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GOLDEN EAGLE PERCH-SITE USE IN THE U.S. SOUTHERN PLAINS: UNDERSTANDING ELECTROCUTION RISK

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Abstract.—Electrocution on overhead electric systems is a primary cause of anthropogenic mortality for Golden Eagles (*Aquila chrysaetos*) in North America. Distribution poles supporting energized equipment are most often involved in electrocutions, but the frequency with which Golden Eagles perch on pole supporting equipment is unknown. To resolve questions of perch frequency, and by extension, electrocution risk and mitigation prioritization, we used Google Earth to identify perch locations of GPS-transmittered preadult Golden Eagles, and specifically to identify perching on poles supporting transformers. We used transformer poles as a proxy for electrocution risk because transformers are visible in Google Earth imagery. We examined 105 randomly selected "perch events" for each of 10 Golden Eagles ($n = 1050$ perch events total) tracked for a mean of 16 consecutive mo after fledging. The most frequently used perch sites were cliffs (24.6%), trees (21.2%), and hills (16.6%). Across individuals, 10.8% of perches were on overhead electric systems (individual ranges = 0.0–34.3%). Seven Golden Eagles perched on a distribution pole at least once. Of these, five perched on a transformer pole at least once. Perching on transformer poles occurred more frequently than expected given the proportion of transformer poles present (Yates' $\chi^2 = 26.5$, $P < 0.001$). Given the frequency of perching on transformer poles revealed in this study and the frequency of electrocution on equipment poles revealed in previous studies, the data suggest that electrocution mitigation measures should be focused on equipment poles. Future research should quantify perching across a wider variety of habitats and Golden Eagle age and sex to identify whether the patterns reported here occur more broadly.

Key Words: *Golden Eagle*; Aquila chrysaetos; *electrocution*; *power pole*; *resource use*; *Southern Great Plains.*

USO DE POSADEROS POR *AQUILA CHRYSAETOS* EN LAS PLANICIES MERIDIONALES DE EEUU: ENTENDIENDO EL RIESGO DE ELECTROCUCIÓN

Resumen.—La electrocución en los sistemas eléctricos aéreos es una de las principales causas de mortalidad antropogénica para *Aquila chrysaetos* en Norteamérica. Los postes de distribución que sostienen equipos eléctricos energizados están por lo general involucrados en las electrocuciones, pero la frecuencia con la que

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los individuos de *A. chrysaetos* se posan en los postes con equipos es desconocida. Para resolver los interrogantes sobre la frecuencia de uso de posaderos y, por extensión, el riesgo de electrocución y las prioridades de mitigación, identificamos mediante Google Earth los posaderos y los postes con transformadores utilizados por *A. chrysaetos* en plumaje pre-adulto equipados con transmisores GPS. Usamos postes con transformadores como un indicador del riesgo de electrocución debido a que los transformadores son visibles en las imágenes de Google Earth. Examinamos 105 "eventos de posado" seleccionados al azar para cada uno de los diez individuos de *A. chrysaetos* ($n = 1050$ eventos de posado en total) seguidos durante un promedio de 16 meses consecutivos a partir de que abandonaron sus nidos. Los posaderos utilizados con mayor frecuencia fueron roquedos (24.6%), árboles (21.2%) y colinas (16.6%). Considerando todos los individuos, el 10.8% de los posaderos involucró sistemas eléctricos aéreos (rangos individuales = 0.0–34.3%). Siete individuos de *A. chrysaetos* se posaron en un poste de distribución al menos una vez. De éstos, cinco se posaron en un poste con transformador al menos una vez. El posado sobre postes con transformadores se registró más frecuentemente de lo esperado, dada la proporción de postes con transformadores (Yates' $\chi^2 = 26.5$, $P < 0.001$). Dada la frecuencia de posado sobre postes con transformadores registrada en este estudio y la frecuencia de electrocución sobre postes con equipos mostrada en estudios previos, nuestros datos sugieren que las medidas empleadas para mitigar la electrocución deberían enfocarse en los postes con equipos. Las investigaciones futuras deberían cuantificar el comportamiento de posado de *A. chrysaetos* en función de una amplia variedad de hábitats, edades y sexo, para así identificar si los patrones registrados en este estudio ocurren de un modo más extenso.

[Traducción del equipo editorial]

Anthropogenic mortality of Golden Eagles (*Aquila chrysaetos*) in North America likely exceeds sustainable limits (US Fish and Wildlife Service [USFWS] 2016a). These mortalities are attributable to a variety of causes. For example, deaths of 43 Golden Eagles attributed to anthropogenic sources reported in Table 8 of USFWS (2016a), include electrocution (26%), shooting (26%), poisoning (21%), collision with power lines, vehicles, or wind turbines (16%), trapping (7%), and lead toxicosis (5%). Shooting, poisoning, trapping, and lead toxicosis do not occur in specific predictable locations, and consequently effective mitigation can be elusive (USFWS 2013, 2016b). In contrast, electrocutions and collisions with power lines, collisions with vehicles, and collisions with wind turbines are limited to power line rights-of-way, roadways, and wind energy projects, respectively, where mitigation can be carefully focused. For example, electrocution risk can be reduced through retrofitting power poles to minimize contact with energized equipment (Avian Power Line Interaction Committee [APLIC] 2006, Dwyer and Mannan 2007, Dwyer et al. 2017, Bedrosian et al. 2020). Because Golden Eagles often scavenge the carcasses of animals killed by vehicle collisions, removing animal carcasses from roadsides can reduce Golden Eagle mortality resulting from vehicle collisions (Grubb et al. 2018, Lonsdorf et al. 2018). Collisions with wind turbines can be reduced by avoiding development in areas where Golden Eagles frequently occur (Watson et al. 2014, Hunt and Watson 2016), and by curtailing operation of specific turbines when Golden Eagles are detected nearby (Sheppard et al. 2015).

In addition to risk reduction options available at wind energy projects, non-intentional killing or injuring (take) of a limited number of Golden Eagles incidental to the operation of a wind energy project may be authorized by permit from the USFWS, provided all reasonable measures have been taken to avoid and minimize such take (USFWS 2013, 2016b). If, despite collision avoidance measures, Golden Eagles are killed in collisions with turbines, take can be programmatically offset by measurably increasing Golden Eagle survival or productivity elsewhere. In these cases, take of Golden Eagles must be offset at a ratio of 1.2:1 (USFWS 2013, 2016b). Modifying power poles to lower electrocution risk is, at the time of this writing, the sole practical option for offsetting Golden Eagle mortality at wind energy projects (USFWS 2013, 2016b). Given this circumstance, it is important that an unbiased mechanism of quantifying perching on power poles is developed so resource managers and electric utilities know which types of poles Golden Eagles tend to use. This information can be employed to better understand electrocution risk so retrofitting measures can be directed to greatest conservation effect.

In this study, our objective was to evaluate the frequency with which preadult Golden Eagles in the Southern Plains of the USA perched on power poles generally, and power poles supporting transformers specifically. We also quantified perching near roads.

Though not directly comparable to electrocution risk in this dataset, the quantification of eagles' perching on power lines and near roads may suggest future perch-based comparisons of mortality risk by electrocutions vs. vehicle collisions.

STUDY AREA AND METHODS

We studied the use of perch sites by Golden Eagles in the Southern Great Plains Region from southwestern Nebraska south to eastern New Mexico and western Texas, and the northern Chihuahuan Desert Region of southern Texas (Fig. 1). Land cover on the Great Plains portion of our study area was characterized by shortgrass prairie, nonnative grasslands, and irrigated croplands. Prairies and grasslands were dominated by blue grama (*Bouteloua gracilis*), and often invaded by cholla cactus (*Cylindropuntia* spp.), juniper (*Juniperus* spp.), and a variety of native and introduced tree species. Cropland was used mainly for production of corn (*Zea mays*), alfalfa (*Medicago sativa*), sorghum (*Sorghum bicolor*), and cotton (*Gossypium hirsutum*), especially in eastern Colorado, western Kansas, and northwestern Texas. Vegetation in the desert portion of our study area was characterized by mixed xerophytes, including cacti, drought-tolerant trees, and scattered forbs, grasses, and shrubs.

From 2015 through 2017, we entered Golden Eagle nests in May and June when nestlings were 7–8 wk old (i.e., near fledging age). At each nest, we fitted nestlings with platform terminal transmitters (PTTs; Solar Argos/GPS model PTT-45; Microwave Telemetry, Inc., Columbia, MD, USA) via "Y-harnesses" (Buehler et al. 1995) made of 0.64-cm wide Teflon ribbon (Bally Ribbon Mills, Bally, PA, USA). GPS fix accuracy reported by the manufacturer for the PTTs was $\pm$19 m. We found this true for 91% of fixes from PTTs at known sites on our study area; another 9% of fixes were within 30 m (R. Murphy unpubl. data). Each PTT weighed about 55 g, <3% of the nestlings' mass. PTTs were programmed to record GPS fixes hourly from 0700 to 1900 H local time, plus midnight, each day. Thus, each PTT recorded up to 14 GPS fixes daily, provided that sunlight needed to power the PTT reached the solar panel.

Our dataset for this study included telemetry fixes for preadult Golden Eagles. We divided the dataset for each Golden Eagle into two temporal phases. The natal phase occurred from fledging at approximately 65 d of age until the onset of dispersal, defined by Weston et al. (2013) as the first occurrence for each individual moving >9 km from the nest and remaining >6 km from the nest for the following 10 d. The dispersal phase occurred from the date of the onset of dispersal until the eagle died or data collection for this study concluded in June 2018 (maximum = 26 mo). Dispersing Golden Eagles in our study did not exhibit prolonged wandering or explorative movement behavior. Instead, they typically settled on what appeared to be temporary ranges by the end of their first year, as Murphy et al. (2017) found for preadult Golden Eagles in the adjacent (west) region. Because none of the Golden Eagles we studied established breeding territories during our study, all data points outside of natal territories were considered to have occurred during the dispersal phase.

To identify perch sites, we subtracted latitude and longitude values for each GPS fix from each previous GPS fix. When the absolute value of those two subtractions equaled zero, we inferred the Golden Eagle was perched in the same site during the previous hour, or since the previous fix in the case of midnight fixes, and thus, that the fix indicated a perch site. We then categorized perch sites into morning (0800–1100 H), afternoon (1300–1600 H), and midnight (0000 H) local time. We limited morning sites to 0800 H and later, and afternoon sites to 1600 H and earlier, to decrease likelihood that we inadvertently included nocturnal roosting data in diurnal categories during the relatively short days of winter.

We randomly selected 35 perch sites from each time category (morning, afternoon, and midnight) for each Golden Eagle. This allowed us to use all perches from the individual with the smallest numbers of perches within a perch time period (morning, afternoon, midnight) while simultaneously ensuring that all Golden Eagles contributed equally to the dataset we evaluated. We tallied the frequency of perch sites used by each eagle, including repeated use of the same perches, to evaluate comparative perch use. We used Google Earth (Google, Mountain View, CA, USA) to inspect each randomly selected fix and we recorded the tallest object within 30 m of each fix as the perch site (Fig. 2). For example, when imagery in Google Earth showed a tree 5 m from a fix in an otherwise open area, we identified the tree as the perch site because Golden Eagles tend to select the tallest perches available (Kochert et al. 2002, Watson 2011). Google Earth imagery dates ranged from 2014–2019.

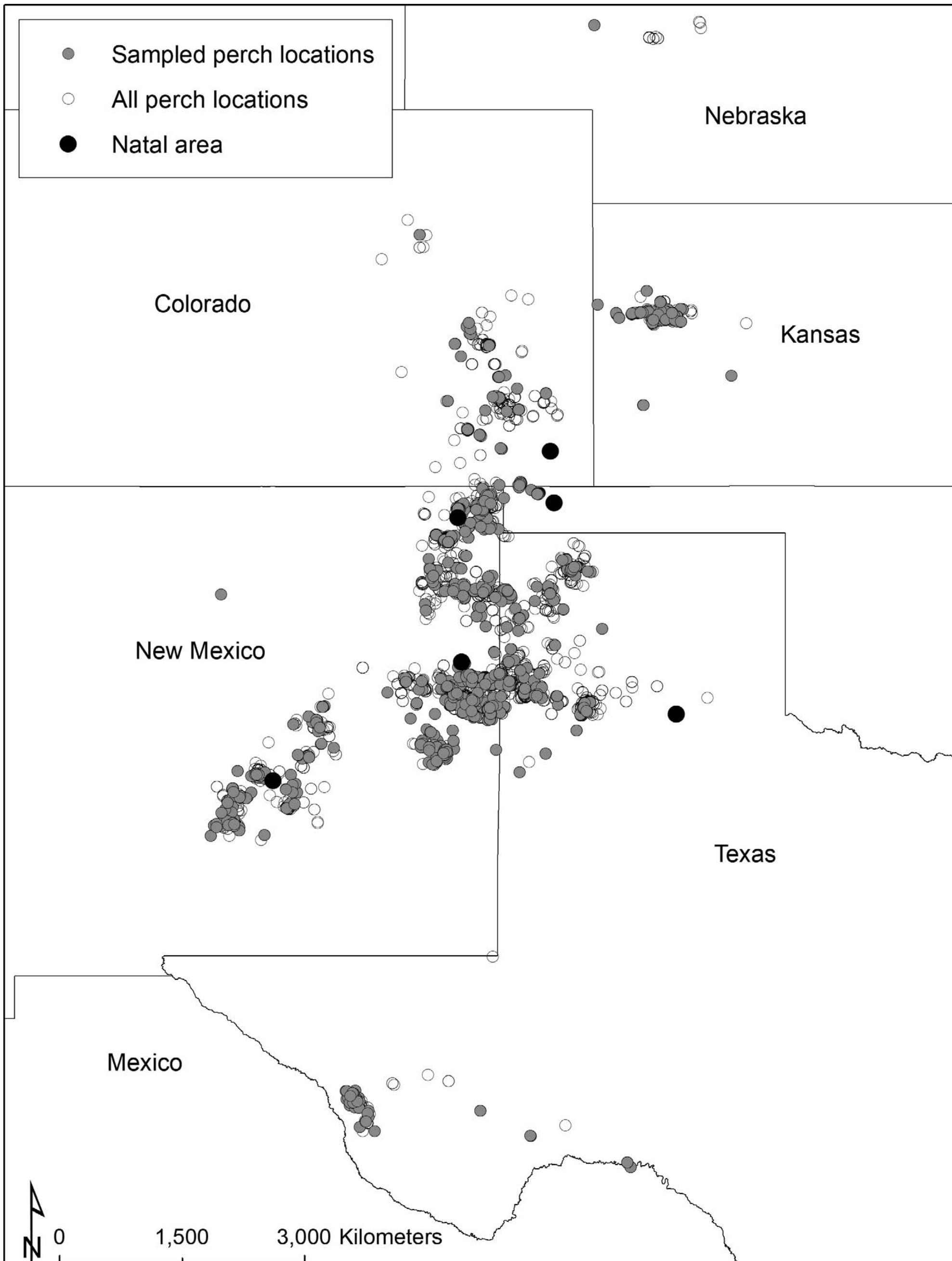

Figure 1. Locations of natal areas and perch sites used by 10 preadult Golden Eagles in the Southern Great Plains during May 2015 through June 2018. Sampled perch locations were selected randomly from all perch locations and were used to evaluate perch-site use.

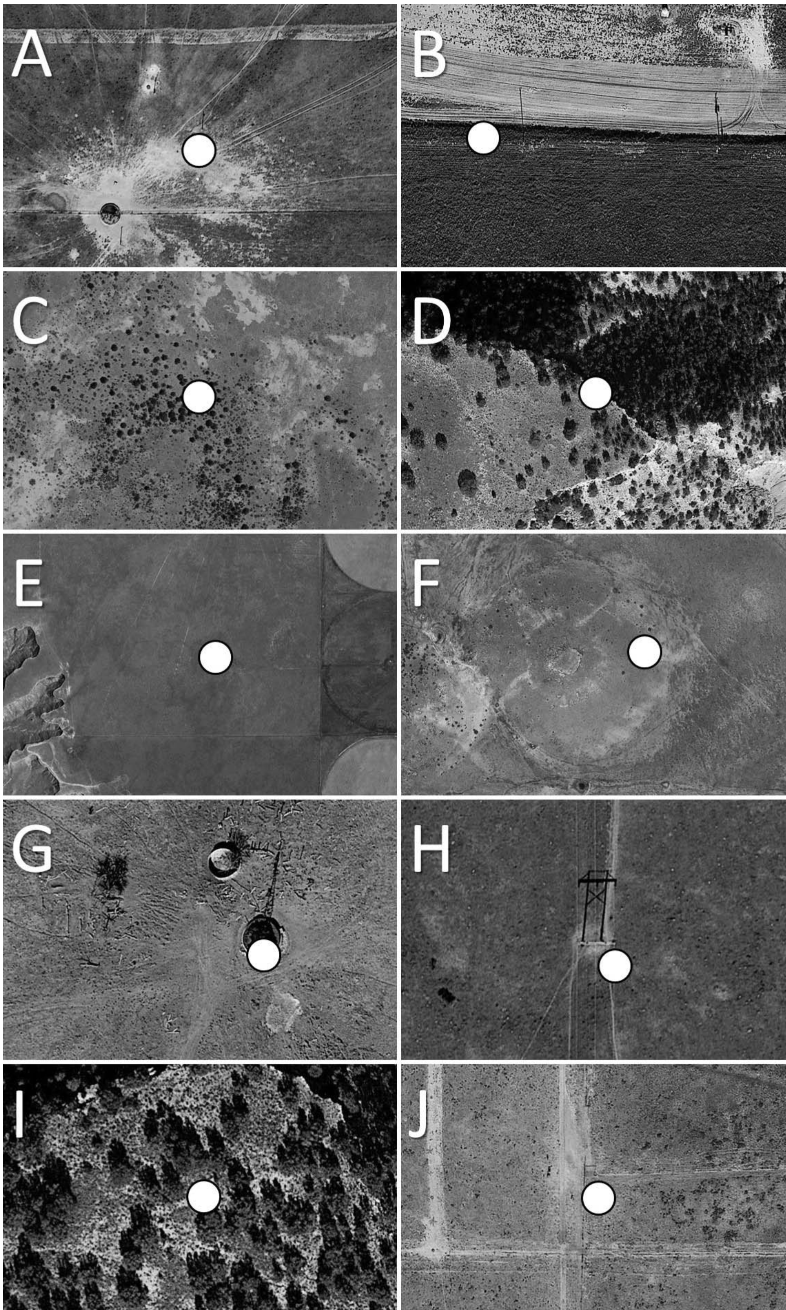

Figure 2. Examples of perch sites used by preadult Golden Eagles May 2015 through June 2018 as viewed in Google Earth (Google, Mountain View, CA): (A) 1-phase distribution, (B) 3-phase distribution, (C) shrub, (D) cliff, (E) flat ground, (F) hill, (G) other (windmill), (H) transmission, (I) tree, and (J) fence post. White dots are GPS fixes from satellite transmitters of Golden Eagles.

Table 1. Categories of perch sites used by Golden Eagles in the Southern High Plains based on a randomly selected sample of 105 perch events by each of 10 Golden Eagles during post-fledging and dispersal, May 2015 through June 2018. Perch-site use was determined by using Google Earth (Google, Mountain View, CA, USA) to inspect GPS fixes derived from satellite telemetry. Google Earth imagery dates ranged from 2014–2019.

PERCH TYPE	APPEARANCE IN GOOGLE EARTH IMAGERY
1-phase distribution	Regular linear spacing of shadows of poles with height of roughly 10–12 m
3-phase distribution	Regular linear spacing of shadows of poles with height of roughly 10–12 m, with 2–3 m long crossarm(s) near pole tops
Transmission	Regular linear spacing of shadows created by poles of height roughly 20 m or taller
Fence post	Regular linear spacing of shadows of fence posts supporting wire fences, with height of roughly 1 m, often with linear vegetation or windblown debris
Flat ground	No elevated natural or anthropogenic structure evident within 30 m of GPS fix
Hill	Top or upper slope of gradually elevated terrain with vegetation
Cliff	Elevated terrain with exposed vertical or near-vertical unvegetated rock or soil, e.g., mesa rim edge
Shrub	Broad woody crown casting short shadow roughly indicating height of 2–3 m
Tree	Broad woody crown casting tall shadow roughly indicating height > 3 m. Tall woody plants not clearly distinguished as either shrub or trees were considered trees
Other	Buildings, metal livestock water tanks, nest platforms, pivot irrigation structures, poles other than power poles, windmills

We identified 10 categories of perch sites (Table 1), including five categories of anthropogenic perches and five categories of natural perches. We also recorded two additional attributes of power pole perch sites. First, because avian electrocutions often occur on power poles supporting energized equipment (Harness and Wilson 2001, Dwyer et al. 2014), we recorded whether power poles used as perch sites supported transformers. Although any pole-mounted distribution equipment can be associated with raptor electrocutions (Dwyer and Mannan 2007, Dwyer et al. 2014, 2017), transformers were the only pole-mounted equipment large enough for us to discern in Google Earth imagery. Second, we assessed Golden Eagle use of transformer poles compared to the proportion of transformer poles on the landscape by identifying whether each of the four poles nearest the perch pole supported a transformer or not; those that did not were termed tangent poles. We limited this assessment to four poles because these generally were within 100 m of the perch pole and likely could have provided the perched Golden Eagle a similar view of the landscape; i.e., were available, but were not selected. We used a Fisher's exact test with a Yates' χ^2 value (Ramsey and Schafer 2002) to identify whether transformer poles were used in proportion to their availability. Because transformer poles occurred on both 1-phase and 3-phase electric systems, the frequencies of transformer-pole perch events and tangent-pole perch events were not equivalent to frequencies of perch events on 1-phase and 3-phase electric systems.

We used χ^2 tests to compare frequencies of perch sites used among times of day (morning, afternoon, and midnight), and between life history stages (natal area and dispersal). Because we used the same data in our analyses of time of day and life history stage, we applied a Bonferroni correction (Ramsey and Schafer 2002), dividing our initial α level (0.05) by the number of tests conducted (two), to define our criterion of statistical significance ($\alpha = 0.025$).

In addition to perch site, we recorded whether each perch site was within 30 m of a paved road. We focused this limited assessment on paved roads because we sought only to identify whether our perch-location methodology might have potential utility in assessing collision risk in future studies, rather than to assess collision risk for this dataset specifically. Our records of perching within 30 m of paved roads were independent from records of perch sites, e.g., if a perch site was a 3-phase transformer pole within 30 m of a paved road, we would have included the perch site in both the electrocution risk and the road proximity categories. In practice, this did not occur in our dataset.

RESULTS

We evaluated data from 10 preadult Golden Eagles, including seven Golden Eagles from natal

Table 2. Duration of observation period and number of GPS satellite telemetry fixes from which random samples of 105 events of perch use were drawn for each of 10 preadult Golden Eagles.

Eagle ID	Start Month Year	End Month Year	Observation Months	Telemetry Fixes	Perch Events
00746	Jun 2016	Jan 2018	20	7351	889
00749	Jun 2016	Sep 2017	16	5860	457
01252	Jun 2016	Jun 2018	24	7389	983
02977	May 2015	Jan 2016	8	2507	336
03869	May 2015	Jun 2017	26	8873	1247
03878	May 2016	Dec 2017	20	6913	782
03885	Jun 2016	Apr 2017	11	3635	374
03891	May 2017	Jun 2018	14	4175	262
03892	Jun 2017	Jun 2018	13	4551	541
03897	Jun 2017	Jun 2018	13	4513	419

areas in northeastern New Mexico and one from a natal area in each of central New Mexico, southeastern Colorado, and western Oklahoma. We tracked the Golden Eagles for a mean of 16.5 consecutive months (SD = 5.8 mo; Table 2) and examined 105 events of perch-site use by each individual ($n = 1050$ perch events, total). Duration of tracking in the Golden Eagles' natal area averaged 134 d (range = 90–226). Perch events were randomly selected from a mean of 629 events per individual Golden Eagle (SD = 327), extracted from a mean of 5577 GPS fixes per individual (SD = 2014).

During morning, afternoon, and midnight periods combined, Golden Eagles most often perched on cliffs (24.6%), trees (21.2%), and hills (16.6%). Golden Eagles perched less frequently on fence posts (11.0%), level ground (8.4%), and transmission structures (6.0%), and infrequently on 1-phase distribution poles (2.7%), shrubs (2.5%), 3-phase distribution poles (2.1%), and other sites (5.0%). We recorded 113 (10.8%) perch events on 1-phase distribution poles, 3-phase distribution poles, and transmission structures combined, including 50 perch events on 1-phase and 3-phase distribution poles combined (4.8%), of which 16 (1.5%) were on transformer poles. Individual Golden Eagles varied substantially in their use of power poles (mean = 11 perch events/individual, range = 0–36). Seven of the 10 Golden Eagles perched on a 1-phase or 3-phase distribution pole at least once, and five of these perched on a transformer pole at least once. Overall, 16 (32.0%) of 50 perch events on distribution poles occurred on transformer poles and 34 (68.0%) occurred on tangent poles. These pole types made up 11 (5.5%) and 189 (94.5%) of the total number of adjacent poles, respectively, indicating that Golden Eagles perched on transformer poles more than expected (Yates' $\chi^2 = 26.5$, $P < 0.001$). Only four perch events within natal areas were on distribution power poles.

Perch-site use varied by time of day ($\chi^2 = 70.76$, df = 18, $P < 0.001$; Fig. 3a), with fence posts used more than expected during morning and less than expected otherwise, transmission structures used more than expected during afternoons and less than expected otherwise, and trees used more than expected at midnight and less than expected otherwise. Perch sites also varied between natal areas and areas encountered during dispersal ($\chi^2 = 121.99$, df = 9, $P < 0.001$; Fig. 3b), with cliff tops used more than expected in natal areas, and perches classified as other (buildings, metal livestock water tanks, poles other than power poles, windmills, etc.) used more than expected during dispersal. We recorded perching within 30 m of a paved road only twice (0.2%), consisting of only one perch event each for two individuals; neither perch site was a power pole.

DISCUSSION

Golden Eagles perched more frequently than expected on transformer poles. We used poles with transformers as a proxy for equipment poles (poles supporting energized equipment and poles where lines intersect) because equipment poles tend to be involved in raptor electrocutions more frequently than tangent poles that do not support any pole-mounted equipment or intersections (Harness and Wilson 2001, Dwyer and Mannan 2007, Mojica et al. 2018). In contrast, tangent poles were perched on relatively infrequently in this study and are also involved in fewer electrocutions in general (Harness

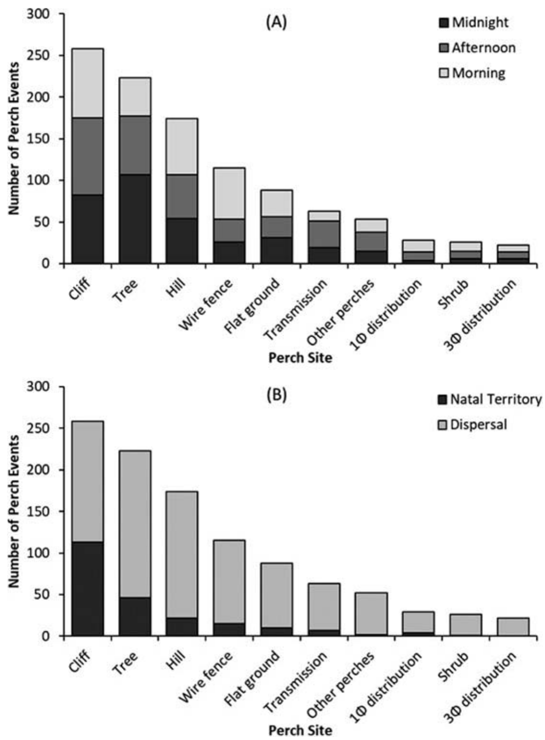

Figure 3. Perch sites used across time of day (A) and dispersal stage (B) for 10 preadult Golden Eagles tracked via satellite telemetry in the Southern Great Plains, May 2015 through June 2018. The dataset is based on a pooled sample of 105 randomly selected perch events for each eagle ($n = 1050$ total perch events).

and Wilson 2001, Dwyer and Mannan 2007, Mojica et al. 2018). Based on this finding, when electrocution-mitigation efforts must be prioritized, the efficacy of those efforts would be increased if a priority were placed on mitigating electrocution risk associated with equipment poles. This understanding is important in assessing the likely effects of retrofitting programs that quantify success based on either (1) the number of poles modified to reduce Golden Eagle electrocution risk, or (2) the level of risk posed by modified poles. Retrofitting tangent poles may meet count-based goals for numbers of poles retrofitted, but may not meet conservation goals for electrocutions prevented because Golden Eagles use tangent poles less than expected (this study), and tend not to be electrocuted on tangent poles (Harness and Wilson 2001, Dwyer and Mannan 2007, Mojica et al. 2018). Rather, equipment poles pose increased risk of electrocution to birds of all sizes, including Golden Eagles, because of close separations between energized components of different electric potential, and between energized components and paths to ground (APLIC 2006). Consequently, it is equipment poles that should be prioritized in retrofitting programs. Understanding this aspect of electrocution risk is critical to developing and implementing effective electrocution mitigation programs, particularly when those programs are explicitly designed to offset take at wind energy projects.

Inferences from our study are limited to preadult Golden Eagles in parts of the Southern Great Plains. The novel method of identifying perch sites developed for this work, or those developed by Duerr et al. (2019), could be applied to a much broader Golden Eagle dataset composed of preadults in their natal areas, dispersers and floaters of all ages, migrants, and adults on territories in various regions of western North America, to identify whether the patterns we observed occur across Golden Eagle populations. Consideration across regions is particularly important because power pole densities vary across the Golden Eagle's range, so frequencies of perching on power poles may not be consistent, and therefore relative risk levels attributable to electrocution may not be consistent. Future research may also benefit from improved resolution in aerial imagery, perhaps enabling detection of other types of equipment poles. Future research also could apply this approach to other raptor species at risk of electrocution.

Collectively, the preadult Golden Eagles we studied perched mostly on cliffs, trees, and hills. In level terrain in northeastern Colorado, Golden Eagles greatly preferred to perch on haystacks and in trees (Marion and Ryder 1975). The affinity for haystacks may parallel the use of hilltops for perching by Golden Eagles in our study, although use of haystacks in Colorado was thought to be tied to proximity to higher concentrations of leporid prey. The relatively infrequent use of power poles as perch sites by Golden Eagles in our study differed somewhat from the pattern noted in northeastern Colorado; there, Golden Eagles exhibited a moderate preference for using power poles as perch sites (Marion and Ryder 1975). Some of this difference may be due to observation bias; we used satellite telemetry to document perch-site use, but the work in northeastern Colorado was based on direct observations from roads.

We also observed that use of certain perch sites differed by time period. Trees were used for perching more than expected at night, perhaps because they provided more secure shelter from commonly occurring strong winds on our study area than did other perch sites. Golden Eagles' increased use of fence posts as perch sites in morning may have been tied in part to a common pattern of morning hunting of black-tailed prairie dogs (*Cynomys ludovicianus*), which typically occupy colonies within fenced livestock pastures on our study area (R. Murphy unpubl. data). Increased use of transmission structures in afternoon may have been related to thermoregulation because Golden Eagles could likely perch on crossarms shaded by poles.

Our data indicated Golden Eagles perched near paved roads only twice. This may reflect relatively infrequent perching near paved roads by the Golden Eagles we studied or may reflect an inability of our assessment methodology to accurately assess perching near paved roads because such perch events may have been relatively brief (e.g., during feeding on roadkill carcasses between vehicle passage events). Future research could use PTTs with higher data collection frequencies to more quickly identify perch sites, or could use a GIS-based approach to compare all perch locations to all road types and to power line densities. In the United States, power line locations are rarely shared by electric utilities but estimates of power pole density are available in Colorado and Wyoming (Dwyer et al. 2016), and throughout much of western North America (Dwyer et al. 2020), and these may be useful in broader assessments of avian electrocution risk. If such an assessment were undertaken, care would be needed to develop an objective comparison between electrocution risk and vehicle collision risk because of the different mechanisms of the two risk types. Specifically, a Golden Eagle perching on a distribution power line may be at some level of electrocution risk for the duration of the perching. In comparison, a Golden Eagle perched near a road is at risk of a vehicle collision only if there is carrion on the road and a vehicle passes by during the perch event. Perhaps evaluating clusters of fixes near roads to simultaneously assess perching and foraging on carrion while allowing for the short rapid movements expected from Golden Eagles reacting to passing cars would facilitate such a risk comparison.

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