009	Total
Collision category	n (%)	n (%)	n (%)
Flight unaltered	8 (7.9)	34 (29.1)	42 (19.3)
Flight hampered	22 (21.8)	42 (35.9)	64 (29.4)
Immediate loss of flight, alive	41 (40.6)	37 (31.6)	78 (35.8)
Fell to ground dead	29 (28.7)	4 (3.4)	33 (15.1)
Outcome unknown	1 (0.9)	0	1 (0.4)
n total	101 [a]	117	218

[a] Excludes one large bird of unknown species that struck the powerline, amidst a flock of Canada geese and sandhill cranes.

strong wind or otherwise inclement weather, e.g., 58.1% of collisions in 2009 occurred when winds were less than 20 km/hour (< 12 mph). Instead, collisions occurred mainly when large flocks of cranes suddenly flushed upward, towards the powerline, after settling on their roost within 0.5 km. Nearly two-thirds (64.4% and 64.1%) of collisions in each of 2008 and 2009 occurred this way. Those in 2008 involved flocks of more than 1000 cranes, while most in 2009 involved smaller flocks (100-1000 cranes, 35.1% of all collisions; > 1000 cranes, 29.0% of all collisions). The most dramatic example of this occurred on 4 April 2008, when 53 sandhill cranes from two flocks of more than 1,000 cranes each collided with the powerline, 71 and 105 minutes after sunset, respectively. The collisions occurred as cranes flew upwards from their roost on sandbars and shallows within roughly 300 m east of the powerline. We could not identify what disturbed the cranes. Coyotes (*Canis latrans*) may have, as we had noted tracks of medium-sized canids and observed a coyote on sandbars during carcass searches. Great horned owls (*Bubo virginiana*), probably the same individual, sometimes perched atop the powerline's support structure and flew out over roosting cranes, but the cranes did not seem to react. Regardless, cranes typically were unsettled as they arrived at the river to roost and often moved from one roost to another during 0.5-1.5 hours after sunset. Cranes mostly flew from east to west in 2008, but the converse was true in 2009.

Illumination by moonlight or extent of cloud cover did not seem to influence the ability of cranes to detect and avoid the powerline marked with FireFlys. Instead, collisions occurred mainly when large flocks of cranes suddenly flushed upward towards the powerline, after settling on their roost within about 600 yards.

At the peak of staging by sandhill cranes in the area in mid-March, we typically observed an average of about 500 cranes/minute pass through the over-river span of the eastern powerline (2009 data, Fig. 1). However, we detected no relationship between local abundance of cranes and number of collisions by cranes through spring ($r = 0.13$, $P = 0.41$). After a week of almost no collisions at the end of each migration season in April, we noted an abrupt increase in collisions (e.g., 9 to 10 April 2009, in Fig. 1).

Reactions by Cranes to Powerlines

We recorded 474 reactions of sandhill crane flocks to the eastern powerline at Rowe in 2009. The proportion of reaction types differed with time (early versus late evening, flock sizes combined: $X^2 = 70.9$, 3 df, $P < 0.001$). During early evening, cranes typically avoided the powerline by climbing gradually as they approached (Fig. 2). In late evening, however, cranes were less likely to climb gradually. This was especially true for small flocks, which in late evening were almost equally likely to flare or reverse direction as they were to climb gradually. Cranes that did not react (7.8% of large flocks during day, 6.4% of small flocks during late evening) generally were in flocks that passed 5-10 m above the static wires, although during late evening, some small flocks passed between static and transmission wires or beneath transmission wires without appearing to react to the wires.

Sandhill cranes we observed reacted more often to the powerline marked with FireFlys and did so more by gradually climbing as they approached, compared to reactions of cranes to powerlines marked with yellow aviation balls or to unmarked powerlines in Morkill and Anderson (1991; $X^2 = 230$ and 384; both, df = 3, $P < 0.001$; Fig. 3). Last, the cranes we observed reacted sooner to the powerline with FireFlys than they did to powerlines with aviation balls or to unmarked powerlines ($X^2 = 230$ and 384; both, df = 3, $P < 0.001$; Fig. 4).

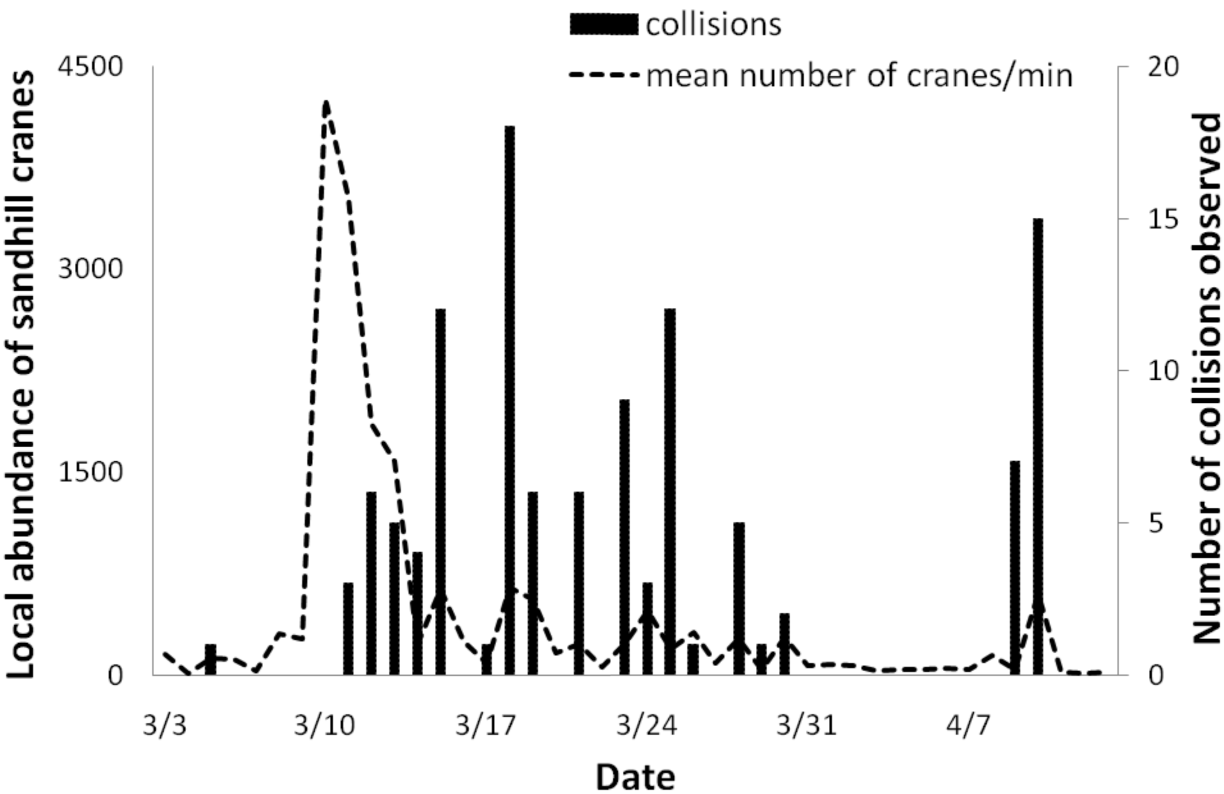


Figure 1. Relationship between the observed number of collisions by sandhill cranes with the eastern powerline over the Platte River at Rowe Sanctuary in Buffalo County, Nebraska, and local abundance of cranes defined as the mean number observed flying past the powerline per minute during evenings (i.e., about 0.5 hours before sunset until 2 hours after sunset), 3 March to 13 April 2009. Data were based on 30-second counts every 5 minutes.

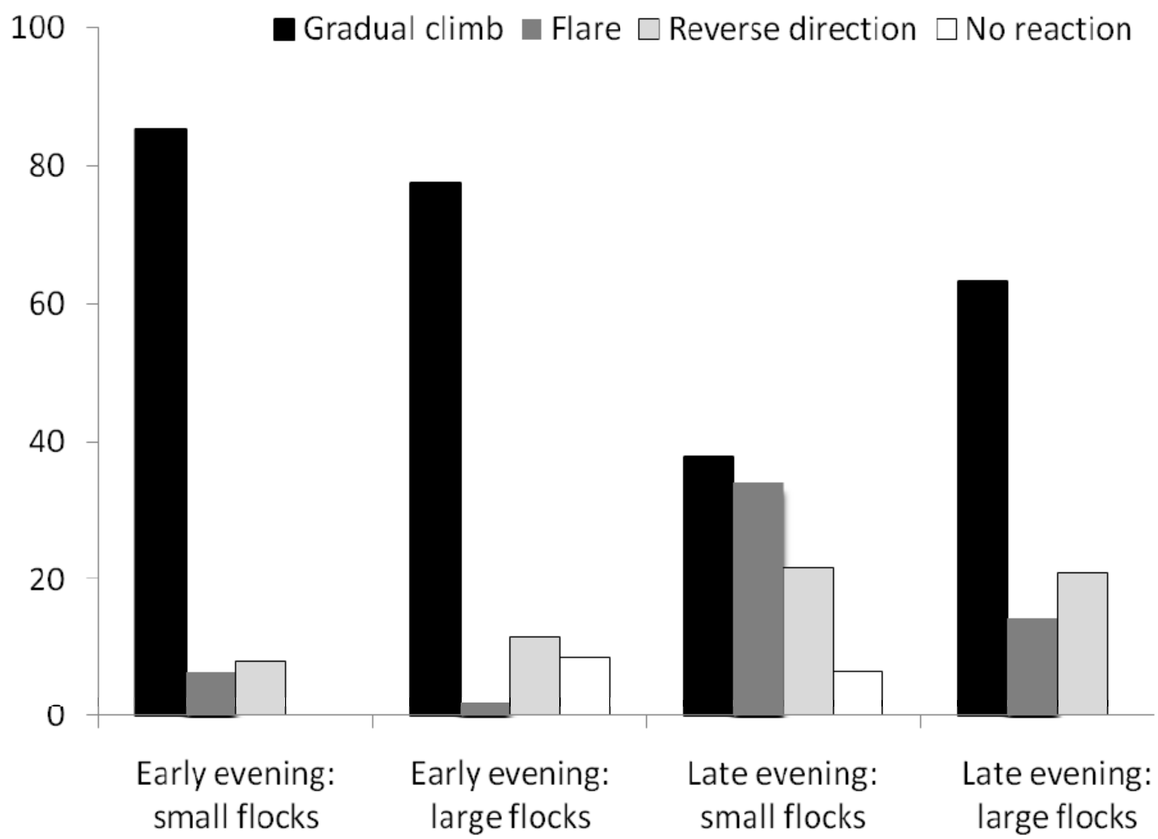


Figure 2. Behavioral reactions of flighted sandhill cranes to a 69-kV powerline over a night roosting area for the cranes on the Platte River at Audubon's Lillian Rowe Sanctuary in south central Nebraska, as determined by direct observation, 3 March to 13 April 2009. Small flocks included one to three individuals and large flocks included more than three individuals. The first flock in each 5-minute interval was included in the sample. Numbers of reaction observations are in parentheses. Data were collected from about 0.5 hours before sunset until 2 hours after sunset; early evening was up to 45 minutes after sunset and late evening was more than 45 minutes after sunset. Flare was defined as a sudden increase in altitude as cranes flapped quickly to rise above the powerline.

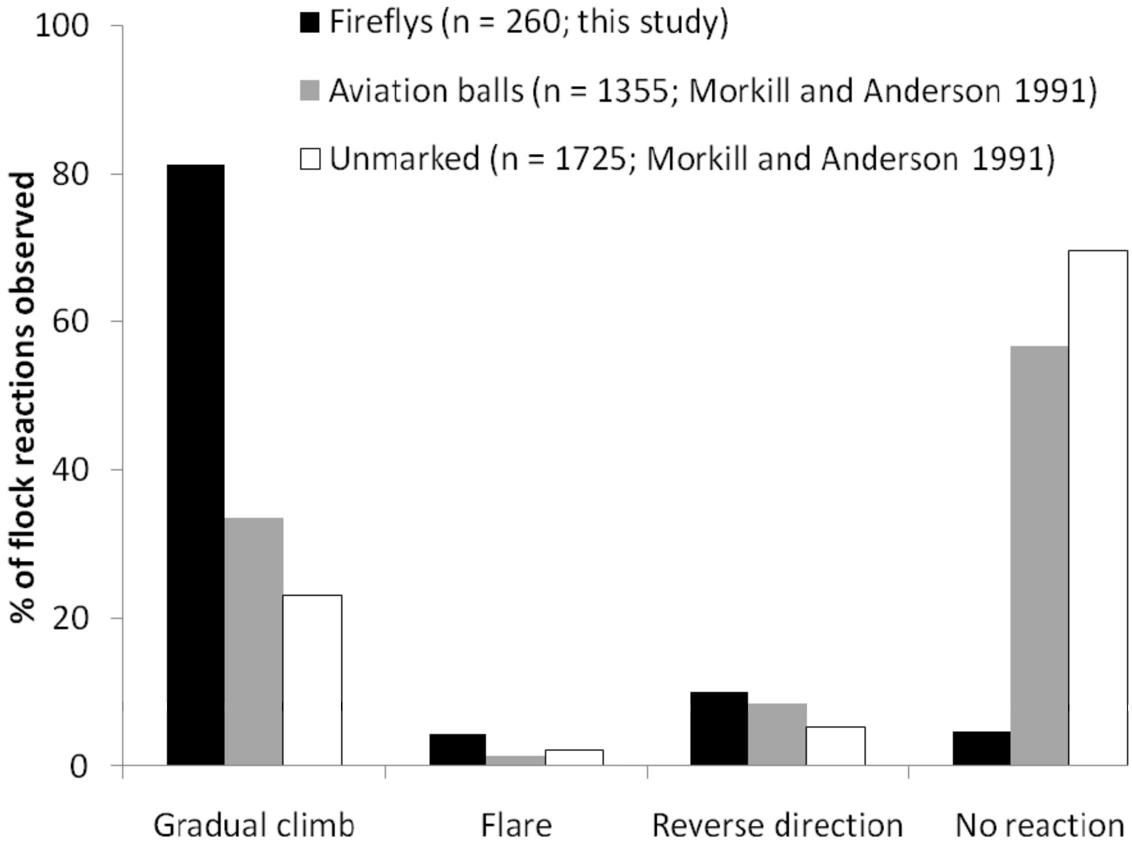


Figure 3. Behavioral responses of flighted sandhill cranes to a 69-kV powerline marked with Firefly avian flight diverters over the Platte River in south-central Nebraska during spring 2009, and of reactions of sandhill cranes to unmarked powerline spans and powerline spans marked with 30-cm diameter aviation marker balls over croplands in south-central Nebraska during spring 1988-1990, based on data in Morkill and Anderson (1991). Sample sizes (i.e., number of flock reactions observed) are in parentheses.

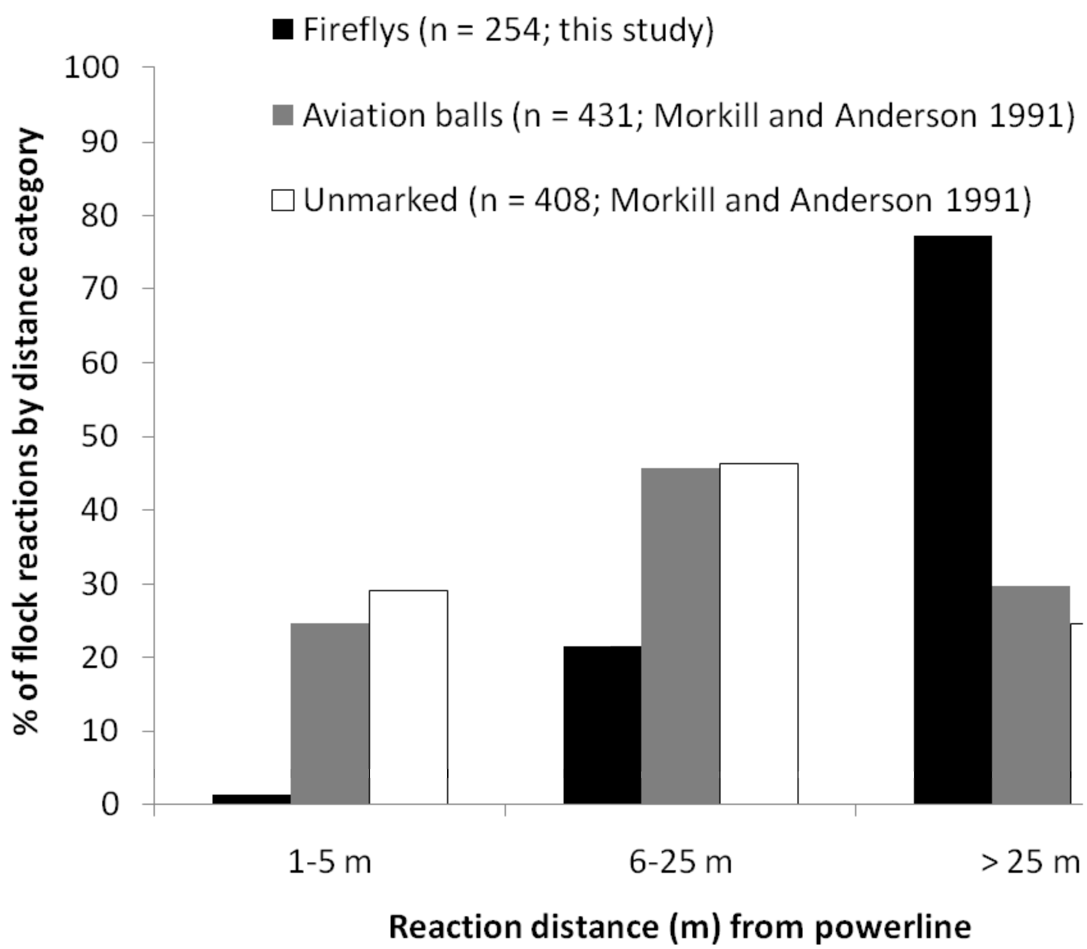


Figure 4. Frequency distribution of distances of initial reactions of flighted sandhill cranes to a 69-kV powerline marked with Firefly avian flight diverters over the Platte River in south-central Nebraska during spring 2009, and of reactions of sandhill cranes to powerline spans marked with 30-cm diameter aviation marker balls and to unmarked spans over croplands in south-central Nebraska during spring 1988-1990, based on data in Morkill and Anderson (1991). Sample sizes (i.e., number of flock reactions observed) are in parentheses.

Collision Incidence based on BSIs

The number of collisions by birds recorded by BSIs each evening correlated closely with the number of collisions by sandhill cranes we directly observed during the same time ($r = 0.86$, $P < 0.001$; Fig. 5). Several BSI records suggested double collisions (i.e., two birds striking a wire simultaneously), while several others suggested collisions that involved two wires (i.e., a bird striking one wire then immediately another). Stemming from this validation of reliability of BSIs, there were 358 collisions, presumably all by birds, with the eastern powerline on 55 days between 11 February and 15 April 2009. Collision incidence indicated by BSIs was distributed unevenly through night and day ($X^2 = 463$; df = 7, $P < 0.001$), with about one-half occurring during evening and nearly all others during the remaining night hours (Fig. 6).

DISCUSSION

Our estimates of 50-93 and 37-70 sandhill cranes killed by the two powerlines at Rowe in 2008 and 2009, based on searches for carcasses, are one-third to one-half of an estimate of 153 to 229 sandhill cranes by Wright et al. (2009) at Rowe for spring 2007, before FireFly diverters were installed. Wright et al. also believed that the level of crane mortality in 2006, based on a more cursory search for carcasses, probably was similar to that in 2007. Previous assessments based on carcass searches have indicated that sandhill crane mortality due to collision with powerlines is roughly halved when the powerlines are marked with diverters (Morkill and Anderson 1991, Brown and Driewen 1995). However, differences in methods especially correction for potential bias in carcass detection cloud close comparison of studies.

A greater proportion of flocks of sandhill cranes we observed reacted to the powerline marked with FireFlys than did flocks of cranes to powerlines not equipped with diverter devices and to powerlines marked with aviation balls as diverter devices in Morkill and Anderson (1991). Also, a greater percentage of crane flocks in our study reacted by gradually climbing. However, our observations were derived from a single powerline over a river roost in south-central Nebraska. Morkill and Anderson (1991) studied behavior of flighted cranes at alternately marked and unmarked spans of nine powerlines over cornfields and meadows in the same area.

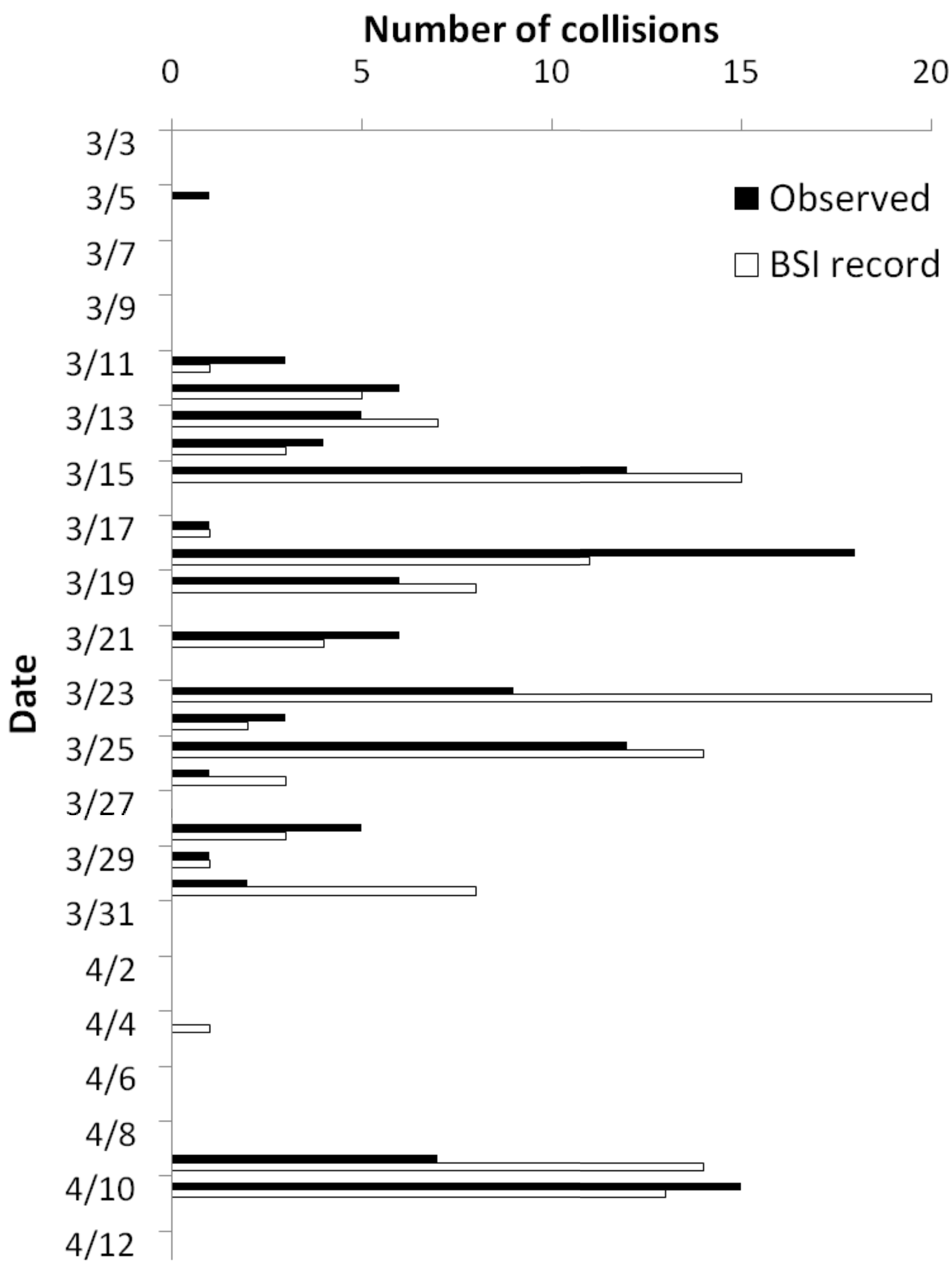


Figure 5. Number of collisions by birds with the eastern powerline over the Platte River at National Audubon Society's Lillian Rowe Sanctuary in south central Nebraska, as recorded by direct observation and by electronic bird strike indicators (BSIs; EDM International, Fort Collins, Colorado) during evenings, 3 March to13 April 2009. All collisions directly observed were of sandhill cranes, while those recorded by BSIs were of relatively large birds of unknown species. No BSI data were collected on 3 March.

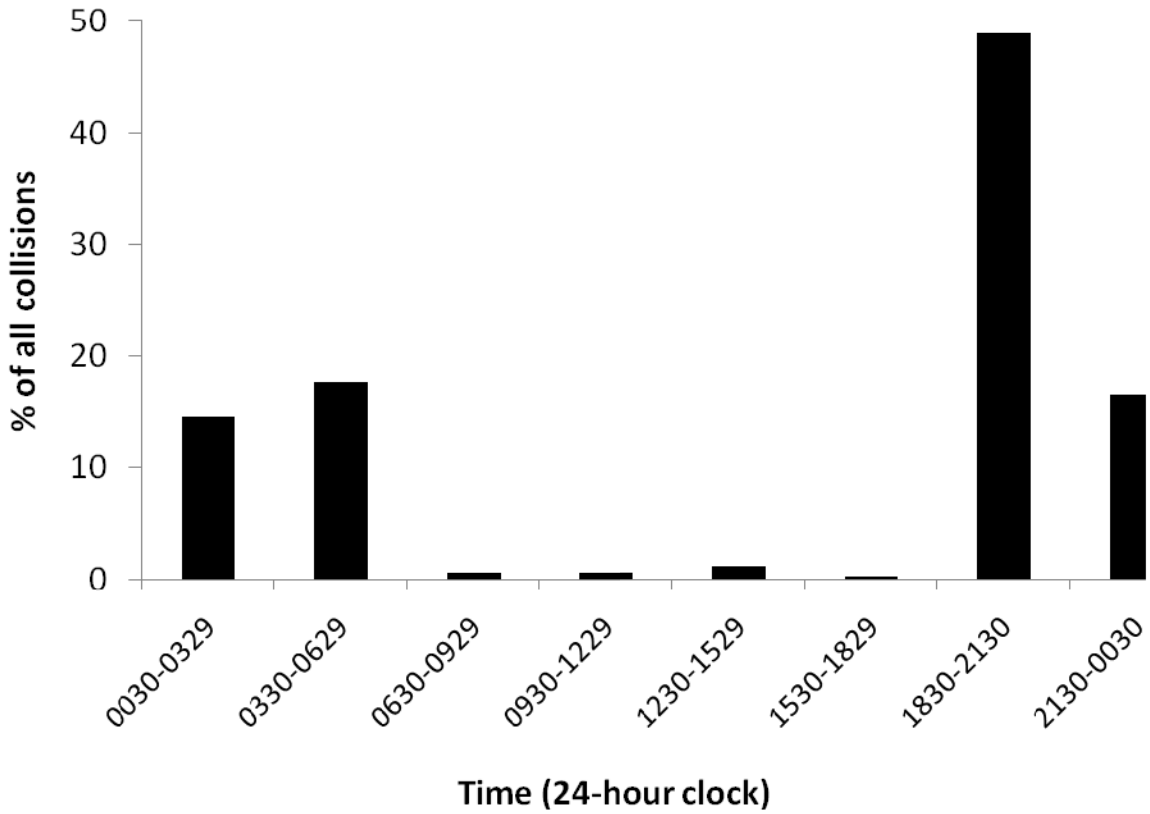


Figure 6. Diel timing of collisions by birds with the eastern powerline at National Audubon Society's Lillian Rowe Sanctuary in south central Nebraska, as detected by electronic bird strike indicators (EDM International, Fort Collins, Colorado) during 11 February to 15 April 2009. Data are presented as percentage of total collisions recorded (n = 358).

We are unsure whether or how differences in study sites influence comparisons. Regardless, our observations suggest FireFlys may alert sandhill cranes to powerlines earlier than aviation balls, giving the cranes more time to react and avoid wires. Finally, small flocks of cranes we observed approaching the eastern powerline at Rowe in late evening were more likely to flare and less likely to gradually climb than large flocks. This observation and similar findings by Morkill and Anderson (1991) suggest an interaction between flock size and diverter type. Clearly, additional studies incorporating at least modestly rigorous experimental design are needed to reliably assess effectiveness of FireFlys for reducing powerline collisions by cranes. Unfortunately, due to legal and logistical constraints, we were unable to implement such a design. Lack of design in our study, i.e., random treatment assignment, controls, and replication, preclude definitive conclusions about effectiveness of FireFlys in decreasing mortality of sandhill cranes, at least in terms of statistical significance.

Flocks of sandhill cranes reacted more often and reacted earlier to Rowe's eastern powerline, marked with FireFly bird diverters, than they did to powerlines not equipped with diverter devices and to powerlines marked with aviation balls as diverter devices in another study in south central Nebraska.

Based on our direct observations, extent of crane mortality due to collisions with powerlines likely is underestimated by regular searches for carcasses beneath the wires, even after accounting for obvious sources of bias especially observer oversight and removal of carcasses by scavengers. Our estimate of the total number of sandhill cranes killed by colliding with the eastern powerline at Rowe, based on carcass searches and correction for several biases, roughly equalled the total number of cranes we observed colliding with the powerline and falling to the ground (2008 and 2009 data combined: 87 to 163 individuals estimated via carcass search versus 111 individuals directly observed falling to the ground). However, a significant source of bias not accounted for in carcass searches was posed by cranes injured by colliding with powerlines but managing to fly or glide beyond our search quadrat. Indeed, nearly one-third of collisions we directly observed were in this "crippling bias" category; such cranes typically were losing height as they left our field of view. We suspect most sandhill cranes that suffer hampered flight from striking powerlines do not complete their spring migration and ultimately are lost from the breeding population. Crippling bias is difficult to assess and often not included in estimates of avian mortality due to collisions with powerlines and other structures, yet the bias could be substantial (Avian Power Line Interaction Committee 1994). Last, in 2009 we observed a greater proportion of cranes that collided with powerlines subsequently glided or continued to fly, obviously hampered by injury, compared to 2008. This difference may be associated with light conditions. Most cranes in 2008 flew along the river from east to west, but most moved west to east in 2009. Perhaps cranes moving westward in 2008 tended to detect and react less quickly to the powerline because FireFlys were backlit by the western sky's glow after sunset. Such subtle differences in reaction time could influence the severity of collisions.

Based on direct observation, we believe most mortality of cranes at the eastern powerline at Rowe occurs when the birds are settling on night roosts close to the powerline during nightfall then are disturbed and suddenly flush upwards in large flocks. We could not qualitatively discern any relationship between incidence of mortality and ambient light or weather conditions during evening observation periods. Nor could we find a correlation between mortality incidence and local abundance of cranes, although no collisions were noted in early April when relatively few cranes remained in the area. A small increase in collisions at the end of the migration period in both years of our study probably was associated with arrival by what we believe were new migrant cranes, less familiar with the area.

Direct observation of the eastern powerline at Rowe indicated many cranes suffer hampered flight after colliding with wires and likely land away from the powerline area, while many others fall close to the powerline, crippled, and may subsequently walk from the area. Either way, most such birds likely die before continuing to migrate. This mortality typically is overlooked in assessments of collision impacts.

Data recorded by BSIs suggest carcass searches and direct observation did not account for a substantial number of collisions by birds with the eastern powerline at Rowe. Specifically, we seldom observed the powerline after evening until dawn, during which time BSIs indicated as many collisions as we observed during the shorter evening observation period. Some, if not most, of these post-evening collisions recorded by BSIs likely were by sandhill cranes, based on two lines of support. First, all collisions we directly observed during evenings were by sandhill cranes (except for one large bird of unknown species). Second, during carcass searches we noted a high ratio of sandhill cranes to other bird species (25:3 in 2008, 17:5 in 2009), although detection rates vary among species, with smaller species likely more sensitive to biases we attempted to account for. Regardless, BSI records suggest our estimates of crane mortality based on carcass searches are ever more biased low. Conversely, we did not directly observe collisions by six other species of birds that were represented in carcass searches at Rowe, indicating that collisions recorded by BSIs after evening included those of bird species other than sandhill cranes. BSI records cannot be relied on to distinguish among bird species or species groups because signatures produced when small birds forcibly strike a wire may resemble those created when large birds, such as cranes or geese, lightly contact a wire (personal communication, A. Pandey and R. Harness, EDM International, Inc., Ft. Collins, Colorado). Also, collisions with wires near support structures produce different signatures than collisions occurring farther away. We used BSIs mainly to assess our notion that relatively few collisions by birds occur during post-evening through dawn and to document collisions during periods of low visibility, e.g., snowstorms, fog. Although we were unable to discern exactly which species or species groups of birds collided with the eastern powerline during post-evening through dawn, close correlation between direct observations and BSI records of collisions by cranes in evenings indicate the technology holds promise for many applications of impact assessment.

MANAGEMENT IMPLICATIONS

Our results might suggest FireFlys reduce the likelihood that a sandhill crane will collide with powerlines at Rowe, but more rigorous experimental design incorporating replication is needed to reliably assess and provide broader inferences on effectiveness of FireFlys in decreasing mortality of cranes and other bird species at powerlines. Compared with other mitigation options (e.g., line burial or rerouting), initial installation of FireFlys is relatively inexpensive but long term costs may be high if diverters must be replaced every 1-2 years. Durability of the spinning model of the FireFly, many of which broke during this study, recently has been improved by changing to a heavy-duty, stainless steel swivel and a heavier metal ring to attach the reflective, plastic tag to the swivel (T. Chervick, FireFly Diverters LCC, personal communication). Other diverter devices could be considered. Spiral vibration dampers that are much longer than those currently on powerlines at Rowe have reduced collision mortality of cranes and other birds elsewhere (Brown and Drewien 1994), but might increase ice loading on wires at Rowe. Continued improvement of diverter devices is critical to bird conservation as powerlines and other structures (e.g., wind turbines) rapidly increase on the landscape.

Regardless, diverter devices cannot be relied on solely. Effective mitigation of collisions by birds with a given powerline or other structure must be tailored to the site's unique physical features and should integrate multiple tools.

Fresh carcass of sandhill crane beneath the western powerline at Rowe in March 2008, with evidence of blunt trauma to the legs, abdomen, and right wing.

ACKNOWLEDGMENTS

This work was supported mainly by a grant from Nebraska Game and Parks Commission (NGPC) via the U.S. Fish and Wildlife Service's (FWS) Section 6 program. Dawson Public Power District installed FireFlys on powerlines at Rowe. NGPC, Nebraska Rural Electric Association, National Audubon Society's Lillian Rowe Sanctuary, and FWS supported this work in many ways. University of Nebraska-Kearney students C. Fickel and M. Morten were key field assistants. M. Fritz (NGPC) facilitated study implementation. J. Runge and R. Harms (FWS) conducted most searches for bird carcasses at the Shelton powerline and, together with M. Fritz, lent excellent technical support. B. Taddicken (Rowe) helped with local logistics. We thank A. Pandey and R. Harness, EDM International, Inc., for collecting and interpreting BSI data, and J. Goodrich-Mahoney, Electric Power Research Institute, for helping support BSI instrumentation. J. Kuebler and J. Falconer, University of Nebraska-Kearney, graciously administered funding for this work.

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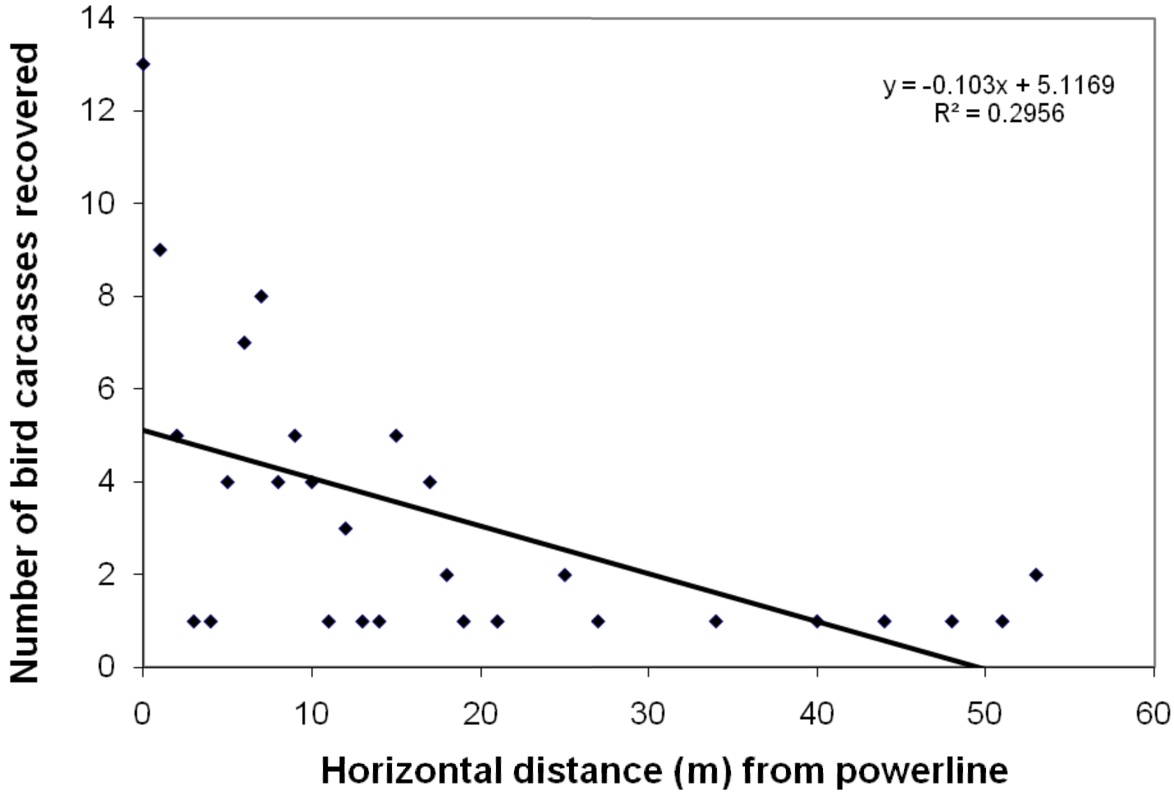

Appendix A. Distribution of distances at which bird carcasses were discovered from powerlines at Rowe, spring 2007 (R. Murphy and T. Smith, University of Nebraska-Kearney, unpublished data).