*Draft summary of Kim Ness' master's research on greater sandhill crane flight reactions and models to predict power line collision risk in Wisconsin (2009-2010).*


## ABSTRACT

Many species of cranes die directly from striking a power line or indirectly from predation or serious injuries following a power line strike. Power lines near important crane roosting habitat may pose a collision risk to cranes. Markers can be placed on power lines to increase line visibility to cranes with the intent to prevent collisions. Yet, marking all power lines near important habitat is impractical and costly. Therefore, this study's research goal was to identify landscape, weather, and flight variables related to collision risk for greater sandhill cranes in south-central Wisconsin.

Collision risk was defined as the probability that a crane flock showed an abrupt flight behavior to avoid striking a line. To estimate collision risk, I recorded flight behaviors 45 m around power lines within 750 m of agricultural fields and wetlands in two study areas, Briggsville and the Mud Lake State Wildlife Area, areas with similar resident and migrating populations of cranes in the southern Wisconsin. Aggregated across seasons and weather, I observed a total of 319 crane behaviors around power lines in 68 dawn or dusk observation periods and conducted weekly carcass searches. I observed 48 (15%) abrupt behaviors, 161 (50.5%) gradual behaviors and 110 (34.5%) unaltered flight behaviors.

I applied Akaike Information Criterion, backward-selection to identify best-fit logistic regression models for predicting unaltered/altered behaviors and gradual/abrupt behaviors. Results revealed that as cranes flew closer to power lines, the likelihood of cranes showing abrupt behaviors increased between 62-80%; this model correctly predicted 80.9% of altered behaviors. Furthermore, cranes that flew at or below 22.4 m had a 50% probability of altering their flight behaviors, considered the "Collision Risk Zone." To predict abrupt behaviors, two best-fit models were selected and showed that cranes had a higher likelihood of showing abrupt behaviors when they: (Model 1) flew at lower flight altitudes, in warmer temperatures, and farther from forest edges (model correctly predicted 76.8% of abrupt behaviors) or (Model 2) farther from forest edges, and in the summer (model correctly predicted 73.9% of abrupt behaviors). Results showed that cranes crossing at or below 11.2 m of a power line, during the summer, and farther from a forest edge had a higher risk of striking the power line.

Future models to predict collision risk should consider that power lines near agricultural fields and wetlands farther from forest edges pose higher risk to cranes flying in the summer and at lower flight altitudes. Moreover future power line siting guidelines should include surveys of flight behaviors to document collision risk.


## INTRODUCTION

This study is about modeling where sandhill cranes chose to fly across power lines between foraging agricultural fields and roosting wetlands. In rural locations, power lines pose a collision risk to large birds such as cranes, swans, and geese. Sandhill cranes (*Grus canadensis tabida)* are a surrogate research species for the rare and endangered whooping crane (*Grus americana)* for their similarities in natural history and power line collision risks. In 1970 whooping cranes were listed as endangered from drastic population decline (Canadian Wildlife Service and USFWS, 2007). Therefore, understanding conservation risks to cranes is critical to protecting future habitats and designing safer flyways for cranes. We identify patterns in flight behavior across wetland-agricultural landscapes to predict future collision risks to cranes.

### *Crane Ecology and Conservation Threats*

In this project, we studied greater sandhill cranes as surrogate research species for whooping cranes. Sandhill cranes number 600,000 worldwide approximately 15,000 in Wisconsin, whereas whooping cranes have a worldwide population of 550. In the eastern flyway, less than 100 (as of Sept 2011) whooping cranes actively migrate in the newly reintroduced Wisconsin Migratory Flock, where reintroduction efforts began in 2001.

Both species have similar migratory and breeding ranges (Meine and Archibald 1996). As a neo-tropical migrant with six sub-species, migratory sandhill cranes have a range extending from northern Mexico and Cuba up through northern Canada and eastern Siberia, while non-migratory sandhill cranes reside in Florida (Johnsgard, 1983). Historically, whooping cranes ranged from southern Texas, eastern US coasts, across North America, and upwards through central Canada (Meine and Archibald, 1996). This study considered risks for whooping cranes in the eastern flyway.

Both whooping cranes and sandhill cranes use a wide variety of habitats. Sandhill cranes select areas with habitats (i.e. land cover) for foraging, roosting, and socializing (Meine and Archibald, 1996). Field studies showed that sandhill cranes rarely used forested areas (Su, 2003; Miller, 2007; Sugden et. al., 1988; Lovvorn and Kirkpatrick, 1982; ICF, unpublished data). Both North American cranes are highly dependent on emergent wetlands (USFWS, 1981; Su, 2003; Miller, 2007) and have adapted to foraging in agricultural fields in place of natural grasslands (Lovvorn and Kirkpatrick, 1982; Sugden et al., 1988). In upland areas, both crane species forage on plant tubers, small vertebrates (e.g. snakes and rodents), insects, and grains (Johnsgard, 1983; Meine and Archibald, 1996).

Serious injury, death, and habitat avoidance are risk related to power line for both crane species (Murphy et al., 2009; Jenkins et al. 2010; Miller et al., 2010). Power lines are the highest known cause of mortality of fledged whooping cranes; 45 whooping crane power line-caused mortalities were documented since 1956 in the Aransas-Wood Buffalo Migratory Flock that migrates from Wood Buffalo National Park in the Northwest Territories to Aransas, Texas (Stehn and Wassenich 2008). Of these collision mortalities, 40% were fledged cranes and 22% were those migrating across the Midwest. As not all cranes die immediately from striking power lines, others suffer injuries (e.g. torn muscles or broken limbs) that increase chances of predation (APLIC, 1994; Van Rooyen, 2003; Hartup et al., 2010; Miller et al,. 2010). The level of scavenging, decomposition, and chances of injured birds wandering off (APLIC, 1994) confounds any estimates of power line-caused death or collision.

Studies on sandhill crane flight behaviors in different weather and landscapes indicate that power line type (e.g. distribution versus transmission wires), habitat surrounding a power line, crane flight experience, and familiarity with the location increase the chances of striking the power line (Brown and Drewien, 1995; Morkill and Anderson, 1991; Ward and Anderson, 1992; Yee, 2008). Furthermore, as large-bodied birds, cranes have less flight maneuverability and cannot react as quickly to avoid power lines in low light conditions at dawn and dusk, in low visibility conditions during fog and rain, or in high winds (APLIC, 1994; Janss, 2000; Janss and Ferrer, 2000).

No research exists on the impact of crane power line collisions with distribution lines in the eastern United States for sandhill cranes. The Wisconsin Migratory Flock migrates through the historical flyway between Wisconsin and Florida in urban-rural landscapes with power lines that stretch across much of this critical flyway. In these areas with a high density of power lines, the collision risk increases as the reintroduced whooping crane population grows. If specific power lines are known to pose collision risk to cranes, several options are available to mitigate these risks to cranes. Options include 1) planting trees near power lines, which cranes fly over (Yee, 2008), 2) placing power line markers on lines (Jenkins et al., 2010), or 3) changing the agricultural fields or rotation schedule (APLIC, 1994).

***Objective of Study***

To prevent future crane collisions in the western U.S., the U.S. Fish and Wildlife Service (USFWS) recommended marking power lines that posed a potential collision risk to whooping cranes. Stehn and Wassenich (2008) found that 75% of these collisions occurred in an 80-mile wide area within the migration corridor. They specifically suggested marking all existing and future power lines in the whooping crane "migration corridor located within 2 miles of a suitable crane wetland or known stopover site." This recommendation to mark all existing power lines motivated my project. It seemed that marking all power lines was impractical and therefore ineffective for protecting whooping cranes. Therefore, I used regression models to predict where sandhill cranes showed an abrupt behavior around power lines to indicate a collision risk. Furthermore, the landscape features around these power lines might uncover patterns that managers could use to predict where power line posed higher collision risk to both whooping cranes and sandhill cranes.

I used flight behavior and landscape features to build and test regression models. I selected variables shown to correlate with crane flight behavior and local movement patterns. Crane flight behaviors strongly correlate with high wind speeds, low light levels, and larger flock sizes (Morkill and Anderson 1991, Murphy et. al. 2009, Martin 2010). Local flights between foraging and roosting sites depend on both the presence of other cranes and proximity to preferred roosting sites in wetlands and foraging sites in agricultural fields (Sugden et. al. 1988). My research was guided by the following three questions:

1) *How do crane flight behaviors vary by flight altitude, flock size, weather (precipitation, temperature, relative percent humidity, and percent cloud) and timing (season and time of day), and study area?*
2) *Is spatial clustering present in the crane flight behavior data?*
3) *Which variables best predict abrupt flight behaviors among cranes?*

To answer these questions, I needed to understand how cranes altered their flights around power lines. My methods included (1) an observational survey for measuring flight behavior of cranes flying around power lines, and evaluating the spatial pattern of those behaviors (2) collecting potential predictors of abrupt flight behaviors, (3) examining how landscape variables related to flight behaviors in multivariate analyses, and (4) quantifying the probability of abrupt flight behaviors in relation to power line attributes and seasonal variations in the surroundings.

## METHODS

### *Study Areas in Wisconsin*

The study area included Briggsville (BV) and the Mud Lake Wildlife Area (ML) in south-central Wisconsin. I selected these Study Areas because both (1) have a history of sandhill crane power line collisions, (2) whooping cranes have been observed in both Study Areas, and (3) have breeding sandhill cranes (e.g. 200-300) and larger migrant sandhill crane populations that use local agricultural fields and wetlands. There were 12 Observation Sites in each Study Area. Study Areas were located within two larger Eco-Regions: the Central Sand Hills and the Southeast Glacial Plains Ecological Landscape. After selecting BV and ML as my Study Areas, the proportion of land cover in the total areas had a similar mosaic of agricultural and wetland patches (Figure 1). Both Study Areas (Figure 1) were dominated by row-crop agriculture, pasture or hay fields, forests, and emergent wetland.

**Briggsville.** The Briggsville (BV 205 km$^2$/79 mi$^2$) Study Area borders Adams, Columbia, and Marquette counties (Figure 1). Researchers at ICF have intensively studied this sandhill crane population since 1988 (Su 2003, Su et. al. 2004, Miller 2007, Ness and Lacy 2010). From daily ground surveys, Su (2003) counted approximately 150-250 cranes, of which 25-35 were breeding pairs. During peak migration in September and October, ICF recorded between 600-1,200 cranes in flight surveys (counts of birds flying into pre-determined wetlands) that stop to forage and roost in BV (ICF unpublished data). In BV, researchers confirmed five sandhill crane collision mortalities, all found 0-50 m from power lines (ICF unpublished data, personal observations). ICF research interns also observed two direct power line collisions in BV (A. Lacy, personal communication, August 5, 2010).

**Mud Lake Wildlife Area.** The Mud Lake Wildlife Study Area (ML) (354 km$^2$/137 mi$^2$) crosses Dodge and Jefferson counties (Figure 1). The migration timing is opposite to that of BV where peak migration occurs in March and April with between 600-1,100 cranes that stopover (M. Ayers, personal communication, April 20, 2009). Whooping cranes have also foraged and roosted in agricultural fields and wetlands in ML (personal observations). Nine whooping cranes remained in the marsh foraging with GSC and alone throughout July and August 2009 (personal observations). In ML, M. Ayers discovered five sandhill crane collision mortalities and observed many abrupt flight reactions around power lines (personal communication, August 16, 2009).

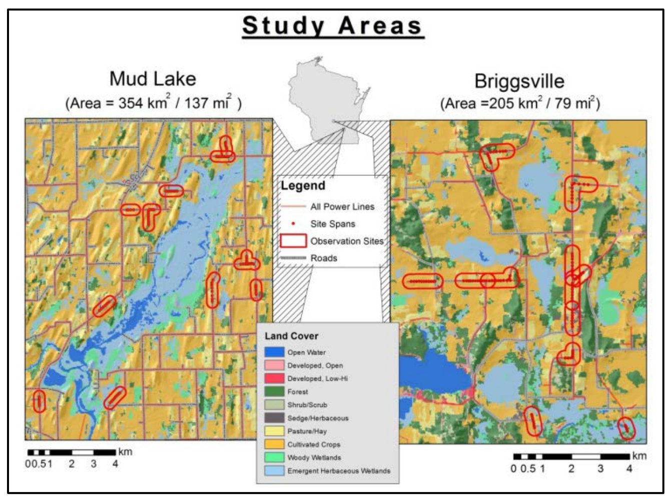


**Figure 1.** Two Study Areas located in southeast Wisconsin with 12 Observation Sites within each Study Area. The red polygons represent 500 m buffers around the 24 Observation Sites.

### *Study Timeline*

I studied sandhill crane flight behaviors at power lines from July 2009 to April 2010 in two phases. During Phase 1, I observed adult resident cranes that actively defended territories and remained separate from the larger non-breeding flocks during the breeding season between 3 July 2009 to 4 October 2009. During Phase 2, I observed migratory cranes in the ML Study Area from 16 October to 14 November 2009 and in BV from 20 March to 3 April 2010. In these Study Areas, cranes migrated at opposite seasons; they migrated through BV in the fall and migrated through ML in the spring.

### *Selection of Observation Power Lines*

I recorded crane flock flight reactions around Site Spans, the center of a length of power line at which I recorded crane flight behaviors. The Site Span was between two consecutive power line poles within the Observation Site. I observed between three and 14 Site Spans at each Observation Site.

I only visited power lines to record crane flight behaviors at power lines that met the following criteria: 1) there was documented past and current crane presence within 500 m of the power line, 2) there were locations for accurate viewing of crane behaviors around the power line, 3) the land cover surrounding power lines was representative of crane habitat use (i.e. it had a combination of row-crop agriculture, pasture/hay, emergent wetland, and forest), and 4) the power line was within 500 m of any wetland [based on results from a study on blue cranes (*Anthropoides paradiseus*) in South Africa showing that more power line collisions occurred within 500 m of roosting wetlands (Kotoane and Shaw, 2006)].

### *Flight Observations at Power Lines*

I visited each power line section twice during the summer (2009), fall (2009), and spring (2010) using a stratified random sample. I only recorded the flight behaviors of cranes flying within 200 m of a power line. I used a 200 m distance because I could accurately measure this distance in fields using wire flag poles positioned at 10 m intervals perpendicular to a line. Researchers noted that cranes flying 50 m above a line had little or no power line collision risk (Brown et. al. 1995, Morkill and Anderson 1991, Yee 2008); therefore only cranes that flew within 50 m above a power line were included in this study.

During these observations, I documented ten variables as inputs for the regression analysis. I recorded variables of crane flights (behavior, direction, altitude, and number of cranes flying in a flock) using 8x50 binoculars. Because cranes flew in flocks as a cohesive unit that showed the same behavior around power lines, I used one flock as the independent unit of analysis. Flight behaviors of flocks included unaltered (no change in altitude or direction), gradual (change in flight altitude or direction within 200 m of a power line), and abrupt (change in flight altitude or direction within 15 m of a power line). I recorded weather variables (temperature, wind speed and direction, cloud cover, relative humidity, precipitation) with a kestrel weather gauge every one hour during an observation period.

### *Carcass Searches under Power Lines*

I quantified sandhill crane power line collision mortality using weekly carcass searches conducted throughout the study timeline at both Study Areas. Upon finding any crane or other waterfowl carcass, I photographed it, recorded GPS coordinates, and collected the carcass to identify cause of death. ICF held the necessary WIDNR scientific collector's permits to transport a crane carcass.

### *Spatial and Statistical Analysis of Crane Flight Behavior*

I separated my data into three analyses accounting for behavior and landscape differences. I linked all flight behavior and weather data to a geographic database to link with landcover data. I used the statistical program R (R Development Core Team 2011) and ArcGIS 10.0 for all analyses. Because of the lack of publically-available power line data for distribution lines, I digitized maps from field-collected power line data using imagery from the National Agriculture Imagery Program (NAIP). I used a filter analysis to estimate proportion of landcover around power lines with a 17x17 pixel window using the 2001 National Land Cover Dataset (Homer et. al. 2004); this distance represented the 250 m buffer around Site Spans.

I used backward step selection logistic regression with Akaike Information Criterion (AIC) selection to model flight behaviors as binary response variables in relation to weather, and flock predictor variables. I used univariate tests to test collinearity for variables in candidate logistic regression models. I constructed two models, one to predict altered/unaltered behaviors and another to predict separate altered behaviors. Altered behaviors included abrupt and gradual flight behaviors. Psudo I used Ripley's K-Function to test whether cranes showed specific flight behaviors in clustered locations and at what level of clustering or dispersion.

I measured all response and predictor variables at the scale of a Site Span. Flight behavior response variables included either altered/unaltered or abrupt/gradual reactions. Categorical predictor variables included season (summer or migration), time of day (AM or PM), weather (clear or fog/rain), and study area (ML or BV). Continuous flight reaction variables included flight altitude and flock size. Continuous spatial variables included proportion of land cover types calculated within 250 m and 500 m buffers around Site Spans (e.g. row-crop agriculture, pasture/hay, agriculture [*row-crop + pasture/hay*]), distance to emergent wetlands, and distance to forest edges.

## RESULTS AND DISCUSSION

***Research Question 1: Comparing Crane Flight Behaviors***

Over 49 days, 68 2.25 hour observation periods, and 153 hours. I observed a total of 1,385 individual cranes flying in 394 flocks flying around power lines. At the four observation sites without behaviors, I recorded cranes in the area within 500 m of the given power line I observed, which shows that cranes were present in the area despite them not flying around power lines. Flight altitude significantly differed between the three flight behaviors (Kruskal-Wallis $X^2$= 90.8274, df = 2, p< 0.001). Additionally, constructing a logisitic regression model revealed that flight altitude alone correctly predicted 80.9% of altered behaviors (i.e. gradual and abrupt behaviors) with a pseudo $R^2$=0.315.

***Research Question 2: Evaluating Spatial Clustering in Crane Flights***

Of the original 201 Site Spans I observed (Figure 1), I only used Site Spans with crane behaviors recorded within 22.4 m of power lines. Flight altitude alone predicted At this flight altitude, a logitistic regression model with results showed that, considered the "Collision Risk Zone." I aggregated the counts of gradual and abrupt behaviors to the Site Spans. Figure 2 displays all Site Spans observed during the study (black points), as it compares with locations of gradual flight behaviors (large blue points) and abrupt behaviors (red points). I did not display the count of behaviors at each Site Span.

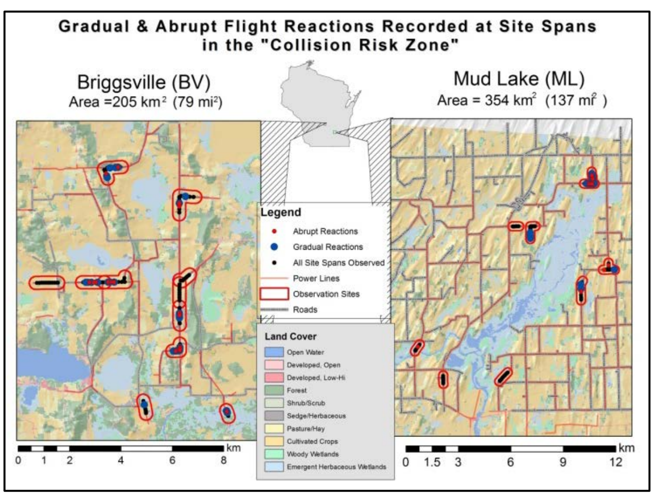


**Figure 2.** Distribution of total number of behaviors (e.g. includes gradual and abrupt behaviors under 22.4 m in altitude) recorded at Site Spans at both Study Areas. The Collision Risk Zone is considered at or below 22.4 m around Site Spans.

Ripley's k-function analysis revealed that significant clustering occurred at all scales of my data (at Site Span, Observation Sites, and Study Areas). Specifically, the locations where I recorded crane reactions (gradual or abrupt) at the 57 Site Spans showed similar clustering as the locations of Site Span centroid. The locations of all flight behaviors (e.g. unaltered, gradual, and abrupt) at the Site Spans were not significantly more clustered or dispersed than the underlying pattern of Site Span points. Specifically, without considering a crane's flight behavior, the location where a crane flew over a power line was random. However, partitioning the data by flight behavior, cranes showed significant clustering at Site Spans for abrupt behaviors than observed in a random point pattern. This suggests that specific power lines may pose a more significant risk that nearby Site Spans in the same area.

***Research Question 3: Predicting Crane Collision Risk with Power Lines***

I tested which predictor variables were significant for predicting abrupt behaviors, where cranes almost flew into power lines. Of the seven candidate regression models I developed after assessing collinearity between predictor variables. I only reported logistic regression model with the highest AIC weight. The best-fit model (Model 1) predicted 76.8% of all abrupt behaviors correctly, with a pseudo $R^2$ of 0.251. Variables for Model 1 included flight altitude, flock size, temperature and distance to forest edge. The second best-fit model correctly predicted 73.9% of abrupt behaviors, with a pseudo $R^2$ of 0.22. Variables for Model 2 included flock size, distance to forest edge, and season.

Overall, flight altitude, temperature, season, and distance to forest edge best predicted whether cranes almost flew into power lines. The effect of each variable on the probability that crane almost flew into power lines varied. Model 1 predicted a 5% (95% CI: 2-8%) increase in the odds of a crane almost striking a power line for each one-degree ($^{o}$F) temperature increase. This showed that crane flying during migration had a 24% (95% CI: 11-51%) less chance of almost striking a power line than flying during the summer. Model 1 and Model 2 predicted that the odds of cranes almost striking a power line increased between 4% (95% CI: 1-10%) and 5% (95% CI: 2-8%) every 10 m increment from a forest edge respectively. As the natural log of flock size increased by one unit, Model 1 and Model 2 predicted a 50% (95% CI: 25-93%) and 47% (95% CI: 24-87%) reduced chance of cranes almost striking power lines respectively. This showed that flock size likely did not impact the behavior because the confidence interval was so wide.

***Carcass Searches and Other Observations***

Although I did not find any crane collision mortalities, the one collision-mortality (e.g. female mallard) does indicate some risk in ML. Both Study Areas had a history of power line collision mortalities. Yet, even with weekly searches under power lines, numerous cranes, ducks, geese, or other large birds could have been missed. In a previous field season, I recorded the length of time a crane, heron, and two turkeys decomposed. The turkeys were gone within one day, the heron was completed scavenged and dragged off within three days while the previously frozen crane carcass remained a month.

That I discovered no dead cranes is encouraging; yet they can still experience potential stress in flight when flying close to power lines. Staff working with ICF observed two cranes nearby the BV Study Area strike power lines and continue flying (A. Lacy, personal communication, August 5, 2010). This confirms that cranes do have a collision risk in these areas despite my lack of finding power line collision-caused crane mortalities. On another occasion, I observed four cranes just after dawn at 6:55 AM fly in direct line with a power line. Within five m of the line, all four cranes showed the abrupt behavior and veered right to avoid striking line and other cranes. I also recorded five crane flocks of either one or two cranes fly under power lines despite the lack of documented flights under power lines in the literature. Another unexpected observation involved three whooping cranes I observed fly within 20 m of the power line in the ML Study Area. Unfortunately, because of the sun's glare behind the white whooping cranes, I could not identify their flight reactions around the power line. Overall, these abrupt reactions, flights under power lines, and presence of whooping cranes provide further evidence of a potential risk that power lines pose to both sandhill cranes and whooping cranes.

***Limitations of Study***

This study was limited by five challenges. First, before I selected power line to observe, I assumed that cranes selected a flyway based on the landscape around them. This meant that they flew over habitats that they were more likely to use for foraging (e.g. any agricultural fields) or roosting (e.g. wetlands). Likewise, breeding and non-breeding cranes could potentially fly over different power lines or show different behaviors. A second challenge related to sampling design and varied effort spent observing cranes in the field across seasons, time of day, weather, and Study Area. Effort varied due to a car accident that prevented my recoding cranes at three observations periods. Third, although searching for dead cranes was time-consuming and labor-intensive, it would have served this study to do a more detailed survey. Fourth, better predictor variables for measuring land cover and wind speed are available. Finally, I observed cranes at power lines that were spatially clustered. Yet, given these limitations to my research and results, future research can benefit by accounting for these conditions and improving the methods.

## CONSERVATION IMPLICATIONS AND FUTURE RESEARCH

My approach incorporated crane flight behavior, habitat use in roosting and foraging areas, and locations for observing crane flight patterns around power lines. Numerous questions surfaced during this research. The major questions on which future research should focus involves (1) obtaining more precise estimates of crane density for assessing density-dependence on collision risk, (2) testing associations of crane breeding status and season with their flight behaviors around power lines, and (3) testing association between distance to forests where a crane flew and its flight behaviors. These research topics should always combine flight behavior surveys to verify cranes fly around power lines.

Flight behavior surveys should become an industry standard for electric companies to evaluate potential collision risk for cranes. Flight behavior indicates only a piece of the collision threat for cranes and other large birds such as swans or herons. Yet, Federal agencies and the electric industry will benefit from implementing these flight behavior surveys because it reduces the effort needed to identify power lines that pose potential collision risk to cranes. If, during flight surveys, cranes frequently almost strike a particular power line, more effort to search under this power line could reveal a larger collision threat to cranes. This risk would warrant placing markers on this power line and thus save time and effort otherwise spent searching for dead cranes near power lines.

Overall, these local areas serve as case studies for the entire migratory flyway where both sandhill cranes and endangered whooping cranes migrate. As the population of re-introduced whooping cranes increases throughout the eastern U.S., I anticipate that more whooping cranes may strike power lines, especially in local wetland and agricultural staging and stopover areas. Therefore, this project provides a starting point for future research throughout the eastern flyway.

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