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Source: Waterbirds, 39(3):312-317.
Published By: The Waterbird Society
https://doi.org/10.1675/063.039.0312
URL: http://www.bioone.org/doi/full/10.1675/063.039.0312

Crippling and Nocturnal Biases in a Study of Sandhill Crane (*Grus canadensis*) Collisions with a Transmission Line

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Abstract.—Collisions with power lines are a widely documented cause of avian mortality. Estimating total mortalities from counts of carcasses is usually accomplished by quantifying biasing factors, but neither crippling nor nocturnal biases are well understood. From 4 March through 13 April 2009, data were collected on Sandhill Crane (*Grus canadensis*) collisions involving a 69-kV transmission line crossing the Platte River in Nebraska, USA, at a major migration stopover area. The line was marked with devices designed to increase visibility to Sandhill Cranes, and thus reduce collisions. Numbers of carcasses detected via traditional searches that involved walking slowly in a zigzag pattern beneath the line were compared to numbers of collisions visually observed through binoculars and night vision spotting scopes and numbers of collisions detected by electronic Bird Strike Indicators (BSI). Seventeen carcasses were found during traditional surveys, 117 collisions were observed visually, and 321 collisions were recorded by BSIs. Most collisions occurred at night, with crippled Sandhill Cranes departing survey transects. Total mortality, including crippling and nocturnal biases, was 2.8 to 3.7 times greater than indicated by a traditional corrected-count mortality estimator. Neither crippling bias nor nocturnal bias were adequately considered by the traditional estimator. Consistent with other studies of avian collision, line marking was only partially successful in reducing collisions. *Received 22 February 2016, accepted 29 April 2016.*

Key words.—Bird Strike Indicator, Central Flyway, *Grus canadensis*, migratory birds, mortality, Nebraska, Platte River, power line collision, Sandhill Crane, survey bias.

Waterbirds 39(3): 312-317, 2016

Collisions with power lines are a widely documented cause of mortality (Avian Power Line Interaction Committee 2012; Rogers *et al.* 2014). Although power line collisions are thought to be a small source of mortality at the population level for most species (Avian Power Line Interaction Committee 2012), they can have major negative impacts on threatened and endangered species like Whooping Cranes (*Grus americana*; Stehn and Wassenich 2008), Sarus Cranes (*Antigone antigone*; Sundar and Choudhury 2005), and Blue Cranes (*Anthropoides paradiseus*; Shaw *et al.* 2010). Most documented power line collisions have involved transmission lines, and occurred when birds flying toward the lines apparently saw the relatively large energized conductor wires, flew upward to avoid them, and then collided with smaller, less visible overhead shield wires above (Martin and Shaw 2010).

Estimating accurate collision rates is important for understanding the impacts of avian collision, but can be hampered by multiple biases, including crippling bias, detection bias, habitat bias, scavenger bias (Savereno *et al.* 1996; Janss and Ferrer 2000; Ponce *et al.* 2010), and what we define here as nocturnal bias, the occurrence of collisions at night. Detection, habitat, and scavenger biases can be addressed by deploying and monitoring carcasses of known origin (Ponce *et al.* 2010; Huso 2011). Evaluation of crippling bias has been limited because it requires accurate mechanisms for observing birds colliding with power lines then flying on (Savereno *et al.* 1996). To our knowledge, nocturnal bias has not been thoroughly investigated. Nocturnal bias may be partially accounted for through careful design of carcass-deployment trials, but this approach fails to explore the causal role of nocturnal flight in avian collision risk. Failure to consider nocturnal bias also likely increases variance in estimates of scavenger bias because the time between the occurrence of a collision and the next survey dictates the exposure period of the carcass to potential scavengers, including nocturnally active mammalian scavengers (Rogers *et al.* 2014).

To provide insight into crippling and nocturnal biases, the primary objectives of this study were to: 1) document crippling bias in Sandhill Cranes (*G. canadensis*) attributed to collision with a transmission line; and 2) quantify timing of Sandhill Crane collisions. A secondary objective was to document the effectiveness of Bird Strike Indicators (BSI; EDM International, Inc.).

Methods

Our study was conducted at the National Audubon Society's Lillian Rowe Sanctuary (hereafter, Rowe), located on the Platte River in Nebraska, USA (40° 40′ 12″ N, 98° 53′ 12″ W), a migration stopover site that hosts about 75% of the world's population of Sandhill Cranes (~500,000; Gerber *et al.* 2014) and 10% of Whooping Cranes each spring (Urbanek and Lewis 2015). The area was federally designated as Critical Habitat for the Aransas-Wood Buffalo National Park population of the federally endangered Whooping Crane in 1978 (Urbanek and Lewis 2015). Sandhill Crane collisions with power lines have been an ongoing management concern at Rowe (Morkill and Anderson 1991; Wright *et al.* 2009).

We studied the more eastern of two 69-kV transmission lines that crossed the Platte River at Rowe. We focused on the eastern line because 86% of 130 Sandhill Crane carcasses discovered by Wright *et al.* (2009) were under this line. The span crossing the Platte River consisted of two overhead shield wires suspended 15 m above the river surface, and three conductor wires 10 m above the river. Prior to our study, the overhead shield wires were equipped with two types of devices to reduce avian collisions by making the wires more visible: FireFly HW Bird Flapper devices (FireFly Diverters LLC), and spiral vibration dampers (PreFormed Line Products). The river channel at Rowe was 250-400 m wide, braided with sandbars and islands, and bordered by grassy meadows and croplands. We installed one observation blind on each of the north and south banks of the Platte River to provide unobstructed views of the wires. Each blind housed a single observer, and the two observers communicated via radio to avoid recording duplicate observations.

Traditional Total Mortality Estimation

We searched for dead or crippled Sandhill Cranes three times per week from 4 March through 13 April 2009. Our search area was 120 m wide and 400 m long, spanning the distance of the power line between riverbanks (Wright *et al.* 2009). We searched by walking slowly (3-4 kmph) in a zigzag pattern (Barrientos *et al.* 2011; Rogers *et al.* 2014), and marked the legs and distal wings of discovered Sandhill Cranes with orange paint to avoid inadvertent recounting. We calculated the total number of Sandhill Crane collisions by using the standard formula for estimated total collisions (Table 1). To quantify total dead birds found, we totaled all dead and crippled Sandhill Cranes found (Avian Power Line Interaction Committee 1994). To quantify search bias and scavenger bias, we placed one to three intact Sandhill Crane carcasses within the study area 1.5 to 4.0 hr after a search (Wright *et al.* 2009). We then recorded whether an uninformed searcher detected the carcasses during the next scheduled survey. Each placed carcass was inconspicuously marked via broken or removed remiges and broken phalanges or tarsi to facilitate identification. To estimate habitat bias, we quantified the proportion of the quadrat where carcasses would persist without being swept downstream (water depth < 12.5 cm; Wright *et al.* 2009). To include crippling bias in traditional total mortality estimates, we calculated the proportion of visually observed collisions resulting in Sandhill Cranes falling within the quadrat (flight terminated or dead). We did not explicitly incorporate nocturnal bias in estimated total collision calculations because traditional methods do not consider nocturnal bias.

Crippling Bias

To expand our understanding of crippling bias, we paired visual and electronic observations. Each evening, we directly observed the transmission line from 0.5 hr before sunset until 2 hr after sunset. When the onset of darkness limited visibility, we switched from 10x50 binoculars to 3x or 5x night vision spotting scopes. Each time we observed a collision, we recorded the time and the wire(s) involved. We recorded the post-collision fate of each bird as: 1) unaltered flight; 2) hampered flight, wherein the Sandhill Crane was losing altitude during departure; 3) flight terminated with the Sandhill Crane flapping while falling; or 4) immediate death indicated by a limp fall.

To identify whether visual monitoring accurately quantified crippling bias and to provide information on when collisions occurred on marked transmission lines, we mounted three BSIs at 90-m intervals on each of the five wires we observed. A BSI is a vibration sensing and recording tool that uses an internal accelerometer to identify vibrations in the line, BSIs automatically quantified the occurrence and timing of power line collisions 24 hr per day.

Each time we observed a collision visually, we aligned the time of the observation with the vibration recorded by a BSI to identify vibration signatures typical of Sandhill Crane collisions. We then searched BSI data for additional vibration signatures to identify collisions undetected by visual observation, and compared the number of carcasses predicted via traditional bias estimation equations (Avian Power Line Interaction Committee 1994) to the number of collisions documented via visual and BSI records.

Nocturnal Bias

We defined nocturnal collisions as occurring during darkness between civil dusk and civil dawn. If col-

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Table 1. Descriptions and formulas for components of collision mortality studies (Avian Power Line Interaction Committee 1994).

Abbreviation	Description	Formula	Value
CB	Crippling bias	CB = (TDBF + SB + RB + HB)/PBK - (TDBF + SB + RB + HB)	56.7
ETC	Estimated total number of collisions	ETC = TDBF + SB + RB + HB + CB	87.3-114.1
HB	Habitat bias	HB = (TDBF + SB + RB)/PS - (TDBF + SB + RB)	6.9-33.7
PBF	Proportion of placed birds found by searchers	N/A	76.5%
PBK	Proportion observed collisions falling in the study area	N/A	35.0%
PNR	Proportion of placed birds not removed by scavengers	N/A	94.1%
PS	Searchable proportion of the study area	N/A	41.2-77.3%
RB	Removal bias	RB = (TDBF + SB)/PNR - (TDBF + SB)	1.4
SB	Search bias	SB = (TDBF/PBF) - TDBF	5.2
TDBF	Total dead birds found	N/A	17

lisions occurred as expected in proportion to observation periods, about one-half of collisions should have occurred during each of the binocular and night vision scope periods. To evaluate this, we calculated the percent of collisions observed during each period. We also categorized each collision recorded via BSI, by time of day, defined as dawn (civil dawn to sunrise; 30 min), day (sunrise to sunset; 12 hr), dusk (sunset to civil dusk; 30 min), or night (civil dusk to civil dawn; 11 hr). We used a chi-square goodness of fit test to compare proportions of collisions occurring within each observation period, assuming a null hypothesis that collisions occurred proportionally to the duration of each period: 2% during dawn, 50% during the day, 2% during dusk, and 46% during the night. To evaluate the potential for a relationship between overhead shield wires and nocturnal bias, we assumed that if collisions occurred in proportion to wire planes, 50% would involve overhead shield wires and 50% would involve conductors.

Results

Traditional Total Mortality Estimate

We found 17 carcasses and no crippled Sandhill Cranes during transect searches. We found 76.5% of carcasses placed during detection trials, and lost only one to scavengers. Most (41.2-77.3%) of the quadrat was not covered by water. Of the 117 Sandhill Crane collisions observed, 56.7 could be attributed to crippling bias. Adjusting carcass counts for these biases, the estimated total collisions based on traditional estimates was 87.3-114.1 Sandhill Crane collisions, depending on river water levels impacting habitat bias.

Crippling Bias

Of 117 Sandhill Crane collisions observed, 3.4% died on impact, and 31.6% resulted in flight termination, with both falling within the search quadrat. Thus, at most, only 35.0% of the total number of collisions recorded could have been detected via traditional carcass searches, though most were not. Of the remaining 76 collisions, 35.9% resulted in crippled Sandhill Cranes with hampered flight moving outside the search area, and 29.1% resulted in Sandhill Cranes with unaltered flight. BSIs recorded 321 collisions, of which 123 occurred during visual observation periods, though not all collisions were seen. Of these 321 collisions, 72.6% were associated with overhead shield wires (Table 2). We found a strong correlation between visual collision records ($n = 117$) and BSI records ($n = 123$; $r = 0.88$, df = 39, $P < 0.001$; Fig. 1). Variation in the two counts occurred when simultaneous collisions exceeded the capacity of BSIs to distinguish or store them.

Nocturnal Bias

We detected all 117 visually observed collisions via night vision scopes. These collisions occurred during dusk (6.0%) or after onset of darkness (94.0%). Consistent with visual observations, the 321 collisions recorded by BSIs were not distributed evenly throughout the 24-hr period ($\chi^2 = 330$; df = 3, $P < 0.001$), with 95.6% occurring during night (Fig. 2). Two-thirds of visually observed collisions occurred when flocks of Sandhill Cranes suddenly flushed upward toward the span, caused by an unknown disturbance. Overall, total mortality based on BSI records incorporating crippling and nocturnal bias was 321 collisions, 2.8-3.7 times greater than the traditional mortality estimator.

Discussion

Our results indicate that carcass searches, even with corrections for disappearance rates, inadequately reflected actual collision rates because most Sandhill Crane carcasses did not fall within surveyed areas, and because crippled Sandhill Cranes escaped detection. We used night vision scopes and BSIs to quantify one of the highest rates of crippling bias (65.0%) in any study of avian collision to date. Previous studies of various species have estimated wide variation in crippling bias rates, ranging from 22% to 82% (Savereno *et al.* 1996; Bevanger and Brøseth 2004), but our study is the first to use night vision scopes to document the outcome of nocturnal collisions. These collisions would not have been observed in other studies, suggesting that crippling bias estimates from other studies may be low.

BSIs provided unique information on collision timing and frequency. However, because BSIs were designed with enough memory to store only four collision records at a time, the total BSI records may underestimate the total collisions that actually occurred, particularly when collisions involved flocks of Sandhill Cranes. If multiple BSIs sharing a base station must download data simultaneously, they form a queue, downloading one after another. Additional collisions occurring prior to downloading overwrite the oldest collision if not already downloaded to the base station. Future studies incorporating BSIs may require multiple base stations to facilitate parallel downloading.

Despite 4 years of effort and the installation of two different line marker types (Brown and Drewien 1995; Wright *et al.* 2009), Sandhill Cranes continue to collide with the lines at Rowe, mostly at night when line markers have little effect, and mostly with the overhead shield wires (64.8%). Persistent post-retrofitting collision problems are consistent across studies where collision mitigation appears to be about 50% effective on average (Morkill and Anderson 1991; Brown and Drewien 1995; Barrientos *et al.* 2011). Perhaps much of the persisting col-

Table 2. Wires involved in collisions of Sandhill Cranes with a 69-kV power line over the Platte River at National Audubon Society's Lillian Rowe Sanctuary, Nebraska, USA, during 4 March-13 April 2009, based on visual observations and Bird Strike Indicators (BSI) records.

Observation	Collision Location	Collision Count	Percentage	95% CI
Visual	Overhead shield wire	46	65	53-75
	Energized conductor	25	35	25-47
	Total	71		
BSI	Overhead shield wire	233	73	67-77
	Energized conductor	88	27	23-33
	Total	321		

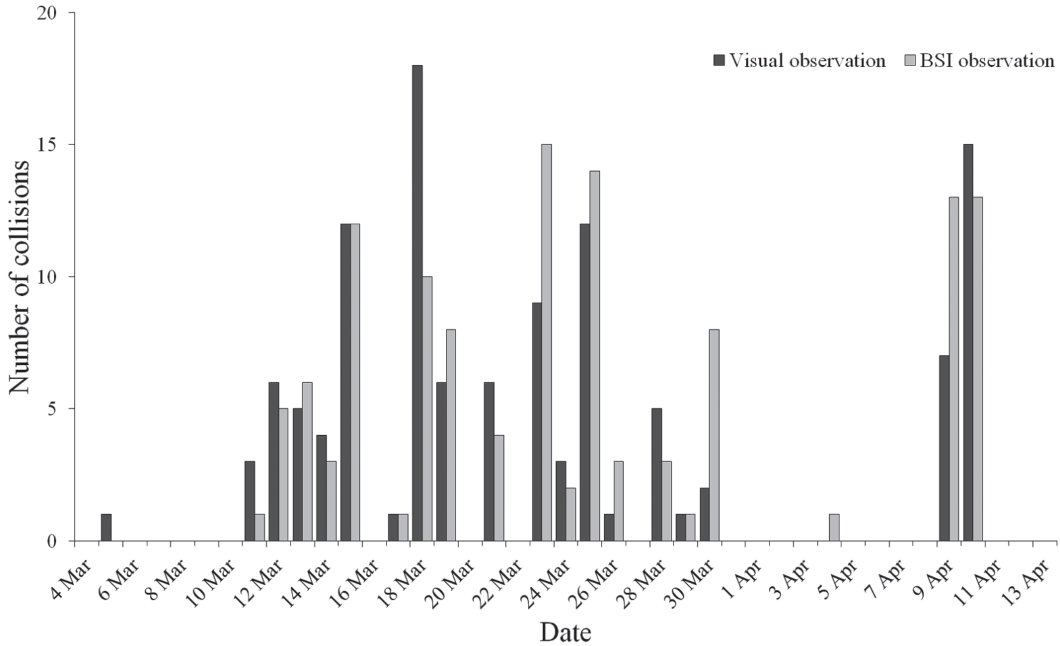

Figure 1. Number of Sandhill Crane collisions with a power line over the Platte River, Nebraska, USA, at the National Audubon Society's Lillian Rowe Sanctuary, recorded by visual observations (n = 117) and Bird Strike Indicators (BSI; n = 123) during the 2.5-hr evening observation periods during 4 March-13 April 2009.

lision problem in previous studies is nocturnal. New strategies designed specifically to mitigate nocturnal collision need to be developed, tested, and, if useful, implemented.

Our study revealed a previously undocumented extent of crippling and nocturnal biases, but most collisions occurred when flocks of Sandhill Cranes suddenly flushed from their night roost. Collision was the proximate cause of death, but disturbance was the ultimate factor that drove Sandhill Cranes into danger. Managers focused on reducing Sandhill Crane collisions at Rowe should work to minimize nocturnal disturbances.

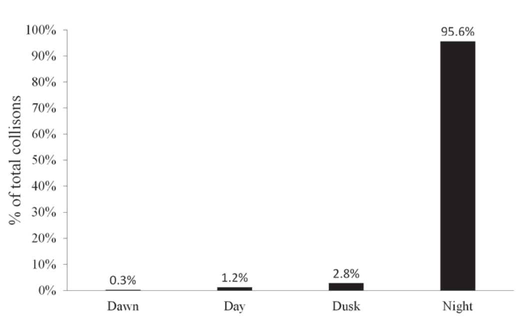

Figure 2. Timing of collisions (n = 321) by Sandhill Cranes with a power line over the Platte River, Nebraska, USA, at the National Audubon Society's Lillian Rowe Sanctuary, as detected by Bird Strike Indicators (BSI) during 4 March-13 April 2009. Time periods were dawn (civil dawn to sunrise; 30 min), day (sunrise to sunset; 12 hr), dusk (sunset to civil dusk; 30 min), and night (civil dusk to civil dawn; 11 hr).

ACKNOWLEDGMENTS

Two anonymous reviewers improved an early draft of this work. Funding from the Nebraska Game and Parks Commission through the U.S. Fish and Wildlife Service supported our fieldwork. Dawson Public Power District installed line markers. We thank the Nebraska Game and Parks Commission, Nebraska Rural Electric Association, National Audubon Society's Lillian Rowe Sanctuary, and U.S. Fish and Wildlife Service for additional support. We are grateful to C. Fickel and M. Morten for field assistance. M. Fritz, B. Taddicken, R. Harms, and J. Runge facilitated study implementation. J. Goodrich-Mahoney helped support BSI instrumentation. Findings and conclusions in this article do not necessarily reflect views of the U.S. Department of the Interior, Fish and Wildlife Service, which employed RKM during analyses and publication. Use of Sandhill Crane carcasses in bias trials were authorized under Migratory Bird Special Purpose permit MBO49028-0.

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