

## Notes

# Reactions of Sandhill Cranes Approaching a Marked Transmission Power Line

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## Abstract

Sandhill cranes *Antigone canadensis*, formerly *Grus canadensis*, are of widespread management focus, particularly where collisions with power lines are an important cause of mortality. Collision mitigation focuses on marking power lines to increase visibility, but collisions persist, perhaps because power line markers are not sufficiently visible in all conditions. Our objective was to compare reaction distances and reaction behaviors during daylight when power lines are presumably more visible, and during darkness when power lines are less visible. The power line we studied was fitted with glow-in-the-dark power line markers intended to increase nocturnal visibility. We found that during daylight, flocks generally avoided the power line by climbing gradually and passed above without making sudden evasive maneuvers. During darkness, flocks, particularly small flocks, were almost equally likely to make sudden evasive maneuvers as to climb gradually. Collision monitoring on the power line we studied conducted concurrent to our study indicated that 94% of collisions occurred during darkness, linking the behaviors we observed to actual mortality. Sandhill cranes also reacted at greater distances and with fewer sudden evasive maneuvers to the glow-in-the-dark-marked power line we studied than to nearby power lines without glowing markers evaluated in a prior study, suggesting that either glowing markers, smaller gaps between markers, or both, improved sandhill cranes' ability to perceive and react to the power line we studied. By correlating behavioral observations with mortality, our study indicates that proactive low-intensity behavioral observations might be useful surrogates to reactive high-intensity carcass searches in identifying high-risk spans. This approach may also be effective for other species.

Keywords: *Antigone canadensis*; collision; Lillian Rowe Sanctuary; mortality; Platte River

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## Introduction

Sandhill cranes *Antigone canadensis*, formerly *Grus canadensis*, are of management focus throughout the

species' range (Gerber et al. 2014, 2015) due primarily to three factors: recovery from population lows in the early 20th century, high value as a game bird, and utility as a model species for endangered whooping cranes *Grus*



*americana*. Nonhunting mortality of sandhill cranes is poorly understood (Gerber et al. 2014) beyond observations that predation is a primary cause of mortality on breeding grounds (Olsen 2004; Nesbitt et al. 2008), and collisions with power lines are an important cause of mortality during migration and wintering (Brown et al. 1987; Morkill and Anderson 1991; Murphy et al. 2009). Collisions with power lines also cause mortality of species of conservation concern such as whooping crane (Miller et al. 2010; Folk et al. 2013; Stehn and Haralson-Strobel 2014), sarus crane *Antigone antigone* (Sundar and Choudhury 2005), and blue crane *Anthropoides paradiseus* (Shaw et al. 2010). Because sandhill crane is ecologically and physiologically similar to other crane species, but more abundant than some at-risk species, this species can serve as a model to facilitate assessment of the effectiveness of collision mitigation measures for crane species in general (Morkill and Anderson 1991; Brown and Drewien 1995).

The primary assumptions underlying mitigation of avian collisions are that birds fail to see wires in their flight path until the wires are too close to avoid and that increasing the visibility of wires can reduce collisions (Martin and Shaw 2010; Avian Power Line Interaction Committee [APLIC] 2012). Collision mitigation is typically accomplished by installing power line markers on suspended wires (Sporer et al. 2013; Luzenski et al. 2016; Murphy et al. 2016). On transmission power lines ( $\geq 60$  kV; APLIC 2012), markers are typically installed only on overhead shield wires for two reasons: first, because corona discharge produces electromagnetic interference, audible noise, a visible glow, and reduced transmission efficiency when power line markers are installed on energized conductor wires (Hurst 2004); and second, because overhead shield wires are involved in collisions more often than are energized conductor wires (76% on average; Faanes 1987; Pandey et al. 2008; Murphy et al. 2016).

Power line markers seem least effective for species with high wing loading and high flight speeds (Sporer et al. 2013) and for species flying at night (Murphy et al. 2016). The effectiveness of power line marking may be limited by the distance at which the markers become visually prominent in flight. Birds such as sandhill cranes with relatively poor maneuverability may not perceive markers until they are too close to the power line to make effective evasive maneuvers, particularly during nocturnal flights (Murphy et al. 2016). This may be particularly true if the field of vision for a bird in flight fails to include all wires of a power line upon close approach (Martin and Shaw 2010).

Given that collisions tend to persist on marked power lines (Morkill and Anderson 1991; Brown and Drewien 1995; Barrientos et al. 2011), there may be room for improvement in collision mitigation through increasing the low-light visibility of, or decreasing the spacing between, power line markers. To evaluate these hypotheses, we investigated reaction distances and reaction behaviors of flocks of sandhill cranes as they approached a transmission power line during daylight and during darkness. The markers included glow-in-the-dark com-

ponents to improve low-light prominence. We compared our behavioral data to data collected in a previous study on power lines marked with more widely spaced nonglowing markers, and on unmarked power lines (Morkill and Anderson 1991). We compared our reaction distance and reaction behavior data to actual collision mortality in a previous study (Morkill and Anderson 1991) and to a concurrent study (Murphy et al. 2016) on the power line we monitored, to correlate reaction data to mortality data. We also evaluated the relationship between the field of vision of blue cranes described by Martin and Shaw (2010) in the context of the actual power line dimensions at our study site to identify whether any types of power line markers were likely to occur within visual fields of crane species generally during flight.

### Study Site

Greater than 500,000 sandhill cranes, and most of the migratory population of whooping cranes, migrate annually through Nebraska (Krapu et al. 2014; Pearse et al. 2015; Urbanek and Lewis 2015). Many of these sandhill and whooping cranes use the Platte River Valley in south central Nebraska as a migratory stopover site (Harner et al. 2015). Within the valley, the Platte River was historically described as a mile wide and an inch deep, and it remains composed of a wide, shallow, braided river channel with extensive sandbar habitat (Krapu et al. 2014). The National Audubon Society's Lillian Rowe Sanctuary (hereafter Rowe) near Gibbon, Nebraska, is a 9.8-km<sup>2</sup> wildlife refuge along the banks of the Platte River and is situated among a matrix of roosting and foraging habitats. Rowe has been a focal point for studies of sandhill crane collisions with power lines because two sets of 69-kV transmission lines cross the Platte River within the sanctuary (Figure 1). Each of the two power lines has a history of sandhill crane collision mortalities (Murphy et al. 2009, 2016; Wright et al. 2009).

### Methods

From 4 March to 8 April 2009, we observed the 283-m span of a power line where it crossed the Platte River within Rowe. This was the same span observed in a concurrent study of crippling and nocturnal biases in estimates of collision mortality of sandhill cranes (Murphy et al. 2016), and the eastern span of two spans studied in 2006 and 2007 (Wright et al. 2009) to identify baseline values for sandhill crane collision mortalities at Rowe. The span we studied was marked with both spiral vibration dampers (PreFormed Line Products, Cleveland, OH) and FireFly™ HW Bird Flapper devices (FireFly Diverters LLC, Grantsville, UT; P&R Tech, Beaverton, OR), the latter of which included a reflective sticker and a glow-in-the-dark sticker on each side (e.g., Figure 2). Reflective stickers were intended to increase the FireFly's visual contrast, improving daytime visibility. Glow-in-the-dark stickers were charged daily by exposure to full sun while hanging on the power line, and they were intended to increase nocturnal visibility. FireFlies were





**Figure 1.** Sandhill cranes *Antigone canadensis* in flight at a migratory stopover roost on the Platte River where from 4 March to 8 April 2009 we studied their reactions to a marked transmission power line bisecting the National Audubon Society's Lillian Rowe Sanctuary in Gibbon, Nebraska (credit: JFD).

attached at 12-m intervals to each of the two overhead shield wires, in an alternating arrangement so that when viewed from perpendicular to the power line, FireFlies occurred at 6-m intervals. These were interspersed with spiral vibration dampers installed several years prior (Wright et al. 2009). We placed a blind on the river bank at each end of the observed span and recorded flocks of sandhill cranes reacting to the power line from 0.5 h before sunset through 2 h after sunset. We used 10 × 50 binoculars to observe sandhill cranes during daylight, and 3× or 5× generation II night-vision spotting scopes to observe sandhill cranes during darkness (Murphy et al. 2016). We used radios to communicate between blinds to avoid creating duplicate records.

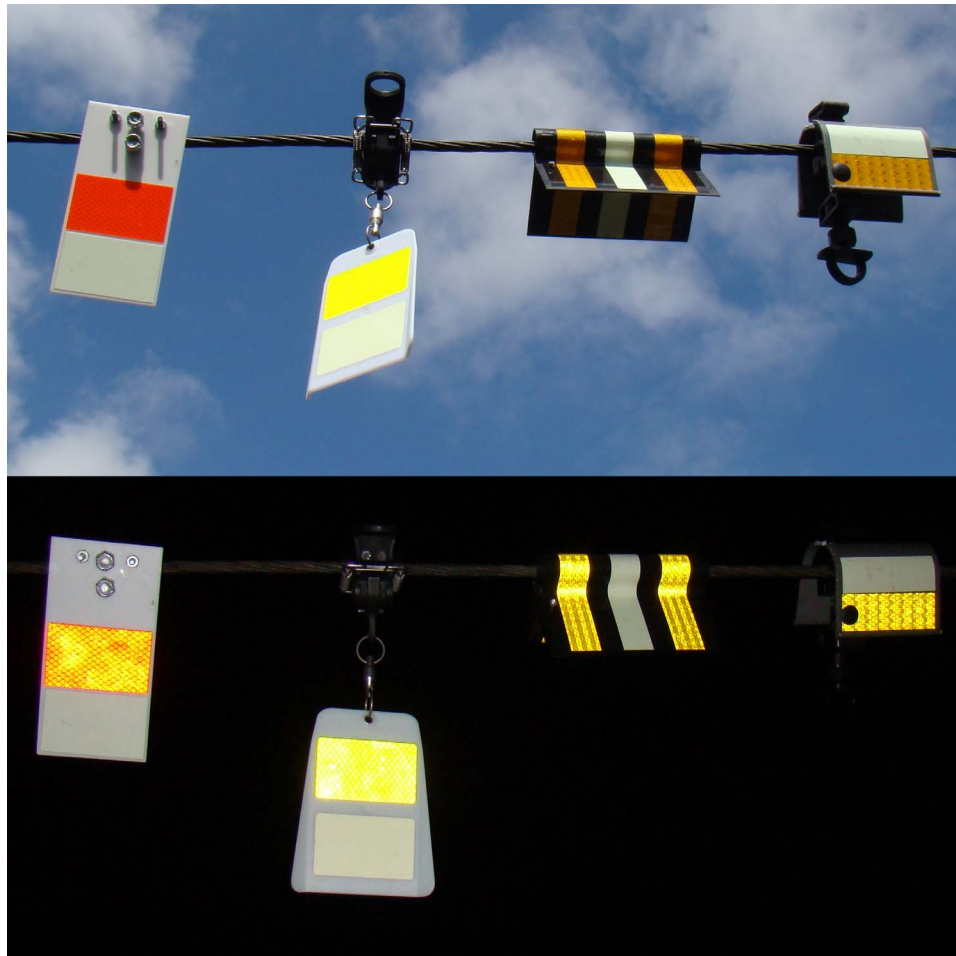
We documented flock size, reaction distance, and reaction behavior for sandhill cranes flying toward the power line, making flocks rather than individual sandhill cranes our sampling unit. To maintain independence of samples, we defined a flock as any individual or group separated by at least 30 m from any other individual or group (Morkill and Anderson 1991), and we only collected data for the first flock observed in each 5-min interval during each survey. We categorized flock sizes as small (one to three individuals) or large (more than four individuals; as in Morkill and Anderson 1991). We categorized reaction distances as 1–5, 6–25, and >25 m from the power line, to facilitate comparison to Morkill and Anderson (1991) who studied similarly configured power lines over uplands within the Platte River Valley. Similar to Morkill and Anderson (1991), we categorized reaction behaviors as 1) no reaction, 2) gradual climb, 3) flare (i.e., sudden climb), and 4) reversed flight path. We only recorded data for flocks flying <10 m above the

overhead shield wires because flocks flying higher were not at risk of collision (Morkill and Anderson 1991).

For analysis, we divided our data into two temporal subsets: 1) diurnal (30 min before to 45 min after sunset) and 2) nocturnal (46–120 min after sunset). This facilitated comparison of our diurnal data with the evening diurnal data collected by Morkill and Anderson (1991). We used  $\chi^2$  tests of independence to compare reaction distances and behaviors by flock size and time period. We excluded “no reaction” data from analyses because in our study, sample sizes were prohibitively small for inclusion in  $\chi^2$  tests. This occurred by design because we specifically focused on flocks at risk of collision (i.e., flying <10 m above the power line). In Morkill and Anderson (1991) more than half of all flocks recorded were well above the power lines involved. In these flocks, there was no collision risk, and thus no reactions by sandhill cranes. Our design prevented disproportionate sample sizes of flocks not likely to result in a collision from precluding detection of an effect of power line markers for flocks that were at risk of collision.

We also used  $\chi^2$  tests to compare reaction distances and behaviors in this study to data reported in Morkill and Anderson (1991) from nearby power lines marked with yellow aviation balls, and from nearby unmarked transmission power lines. In this analysis, we compared only data where sandhill cranes reacted to power lines because Morkill and Anderson (1991) included hundreds of records of sandhill cranes not reacting when flying well above power lines, as would be expected given that no collision risk existed in those overflights. Thus, we conducted four  $\chi^2$  tests: 1) reaction distances by lighting and flock size (Table 1, reaction distances block), 2)





**Figure 2.** Examples of power line markers with reflective and glow-in-the-dark components designed to increase visual prominence to birds during low-light conditions and thus maximize their effectiveness in reducing avian collisions with power lines in a study of sandhill crane *Antigone canadensis* reaction behavior. Manufacturers are, from left to right, P&R Tech (Beaverton, OR), P&R Tech, Power Line Sentry (Fort Collins, CO), and TE Connectivity (Berwyn, PA). The two P&R Tech markers on the left are the most similar to those we observed in a study of reaction behavior from 4 March to 8 April 2009 at a marked transmission power line bisecting the National Audubon Society's Lillian Rowe Sanctuary in Gibbon, Nebraska.

**Table 1.** Counts of reaction distances and reaction behaviors by flocks of sandhill cranes *Antigone canadensis* in flight toward a marked transmission power line bisecting the National Audubon Society's Lillian Rowe Sanctuary in Gibbon, Nebraska, from 4 March to 8 April 2009. Small flocks were composed of one to three individuals; large flocks were composed of four or more individuals (Morkill and Anderson 1991).

	Reaction distance (m)			No reaction	Row total
	>25	6–25	1–5		
Diurnal small flocks	92	27	3	NA <sup>a</sup>	122
Diurnal large flocks	98	24	0	NA	122
Nocturnal small flocks	20	69	44	NA	133
Nocturnal large flocks	29	36	6	NA	71
Reaction distance total	239	156	53	NA	448

	Reaction behavior				Row total
	Climb	Flare	Reverse	No reaction <sup>b</sup>	
Diurnal small flocks	105	8	9	0	122
Diurnal large flocks	102	3	16	1	122
Nocturnal small flocks	53	44	30	6	133
Nocturnal large flocks	44	11	16	0	71
Reaction behavior total	304	66	71	7	448

<sup>a</sup> NA = not applicable.

<sup>b</sup> No reaction data were not included in analyses because small sample sizes violated assumptions of  $\chi^2$  tests.

**Table 2.** Counts of reaction distances and reaction behaviors by flocks of sandhill cranes *Antigone canadensis* in flight toward a transmission power line marked with FireFlies and Swan Flight Diversifiers bisecting the National Audubon Society's Lillian Rowe Sanctuary in Gibbon, Nebraska, from 4 March to 8 April 2009, compared to flights toward power lines marked with aviation balls and toward unmarked power lines reported in Morkill and Anderson (1991). Small flocks were composed of one to three individuals; large flocks were composed of four or more individuals (Morkill and Anderson 1991).

	Reaction distance (m)			No reaction	Row total
	>25	6-25	1-5		
FireFlies	190	51	3	NA <sup>a</sup>	244
Aviation balls	128	197	106	NA	431
Unmarked	100	189	119	NA	408
Reaction distance total	418	437	228	NA	1,083
	Reaction behavior			No reaction <sup>b</sup>	Row total
	Climb	Flare	Reverse		
FireFlies	207	11	25	1	244
Aviation balls	454	19	114	768	587
Unmarked	397	36	92	1,200	525
Reaction distance total	1,058	66	231	1,969	1,355

<sup>a</sup> NA = not applicable.

<sup>b</sup> No reaction data were not included in analyses because Morkill and Anderson (1991) included hundreds of records of sandhill cranes not reacting when flying well above power lines, as would be expected given that no collision risk existed in those overflights.

reaction distances by power line marker type (Table 2, reaction distances block), 3) reaction behaviors by lighting and flock size (Table 1, reaction behaviors block), and 4) reaction behaviors by power line marker type (Table 2, reaction behaviors block). We applied Bonferroni corrections for multiple comparisons (Sokal and Rohlf 1995). Given an initial critical value of  $\alpha = 0.05$ , for the four comparisons made, we considered  $\alpha = 0.01$  to indicate statistical significance.

In a concurrent study on crippling and nocturnal biases in collision mortality estimates, Murphy et al. (2016) documented collisions of sandhill cranes with the power line observed in this study. Therein, 117 collisions were observed via night-vision optics, and 321 collisions were recorded via automated electronic Bird Strike Indicators (EDM International, Fort Collins, CO). We compared the reaction timing and behaviors observed in our study to collision timing in Murphy et al. (2016) to examine the assumption that increased reaction intensity and decreased reaction distances correlated with increased collision risk.

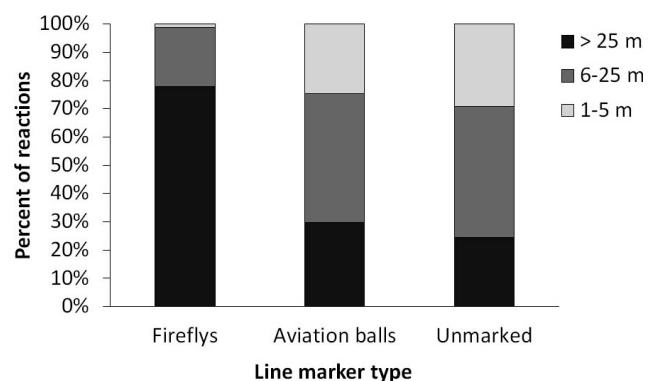
## Results

We recorded the reactions of 448 flocks of sandhill cranes to the eastern power line at Rowe in 2009 (Table 1; Table S1). Flock size averaged 18.5 (SE = 4.8) individuals, with a minimum of 1, median of 3, and maximum of 2,000. Consolidating across analyses, flocks tended to climb gradually >25 m from the power line marked with spiral vibration dampers and FireFly Bird Flapper devices, and flare or reverse direction <25 m from power lines marked with aviation balls or from unmarked power lines.

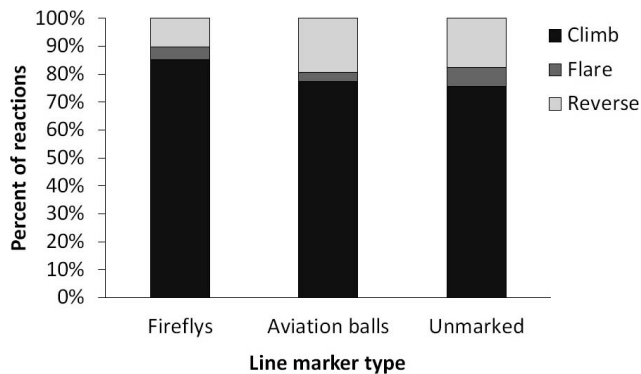
### Reaction distances

Proportions of reaction distances differed in daylight vs. night ( $\chi^2 = 171.34$ ;  $df = 6$ ;  $P < 0.001$ ). Specifically,

flocks tended to react >25 m from the power line during daylight and <25 m from the power line during darkness, regardless of flock size. Reactions within 5 m were particularly different; the reactions of only 1.2% of 244 diurnal flights occurred within 5 m, and the reactions of 24.5% of 204 nocturnal flights occurred within 5 m. Proportions of reaction distances also differed in our study compared to the Morkill and Anderson (1991) study of sandhill cranes approaching power lines marked with yellow aviation balls and unmarked power lines ( $\chi^2 = 217.7$ ;  $df = 4$ ;  $P < 0.001$ ; Table 2; Figure 3). Specifically, flocks tended to react from >25 m away when approaching the power line we studied (85.2% of diurnal observations). Flocks tended to react from <25 m away



**Figure 3.** Frequency distribution of reaction distances by sandhill cranes *Antigone canadensis* from 4 March to 8 April 2009 to a marked transmission power line bisecting the National Audubon Society's Lillian Rowe Sanctuary in Gibbon, Nebraska, compared to other nearby power lines. Flock reactions ( $n = 244$ ) to FireFlies were observed in this study; reactions to power lines marked with aviation balls ( $n = 1,199$ ) and unmarked power lines ( $n = 1,608$ ) and to were observed by Morkill and Anderson (1991).



**Figure 4.** Frequency distribution of behavioral responses by sandhill cranes *Antigone canadensis* from 4 March to 8 April 2009 to a marked transmission power line bisecting the National Audubon Society's Lillian Rowe Sanctuary in Gibbon, Nebraska, compared to other nearby power lines. Flock reactions ( $n = 243$ ) to FireFlies were observed in this study; reactions to power lines marked with aviation balls ( $n = 587$ ) and unmarked power lines ( $n = 525$ ) and to were observed by Morkill and Anderson (1991).

when approaching aviation balls (70.3% of aviation ball observations), or unmarked power lines (75.5% of unmarked power line observations; Morkill and Anderson 1991).

### Reaction behaviors

Proportions of reaction behaviors differed with daylight versus night ( $\chi^2 = 89.6$ ;  $df = 6$ ;  $P < 0.001$ ). Specifically, flocks tended to react with gradual climbs during daylight, and to flare or reverse flight paths during darkness, regardless of flock size. Reactions involving gradual climbs were particularly different, including on 85.2% of diurnal flights and 49.0% of nocturnal flights. Proportions of reaction behaviors also differed between our study and the Morkill and Anderson (1991) study for sandhill cranes approaching power lines marked with yellow aviation balls and unmarked power lines ( $\chi^2 = 18.1$ ;  $df = 4$ ;  $P = 0.001$ ; Table 3; Figure 4). Specifically, flocks tended to react with gradual climbs when approaching the power line we studied (85.2% of diurnal observations). Flocks were less likely to climb gradually when approaching aviation balls (77.3% of aviation ball observations) or unmarked power lines (75.6% of unmarked power line observations; Morkill and Anderson 1991).

### Mortalities

Murphy et al. (2016) found 6% of 117 observed collisions during daylight and 94% during darkness, where diurnal and nocturnal survey periods were identical to those used in this study. Consolidating across analyses, flocks tended to climb gradually  $>25$  m away from the power line during daylight (37.5% of all observations; 68.9% of diurnal observations) when collisions were rare. Flocks more often flared or reversed directions  $<25$  m from the power line during darkness

(19.9% of all observations; 43.6% of nocturnal observations) when collisions were comparatively frequent. Of 36 collisions reported in Morkill and Anderson (1991), 69.4% occurred on unmarked power lines, correlating reaction distances and behaviors with actual mortality because the number of cranes flying over marked power lines and unmarked power lines did not statistically differ.

## Discussion

Sandhill cranes reacted at greater distances and with more gradual avoidance behaviors during daylight than during darkness. Sandhill cranes also reacted at greater distances and with more gradual avoidance behaviors to the power line marked with FireFlies and Swan Flight Diverters than to the power line marked with aviation balls, and reaction distances were greater when approaching the power line marked with aviation balls compared to unmarked power lines (Morkill and Anderson 1991). Mortalities also were less prevalent during daylight than during darkness on the power line we studied (Murphy et al. 2016), and they were less prevalent on power lines marked with aviation balls than on unmarked power lines (Morkill and Anderson 1991), confirming that flight reaction behavior has direct inference to collision mortality. Thus, closely spaced glow-in-the-dark markers were more effective in mitigating collision mortality than widely spaced nonglowing markers, although nonglowing markers did reduce collision compared to unmarked wires.

The differences we found in reaction distances and behaviors were particularly pronounced for small flocks. In previous studies, individual birds in larger flocks were perceived as being at higher risk of collision (Brown 1993; APLIC 2012) because maneuvering room can be reduced within flocks, and because leading birds obscure the view of trailing birds. The apparent paradox between our findings and previous studies is resolved by considering relative detection probabilities of power lines for individuals within flocks during diurnal and nocturnal flights. During a diurnal flight, the odds that an individual bird within a small flock will see an approaching power line may be relatively high, as may be the odds that trailing birds in that flock, if present, will see and follow the bird into a gradual climb. During a nocturnal flight, the odds that an individual bird within a small flock will see an approaching power line may be relatively low, as may be the odds that trailing birds in that flock, if present, will be able to precisely follow a sudden evasive maneuver immediately before collision if they do not know what the obstacle is or where in their path the obstacle lies.

These observations facilitate increased understanding of when and how collision mitigation devices work and thus where continued innovation may facilitate increased effectiveness. Apparently, when sandhill cranes flew together, the likelihood that one of them would see and react to power line markers earlier upon approach increased with increasing numbers of birds. This indicates that power line markers were visible, but not

always sufficiently prominently for sandhill cranes to correctly conceptualize in three-dimensional space. Presumably, if power line markers were more prominent, either through increased visibility of individual markers or through reduced spacing between markers, then markers would become apparent to sandhill cranes at a greater distance, even to small flocks. Increased visibility may be achieved by incorporating materials with brighter and longer lasting glow-in-the-dark characteristics. Reduced spacing of glowing markers may help birds avoid a wire suspended between markers either through illumination of the wire itself or through avoidance of flying between markers. Although these approaches seem intuitive, three potential concerns exist. First, very prominent glowing power line markers suspended on wires may be disagreeable to the public. Second, reduced spacing between power line markers would add weight and loading to power lines, particularly during high winds and ice storms. Third, birds can be attracted to nocturnally lit structures (Jones and Francis 2003; Poot et al. 2008), so bird's reactions to markers with increased illumination may not be entirely as desired. Consequently, the relative effectiveness of increasing power line marker prominence should be quantitatively evaluated within the context of a study designed to consider negative impacts.

Avian collision risk can be exacerbated during poor weather (Brown et al. 1987; Jones and Francis 2003; Kirsh et al. 2015). Our study did not report weather effects in reaction distances because we had too few days with weather-obscured power lines to draw statistically meaningful comparisons. However, Brown et al. (1987) also recorded reaction behaviors of sandhill cranes approaching a power line, and they were able to consider weather effects. In their study, sandhill cranes' maneuverability and control were impaired by high winds, and 69% of sandhill crane mortality occurred on days with high winds, fog, or precipitation. Kirsch et al. (2015) also found that sandhill crane flight behavior differed when fog covered roost sites, leading to reduced flight distances and increased circling. If a power line exists in or near a roost, then increased circling during fog may increase collision risk. Future study should include weather data in multivariate analyses of the effectiveness of power line markers.

Martin and Shaw (2010) postulated that the field of view of some bird species during flight may preclude detection of suspended obstacles directly ahead, a reasonable hypothesis given that birds did not evolve in the presence of suspended obstacles. Evaluation of this hypothesis is critical, because if correct, then power line marking may not be effective mitigation measure regardless of type, glow, or spacing. Martin and Shaw (2010) specifically identified the field of view of blue cranes *Anthropoides paradiseus* as extending from 15° below the bill to 60° above the bill. A blue crane rotating its head >60° downward during flight could lose sight of suspended obstacles within its flight path (Martin and Shaw 2010). Following this logic, blue cranes, and presumably similarly structured sandhill cranes and whooping cranes, could hypothetically approach and collide with a power line

without the power line ever entering the blue crane's field of view. Our finding that reactions of sandhill cranes to marked power lines in proportion to the level of marking (none, aviation balls, power line markers) refutes this hypothesis, at least with respect to drawing inference beyond blue cranes to sandhill cranes. Future research could compare studies of collision mortality among various crane species, including at-risk whooping cranes, sarus cranes, and free-flying blue cranes to identify whether solutions implemented to protect some might also protect others. Future research also should include other migratory stopover locations, such as the San Luis Valley in southern Colorado, where sandhill cranes and whooping cranes also experience collision mortality (Brown et al. 1987; Brown 1993; Brown and Drewien 1995), but where roost sites are distributed through scattered wetlands rather than along a linear river feature.

### Management Implications

Our study provides a novel behavior-based approach to evaluating avian collision risk that may be useful elsewhere. Resource managers with concerns about the occurrence of avian collisions may not need to rely on a carcass survey that can be a time- and labor-intensive task; yield low sample sizes; and be fundamentally reactive because first a mortality has to be detected. Rather, managers may be able to evaluate flight reaction behavior to identify whether proactive collision mitigation may be warranted. This could be a particularly important surrogate for mortality monitoring if the species hypothesized to be involved are small bodied, because small-bodied carcasses can be quickly removed by scavengers (Rogers et al. 2014). The approach could be coupled with Bird Strike Indicators (EDM International, Inc.; Murphy et al. 2016) in areas where power lines of concern traverse water, preventing effective carcass surveys.

### Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

**Table S1.** Counts of reaction distances and reaction behaviors by flocks of sandhill cranes *Antigone canadensis* in flight toward a marked transmission power line bisecting the National Audubon Society's Lillian Rowe Sanctuary in Gibbon, Nebraska, from 4 March to 8 April 2009. Small flocks were composed of one to three individuals; large flocks were composed of four or more individuals (Morkill and Anderson 1991).

Found at DOI: <http://dx.doi.org/10.3996/052016-JFWM-037.S1> (31 KB XLSX).

**Reference S1.** Brown WM, Drewien RC, Bizeau EG. 1987. Mortality of cranes and waterfowl from power line collisions in the San Luis Valley, Colorado. Pages 128–136 in Lewis, JC, editor. Proceedings of the 1985 North American Crane Workshop. Platte River Whooping Crane





Maintenance Trust, Grand Island, Nebraska, and U.S. Fish and Wildlife Service, Washington, D.C.

Found at DOI: <http://dx.doi.org/10.3996/052016-JFWM-037.S2> (430 KB PDF); also available at <http://www.nacwg.org/proceedings4.html>.

**Reference S2.** Faanes CA. 1987. Bird behavior and mortality in relation to power lines in prairie habitats. Washington, D.C.: U.S. Fish and Wildlife Service Technical Report 7.

Found at DOI: <http://dx.doi.org/10.3996/052016-JFWM-037.S3> (2119 KB PDF); also available at <https://pubs.er.usgs.gov/publication/2000102>.

**Reference S3.** Hurst N. 2004. Corona testing devices used to mitigate bird collisions. California Energy Commission, PIER energy-related environmental research 500-04-086F. EDM International, Inc., Fort Collins, Colorado.

Found at DOI: <http://dx.doi.org/10.3996/052016-JFWM-037.S4> (1198 KB PDF); also available at <http://www.energy.ca.gov/reports/CEC-500-2004-086F.PDF>.

**Reference S4.** Miller JL, Spalding MG, Folk MJ. 2010. Leg problems and power line interactions in the Florida resident flock of whooping cranes. Pages 156–165 in Hartup, BK, editor. Proceedings of the Eleventh North American Crane Workshop. North American Crane Working Group, Wisconsin Dells, Wisconsin.

Found at DOI: <http://dx.doi.org/10.3996/052016-JFWM-037.S5> (510 KB PDF); also available at <https://www.savingcranes.org/proceedings-of-the-eleventh-north-american-crane-workshop/>. (September 2016).

**Reference S5.** Murphy RK, McPherron SM, Wright GD, Serbousek KL. 2009. Effectiveness of avian collision averters in preventing migratory bird mortality from powerline strikes in the central Platte River, Nebraska. 2008–2009 Final Report. Nebraska Game and Parks Commission (NGPC) via US Fish and Wildlife Service Section 6 Program.

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