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Case Study

The emerging conflict of common ravens roosting on electric power transmission line towers in Montana, USA

Marco Restani, NorthWestern Energy, 11 East Park Street, Butte, MT 59701, USA
marco.restani@northwestern.com
James S. Lueck, NorthWestern Energy, 11 East Park Street, Butte, MT 59701, USA

Abstract: Bird interactions with electric power lines can cause faults (e.g., disruption of electrical service). Faults on 500kV transmission lines in Montana, USA, which are integral to the Northwest USA power grid, became concerning during winter 2016–2017. In 2017 we found insulators contaminated with bird droppings and discovered a large nocturnal roost of common ravens (*Corvus corax*). To assess the potential magnitude of the impact of raven roosts on electric power transmission, we summarized fault data obtained from the Energy Management System and raven abundance data obtained from the Christmas Bird Count in central Montana from 2005 to 2020. We also conducted counts at 7 roosts in the study area in winter 2019–2020. We detected a positive relationship between the number of faults reported and raven abundance. The 3 largest roosts we surveyed peaked at 1,000–1,500 ravens on single evenings. The number of faults reported in winter 2019–2020 decreased after use of silicon-coated insulators, perch deterrents, and periodic washing of insulators. Increased raven populations throughout their range may cause similar conflicts for other electric utilities. Long-term management of ravens will need to integrate approaches at both local and landscape scales.

Key words: common raven, *Corvus corax*, electric power transmission line, electrical fault, human–wildlife conflicts, Montana, nocturnal roost, perch deterrent, raven abundance

Bird use of electric power distribution poles and transmission line towers for perching and nesting can affect species conservation and the reliability of electrical service (Avian Power Line Interaction Committee [APLIC] 2006). For example, the number of electrocutions of golden eagles (*Aquila chrysaetos*) across North America is of conservation concern (Mojica et al. 2018). Other species such as the common raven (*Corvus corax*) use utility corridor infrastructures for perching, nesting, and roosting. Increased raven abundance related to anthropogenic habitat subsidies have been implicated in declines of greater sage-grouse (*Centrocercus urophasianus*; Coates et al. 2014).

Bird–power line interactions can also lead to disruption of electrical service via faults. A fault is an interruption of power that may or may not produce an outage (Short 2005). Depending on the equipment impacted, faults can be either temporary (i.e., power is quickly restored through automated mechanisms) or sustained (i.e., power is restored only after site inspection and manual operations).

The parallel, single-circuit 500kV electric power transmission lines in central Montana, USA are an integral part of the Northwest power grid, which stretches from Montana to Washington, USA. These lines have experienced faults of unknown origin since being energized in 1983 (J. S. Lueck, NorthWestern Energy, unpublished data). Large transmission lines can fault through flashovers precipitated by lightning, fire, ice, and line galloping. Research conducted along the 500kV lines (Maehl 1996; D. N. March, March Engineering, Inc., unpublished report) and subsequent analyses of electrical data from 2002 to 2010 determined that faults were likely caused by raptor "streamers" (i.e., fluid feces many meters in length that are conductive and able to bridge the air gap between conductors and towers; Burnham 1995).

More recent faults on the 500kV transmission lines from January to March 2017 differed from past events by being sustained and, therefore, were of greater concern and consequence to service of the Northwest power grid (J. S. Lueck,

NorthWestern Energy, unpublished data). The subsequent discovery of insulators heavily contaminated with bird droppings suggested that recent faults were not caused by raptor streamers (Burnham 1995). Faults occurred most often during dense fog or misty precipitation in late winter and early spring, which also suggested a different electrical mechanism responsible for the problem (e.g., insulation breakdown, not air gap breakdown). During several evenings in November 2017, we discovered hundreds of common ravens roosting on 500kV towers previously contaminated with bird droppings, thereby seemingly identifying the cause of recent faults.

Ravens roost on trees, cliffs, and anthropogenic structures such as towers, buildings, and bridges (Engel et al. 1992, Restani et al. 1996, Janicke and Chakarov 2007, Peebles and Conover 2017). The single-night number of ravens counted at an individual roost can be impressive; 2,100 in Idaho, USA (Engel et al. 1992), 1,900 in Wales, United Kingdom, (Wright et al. 2003), 1,500 in California, USA (Cotterman and Heinrich 1993), and 800 in Oregon, USA (Stiehl 1981). Raven roosts are typically seasonal, forming in autumn and disappearing in late spring as individuals disperse to breeding territories (Stiehl 1981, Wright et al. 2003, Janicke and Chakarov 2007). Many roosts are traditional, with some existing for 10–15 years (Stiehl 1981, Engel et al. 1992, Wright et al. 2003).

Raven roosts also had been reported on electric power transmission towers supporting a 500kV transmission line that crosses southern Idaho and Oregon in the 1980s (Engel and Young 1989, Engel et al. 1992). No mention was made of faults caused by roosting, although that concern was what prompted management-oriented research published in federal agency reports (Young and Engel 1988, Beck 1989). Perch deterrents were installed to reduce the number of ravens roosting directly above insulators. Positioning of deterrents, however, allowed the use of other portions of a tower. The Idaho-Oregon roosts were occupied almost exclusively during summer, a pattern that appeared to differ from our cursory observations in Montana (J. S. Lueck, NorthWestern Energy, unpublished data).

The 500kV transmission lines in Montana have been in service for nearly 40 years, and their use by roosting ravens appeared to be a recent phenomenon. We reviewed the scientific literature and readily available government reports seeking guidance on how to manage the emerging conflict. We found only the study conducted in Idaho-Oregon (Young and Engel 1988, Engel and Young 1989). We also posted an inquiry to the APLIC member listserv soliciting information of ravens roosting on transmission towers (>230 kV). The listserv included approximately 225 representatives from >50 electric utilities throughout the United States and Canada. No responses were received. Finally, we contacted utility company biologists in several western U.S. states (California, Colorado, Idaho, Utah, Wyoming), and none knew of ravens roosting on transmission towers.

The limited amount of literature and lack of expertise held by utility companies prompted our descriptive study. First, we evaluated trend in the number of faults over time (2005–2020). We then investigated the relationship between raven abundance from 2005 to 2019 (i.e., data from the Christmas Bird Count) and the number of faults. We also conducted roost counts during winter 2019–2020 to gain perspective on the magnitude of raven use of 500kV towers, something unknown in our study area and which augmented information from the only study we found concerning this phenomenon (Engel and Young 1989, Engel et al. 1992). Finally, from 2017 to 2020, we implemented several management actions to reduce the number of raven-caused faults. We also present the initial results on the effectiveness of perch deterrents.

Study area

The study area was located in central Montana and extended approximately 230 km along the parallel, single-circuit 500kV electric power transmission lines from Treasure County to Wheatland County (45.958305, -107.218042 to 46.295394, -110.020110; Figure 1). The steel lattice towers, most of which were supported by 4 guy wires, were spaced 350–450 m apart depending on topography and line corridor. Towers ranged in height from 17–43 m. V-insulator strings 3.2–3.7 m in length supported 3 phases, each comprised of 4 bundled conductors, 1 located higher at the center of towers, and 2 located lower below the outside arms. Towers were protected from lightning

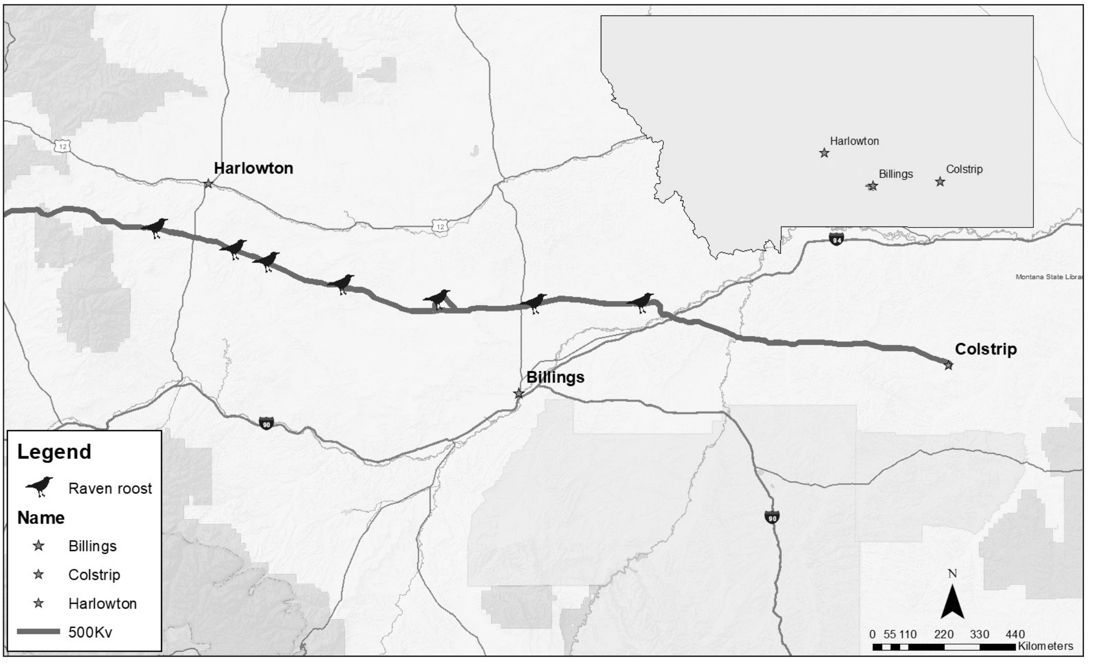

Figure 1. Location of the study area in central Montana, USA.

strikes by 2 overhead ground wires.

The electric power transmission lines traversed flat to hilly topography (elevation 845–1,575 m) dominated by a mixture of agricultural land embedded within sagebrush-steppe (*Artemisia* spp.). Agricultural lands supported both dryland and irrigated crops, grazing, and feedlots. Hilly terrain broken by sandstone cliffs and coulees supported scattered stands of Ponderosa pine (*Pinus ponderosa*).

The transmission lines were purposefully constructed away from human settlements, and the nearest small towns (population 50–200) were located approximately 5–15 km from the lines. The largest town (Billings, Montana; population 110,000) was located 30 km from the lines. Within the study area, the transmission lines crossed 1 state highway, 2 U.S. highways, and 1 interstate highway. Another U.S. highway ran approximately parallel 15–40 km to the north of the transmission lines for 150 km. In general, features of the human-altered landscape of the study area appeared similar to landscapes that supported large raven populations across the species range (Boarman and Heinrich 2020). The Great Plains Mixedgrass Prairie has a semi-arid, mid-continental climate with hot summers and cold winters. Most annual precipitation (25–40 cm) occurred in late spring and early summer.

Methods

Substation terminals along the 500kV transmission lines included protective relay devices that detected faults. Faults were initially identified through the Energy Management System by Supervisory Control and Data Acquisition processes. From 2005 to 2020, we obtained data of faults from NorthWestern Energy Grid Operations and were able to determine the precise towers where faults occurred. We also examined these data to determine if the transmission line reclosed, amperage shifts, distance from a substation, and tower location. This information allowed us to identify suspected bird-caused faults (i.e., raptor streamers) and faults of unknown origin. We subsequently visited towers to investigate faults of unknown origin but that bore similarities to raven-caused faults (e.g., insulators contaminated with droppings, repeated faults in specific locales, recent weather events promoting leakage of electrical current, season).

Beginning in 2017, we implemented several actions to mitigate raven-caused faults. First, tower crews replaced standard glass insulators

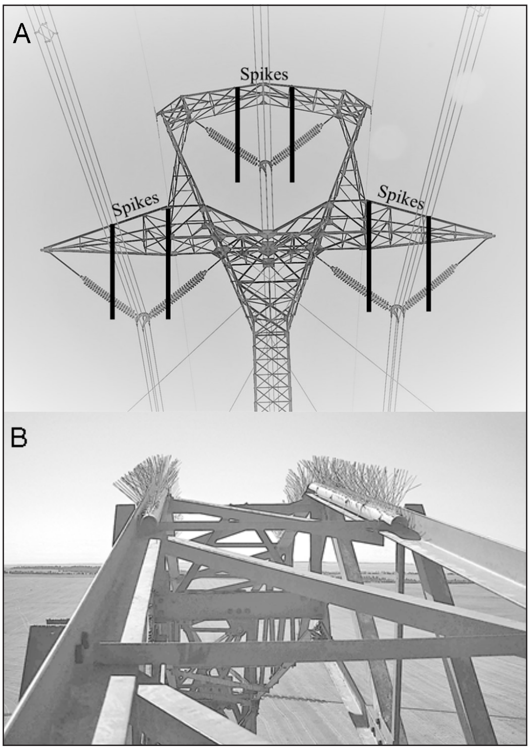

Figure 2. The location of perch deterrent spikes on a 500kV electric power transmission line tower in central Montana, USA, 2018–2020 (A). Vertical lines depict how the mounting of perch deterrents protected half of each insulator string from accumulating droppings associated with common ravens (*Corvus corax*) roosting on beams above the insulators. Close-up of spike attachment (B).

with silicon-coated insulators on towers within the largest roosts along the 500kV transmission lines. Silicon-coated insulators have typically been used in marine environments to mitigate faults derived from salt accumulation and coastal fog (Hall and Orbeck 1982). We believed that the physical properties of silicon-coated insulators (i.e., hydrophobic, higher flashover voltage ratings, longer current leakage paths) might also protect against contamination from raven droppings.

In addition, between 2017 and 2019, tower crews washed contaminated insulators within roosts. Contaminated insulators were also discovered through transmission line maintenance flights (i.e., preemptive cleaning) and from ground inspections following faults (i.e., retroactive cleaning). Crews accessed towers by either direct climb from the ground or by bucket truck. Contaminated insulators were cleaned by hand or power washer.

Finally, from 2018 to 2019, crews installed perch deterrents (e.g., stainless steel spikes; Bird-X, Elmhurst, Illinois, USA) to the beams above insulators on towers within roosts where faults occurred. Spikes 22 cm in length were ordered in coiled strips of 30 m. Spike strips of varying lengths were then attached with screws to a PVC conduit 8 cm in diameter that had been custom cut to fit tower beams of differing sizes and configurations. Crews used metal zip ties to attach conduits fitted with spike strips to tower beams. Only beams above insulators were fitted with perch deterrents, which allowed ravens to roost on other portions of towers (Figure 2).

To characterize the relative size and trend of the local raven population, we used data from the Christmas Bird Count (1939–2019) for Billings, Montana, the count circle nearest to roosts (29–128 km) on the 500kV transmission lines (National Audubon Society 2020). The count circle had a radius of 12.1 km and was located at 45.816656, -108.433380. The location and size of the count circle were fixed over time, and counts were conducted in December of each year. Raw annual Christmas Bird Count data were standardized to observer effort (i.e., party hour) because the number of observers and survey durations varied annually. Before evaluating the trend of raven abundance, we visually examined the count data to characterize population growth (i.e., exponential, linear, logistic).

We summed the number of bird-caused faults for each October–April period from 2005 to 2020, the months we suspected the vast majority of ravens roosted on towers based on behavior reported in the literature (Wright et al. 2003, Janicke and Chakarov 2007, Peebles and Conover 2017). We then used simple linear regression to determine whether there was a trend in the number of faults for each October–April period and the corresponding winter period (e.g., 2005–2006) from 2005 to 2020. We also used simple linear regression to evaluate the relationship between the number of faults during a winter (e.g., October 2018 to April 2019) and the corresponding size of the raven population estimated from the annual Billings Christmas Bird Count (e.g., December 2018).

From November 2019 through April 2020, we counted the number of ravens at the known

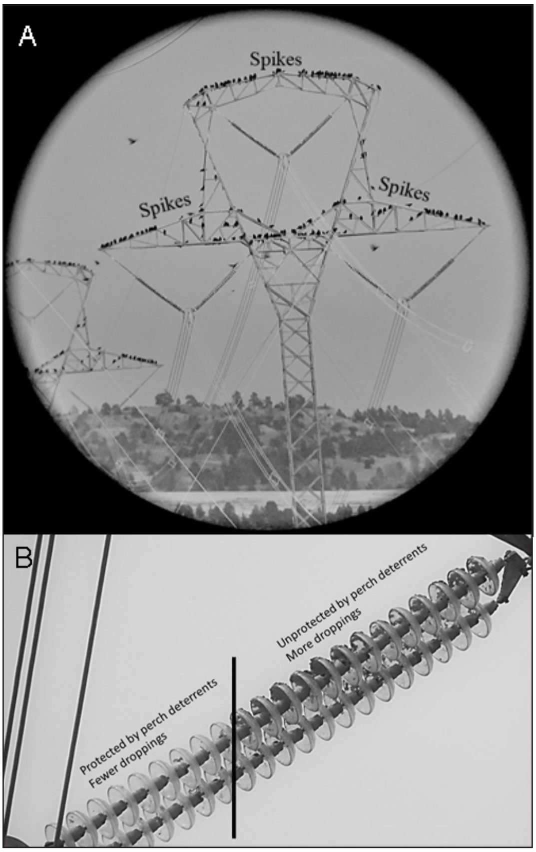

Figure 3. Perch locations of common ravens (*Corvus corax*) roosting on 500kV transmission line towers fitted with deterrents (spikes) in central Montana, USA, during winter 2019–2020 (A). Ravens avoided perch deterrents, which reduced the accumulation of droppings on half of each insulator string (B).

nocturnal roosts (n = 7) once a month. Counts were conducted from a vehicle parked at a good vantage point approximately 1,000–2,600 m from the nearest tower used for roosting based on the presence of contaminated insulators or prior fault history. Depending on location, roosts were comprised of 2–10 towers, and vantage points selected gave unobstructed views of the entire roost and raven flight paths. We used binoculars (10 x 40) and a spotting scope (20–60 x 80) to count ravens from 60–210 minutes before sunset until darkness when ravens no longer arrived to roosts, usually 35–45 minutes after sunset. Before ravens began to arrive, we checked tower insulators from the ground and ranked the accumulation of droppings as clean, light, moderate, or heavy. We also conveyed this information to the tower crews responsible for washing insulators.

Results

Crews replaced all of the standard glass insulators with silicon-coated insulators on 7 towers within 2 roosts during September 2017. From October 2018 through October 2019, crews installed perch deterrents on 92 towers. Crews installed deterrents on an average of 4 towers per day, depending on travel time to field sites. The vast majority (92%) of deterrents were installed from April 2019 to October 2019. Perch deterrents were mounted above and over approximately half of each insulator string on 3 areas of each tower. Ravens were able to roost on other portions of the tower while deterrents reduced the accumulation of droppings on about half of each insulator string (Figure 3).

From 2017 through 2019, field crews washed insulators contaminated with raven droppings. Effort expended by crews to wash towers totaled 10 days in 2017, 11 days in 2018, and 8 days in 2019. Only 1 tower per day could be washed if done by hand while climbing. The number of towers that could be cleaned increased with the use of a bucket truck and sprayer (2–3 towers per day) and was greatest in late winter 2020 when a helicopter-mounted sprayer was entered into service (8 towers per day). The helicopter was used for 10 days in 2020.

The number of bird-caused faults has increased from winter 2005–2006 to winter 2019–2020 ($r^2 = 0.26$, $F_{1,13} = 4.62$, $P = 0.051$). The number of faults declined after crews completed the installation of perch deterrents in 2019 (i.e., 6 faults in winter 2019–2020 vs. 10–19 faults per winter from 2015–2016 to 2018–2019). When winter 2019–2020 was excluded from the analysis, the strength of the relationship increased ($r^2 = 0.38$, $F_{1,12} = 7.43$, $P = 0.018$).

The number of ravens observed during the Billings Christmas Bird Count has grown exponentially ($r^2 = 0.84$, $F_{4,37} = 48.74$, $P < 0.001$; Figure 4). The Billings count began in 1939 and has run annually since 1949. The first raven was observed in 1979. A positive relationship existed between the number of bird-caused faults during the October–April roosting period and the number of ravens observed on the Billings Christmas Bird Count from 2005–2006 to 2018–2019 ($r^2 = 0.28$, $F_{1,12} = 5.15$, $P = 0.045$; Figure 5). We excluded winter 2019–2020 from the analysis because the installation of perch deterrents mentioned previously reduced the

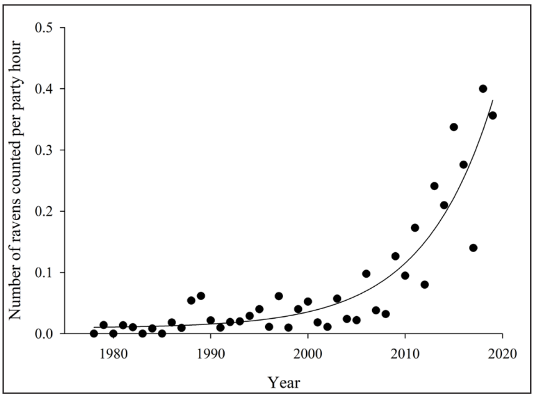

Figure 4. Abundance of common ravens (*Corvus corax*) from the Christmas Bird Count in Billings, Montana, USA, at the count circle nearest to the 500kV transmission lines. Christmas Bird Count data (1978–2019) from National Audubon Society (2020).

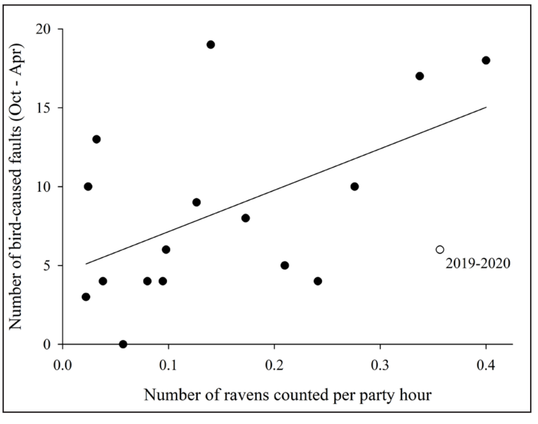

Figure 5. The relationship between the number of common ravens (*Corvus corax*) counted on the Billings Christmas Bird Count and the number of bird-caused faults recorded on 500kV transmission lines in central Montana, USA, 2005–2020. Data from 2019–2020 (open circle) excluded from analysis (see text).

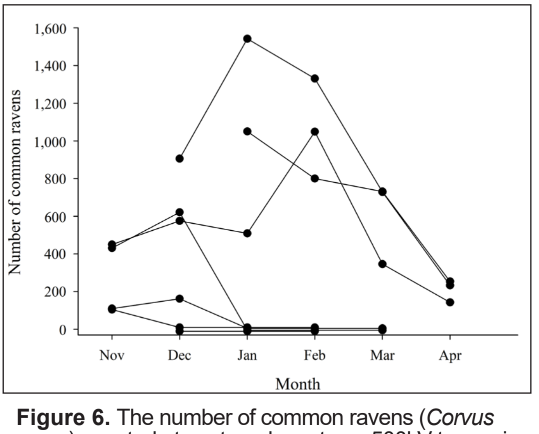

Figure 6. The number of common ravens (*Corvus corax*) counted at nocturnal roosts on 500kV transmission line towers in central Montana, USA, during winter 2019–2020. Each line represents a different roost.

number of faults by 40–69% annually.

We conducted raven counts at the 7 known roosts during winter 2019–2020 (Figure 6). Depending on the roost, the number of ravens peaked between December and February. Three roosts supported ravens in early winter but were abandoned as the season progressed. The number of towers used for roosting varied from 2–10 at specific locations, and most used by ravens were 36 m tall. The $\bar{x} \pm$ SE distance between roosts was 36.5 ± 5.4 km ($n = 7$). Ravens congregated at pre-roosts from 20–50 minutes before sunset and, in general, ravens arrived at the larger roosts earlier than the smaller roosts. Pre-roosts were located on the ground in flat areas devoid of tall vegetation (e.g., prairie dog [*Cynomys ludovicianus*] colonies, stubble fields, frozen lakes). Distance from pre-roosts to towers used for roosting averaged 1,720 ± 488 m ($n = 7$).

Discussion

Raven abundance in central Montana has increased significantly the past 10–15 years (Pardieck et al. 2019). Our analyses suggested a relationship between the increased faults experienced on the 500kV electric power transmission lines in our study area and raven abundance. Population growth of ravens in Montana reflected increases (125–1,500%) recorded across the species range in the United States, Canada, and Europe the past few decades (Marzluff et al. 1994, BirdLife International 2004, Boarman et al. 2006).

As elsewhere, a combination of factors at the landscape scale likely facilitated raven population growth in central Montana. Ravens have proliferated in fragmented landscapes containing patches of agriculture and energy production embedded within sagebrush-steppe and native grassland (Bui et al. 2010, Coates et al. 2014). Ravens are generalist feeders, and human-altered landscapes provided food subsidies (e.g., cereal grains [Engel and Young 1989]; landfills, [Restani et al. 1996]) and natural prey (Bui et al. 2010). Ravens often foraged along roads where vehicle-killed mammals and birds were available food sources (Conner and Adkisson 1976, Knight and Kawashima 1993). Ravens also exploited ungulate remains left by hunters (Restani et al. 2001, White 2006) and large carnivores (e.g., wolves [*Canis lupus*]; Stahler et al. 2002). Finally, raven populations

have probably benefitted from decreases in the indirect mortality associated with poisoning campaigns for large predators (Boarman and Heinrich 2020) and the direct mortality from indiscriminate and bounty-rewarded shooting (Restani et al. 2001).

The winter raven population in central Montana is exhibiting exponential growth, and continuing challenges to the operation of the 500kV transmission lines should be expected. First, existing roosts have the potential to become larger and spread onto previously unused towers because the largest roost in this study (>1,500 ravens) was substantially smaller than a roost (>2,100 ravens) in Idaho-Oregon (Engel et al. 1992). Second, new roosts may also form. The distance between roosts in this study averaged 36.5 km, which was 3 times greater than that reported in Idaho-Oregon (12.4 km; Engel et al. 1992). Thus, the number and location of roosts in central Montana do not appear to be space-limited. Both circumstances would require the installation of perch deterrents to additional towers and the periodic washing of insulators.

The number of ravens roosting on 500kV towers showed a predictable seasonal pattern with counts highest in mid-winter. Thereafter, size of roosts declined, presumably as breeding pairs dispersed to establish territories in March and April. These patterns were similar to seasonal use in Utah (December to February; Peebles and Conover 2017), Wales (January; Wright et al. 2003), and Germany (February; Janicke and Chakarov 2007).

The 3 largest roosts on the 500kV towers in our study area in central Montana peaked at 1,542, 1,050, and 1,049 ravens, respectively. These numbers were comparable to or exceeded raven roost counts in Utah (750; Peebles and Conover 2017), Wales (1,900; Wright et al. 2003), and Germany (500; Janicke and Chakarov 2007). As winter progressed, the number of roosts on the 500kV towers declined and 3 "super roosts" formed, a pattern similar to Idaho-Oregon where researchers monitored 13 roosts, of which only 5 were considered major roosts (Engel et al. 1992).

We did not record the perch locations of roosting ravens, although the vast majority appeared to roost on the tops of towers and on the arms supporting outside conductors. Counts were scheduled for evenings expected to have good visibility and no precipitation. Thus, we did not determine how weather affected arrival times and perch locations. Other researchers have reported little effect of wind and precipitation on roost arrival times, tower perch locations, or roost size (Engel et al. 1992, Janicke and Chakarov 2007, Peebles and Conover 2017).

Ravens have commuted daily 25–55 km 1-way to nocturnal roosts in other regions (Wright et al. 2003, Preston 2005). Therefore, the roosts along the 500kV lines in central Montana could have attracted ravens that foraged during the day at the Billings landfill, along highways supplying vehicle-killed carrion, and at agricultural operations. Very few ravens were observed in the vicinity of roosts during the day, which made initial identification of their role in faults difficult to detect. The seasonal movements of ravens in other regions have also played a role in roost formation, where individuals migrated 500 km from their breeding range during autumn to food-rich areas in winter (Restani et al. 2001, Webb et al. 2009, Baltensperger et al. 2013, Loretto et al. 2016). The combination of conspecific attraction and anthropogenic food sources was the strongest factor explaining the movements of juvenile ravens after fledging. For example, a juvenile raven that was radio-tagged in Yellowstone National Park in November 2019 used a broad geographic area in central Montana and spent nights at several roosts along the 500kV transmission lines during winter before migrating to Alberta, Canada in April 2020 (J. Marzluff, University of Washington, personal communication).

We installed and positioned perch deterrents to protect approximately half of the insulator strings, which effectively broke the leakage path of current responsible for faults. By design, deterrents limited but did not exclude raven use of specific towers. Somewhat counterintuitively, our goal was to keep ravens on the towers they were using to discourage them from spreading to new towers, which would have created additional fault risks and mitigative effort.

Installing perch deterrents was labor and time intensive. We did not follow an experimental design, and thus our result that the number of faults from 2019–2020 decreased on towers with deterrents despite continued increases in raven abundance should be viewed

as preliminary. Although wind-dispersed raven droppings eventually contaminated the entire length of insulator strings on towers with perch deterrents, the rate of accumulation was much decreased, which reduced the time and effort needed for washing. Seasonal rains and declining roost sizes kept insulators free of contamination from spring to autumn.

The silicon-coated insulators installed on 7 towers within the largest roosts in 2017 provided superior protection from the current leakage paths created by raven droppings. These insulators did not need to be washed and were an effective long-term option to reduce faults, but they were expensive; thus, wider use was cost-prohibitive relative to other management actions.

We considered but ultimately decided against hazing, shooting, and effigies or carcasses to reduce the size of raven roosts (Merrell 2012, Peebles and Spencer 2020) because these methods can illicit strong negative reactions from the public. More importantly, these methods have the additional potential drawback of dispersing ravens to other towers, thereby spreading the risk of contamination and increasing the possibility for faults over a wider area.

Perhaps the best long-term means to manage ravens is to reduce the habitats and food resources that sustain populations and support growth (Boarman et al. 2006, Webb et al. 2009, Bui et al. 2010, Baltensperger et al. 2013). Managers recommend reducing food availability at landfills, changing feedlot and dairy operations, burying dead livestock, removing vehicle-killed animals, and covering commercial dumpsters. These efforts would take years—perhaps decades—to have a noticeable effect on raven populations in central Montana and would need to occur over a spatial scale measuring 230 km by 55 km (i.e., the length of our study area by the distance ravens commute to roosts). Such actions are currently impractical to reduce raven-caused faults on the 500kV transmission lines.

Management implications

Our analyses suggested a relationship between the increased faults experienced on the 500kV electric power transmission lines in our study area and raven abundance. Increasing raven populations, which are often associated with anthropogenic subsidies, are not only a concern for public utilities but for several at-risk wildlife species. To mitigate short- and long-term human–wildlife conflicts associated with increasing raven populations, researchers and managers will need to consider and integrate approaches at both local and landscape scales.

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Associate Editor: Peter S. Coates

Marco Restani is a wildlife biologist for NorthWestern Energy. He is also professor emeritus,

St. Cloud State University. His research and management program focuses on raptors and ravens. He holds a B.S. degree from the University of Montana, M.S. degree from Montana State University, and Ph.D. degree from Utah State University.

James S. Lueck has worked for NorthWestern Energy within the electric transmission department

since 1975. He is currently the advisor for the 500kV electric transmission operations. He holds an associate degree in electrical engineering technology.