USING ABRUPT FLIGHT REACTIONS AS INDICATORS OF POWER LINE COLLISION RISK FOR GREATER SANDHILL CRANES (*GRUS CANADENSIS TABIDA*) ACROSS TWO SOUTH-CENTRAL WISCONSIN LANDSCAPES.

by

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I dedicate all my work and writing to the most important part of my life: my family. I am forever grateful for the three generations of women in my life who helped me grow and learn through all of my struggles. Kris, Nancy, and Ellen—my sister, mother, and grandmother—continue to be my guiding lights. Their leadership, encouragement, and love motivated me to strive for greater things.

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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, my research goal was to identify landscape and flight variables related to collision risk for greater sandhill cranes in south-central Wisconsin. I defined collision risk as the probability that a crane flock showed an abrupt flight reaction to avoid striking a line.

I estimated collision risk by recording flight reactions 45 meters around power lines within 750 m of agricultural fields and wetlands. The land cover surrounding these power lines were representative of Wisconsin land cover in Briggsville and the Mud Lake State Wildlife Area in the "Central Sand Hills" and the "Southeast Glacial Plains" Ecological Landscapes respectively. Aggregated across seasons and weather, I observed a total of 319 crane reactions around power lines in 68 dawn or dusk observation periods and conducted weekly carcass searches. I observed 48 (15%) abrupt reactions, 161 (50.5%) gradual reactions and 110 (34.5%) unaltered flight behaviors.

I used Akaike Information Criterion to select the best-fit logistic regression models for predicting unaltered/altered ("ALTERED model") and gradual/abrupt ("ABRUPT model") reactions. The ALTERED model predicted that the odds of altered reactions increased between 62-80% as cranes flew at lower altitudes; this correctly predicted 80.9% of altered reactions. Furthermore, cranes that flew at or below 22.4 m had a 50% probability of altering their flight reactions. The two best-fit ABRUPT models showed that the likelihood of abrupt reactions either (1) increased at lower flight altitudes, in flocks of one to two cranes, in warmer temperatures, and farther from forest edges (model correctly predicted 76.8% of abrupt reactions) or (2) increased when cranes flew in flock sizes of one or two cranes, farther from forest edges, and in the summer (model correctly predicted 73.9% of abrupt reactions). Overall, this research suggests that one or two cranes, flying together and crossing at or below 11.2 m of a power line, during the summer, and farther from a forest edge have a 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 reactions to document collision risk.

1.0 INTRODUCTION

People have long admired cranes *(*genera *Anthropoides, Balearica, Bugeranus,* and *Grus)* for their tall and stately posture, their monogamous pair bonds involving ritual courtship dances and territorial unison calls, and their majestic flight. In some cultures, cranes symbolize peace and freedom. Whooping cranes (*Grus americana)* and greater sandhill cranes (*Grus canadensis tabida)* are the only cranes native to North America. These cranes experience population threats as habitat loss and degradation, over-hunting, removal from the wild (Meine and Archibald 1996) and collisions with man-made objects such as fences, wind turbines, and power lines (Murphy et. al. 2009, Jenkins et. al. 2010, Martin 2011).

1.1 Natural History and Conservation Threats

In this project, I studied the greater sandhill crane. Because this and other studies commonly use sandhill cranes as a surrogate research species for the rare and endangered whooping cranes, I review similarities in natural history and collision risks to both sandhill cranes and whooping cranes. Sandhill cranes have worldwide population of approximately 600,000 and a population of 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 migratory flock. Both species use similar habitats (Meine and Archibald

1996). They also have similar migratory and breeding ranges. 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).

Both whooping cranes and sandhill cranes use a wide variety of habitats within the landscape. Sandhill cranes select areas with habitats (i.e. land cover) for foraging, roosting, and socializing. 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).

Within the past 150 years, the greater sandhill crane, the subspecies found in the Midwest, experienced major declines due to land-use change and hunting pressure across the Midwest (Su 2003). In Wisconsin, this once abundant sandhill crane population diminished to only 25 breeding pairs by the 1930’s from overhunting and land-use conversion (Henika 1936, Su et. al. 2000). However, this population recovered as wetlands were protected and restored and as hunting pressure diminished. With current population size estimated over 15,000, this subspecies is considered stable in Wisconsin and adapts well to changing landscapes (Su et. al. 2004).

Unfortunately, whooping cranes have not had the same fortune as sandhill cranes. Due to prolific hunting, egg and wild bird collection, and habitat loss with westward settlement, populations declined to approximately 16 breeding pairs in 1941 in the Aransas-Wood Buffalo Migratory Flock and were extirpated in the eastern flyway (Meine and Archibald 1996). The self-sustaining Aransas-Wood Buffalo Migratory Flock migrated from the Wood Buffalo National Park in the Northwest Territories to Aransas, Texas. However, the Aransas-Wood Buffalo Migratory Flock population size remained under 40 until 1964 (ICF 2010). As a result, in 1967 whooping cranes were listed as threatened with extinction and in 1970 as endangered (Canadian Wildlife Service and USFWS 2007).

To prevent further population decline and possible extinction, the U.S. and Canadian Whooping Crane Recovery Team (Recovery Team) developed conservation strategies to increase population sizes. This international joint Recovery Team recommended reintroducing cranes to supplement the Aransas-Wood Buffalo Migratory Flock, known as the Rocky Mountain Flock in 1975 (Canadian Wildlife Service and USFWS 2007). In 1993, the Recovery Team decided a second flock of whooping cranes would help prevent extinction in case a “disaster struck the natural flock” (ICF 2010). Therefore, researchers released whooping cranes in the Florida Kissimmee Prairie as a non-migratory flock in 1993 (Canadian Wildlife Service and USFWS 2007). Later in 2001, the Whooping Crane Eastern Partnership (WCEP) collaborated to reintroduce a migratory whooping crane flock to the historical eastern flyway, known as the Wisconsin Migratory Flock (WCEP 2011). WCEP consisted of non-profit conservation groups and federal agencies, including the International Crane Foundation (ICF) in Baraboo, Wisconsin. Biologists reintroduced whooping cranes using a captive rearing program coupled with a migration training program to “teach” cranes the Wisconsin to Florida migration route.

As of August 2011, total flock population sizes (including adults and young) number 115 in the Wisconsin Migratory Flock, 20 in the Florida Kissimmee Prairie Non-migratory Flock, 0 in the Rocky Mountain Flock, 24 in the Louisiana Non-migratory Flock, and 27 in the Aransas-Wood Buffalo Migratory Flock (Stehn 2011). An additional 162 whooping cranes reside in captivity in zoos or research centers, bringing the total whooping crane population to 599 in wild and captive populations (Stehn 2011).

Threats to whooping cranes include power line collisions, predation, disease, and infection. Recent research categorized leading causes of mortality for three reintroduced population flocks of whooping cranes. Hartup et. al. (2010) retrospectively analyzed causes of mortality for the Rocky Mountain Flock, Florida Kissimmee Prairie Non-migratory Flock, and Wisconsin Migratory Flock. This included traumatic injury, infectious diseases, and unknown causes. For all mortality cases (n=240) in the three flocks, traumatic wounds were the leading cause of mortality. Predation accounted for 120 deaths (50%), while collisions with power lines or fences accounted for 22 (9%) of deaths. The second cause of death included “infectious etiology” that were parasitic, bacterial, fungal, or viral in nature. Scavenging and decomposition limited the known causes of mortality in 64 (27%) mortalities.

Another retrospective study on the Florida Kissimmee Prairie Non-migratory Flock showed that both power line interactions and predation (usually by bobcats) were the leading cause of leg problems to whooping cranes. Miller et. al. (2010) defined a “power line interaction” as any injury a crane suffered from direct collision with a power line, including subsequent predation of the injured crane. Of the total 306 whooping cranes in this Florida Non-migratory Flock, 50% had leg-related injuries. These leg injuries were attributed to four main causes: direct power line collision (n=39 or 13%), trauma (n=94 or 31%) such as a car collision, “leg dangle” (leg deviated from regular position), deformities (n=28 or 14%), and miscellaneous conditions (n=106 or 35%) such as calluses, or tumors. Of 44 health records that documented power line collisions, 22 (50%) cases involved a “leg-mounted radio transmitter.” Some birds suffered electrocution, while others only lost the leg-mounted transmitter after striking power lines. Although more leg injuries fell under “trauma,” direct power line collisions can cause such injuries (APLIC 1994). In sum, these examples illustrate that power line collisions present a major conservation threat to both sandhill cranes and whooping cranes.

1.2 The Threat of Power Line Collisions

Crane collisions with power lines are a worldwide problem and may have significant impact on local populations of endangered or threatened cranes (APLIC 1994, Van Rooyen 2003). The growing wind energy industry will likely place more power lines on the landscape to meet electricity demands. As a result, cranes may encounter more power lines near agricultural fields and wetlands in which they forage or roost. Thus, cranes may strike power lines more frequently.

Even a loss of one whooping crane from direct power line collisions each year in the Wisconsin Migratory flock is a significant loss. Since reintroduction efforts began in 2001, five whooping cranes in the Wisconsin Migratory Flock have died from direct power line collision (ICF unpublished data). Furthermore, power lines are the highest known cause of mortality of fledged whooping cranes; 45 whooping cranes have been documented dying near power lines since 1956 in the Rocky Mountain Migratory Flock (Stehn and Wassenich 2008). Of these collision mortalities, 40% were fledged cranes and 22% were those migrating across the Midwest. Still, as these mortalities are the only ones fully documented, we cannot estimate the full extent of collision-related injuries or deaths.

Not all cranes die immediately from striking power lines. Many suffer injuries from which they can recover. For example, some cranes can still fly or walk with leg or wing injuries after striking a power line (Brown et. al. 1984, 1987, Morkill and Anderson 1991, APLIC 1994, Brown and Drewien 1995). Yet, collision injuries also cause infections, fractured wings or legs, abrasions, torn muscles, ruptured internal organs, or severed limbs caused from collisions (Hartup et. al. 2010, Miller et. al. 2010, Van Rooyen 2003, APLIC 1994). These make them more vulnerable to predators.

Estimating reliable power line-collision mortality rates proves difficult. These four biases influence the detectability of dead cranes around power lines: searcher efficiency (e.g. the likelihood that a person searching for a carcass will find a dead crane present), injury/wandering (e.g. a crane injured from striking a power line wanders off and dies from infection, predation, or other complications), scavenging (e.g. scavengers consume the dead crane before people find it), and decomposition (e.g. a dead crane decomposes before a person finds it) (APLIC 1994).

For sandhill cranes, the overall mortality rate from power lines is less well-known. Researchers estimate this mortality rate by incidentally finding dead birds near power lines. However, with an estimated 15,000 cranes in Wisconsin, a mortality rate similar to that of the eastern migratory whooping cranes would indicate several hundred to one thousand sandhill cranes might die from power line strikes each year. Research in the United States provides evidence of crane-power line collisions in several key staging areas for regional crane populations in Colorado (Morkill and Anderson 1991; Ward and Anderson 1992), Nebraska (Brown and Drewien 1995, Murphy et. al. 2009), and California (Yee 2008). Because cranes typically stop to roost and forage approximately six to fifteen times throughout migration (Johnson 1980, Kuyt, 1983), they may risk hitting power lines in unfamiliar areas. Additionally, juveniles are at increased collision risk relative to adults because of their inexperience flying (Buller 1976, Lewis 1993, Tacha et. al. 1978); documented power line collision mortalities of juvenile whooping crane supports this claim.

Researchers have documented power line-related collisions and mortalities for sandhill cranes in four major US staging areas. At the Sacramento Valley, California, Yee (2008) recorded 3 crane collision mortalities at distribution lines. At the San Luis Valley, Colorado at transmission lines, Brown and Drewien (1995) recorded 23 crane collision mortalities. Near the Platte River, Nebraska, Morkill and Anderson (1991) recorded 36 crane collision mortalities under 13.2 km of transmission and distribution power lines; while Ward and Anderson (1992) recorded 135 total crane collision mortalities under transmission and distribution lines, where 60 cranes were found under 596 km of power line in 1986 and 75 cranes were found under 210 km of power line in 1987. Also near the Platte River, Nebraska, Murphy et. al. (2009) estimated that between 37 and 93 sandhill cranes fatally collided with power lines in their two-year study. At four central

North Dakota sites with power lines spanning 1.1-1.8 km, Faanes and Johnson (1992) recorded 52 crane collision mortalities.

Overall, studies on sandhill crane flight reaction in different weather and surroundings suggest that several variables increase the risk of hitting power lines. These include power line type, weather, habitat surrounding a power line, crane flight experience, and familiarity with the location (Brown and Drewien 1995, Morkill and Anderson 1991, Ward and Anderson 1992, Yee 2008). 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).

If specific power lines are known to pose collision risk to cranes, several options are available to mitigate these risks to cranes. Researchers have worked with resource managers to use power line markers to increase visibility of power lines for cranes. Several studies found that markers increased power line visibility and effectively deterred cranes from striking lines. Tested markers included colored aviation balls (Morkill and Anderson 1991, Savereno et. al. 1996), static vibration dampers (also called spirals, bird flight diverters, or “pigtails”) (Alonso et. al. 1994, Brown and Drewien 1995, Janss and Ferrer 1998, Crowder 2000, Anderson 2002, De la Zerda and Roselli 2003) and swinging plates or “flappers” (Brown and Drewien 1995, Yee 2008). Most of this research on collisions with power lines occurred in central North America (Canada and the United States), Scandinavia, and South Africa (Jenkins et. al. 2010). These studies over the last thirty years used differing collection, analysis, and reporting methods; therefore, it is difficult to compare these results between both distribution (<69 kV electric wires, <12 m tall) and transmission lines (>69 kV electric wires, >12 m tall).

No research exists on the impact of crane power line collisions with distribution lines in the eastern United States. 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 this newly reintroduced whooping crane population grows.

1.3 Visual Perception of Cranes

How a crane perceives risks from predators or flight obstacles depends largely on it field of view in flight. Martin and Shaw (2010) explained that cranes with eyes placed more laterally have more limited visual fields in front than birds with frontally-placed eyes (e.g., owls). Martin (2011) later claimed that four sets of variables make cranes vulnerable to power line collision: 1) color of the landscape, 2) individual visual acuity, 3) relative depth of an object in the distance, distance, and time to contact, and 4) fields of view. I make no claim on how a crane's flight reaction is related to its visual acuity or how it perceives color. However, the potential risk of collision with a power line is related to cranes' visual perception and the distance and time a crane takes to cross a power line. Cranes flying together in a flock may experience added distraction or visual obstruction. Murphy et. al. (2009) showed that the collision risk for cranes increases as crane flock size increases. I considered many of these factors when making observations of crane flight reactions near power lines. I can then make associations between crane flight reactions and other landscape, weather, and flock interactions.

When cranes do perceive power lines as flight obstacles, they may show flight reactions to avoid striking a power line. Cranes exhibit avoidance flight reactions in two ways: gradually and abruptly. Morkill and Anderson 1991 observed that cranes gradually increased their flight altitude starting 200 m before crossing a power line. With these reactions, a crane increased its flight altitude to approximately 50 m above the line as it crossed the power line. At this flight altitude above a power line, cranes have little to no chance of striking a power line. Cranes may however alter their flight reactions when crossing below 50 m above a line. This reaction may indicate whether a crane perceives a potential collision threat (i.e. flight obstacle). Numerous studies documented cranes reacting abruptly within 20 m of a power line (Morkill and Anderson 1991, Jenkins et. al. 2010, Martin 2011) because something in in the crane's visual field alarmed it into immediately changing its flight pattern. Furthermore, in low visibility (e.g. fog or mist) or high wind conditions where cranes have less flight control, they have more difficulty reacting in time to avoid striking a power line (APLIC 1994). Yee

(2008) also showed that flight distance strongly correlated with a crane's flight altitude crossing a power line. Cranes flying from farther distances crossed power lines at higher altitudes and cranes taking flight from nearby fields crossed power lines at lower altitudes (Yee 2008).

A major indicator of collision risk occurs when a crane exhibits an "abrupt reaction" as it flies under or above a power line. Several studies documented these abrupt flight reactions prior to a crane striking a line. During flight reaction surveys, Ward and Anderson (1992) observed 15 sandhill cranes exhibiting flight reactions to avoid striking a power line. Faanes and Johnson (1992) received a report that a whooping crane flared immediately prior to striking the power line in Glaslyn, Saskatchewan.

2.0 PROJECT GOALS

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 could be ineffective for protecting whooping cranes. Therefore, I used regression models to predict where sandhill cranes showed an abrupt reaction 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 reaction and local movement patterns. Crane flight reactions 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 five questions:

1) *How do crane flight reactions 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) *Which variables best predict if a crane alters its flight around a power line?*
3) *Is spatial clustering present in the crane flight reaction data?*

4) *Which variables best predict abrupt flight reactions among cranes?*
5) *Does the proportion of cranes that showed abrupt reactions at Observation Sites correlate with landscape variables?*

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 reaction of cranes flying around power lines, and evaluating the spatial pattern of those reactions (2) collecting potential predictors of abrupt flight reactions, (3) examining how landscape variables related to flight reactions in multivariate analyses, and (4) quantifying the probability of abrupt flight reactions in relation to power line attributes and seasonal variations in the surroundings.

3.0 METHODS

3.1 Study Definitions

For consistency, I used the following terms to define how I recorded and analyzed crane flight reactions around power lines. This included flight reactions of cranes flying under or above a power line up to 45 m above the topmost line and 200 m horizontal distance surrounding it.

Crane Flock: One or more sandhill cranes that fly closely together. This is the independent observational unit for analysis.

Flight Reaction: Describes how a crane flock alters its flight pattern around a power line, which includes either the unaltered, gradual, or abrupt flight reaction.

Site Span: One length of electric wire (i.e. power line) where I geocoded cranes flying around a power line. This is the line between two consecutive power line poles within the Observation Site. I used four Observation Sites for each Land Cover Group.

Observation Site: Locations I observed cranes flying around consecutive power line Site Spans, made up of four to 15 Site Spans.

Observation Period: The 2.25 hr. time I observed and recorded crane flight reactions around power lines, either beginning 15 min. before dawn for two hrs. ("AM"), or beginning two hrs. before dusk and 15 min. after dusk ("PM").

3.2 Study Areas

Study Areas in Wisconsin

My Study Areas 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. Table 1 lists proportion and count of pixels with 30 m resolution of land cover in each Study Area.

Briggsville. The Briggsville (BV 205 km^2/79 mi^2) Study Area borders Adams, Columbia, and Marquette counties in the Central Sand Hills Eco-Region (Figure 1 and 2). Researchers at the 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 Briggsville (A. Lacy, personal communication, August 5, 2010).

Mud Lake Wildlife Area. The Mud Lake Wildlife Study Area (ML) (354 km^2/137 mi^2) is on the edges of Dodge and Jefferson counties in the Southeast Glacial Plains Ecological Landscape (Figure 1 and 2). In ML, 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).

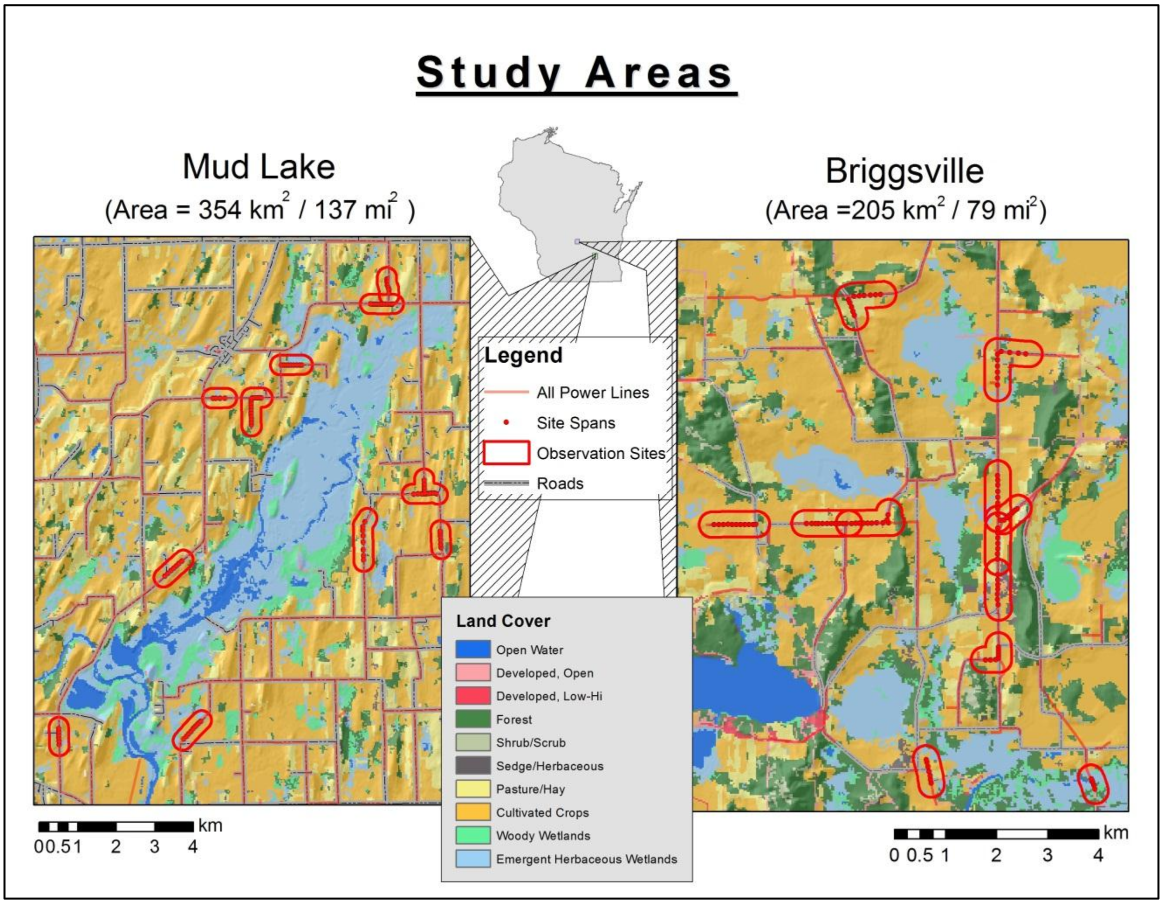


Figure 1. Two study areas located in southeast Wisconsin. The red polygons represent 500 m buffers around the 24 Observation Sites.

Ecological Landscapes

Study Areas were located within two larger "Ecological Landscapes" (Figure 2), which the Wisconsin Department of Natural Resources (WIDNR) differentiates by management opportunities, socioeconomic characteristics, and ecosystem features of geology, hydrology, soil, and vegetation. Information provided below summarizes the

WIDNR's Handbook section on Ecological Landscapes of Wisconsin (http://www.dnr.state.wi.us/landscapes).

The Central Sand Hills. This central Wisconsin Ecological Landscape is the previous bed rock of Glacial Lake Wisconsin and crosses 12 counties. Shaped by glacial moraines, this region has “woodlots, wetlands, small kettle lakes [and ponds], and cold water streams, all on sandy soils.” However, its groundwater has the poorest rating of all Ecological Landscapes. This Ecological Landscape encompasses 1.4 million acres where 28 percent is classified as timberland and only four percent of this Ecological Landscape is publicly-owned. Population density is 54 persons per mi^2 and is used predominantly for farmland, with major industries for potatoes, sweet corn, peas, and snap beans. (http://www.dnr.state.wi.us/landscapes).

Southeast Glacial Plains. In the southeastern corner of Wisconsin, this Ecological Landscape crosses 21 counties. This Ecological Landscape has the “highest aquatic productivity for plants, insects, invertebrates, and fish" (WIDNR in press). The major wetland in ML is an important for flood control in Wisconsin (M. Ayers, personal communication, April 4, 2009). Throughout this Ecological Landscape, many kettle lakes exist that contain wet prairies, wet-mesic prairies, tamarack swamps, and fens. It encompasses 4.9 million acres, with only four percent in public ownership and a population density of 188 per mi^2. Both urban and rural markets support the major agriculture and milk industries. (http://www.dnr.state.wi.us/landscapes).

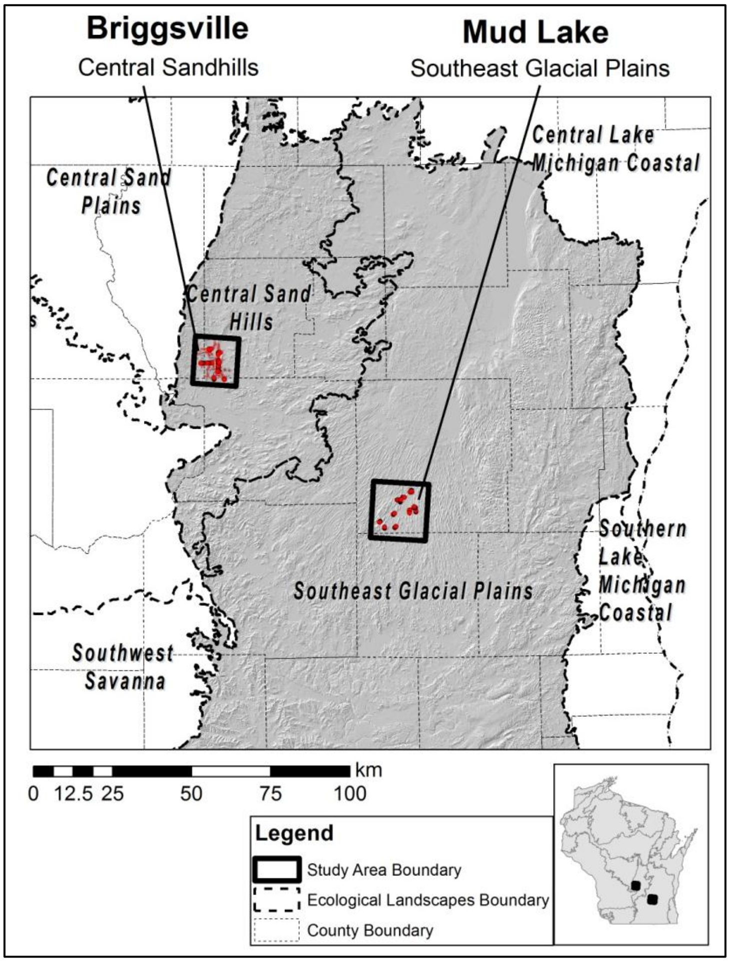


Figure 2. Locations of Study Areas within Wisconsin Ecological Landscapes. Thick black lines outline BV and ML.

Table 1. Proportion of reclassified National Land Cover Dataset land cover types separated by my two Study Areas. Bold face text lists the variables used for analysis in regression modeling to represent land cover types.

	Briggsville (BV) (205 km^2 or 79 mi^2)		**Mud Lake (ML) (354 km^2 or 137 mi^2)**	
Land Cover	**%**	**Area (km^2)**	**%**	**Area (km^2)**
Open Water	3.0	6,093	2.0	6,928
Developed (open)	3.7	7,578	2.5	8,807
Developed (low & high intensity)	1.2	2,414	2.3	8,285
Barren	0.0	5	0.1	276
Shrub & Scrub	1.5	3,065	0.6	1,962
Sedge & Herbaceous	1.2	2,394	0.5	1,904
Woody Wetland	4.4	9,070	3.7	13,259
Row-Crop Agriculture	**44.0**	90,269	**56.5**	200,094
Pasture & Hay	**7.0**	14,449	**15.6**	55,188
Forest	**22.7**	46,561	**5.2**	18,397
Emergent Wetland	**11.4**	23,333	**11.0**	39,009
Total	100	205,232	100	354,110

3.3 Observation Site Selection for Recording Crane Flight Reactions

I followed research from Kotoane and Shaw (2006) and expanded their modeling approach for blue cranes (*Anthropoides paradiseus*) in South Africa (Kotoane and Shaw 2006). They mapped power lines in South Africa within 500 m of roosting wetlands and evaluated whether specific landscape variables correlated with collision mortalities. Unfortunately, their spatial resolution was too low to identify which wetland features correlated with crane collision locations. They showed that agriculture significantly predicted where crane collisions occurred as other research (Sugden et. al. 1988, Su 2003, Miller 2007) also suggested. I therefore sought to quantify this collision risk at a finer scale using abrupt reactions as proxies for collision mortalities.

There are three levels of study: Site Spans, Observation Sites, and Study Area. These levels are defined earlier in the "Study Definitions" section. I recorded crane flock flight reactions around Site Spans; I observed between three and 14 Site Spans at each Observation Site. I hypothesized that how cranes react around power lines may correlate with land cover types that cranes use or avoid. Both whooping cranes and sandhill use row-crop agriculture or pasture/hay fields in which to forage (Miller 2007, Su 2003, Lovvorn and Kirkpatrick 1992).

I only visited power lines to record crane flight reactions 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 reactions 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.

I selected power lines at which to observe crane reactions with varied combinations of row-crop agriculture, pasture/hay, emergent wetlands, and forest. These land cover types encompassed the majority of land cover surrounding power lines. Crane presence was determined based on reported observations from crane experts and the presence of habitat specific for foraging, resting or roosting (A. Lacy, pers. comm, and M. Ayers, per. comm.). I calculated the proportion of land cover under power lines in Observation Sites by extracting the NLCD raster attribute data within a 500 m buffer of all potential power lines in study area. Twenty-three of the 24 selected Observation Sites were within 500 m of emergent wetlands. I chose the remaining Observation Site because it fell within 750 m of a wetland and was a popular field for cranes foraging during the summer and migration in BV (personal observation). Land cover proportions calculated within 500 m buffers around power lines within Observation Site are listed in Appendix A for BV and Appendix B for ML.

3.4 Crane Flight Reaction Observations

Study Timeline

I observed sandhill crane flight reactions around power lines (see Appendix C for the flight reaction observation sheet), during two phases that capture different crane populations. 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. During Phase 2, I observed migratory cranes. By separating observations into two phases (outlined below), recording reactions for both breeding and nonbreeding cranes could be studied.

- **Phase 1:** Breeding and non-breeding resident GSC in both study areas
    - **Period 1** (*3 July 2009 - 5 August 2009*): resident breeding and non-breeding adults
    - **Period 2** (*21 August 2009 - 4 October 2009*): resident breeding and non-breeding adults and fledged juveniles
- **Phase 2:** All non-breeding, resident and migrant cranes, fledged juvenile and adult GSC
    - **Period 1** (*16 October 2009 - 14 November 2009*): BV
    - **Period 2** (*20 March 2010 - 3 April 2010*): ML Wildlife Area

My goal was to visit every Observation Site once every five to six weeks to record flight reactions for two and one-quarter hrs. at sunrise or before sunset, depending on when the Observation Site was randomly selected for observation. All the Observation Sites visited are listed in Appendix D and E. I visited all 24 Observation Sites in Phase 1, Period 1, all 12 BV Observation Sites in Phase 2, Period 1, and all 12 ML Observation Sites in Phase 2, Period 2. However, at the end of Phase 1, Period 2, an automobile accident in the field prevented me from visiting four Observation Sites BV-11, ML-16, ML-19, and ML-21.

I only recorded the flight reactions of cranes flying within 200 m of a power line. Several studies that used flight surveys found that cranes originating their flights within

250 m tended to fly at lower altitudes (Yee 2008, Brown and Drewien 1995, Morkill and Anderson 1991). 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. Once I could identify these distances accurately, I removed the flags. Yee (2008) also showed that flight distance strongly correlated with a crane's flight altitude crossing a power line. Cranes flying from farther distances crossed power lines at higher altitudes, whereas cranes taking off within 200 m of a power line flew at lower altitudes (Yee 2008). This "reaction distance" potentially confounded analysis of flight altitude and reaction data; therefore, distance from a power line and height above the power line were likely to predict the frequency of altered flights and abrupt reactions. 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 listed in Table 2 below. I recorded crane reactions using 8x50 binoculars. Hereafter, any "reaction" (e.g. "flight reaction" or "crane reaction,") refers to the flight reaction that a crane flock (i.e. one or more cranes flying in a group) show around a power line. I excluded flight direction because I recorded only two crane flocks that flew in the direction of the sun, east in the AM and west in PM. I ruled out the sun blinding a crane flying for the rest of the reactions.

Table 2. Variables recorded during Observation Periods (2.25 hrs.) at Observation Sites. The categories or ranges include all the attributes of the variables. The Definitions column describes the specific categories.

Category of Variables	**Variables [1]**	**Measurement Method**	**Categories or Ranges**	**Definition**	**Data Structure**
Crane Flight Reaction	Flight Reaction	Measured altitude changed as cranes approach within 200 m of power line	Abrupt, Gradual, Unaltered	**UNALTERED** *(No change in flight direction or altitude)* **GRADUAL** (Increase *in flight altitude slowly within the entire 200 m of the power line;* Decrease *in flight altitude slowly within the entire 200 m of the power line*) **ABRUPT** (Flare [*Flying upwards or horizontally within 15 m of power lines*] , Zigzag [*Flying parallel, then upwards and over to clear a power line*], Change Direction [*Turning around* 90^o *or* 180^o *and still flying over the power line*] , Abort [*Same as "change direction," except that cranes do not cross the power line*])	Categorical
Crane Flocks	Flight Altitude	Relative to pole height (1 pole = 11.2 m)	-5.6 m – 44.8 m	Assign altitude as "1.0" pole height above the power line, equivalent to 11.2 m	Continuous
	No. of cranes in a flock	Counted per flock flying over power lines	1-200	A group of cranes considered to fly and react the same as one unit	Continuous

	Flight Direction	Observe bird flight path	8 compass bearings	N, E, W, S, NW, NE, SW, SE	Categorical
Weather	Relative Percent Humidity	Kestrel weather gauge	0-100%		Continuous
	Temp.		30-75 ^{o}F		Continuous
	Wind Direction		8 compass bearings	N, E, W, S, NW, NE, SW, SE	Categorical
	Maximum Wind Speed		0-32 kmph		Continuous
	Percent Cloud Cover	Observation	0-100%	Imagine grid in sky and categorize clouds as 25, 33, 50, 75, 90, 100% cloud cover	Continuous
	Weather	Observation	Clear or Fog/Rain	Fog/Rain was: *light rain, occasional rain, heavy rain, t-storm, fog, dense fog.* Clear was no precipitation.	Ordinal

Land Cover	Proportion Cultivated Crops	Buffered 250 m and 500 m from Power Line Observation Sites.	1-100%	"Annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled."	Continuous
	Proportion Pasture/Hay		1-100%	"Grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation."	Continuous
	Distance to Forest	Euclidean distance (m) to nearest forest/ wetland edge measured from power line span, with median representing observation sites	0-1000 m	This includes all mixed, deciduous and evergreen forest	Continuous
	Distance to Emergent Herbaceous Wetlands		0-1000 m	"Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water."	Continuous

[1] Italic text in parentheses represents how each variable is shown in regression analyses in the RESULTS section.

3.5 Carcass Searches

I quantified sandhill crane power line collision mortality using weekly carcass searches conducted throughout the study periods 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.

3.6 Measuring Landscape Variables Using GIS

I used a variety of spatial data and processing tools to identify and measure specific features. I used ArcGIS 10 (ESRI 2010) to manage, create and edit spatial data. I used the National Land Cover Dataset (Homer et. al. 2004) based on 2001 LANDSAT imagery as the base layer for quantifying land cover-based percentages and distances from power lines. This land cover data is publically available from the US Geological Service Land Cover Institute (http://landcover.usgs.gov/).

In this section, I describe methods for using geo-located crane flights to measure specific landscape variables at Site Spans. I used ArcGIS 10's geocoding tool to join all tabular crane flight reactions to each Site Span. Using these geographic locations, I extracted all landscape variables, including percent row-crop agriculture, percent pasture, distance to emergent wetlands and distance to forests.

Digitizing Power Line Site Spans

I digitized power lines and Site Spans within each Observation Site using GPS coordinates of power line poles recorded from the field. I cross-checked these coordinates with a 2008 National Agriculture Imagery Program (NAIP) satellite imagery available from the US Department of Agriculture, Farm Service Agency (USDA 2010). NAIP images are digital orthographically-corrected photographs accurate to one-meter units with horizontal accuracy to six meters, which are created over a five-year period. These are also publically available on the FSA website (http://www.fsa.usda.gov/FSA).

Linking Crane Reactions to Power Line Site Spans

I linked crane reaction data to Site Spans using ArcGIS 10's geocoding tool. I geocoded each flight reaction to power line Site Spans using a single-field address locator built from my power line dataset. I assigned the address field as the power line Site Span, with the reference data set as my dataset. This method created centroids at the midpoint of each power line Site Span.

Estimating Land Cover Variables at Site Spans

Proportion Row-Crop Agriculture & Pasture Measured at Site Spans. To address how cranes viewed a local landscape where they forage and roost, I considered two distances in which to calculate a buffer: 250 m and 500 m buffers from Site Spans. With these buffer distances, I sought to capture the landscape features a crane might be attracted.

I used a focal mean analysis (i.e. "moving window" analysis) to more efficiently calculate the percent land cover around each Site Span. Using the mid-point of each

Site Span, I performed this neighborhood operation to calculate the mean of all binary cells within the buffered distances of 250 and 500 m. This summed all cells with a value of one (i.e. a value of one represented a target land cover types), and divided this sum by the total number of cells within the 250 or 500 m buffered region. I defined the neighborhood for this moving window operation as the set of cells surrounding the "processing cell," which was the center cell (Bolstad 2009 p 395-396). The focal mean calculation for the 250 m distance used a neighborhood of eight cells, which only calculated a 240 m buffer distance. The focal mean calculation for the 500 m distance used a neighborhood of 17 cells, which only calculated a 510 m buffer.

Distance to Wetlands and Forest Edges Measured at Site Spans. I selected land cover variables that represented key resource and habitat uses for cranes. Habitat selection studies revealed that cranes foraged within 300 to 900 meters of emergent wetlands (Su et. al. 2004, Miller 2007). I used the distance to wetlands as a predictor variable. Additionally, I calculated the distance to nearest forest edges because it is unknown how this variable may influence crane reactions. For both variables, I calculated the straight line Euclidean distance to nearest wetlands and to forest edges. I used Euclidean distance to represent bird's flight ability between forest patches, wetlands, or agricultural fields.

Estimating Land Cover Variables at Observation Sites

Proportion Row-Crop Agriculture and Pasture Measured at Observation Sites. I summarized proportion row-crop agriculture, pasture/hay, and the sum of all agriculture types ("agriculture") by extracting land cover from the NLCD in 500 m buffers around the length of the power line at the Observation Site. I list proportion of land cover types by Observation Sites in Appendix A.

Distance to Wetlands and Forest Edges at Observation Sites. I aggregated the distance to wetlands and forest edges measured at each Site Span to its corresponding Observation Site level. I used the median of all Site Span values within each Observation Site to represent these distances at the Observation Site level because the sample size of Site Spans within Observation Sites was small (e.g. typically less than 8).

3.7 Statistical Analysis Methods

Analysis Goals

My overall goal was to predict the conditions under which cranes would abruptly react around power lines. To understand how and where cranes experience potential power line collision risk, I separated my data into three analyses accounting for reaction and landscape differences. I used the statistical program R (R Development Core Team 2011) for all analyses. I used logistic regression to model flight reactions as binary response variables in relation to weather, and flock predictor variables. I used univariate tests to analyze associations between landscape features (e.g. distance to forest) and the proportion of cranes that showed abrupt flight reactions at Observation Sites. I measured all response and predictor variables at the scale of a Site Span. Flight reaction 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.

Response Variables

I used three response variables for the three regression models I developed. For the two flight logistic regression models, I defined the binary response variables as ALTERED_bin and ABRUPT_bin. For the landscape multiple linear regression models, I used the continuous response variable Pr_ABRUPT.

ALTERED_bin and ABRUPT_bin represented different binary crane flight reactions. ALTERED_bin represented presence or absence of any altered reaction or unaltered reaction; I grouped the abrupt and gradual reactions together and reclassified them as an “altered” reaction. ABRUPT_bin represents presence or absence of an abrupt flight reaction for crane reactions within two pole lengths in altitude of a power line. For this variable, I excluded all unaltered flight reactions because I was only interested in flight reactions that indicated a change in altitude. In other words, I excluded unaltered flight reactions because I could determine whether a crane saw or did not see the power line, which was in fact, a non-reaction.

For the landscape-reaction dataset, I used the response variable Pr_ABRUPT as the proportion of abrupt reactions out of all abrupt and gradual reactions I recorded at Observation Sites. I calculated this by aggregating all ABRUPT_bin reactions to the scale of each Observation Site. I then divided the total abrupt reactions by the total number of abrupt and gradual reactions.

Assessing Association between Response and Predictor Variables

To measure the level of association between response variables (e.g. ALTERED_bin, ABRUPT_bin, and Pr_ABRUPT) and predictors variables, I used Pearson's correlation coefficients to measure collinearity between continuous predictors, Wilcoxon rank sum test to measure relationships between continuous and ordinal variables, Fisher's exact test to measure relationships between binary categorical variables, and Chi-square tests to measure relationships between two categorical variables. I also used the non-parametric Kruskal-Wallis Chi-squared test to measure the association between the three flight reactions and flight altitude (e.g. between unaltered, gradual, and abrupt reactions). I used $r>0.7$ as the threshold to indicate collinearity for Pearson's correlation, and $p<0.1$ as the threshold to indicate collinearity for the Wilcoxon rank sum test, Fisher's exact tests, and Chi-square tests. When predictors covaried with other predictors significantly with $p<0.01$, I discarded that variable with the higher p-value in the univariate tests for the response variables. I used this smaller p-value to indicate collinearity between predictor variables because a more significant association between predictor variables may inflate the true significance between the response variable and predictor variables. Finally, I used univariate analyses to refine the set of predictors used in backward stepwise model selection.

Predicting Reactions Using Logistic Regression Models at the Site Span Level

I created two datasets to explain altered reactions (hereafter "ALTERED model") and another to explain abrupt reactions (hereafter "ABRUPT model"). I used logistic regression coupled with AIC model selection to select the best-fit model for different combinations of predictor variables.

I compared the explanatory power of five logistic regression models for ABRUPT_bin. Each model was compared with the initial model where I only used predictor variables flight altitude and precipitation to predict ABRUPT_bin (hereafter "ABRUPT Model"). I then sequentially compared these regression results with models that added spatial predictors. For example, I tested how flight altitude, precipitation, and percent row-crop agriculture predicted ABRUPT_bin, and compared these results with another model where I tested flight altitude, precipitation, and distance to wetlands. I ran logistic regressions for each of these spatial variables added in the model individually: percent row-crop agriculture, percent pasture, percent agriculture (row-crop + pasture), distance to wetlands, and distance to forest. I compared each candidate model with the null model (e.g. predictor variable coefficient is equal to one) using a maximum likelihood test. This test showed whether the model with parameters explained the response variables better than the null model.

Candidate Logistic Regression Models. I refined the list of predictor variables to compare candidate regression models using AIC model selection criteria after assessing collinearity between predictor variables. I ranked models using the AIC weight and selected a final models with AIC weight <2.0 (Burnham and Anderson 2006). I compared these final models based on the "stability of parameter estimates (i.e., the best model for which the 95% confidence intervals of each parameter did not include zero)" (Compton et. al. 2002).

Interpretation of Logistic Regression Models. This section describes interpretation of logistic parameters and assessing model fit. I used a binary presence or absence response variable that was constrained between the values zero and one, with non-normal error terms and non-constant error variance. A value of one indicated collision risk and a zero indicated no risk. Gelman and Hill (2007) described a binary response variable by equation 1:

$$\text{Probability of Abrupt Reaction} = \Pr(Y=1) = \pi(x) = \frac{1}{1+e^{z}} \qquad (1)$$

Where:

$z = (\alpha + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_\rho x_\rho)$

$\pi(x)$ = probability that cranes showed an abrupt reaction as “1”, as the odds ratio

α = when the value of all predictor variables are zero

β = regression coefficient of predictor variable

x = value of predictor variable

For logistic regression, I constructed an odds ratio ($\pi(x)$), as the probability of success divided by the probability of failure. Specifically, the response variables for “success” refer to either an altered or abrupt reaction while a “failure” refers to an unaltered or gradual reaction respectively. Taking the natural log of this ratio is the logit transformation as described below ($\mathrm{g(x)}$) in equation 2 and 3. The response variables are thus transformed into a continuous form and can be modeled as a linear relationship:

$$\mathbf{g(x)} = \ln \text{(Odds Ratio)} = \ln\left(\frac{\pi(x)}{1-\pi(x)}\right) = B_o + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_\rho x_\rho \qquad (2)$$

$$\mathbf{g(x)} = \text{logit}\,[\pi(x)\,] \qquad (3)$$

Where:

B_o = value of $\mathbf{g(x)}$ when all predictor variables are set to 1

β = logit coefficient of predictor variable

x = value of coefficient in each cell

To interpret these coefficients, the exponential of the natural log of the odds ratio is reported, meaning that for every unit increase in the predictor variable, β, the odds of cranes showing an abrupt reactions increase multiplicatively by e^{β} (Gilmen and Hill 2006, p 60). The significance of each coefficient is formally tested with the Wald test, which tests whether the coefficient is equal to zero (and therefore has no effect on the odds of the response variable). This tests whether all regression coefficients associated with a regression variable is zero, comparing this distribution with an X^2 distribution. Most interesting coefficients differ from 1.0, where a log-odds ratio means there is a 50% chance of the response variable—in other words, a random chance. If the odds ratio is greater than one, the predictor variable increases the odds of the response variable by a factor of 1.xx (e.g. 1.52 equates to an increase in the odds ratio by a factor of 1.52 or 52% increase in the odds), whereas if the odds ratio is less than one (e.g. 0.75), the variable decreases the odds ratio by 25%.

To compare alternative models, I used Akaike's Information Criteria (AIC). This AIC is useful for weighting the most parsimonious predictive model where Akaike weights are the relative likelihood that a model is the best given the parameters. This is based on maximum likelihood estimation where values for the predictor variables maximize the likelihood function of the given model. The best-fit model is selected with coefficients that make the observed results most likely (Chatterjee and Hadi 2007, p 318). Likelihood is the probability of the observed results given the model predictor variables. Relative likelihood of the given models is calculated using $e^{(-0.5 * \Delta\text{AIC model score})}$. Therefore, the Akaike weight for each model is likelihood divided by the sum of all model likelihoods (Burnham and Anderson p 84). This AIC is used to identify the best-fit model with the fewest number of variables, given all the potential models and variable combinations. I used a backward selection because it iteratively recalculated negative log-likelihood estimates until all non-significant predictors were removed. The resulting models were the most parsimonious models, which the AIC weights reflected.

I ran the AIC using a general linear model with a logit link function for logistic regression to predict presence and absence of an altered or abrupt flight reaction for each crane flight I observed. I used backward selection because it is considered more robust than forward selection and less susceptible to collinearity (Chatterjee and Hadi 2007, p 290). Backward selection allowed comparison of AIC weights between candidate (i.e. "nested") models. I only retained candidate models with variables that added significantly to predicting the response variable according the Wald test results. AIC weights between the full (e.g. included all variables) and reduced models (i.e. included only significant variables). I reported comparison AIC weights between these models listed as the change in AIC (ΔAIC). I retained models with ΔAIC< 2.0 where the ΔAIC is the difference between that model and the most parsimonious model as suggested by Burnham and Anderson (2006, p 70). I present results as AIC weights, as the likelihood of the model given the data. I used a sample size of n=319 for the ALTERED model and n=191 for the ABRUPT model. I initially removed 58 reactions where cranes flew two pole heights above power lines. My large sample sizes in both the ALTERED model (n=319) and ABRUPT model (n=191) warranted my use of first order AIC selection equation shown in equation 4:

$$\mathbf{AIC} = -2\,(\ln(\mathit{likelihood})) + 2\,K \tag{4}$$

Where:

$\boldsymbol{Likelihood}$ = probability of the model parameters (predictor variables), given the data

$\boldsymbol{K}$ = number of parameters (predictor variables) included in a model

For model diagnostic tests, I assessed model fit looking at patterns in binned residuals, the predictive accuracy of each model under the receiver operating characteristic (ROC) curve (AUC), and pseudo R^2. I used a binned residuals plot, with ten bins. These bins represent the number of categories of their fitted values that divide the data into equal number of bins. To accurately evaluate the residuals in a logistic regression model, I checked that all the averaged fitted values were within the 95% confidence interval line. The ROC provides the accuracy of the model in discriminating the response variable. These values are reported as area under the ROC curve (AUC). For example, for an AUC of 0.5, the model correctly discriminated only 50% of altered reactions in the response variable, ALTERED_bin (altered or unaltered reactions). This means that of 319 reactions (n=209 altered reactions; n=110 unaltered reactions), this particular model correctly predicted only 105 altered reactions, whereas, if a model has an AUC of 0.8, then the model is considered to be well-fitted by correctly discriminating 80% of reactions. ROC values are measured between zero and one, where 0.5 indicated a random fit of data and one indicated a perfect fit of the data.

I additionally used a pseudo R^2 statistic to measure the strength of association between binary response variables and the predictors. This statistic (equation 5) is similar to the correlation coefficient, R^2, which seeks to explain the percent of model variance. Similar to the ROC value, this statistic also ranges between zero and one. And a pseudo-R^2 of one indicates a perfect fit and a value of zero indicates no relationship.

Clark and Hosking (1986) considered a pseudo R^2 value of greater than 0.2 a good fit of the data. The pseudo-R^2 statistic is calculated as follows:

$$\mathbf{Pseudo} - \boldsymbol{R^2} \quad = \quad \frac{1 - LN(Likelihood\ of\ Model)/N}{LN(L_o)} \tag{5}$$

Where:

Likelihood = probability of the model parameters (predictor variables) given the data value of the likelihood function for the full fitted logistic model.

L_o = value of the likelihood function if all coefficients except the intercept are 0

N= Total sample size of data set

Assessing Independence & Spatial Clustering of Site Span Locations. Regression analysis requires that observational units are independent; I therefore assessed whether reactions were spatially clustered because I had measured crane reactions at Site Span locations less than 100 m apart in some areas. I tested whether Site Spans showed significant clustering in locations with abrupt or gradual flight reactions of cranes that flew at or below 22.4 m above power lines using Ripley's K function. I used Ripley's k-function to measure the level of spatial dependence over a range of distances of Site Spans. This analysis estimates the total amount of spatial clustering at each distance (Lee and Wong 2006, Mitchell 2005). Using Ripley's K function, I tested whether the values at Site Span point locations showed significant clustering at different distances from each Site Span. I used two weighting strategies, one using the count of altered reactions and another using the count abrupt reactions recorded at Site Spans to the assign relative importance of the value at each Site Span. Later, I refer to these as the "ALTERED Site Span Pattern" and the "ABRUPT Site Span Pattern" respectively.

I analyzed whether point densities were clustered or dispersed and compared the observed point pattern to a random point pattern. The point density function, $\boldsymbol{n(h)}$, as described in equation 6, is calculated for each spatial lag distance ($\boldsymbol{h}$)—the buffer distance around each individual point (referred to as "Distance Band" in ArcGIS software in Figure 3) (Lee and Wong 2006). In Figure 3, this point density represents the number of points within the buffer of distance band one through three.

$$\boldsymbol{n}(\boldsymbol{h}) = \sum_{i=1}^{n}\sum_{j=1}^{n} I_h(d_{ij}),\ i \neq j \tag{6}$$

Where:

$\boldsymbol{h}$ = lag distance between buffers around individual points

$\boldsymbol{i}$ and $\boldsymbol{j}$ = indices of points

$\boldsymbol{d_{ij}}$ = distance between two points, $\boldsymbol{i}$ and $\boldsymbol{j}$

$\boldsymbol{I_h}$ = indicator function such that $\boldsymbol{I_h} = 1$ if $\boldsymbol{d_{ij}} < \mathrm{h}$ and $\boldsymbol{I_h} = 0$ otherwise

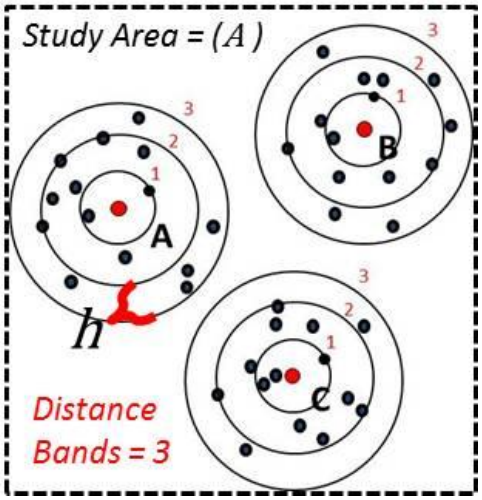


Figure 3. Estimation of the k-function illustrating distance bands (i.e. "spatial lags", *h*) used in ArcGIS's 2010 default option for three points, A, B, and C. This represents a given study area of area (*A*) bounded within the dashed lines, with three distance bands to calculate number of points, *n(h)*, within each distance band buffer around points A, B, and C. (Modified from Lee and Wong 2006).

Formally, the k-function (equation 7) is the sum of each of these individual point densities at each distance from each point. This point density function becomes the k-function by including a density scaling factor of inverse aerial point density (Lee and Wong 2006).

$$\boldsymbol{K}(\boldsymbol{h}) = \frac{A}{N^2}\sum_{i=1}^{n}\sum_{j=1}^{n}\frac{I_h(d_{ij})}{w_i} \tag{7}$$

Where:

A = Area of the entire region (e.g. BV or ML)

N^2 = Point density within each buffer around each point; ≈ $n(h)$ as above

w_i = a weight at each point location (i.e. total number of crane reactions at a Site Span)

It is most useful to compare the observed spatial pattern in this k-function to a random point pattern (equation 8) (Lee and Wong 2006). A random point pattern is approximately πh^2 (Wong and Lee 2006, p 256). If the point density is above this estimate, we interpret the point pattern as clustered. If my observed point density is below this estimate, I interpret the point pattern as dispersed. ArcGIS uses the derived difference between the observed point pattern, $K(h)$, and this random point pattern (estimated as πh^2), which is defined as the function $L(d)$ below.

$$\boldsymbol{L}(\boldsymbol{d}) = \sqrt{\frac{K(h)}{\pi}} - h \tag{8}$$

To get a baseline for the level of clustering inherent at Site Spans separate from the altered reactions at or below 22.4 m above a power line, I ran the analysis using “un-weighted” and “weighted” calculations. The “Un-weighted Site Span Pattern” is the point pattern of only the locations of Site Spans. I define the “ALTERED Reaction Site Span Pattern” as the point pattern of the total number of altered reactions (abrupt +

gradual reactions) at each Site Span. The "ABRUPT Reaction Site Span Pattern" as the point pattern weighted by the total number of abrupt reactions at each Site Span. I define the "Random Point Pattern" as point pattern with no spatial clustering or dispersion (i.e. a random spatial distribution). I displayed these three Site Span Patterns with solid black lines, labeled as "Observed Site Span Pattern." I compared the Site Span Patterns with the Random Point Pattern (thick dashed lines). I compared the level of point clustering at in the Un-weighted Site Span Pattern to both the ALTERED Site Span Pattern and ABRUPT Site Span Pattern.

I used the default ArcGIS 10's option to compute confidence envelopes (CE). These are similar to a confidence interval where a 99% CE represents the k-function re-calculated 99 permutations (e.g. 99 repeated calculations of random locations or counts at Site Spans) of 57 point locations of Site Spans and 99 permutations of 191 counts of altered recorded at each Site Span point (i.e. for the ALTERED Reaction Site Span Pattern and the ABRUPT Reaction Site Span Pattern). For the weighted analysis, the point locations remain fixed while the count data are randomly re-distributed across the fixed point locations. I used the default option in ArcGIS' Ripley's k-function tool to display the CE, which I displayed as the dashed grey line. The upper line and lower lines represent points with the largest and smallest k-value that deviated from the Random Point Pattern.

I used two suggested hypothesis tests from Mitchell (2005) to guide my cluster analysis comparison. The two corresponding null hypotheses are as follows:

1. The point pattern of altered (ALTERED Reaction Site Span Pattern) or abrupt reactions (ABRUPT Reaction Site Span Pattern) at Site Spans **is not significantly more clustered (or dispersed)** than the point pattern of the Site Spans (Un-weighted Site Span Pattern).
2. The point pattern of altered reactions (ALTERED Reaction Site Span Pattern) or of abrupt reactions (ABRUPT Reaction Site Span Pattern) at Site Spans **is more clustered (or dispersed)** than the Random Point Pattern.

I rejected each of these null hypotheses following this logic; I rejected the first hypothesis if the ABRUPT Reaction Site Span Pattern or the ALTERED Reaction Site Span Pattern fell outside the confidence envelope for the Un-weighted Site Span Pattern. This implied the count of all altered reactions or abrupt reactions recorded in the Collision Risk Zone around Site Spans was significantly more clustered than the underlying point pattern of Site Spans. I rejected the second hypothesis if the Un-weighted Site Span Pattern fell within the confidence enveloped of the Random Point Pattern. This suggested three things. First, locations of Site Span points were not more clustered than the Random Point pattern. Second, the point pattern of Site Spans that were weighted by either altered reactions or only abrupt reactions was more clustered (or dispersed) than the underlying point pattern of Site Spans. Additionally, if the point pattern for the ABRUPT Reaction Site Span Pattern fell within the CE of the ALTERED Reaction Site Span Pattern, then there was no difference in where cranes showed abrupt reaction compared with where they showed all altered reactions around Site Spans.

Testing Correlations in the Proportion of Abrupt Reactions at the Observation Site-Level

If Site Spans showed significant spatial clustering from Ripley's k-function, I analyzed gradual and abrupt reaction data aggregated to the scale of Observation Sites. My goal was to determine if landscape variables at this broader scale further explained abrupt flight reactions beyond what the best ALTERED and ABRUPT models explained using the response variable Pr_ABRUPT.

I assessed normality of distribution for predictor variables prior to using Pearson's product-moment correlation test. If variables had non-normal distributions, I transformed the distribution to test correlations in Pr_ABRUPT and each landscape variables at each Observation Site locations of gradual versus abrupt reactions. I used $r>0.5$ ($p=0.1$) as an indicator of any level of correlation for this exploratory analysis.

4.0 RESULTS

4.1 Flight Reaction Comparisons

Research Question 1): How do crane flight reactions vary by flight altitude, flock size, weather (precipitation, temperature, relative percent humidity, and percent cloud), timing (season and time of day), and study area?

Over 49 days, 68 2.25 hour observation periods, and 153 hours (Appendix D and E), I observed a total of 1,385 individual cranes flying in 394 flocks flying around power lines at 20 of the 24 observation sites. At the four observation sites without reactions, 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. Reactions represent independent observations because I recorded the flight reaction that cranes exhibited around a power line as a flock where all cranes showed the same flight reaction. These reactions were not dependent on nearby flock reactions. Of these reactions, I removed 43 reactions with missing data for altitude, flock size, site span, or reaction. This left a total sample size of 352 crane reactions for analysis. I removed an additional 33 reactions from three ML Observation Sites that I did not visit in each season (see Appendix G.1. – G.4.). I did not observe any reaction s at Observation Site BV-11. Also, I did not visit the four Observation Sites due to a car accident. This left a final sample size of 319 reactions.

In the final sample size, 34.5% (n=110) cranes showed no alteration of reaction ("unaltered reaction"), 50.5% (n=161) showed gradual increases or decreases in altitude ("gradual reaction"), and 15.0% (n=48) showed abrupt reactions. Cranes flew an average of 15.7 m above power lines (median of 11.2 m). This ranged from 5.6 m below a line to 45 m above the line. Cranes flew in mean flock sizes of three cranes, with a range between one and 26 cranes. I recorded cranes flying during mean wind speeds of 7.1 kmph and a median of 5.3 kmph.

Flight altitude significantly differed between the three flight reactions (Kruskal-Wallis X^2= 90.8274, df = 2, p< 0.001), as the boxplot in Figure 4 illustrates. Notches in boxplots represent the 95% confidence interval for the median for flight reactions. The two outliers in the boxplots represent cranes that showed an abrupt reaction and a gradual reaction, but were only different in the flight altitude at which cranes flew. I therefore I included these data for analyses.

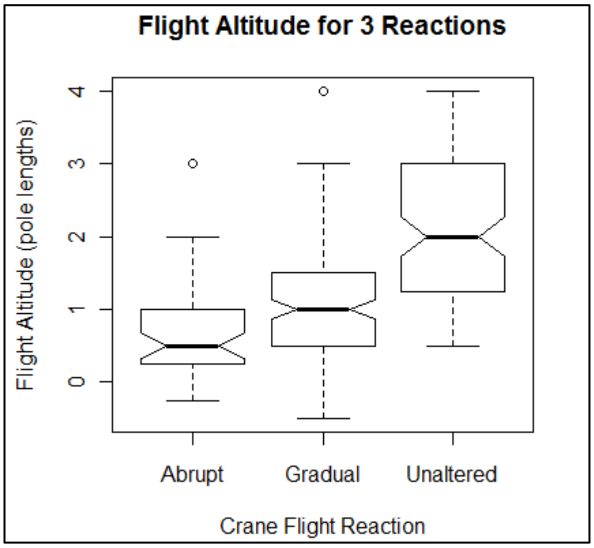


Figure 4. Boxplot of crane reaction altitude in terms of pole heights grouped by flight reaction around a power line. One pole length is equivalent to 11.2 m. Notches in boxplots represent the 95% confidence interval for the median flight altitude.

There was some difference in the proportions of each flight reaction between study areas (X^2 = 10.38, df= 2, p = 0.006) (Table 3), between weather conditions(X^2 = 6.27, df = 2, p = 0.044) (Table 4), and between seasons (X^2 = 17.54, df = 2, p = <0.001) (Table 5), but not by time of day (X^2 = 7.04, df = 2, p = 0.0296) (Table 6). However, these univariate tests may reflect the sampling effort (time spent in field) observing cranes during study area, season, weather, or time of day. I also compared Tables 3-6 with sampling effort in Appendix F and G. I spent 13.5 more hrs. in the field observing cranes in BV (33 Observation Periods x 2.25 hrs., 74.3 hrs.) than in ML (27 Observation Periods x 2.25 hrs., 60.8 hrs.). I spent twice as much time (40 Observation Periods, 90 hrs.) in the field observing crane reactions in the summer than in migration. I spent 2.4 times more time in the field observing cranes in clear weather (34 full and 17 half Observation Periods, 95.6 hrs.) than in fog/rainy weather (nine full and ten half-Observation Periods, 39.4 hrs.). A "half-Observation Period" was an Observation Period where half of the time was clear weather and the other half was fog or rainy weather. I spent 18 more hours in the field observing cranes during AM Observation Periods (36 Observation Periods x 2.25 hrs.) than during PM Observation Periods (26 Observation Periods x 2.25 hrs.).

Table 3. Summary of cranes flight reactions grouped by study area.

Flight Reaction	**STUDY AREA**		***Total***
	Briggsville	***Mud Lake***	
Abrupt	36 (19.1%)	12 (9.2%)	48 (15.0%)
Gradual	82 (43.6%)	79 (60.3%)	161 (50.5%)
Unaltered	70 (37.2%)	40 (30.5%)	110 (34.5%)
Total	188	131	319

Table 4. Summary of cranes flight reactions grouped by precipitation.

Flight Reaction	**PRECIPITATION**		***Total***
	Clear	***Rain/Fog***	
Abrupt	39 (13.7%)	9 (26.5%)	48 (15.0%)
Gradual	150 (52.6%)	11 (32.4%)	161 (50.5%)
Unaltered	96 (33.7%)	14 (41.2%)	110 (34.5%)
Total	285	34	319

Table 5. Summary of cranes flight reactions grouped by season.

Flight Reaction	**SEASON**		***Total***
	Migration	***Summer***	
Abrupt	25 (10.3%)	23 (29.9%)	48 (15.0%)
Gradual	130 (53.7%)	31 (40.3%)	161 (50.5%)
Unaltered	87 (36.0%)	23 (29.9%)	110 (34.5%)
Total	242	77	319

Table 6. Summary of cranes flight reactions grouped by time of day.

Flight Reaction	**TIME OF DAY**		***Total***
	AM	***PM***	
Abrupt	30 (14.0%)	18 (17.1%)	48 (15.0%)
Gradual	119 (55.6%)	42 (40.0%)	161 (50.5%)
Unaltered	65 (30.4%)	45 (42.9%)	110 (34.5%)
Total	214	105	319

4.2. Carcass Searches

I did not find any crane carcasses during the weekly carcass searches. In total, interns from ICF and I conducted 30 searches during the summer (15 in BV and ML) and eight searches during migration (4 in BV and ML). I found one female mallard with a broken wing directly beneath a power line in a ML-19 Observation Site on 13 September 2009 20 m southeast of a recently harvest wheat field where I observed cranes regularly during the Observation Period for this location.

4.3 ALTERED Model

Research Question 2): Which variables best predict if a crane alters its flight around a power line?

I tested which predictor variables were significant for ALTERED_bin, the binary response variable for cranes that altered their flight reaction or did not alter their flight (i.e. unaltered reaction) around power lines at all flight altitudes (Table 6). These variables were significant in ALTERED_bin reactions: flight altitude, percent cloud cover, relative percent humidity, proportion agriculture, row-crop, and pasture/hay within 500 m buffers around Site Spans, distance to forest edges, and time of day. Variables not significant in ALTERED_bin reactions included flock size, maximum wind speed, proportion agriculture, row-crop, and pasture/hay within a 250 buffer, distance to emergent wetlands, precipitation, season, and study area. I then assessed whether each significant variables was collinear with other significant variables. There is a possible confounding effect that the time of day may have had on the proportion of reactions due to the difference in the time I spent in the field observing cranes in the AM or PM (see Appendix G for sampling effort and raw count data of reactions).

Table 7. Results of univariate tests for ALTERED_bin. Sample sizes for all tests were 319. “OR” refers to the odds ratio of probability of an abrupt reaction occurring divided by the probability of an abrupt reaction not occurring. The 95% confidence interval for the OR is contained in the parentheses.

Predictor	Test	Test statistic	p-value
Flight Altitude[a]	**Wilcoxon Rank Sum Test**	**W = 18595.5**	**<0.0001**
Flock Size	Wilcoxon Rank Sum Test	W = 10374.5	0.142
Percent Clouds	**Wilcoxon Rank Sum Test**	**W = 13602**	**0.006**
Maximum wind speed	Wilcoxon Rank Sum Test	W = 12383.5	0.256
Relative Percent	**Wilcoxon Rank Sum Test**	**W = 9371.5**	**0.007**
Temperature	Wilcoxon Rank Sum Test	W = 12542	0.180
Proportion Agriculture	Wilcoxon Rank Sum Test	W = 11734.5	0.759
Proportion Agriculture	**Wilcoxon Rank Sum Test**	**W = 13178.5**	**0.032**
Proportion Row-Crop	Wilcoxon Rank Sum Test	W = 12006	0.514
Proportion Row-Crop	**Wilcoxon Rank Sum Test**	**W = 15215**	**<0.0001**
Percent Pasture/Hay	Wilcoxon Rank Sum Test	W = 11290.5	0.794
Proportion	**Wilcoxon Rank Sum Test**	**W = 9797.5**	**0.030**
Distance to Forest	**Wilcoxon Rank Sum Test**	**W = 14364**	**0.0002**
Distance to Emergent	Wilcoxon Rank Sum Test	W = 11182	0.690
Precipitation	Fisher's Exact Test	OR = 0.73 (0.33, 1.63)	0.446
Season	Fisher's Exact Test	OR = 1.316 (0.74, 2.41)	0.409
Time of Day	**Fisher's Exact Test**	**OR = 0.58 (0.35, 0.97)**	**0.033**
Study Area	Fisher's Exact Test	OR = 1.35 (0.82, 2.24)	0.233

[a] Bold font indicates variables with p-value < 0.1

[b] Percent land cover type calculated within a 250 m buffer around Site Spans

[c] Percent land cover type calculated within a 500 m buffer around Site Spans

Refer to Appendix H and I for tests of collinearity between predictor variables. None of the continuous variables were collinear. However, time of day (AM or PM) was collinear with flight altitude (Wilcoxon Rank Sum Test, W=9053, p=0.004), relative percent humidity (Wilcoxon Rank Sum Test, W=16732, p<0.001), proportion agriculture in 500 m buffers (Wilcoxon Rank Sum Test, W=14787.5, p<0.001), and proportion pasture/hay in 500 m buffers (Wilcoxon Rank Sum Test, W=16732, p<0.001). Time of day was not collinear with percent clouds (Wilcoxon Rank Sum Test, W=10930.5, p=0.688), proportion row-crop in 500 m buffers (Wilcoxon Rank Sum Test, W=12495, p=0.103), or distance to forest (Wilcoxon Rank Sum Test, W=10609.5, p=0.419).

Following these collinearity tests, I developed six candidate logistic regression models to predict ALTERED_bin. After ranking AIC models, and comparing AUC and pseudo R^2 values, I selected two models as the best-fit models for predicting whether a crane altered its flight pattern around a power line (Appendix J). Full models included all variables that I found to be significant for ALTERED_bin while Reduced models include the variables after backward step selection and removed any non-significant variables in the model. Appendix J lists model coefficients for the two best-fit models, which I compared against model 1 where only flight altitude predicted ALTERED_bin. The best-fit models (i.e. “2-reduced” and “3-reduced”) had ΔAIC <2.0 and predicted 81.9% of all altered reactions correctly. The “2-reduced” model had a pseudo R^2=0.357 while the “3-reduced” model had a pseudo R^2=0.366. Flight altitude alone predicted

80.9% of altered reactions correctly and had a pseudo R^2=0.315. Although these two best-fit models appeared to better predict ALTERED_bin, adding proportion of agriculture in a 500 m buffer (“2-reduced”) or the addition of proportion of row-crop and pasture/hay in a 500 m buffer (“3-reduced”) only explained another 1.0% of reactions (e.g. AUC=81.9%).

ALTERED models 1, “2-reduced,” and “3-reduced” predicted that for every increase in flight altitude (by one pole length) the odds that a crane would alter its flight around a power line decreased by 28% (95% CI: 20-38%), by 24% (95% CI: 17-34%), and by 25% (95% CI: 18-36%) respectively. In other words, as cranes flew at lower altitudes, their odds of altering their flight increased between 72-76% for all ALTERED models. Model “2-reduced” predicted a 70% (95% CI: 10-310%) decrease in the odds that a crane flock showed an altered reaction as the proportion of agriculture increased by ten within a 500 m buffer around the Site Span. Alternatively, model “3-reduced” predicted a 40% (95% CI: 10-200%) increase in the odds that a crane flock showed an altered reaction as the proportion of row-crop decreased by ten within a 500 m buffer around the Site Span. ALTERED model “3-reduced” also predicted a 17% (95% CI: 2-119%) decrease in the odds that a crane flock showed an altered reaction as the proportion of row-crop decreased by one within a 500 m buffer around the Site Span.

My initial tests showed the strongest predictor of ALTERED_bin was flight altitude. I compared probability curves (i.e. prediction curves) that cranes would alter their flight around power lines given a certain flight altitude for ALTERED models 1 with the two best-fit ALTERED models “2-reduced” and “3-reduced” in Figure 5. Almost all of the cranes that showed either gradual or abrupt flight reactions flew at or below 22.4 m above the power line. I therefore considered this altitude a “Collision Risk Zone.” The 50% cut-off of this curve was at 22.4 m, meaning that half of cranes flying at this altitude were predicted alter their flight. I used this flight altitude to partition the data and I used the smaller data set for the ABRUPT model.

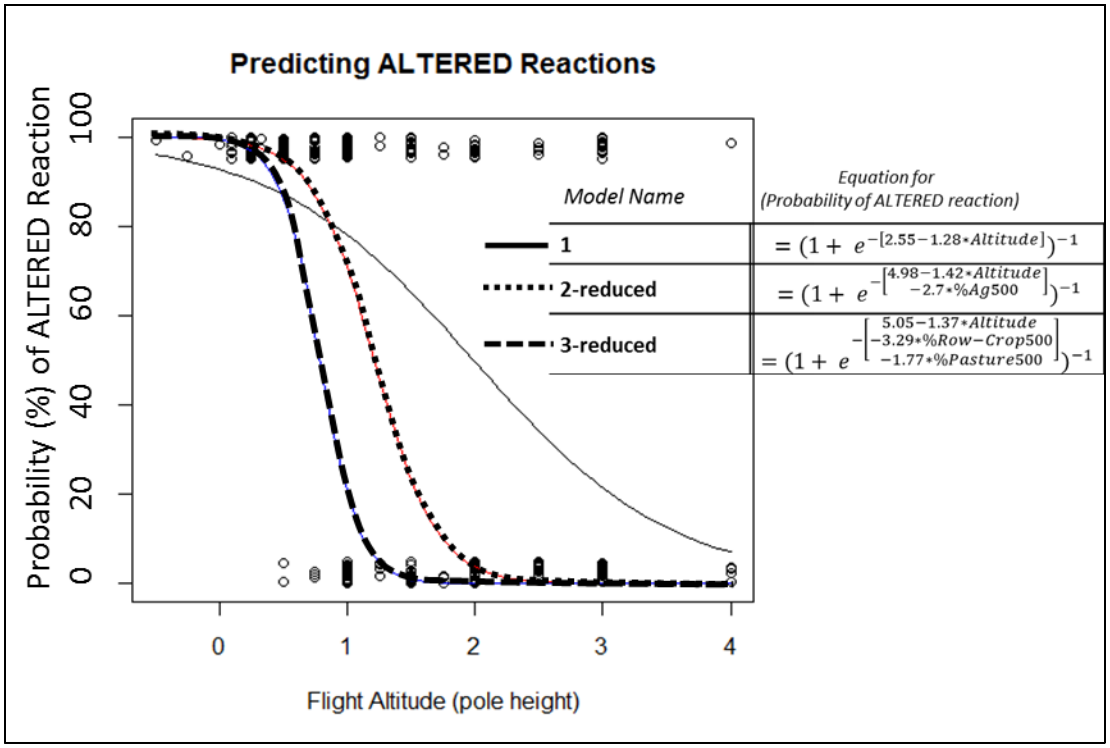


Figure 5. Prediction curves of the two best-fit logistic regression ALTERED models “2-reduced” and “3-reduced” compared with ALTERED model 1 (only flight altitude) describing the probability that cranes would alter their flight reaction around a power

line logistic regression models. Data points are “jittered” (R Development Core Team 2011) to display the number of observations recorded for either altered reactions or unaltered reactions.

4.4 Evaluating Spatial Clustering Using Ripley’s K-function

Research Question 3): Is the crane flight reaction data spatially clustered?

Of the original 201 Site Spans I observed (Figure 1), I only used Site Spans with crane reactions recorded within 22.4 m of power lines. I aggregated the counts of gradual and abrupt reactions to the Site Spans. In Figure 6, I display all the Site Spans I observed in my study, but only display the gradual (large blue points) and abrupt reactions (red points) when cranes flew within the Collision Risk Zone; I did not display the count of reactions at each Site Span.

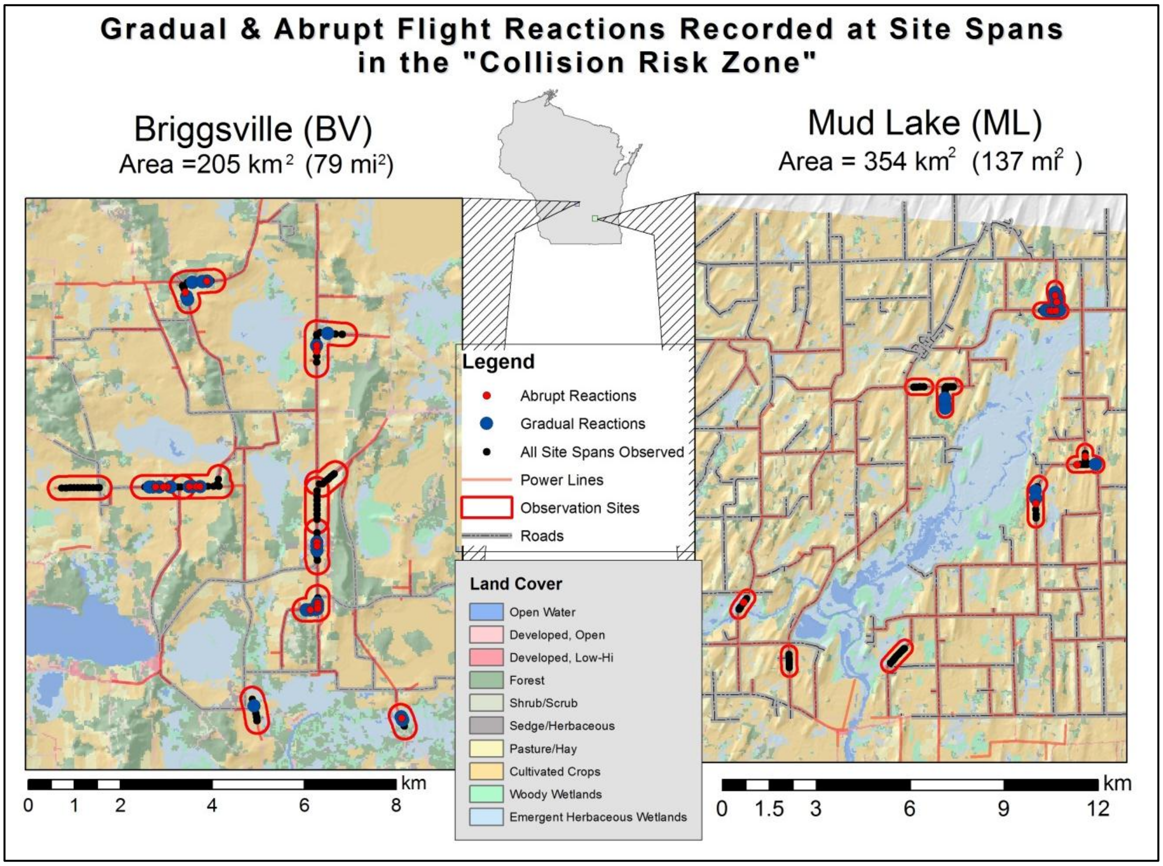


Figure 6. Distribution of total number of reactions (e.g. includes gradual and abrupt reactions under 22.4 m in altitude) recorded at Site Spans at both study areas. The Collision Risk Zone is considered at or below 22.4 m around Site Spans.

Table 8 lists summary statistics for the number of crane reactions I recorded at each Site Span in BV and ML. This only summarizes the ABRUPT model data, which considered gradual and abrupt reactions recorded within the Collision Risk Zone. I observed all the black Site Spans in the 20 Observation Sites, but only recorded gradual reactions

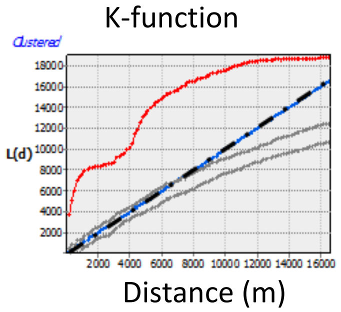
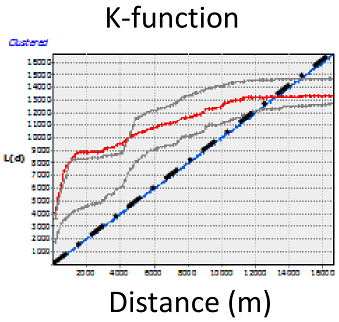
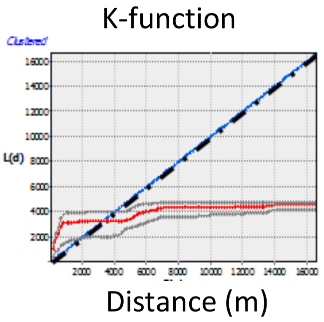
Table 8. Summary statistics for number of crane flock reactions recorded over Site Spans for the ABRUPT model using only gradual and abrupt reactions recorded within the Collision Risk Zone.

No. Site Spans with Reactions	No. Reactions Recorded	Summary Statistics for No. Crane Flock			
		Mean	Median	SD	Range
57	191	3.4	2.0	4.0	1-19
47	147	3.1	1.0	3.3	1-15
27	44	1.7	1.0	1.5	1-8

Ripley's k-function analysis revealed that significant clustering occurred at all scales of my data. 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 point. The locations of reactions at the Site Spans are not significantly more clustered or dispersed than the underlying pattern of Site Span points. Site Spans were weighted by the number of reactions recorded at each Site Span. I displayed formal graphical tests for spatial clustering or dispersion of Ripley's k-function for the datasets with both study areas (Figure 7), and for individual dataset of BV data (Figure 8), and ML data (Figure 9).

For the 57 Site Spans in both Study Areas, the Un-weighted Site Span Pattern (solid black line, Figure 7a) showed significantly more clustering than the Random Point Pattern (thick dashed line). Figure 7b showed that the number of crane reactions (gradual or abrupt) recorded at the 57 Site Spans have similar clustering (i.e. are not significantly more clustered or dispersed) as the point locations of the Site Spans. In figure 7, the observed ALTERED Reaction Site Span Pattern (b) fell within the CE of the

Un-weighted Site Span Pattern (a). This means that the locations of all altered reactions recorded in the Collision Risk Zone at Site Spans were not more clustered than the underlying point pattern of Site Span locations (i.e. Un-weighted Site Span Pattern). I also estimated the k-function using Site Spans weighted by the number of abrupt reactions recorded at each Site Span. Results in Figure 7c showed that the number of crane abrupt reactions recorded at the 57 Site Spans were significantly more clustered than a Random Point Pattern around 1 km, but became significantly more dispersed at distanced beyond 4.5 km.

Un-Weighted Site Span Pattern *(Compares Site Span points with Random Point Pattern)* (a)	**ALTERED Reaction Site Span Pattern** *(Weighted by No. Altered [Gradual + Abrupt] Reactions/Site Span)* (b)	**ABRUPT Reaction Site Span Pattern** *(Weighted by No. Abrupt Reactions/Site Span)* (c)
		

— Observed Site Span Pattern
– · – Random Point Pattern
-------- 99% Confidence Envelope

Figure 7. Ripley's k-function, *L(d),* results for both study areas together using un-weighted and weighted data. The thick dashed line represents the random point pattern with no clustering or dispersion. (a) *L(d*) for un-weighted Site Span point locations calculated for only Site

Span points. (b) *L(d)* for Site Span point locations weighted by number of altered reaction s(gradual + abrupt reactions) at each Site Span point. (c) *L(d)* for Site Span point locations weighted by number of abrupt reactions at each Site Span point.

The Un-weighted Site Span Pattern in BV (Figure 8) showed significant clustering in the point locations between 200m and 1.4 km relative to the Random Point Pattern (thick dashed line). I expected clustering at the local Site Span level given that I observed consecutive Site Spans within each Observation Site. Locations of altered or abrupt reactions actually became significantly dispersed beyond 1.6 km. The clustering at the 1.4 km level could be a circumstance of BV being one-third the size of the ML Study Area, where I selected Observation Sites closer together.

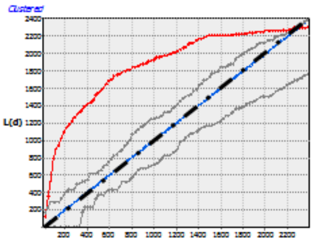
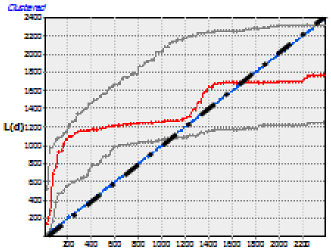
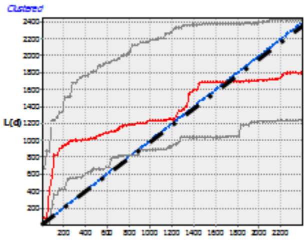
BV—Un-Weighted Site Span Pattern *(Compares Site Span points with Random Point Pattern)* (a)	**BV—ALTERED Reaction Site Span Pattern** *(Weighted by No. Altered [Gradual + Abrupt] Reactions/Site Span)* (b)	**BV—ABRUPT Reaction Site Span Pattern** *(Weighted by No. Abrupt Reactions/Site Span)* (c)
K-function  Distance (m)	K-function  Distance (m)	K-function  Distance (m)

Figure 8. Ripley's k-function, *L(d),* results for the BV Study Areas using un-weighted and weighted data. The thick dashed line represents the random point pattern with no clustering or dispersion. (a) *L(d)* for un-weighted Site Span point locations calculated for only Site Span points. (b) *L(d)* for Site Span point locations weighted by number of altered reactions (gradual + abrupt reactions) at each Site Span point. (c) *L(d)* for Site Span point locations weighted by number of abrupt reactions at each Site Span point.

— Observed Site Span Pattern
– · – Random Point Pattern
-------- 99% Confidence Envelope

In Figures 9a, b, and c, for ML, the Un-weighted, ALTERED Reaction and ABRUPT Reaction Site Spans Patterns were all significantly more clustered than the Random Point Pattern (thick dashed line). However, the point pattern was similar for all three analyses of un-weighted and weighted Site Span data. For example, the solid black line for the Observation Site Span Patterns in Figures 9a, b, and c all show the same pattern.

Figure 9a shows that Site Span locations are significantly more clustered than 99 permutations of a random point pattern (thick dashed line). Recall that CE is calculated as a confidence interval with 99 permutations of a random distribution, meaning that although the solid black lines in the ALTERED and ABRUPT Site Span Patterns, the CE's are much wider in this analysis. Furthermore, although the ABRUPT Reaction Site Span Pattern (Figure 9c) appears to have less clustering than both the Unweighted (Figure 9a) and ALTERED Reaction Site Span Pattern (Figure 9b), the CE's of both weighted Site Span Pattern are approximately the same. Therefore, the level of clustering is not significantly different between the Site Span locations, where cranes altered their flight, or where they showed abrupt reactions at Site Spans. However, the amount of spatial clustering in the Site Spans point leveled off between 1-1.5 km around Site Spans.

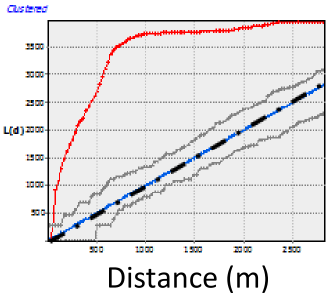
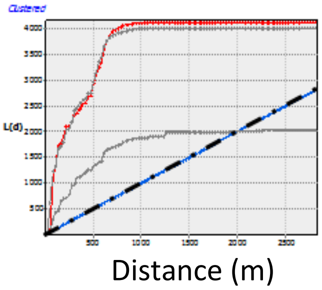
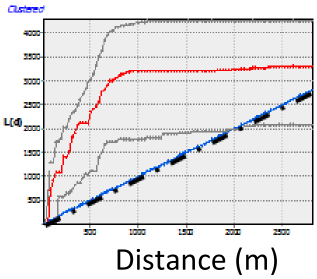
ML—Un Weighted Site Span Pattern *(Compares Site Span points with Random Point Pattern)* (a)	**ML—ALTERED Reaction Site Span Pattern** *(Weighted by No. Altered [Gradual + Abrupt] Reactions/Site Span)* (b)	**ML—ABRUPT Reaction Site Span Pattern** *(Weighted by No. Abrupt Reactions/Site Span)* (c)
K-function 	K-function 	K-function 

Figure 9. Ripley's k-function, *L(d),* results for the ML Study Area using un-weighted and weighted data. The thick dashed line represents the random point pattern with no clustering or dispersion. (a) *L(d*) for un-weighted Site Span point locations calculated for only Site Span points. (b) *L(d)* for Site Span point locations weighted by number of altered reaction s(gradual + abrupt reactions) at each Site Span point. (c) *L(d)* for Site Span point locations weighted by number of abrupt reactions at each Site Span point.

— Observed Site Span Pattern
– · – Random Point Pattern
-------- 99% Confidence Envelope

4.5 ABRUPT Model

Research Question 4): Which variables best predict abrupt flight reactions among cranes?

I tested which predictor variables were significant for ABRUPT_bin, the binary response variable for cranes that either showed gradual or abrupt flight reaction around power lines within the Collision Risk Zone (within 22.4 m power line). Prior to including predictor variables in logistic regression analyses in the ABRUPT model, I tested which predictor variables were significant for ABRUPT_bin in univariate tests. Table 9 list results from univariate tests between abrupt and gradual reactions in the ABRUPT model, which included only reactions recorded in the Collision Risk Zone. Variables that were significant for ABRUPT_bin (Table 9) included flight altitude, flock size, temperature, proportion pasture/hay in a 500 m buffer, distance to forest edge, season, time of day, and study area. I did not include the following variables in logistic models because they were not significant for ABRUPT_bin: percent cloud cover, maximum wind speed, relative percent humidity, proportion agriculture in 250 or 500 m buffers, proportion row-crop in 250 or 500 m buffer, proportion pasture/hay in 250 m buffers, distance to emergent wetlands, and precipitation.

Table 9. Results of univariate tests for ABRUPT_bin. Sample sizes for all tests were 191. "OR" refers to the odds ratio of probability of an abrupt reaction occurring divided by the probability of an abrupt reaction not occurring. The 95% confidence interval for the OR is contained in the parentheses.

Predictor	Test	Tests Statistic	p-
Flight Altitude [a]	**Mann Whitney U Test**	**W =4318.5**	**0.001**
Flock Size	**Mann Whitney U Test**	**W = 4017**	**0.020**
Percent Clouds	Mann Whitney U Test	W = 3641.5	0.263
Maximum wind speed	Mann Whitney U Test	W =3765.5	0.137
Relative Percent Humidity	Mann Whitney U Test	W = 2843	0.172
Temperature	**Mann Whitney U Test**	**W = 4045**	**<0.001**
Proportion Agriculture	Wilcoxon Rank Sum Test	W = 3778	0.127
Proportion Agriculture	Wilcoxon Rank Sum Test	W = 3608	0.319
Proportion Row-Crop	Wilcoxon Rank Sum Test	W = 3312.5	0.934
Proportion Row-Crop	Wilcoxon Rank Sum Test	W = 2770.5	0.112
Proportion Pasture/Hay	Wilcoxon Rank Sum Test	W = 3254	0.925
Proportion Pasture/Hay	**Wilcoxon Rank Sum Test**	**W = 4067.5**	**0.016**
Distance to Forest	**Wilcoxon Rank Sum Test**	**W = 2482**	**0.013**
Distance to Emergent	Wilcoxon Rank Sum Test	W = 2943.5	0.292
Precipitation	Fisher's Exact Test	OR= 1.38, (0.61, 3.01)	0.446

Season	**Fisher's Exact Test**	**OR=0.26, (0.12, 0.56)**	**<0.001**
Time of Day	**Fisher's Exact Test**	**OR=3.22, (1.48, 7.43)**	**0.002**
Study Area	**Fisher's Exact Test**	**OR=3.22, (1.48, 7.43)**	**0.002**

[a] Bold font indicates variables with p-value < 0.1
[b] Percent land cover type calculated within a 250 m buffer around Site Spans
[c] Percent land cover type calculated within a 500 m buffer around Site Spans

For those variables significant for ABRUPT_bin, I assessed collinearity between predictor variables (refer to Appendix L and M). None of the continous variables were collinear. However season was collinear with flight altitude (Wilcoxon Rank Sum Test, W= 4736, p= 0.002), temperature (Wilcoxon Rank Sum Test, W=0, p<0.001), time of day (Fisher’s exact test, odds ratio=14.67, p<0.001), and study area (Fisher’s exact test, odds ratio=0.27, p=0.0002). Time of day was collinear with temperature (Wilcoxon Rank Sum Test, W=950, p<0.001), proportion pasture/hay in 500 m buffers (Wilcoxon Rank Sum Test, W=5124, p < 0.001), and study area (Fisher’s exact test, odds ratio=0.19, p<0.001). Study area was collinear with temperature (Wilcoxon Rank Sum Test, W=7805, p<0.001), proportion pasture/hay in 500 m buffers (Wilcoxon Rank Sum Test, W=1219.5, p<0.001), and distance to forest (Wilcoxon Rank Sum Test, W=5554, p=0.008).

Following these collinearity tests, I developed seven candidate logistic regression models to predict ABRUPT_bin (see Appendix N). After ranking AIC models, and comparing AUC and pseudo R^2 values, I selected two models as the best-fit models for predicting whether a crane showed an abrupt reaction around a power line. Full models included all variables that I found to be significant for ABRUPT_bin while Reduced models include the variables after backward step selection and removed any non-significant variables in the model. Appendix N lists model coefficients for the two best-fit models, which I compared against model 1 where only flight altitude predicted ABRUPT_bin. The best-fit model, “2-reduced,” had the lowest AIC weight, predicted 76.8% of all abrupt reactions correctly, and had a pseudo R^2=0.251. I also compared this model with the second best-fit model, “5-reduced,” because it had a small ΔAIC (=3.2), albeit not ΔAIC<2.0. This “5-reduced” model correctly predicted 73.9% of abrupt reactions, and also had a pseudo R^2=0.22. In contrast to the ALTERED model, flight altitude alone was not as predictive in that it predicted 65.7% of abrupt reactions correctly and had a low pseudo R^2=0.073. I compared the prediction curves for the final ABRUPT models in Figure 10 against for flight altitude in model 1 and model “2-reduced.” Because model “5-reduced” did not include flight altitude, I only compared this model alongside model 1 and model “2-reduced” using the natural log of flock size (Figure 11).

ABRUPT models 1 and “2-reduced” predicted abrupt reactions for several variables. Figure 10 shows that for every increase in flight altitude (by one pole length or 11.2 m) the odds that a crane flock showed an abrupt reaction around a power line decreased by 35% (95% CI: 16-69%) and by 46% (95% CI: 21-97%) respectively. As the natural log of flock size increased by one unit, models “2-reduced” and “5-reduced” predicted a 50% (95% CI: 25-93%) and 47% (95% CI: 24-87%) decrease in the odds of abrupt reactions. Figure 11 shows that for every 10 m. increase a crane flock flew from a forest edge, ABRUPT models “2-reduced” and “5-reduced” predicted a 4% (95% CI: 1-10%) and 5% (95% CI: 2-8%) increase in the odds of an abrupt reaction. Model “2-reduced” predicted a 5% (95% CI: 2-8%) increase in the odds of abrupt reactions as temperature increased one degree (^{O}F). Model “5-reduced” predicted a 24% (95% CI: 11-51%) decrease in the odds of abrupt reactions if a crane flock flew during migration.

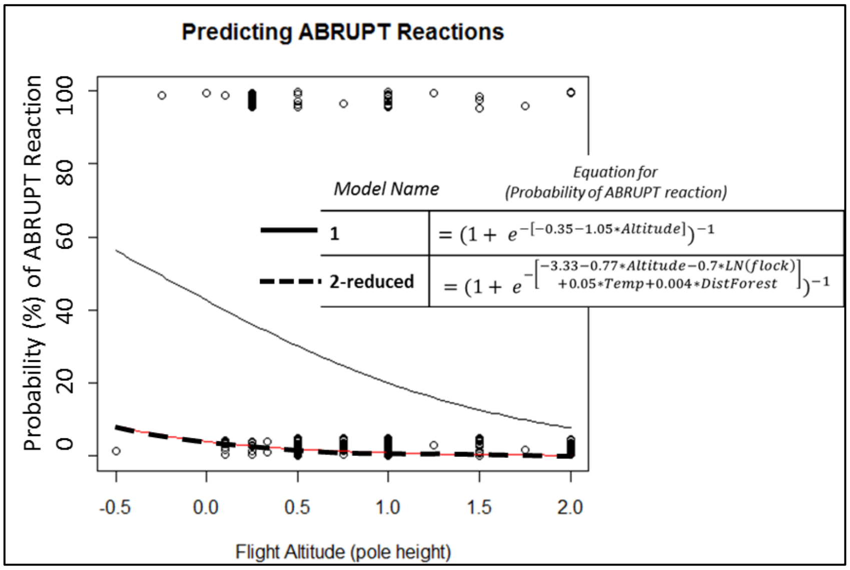


Figure 10. Prediction curves for abrupt reactions from the best-fit logistic regression models based on flight altitude for model 1 and model “2-reduced.” Data points are “jittered” (R Development Core Team 2011) to display the number of observations recorded for either abrupt reactions or gradual reactions.

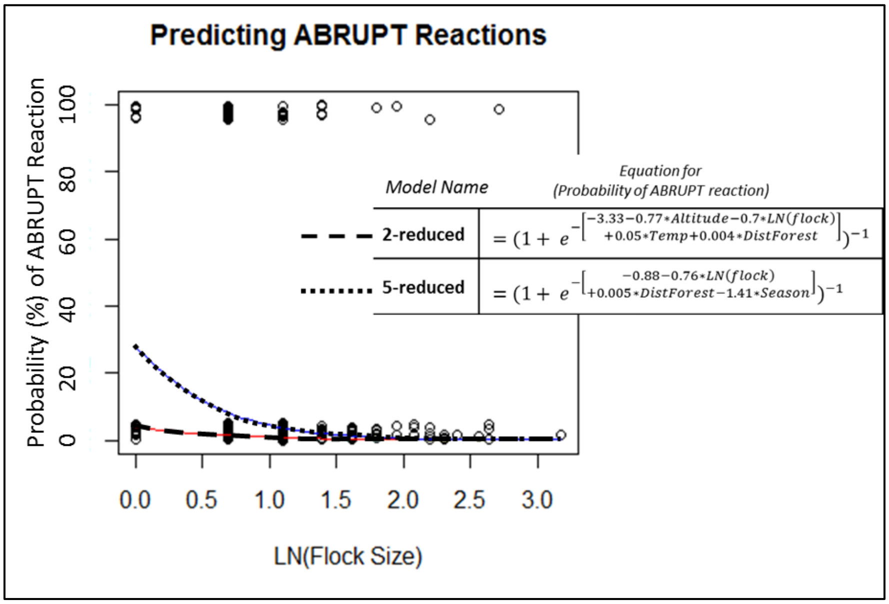


Figure 11. Prediction curves for abrupt reactions from the two best-fit logistic regression models based on natural log of flock size for model “2-reduced” and model “5-reduced.” Data points are “jittered” (R Development Core Team 2011) to display the number of observations recorded for either abrupt reactions or gradual reactions.

4.6 Observation Site Landscape Analysis

Research Question 5): Does the proportion of cranes that showed abrupt reactions at Observation Sites correlate with landscape variables?

I tested for associations between seven predictor variables and the proportion of abrupt reactions aggregated to Observation Sites. I listed these variables in Table 10. I transformed those variables with non-normal distributions. Final correlations showed that Pr_ABRUPT significantly correlated with the mean distance to forest edges (Pearson's product-moment correlation, r=0.58, p=0.079) and median distance to emergent wetlands (Pearson's product-moment correlation, r=0.55, p=0.099). I did not include these variables in a regression model because they were significantly collinear (Pearson's product-moment correlation, r=0.992, p<0.001).

Table 10. Results of Pearson's product-moment correlation tests between Pr_ABRUPT and predictor variables measured at the Observation Site level.

Predictor Variable	R	95% CI	p-value
Mean distance to forest edge[a]	**0.580**	**-0.078, 0.886**	**0.079**
Median distance to forest edge	0.079	-0.580, 0.675	0.829
Mean distance to emergent wetlands	0.232	-0.466, 0.752	0.519
Median distance to emergent wetlands	**0.551**	**-0.120, 0.877**	**0.099**
LN(proportion of pasture & hay in 500 m	-0.306	-0.784, 0.401	0.390
SQUARE(proportion of row-crop in 500 m	0.393	-0.314, 0.820	0.261
SQUARE(proportion of agriculture[pasture	0.121	-0.550, 0.698	0.739

[a] Bold font indicates correlations with p<0.1

5.0 DISCUSSION

This research provided evidence that sandhill cranes have a collision risk around power lines based on weather, flock reaction, and distance to forest edges. In this section, I compare how each landscape combination influences the odds that cranes show abrupt reactions. This analysis can be a tool for future research looking at how specific spatial variables influence collision risk for cranes and perhaps other large birds, and leads into answering my final research question. Does the proportion of cranes that showed abrupt reactions at Observation Sites correlate with landscape variables?

5.1 ALTERED Model

From the ALTERED model, flight altitude alone correctly discriminated 80.9% (AUC=0.809) of the flight reactions (ALTERED model 1), or correctly predicted 258 of the 319 reactions as either altered or unaltered. Furthermore, this model showed that cranes are more likely to alter their flight reaction around within 22.4 of a power line. The two best models ranked from the AIC model selection criteria included either percent agriculture (ALTERED model “2-reduced”) or percent row-crop and percent pasture/hay (ALTERED model “3-reduced”) measured within 500 m of Site Spans.

The ALTERED models showed that cranes are more likely to alter their flight behavior around power lines when flying at lower altitudes, which makes intuitive sense. The confidence interval for the association of flight altitude and altered reactions was small, between 20-38%. As flight altitude was the most important predictor of altered reactions, the association that agriculture, row-crop, and pasture has with crane altered reactions was only speculative. The wide confidence interval for the odds ratios in ALTERED model “2-reduced” suggested the odds ratios for the association of agriculture was between 10% and 310%. Likewise, for the ALTERED model “3-reduced” the confidence interval was 10-200% for row-crop and was 20-119% for pasture and hay. Moreover, these land cover variables only explained one percent of the altered reactions and are therefore not useful as predictor of crane reactions around power lines.

5.2 ABRUPT Model

Based on the ALTERED model showing flight altitude as the main predictor, I refined my analysis to consider only those cranes that changed their flight reactions (e.g. gradual or abrupt reactions). I asked, what other environmental or flock-related variables best explained when a crane showed these reactions? From the two best ABRUPT models, small flock sizes, and farther distances from forest edges both were important predictors. In the ABRUPT model “2-reduced,” flight altitude was only slightly significant compared to the natural log of flock size distance to forest edge and temperature. In Section 6.1 on abrupt flight reactions as indicators of collision risk I refer to other studies that showed similar results.

5.3 Correlations at the Observation Site Level

I tested associations between the proportion of abrupt reactions and variables within a 500 m buffer of Observation Sites. This revealed only weak correlations with the mean distance to forest edges and median distance to emergent wetlands Because I pooled my data across all seasons, times of day, and weather, this analysis could assess any spatial variables that correlated with those Observation Sites that had a higher proportion of cranes showing abrupt reactions. As expected, these results confirmed my expectation that a higher proportion of cranes showed abrupt reactions farther from forest edges.

5.4 Limitations of Study

This study was limited by five challenges, each elaborated below. 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 reactions. A second challenge related to sampling design and effort spent observing cranes in the field across seasons, time of day, weather, and Study Area. 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.

(1) Assumptions of Breeding Age and Crane Habitat Selection from Ground Surveys

I had expected specific land cover combinations (e.g. forest, wetland, row-crop agriculture, and pasture) might indicate higher collision risk to cranes in flight. For cranes on the ground, the spatial arrangement of habitat patches influences where cranes select habitats (Gulzwiller and Anderson 1992). This in turn may influence population dynamics through increased breeding success, nest selection, and habitat use (Pulliam and Danielson 1991). I made a reasonable assumption that cranes might fly over power lines more frequently over habitats used for foraging or roosting.

Although a principal question in crane natural history, I assumed that a cranes breeding status did not affect its flight reaction. However, breeding cranes fly much less frequently than non-breeding cranes. Su (2003) found that non-breeding cranes had larger home ranges farther from wetlands and breeding cranes (seen with chicks or a mate) had smaller home ranges closer to wetlands. This suggests that breeding cranes would make frequent flights over nearby power lines and non-breeding cranes would cross many more power lines in their larger home ranges, which could significantly increase the collision risk for breeding cranes. Sundar and Choudhurry (2005) studied power line placement on the collision mortalities rate for Sarus cranes in India. Of mortalities related to power line collision, 86% (n=30) were adults, of which 77% (n=27) were non-breeding birds. However, Sundar and Choudhurry (2005) distinguished sub-adults only by the territories Sarus cranes used. Using this guideline for identifying crane age was not useful when observing cranes flying around power lines because I had no prior knowledge of the crane's territorial behavior.

(2) Sampling Design & Crane Observation Effort

Following analyses, a challenge to accurate inference from regression results involved the varied sampling effort of field observations of crane reactions. I missed four potential observation days (one in BV and three in ML) due to a car collision in the field. This reduced my overall sampling effort in ML. Because my goal was to compare crane reactions at these locations across different seasons and weather (e.g. clear/fog vs. clear weather), I excluded data from these four Observation Sites. At Observation Site BV-11, I did not record any cranes; therefore no data was lost. However, I removed data from three ML Observation Sites in other seasons including a total of 33 crane reactions from my dataset. This may explain why there were fewer reactions recorded in ML overall because I only used crane flock reactions recorded in nine ML Observation Sites compared to the 11 BV Observation Sites. Although I selected Observation Sites that were representative of the overall study area landscape and land cover, the data I could have collected at these Observation Sites may have changed the overall proportions of abrupt reactions.

There is also potential for confounding effects of season, weather, and study area on crane flight reactions recorded at Observation Sites. With fewer cranes present during summer seasons (e.g. 200-300 cranes in each Study Area) than in migration (e.g. 600-1,200 cranes in each Study Area), I sampled Observation Sites twice during the summer to increase my sample size of crane reactions; this resulted in a comparable dataset between seasons. Numerous studies suggest that high winds and/or fog increase collision risk for cranes (Yee 2008, Brown and Drewien 1995, Morkill and Anderson 1991). As such, most Observation Periods occurred in clear weather, which could explain why fogy/rainy weather did not show significant relationship as I expected.

(3) Carcass Searches

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.

(4) Estimating Predictor Variables

This research involved specific spatial analysis, which I based on assumptions of previously estimated land cover data. Due to availability at the start of my research, I used an older version of the National Land Cover Dataset, classified from 2001 LANDSAT images. However, the recently available 2006 updated National Land Cover Dataset will be useful for future studies.

I encountered issues in my field methodology related to the potential influence of a flock's second reaction. While observing crane reactions at power lines, at times they "doubled-back" and flew over power lines again. Although I collected this information, I did not consider how this additional crossing effect could have influenced the probability a crane would show an abrupt reaction. When I did record these, I did not include these in analysis to ensure each reaction was an independent event.

Additionally, I subjectively decided to use maximum wind speed as a predictor variable over using the Beaufort landscape-scale wind speed category as a predictor variable. Although only four days had maximum wind speeds above 14.4 kmph, my measurement method on the ground may not have captured how much wind speeds affected cranes flying at higher altitudes. Future reaction surveys should use the Beaufort wind speed scales (measured relative to the movement of grasses and trees) as a predictor because it captures the larger landscape for crane flights, whereas wind speed at the ground level only captured lower-level wind speeds. The highest winds speed was 25.9 kmph, when five crane flocks flew 34 m above power lines during migration in BV at night. Moreover, I recorded cranes flight reactions with mean wind speeds of only 7.0 kmph, median of 5.3 kmph, which likely explains why wind speed did not help predict any flight reactions.

(5) Assessing Spatial Clustering

Despite the differences in study areas in land cover, both the ALTERED and ABRUPT models performed well given the presence of spatial clustering at the Site Span level and somewhat at the Observation Site level. In Figure 7, the highest clustering appeared at 1 km, plateaued, then spiked again at 5 km for all 57 Site Spans in both Study Areas; therefore, future analysis could more stringently select sites farther apart to reduce this confounding issue. Spatial clustering potentially inflates the significance of variable relationships. Methods could be used to account for this condition. With spatially independent observations, there would be potential for using spatial interpolation to estimate collision risk across a larger area.

6.0 CONSERVATION IMPLICATIONS AND FUTURE RESEARCH

My approach incorporated crane flight reaction, habitat use in roosting and foraging areas, and locations for observing crane flight patterns around power lines. Future power line siting projects should use similar flight reactions surveys to classify GSC behaviors and flight altitudes around particular power lines.

This insight informs government, local landowners, and conservation organizations who seek to protect important staging and stopover areas for sandhill cranes. However, agencies or power line utilities assessing the collision risk potential of a power line need to know which landscape variables increase a crane's risk of collision. Assessing this risk should include flight reaction surveys.

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.

6.1 Abrupt Flight Reactions as Indicators of Collision Risk

Observing a crane strike a power line is a rare event. This is why many studies opt to use carcass searches under power lines to confirm that cranes die from striking power lines. How to define collision risk presents several obstacles. Should researchers define collision risk only by a death toll, standardized by several bias estimates (e.g. chance of finding a crane, decomposition rate, location in grass)? Or, should researchers factor in all the risk variables in a given landscape? I attempted to answer whether there are other important risk factors within different landscapes.

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 5 m of the line, all four cranes showed the abrupt reaction and veered right to avoid striking line and the other cranes. I also recorded five crane flocks of either one or two cranes fly under power lines (Appendix P) despite the lack of documented flights under power lines in the literature Another unexpected observation involved recording three whooping cranes fly within 20 m of the power line in Observation Site ML-13. 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.

I recommend that collision risk not be defined as whether a crane strikes a power line, but include flight reactions indicative of the potential for collision. My research on estimating where and when cranes showed abrupt flight reactions follows what several other researchers noticed in their results. In a 1991 study, Morkill and Anderson observed no collisions during their study, but recorded nine sandhill cranes that were injured and survived or were scavenged and dragged off after striking a power line. Of the three sandhill cranes that Faanes and Johnson (1992) observed striking power lines, two showed no reaction while the third abruptly reacted and flew upwards to clear the power line. Ward and Anderson (1992) observed eight sandhill cranes strike the transmission static wire, six of which recovered and continued flying. Oftentimes, cranes may not adjust their flight altitude or direction when crossing a power line even when flying within five m of a power line (Morkill and Anderson 1991, personal observations). Unfortunately, researchers may interpret this non-reaction as having no collision-risk around that power line; however there are two possible scenarios for why a crane does not change its flight pattern or altitude within five m of a power line: 1) the crane does not see the power line from low visibility conditions or 2) the crane sees the power line, but does not perceive a threat.

6.2 Future Research

Numerous questions surfaced during and following my research. The major questions on which future research should focus involves (1) obtaining more precise estimates of crane density for analyzing assessing density-dependence on collision risk, (2) testing associations of crane breeding status and season with their flight reactions around power lines, and (3) testing association between distance to forests where a crane flew and flight reactions.

(1) Consider Digitizing Crane Locations with Current Flight Behaviors

Additional research should focus on collecting and digitizing better estimates of whooping crane and sandhill crane density from ground population counts. Identifying locations with relatively small populations of resident and migrant cranes—similar to those of the BV and ML Study Areas—are critical for assessing whether specific power line pose a collision risk to cranes. Power lines that cross through preferred habitat for cranes in these local stopover sites pose a collision risk. Data on crane flight behavior at these power lines is especially lacking for summer roosting and foraging locations.

<u>(2) Consider Crane Breeding Status and Season</u>

Most research assumes cranes have a higher risk of power line collisions during migration (APLIC 1994, Brown et. al. 1994, Brown et. al. 1987, Faanes and Johnson 1992, Jenkins et. al. 2010). Hence, we need more research on flight behavior around power lines for local, resident flocks during summer months to fully understand the potential power line collision risk. Considering that I used twice the sampling effort and only recorded half as many cranes during the summer season, this is likely an effect of crane density. Yet, of cranes I observed during the summer, 30% showed abrupt reactions while only 10% of those in migration showed abrupt reactions (Table 5). On average, during each Observation Period I observed 12 cranes flying around power lines in migration compared to only two cranes during the summer (Appendix G.2). However, the proportion of cranes that showed abrupt reactions was three times higher in the summer. This increase in the proportion of abrupt reaction may relate to the presence of recently fledged crane chicks that might react more abruptly around power lines because they were still learning to fly.

I recommend further research focused on observing flight behavior of newly fledged cranes around power lines. I had no standardized method to record the age of a crane as it flew around a power line except for its call. Sandhill crane chicks have a distinctive high-pitched call compared to the adult's echoing bugle, which I occasionally recorded during Observation Periods. However, even with a crane's call, distinguishing a “sub-adult” from an “adult” crane proves challenging. Plumage characteristics are most definitive to distinguishin newly fledged cranes (Lewis 1979), but becomes difficult if numerous cranes fly in large flocks. Newly fledged cranes (both sandhill cranes and whooping cranes) may have a higher risk of striking power lines prior to the start of migration; thus, an experiment should test whether newly fledged chicks do in fact react differently than adults.

(3) Consider Distance to Forest Edges and Flight Direction

I recommend adapting the predictor variable of “distance to forest edge” to incorporate crane fight direction around a power line. I expected that cranes would fly closer to power lines farther from forest edges; yet in both ABRUPT models (e.g. “2-reduced” and “5-reduced”), distance to forest edge was less informative than flight altitude and season without considering where a crane flew relative to the line. Distance to forest edge may not relate to how a crane perceives its surroundings; incorporating flight direction and the distance to a forest edge in a crane’s visual field may answer whether a crane reacts to this distance to a forest edge.

7.0 SUMMARY

Power lines pose a significant collision risk for all species of cranes. Cranes that directly strike power lines suffer serious injuries that either immediately lead to death or indirectly increases chances of predation (Hartup et. al. 2010, Miller et. al. 2010, Van

Rooyen 2003, APLIC 1994). Power lines with a history of collision mortalities or are within 500 m of an important roosting wetland for cranes pose a particular collision risk. In North America, whooping cranes and sandhill cranes have died from striking power lines (Miller et. al. 2010, Murphy et. al. 2009, personal observations). Additionally, power lines are the highest known cause of mortality of fledged whooping cranes (Stehn and Wassenich 2008). Estimates of collision mortality rates for sandhill cranes vary; however, with approximately 15,000 greater sandhill cranes in Wisconsin, even a conservative estimate suggests that between several hundred to one thousand GSC could strike power lines and potentially die each year.

In my study, flight altitude alone most accurately predicted whether cranes altered their flights around power lines. If cranes crossed a power line flying at or below 22.4 m above the line, cranes had a 50% chance of altering their reaction. The likelihood that cranes showed an abrupt reaction increased if they flew in a flock of one or two cranes, at lower altitudes or under the power line, farther from forest edges, and in the summer.

Flight reaction 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 reaction surveys because it reduces the effort needed to identify power lines that pose potential collision risk to cranes. If, during flight surveys, cranes show abrupt reactions frequently at 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 all power lines for cranes.

8.0 LITERATURE CITED

Alonso J. A., and J. C. Alonso. 1999. Collision of birds with overhead transmission lines in Spain. Pages 57-82 *in*: M. Ferrer and F. E. Janss, ed. Birds and powerlines: Quercus, Madrid.

Alonso, J. C., J. A. Alonso, and R. Munoz-Pulido. 1994. Mitigation of bird collisions with transmission lines through groundwire marking. Biol. Conserv. 67:129–134.

Anderson, M. D. 2002. Karoo Large terrestrial bird powerline project, report No. 1. Johannesburg: Eskom (Unpublished report).

Avian Power Line Interaction Committee (APLIC). 1994. Mitigating bird collisions with power lines: State of the art in 1994. Report 06-94-33, Edison Electric Institute, Washington, D.C., USA.

Bolstad, P. *GIS Fundamentals: A First Text on Geographic Information Systems.* 3rd ed. White Bear Lake, Minnesota. Eider Press. 2008. Print.

Brown, W. M. and R. C. Drewien. 1995. Evaluation of two power line markers to reduce crane and waterfowl collision mortality. Wildlife Society Bulletin 23(2):217-227.

_____, _____, and D. L.Walker. 1984. Crane flight reaction and mortality associated with power lines in the San Luis Valley, Colorado. Forest, Wildlife and Range Experiment Station, University of Idaho, Moscow, Idaho, USA.

_____, _____, and E. G. Bizeau. 1987. Mortality of cranes and waterfowl from power line collisions in the San Luis Valley, Colorado. Pages 128-136 in J. C. Lewis, editor. Proceedings of 1985 Crane Workshop. Platte River Whooping Crane Habitat Maintenance Trust, Grand Island, Nebraska, USA.

Buller, R. J. 1976. Recent studies of age ratios of sandhill cranes in the central flyway. Pages 78-85 *in* J. C. Lewis, editor. Proceedings of the 1978 International Crane Workshop, Baraboo, WI, USA.

Burnham, K. P. and D. R. Anderson. *Model selection and multimodel inference: a practical information-theoretic approach.* 2nd ed. Springer, New York. 2002. Print.

Canadian Wildlife Service and U.S. Fish and Wildlife Service. 2007. International recovery plan for the whooping crane. Ottawa: Recovery of Nationally Endangered Wildlife (RENEW), and U.S. Fish and Wildlife Service, Albuquerque, New Mexico. 162 pp.

Chatterjee, S. and A. S. Hadi. “Variable Selection Procedures.” *Regression Analysis by Example*. 4th ed. Hoboken, New Jersey, John Wiley and Sons, Inc. 2006. Print.

Clark, W. A. V. and P. L. Hosking. *Statistical Methods for Geographers*. New York: New York. Wiley. 1986.

Compton, B. W., J. M. Rhymer, and M. McCollough. 2002. Habitat selection by wood turtles (*Clemmys inscultpa*): an application of paired logistic regression. Ecology 83(3):833-843.

Crowder, M. R. 2000. Assessment of devices designed to lower the incidence of avian power line strikes [M.S. Thesis]. West Lafayette, IN: Purdue University.

De la Zerda, S. and Roselli, L. 2003. Mitigacio ´n de collision de aves contra lı´neas de transmission ele´ctrica con marcaje del cable de guarda. Ornithologı´a Colombiana 1:42–62.

Environmental Systems Resource Institute [ESRI]. 2010. ArcMap 10.0. ESRI, Redlands, California.

Faanes, C. A. and D. H. Johnson. 1992. Cranes and power line: an analysis of the issue. Pages197-202 in D. A. Wood, editor; S. A. Nesbitt, and L. E. Jr. Williams, technical co-editors. Proceedings of the 1988 North American Crane Workshop. Florida Game Fresh Water Fish Commission in Nongame Wildlife Program Technical Report 12. River Ranch Outdoor Resort, Lake Wales, Florida, USA.

Fondow, E. A and S. A. Temple. 2010. Habitat selection of eastern migratory whooping cranes on their wintering grounds. Proceedings of the North American Crane Workshop 11:200.

Gelman, A. and J. Hill. “Logistic Regression.” *Data Analysis Using Regression and Multilevel/Hierarchical Models.* New York: Cambridge, University Press, 2007. Print.

Gutzwiller, K. J., and S. H. Anderson. 1992. Interception of moving organism: influence of patch shape, size and orientation on community structure. Landscape Ecology 6:293-303.

Hartup, B. K., M. G., Spalding, N. J. Thomas, G. A. Cole, and Y. J. Kim. 2010. Thirty years of mortality assessment in whooping crane reintroductions: patterns and implications. Proceedings of the North American Crane Workshop 11:204

Henika, F. S. 1936. Sandhill cranes in Wisconsin and other lake states. Proceeding of the North American Wildlife Conference 1:644-646.

Homer, C., C. Huang, L. Yang, B. Wylie, and M. Coan. 2004. Development of a 2001 National Land cover Database for the United States. Photogrammetric Engineering and Remote Sensing 70(7):829-840.

International Crane Foundation [ICF]. 2010. “Historic Whooping Crane Numbers.” <http://www.savingcranes.org/whooping-crane.html/>. Accessed 2 Aug 2011.

Janss, G. F. E. and M. Ferrer. 1998. Rate of bird collision with power lines: effects of conductor-marking and static wiremarking. Journal of Field Ornithology 69:8–17.

Janss, G. F. E. 2000. Avian mortality from power lines: a morphologic approach of a species-specific mortality. Biological Conservation 95:333-359.

Janss, G. F. E. and M. Ferrer. 2000. Common crane and great bustard collision with power lines: collision rate and risk exposure. Wildlife Society Bulletin 28(3):675-680.

Jenkins, A. R., J. J. Smallie, and M. Diamond. 2010. Avian collisions with power lines: a global review of causes and mitigation with a South African perspective. Bird Conservation International 20:263–278. BirdLife International, 2010.

Johnsgard, P. A.. *Cranes of the world*. Bloomington, Indiana University Press, 1983. Print.

Johnson, D.H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology. 6:65-71.

Kotoane, M., and K.A. Shaw. 2006. Applying GIS to identify power lines that pose a high risk to blue cranes (*Anthropoides paradiseus*) in the Overberg region. Indwa 5:12-13.

Kuyt, E. 1983. Whooping Crane Migration Studies 1981-82. Pages 371-379 *in* G. W. Archibald, and R. F. Pasquier, editors. Proceedings of the 1983 International Crane Workshop. International Crane Foundation, Baraboo, WI, USA.

Lee, J. and D. W. S. Wong. “Point Pattern Analyzers.” *Statistical Analysis of Geographic Information with ArcView GIS And ArcGIS.* Hoboken, New Jersey, John Wiley and Sons, Inc., 2006. Print

Lewis, J. C. 1979. Field identification of juvenile sandhill cranes. Journal of Wildlife Management. 43:211-214.

Lovvorn, J. R. and C. M. Kirkpatrick. 1982. Field use by staging eastern greater sandhill cranes. Journal of Wildlife Management 46(1):99-108.

Maguire, K. J. 2008. Habitat selection of reintroduced whooping cranes, *Grus Americana*, on their breeding range [M.S. Thesis]. Madison, WI: University of Wisconsin-Madison. 58 p.

Martin, G. R. and J. M. Shaw. 2010. Bird collisions with power lines: Failing to see the way ahead? Biological Conservation 143(11):2695-2702.

Martin, G. R. 2011. Understanding bird collisions with man-made objects: a sensory ecology approach. International Journal of Avian Science. Ibis 153:239-254. DOI: 10.1111/j.1474-919X.2011.01117.x

Meine, C. D. and G. W. Archibald (Eds). *The cranes: - Status survey and conservation action plan.* IUCN, Gland, Switzerland, and Cambridge, U.K. 294 pp. 1996. Online. Northern Prairie Wildlife Research Center Online. Online: <http://www.npwrc.usgs.gov/resource/birds/cranes/index.htm>

(Version 02MAR98).

Miller, T. P. 2007. Habitat selection by breeding sandhill cranes in central Wisconsin. [M.S. Thesis]. Stevens Point, WI: University of Wisconsin-Stevens Point. 26 p.

Miller, J. L., M. G. Spalding, and M. J. Folk. 2010. Leg problems and power line interactions in the Florida resident flock of whooping cranes. Proceedings of the North American Crane Workshop 11: 156-165.

Mitchell, A. *The ESRI Guide to GIS Analysis: Volume 2: Spatial Measurements and Statistics*. ESRI Press: Redlands, CA. 2005. Print.

Morkill, A. E. and S. H. Anderson. 1991. Effectiveness of markers in reducing sandhill crane collisions with powerlines. Wildlife Society Bulletin 19:442-49.

Murphy, R. K., S. M. McPherron, G. D. Wright, and K. L. 2009. Effectiveness of avian collision averters in preventing migratory bird mortality from powerline strikes in the Central Platte River, Nebraska: 2008-2009 Final Report.

Ness. K. H. and A. E. Lacy. 2010. Assessing sandhill crane flight alterations to power lines in south-central Wisconsin. Proceedings of the North American Crane Workshop 11:217.

Pulliam, H. R., and B. J. Danielson. 1991. Sources, sinks, and habitat selection: a landscape perspective on population dynamics. American Naturalist 137(Suppl):S50-S66.

R Development Core Team. 2011. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL <http://www.R-project.org>.

Savereno, A. J., L. A.Savereno,R. Boettcher and S. M. Haig. 1996. Avian behaviour and mortality at power lines in coastal South Carolina. Wildlife Society Bulletin 24:636–648.

Stehn, T. V. 2011. Whooping crane recovery activities: October, 2010 – August, 2011. U.S. Fish and Wildlife Service Technical Report. Unpublished.

Stehn T. V. and T. Wassenich. 2008. Whooping crane collisions with power lines: an issue paper. Proceedings of the North American Crane Workshop 10:25-36.

Su, L. 2003. Habitat selection by sandhill cranes, Grus canadensis tabida, at multiple geographic scales in Wisconsin [Ph.D. Dissertation]. Madison, WI: University of Wisconsin-Madison. 141 p.

Su, L., J. Barzen, and T. Brieby. 2000. Habitat selection by sandhill cranes at multiple geographic scales in Wisconsin—Progress report on greater sandhill crane research in Wisconsin. Unpublished report from the International Crane Foundation to Wisconsin Department of Natural Resources. 54 pp.

Su, L., J. Harris, and J. Barzen. 2004. Changes in populations and distribution for greater sandhill cranes in Wisconsin. Passenger Pigeon. 66.

Sugden, L. G., R. G. Clark, E. J. Woodsworth, and H. Greedwood. 1988. Use of cereal fields by foraging sandhill cranes in Saskatchewan. Journal of Applied Ecology 25:111-124.

Sundar, K. S. G. and D. B.C. Choudhury. 2005. Mortality of sarus cranes (Grus antigone) due to electricity wires in Uttar Pradesh, India. Environmental Conservation 32 (3): 260–269. DOI:10.1017/S0376892905002341.

Tacha, T. C., D. S. Martin, and C. G. Endicott. 1978. Mortality of Sandhill Cranes Associated with Utility Highlines in Texas. Pages 175-176 *in* Proceedings of the 1978 Crane Workshop, Rockport, Texas, USA.

U.S. Department of Agriculture, Farm Service Agency [FSA]. “National Agriculture Imagery Program.” <http://www.fsa.usda.gov/FSA>. Accessed April 10 2009.

U.S. Fish and Wildlife Service [USFWS]. 1981. “Sandhill Cranes.” *The Platte River ecology study special research report.* U.S. Fish and Wildlife Service, Jamestown, ND. Jamestown, ND: Northern Prairie Wildlife Research Center Online. <http://www.npwrc.usgs.gov/resource/habitat/plriveco/index.htm> (Version 16JUL97).

Van Rooyen, C. 2003. The Management of wildlife interactions with overhead power lines. African Centre for Energy and Environment, Eskom. Johannesburg, South Africa.

Ward, J. P. and S. H. Anderson. 1992. Sandhill crane collisions with power lines in south central Nebraska. Pages 189-195 in D. A. Wood, editor; S. A. Nesbitt, and L. E. Jr. Williams, technical co-editors. Proceedings of the 1988 North American Crane Workshop. Florida Game Fresh Water Fish Commission in Nongame Wildlife Program Technical Report 12. River Ranch Outdoor Resort, Lake Wales, Florida, USA.

Wisconsin Department of Natural Resources [WDNR]. In prep. DRAFT Ecological Landscapes of Wisconsin. State of Wisconsin, Department of Natural Resources, Handbook. 1805.1. Madison, Wisconsin, USA. <http://www.dnr.state.wi.us/landscapes/>. Accessed 29 August 2011.

Whooping Crane Eastern Partnership [WCEP]. 2010. “Whooping Crane Numbers-September 30, 2010.“ <http://www.bringbackthecranes.org/recovery/wcrane-nos2010.html>. Accessed 2 Aug 2011.

Yee, M. L. 2008. Testing the effectiveness of an avian flight diverter for reducing avian collisions with distribution power lines in the Sacramento Valley, California. Sacramento, CA: California Energy Commission, PIER Energy-Related Environmental Research Program. CEC-500-2007-122.

APPENDICES

Appendix A. Area (km^2) and proportion of land cover types of 30-m pixels from the reclassified 2001 National Land Cover Dataset (Homer et. al. 2004) in 500 m buffers around power lines within Observation Sites in Briggsville (BV).

		Land Cover										
Obs. Sites in Briggsville		**Open Water**	**Developed, open**	**Developed, Low & High**	**Forest**	**Shrub & Scrub**	**Sedge & Herbaceous**	**Pasture & Hay**	**Row-Crop Agriculture**	**Woody Wetland**	**Emergent Wetland**	**Total**
1	**Area (km^2)**	0	65.7	35.1	498.6	12.6	3.6	393.3	782.1	0	9.9	1800.9
	%	0	4	2	28	1	0	22	43	0	1	100
2	**Area (km^2)**	0	49.5	27.9	75.6	0	5.4	66.6	1385.1	0	59.4	1669.5
	%	0	3	2	5	0	0	4	83	0	4	100
3	**Area (km^2)**	0	50.4	66.6	27.9	0	9.9	214.2	1266.3	9	6.3	1650.6
	%	0	3	4	2	0	1	13	77	1	0	100
4	**Area (km^2)**	0	63	22.5	234	63	25.2	152.1	750.6	0	0	1310.4
	%	0	5	2	18	5	2	12	57	0	0	100
5	**Area (km^2)**	0	92.7	33.3	126	36.9	0	219.6	660.6	0	112.5	1281.6
	%	0	7	3	10	3	0	17	52	0	9	100

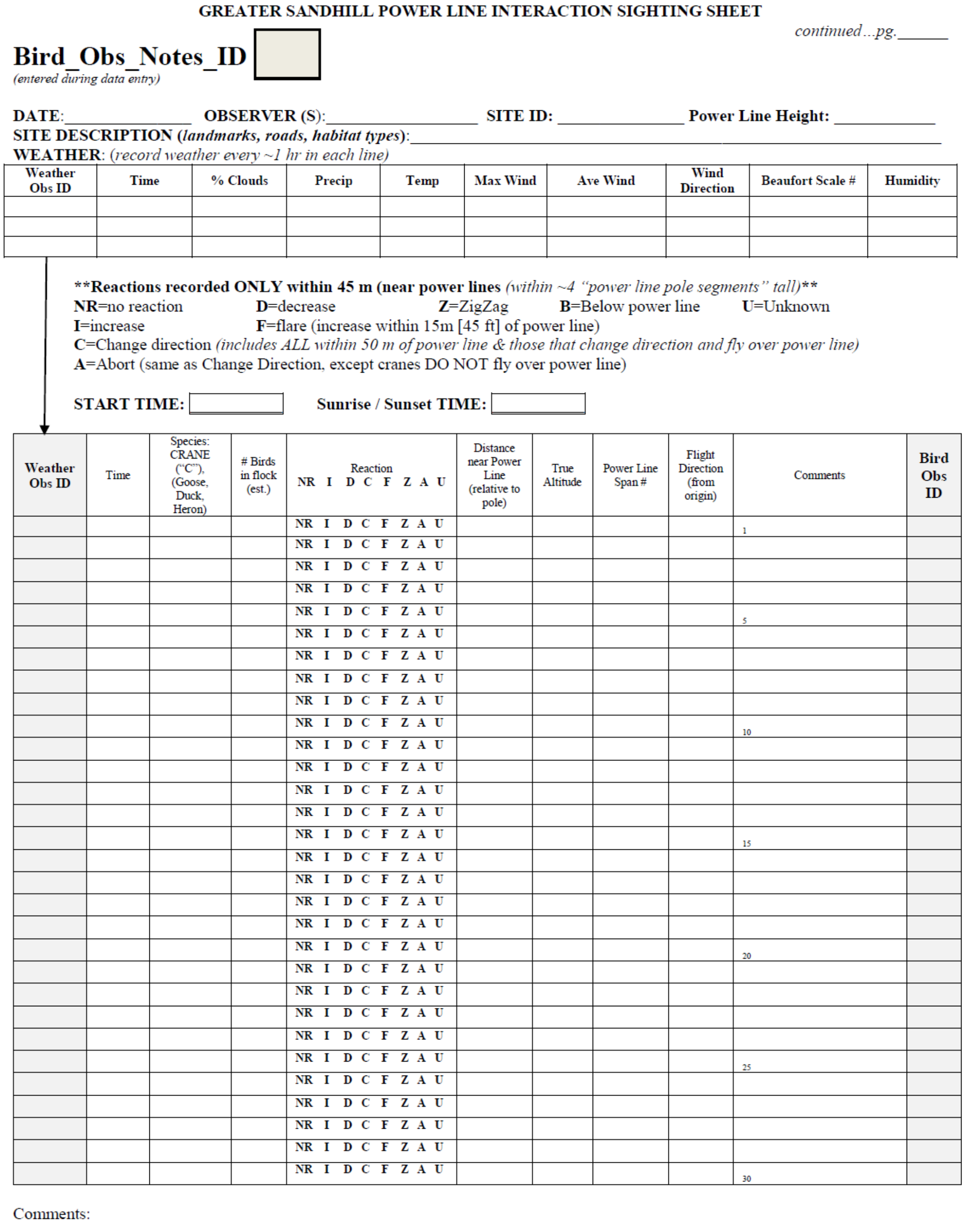
12		11		10		9		8		7		6	
%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)
0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	17.1	3	53.1	4	75.6	5	98.1	6	76.5	8	126	6	90.9
5	57.6	3	43.2	4	79.2	0	9	0	0	1	11.7	2	24.3
16	172.8	8	135	12	207.9	6	133.2	12	156.6	21	309.6	24	355.5
0	3.6	1	21.6	0	3.6	0	0	1	7.2	2	32.4	1	21.6
3	35.1	0	6.3	0	6.3	2	32.4	6	72.9	15	225.9	4	60.3
4	39.6	11	190.8	5	87.3	2	37.8	4	50.4	11	170.1	17	261
14	144.9	63	1051.2	70	1233	74	1530	50	657	37	554.4	38	562.5
10	108	0	0	0	0	2	32.4	4	54	1	14.4	1	16.2
45	480.6	10	164.7	4	74.7	10	198	18	235.8	3	38.7	7	100.8
100	1059.3	100	1665.9	100	1767.6	100	2070.9	100	1310.4	100	1483.2	100	1493.1

Appendix B. Area (km^2) and proportion of land cover types of 30-m pixels from the reclassified 2001 National Land Cover Dataset (Homer et. al. 2004) in 500 m buffers around power lines within Observation Sites in Mud Lake (ML).

		Land Cover										
Obs. Sites in Mud Lake		**Open Water**	**Developed-open**	**Developed-Low & High**	**Forest**	**Shrub & Scrub**	**Sedge & Herbaceous**	**Pasture & Hay**	**Row-Crop Agriculture**	**Woody Wetland**	**Emergent Wetland**	**Total**
13	**Area (km^2)**	0	84.6	5.4	150.3	8.1	19.8	76.5	1355.4	55.8	16.2	**1772.1**
	%	0	5	0	8	0	1	4	76	3	1	**100**
14	**Area (km^2)**	0	71.1	20.7	26.1	0	0	135.9	874.8	0	50.4	**1179**
	%	0	6	2	2	0	0	12	74	0	4	**100**
15	**Area (km^2)**	0	37.8	54.9	49.5	0	5.4	129.6	1458.9	0	19.8	**1755.9**
	%	0	2	3	3	0	0	7	83	0	1	**100**
16	**Area (km^2)**	0	13.5	57.6	98.1	4.5	10.8	111.6	971.1	0	4.5	**1271.7**
	%	0	1	5	8	0	1	9	76	0	0	**100**
17	**Area (km^2)**	0	12.6	38.7	27	8.1	0	503.1	644.4	7.2	24.3	**1265.4**
	%	0	1	3	2	1	0	40	51	1	2	**100**

24		23		22		21		20		19		18	
%	**Area (km^2)**	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**	**Area (km^2)**	**%**	**Area (km^2)**
0	0	7	86.4	0	0	0	3.6	0	0	0	0	0	0
5	81	2	23.4	2	30.6	6	81	7	92.7	9	128.7	0	1.8
0	3.6	4	49.5	1	23.4	1	14.4	1	9.9	0	4.5	4	49.5
2	32.4	1	17.1	8	152.1	5	69.3	2	27	8	118.8	3	36
0	2.7	0	0.9	2	45	2	28.8	1	7.2	0	0	1	8.1
0	0	0	4.5	0	7.2	0	2.7	0	0	1	9	0	0
2	36	23	298.8	16	317.7	18	240.3	16	204.3	18	271.8	20	279
59	884.7	22	279.9	53	1036.8	45	615.6	65	833.4	59	873	58	810.9
9	139.5	11	141.3	6	118.8	2	28.8	2	29.7	2	36.9	4	62.1
22	331.2	30	380.7	12	228.6	21	285.3	6	80.1	2	35.1	11	155.7
100	**1511.1**	**100**	**1282.5**	**100**	**1960.2**	**100**	**1369.8**	**100**	**1284.3**	**100**	**1477.8**	**100**	**1403.1**

Appendix C. Crane Observation Flight Survey Sheet



GREATER SANDHILL POWER LINE INTERACTION SIGHTING SHEET

continued…pg.______

Bird_Obs_Notes_ID ☐
(entered during data entry)

DATE:______________ **OBSERVER (S)**:_________________ **SITE ID:** ______________ **Power Line Height:** ____________
SITE DESCRIPTION (***landmarks, roads, habitat types***):____
WEATHER: *(record weather every ~1 hr in each line)*

Weather Obs ID	Time	% Clouds	Precip	Temp	Max Wind	Ave Wind	Wind Direction	Beaufort Scale #	Humidity

****Reactions recorded ONLY within 45 m (near power lines** *(within ~4 "power line pole segments" tall)*****
NR=no reaction **D**=decrease **Z**=ZigZag **B**=Below power line **U**=Unknown
I=increase **F**=flare (increase within 15m [45 ft] of power line)
C=Change direction *(includes ALL within 50 m of power line & those that change direction and fly over power line)*
A=Abort (same as Change Direction, except cranes DO NOT fly over power line)

START TIME: ☐ **Sunrise / Sunset TIME:** ☐

Weather Obs ID	Time	Species: CRANE ("C"), (Goose, Duck, Heron)	# Birds in flock (est.)	Reaction NR I D C F Z A U	Distance near Power Line (relative to pole)	True Altitude	Power Line Span #	Flight Direction (from origin)	Comments	Bird Obs ID
				NR I D C F Z A U					1	
				NR I D C F Z A U						
				NR I D C F Z A U						
				NR I D C F Z A U						
				NR I D C F Z A U					5	
				NR I D C F Z A U						
				NR I D C F Z A U						
				NR I D C F Z A U						
				NR I D C F Z A U						
				NR I D C F Z A U					10	
				NR I D C F Z A U						
				NR I D C F Z A U						
				NR I D C F Z A U						
				NR I D C F Z A U						
				NR I D C F Z A U					15	
				NR I D C F Z A U						
				NR I D C F Z A U						
				NR I D C F Z A U						
				NR I D C F Z A U						
				NR I D C F Z A U					20	
				NR I D C F Z A U						
				NR I D C F Z A U						
				NR I D C F Z A U						
				NR I D C F Z A U						
				NR I D C F Z A U					25	
				NR I D C F Z A U						
				NR I D C F Z A U						
				NR I D C F Z A U						
				NR I D C F Z A U						
				NR I D C F Z A U					30	

Comments:

Appendix D. List of Observation Sites visited, ordered by date. Seasons are seperated with tables highlighted in light grey.

Observation Date	Season	Observation Site	Time of Day	Weather	Abrupt	Gradual	Unaltered	Total Reactions
7/3/2009	Early Summer	ML-18	PM	Clear	2	1	0	3
7/3/2009		ML-22	AM	Clear	0	0	0	0[a]
7/4/2009		ML-15	AM	Fog/Rain	2	1	3	6
7/5/2009		BV-8	PM	Clear	0	0	0	0[a]
7/6/2009		BV-3	AM	Fog/Rain	2	0	0	2
				Clear	1	0	0	1
7/6/2009		BV-10	PM	Clear	2	0	1	3
7/7/2009		BV-12	AM	Fog/Rain	0	0	0	0[a]
7/12/2009		ML-23	PM	Clear	0	0	0	0[a]
7/13/2009[c]		ML-16	AM	Fog/Rain	1	0	1	2
				Clear	0	0	0	0[a]
7/13/2009[c]		ML-19	PM	Clear	0	0	0	0[a]
7/14/2009		ML-20	AM	Clear	0	0	0	0[a]
7/16/2009		BV-1	AM	Fog/Rain	1	6	1	8
				Clear	1	1	0	2
7/20/2009		BV-2	PM	Clear	0	0	0	0[a]
7/20/2009		BV-6	AM	Fog/Rain	0	0	0	0[a]
				Clear	0	0	0	0[a]
7/21/2009		BV-5	AM	Fog/Rain	0	0	0	0[a]
				Clear	0	0	0	0[a]
7/26/2009		ML-13	PM	Fog/Rain	0	0	2	2
				Clear	0	0	0	0[a]
7/27/2009		ML-14	AM	Fog/Rain	0	0	0	0[a]
7/27/2009		ML-17	PM	Fog/Rain	1	1	0	2
7/30/2009[c]		ML-21	AM	Fog/Rain	0	8	22	30
7/31/2009		ML-24	AM	Fog/Rain	0	0	0	0[a]
				Clear	0	0	0	0[a]
8/3/2009		BV-4	PM	Clear	0	0	0	0[a]
8/3/2009[c]		BV-11	AM	Fog/Rain	0	0	0	0[a]
				Clear	0	0	0	0[a]
8/4/2009		BV-9	AM	Fog/Rain	0	0	0	0[a]
				Clear	0	0	0	0[a]

8/5/2009		BV-7	PM	Clear	6	12	0	18
8/21/2009	Late Summer	BV-2	AM	Fog/Rain	0	0	1	1
8/21/2009		BV-9	PM	Clear	1	0	0	1
8/22/2009		BV-1	AM	Clear	0	0	0	0 [a]
8/22/2009		BV-5	PM	Clear	0	0	0	0 [a]
8/28/2009		ML-23	AM	Clear	1	0	0	1
8/30/2009		ML-14	AM	Clear	0	0	1	1
8/31/2009		ML-18	AM	Fog/Rain	1	0	1	2
				Clear	0	0	0	0 [a]
8/31/2009		ML-24	PM	Fog/Rain	0	0	0	0 [a]
				Clear	0	0	0	0 [a]
9/5/2009		BV-6	PM	Clear	0	0	0	0 [a]
9/5/2009		BV-8	AM	Fog/Rain	0	0	0	0 [a]
				Clear	0	1	0	1
9/6/2009		BV-3	PM	Fog/Rain	0	0	0	0 [a]
				Clear	0	3	2	5
9/6/2009		BV-12	AM	Fog/Rain	0	0	0	0 [a]
9/12/2009		ML-17	PM	Clear	0	0	0	0 [a]
9/13/2009		ML-22	AM	Fog/Rain	1	0	3	4
				Clear	0	0	0	0 [a]
9/19/2009		BV-10	AM	Fog/Rain	0	0	0	0 [a]
				Clear	0	0	0	0 [a]
9/20/2009		ML-13	PM	Fog/Rain	0	0	0	0 [a]
				Clear	0	3	4	7
9/20/2009		ML-20	AM	Fog/Rain	0	0	1	1
9/27/2009		ML-15	AM	Fog/Rain	0	0	0	0 [a]
				Clear	0	0	0	0 [a]
10/2/2009		BV-4	PM	Fog/Rain	1	2	1	4
10/3/2009		BV-7	AM	Clear	0	0	2	2
10/4/2009 [c]		ML-19	na	na	na	na	na	na [b]
10/4/2009 [c]		ML-21	na	na	na	na	na	na [b]
10/5/2009 [c]		ML-16	na	na	na	na	na	na [b]
10/6/2009 [c]		BV-11	na	na	na	na	na	na [b]
10/16/2009	Migration: BV	BV-12	PM	Clear	3	11	6	20
10/17/2009		BV-3	PM	Clear	2	4	23	29
10/17/2009		BV-10	AM	Clear	2	4	12	18
10/23/2009 [c]		BV-11	PM	Fog/Rain	0	0	0	0 [a]
				Clear	0	0	0	0 [a]
10/24/2009		BV-1	PM	Clear	0	2	1	3
10/24/2009		BV-9	AM	Clear	1	3	4	8

10/26/2009		BV-4	AM	Clear	13	31	11	55
10/28/2009		BV-5	AM	Fog/Rain	0	0	0	0 [a]
10/30/2009		BV-7	PM	Clear	0	1	4	5
10/31/2009		BV-6	PM	Clear	0	0	0	0 [a]
10/31/2009		BV-8	AM	Fog/Rain	0	1	1	2
				Clear	0	0	0	0 [a]
11/6/2009		BV-2	AM	Clear	0	0	0	0 [a]
3/20/2010	Migration: ML	ML-17	AM	Clear	3	31	14	48
3/20/2010		ML-23	PM	Fog/Rain	0	0	0	0 [a]
				Clear	0	0	0	0 [a]
3/21/2010 [c]		ML-19	PM	Clear	1	0	0	1
3/27/2010		ML-14	AM	Clear	0	0	0	0 [a]
3/28/2010		ML-18	AM	Clear	1	39	9	49
4/3/2010		ML-20	PM	Clear	0	0	0	0 [a]
4/3/2010		ML-22	PM	Clear	0	2	0	2
4/4/2010		ML-13	AM	Clear	0	1	1	2
4/9/2010 [c]		ML-16	AM	Clear	0	0	0	0 [a]
4/9/2010 [c]		ML-21	PM	Clear	0	0	0	0 [a]
4/10/2010		ML-15	PM	Clear	0	0	1	1
4/11/2010		ML-24	AM	Clear	0	0	0	0 [a]
				Total	50	169	**133**	**352**

[a] No crane reactions were observed, but cranes were present within 500 m of the observed power line

[b] Missed visiting Observation Site due to car accident

[c] Data collected at these Observation Sites were removed to reduce effects of confounding effects of season

Appendix E. List of Observation Sites visited, ordered by Observation Site. Observation Periods with two weather types are seperated highlighted with light grey.

Obs. Date	Season	Obs. Site	Time of Day	Weather	Abrupt	Gradual	Unaltered	Total Reactions
7/16/2009	Summer 1	BV-1	AM	Fog/Rain	1	6	1	8
				Clear	1	1	0	2
8/22/2009	Summer 2	BV-1	AM	Clear	0	0	0	0[a]
10/24/2009	Migration: BV	BV-1	PM	Clear	0	2	1	3
7/20/2009	Summer 1	BV-2	PM	Clear	0	0	0	0[a]
8/21/2009	Summer 2	BV-2	AM	Fog/Rain	0	0	1	1
11/6/2009	Migration: BV	BV-2	AM	Clear	0	0	0	0[a]
7/6/2009	Summer 1	BV-3	AM	Fog/Rain	2	0	0	2
				Clear	1	0	0	1
9/6/2009	Summer 2	BV-3	PM	Fog/Rain	0	0	0	0[a]
				Clear	0	3	2	5
10/17/2009	Migration: BV	BV-3	PM	Clear	2	4	23	29
8/3/2009	Summer 1	BV-4	PM	Clear	0	0	0	0[a]
10/2/2009	Summer 2	BV-4	PM	Fog/Rain	1	2	1	4
10/26/2009	Migration: BV	BV-4	AM	Clear	13	31	11	55
7/21/2009	Summer 1	BV-5	AM	Fog/Rain	0	0	0	0[a]
				Clear	0	0	0	0[a]
8/22/2009	Summer 2	BV-5	PM	Clear	0	0	0	0[a]
10/28/2009	Migration: BV	BV-5	AM	Fog/Rain	0	0	0	0[a]
7/20/2009	Summer 1	BV-6	AM	Fog/Rain	0	0	0	0[a]
				Clear	0	0	0	0[a]
9/5/2009	Summer 2	BV-6	PM	Clear	0	0	0	0[a]
10/31/2009	Migration: BV	BV-6	PM	Clear	0	0	0	0[a]
8/5/2009	Summer 1	BV-7	PM	Clear	6	12	0	18
10/3/2009	Summer 2	BV-7	AM	Clear	0	0	2	2
10/30/2009	Migration: BV	BV-7	PM	Clear	0	1	4	5
7/5/2009	Summer 1	BV-8	PM	Clear	0	0	0	0[a]
9/5/2009	Summer 2	BV-8	AM	Fog/Rain	0	0	0	0[a]
				Clear	0	1	0	1
10/31/2009	Migration: BV	BV-8	AM	Fog/Rain	0	1	1	2
				Clear	0	0	0	0[a]

8/4/2009	Summer 1	BV-9	AM	Fog/Rain	0	0	0	0[a]
				Clear	0	0	0	0[a]
8/21/2009	Summer 2	BV-9	PM	Clear	1	0	0	1
10/24/2009	Migration: BV	BV-9	AM	Clear	1	3	4	8
7/6/2009	Summer 1	BV-10	PM	Clear	2	0	1	3
9/19/2009	Summer 2	BV-10	AM	Fog/Rain	0	0	0	0[a]
				Clear	0	0	0	0[a]
10/17/2009	Migration: BV	BV-10	AM	Clear	2	4	12	18
8/3/2009[c]	Summer 1	BV-11	AM	Fog/Rain	0	0	0	0[a]
				Clear	0	0	0	0[a]
10/6/2009[c]	Summer 2	BV-11	na	Na	na	na	na	na[b]
10/23/2009[c]	Migration: BV	BV-11	PM	Fog/Rain	0	0	0	0[a]
				Clear	0	0	0	0[a]
7/7/2009	Summer 1	BV-12	AM	Fog/Rain	0	0	0	0[a]
9/6/2009	Summer 2	BV-12	AM	Fog/Rain	0	0	0	0[a]
10/16/2009	Migration: BV	BV-12	PM	Clear	3	11	6	20
7/26/2009	Summer 1	ML-13	PM	Fog/Rain	0	0	2	2
				Clear	0	0	0	0[a]
9/20/2009	Summer 2	ML-13	PM	Fog/Rain	0	0	0	0[a]
				Clear	0	3	4	7
4/4/2010	Migration: ML	ML-13	AM	Clear	0	1	1	2
7/27/2009	Summer 1	ML-14	AM	Fog/Rain	0	0	0	0[a]
8/30/2009	Summer 2	ML-14	AM	Clear	0	0	1	1
3/27/2010	Migration: ML	ML-14	AM	Clear	0	0	0	0[a]
7/4/2009	Summer 1	ML-15	AM	Fog/Rain	2	1	3	6
9/27/2009	Summer 2	ML-15	AM	Fog/Rain	0	0	0	0[a]
				Clear	0	0	0	0[a]
4/10/2010	Migration: ML	ML-15	PM	Clear	0	0	1	1
7/13/2009[c]	Summer 1	ML-16	AM	Fog/Rain	1	0	1	2
				Clear	0	0	0	0[a]
10/5/2009[c]	Summer 2	ML-16	na	Na	na	na	na	na[b]
4/9/2010[c]	Migration: ML	ML-16	AM	Clear	0	0	0	0[a]
7/27/2009	Summer 1	ML-17	PM	Fog/Rain	1	1	0	2
9/12/2009	Summer 2	ML-17	PM	Clear	0	0	0	0[a]
3/20/2010	Migration: ML	ML-17	AM	Clear	3	31	14	48
7/3/2009	Summer 1	ML-18	PM	Clear	2	1	0	3
8/31/2009	Summer 2	ML-18	AM	Fog/Rain	1	0	1	2
				Clear	0	0	0	0[a]
3/28/2010	Migration: ML	ML-18	AM	Clear	1	39	9	49
7/13/2009[c]	Summer 1	ML-19	PM	Clear	0	0	0	0[a]

10/4/2009[c]	Summer 2	ML-19	na	Na	na	na	na	na[b]
3/21/2010[c]	Migration: ML	ML-19	PM	Clear	1	0	0	1
7/14/2009	Summer 1	ML-20	AM	Clear	0	0	0	0[a]
9/20/2009	Summer 2	ML-20	AM	Fog/Rain	0	0	1	1
4/3/2010	Migration: ML	ML-20	PM	Clear	0	0	0	0[a]
7/30/2009[c]	Summer 1	ML-21	AM	Fog/Rain	0	8	22	30
10/4/2009[c]	Summer 2	ML-21	na	Na	na	na	na	na[b]
4/9/2010[c]	Migration: ML	ML-21	PM	Clear	0	0	0	0[a]
7/3/2009	Summer 1	ML-22	AM	Clear	0	0	0	0[a]
9/13/2009	Summer 2	ML-22	AM	Fog/Rain	1	0	3	4
				Clear	0	0	0	0[a]
4/3/2010	Migration: ML	ML-22	PM	Clear	0	2	0	2
7/12/2009	Summer 1	ML-23	PM	Clear	0	0	0	0[a]
8/28/2009	Summer 2	ML-23	AM	Clear	1	0	0	1
3/20/2010	Migration: ML	ML-23	PM	Fog/Rain	0	0	0	0[a]
				Clear	0	0	0	0[a]
7/31/2009	Summer 1	ML-24	AM	Fog/Rain	0	0	0	0[a]
				Clear	0	0	0	0[a]
8/31/2009	Summer 2	ML-24	PM	Fog/Rain	0	0	0	0[a]
				Clear	0	0	0	0[a]
4/11/2010	Migration: ML	ML-24	AM	Clear	0	0	0	0[a]
				Total	50	16	**13**	**352**

[a] No crane reactions were observed, but cranes were present within 500 m of the observed power line

[b] Missed visiting Observation Site due to car accident

[c] Data collected at these Observation Sites were removed to reduce effects of confounding effects of season

Appendix F. Count of unaltered reactions of cranes that flew above the Collision Risk Zone (22.4 m above power lines) that were removed from the ALTERED model to create the ABRUPT model.

			Study Area		
Season	**Weather**	**Time of Day**	**Briggsville**	**Mud Lake**	
Summer	Clear	AM	0	0	
		PM	3	4	
	Fog/Rain	AM	2	8	
		PM	1	2	
Migration	Clear	AM	11	24	
		PM	14	1	
	Fog/Rain	AM	0	0	
		PM	0	0	
		Total	**31**	**39**	**70**

Appendix G.1. Raw count of crane reactions, standardized by sampling effort, and sampling effort spent observing cranes around power lines, grouped by Study Area.

Contingency tables of crane reactions binned by categorical predictor with X^2 tests

	Study Area		
Flight Behavior	**BV**	**ML**	**Total**
Abrupt	36	12	48
Gradual	82	79	161
Unaltered	70	40	110
Total	188	131	319

X^2 = 10.38, df = 2, p-value = 0.006

Number of crane reactions per Observation Period (2.25 hrs)

	Study Area	
Flight Behavior	**BV**	**ML**
Abrupt	36/33 = 1.1	12/27 = 0.4
Gradual	82/33 = 2.5	79/27 = 2.9
Unaltered	70/33 = 2.1	40/27 = 1.5
Total	188/33 = 5.7	131/27 = 4.9

Number of Observation Periods

Study Area	No. Obs. Periods	Total hrs.
BV	33	74.25
ML	27	60.75

Appendix G.2. Raw count of crane reactions, standardized by sampling effort, and sampling effort spent observing cranes around power lines, grouped by season.

Contingency tables of crane reactions binned by categorical predictor with X^2 tests			
	Season		
Flight Behavior	**Migration**	**Summer**	**Total**
Abrupt	25	23	48
Gradual	130	31	161
Unaltered	87	23	110
Total	242	77	319

X^2 = 17.54, df = 2, p-value = 0.0002

Number of crane reactions per Observation Period (2.25 hrs)		
	Season	
Flight Behavior	**Migration**	**Summer**
Abrupt	25/20 =1.3	23/40 =0.6
Gradual	130/20 =6.5	31/40 =0.8
Unaltered	87/20 =4.4	23/40 0.6
Total	242/20 =12.1	77/40 =1.9

Number of Observation Periods		
Season	**No. Obs. Periods**	**Total hrs.**
Migration	20	45
Summer	40	90

Appendix G.3. Raw count of crane reactions, standardized by sampling effort, and sampling effort spent observing cranes around power lines, grouped by Weather condition.

Contingency tables of crane reactions binned by categorical predictor with X^2 tests

	Weather		
Flight Behavior	**Clear**	**Fog/Rain**	**Total**
Abrupt	39	9	48
Gradual	150	11	161
Unaltered	96	14	110
Total	285	34	319

X^2 = 6.27, df = 2, p-value = 0.044

Number of crane reactions per Observation Period (2.25 hrs)

	Weather	
Flight Behavior	**Clear**	**Fog/Rain**
Abrupt	39/42.5 =0.9	9/17.5 =0.5
Gradual	150/42.5 =3.5	11/17.5 =0.6
Unaltered	96/42.5= 2.3	14/17/5 =0.8
Total	285/42.5= 6.7	34/17.5 =1.9

Number of Observation Periods

Weather	**No. Obs. Periods**	**No. 1/2 Obs. Period**	**Total hrs.**
Clear	34	17	95.63
Fog/ Clear	9	17	39.38

Appendix G.4 Raw count of crane reactions, standardized by sampling effort, and sampling effort spent observing cranes around power lines, grouped by time of day. “AM” represents Observations Periods beginning 15 minutes before dawn and two hours after. “PM” represents Observation Periods beginning two hours before dusk and 15 minutes after.

Contingency tables of crane reactions binned by categorical predictor with X^2 tests

	Time of Day		
Flight Behavior	**AM**	**PM**	**Total**
Abrupt	30	18	48
Gradual	119	42	161
Unaltered	65	45	110
Total	214	105	319

X^2 = 7.04, df = 2, p-value = 0.030

Number of crane reactions per Observation Period (2.25 hrs)

	Time of Day	
Flight Behavior	**AM**	**PM**
Abrupt	30/34 =0.9	18/26= 0.7
Gradual	119/34 = 3.5	42/26 = 1.6
Unaltered	65/34= 1.9	45/26= 1.7
Total	214/34 =6.3	105/26= 4.0

Number of Observation Periods

Time of Day	**No. Obs. Periods**	**Total hrs.**
AM	**34**	**76.5**
PM	**26**	**58.5**

Appendix H. Results of Pearson's correlation coefficient used to calculate collinearity between continuous predictor variables in ALTERED model. Only predictors that were significant for ALTERED_bin (altered or unaltered flight behavior) were included in tests. Sample sizes were 319 for all tests.

	Flight Altitude	**Percent Clouds**	**Relative Percent Humidity**	**Proportion Agriculture (500 m)[a]**	**Proportion Row-Crop (500 m)[a]**	**Proportion Pasture/Hay (500 m)[a]**	**Distance to Forest**
Flight Altitude	1	0.165	-0.22	-0.124	0.063	-0.221	0.154
Percent Clouds	0.165	1	0.222	0.317	0.056	0.316	-0.043
Relative Percent Humidity	-0.22	0.222	1	0.154	-0.013	0.201	-0.087
Proportion Agriculture (500 m)[a]	-0.124	0.317	0.154	1	0.637	0.471	0.408
Proportion Row-Crop (500 m)[a]	0.063	0.056	-0.013	0.637	1	-0.38	0.545
Proportion Pasture/Hay (500 m)[a]	-0.221	0.316	0.201	0.471	-0.38	1	-0.134
Distance to Forest	0.154	-0.043	-0.087	0.408	0.545	-0.134	1

[a] Proportion land cover type calculated within a 500 m buffer around Site Spans

Appendix I. Results of Wilcoxon Rank Sum Test used to calculate collinearity between Time of Day (AM or PM) and continuous predictor variables in ALTERED model. Only predictors that were significant for ALTERED_bin (altered or unaltered flight behavior) were included in tests. Sample sizes were 319 for all tests.

	Flight Altitude	**Percent Clouds**	**Relative Percent Humidity**	**Proportion Agriculture (500 m)[c]**	**Proportion Row-Crop (500 m)[c]**	**Proportion Pasture/Hay (500 m)[c]**	**Distance to Forest**
Time of Day	**W= 9053, p =0.004**	W = 10930.5, p = 0.688	**W = 16732, p < 0.001**	**W = 14787.5, p < 0.001**	W = 12495, p = 0.103	**W = 14254.5, p < 0.001**	W = 10609.5, p = 0.419

[a] Bold font indicates variables with p-value < 0.01

Appendix J. Results of ALTERED logistic regression model to predict ALTERED_bin (altered or unaltered flight behavior).

ALTERED Model Name	**Predictors**	**N**	**AIC**	**ΔAIC**	**AIC weight**	**Test against Model 1**	**Test against Model 1**	**AUC**	**Pseudo R^2**
1	*altitude*	319	332.43	11.64	0.0030	-		80.9	0.315
2-Full	*altitude + %clouds + %humidity + %ag(500) + distforest*	319	324.45	3.66	0.1604	15.98, df=4	0.003	82.2	0.367
2-Reduced	***altitude + %ag(500)***	**319**	**321.52**	**0.73**	**0.6942**	**12.91, df=1**	**< 0.001**	**81.9**	**0.357**
3-Full	*altitude + %clouds + %humidity + %row-crop(500) + %pasture(500) + distforest*	319	324.37	3.58	0.1670	18.06, df=5	0.00	82.1	0.373
3-Reduced	***altitude + %row-crop(500) + %pasture(500)***	**319**	**320.79**	**0**	**1.0**	**15.65, df=2**	**< 0.001**	**81.9**	**0.366**
4	*day + %clouds + %row-crop(500) + distforest*	319	386.72	65.93	0.0000	34.27, df=4[a]	< 0.001[a]	68.9	0.141

[a] Maximum likelihood estimation test used the null model (coefficient = 1; with no predictors) to test against Model 4

Appendix K. Model coefficients and equations for the ALTERED model 1 (only flight altitude) compared with the two best ALTERED models ranked by AIC weight of the ALTERED model 1. Sample size for each model was 319. Odds ratios were calculated by taking the exponent of the natural log of the slope (***β***) estimate of the natural log of the odds ratio. Model equations predict the probability of a crane altering its flight behavior around a power line given the predictor variables.

ALTERED Model Name	**Final Model Equation for Predicting Probability of ALTERED Flight Behavior**	**Predictors**	***β*** **Estimate**	**[Log(Odds Ratio)] , (95% Conf. Interval)**	**Std. Error of *β* Estimate**	**Odds Ratio,**	**(95% Conf. Interval)**	**Z-value**	**Wald test p-value**
1	$= (1 + e^{-\begin{bmatrix} 2.55 \\ -1.28 * Altitude \end{bmatrix}})^{-1}$	*(Intercept)*	2.55	(2.01, 3.13)	0.29	12.80	(7.49, 22.95)	8.94	< 0.0001
		Altitude	-1.28	(-1.62, -0.98)	0.16	0.28	(0.20, 0.38)	-7.85	< 0.0001
2-reduced	$= (1 + e^{-\begin{bmatrix} 4.98 \\ -1.42 * Altitude \\ -2.7 * \%Ag500 \end{bmatrix}})^{-1}$	*(Intercept)*	4.98	(3.4, 6.7)	0.82	146.13	(32.11, 814.52)	6.07	< 0.0001
		Altitude	-1.42	(-1.78, -1.09)	0.18	0.24	(0.17, 0.34)	-8.08	< 0.0001
		% Ag.(500m)	-2.70	(-4.36, -1.18)	0.81	0.07	(0.01, 0.31)	-3.34	0.0008
3-reduced	$= (1 + e^{-\begin{bmatrix} 5.05 \\ -1.37 * Altitude \\ -3.29 * \%Row \\ -Crop500 \\ -1.77 * \%Pasture500 \end{bmatrix}})^{-1}$	*(Intercept)*	5.05	(3.53, 6.79)	0.83	156.52	(33.97, 887.08)	6.09	< 0.0001
		Altitude	-1.37	(-1.73, -1.04)	0.18	0.25	(0.18, 0.35)	-7.77	< 0.0001
		% Row-Crop(500m)	-3.29	(-5.12, -1.61)	0.89	0.04	(0.01, 0.20)	-3.68	0.0002
		%Past(500m	-1.77	(-3.76, 0.18)	1.00	0.17	(0.02, 1.19)	-1.77	0.077

Appendix L. Results of Pearson's correlation coefficient used to calculate collinearity between continuous predictor variables in ABRUPT model. Only predictors that were significant for ABRUPT_bin (gradual or abrupt flight behaviors) were included in tests. Sample sizes were 191 for all tests.

	Flight Altitude	**Flock Size**	**Temperature**	**Proportion Pasture/Hay (500 m)[a]**	**Distance to Forest**
Flight Altitude	1	0.165	-0.22	-0.221	0.154
Flock Size	0.165	1	0.222	0.316	-0.043
Temperature	-0.22	0.222	1	0.201	-0.087
Proportion Pasture/Hay (500 m)[a]	-0.124	0.317	0.154	0.471	0.408
Distance to Forest	0.154	-0.043	-0.087	-0.134	1

[a] Proportion land cover type calculated within a 500 m buffer around Site Spans

Appendix M. Results of Wilcoxon Rank Sum Test used to calculate collinearity between Season (Summer or Migration), Study Area (ML or BV), and Time of Day (AM or PM) and continuous predictor variables in ABRUPT model. Only predictors that were significant for ABRUPT_bin (gradual or abrupt flight behaviors) were included in tests. Sample sizes were 191 for all tests.

	Season	**Time of Day**	**Study Area**
Flight Altitude [a]	**W = 4736, p = 0.002**	W = 3779, p = 0.441	W = 3838, p = 0.057
Flock Size	W = 4037.5, p = 0.309	W = 3316, p = 0.521	W = 4570.5, p = 0.957
Temperature	**W = 0, p < 0.001**	**W = 950, p < 0.001**	**W = 7805, p < 0.001**
Proportion Pasture/Hay (500 m)[c]	W = 4310, p = 0.076	**W = 5124, p < 0.001**	**W = 1219.5, p < 0.001**
Distance to Forest	W = 3583.5, p = 0.738	W = 3329, p = 0.560	**W = 5554, p = 0.008**
Season	1	**OR[b]=14.67,** **95% CI: (6.47, 35.06),** **p < 0.001**	**OR[b]=0.27,** **95% CI: (0.13, 0.57),** **p = 0.0002**
Time of Day	**OR[b]=14.67,** **95% CI: (6.47, 35.06),** **p < 0.001**	1	**OR[b]=0.19,** **95% CI: (0.08, 0.42),** **p < 0.001**
Study Area	**OR[b]=0.27,** **95% CI: (0.13, 0.57),** **p = 0.0002**	**OR[b]=0.19,** **95% CI: (0.08, 0.42),** **p < 0.001**	**1**

[a] Bold font indicates variables with p < 0.01

[b] "OR" represents the odds ratio test statistic for Fisher's exact test

[c] Proportion land cover type calculated within a 500 m buffer around Site Spans

Appendix N. Results of ABRUPT logistic regression model to predict ABRUPT_bin (gradual or abrupt flight behavior). Sample size for each model was 191.

Model Name	**Predictors**	**N**	**AIC**	**ΔAIC**	**AIC weight**	**Test against Model 1 (X^2)**	**Test against Model 1 (p-value)**	**ROC**	**Pseudo R^2**
1	*altitude*	191	203.02	19.3	0.0001	-	-	0.657	0.073
2-full	*altitude + flock + temp + %pasture(500) + distforest*	191	185.27	1.57	0.4561	25.75, df=4	<0.001	0.767	0.254
2-reduced	***altitude + flock + temp + distforest***	**191**	**183.7**	**0**	**1.0**	**25.32, df=3**	**<0.001**	**0.768**	**0.251**
3-full	*altitude +flock + distforest + day*	191	194.65	10.9	0.0042	14.37, df=3	0.002	0.719	0.177
4-Full	*altitude + flock + studyarea*	191	193.11	9.41	0.0091	13.91, df=2	<0.001	0.732	0.174
5-Full	*flock + %pasture(500) + distforest + season*	191	188.35	4.65	0.0978	23.91, df=3 [a]	<0.001 [a]	0.75	0.22
5-Reduced	***flock + distforest + season***	**191**	**186.9**	**3.2**	**0.2019**	**18.86, df=2 [a]**	**<0.001 [a]**	**0.739**	**0.208**

[a] Maximum likelihood estimation test used the null model (coefficient = 1; with no predictors) to test against Model 4

Appendix O. Model coefficients and equations for the ABRUPT model 1 compared with the two best ABRUPT models ranked by AIC weight. Odds ratios were calculated by taking the exponent of the natural log of the odds ratio. Model equations predict the probability of abrupt reactions, given the predictor variables. Sample size for each model was 191.

ABRUPT Model Name	Final Model Equation for Predicting Probability of ABRUPT Flight Behavior	Predictors	*β* Estimate [Log(Odds Ratio)] ,	(95% Conf. Interval)	Std. Error of *β* Estimate	Odds Ratio,	(95% Conf. Interval)	Z-value	Wald test p-value
1	$= (1 + e^{-\begin{bmatrix} -0.35 \\ -1.05*Altitude \end{bmatrix}})^{-1}$	*(Intercept)*	-0.35	(-0.97, 0.26)	0.31	0.70	(0.38, 0.35)	-1.13	0.257
		Altitude	-1.05	(-1.80, -0.37)	0.37	0.35	(0.16, 0.69)	-2.89	0.004
2-reduced	$= (1 + e^{-\begin{bmatrix} -3.33 \\ -0.77*Altitude \\ -0.7*LN(flock) \\ +0.05*Temp \\ +0.004*DistForest \end{bmatrix}})^{-1}$	*(Intercept)*	-3.33	(-5.23, -1.56)	0.93	0.04	(0.01, 0.21)	-3.58	0.0003
		Altitude	-0.77	(-1.57, -0.03)	0.39	0.46	(0.21, 0.97)	-1.97	0.049
		LN(Flock)	-0.70	(-1.38, -0.072)	0.33	0.50	(0.25, 0.93)	-2.10	0.035
		Temp.	0.05	(0.02, 0.07)	0.01	1.05	(1.02, 1.08)	3.59	0.0003
		DistForest	0.004	(0.001, 0.01)	0.002	1.004	(1.001, 1.01)	2.25	0.024
5-reduced	$= (1 + e^{-\begin{bmatrix} -0.88-0.76*LN(flock) \\ +0.005*DistForest \\ -1.41*Season \end{bmatrix}})^{-1}$	*(Intercept)*	-0.88	(-2.06, 0.28)	0.59	0.42	(0.13, 1.32)	-1.48	0.138
		LN(Flock)	-0.76	(-1.43, -0.14)	0.33	0.47	(0.24, 0.87)	-2.33	0.020
		DistForest	0.005	(0.002, 0.008)	0.002	1.005	(1.002, 1.01)	2.87	0.004
		Season[a]	-1.41	(-2.18, -0.67)	0.38	0.24	(0.11, 0.51)	-3.69	0.0002

[a] Season is represented by Summer=0 Migration=1

Appendix P. Observation of crane flocks that flew under power lines.

	Crane Flock 1[a]	Crane Flock 2	Crane Flock 3	Crane Flock 4	Crane Flock 5
Altitude (m)	-5.6	-2.8	-5.6	-5.6	-5.6
Reactions	Abrupt (*flare*)	Abrupt (*flare*)	Gradual (*decrease*)	Unknown[b]	Abrupt (*flare*)
Flock Size	2	1	2	1	1
Flight Time (military time)	19:10	6:15	7:00	7:16	9:16
Time of Day	PM	AM	AM	AM	AM
Observation Site	BV-9	BV-3	BV-1	ML-18	BV-4
Season	Trial-Early	Early Summer	Early Summer	Migration	Migration
Date	6/11/2009	7/6/2009	7/16/2009	8/31/2009	10/26/2009
% Cloud Cover	75	10	0	10	100
Weather	None	Fog	None	Fog	None
Temp. (°F)	70	56	66	55	48
Max. Wind Speed	9.0 kmph	1.4 kmph	1.6 kmph	1.3 kmph	10.7 kmph
Relative % Humidity	61	80	54	60	80
Notes	Cranes called for 1 hr. before flying under the power line		Cranes walked on road as a car approached, scaring the cranes into flight		Cranes flew into wind and then over power line

[a] I excluded this observation in data for analysis because this Observation Period was a trial period prior to surveys beginning.

[b] I excluded this observation because the craneflight reaction was not recorded.