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Testing systems of avian perch deterrents on electric power distribution poles in sage-brush habitat

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Abstract: In Lincoln County, Washington, USA, greater sage-grouse (*Centrocercus urophasianus*) and Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) are managed as reintroduced and augmented populations, respectively. Predation by raptors and corvids is a concern, particularly where utility poles may provide hunting perches near leks (i.e., breeding areas). Perch deterrents may offer a mitigating strategy if deterrents reduce the frequency or duration of perching. To investigate the effects of various perch deterrents, we deployed deterrents on 5 power poles retained for use in this study when 33 poles were removed from occupied grouse habitat. We rotated deterrents among poles every 15 to 28 days ($\bar{x}$ = 19.4 days) from November 17, 2011, through November 20, 2012, so that all deterrents occurred multiple times on all poles. We compared perch frequency and duration on 4 pole caps, 3 insulator deterrents, an untreated control cross arm, and 5 cross-arm-length deterrents: Pupi™ cross arms mounted at a 22° angle from horizontal; Birdzoff™ deterrents; an experimental shroud; Power Line Sentry X™ deterrents; and Zena Designs™ mini-spike deterrents. We collected 862 independent records of perching events. Raptors and corvids perched most often (χ^2 = 146.0, P < 0.0001) on untreated cross arms ($\bar{x}$ = 0.60 perches/day), and insulator deterrents ($\bar{x}$ = 0.47 perches/day), and perched least often on pole caps with spikes ($\bar{x}$ = 0.11 perches/day) and Zena Designs mini-spikes ($\bar{x}$ = 0.10 perches/day). Perching events were shorter on pole caps with spikes and Zena Designs mini-spikes compared to all other treatments ($F_{8,853}$ = 23.53, P < 0.0001). Prey captures also were significantly less likely from treated cross arms than from the control cross arm (χ^2 = 86.5, df = 4, P < 0.0001). Birds attempting to perch on deterrents often flapped their wings broadly where energized conductors would have existed if the poles had not been decommissioned. On energized poles, electrocution would have been possible in this situation. When perch deterrents are used, insulation or isolation of energized equipment also must be installed to minimize electrocution risk.

Key words: *Centrocercus urophasianus*, Columbian sharp-tailed grouse, corvid, electrocution, greater sage-grouse, perch deterrent, power line, raptor, *Tympanuchus phasianellus columbianus*

As a consequence of landscape conversion, fragmentation, and degradation, sagebrush (*Artemesia* spp.) ecosystems are among the most threatened landscapes in North America (Noss and Peters 1995, Mac et al. 1998), and populations of many sagebrush-dependent species are declining (Hanser and Knick 2011). Greater sage-grouse (*Centrocercus urophasianus*) and Columbian sharp-tailed grouse (*Tympanuchus phasianellus columbianus*) exemplify the risks faced by sagebrush-dependent species. Habitat changes, hunting, disturbance, invasive species, disease, mining, livestock grazing, and changes in fire regimes have led to extirpation of greater sage-grouse from almost half its native range (Schroeder et al. 1999, 2004, Wisdom et al. 2011), and extirpation of sharp-tailed grouse from approximately 40% of the states they once occupied (Connelly et al. 1998). Because ≥350 species use sagebrush ecosystems during at least some part of the year (Wisdom et al. 2005), both grouse species have come to be viewed as "umbrella species" whose conservation at a landscape scale might directly enable the conservation of other species (Hanser and Knick 2011).

Responses by grouse to energy infrastructure development and electric energy distribution and transmission are not well-known, but they are topics of particular interest to researchers and managers (Lyon and Anderson 2003, Doherty et al. 2008, Holloran et al. 2010). Potential avian predators routinely perch on utility poles (Prather and Messmer 2010, Dwyer and Leiker 2012), and utility poles may offer hunting sites for avian predators near leks and grouse nesting areas where tall perches are naturally scarce. Corvidae and raptor species at or near leks may lead to reduced survival of grouse (Ellis 1984, Schroeder et al. 1999). For example, 23 of 91 greater sage-grouse mortalities and 21 of 78 sharp-tailed grouse mortalities documented from the spring of 2008 through the spring of 2011 in eastern Washington were attributed to avian predators (Schroeder et al 2012*a*, 2012*b*). Consequently, Washington state's Columbian sharp-tailed grouse recovery plan called for installation of perch management devices on utility poles in grouse habitat (Stinson and Schroeder 2012).

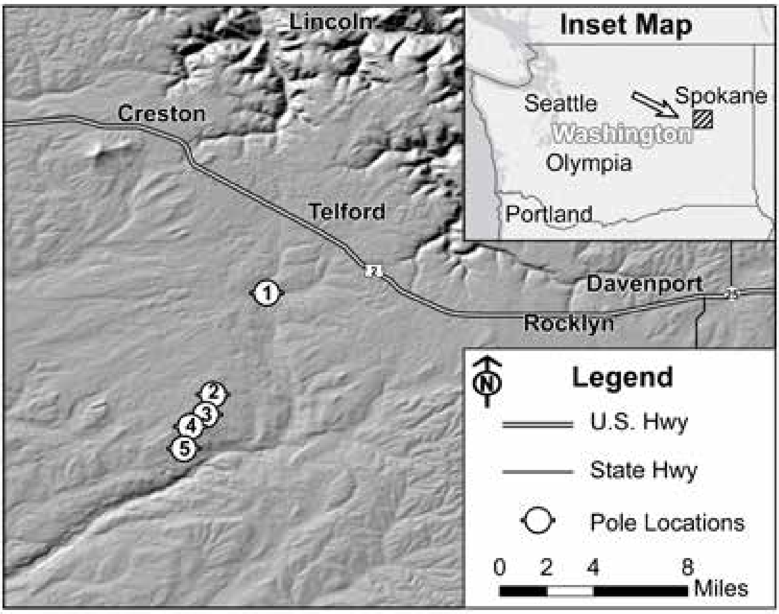

Figure 1. Locations of utility poles included in this study in Lincoln County, Washington.

Perch management devices are used primarily to prevent avian electrocution on power poles, but often they are less effective than covering energized parts American Power Line Interaction Committee (2006). Where perch management has been investigated with respect to predation, Slater and Smith (2010) reported reduced perch frequency on a transmission line where all horizontal surfaces were fitted with spiked perch deterrents. In contrast, Lammers and Collopy (2007) and Prather and Messmer (2010) found little evidence that commercially available perch deterrents substantially reduced perching. However, Lammers and Collopy (2007) report that their conclusions were confounded by small sample size and overlapping confidence intervals, and all of the images of perching birds in Prather and Messmer (2010) are of birds perching on pole tops and insulators where deterrents were not installed. When pole-cap deterrents were installed, perch management tended to be more effective (Slater and Smith 2010). A pole cap is any device that is placed on the top end of a pole and that is meant to prevent birds from perching.

Thus, though some perch deterrents appear to be effective, the best available science is inconclusive overall, with no data available comparing the relative effectiveness of various recently developed perch deterrents. Distribution power structures, i.e., those typically observed providing power to residences and businesses, typically include a pole, a cross arm, and 3 insulators, where each insulator supports 1 energized wire. We hypothesized that perching could be reduced if the tops of poles were fitted with pole caps, cross arms were fitted with cross-arm-length deterrents, and insulators were fitted with insulator deterrents in a deterrent system covering all horizontal surfaces. We specifically hypothesized that some deterrents would be more effective than others. We also believed that if new technologies could be incorporated to reduce the human effort required to monitor deterrent devices, sample sizes might be improved. Herein, we describe a study comparing perching on poles with a control cross arm to perching on poles incorporating 12 different types of perch deterrents.

Methods

Study area

We conducted this study in Lincoln County, Washington, approximately 23 km west of Davenport, Washington (Figure 1), on the Twin Lakes scablands (latitude 47.581300 N, longitude –118.464000 W). The Twin Lakes scablands were jointly managed by the Bureau of Land Management (BLM) and the Washington State Department of Fish and Wildlife (WDFW) in non-overlapping sections. Scablands were composed of a series of shallow channels and rounded ridges formed approximately 12,000 years ago by high volume floods following cyclic collapses of a Cordilleran ice dam (David 2001). Elevations range from 670 to 700 m. The land was managed for wildlife habitat, recreation, and seasonal livestock grazing. Managers used a combination of prescribed fire, mechanical and chemical controls, and native and nonnative planting projects to maintain a high-quality sagebrush ecosystem. Alternate perches were rare, though scattered trees and power lines existed throughout the management area, and wire fences were common.

Selection of study poles

Power poles typically support 1, 2, or 3 energized wires called "phases." The most common configurations in the United States are 3-phase structures with 3 energized wires and a non-energized neutral wire (American Power Line Interaction Committee 2006). Prior to the initiation of this study, 2 3-phase distribution overhead power lines extended perpendicularly to terminal structures from a longer power line bisecting the study area. These terminating lines were decommissioned, and all but four of the 33 poles supporting the lines were removed. Each of the 4 remaining poles was retained for this study because they were regularly used by raptors before the line was removed (K. Doloughan, personal observation), occurred on a prominent position in the landscape, were near telemetry locations for radio-tagged greater sage-grouse and Columbian sharp-tailed grouse and occurred within 2 to 5 km of ≥1 grouse (Bureau of Land Management, unpublished data). A fifth, de-energized pole overlooking a pasture and in similar proximity to a grouse lek, but not part of the same power line as the other poles, also was installed to help diversify the characteristics of the studied poles and facilitate testing a greater number of deterrents. Average separation between poles was 2.86 km (minimum 1.09 km, maximum 7.41 km, SE 1.52 km). Average distance from poles to the nearest grouse telemetry data was 336 m (minimum 55 m; maximum 1,315 m; SE 245 m). The characteristics of each of these poles ensured that it would be attractive to potential avian predators, thus, enabling us to compare various perch deterrents.

Selection of perch deterrents

We tested 4 types of pole caps, 3 types of insulator deterrents, and 5 cross-arm-length deterrents (Table 1). We began our study with a control cross arm, 4 cross-arm-length deterrents, a pole cap on each pole, including the pole fitted with the control cross arm, and 3 insulator deterrents (one for each of 3 insulators) on each treated cross arm. We intended to focus on the effectiveness of the cross arm-length deterrents because we assumed that the pole caps and insulator deterrents would be effective ancillary components. However, during the first month of our study, we found substantial perching on nonspiked pole caps and insulator deterrents, such that birds could avoid cross arm-length perch deterrents by perching exclusively on these components.

We subsequently modified pole caps (Figure 2a through 2c) and insulator deterrents to include spikes (Figure 2d through 2f; Table 1). The unspiked pole cap was manufactured by Zena Designs (Odenville, Ala.). Our first spiked pole cap was constructed by drilling a hole in the top of the Zena Designs pole cap and inserting a spike from the Zena Designs cross-arm-length perch deterrent, described below. After describing this modification to product representatives of Birdzoff (Santa Monica, Calif.), and Kaddas Enterprises (Salt Lake City, Ut.), we replaced our home-made spiked pole cap with commercial designs by these manufacturers.

Prior to this study, we were aware of only 1 manufacturer of insulator deterrents (Power Line Sentry™, Fort Collins, Col.). This deterrent

Table 1. Use of deterrents throughout the 19 rotation study in central Washington. Dots reflect the time when a each deterrent was employed.

	2011			2012															
	Nov	Dec		Jan	Feb	Mar		Apr		May	Jun	Jul		Aug	Sept		Oct	Nov	
Deterrent rotation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Deterrents																			
Pole caps																			
Zena designs unspiked	•	•	•	•															
Zena designs spiked					•	•	•	•	•	•									
Birdzoff spiked											•	•	•	•					
Kaddas spiked															•	•	•	•	•
Insulators																			
Unspiked	•	•	•	•															
Angled spike					•	•	•	•	•	•									
Vertical spike											•	•	•	•	•	•	•	•	•
Cross arm treatments																			
Pupi cross arm at 22°	•	•	•	•	•	•	•	•	•										
Birdzoff										•	•	•	•	•	•	•	•	•	•
Shroud	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Power Line Sentry Xs	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Zena Designs spikes	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Undeterred controls																			
Control cross arm	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Control insulator	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

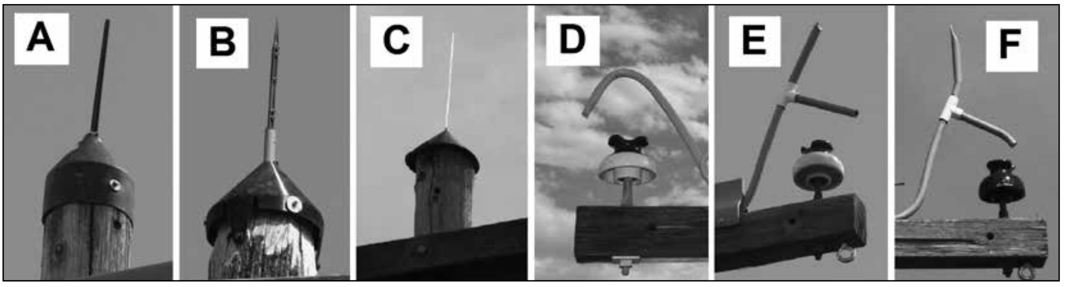

Figure 2. Perch deterrents tested: (A) Zena Designs pole cap with spike (Zena pole caps without spikes were also tested); (B) Birdzoff pole cap with spike; (C) Kaddas pole cap with spike; (D) nonspiked insulator deterrent; (E) angle-spiked insulator deterrent; (F) vertically-spiked insulator deterrent.

was designed specifically as an accessory for Power Line Sentry's cross-arm-length deterrent. To facilitate this study, we worked with Power Line Sentry to adapt their insulator deterrent to be mounted independently, so that all treated cross arms could be fitted with insulator deterrents. We modified insulator deterrents after 4 rotations to include a spike (Table 1), and again after 6 more rotations to make the spike more vertical because birds readily perched on these deterrents otherwise.

We evaluated perching on 5 cross-arm-length perch deterrents (Figure 3a through 3e). The first cross arm-length deterrent evaluated was a Pupi™ (Stewartville, Minn.) fiberglass cross arm mounted at a 22° angle from horizontal. Following discussions with members of the electric industry, we understood the angled cross arm was unlikely to be accepted by the electric industry even if it were successful because it reduced clearances between energized wires and the ground, so we replaced it after 9 rotations (Table 1) with a cross arm fitted with a Birdzoff spike and cord deterrent. Each of the

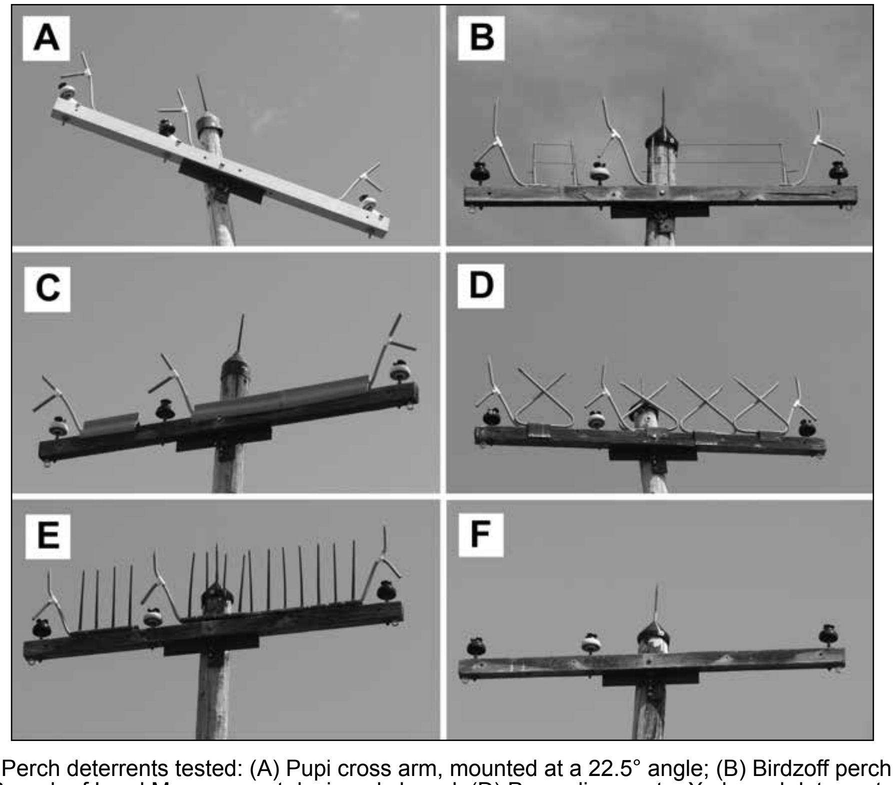

Figure 3. Perch deterrents tested: (A) Pupi cross arm, mounted at a 22.5° angle; (B) Birdzoff perch deterrent; (C) Bureah of Land Management designed shroud; (D) Power line sentry X-shaped deterrent; (E) Zena Designs mini-spikes; (F) control cross arm and control insulators without perch deterrents other than a pole cap.

Figure 4. Example of studied pole (left) and camera pole (right). Experimental deterrents were added to the trial pole during each rotation.

other cross-arm-length deterrents was tested for the duration of the study. These included a cross arm fitted with a cross-arm-length shroud designed to minimize the surface area of a cross arm, a cross arm fitted with Power Line Sentry X-shaped perch deterrents, and a cross arm fitted with Zena Designs spiked deterrents.

Quantifying perching

We used an Orion RC-5030 BuckEye Cam Wireless camera (Athens Technical Specialists Inc., Athens, Ohio) to record raptor and corvid perching on each pole. Each Buckeye camera was mounted on a pole installed approximately 6 m south of the study pole. To deter perching on camera poles, each camera pole was equipped with angled shields over all horizontal surfaces and a Zena Designs pole cap augmented with a central spike (Figure 4).

The Buckeye cameras used motion and infrared sensors to trigger collection of still photos during day and night, respectively, and recorded 0.3 megapixel images. The relatively low resolution images allowed more images to be collected, so that all perch events could be recorded between weekly downloads. Each time the camera was triggered, we recorded 2 images 1 second apart. The first image documented the arrival time of a bird, but, occasionally, it was too blurred to identify the species. The second image documented the bird on the structure and consistently allowed us to identify species. When birds departed, their movement again triggered the camera and 2 photos were recorded 1 second apart. The first photo showed an image of the bird departing, and the second photo verified that the bird was absent. All images were time and date stamped (Figure 5), allowing us to use the time difference between the photo taken when the bird arrived and the photo taken when the bird departed to identify perch duration for each perch event.

The control cross arm and each of the cross-arm-length deterrents were installed on one of the 5 poles at all times for the duration of the study and moved among the 5 poles every 15 to 28 days ($\bar{x}$ = 19.3 days) in a randomized design, so that all cross-arm-length deterrents were used on all poles. Each time cross arms were moved among poles, they all were moved on the same day. When cross arms were moved, they were assigned to poles randomly each time with the caveats that no cross-arm-length deterrent stayed on the same pole when other cross arms were moved among poles, and no structure received the same cross-arm-length deterrent n+1 times until all structures received the deterrent n times. These caveats were necessary to assure that all treatments occurred on all poles approximately equally.

Statistical analyses

We needed to use individual perching events as sampling units to enable collection of

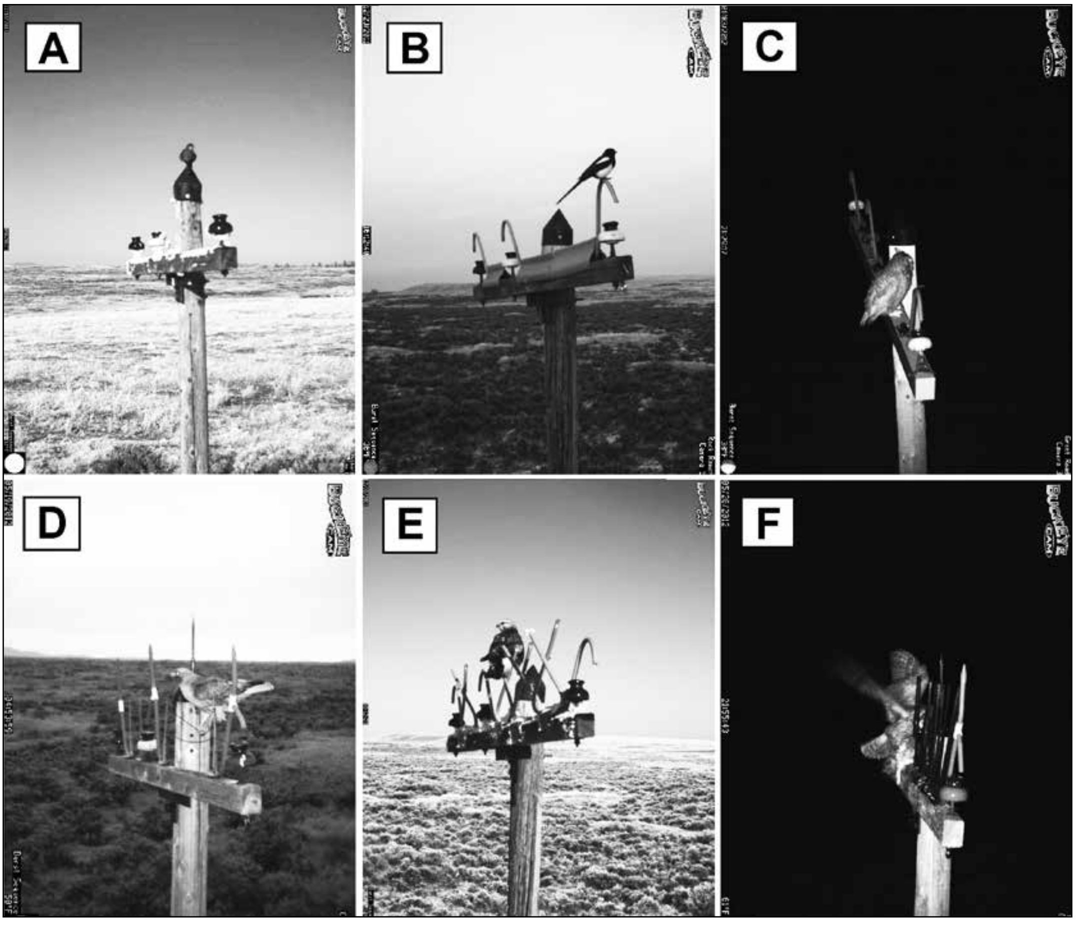

Figure 5. Raptors and corvids perched on perch deterrents: (A) American kestrel perched on pole cap without spike; (B) black-billed magpie perched on insulator deterrent; (C) great-horned owl perched on Pupi cross arm mounted at a 22° angle; (D) red-tailed hawk perched on Birdzoff deterrent; (E) red-tailed hawk perched on Power Line Sentry X; (F) great-horned owl landing with Phasianidae prey on Zena mini-spike.

sufficient data for analyses, but if the same bird was repeatedly exposed to the same cross-arm-length deterrent on the same pole, perching events would not be independent. To prevent repeated perching by a single individual from biasing the data set through pseudoreplication, we: (1) rotated deterrents among poles; (2) recorded and analyzed only 1 perch event per species per 6 hours, and, if we could distinguish >1 bird of the same species based on plumage, we selected different individuals when available; (3) recorded perching year-round to minimize the risk that perching by breeding birds during summer or winter would otherwise disproportionately affect our dataset; and (4) limited data collection to only the first perch location when a bird moved between perch locations on a single pole (i.e, landed on a pole cap then moved to an insulator deterrent). Thus, our data provide a minimum reflection of use by raptors of the poles we monitored, rather than true estimates of cumulative year-round duration of perching.

To evaluate perch frequency, we used χ^2 test to compare observed perches versus expected numbers of perches on each device, assuming that if all devices were equally effective, the number of perch events would be proportional to the days of exposure. Pole caps occurred on each pole (including the pole supporting the control cross arm at any given time) and insulator deterrents occurred on each cross arm except the control cross arm. Thus, because pole caps and insulator deterrents were present on 4 to 5 poles at all times, but each cross arm-length deterrent was present on only 1 pole at any given time, pole caps and insulator deterrents had potentially more daily exposure to perching than cross-arm-length deterrents. However, pole caps and insulator deterrents occupied less space on the pole-top and cross arm than cross-arm-length deterrents, thus, potentially reducing the probability that a bird would select these devices as perch sites instead of cross-arm-length deterrents. To balance these competing interpretations, we tested pole caps and insulator deterrents as having equal daily exposure as crossarm-length deterrents.

To evaluate perch duration, we converted perch duration from seconds to log (seconds) for analysis to meet the assumption of normal distribution required for nonparametric analyses. Some perch events lasted <1 second, which when rounded to zero could not be log transformed. Each of these events was rounded to 1 second for analysis. We used the gmulti package (Calcagno and Mazancourt 2010) for Program R (The R Foundation for Statistical Computing, Vienna, Austria; R Development Core Team 2011) to model all possible subsets of the 5 candidate predictor variables (*n* = 32 candidate models), to rank models using AICc, to calculate an averaged model, and to identify the relative importance of each variable in the averaged model.

We modeled log(seconds) of perch duration as a dependent variable, and perch location, taxonomic group, season, rotation number (trial), and pole location as independent variables. The perch location variable included 9 possible locations: (1) pole cap; (2) insulator deterrent; (3) Pupi cross arm at a 22° angle; (4) Birdzoff perch deterrent; (5) BLM-designed shroud; (6) Power Line Sentry X deterrent; (7) Zena Designs mini-spikes; (8) control cross arm; and (9) control insulators. The taxonomic group variable included 4 categories: (1) corvid (black-billed magpie [*Pica hudsonia*] and common raven [*Corvus corax*]); (2) falcon (American kestrel [*Falco sparverius*] and prairie falcon [*Falco mexicanus*]); (3) hawk (Cooper's hawk [*Accipiter cooperii*], red-tailed hawk [*Buteo jamaicensis*], rough-legged hawk [*Buteo lagopus*], and Swainson's hawk [*Buteo swainsonii*]); and (4) owl (barn owl [*Tyto alba*], great-horned owl [*Bubo virginianus*], and short-eared owl [*Asio flammeus*]). We used these categories because nine of the 11 species we recorded each contributed <5% to the total number of perch events recorded and <10% combined, thus, introducing substantial variation into the analysis when all species were evaluated separately. Perch season included 2 categories: (1) breeding season (March to August) and (2) nonbreeding season (September to February). This variable was intended to control for the possibility that perch duration might differ among birds perching within relatively small breeding ranges compared to birds perching within much larger migrating or wintering ranges. Rotation number (trial) included each of the 19 rotations as categories. The pole location variable included each of the 5 pole locations.

We modeled all possible combinations of candidate variables because we had no *a priori* evidence that some models might be spurious. Relative support for competing models may be inferred through relative AICc values (AIC corrected for small sample size), and through evidence ratios (Burnham et al. 2011). Differences in AICc (ΔAICc) values enable comparison of the relative goodness-of-fit of competing models, and evidence ratios, generated by dividing the AICc weight of the best model by the AICc weight of each other model enable precise quantification of how much better 1 model fits the data than another. We report ΔAICc values and evidence ratios for all models tested, and consider values within 7 AICc of the best model to fit the data approximately equally well (Burnham et al. 2011). Relative importance of variables can help distinguish which variables are most influential to model results. Based on the relative importance of variables from multivariate analyses, we used univariate analyses of log (seconds) of perch duration to illustrate and compare effect sizes of important variables. This approach to illustrating effect size is intended to increase the accessibility of results for personnel unfamiliar with interpreting the results of multivariate analyses.

Prey captures

Independent of the analyses described above, we also recorded each occurrence of a bird departing a pole without prey and returning within 5 minutes with prey. The birds we monitored were not fitted with leg bands or other auxiliary markers, and were not visible when hunting outside of the camera's frame. We chose 5 minutes to minimize the possibility that 2 different birds of the same species would inadvertently be considered the same bird. We used Chi-square to test the null hypothesis that prey captures occurred with equal frequency from each cross arm deterrent. We generated expected values by dividing the total number of these events by 5 (the number of poles in the study) and combining prey captures from cross arms with Pupi and Birdzoff deterrents, because the former was replaced by the latter after 9 rotations.

Results

During 19 rotations (Table 1) completed from November 17, 2011, through November 20, 2012, we recorded 878 independent perching events. We rotated deterrents every 15 to 28 days ($\bar{x}$ = 19.4). Perching events included 12 species of interest (Table 2) and occurred on all perch deterrents (Figure 5 a through f).

Perch frequency

Raptors and corvids perched most often on untreated cross arms, insulator deterrents, and shrouds, and perched least often on pole caps and Zena Designs mini-spikes (χ^2 = 146.0, df = 8, $P < 0.0001$; Table 3).

Perch duration

Most perch events were relatively short with approximately 55% of them ≤5 minutes; durations of perch events are shown in Figure 6. Log transformation substantially improved the normality of the distribution of perch durations (Figure 7), so log transformed data were used for all multivariate and univariate analyses of perch duration. Multivariate analyses indicated 7 models within 7 ΔAICc of our top model (Table 4), and the following importance of each variable in predicting model-averaged results: perch location 1.000; species group 0.999; season 0.505; trial 0.347; and pole location 0.274. All of the top models included perch location and species group as important variables. Because the other 3 variables provided little additional insight into perch duration, they were not examined in univariate analyses.

We found no difference in perch duration among pole caps ($F_{3,40}$ = 0.80, P = 0.50) or insulator deterrents ($F_{2,160}$ = 1.23, P = 0.30). However, we did find differences in perch duration when comparing perch duration on pole caps and insulator deterrents to perching on each cross arm-length deterrent ($F_{8,853}$ = 23.53, $P < 0.0001$). Specifically, analyses indicated insulator deterrents (spiked and un-spiked), Zena Designs mini-spikes, and pole caps (spiked and unspiked) were the only deterrents associated with significantly shorter perch durations than control cross arms or control insulators (Figure 8).

Corvids showed the shortest perch durations across all treatments ($\bar{x}$ = 1.55, 95% C.I. = 1.28 to 1.80), followed by falcons ($\bar{x}$ = 2.04, 95% C.I. = 1.93 to 2.14), hawks ($\bar{x}$ = 2.45, 95% C.I. = 2.34 to 2.56), and owls ($\bar{x}$ = 2.18, 95% C.I. = 2.06 to 2.29). Though corvids showed the shortest perch duration, they also showed the least reduction in perch duration across all deterrents (Table 5). Falcons and owls showed intermediate reductions in perch durations across treatments, and hawks showed the greatest reduction in perch duration.

Prey captures

We recorded 44 prey captures from poles, including 32 prey captures by red-tailed hawks. Of these, 33 (75%) captures were initiated from the control cross arm, six (14%) from the Shroud, and one each (2% each) from the Pupi, Birdzoff, Power Line Sentry X, and Zena Designs mini-spikes treated cross arms. Prey captures were significantly less likely from treated cross arms than from the control cross arm (χ^2 = 86.5, df = 4, $P < 0.0001$). Prey captured from poles were exclusively small mammals and passerines, but could not be identified to species due to the resolution of the cameras used. We observed 1 great-horned owl with a captured gallinaceous bird (apparently a grouse species), but the owl was not observed on the pole prior to arrival with prey, and we could not distinguish the prey to species.

Other observations

We observed 2 perch deterrent products bend under the weight of perching birds. The Birdzoff deterrent was constructed of 2 spikes linked by 2 parallel lengths of cord. When birds perched on the cord, or on the adjacent cross arm the cord flexed beneath the weight of the bird, apparently allowing perching. Prior to log transformation, mean perch duration on the Birdzoff deterrent also was heavily influenced

Table 2. Number and perch location of independent perch events by species. Independent perch events were defined as separated by ≥6 hours from another perch event by the same species on the same pole.

	Perch location*									
Species	POC	IND	PUP	BDZ	SHR	PLS	ZDM	COC	COI	Total
American kestrel (*Falco sparverius*)	15	57	4	33	50	28	22	56	27	292
Red-tailed hawk (*Buteo jamaicensis*)	3	39	15	9	42	6	5	120	1	245
Great-horned owl (*Bubo virginianus*)	16	59	13	5	41	19	6	27	48	234
Black-billed magpie (*Pica hudsonia*)	4	6	4	0	5	8	1	7	0	35
Short-eared owl (*Asio flammeus*)	2	7	3	0	0	2	0	2	0	16
Rough-legged hawk (*Buteo lagopus*)	0	3	4	0	4	2	1	1	0	15
Common raven (*Corvus corax*)	0	1	1	0	3	1	0	7	0	13
Swainson's hawk (*Buteo swainsonii*)	0	0	0	3	2	0	0	1	1	7
Prairie falcon (*Falco mexicanus*)	1	0	0	0	1	0	0	1	0	3
Barn owl (*Tyto alba*)	0	0	0	0	0	0	0	1	0	1
Cooper's hawk (*Accipiter cooperii*)	1	0	0	0	0	0	0	0	0	1
Northern goshawk (*Accipiter gentilis*)	1	0	0	0	0	0	0	0	0	**
Total	43	172	44	50	153	66	35	223	77	862

*BDZ = Birdzoff; COC = control cross arm; COI = control insulators; IND = insulator deterrents (spiked and unspiked); PLS = Power Line Sentry Xs; POC = pole caps (spiked and unspiked); PUP = Pupi cross arm at 22° angle; SHR = shroud; ZDM = Zena Designs mini-spikes.
**This perching event was recorded incidentally following the conclusion of data entry and is not included in any analyses.

Table 3. Number of independent perch events by deterrent type. Independent perch events were defined as separated by ≥6 hours from another perch event by the same species on the same pole.

Perch location	Observed perch events	Days in study	Expected perch events*
Pole caps (spiked and unspiked)	41	370	109
Insulator deterrents (spiked and unspiked)	172	370	109
Pupi cross arm at 22° angle	44	163	48
Birdzoff deterrent	50	207	51
Shroud	153	370	109
Power line sentry Xs	66	370	109
Zena designs mini-spike	35	370	109
Control cross arm	223	370	109
Control insulator	77	370	109

*Expected perch events assumes equal number of perches on all deterrent types corrected for days of exposure.

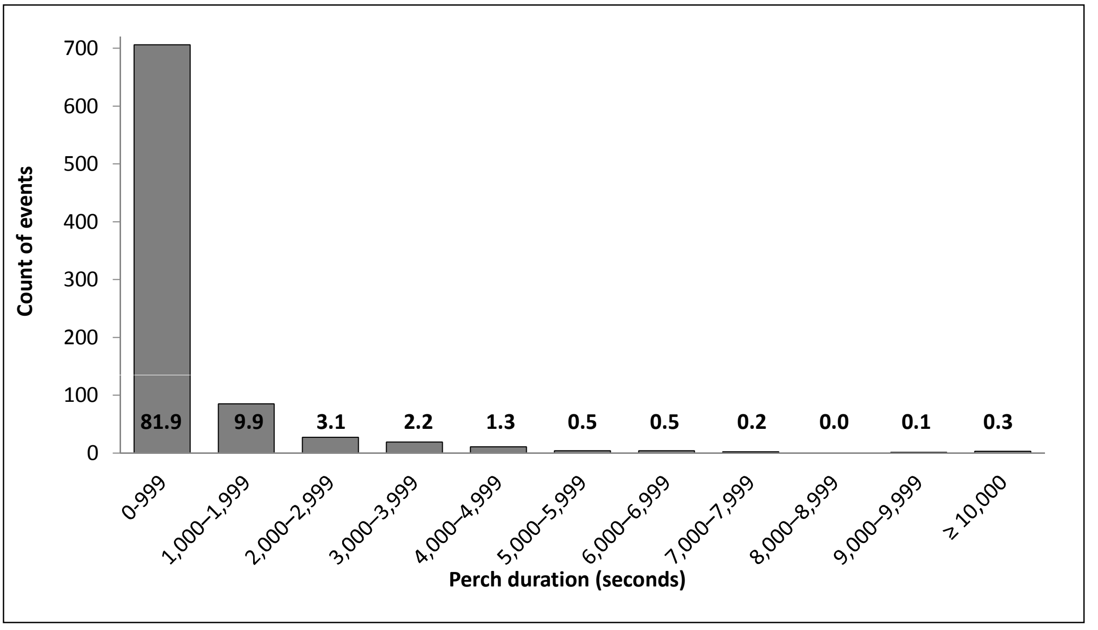

Figure 6. Distribution of perch durations prior to log transformation. Percentages of total indicated on each bar. Data collected November 17, 2011, through November 20, 2012, in Lincoln County, Washington.

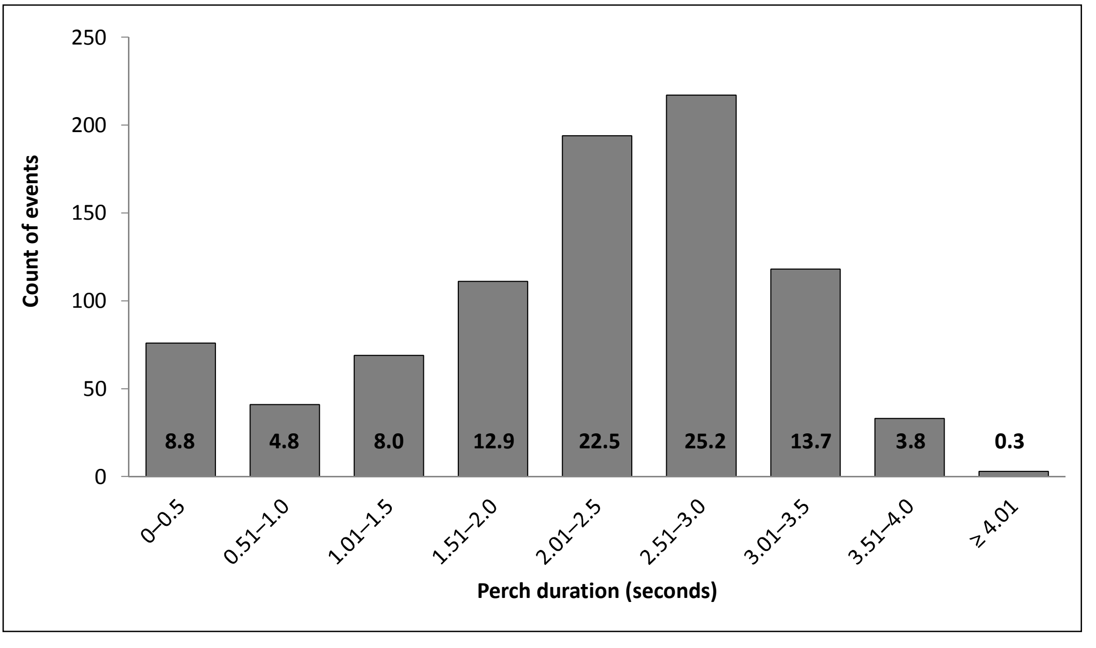

Figure 7. Distribution of perch durations after log transformation. Percentage of total indicated on each bar. Data collected November 17, 2011, through November 20, 2012, in Lincoln County, Washington.

by a single outlier recorded when a red-tailed hawk slept overnight on the deterrent for 6.5 hours. We recorded no other observations of overnight use of any deterrent. We also observed birds attempting to perch on or adjacent to the flexible spike of the Kaddas pole cap. We occasionally observed birds struggling to perch on cross arm-length perch deterrents or beneath insulator deterrents, and moving on poles while engaged in social interactions. Bird movements during these events often included broad wing-flaps at cross arm-height that would likely have led to simultaneous contact with multiple energized wires, and subsequent

Table 4. Mulitvariate modeling results.

	Model*									K	ΔAICc	Weight	Support
1	perch	+	species	+	season	+	--	+	--	3	0.00	4.4E-01	1.0
2	perch	+	species	+	--	+	trial	+	pole	4	2.23	1.4E-01	3.0
3	perch	+	species	+	--	+	--	+	--	2	2.34	1.4E-01	3.2
4	perch	+	species	+	--	+	trial	+	--	3	2.71	1.1E-01	3.9
5	perch	+	species	+	season	+	--	+	pole	4	3.74	6.8E-02	6.5
6	perch	+	species	+	season	+	trial	+	pole	5	4.34	5.0E-02	8.8
7	perch	+	species	+	season	+	trial	+	--	4	4.80	4.0E-02	11.0
8	perch	+	species	+	--	+	--	+	pole	3	7.12	1.2E-02	35.2
9	perch	+	--	+	--	+	trial	+	pole	3	28.26	3.2E-07	1.4E-06
10	perch	+	--	+	season	+	trial	+	pole	4	30.32	1.1E-07	3.8E-06
11	perch	+	--	+	season	+	--	+	pole	3	30.37	1.1E-07	3.9E-06
12	perch	+	--	+	season	+	--	+	--	2	31.10	7.7E-08	5.7E-06
13	perch	+	--	+	--	+	trial	+	--	2	33.19	2.7E-08	1.6E-07
14	perch	+	--	+	season	+	trial	+	--	3	35.27	9.6E-09	4.6E-07
15	perch	+	--	+	--	+	--	+	--	1	35.37	9.1E-09	4.8E-07
16	perch	+	--	+	--	+	--	+	pole	2	35.81	7.3E-09	6.0E-07
17	--	+	species	+	--	+	trial	+	--	2	130.72	1.8E-29	2.4E-28
18	--	+	species	+	season	+	trial	+	--	3	131.61	1.2E-29	3.8E-28
19	--	+	species	+	--	+	trial	+	pole	3	131.95	9.7E-30	4.5E-28
20	--	+	species	+	season	+	trial	+	pole	4	133.07	5.6E-30	7.9E-28
21	--	+	species	+	season	+	--	+	--	2	137.13	7.3E-31	6.0E-29
22	--	+	species	+	season	+	--	+	pole	3	137.91	5.0E-31	8.8E-29
23	--	+	species	+	--	+	--	+	--	1	142.81	4.3E-32	1.0E-31
24	--	+	species	+	--	+	--	+	pole	2	143.96	2.4E-32	1.8E-31
25	--	+	--	+	--	+	trial	+	--	1	177.28	1.4E-39	3.1E-38
26	--	+	--	+	season	+	trial	+	--	2	177.93	1.0E-39	4.3E-38
27	--	+	--	+	--	+	trial	+	pole	2	177.98	9.8E-40	4.5E-38
28	--	+	--	+	season	+	trial	+	pole	3	178.70	6.9E-40	6.4E-38
29	--	+	--	+	season	+	--	+	--	1	180.22	3.2E-40	1.4E-39
30	--	+	--	+	season	+	--	+	pole	2	181.64	1.6E-40	2.8E-39
31	--	+	--	+	--	+	--	+	--	0	191.00	1.5E-42	3.0E-41
32	--	+	--	+	--	+	--	+	pole	1	192.57	6.7E-43	6.6E-41

*Perch = perch location; species = taxonomic group; season = breeding versus nonbreeding perch; trial = rotation number; and pole = pole location.

electrocution if energized wires had been present (Figure 9 a through f).

Discussion

Perch deterrents reduced perch frequency, perch duration, and prey capture events from the poles we monitored in grouse habitat. Thus, perch deterrents may provide an effective supplement to grouse management programs. However, because the true effect of foraging raptors on grouse populations remains unknown, benefits of this management practice

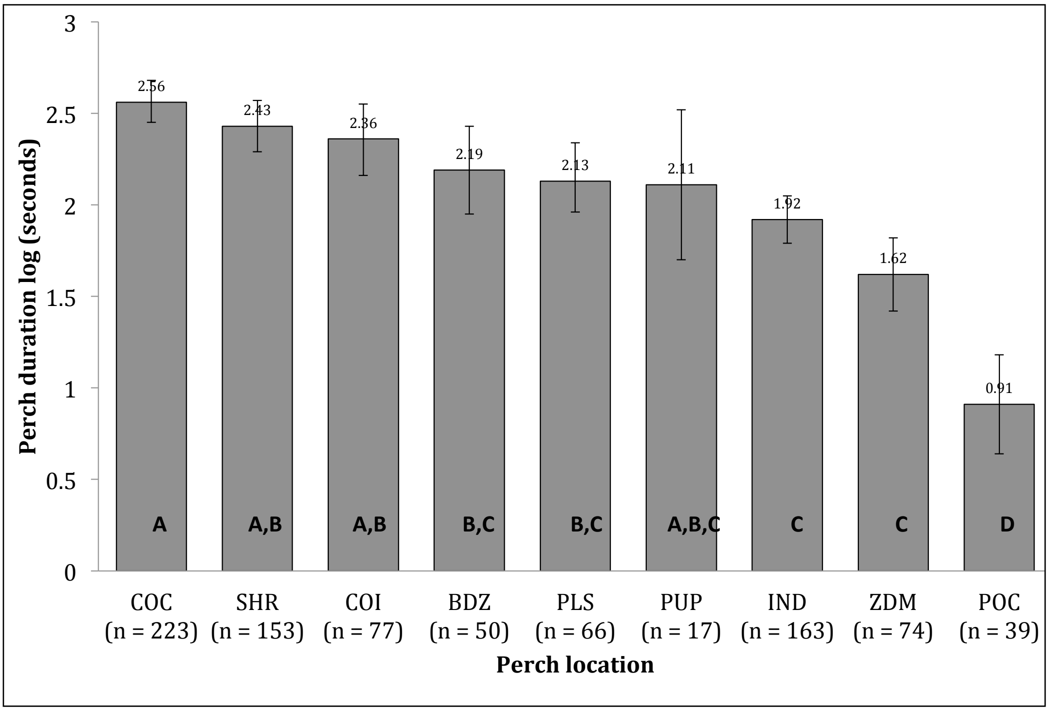

Figure 8. Log (seconds) of perch durations. Error bars indicate 95% confidence intervals (C.I.s). BDZ = Birdzoff; COC = control cro)ss arm; COI = control insulators; IND = insulator deterrents (spiked and unspiked); PLS = Power Line Sentry X; POC = pole caps (spiked and unspiked); PUP = Pupi cross arm at 22° angle; SHR = shroud; ZDM = Zena Designs mini-spikes. Data collected November 2011, 17, through November 20, 2012, in Lincoln County, Wahington. Bars with same groupings (e.g., "A") are not significantly different from one another.

for grouse populations remain unresolved. Though all commercially available deterrents tested reduced perch frequency and duration to some extent, spiked deterrents were most effective, but only if all horizontal surfaces were fitted with spikes. Slater and Smith (2010) also found that spiked deterrents reduced perching by raptors on transmission structures. If cross arms are fitted with deterrents but pole-tops and insulators remain exposed, perching is likely to continue unabated (as in Prather and Messmer 2010). If all horizontal surfaces on power poles are fitted with perch deterrents, raptors may perch on fence posts, hunt while soaring or during powered flight, or depart the area. Future research would need to

Table 5. Changes in average perch duration in log (seconds) for each species on each deterrent type relative to control cross arms.

	Taxonomic group				
Deterrent	Corvid	Falcon	Owl	Hawk	Average
Shroud	0.28	-0.18	0.04	-0.09	0.01
Control insulator	–	-0.32	0.10	-0.32	-0.18
Pupi cross arm at 22° angle	–	0.08	-0.05	-0.63	-0.20
Power Line Sentry X	0.13	-0.11	-0.41	-0.51	-0.23
Birdzoff	–	-0.15	-0.45	-0.64	-0.41
Insulator deterrent	-0.31	-0.64	-0.26	-0.87	-0.52
Zena designs mini-spike	-0.42	-1.03	-0.48	-0.99	-0.73
Pole cap	-0.87	-1.20	-1.54	-2.58	-1.55

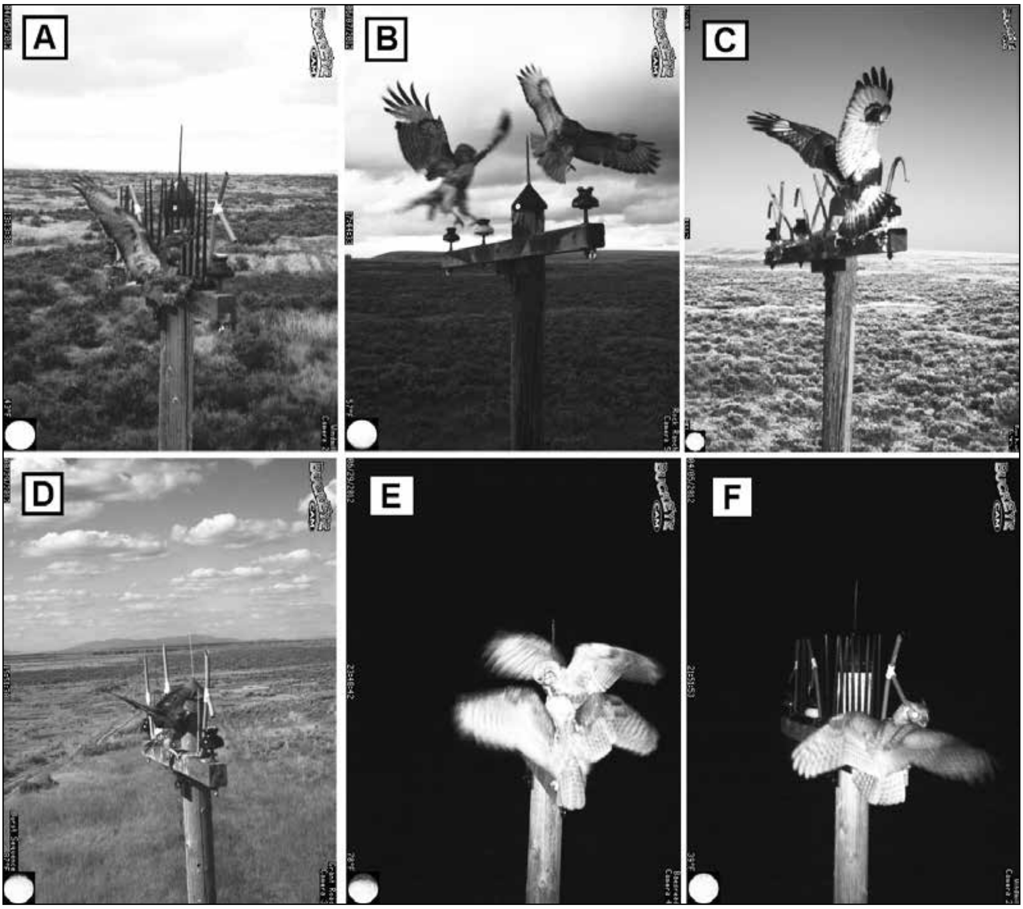

Figure 9. Raptors perched on perch deterrents: (A) red-tailed hawk attempting to perch on Zena mini-spike; (B) 2 red-tailed hawks interacting on cross arm; (C) rough-legged hawk attempting to perch beneath insulator deterrent; (D) red-tailed hawk attempting to perch on Birdzoff; (E) 2 juvenile great-horned owls interacting on cross arm; (F) great-horned owl attempting to perch beneath insulator deterrent.

incorporate behavioral observations beyond poles to resolve this question (as in Slater and Smith 2010).

Installation of perch deterrents on all horizontal surfaces involves substantial costs (Avian Power Line Interaction Committee 2006) and can complicate routine maintenance. Slater and Smith (2010) reported that a few of the perch deterrents they studied fell off of study structures, and birds subsequently perched on treated structures where deterrents were absent. Deterrents in our study did not fall off, but we reiterate that devices must be durable and must fit well (Dwyer and Leiker 2012) or they will not meet long-term goals, particularly in light of their costs.

Perch deterrents are likely to be least effective for the smallest species, such as corvids and American kestrels. It seems that no deterrent strategy is likely to substantially influence perching by these species because they readily perch on wires (Slater and Smith 2010). In these species, and for potential avian predators of grouse in general, the best deterrent will be to eliminate perches completely by removing disused overhead power lines wherever possible. Perch deterrents were most effective for hawks, particularly red-tailed hawks. We designed this study to occur within the breeding and migrating range of golden eagles (*Aquila chrysaetos*), so that perch deterrents would be encountered by this species. Despite our efforts, we never recorded a perch event by a golden eagle on any monitored pole. Thus, our data do not have direct implication to golden eagles.

New products for power lines are regularly being brought to market. During this study, we were alerted to a spiked deterrent under development by Power Line Sentry (Fort Collins, Colorado) that incorporates an insulator deterrent, a spiked deterrent by Preformed Line Products (Mayfield Village, Oh.) that incorporates customized spacing between spikes, and innovation in the Zena Designs mini-spike that allows the spike to be mounted atop pole caps with the use of self-tapping screw(s). Birdzoff, Kaddas, and Power Line Sentry each also market additional perch deterrents for structure-specific and species specific applications. Future research should compare the effectiveness of these products to the spiked products tested here, as well as investigate the relative effectiveness of various spike heights. We expected the new camera technology employed here to simultaneously reduce monitoring effort and increase sample size. Our expectations were met, and because raptors and corvids can be sensitive to human presence, future research should continue to use these technologies to understand interactions between raptors and power poles.

Avian electrocutions can result in outages, equipment damage, as well as fines under the Endangered Species Act, Bald and Golden Eagle Protection Act, and Migratory Bird Treaty Act (Avian Power Line Interaction Committee 2006, Harness 2007). The electrocution of birds of prey on power poles is a persistent problem throughout North America and worldwide (Avian Power Line Interaction Committee 2006, Garrido and Fernández-Cruz 2003, Dwyer and Mannan 2007, Harness et al. 2008). Electrocution is believed to cause population level effects even in carefully managed species (Sergio et al. 2004), has been implicated in disruptive effects to social ecology (Dawson 1988), and can be particularly problematic for very large species, such as golden eagles, a regularly implicated predator of grouse. Birds sometimes struggle to balance on perch deterrents (Slater and Smith 2010). Our observation of birds undertaking broad wing-flaps at cross arm-height while trying to balance on cross arm-length perch deterrents suggests that electrocution risks for raptors may be exacerbated if all possible perch locations on a pole are fitted with perch deterrents.

Numerous materials are commercially available to cover energized equipment to reduce avian electrocution risk. The Power Line Sentry X deterrent tested here was explicitly designed to reduce electrocution risk by discouraging birds from perching near energized equipment while allowing perching on adjacent areas of a pole away from energized equipment. If all horizontal surfaces of energized poles should be outfitted with equipment to deter perching, then all energized equipment on the pole, including the center phase and any pole-mounted equipment, also must be thoroughly insulated or isolated to prevent avian electrocutions.

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