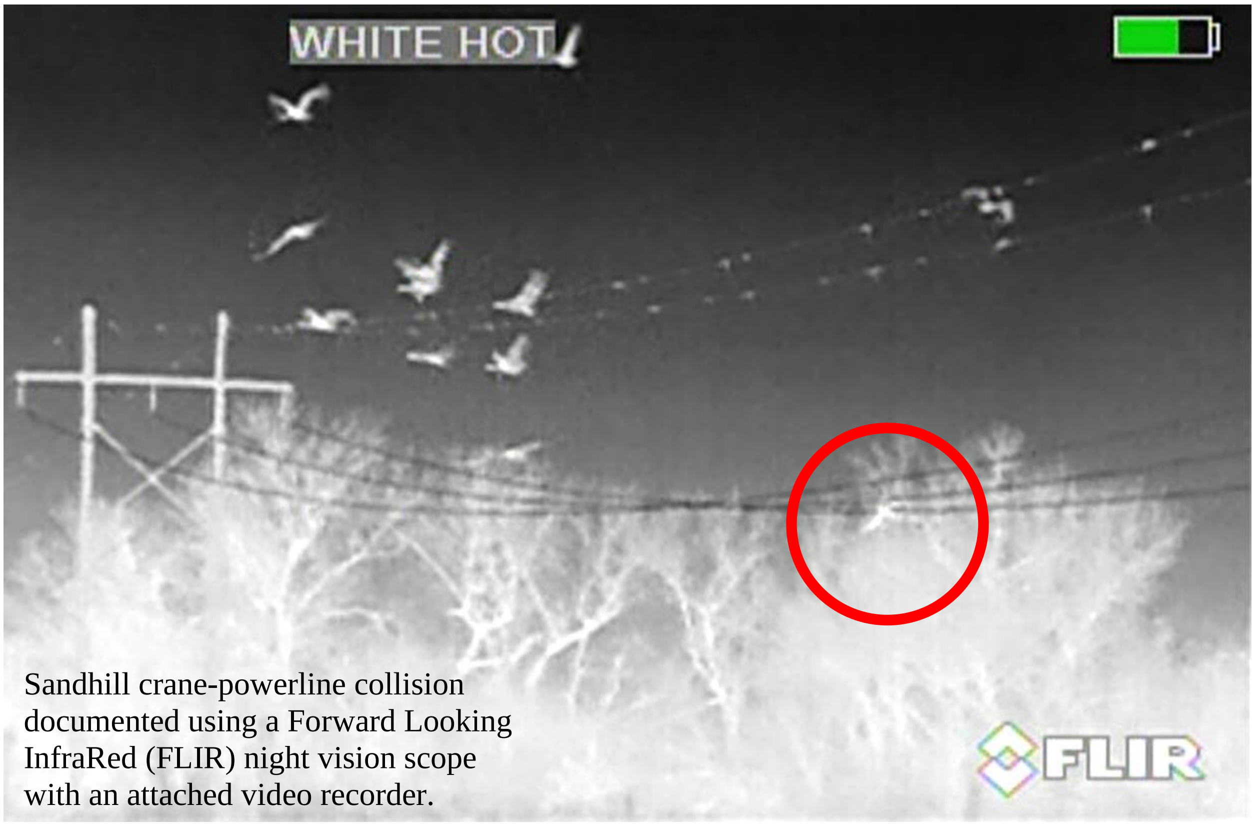
Avian Species' Response to Powerlines Illuminated by Near-ultraviolet Avian Collision Avoidance Systems: Summary Report



Sandhill crane-powerline collision documented using a Forward Looking InfraRed (FLIR) night vision scope with an attached video recorder.

Prepared for the Nebraska Game and Parks Commission
By
Audubon's Rowe Sanctuary
In cooperation with the Crane Trust and EDM International, Inc.

04/29/2021

Suggested citation: Baasch, D.M., J.F. Dwyer, B. Taddicken, A.J. Caven, A. Hegg, C. Wagner, C. Worley, A. Medaries, P. Dunbar, and N. Mittman. 2021. Avian Species' Response to Powerlines Illuminated by Near-ultraviolet Avian Collision Avoidance Systems: Summary Report. Audubon's Rowe Sanctuary, Gibbon, Nebraska, USA, 18 pp.

Correspondence: btaddicken@audubon.org; (308)468-5282

Avian Species' Response to Powerlines Illuminated by Near-ultraviolet Avian Collision Avoidance Systems: Summary Report

AUTHORS

David M. Baasch (Principal Investigator), Threatened and Endangered Species Specialist, Crane Trust, Wood River, NE; dbaasch@cranetrust.org, (308)390-0456.

James F. Dwyer (Co-principal Investigator), Certified Wildlife Biologist, EDM International Inc., Fort Collins, CO; jdwyer@edmlink.com, (863)464-0272.

Bill Taddicken (Cooperator / Funding Agent), Director, Iain Nicolson Audubon Center at Rowe Sanctuary, Gibbon NE; btaddicken@audubon.org, (308)468-5282.

Andrew J. Caven (Cooperator), Director of Conservation Research, Crane Trust, Wood River, NE; acaven@cranetrust.org, (605)252-8007.

Amanda Hegg (Cooperator), Conservation Program Associate, Iain Nicolson Audubon Center at Rowe Sanctuary, Gibbon NE; amanda.hegg@audubon.org, (605)999-6136.

Cody Wagner (Cooperator), Conservation Program Manager, Iain Nicolson Audubon Center at Rowe Sanctuary, Gibbon NE; cody.wagner@audubon.org, (308)380-3950.

Catherine Worley (Cooperator), Marian Langan Conservation Intern, Iain Nicolson Audubon Center at Rowe Sanctuary, Gibbon NE; catherine.worley@audubon.org, (469)487-8723

Amanda Medaries (Field Technician), Graduate Student, University of Nebraska-Kearney, medariesa@lopers.unk.edu, (318)557-2559.

Phoebe Dunbar (Field Technician), Undergraduate Student, University of Nebraska-Kearney, dunbarpg@lopers.unk.edu, (402)984-7190.

Nicole Mittman (Field Technician), Undergraduate Student, University of Nebraska-Kearney, mittmannicole@gmail.com, (402)366-3212.

INTRODUCTION

For decades, mid-flight collisions with powerlines have been documented to impact numerous avian species and cause millions of deaths worldwide (Markus 1972; Haas 1980; Ferrer and Hiraldo 1991; Janss 2000; Wright et al. 2009; Demerdzhiev 2009; Bernardino et al. 2018; Dwyer et al. 2019). Powerline collisions have been identified as a threat to numerous crane species including the sandhill crane (*Antigone canadensis*) and the endangered whooping crane (*Grus americana*), which numbers just over 500 individuals in the last remaining wild population that migrates through the Great Plains of North America (Aransas – Wood Buffalo Population) and about 160 individuals across three reintroduced populations (Eastern Migratory, Louisiana Non-Migratory, and Florida Non-Migratory Populations; Sundar and Choudhury 2005; Stehn and Wassenich 2008; Wright et al. 2009; Shaw et al. 2010; Stehn and Haralson-Strobel 2014; Murphy et al. 2016a and 2016b; Dwyer et al. 2019; Harrell and Bidwell 2020). Over 1 million sandhill cranes and millions of other large-bodied avian species migrate through central

Nebraska annually, and many of these birds use the Platte River Valley as a migratory stopover site (Vrtiska and Sullivan 2009; Gerber et al. 2014; Caven et al. 2020). Attempts to reduce mortality from such collisions have included placing bird flight diverters (i.e., wire markers in the form of spirals, swivels, plates, spheres, etc.) on static and some electrified wires to increase their visibility. While powerlines on the Iain Nicolson Audubon Center at Rowe Sanctuary (Rowe Sanctuary) have been fitted with glow-in-the-dark line markers to increase their visibility, collisions persist because most occur nocturnally when line markers are least visible (Wright et al. 2009; Murphy et al. 2016; Dwyer et al. 2019). Every year hundreds of sandhill cranes die due to collisions with marked powerlines at Rowe Sanctuary, a major migratory stopover location near Gibbon, Nebraska USA (Kinzel et al. 2006; Dwyer et al. 2019).

Recent research has indicated that near-ultraviolet light outside the spectrum visible to humans may be effective in reducing nighttime powerline collisions for cranes and provide a cost-effective alternative to powerline burial (Dwyer et al. 2019). However, applied technologies are evolving and the effectiveness of experimental units and their ultimate specifications have yet to be defined. We examine the effectiveness of experimental Avian Collision Avoidance Systems (ACAS) using near-ultraviolet light to illuminate two powerlines crossing the Platte River near Rowe Sanctuary, an area with one of the highest roosting densities of Sandhill Cranes in the Central Platte River Valley (CPRV) of Nebraska (Kinzel et al. 2006; Caven et al. 2019). The objective of our study was to determine the efficacy of two Avian Collision Avoidance Systems (ACAS) at minimizing bird-powerline collisions.

METHODS

Study Area

We studied the efficacy of the ACASs on two powerlines crossing the Platte River near Rowe Sanctuary (Universal Transverse Mercator 14 T, 509599 m E, 4502114 m N) within the CPRV, near Gibbon, Nebraska, USA. These are the same powerlines where hundreds of sandhill crane and other avian species collisions have historically been documented despite the presence of FireFly and BFD powerline markers (Wright et al. 2009, Murphy et al. 2016a, 2016b; Dwyer et al. 2019). Rowe Sanctuary is composed of braided river with emergent sandbars, wet meadow, lowland prairie, and riparian woodland habitats that have been managed and restored to create and protect roosting, foraging, and loafing habitat for sandhill cranes, whooping cranes, and many other avian species during migration (Nagel and Kolstad 1987, Strom 1987).

Field Methods

We used a randomized design to test collision mitigation effects of pole-mounted, solar-powered, near-ultraviolet light (UV-A; 380–395 nm) ACAS units on two powerlines crossing the Platte River on Rowe Sanctuary to evaluate our avian-powerline collision mitigation strategy. Each ACAS was comprised of two UV-A light boxes, with each box containing three LED UV-A lights. One of the UV-A lights in each light box was designed to project light through a relatively wide cone. This light illuminated all wires in proximity to the H-frame structure upon which it was mounted, but was attenuated so it did not reach the mid-span. The other two UV-A lights in each light box were designed to project light through a relatively narrow cone. The beams from these two lights were too narrow to illuminate all the wires close to the H-frame structure upon which they were mounted, but because their energy was more focused, they attenuated less quickly allowing them to illuminate the span beyond the reach of the light from the wide cone. Each ACAS was also composed of a junction box, solar panels, power storage and control box, cabling to connect those components, and a remote control (Figure 1). Each UV-A light was mounted to the crossarm of the H-frame structure supporting the powerline spans we studied, and each light produced peak wavelengths between 380 nm and 395 nm. Each light was built around a Chanzon (Shenzhen, Guangdong, China) High Power LED Chip 100W Purple Ultraviolet light. We estimated each ACAS produced approximately 8,000–9,000 lumens per light, depending on ambient temperature, but this light did not appear bright to the human eye. The junction box was mounted just below the crossarm to distribute power to the UV-A lights. The pole-mounted solar panels charged batteries in the power storage and control unit located on a 0.5 m-high platform at the base of the H-frame structure. The power storage and control unit contained batteries, custom-built control boards, and switches to store and route electrical power from the solar panels, through the junction box, and into the UV-A lights. The total cost for all components of each ACAS unit was approximately $6,000.

Figure 1. Avian Collision Avoidance System (ACAS) unit mounted on the H-frame structure of a power line crossing the Platte River at Rowe Sanctuary.

We mounted the ACAS units on existing H-frame structures. One was mounted on the north bank of the central Platte River at Rowe Sanctuary and directed the UV-A lights southward along the 258-m span of the eastern powerline crossing the river. The other was mounted on the south bank of the river and directed UV-A light northward along the western powerline. The towers upon which the ACAS units were mounted were selected for accessibility via bucket truck. At each powerline, the tower on the opposite end of the span being illuminated was not accessible by truck due to river channels and river pooling around the structure. The upper wires of the powerline were ~15 m above the surface of the river and adjacent banks. Dawson Public Power (Kearney, Nebraska), the owner and operator of the powerlines we studied, installed the ACAS's during mid-February, 2021, prior to the arrival of migrating sandhill cranes and whooping cranes. We monitored large-bodied avian species' (e.g., sandhill cranes, whooping cranes, pelicans, swan, ducks, geese, bald eagles, and other raptors) responses to the ACASs seven nights per week from 25 February, 2021 through 6 April, 2021, bracketing the historical timing of collisions; March 4 to April 13 (Wright et al. 2009; Murphy et al. 2016b, Dwyer et al. 2019). We did not collect data on one night, March 22 due to heavy rains which prevented us from observing the power line. We randomly assigned each ACAS unit to be on or off during each night of observation. We observed reaction behavior as flocks approached the powerline, reaction distances within 50 m and perpendicular to the powerline along the river, collisions with the powerlines, and post-collision flight behavior (Murphy et al. 2016a) from a blind on the bank near the base of the H-frame structure on which each ACAS unit was installed. Observations occurred nightly from 1 hr before sunset until 4.5 hr after sunset. We recorded observations identically regardless of whether the ACAS was on or off. During daylight and dusk, we conducted observations using 8x42 binoculars. After dusk, we conducted observations with a 3–12x50 thermal imaging monocular (Prometheus 336; Armasight, San Francisco, California, USA) or forward-looking infrared (FLIR) cameras.

For our primary analyses, we recorded flight behavior when individuals or flocks of avian species approached at a distance of ≤ 50 m and/or fly over each powerline within 25 m above river surface (10 m above the top of the powerlines) as was done in previous studies (Murphy et al. 2016a; Dwyer 2019). Doing so in our primary analyses allowed us to focus specifically on birds that were at risk of collision, and to avoid recording birds flying well above the powerline that were at a much lower risk of collision, which would reduce the sensitivity of our analyses (Murphy et al. 2016a). For a secondary set of analyses, we recorded the occurrences of flights that were 11-20 m above the powerline (26-35 m above water surface) and recorded flight behavior similar as we did for our primary analyses as described below. We used the known height of the powerlines and known distances between the wires comprising the powerline to gauge the flight height of birds crossing over the powerline and the distance along the river from the powerline at which flight behavior changed. Similar to previous studies of sandhill crane collisions with powerlines in our general study area (Morkill and Anderson 1991), and with previous studies at these sites (Murphy et al. 2016a; Dwyer 2019), we defined a flock passing over each powerline as an individual or discrete group of birds within 100 m of the previous crane in the passing flock which was equivalent to ~20 seconds of flight time. To ensure independence among data points, we did not record approaches or passages over the powerlines of flocks within 100 m of a previous flock unless a different species was observed approaching the powerline. This approach made flocks, rather than individual birds, our sampling unit for statistical analyses (Murphy et al. 2016a).

Each time a flock of birds crossed over the powerline and within 35 m above the river surface, we recorded whether the ACAS was on or off, whether a collision occurred, whether it was day (1 hr before sunset to the end of civil twilight at ~0.5 hr after sunset) or night (civil twilight to 4.5 hr after sunset), whether and how birds maneuvered to avoid the powerline, and the perpendicular distance from the powerline at which maneuvers occurred. If one or more collisions occurred, we recorded the wire involved, the approximate midspan distance from H-frame structure upon which the ACAS was installed, and the subsequent flight behavior of the birds involved. Similar to previous studies, we categorized maneuvers to avoid the powerline as No Risk Flights (NR; 11–20 m above powerline), Low Risk Climbs (LRC), Low Risk Flares (LRF), No reaction Above powerline (NA), Gradual Climb (GC), Flare (FL), Reverse (RE), No reaction Below powerline (NB), Extremely Dangerous Flights (EDF), or No reaction Collision (NC; Murphy et al. 2016a; Dwyer et al. 2019). "No Reactions" occurred when the entire flock maintained the same direction, speed, and elevation above the river level before and after approaching the powerline. For these behaviors, reaction distances were defined as zero meters. When no reaction occurred within 15 m above the river surface (i.e., below or between the powerlines), we categorized these as an "Extremely Dangerous Flight" (EDF). When no reaction occurred above 25 m and below 35 m above the river surface (i.e., 11–20 m above powerlines), we categorized these as "No Risk Flights". When no reaction occurred above 15 m and below 25 m above the river surface (i.e., 0–10 m above powerlines), we categorized these as "High Risk Flights". A "Gradual Climb" (GC or LRC) was recorded when the entire flock maintained consistent flight direction, speed, and wingbeat, but adjusted flight height gradually to pass 0–20 m above the powerline. When a "Gradual Climb" did not exceed 25 m above the river surface, we categorized these reactions as "Dangerous Flights". A "Flare" (FL or LRF) was documented when at least one member of the flock altered direction, speed, and wingbeat to suddenly gain the elevation needed to pass over the powerline while still passing 0–20 m above the powerline. When a "Gradual Climb" or "Flare" placed birds 25–35 m above the river surface (i.e., 11–20 m above the powerline), we categorized these reactions as a "Low Risk Flights" (LRC or LRF, respectively). A "Reverse" (RE) was recorded when at least one member of the flock altered direction, speed, and wingbeat to suddenly turn away from the powerline. An "Extremely Dangerous Flight" (EDF) was recorded when at least one member of the flock reacted within or flew between the powerlines. We recorded "Gradual Climbs," "Flares,", "Reverses", and "Extremely Dangerous Flights" even if only a single member of the flock reacted because those behaviors were previously demonstrated to occur when at least some cranes in the flock were in danger of collision (Murphy et al. 2016a; Dwyer et al. 2019). When a collision occurred, we recorded the reaction (if any) and the distance from the powerline where any reaction occurred and recorded 0 m when no reaction occurred prior to the collision. We recorded post-collision flights as "Normal Flight" (steady wingbeats and elevation maintained), "Hampered Flight" (unsteady wingbeats and elevation maintained), "Flapping Fall" (unsteady wingbeats and elevation not maintained), and "Limp Fall" (no wingbeats and elevation not maintained).

In addition, we recorded basic environmental conditions during all observations, which allowed us to determine what environmental covariates influence the probability of collision when the ACAS units were off and what environmental covariates influence the effectiveness of ACAS units. Environmental variables recorded in the field included moon visibility (0,1), cloud cover (%), precipitation (0,1), and fog presence that reduced visibility to < 800 m (0,1). Moon illumination (%), temperature, humidity, precipitation, and wind speed and direction were included in the dataset from an on-site weather station or secondary data sources. Besides moon visibility, environmental conditions were not analyzed in this Summary Report, but will be included in our full analyses for publication.

We designed our study to include three ACAS conditions: on-on occurred when both ACAS units were on. On-off occurred when one ACAS unit was on and the other was off. Off-off occurred when both ACAS units were off. The UV lights on one of the ACAS units stopped operating midway through the study. The ACAS unit was partially repaired, but with only one functioning light box, not two. This led us to add an "on-ONF" category when one ACAS unit was on and the other was operating at half illumination and an "off-ONF" condition when one ACAS unit was off and the other was operating at half illumination.

Ethical guidelines were followed in this study as to not disturb roosting birds. To achieve this, we scheduled installation of our ACAS units prior to the arrival during spring migration of sandhill cranes and whooping cranes into the CPRV. We also ensured our observations did not disturb roosting birds, which could cause flocks to fly up into the powerline. We did this by entering the blinds at least one hour before sunset, which was well before birds began roosting on the river, and by exiting the blinds under the cover of darkness 4.5 hours after civil twilight.

RESULTS

During 40 nights of observation, we documented 6,657 flock flights within the focal area of our study (0–35 m above the river surface). Of these flights, 4,297 were classified as high-risk flights given they occurred within 25 m of the river's surface (i.e., within 10 m of the powerline). Low-risk flight types (11-20 m above the powerline) accounted for 2,360 of the flights observed. Daily observations increased rapidly as sandhill crane numbers increased and roosts became closer and closer to the powerlines; however, when flooding occurred (3/12–3/16 & 3/25–3/27), observation numbers decreased quickly as birds began roosting off-channel (Figure 2).

We recorded 36% more observations within our focal area when the ACAS unit was off than when it was on and 22% more observations when the ACAS was half on (ONF) than when it was fully functional (Figure 3). We recorded 58% more observations when the ACAS units were both off than when they were both on and fully functional (Figure 4). Similarly, we observed more observations than expected when the ACAS units were both off or one unit was half on (ONF) and the other unit was off and less than expected when at least one of the ACAS units were on and fully functional (Figure 5).

Figure 2. Count of observations, by date and powerline, during 40 nights of observation.

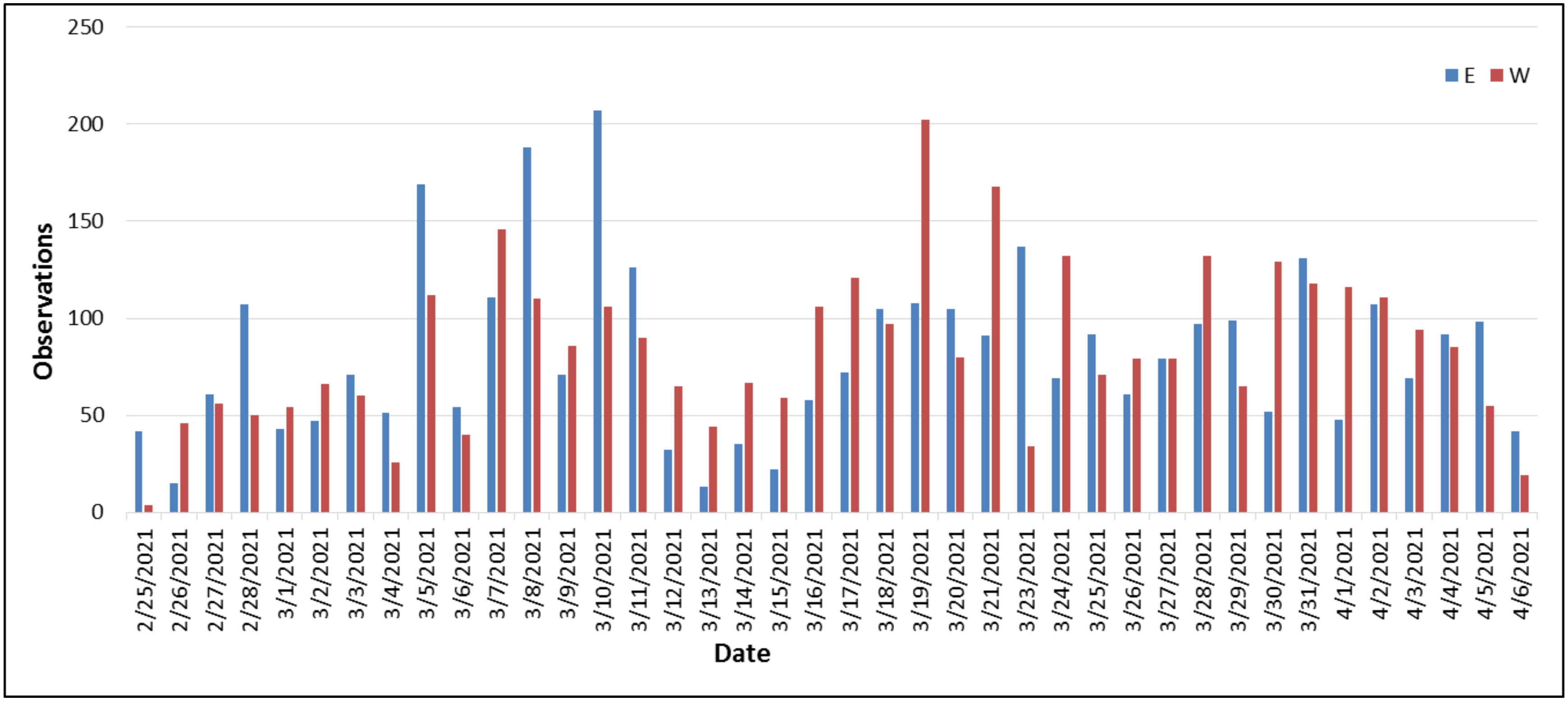


Figure 3. Number of observations per night when the avian collision avoidance system (ACAS) was off (n = 41), when half on (ONF; n = 9), and when the ACAS unit was on and fully functional (n = 30) during 40 nights of observation.

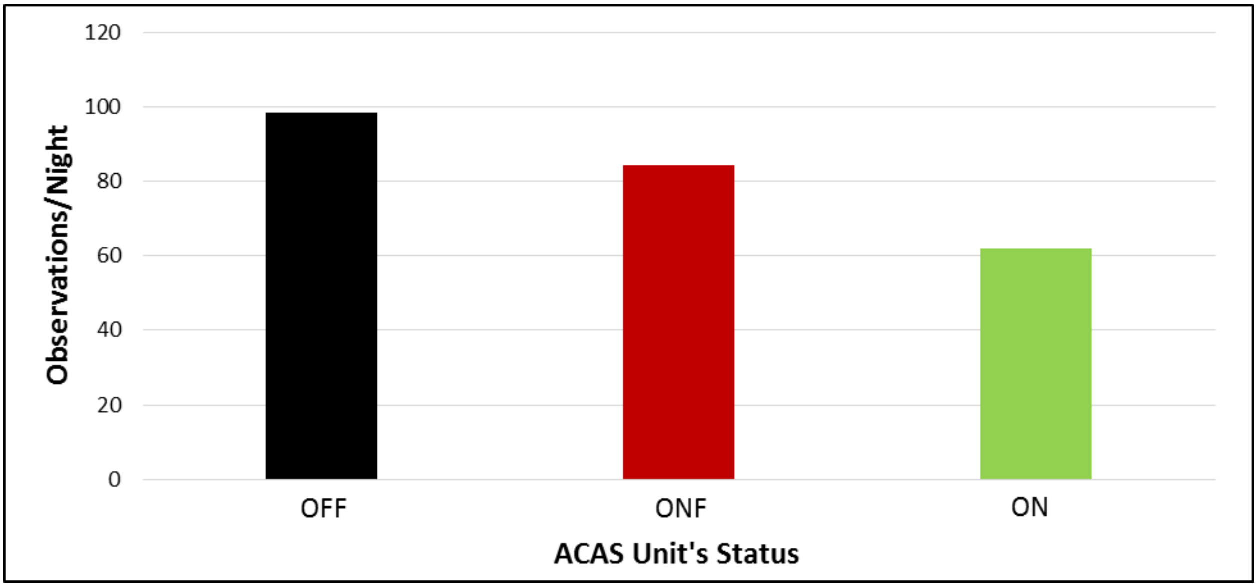


Figure 4. Number of observations recorded per night when both the avian collision avoidance system (ACAS) units were off (n = 13), when one was half on (ONF) and the other was off (n = 3), when one unit was on and the other was off (n = 11), when one unit was on and the other was half on (n = 6), and when both ACAS units were on and fully functional (n = 7) during 40 nights of observation. when both ACAS units were on and fully functional (n = 7) during 40 nights of observation.

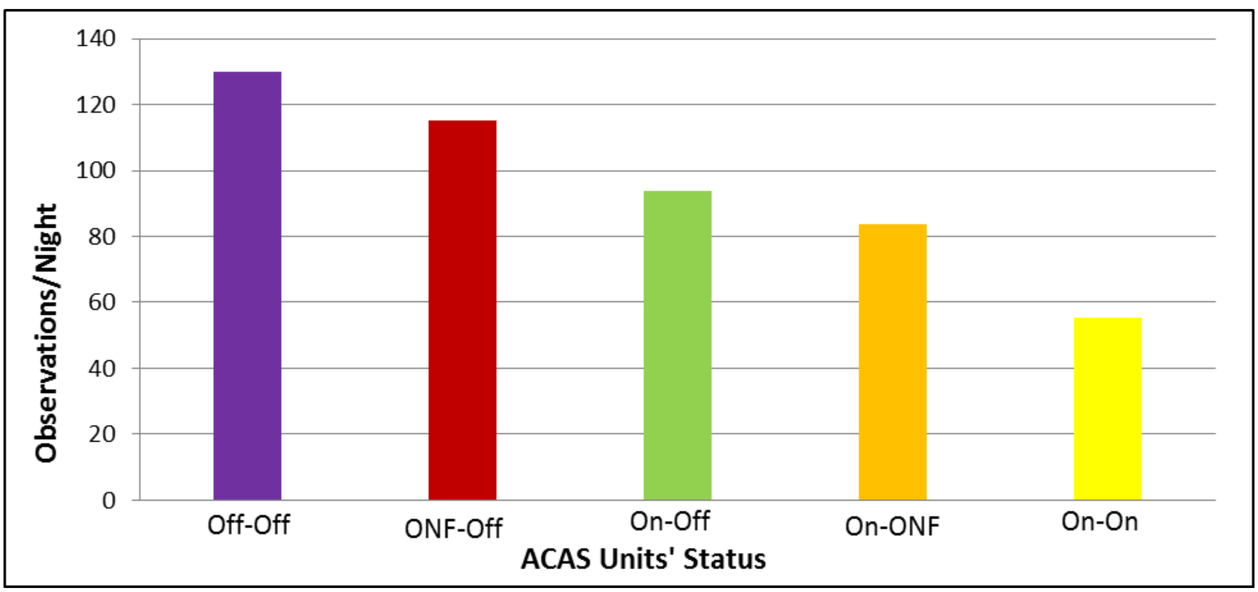
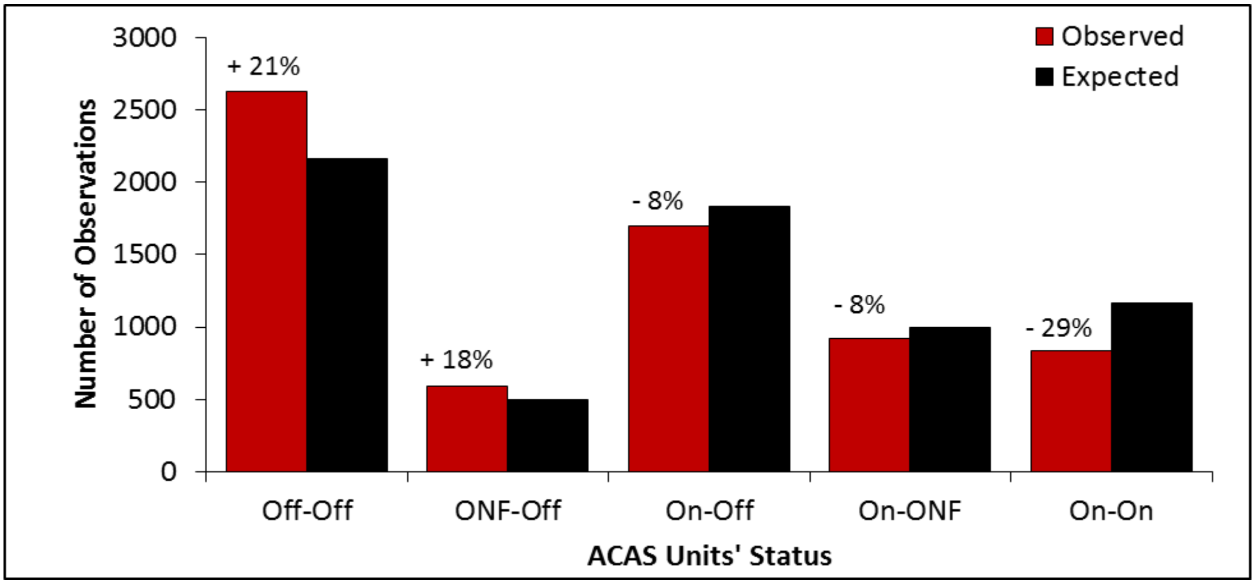


Figure 5. Comparison between the number of observations observed versus what would be expected if the avian collision avoidance system (ACAS) units were not effective when both ACAS units were off (n = 13), when one was half on (ONF) and the other was off (n = 3), when one unit was on and the other was off (n = 11), when one unit was on and the other was half on (n = 6), and when both ACAS units were on and fully functional (n = 7) during 40 nights of observation.



We found birds were as likely to collide with a powerline during the day as they were during the night when the ACAS unit was on. In addition, we observed 20 times more collisions when the ACAS units were both off at night than when they were both on (Figure 6). During the 9 nights of observation on the west line when only 1 light was on (ONF), the ACAS unit was two times as effective as when it was off, but not nearly as effective as when 2 lights were on, as there were 4-times the expected number of collisions observed as when the ACAS was on and fully functional.

More than 60% of collisions occurred when both ACAS units were off. In addition to the strong influence the ACAS unit played on reducing the likelihood of collision with the powerline it was illuminating, we also observed an influence of each ACAS unit on the other powerline which is an indication the 2 study areas were not truly independent (Figure 6). We observed more collisions than expected during nights when the ACAS units were off and when one ACAS unit was half on (ONF) and fewer collisions than expected when at least on ACAS unit was on and fully functional (Figure 7). We observed 21 collisions after civil twilight every seven nights we monitored the powerlines when both ACAS units were off while we only observed one collision every 7 nights when both units were on and fully functional. In summary, the more lights that were on across both powerlines, the more effective the ACAS units were at reducing collisions (Figures 7). Surprisingly, we observed more collisions during times when the moon was visible than when it was not (Figure 8).

Figure 6. Number of collisions observed per night when both the avian collision avoidance system (ACAS) units were off (n = 13), when one was half on (ONF) and the other was off (n = 3), when one unit was on and the other was off (n = 11), when one unit was on and the other was half on (n = 6), and when both ACAS units were on and fully functional (n = 7) during 40 nights of observation.

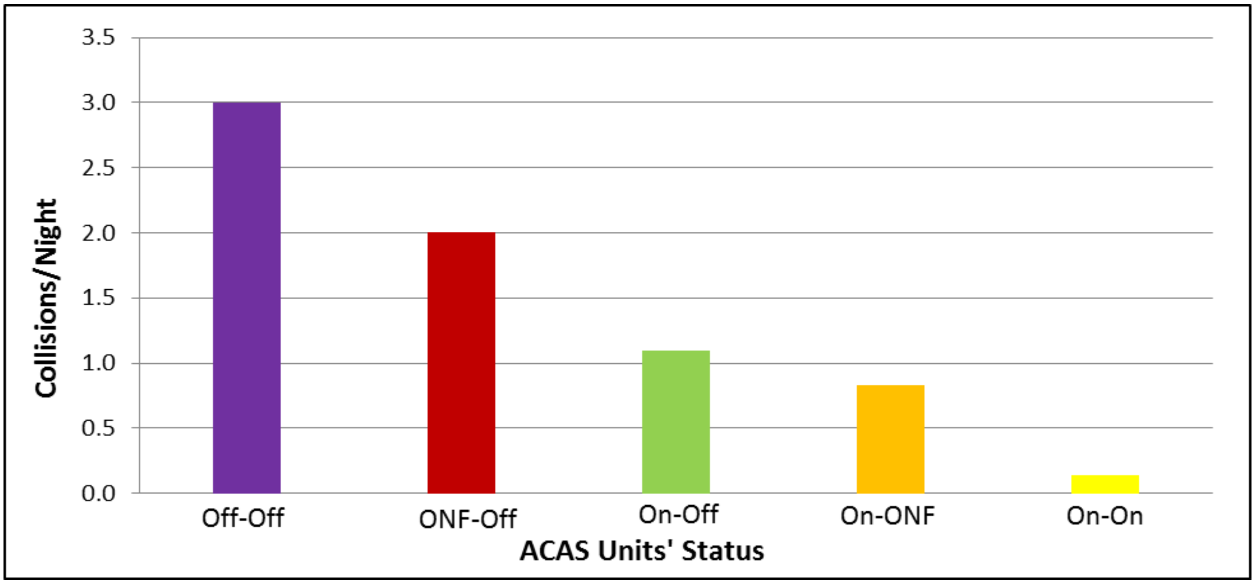


Figure 7. Comparison between the number of collisions observed versus what would be expected if the avian collision avoidance system (ACAS) units were not effective when both ACAS units were off (n = 13), when one was half on (ONF) and the other was off (n = 3), when one unit was on and the other was off (n = 11), when one unit was on and the other was half on (n = 6), and when both ACAS units were on and fully functional (n = 7) during 40 nights of observation.

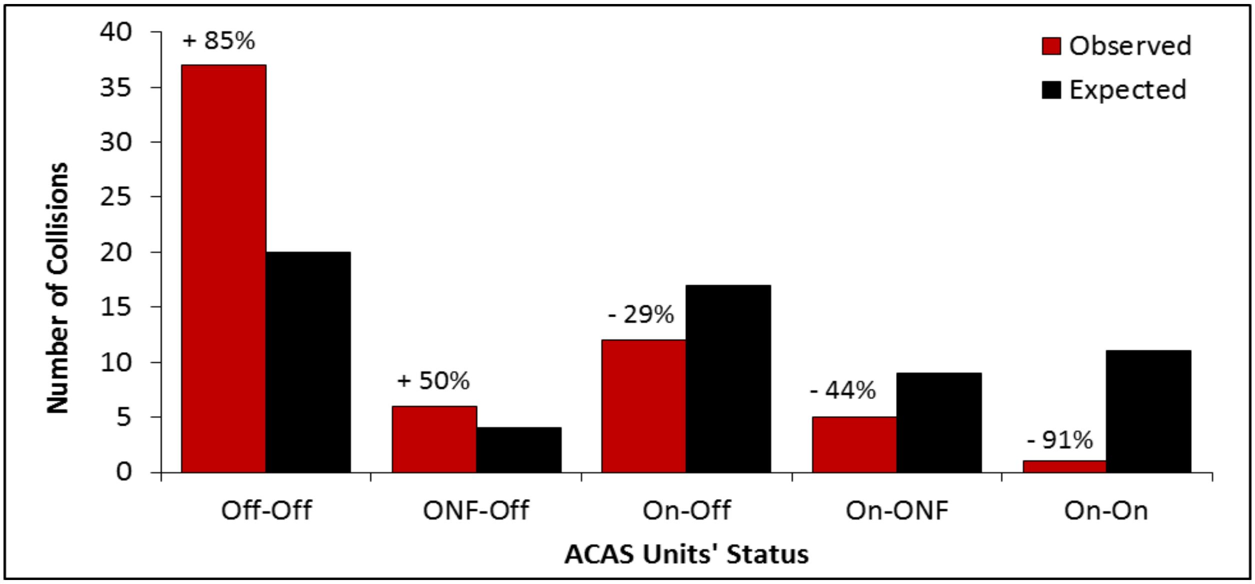
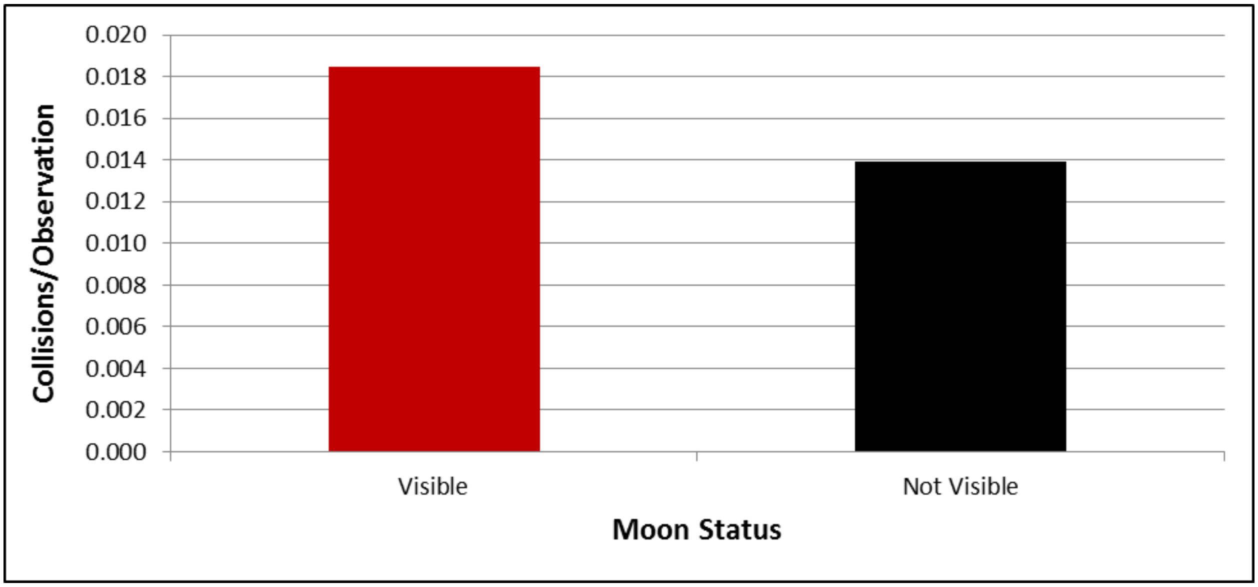


Figure 8. Count of collisions per observation when the moon was visible (n = 1,464 observations) and when it was not (n = 2,584 observations).



As expected, counts of all reaction types per day were similar when the ACAS was on as when it was off or only 1 light was on during the day (Figure 9). During the night, however, high risk climbs (CL), flares (FL), reverses (RE), and "extremely dangerous flights" (EDF) were more common when the ACAS unit was off than when it was on or when only 1 light was on (ONF; Figure 10). We observed more high-risk flights (0–25 m above the water surface) than expected when the ACAS units were both off and when one unit was half on (ONF) and the other was off and fewer high-risk flights than expected when at least on ACAS unit was on (Figure 11).

Figure 9. Number of responses per day, by type, observed during daylight hours when the avian collision avoidance system (ACAS) unit was off (n = 41), when the ACAS unit was half on (ONF; n = 9), and when the ACAS unit was on (n = 30) during 40 nights of observation.

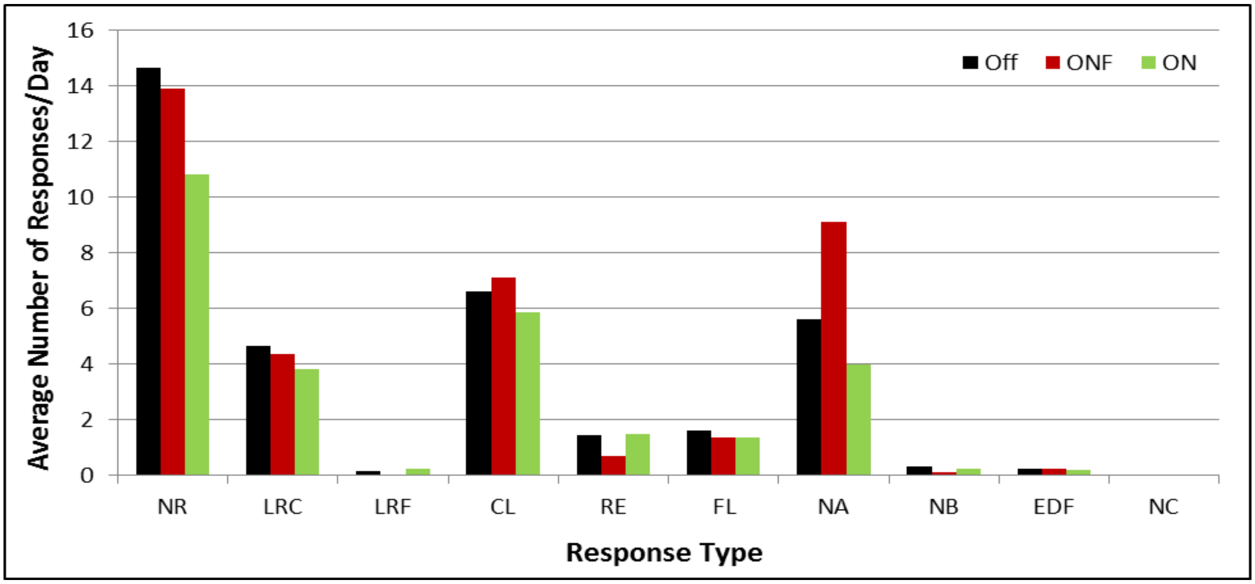


Figure 10. Number of responses per night, by type, observed during the night when the avian collision avoidance system (ACAS) unit was off (n = 41), when the ACAS unit was half on (ONF; n = 9), and when the ACAS unit was on (n = 30) during 40 nights of observation.

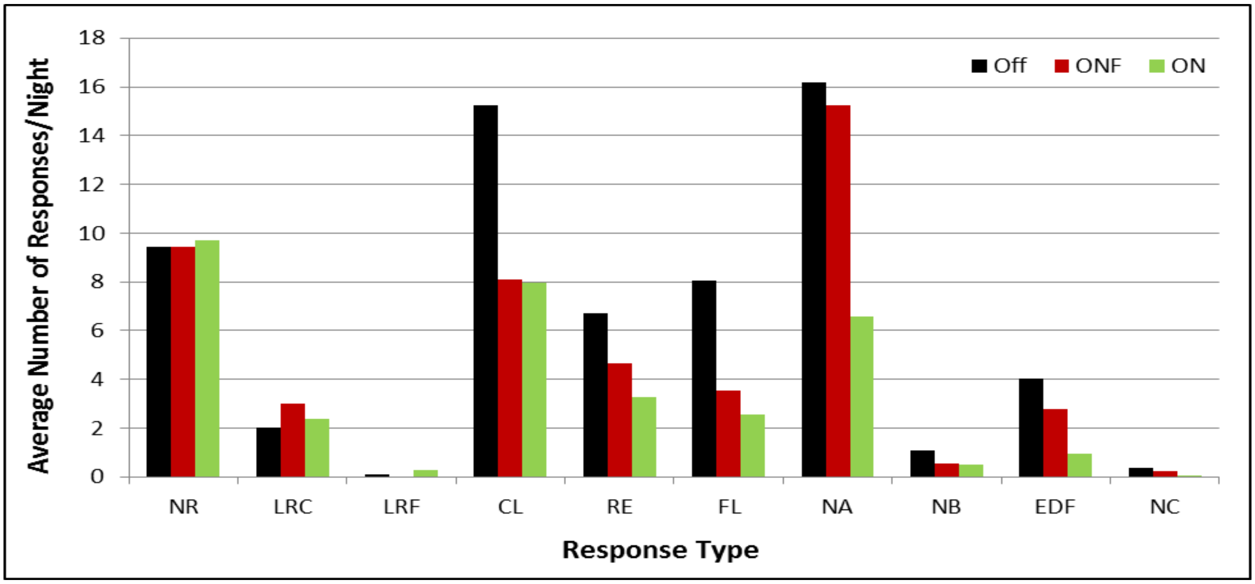
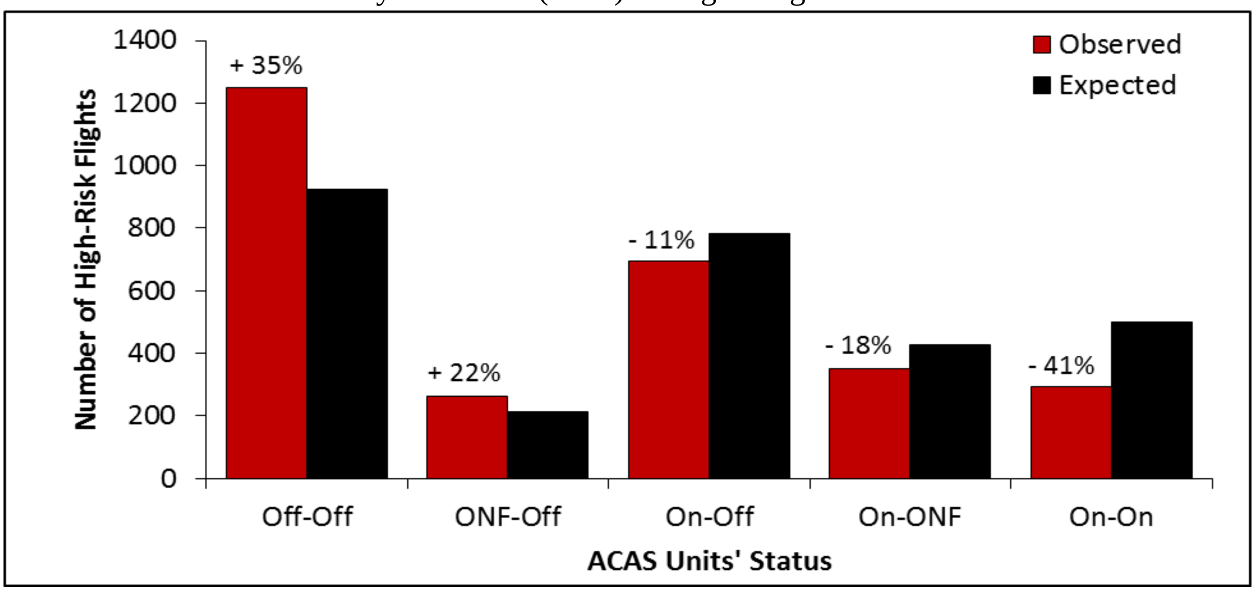


Figure 11. Number of high-risk flight types observed versus what would be expected if the avian collision avoidance system (ACAS) units were not effective when both ACAS units were off (n = 13), when one was half on (ONF) and the other was off (n = 3), when one unit was on and the other was off (n = 11), when one unit was on and the other was half on (n = 6), and when both ACAS units were on and fully functional (n = 7) during 40 nights of observation.



Except for extremely dangerous flights (EDF), all types of reaction distances were similar when the ACAS was on during the day as when it was off or only one light was on (ONF; Figure 12). In addition, reaction distances generally increased as the risk of collision decreased (Figures

12 & 13). At night, however, reaction distance generally occurred much sooner when the ACAS unit was on than when it was off or when the ACAS unit was half on (ONF; Figure 13).

Figure 12. Average response distance, by reaction type, during daylight hours when the avian collision avoidance system (ACAS) unit was off (n = 41), when the ACAS unit was half on (ONF; n = 9), and when the ACAS unit was on (n = 30) during 40 nights of observation.

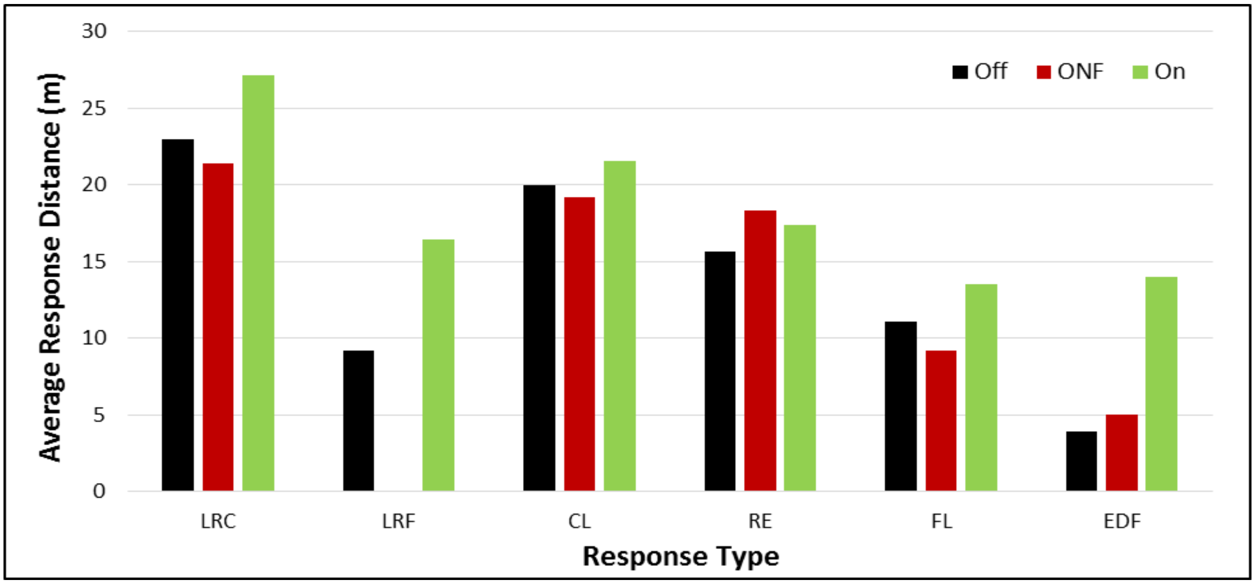
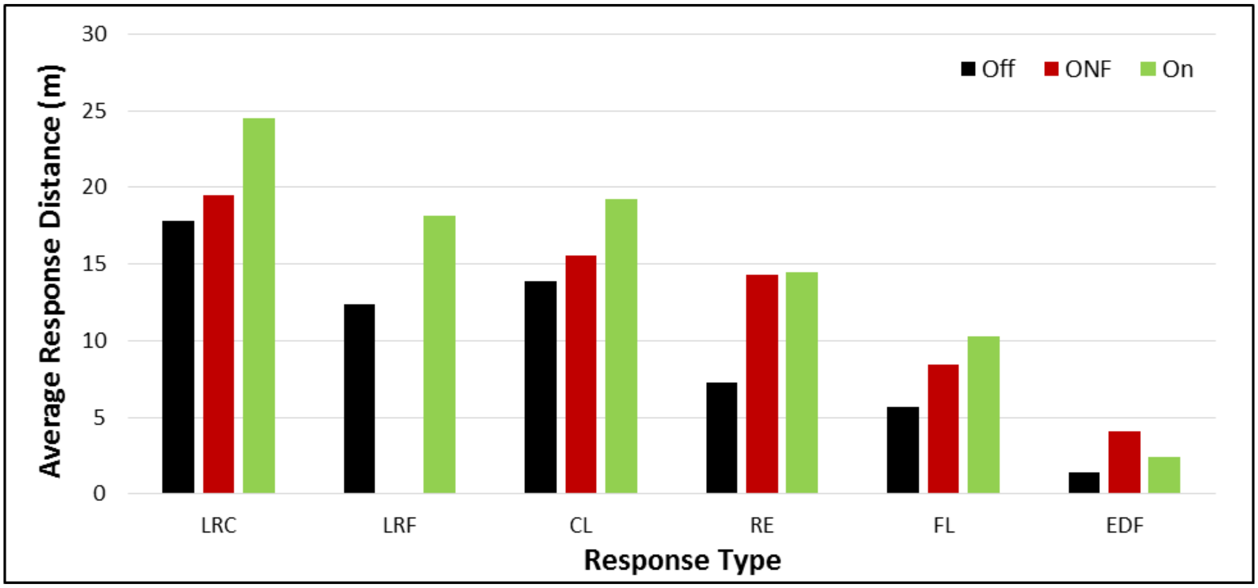
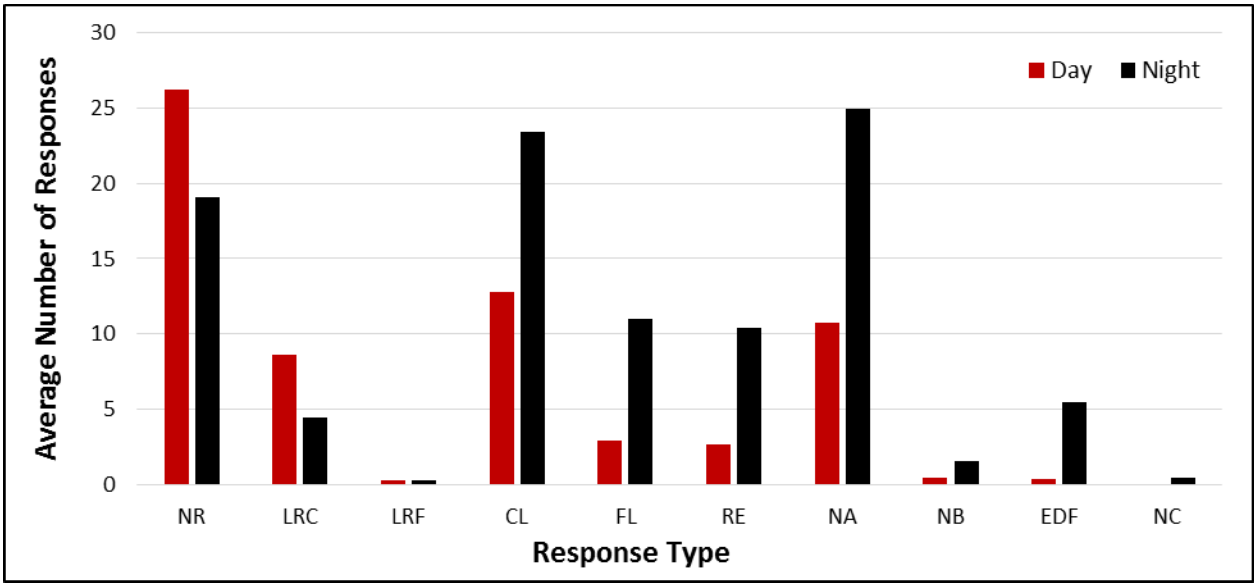


Figure 13. Average response distance, by reaction type, during the night when the avian collision avoidance system (ACAS) unit was off (n = 41), when 1 light was on (ONF; n = 9), and when the ACAS unit was on (n = 30) during 40 nights of observation.



We observed more "high-risk" flight types (CL, FL, RE, NA, NB, and EDF) per day during the night than during the day while "low risk" flight types (NR, LRC, and LRF) were observed more often during the day (Figure 14).

Figure 14. Average number of responses, by type, observed during the day and night.



CONCLUSION

We found the ACAS units were highly effective at reducing avian collisions with the powerlines on Rowe Sanctuary. This was especially true when both ACAS units were on, however, when only one ACAS unit was on it appeared to provide benefits to both powerlines to some degree even though only one powerline was illuminated. We observed 21 collisions per week of observation (i.e., 1 collision per 2 hours of observation) when both ACAS units were off and only one collision per week of observation (i.e., 1 collision per 42 hours of observation) when both ACAS units were on and fully functional. The ACAS units effectively reduced collisions by 95% when both units were on and fully functional, but only reduced collisions by 30% when one ACAS unit was off and the other ACAS unit was half on (ONF). In addition to reducing avian-powerline collisions, average response distances were greater when the ACAS units were on than when they were off. Installation of ACASs on high-risk spans of powerlines such as Rowe Sanctuary, and perhaps on other anthropogenic obstacles where birds collide, may offer a more effective and affordable long-term solution to a long-standing conservation dilemma than previous mitigation strategies have.

While not anticipated, one of the ACAS units failed mid-way through the study which introduced a third treatment level, ACAS unit half on (ONF). While this complicated our study design, our results indicate having an ACAS half on was slightly better than having it off, but not nearly as good as having it on and fully functional. In addition, the west ACAS unit was not properly focused on the powerline after it was repaired which may have limited its effectiveness when the one ACAS unit failed. However, before the ACAS unit failed, we observed no collisions with the west line which is an indication that the unit was providing a high degree of protection to the birds while it was on and fully functional even though the one ACAS unit was not properly directed on the powerline.

ACKNOWLEDGEMENTS

We would like to thank the Nebraska Game and Parks Commission (Agreement # 2021-550-01), Audubon Society, and Dawson Public Power for contributing funding for this study. We also thank Barb and Dudley Friskopp, Doug Wingfield, and Heidi Swanson for their assistance with the field work portion of this study.

LITERATURE CITED

Bernardino, J., K. Bevanger, R. Barrientos, J.F. Dwyer, A.T. Marques, R.C. Martins, J.M. Shaw, J.P. Silva, and F. Moreira. 2018. Bird collisions with powerlines: State of the art and priority 1 areas for research. Biological Conservation 222:1–13.

Caven, A.J., E.M. Brinley Buckley, K.C. King, J.D. Wiese, D.M. Baasch, G.D. Wright, M.J. Harner, A.T. Pearse, M. Rabbe, D.M. Varner, B. Krohn, N. Arcilla, K.D. Schroeder, K.F. Dinan. 2019. Temporospatial shifts in Sandhill Crane staging in the Central Platte River Valley in response to climatic variation and habitat change. Monographs of the Western North American Naturalist 11:33-76.

Caven, A.J., D.M. Varner, J. and J. Drahota. 2020. Sandhill Crane abundance in Nebraska during spring migration: making sense of multiple data points. Transactions of the Nebraska Academy of Sciences and Affiliated Societies 40:6–18.

Demerdzhiev, D.A., S.A. Stoychev, T.H. Petrov, I.D. Angelov, and N.P. Nedyalkov. 2009. Impact of powerlines on bird mortality in southern Bulgaria. Acta Zoologica Bulgaria 61:175–183

Dwyer, J.F., A.K. Pandey, L.A. McHale, and R.E. Harness. 2019. Near-ultraviolet light reduced Sandhill Crane collisions with a powerline by 98%. The Condor, https://doi.org/10.1093/condor/duz008.

Ferrer M., F. Hiraldo 1991. Evaluations of management techniques for the Spanish Imperial Eagle. Wildlife Society Bulletin 19:436–442.

Gerber, B.D., J.F. Dwyer, S.A. Nesbitt, R.C. Drewien, C.D. Littlefield, T.C. Tacha, and P.A. Vohs. 2014. Sandhill Crane (*Antigone canadensis*). In The Birds of North America (A. F. Poole, Editor). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bna.31

Haas D. 1980. Endangerment of our large birds by electrocution documentation. Okolgie der Vogel 2:7–57.

Harrell, M., and M. Bidwell. 2020. Report on Whooping Crane Recovery Activities 2019 breeding season-2020 spring migration. U.S. Fish and Wildlife Service, Aransas National Wildlife Refuge, Austwell, TX, USA, and Canadian Wildlife Service, Saskatoon, Saskatchewan, Canada, 61 pp.

Janss G.F. 2000. Avian mortality from powerlines: a morphological approach of a species-specific mortality. Biological Conservation 95:353–359.

Kinzel, P.J., J.M. Nelson, R.S. Parker, and L.R. Davis. 2006. Spring census of mid-continent sandhill cranes using aerial infrared videography. The Journal of Wildlife Management 70:70–77.

Markus M.B. 1972. Mortality of vultures caused by electrocution. Nature 238. https://doi.org/10.1038/238228b0

Morkill, A.E., and S.H. Anderson. 1991. Effectiveness of marking powerlines to reduce sandhill crane collisions. Wildlife Society Bulletin 19:442–449.

Murphy, R.K., J.F. Dwyer, E.K. Mojica, M.M. McPherron, and R.E. Harness. 2016a. Reactions of sandhill cranes approaching a marked transmission powerline. Journal of Fish and Wildlife Management 7:480–489.

Murphy, R.K., E.K. Mojica, J.F. Dwyer, M.M. McPherron, G.D. Wright, R.E. Harness, A.K. Pandey, and K.L. Serbousek. 2016b. Crippling and nocturnal biases in a study of sandhill crane (*Grus canadensis*) collisions with a transmission line. Waterbirds 39:312–317.

Nagel, H.G., and O.A. Kolstad. 1987. Comparison of plant species composition of Mormon Island Crane Meadows and Lillian Annette Rowe Sanctuary in central Nebraska. Transactions of the Nebraska Academy of Sciences 15:37–48.

Shaw J.M., A.R. Jenkins, J.J. Smallie, and P.G. Ryan. 2010. Modelling power-line collision risk for the blue crane *Anthropoides paradiseus* in South Africa. Ibis 152:590–599.

Stehn T.V., and C. Haralson-Strobel. 2014. An update on mortality of fledged whooping cranes in the Aransas/Wood Buffalo population. Pages 43–50 in Proceedings of the Twelfth North American Crane Workshop. North American Crane Working Group, Grand Island (see Supplemental Material, Reference S8. Found at DOI: http://dx.doi.org/10.3996/052016-JFWM-037.S9 (936 KB PDF); also available: http:// www.nacwg.org/proceedings12.html (September 2016).

Stehn, T.V., and T. Wassenich. 2008. Whooping Crane collisions with powerlines: an issue paper. Proceedings of the North American Crane Workshop 10:25–36.

Strom, K.J. 1987. Lillian Annette Rowe Sanctuary—Managing migratory crane habitat on the Platte River, Nebraska. Pages 328–330 in J. C. Lewis, editor. Proceedings of the 1985 Crane Workshop. Platte River Whooping Crane Habitat Maintenance Trust, Grand Island, Nebraska, USA.

Sundar K.S.G., and B.C. Choudhury. 2005. Mortality of sarus cranes *Grus antigone* due to electricity wires in Uttar Pradesh, India. Environmental Conservation 32:260–269.

Vrtiska, M.P., and S. Sullivan. 2009. Abundance and distribution of lesser snow and Ross's geese in the Rainwater Basin and central Platte River Valley of Nebraska. Great Plains Research, 147-155.

Wright, G.D., T.J. Smith, R.K. Murphy, J.T. Runge, and R.R. Harms. 2009. Mortality of cranes (*Gruidae*) associated with powerlines over a major roost on the Platte River, Nebraska. Prairie Naturalist 41:116–120.