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Conservation Letter: Raptor Collisions in Built Environments

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INTRODUCTION

Raptor interactions with built environments have the potential to negatively affect individual birds, populations, and species, often in the form of collisions with human-made structures and vehicles. This letter aims to serve as an overview of the known impacts of collisions on raptors around the world and to offer practical mitigation strategies and directions for future research. This letter is not intended as an exhaustive literature review. Rather, the intent of the Raptor Research Foundation (RRF) is to provide readers with enough evidence-based examples so that readers can appreciate the scope and prevalence of raptor collisions with built environments and understand the potential effects on raptor species and populations as well as the challenges associated with addressing these effects across regions. In this letter, "built environments" refers to landscapes modified by humans, including structures and infrastructure systems.

Many raptors are attracted to built environments because of high availability of prey and carrion, and novel perches and nest sites, yet living in such environments puts raptors at risk of collisions (Dykstra 2018). Raptors are vulnerable to collisions with stationary and mobile human-made objects, which frequently result in traumatic injuries or death (Loss et al. 2015, Dwyer et al. 2018, Šálek et al. 2023). Globally, collisions are consistently reported among the top causes of raptor admissions to rehabilitation centers (Thompson et al. 2013, Maphalala et al. 2021). These records only represent a fraction of all raptor collisions, as many occur in areas with limited accessibility; and many raptors found dead, rather than injured, go unreported (Hager 2009, Panter et al. 2022). Multiple collision risks pose threats to raptors in urban and rural areas alike, though some have been better studied than others.

Most studies on raptor collisions focus on vehicles, wind turbines, or to a lesser degree, windows and buildings. Numerous other collision risks in built environments remain under-studied, such as aircraft, overhead power lines, communication towers, and fences.

IMPACTS OF COLLISIONS ON RAPTORS

Vehicle Collisions. As the world becomes increasingly urbanized, vehicles are increasingly traversing transportation networks (Coffin 2007). Despite improving connectivity and logistical capabilities for humans, road and rail networks pose a risk to raptors via collisions (De Pascalis et al. 2020). For owls, vehicle collisions represent a substantial threat to wild populations and are a major cause of owl mortality (Molina-López et al. 2011, Arnold et al. 2018, Hernandez et al. 2018). Owls are especially at risk from vehicle collisions due to blinding by motor vehicle headlights at night (Bullock et al. 2011). Owl–vehicle collisions can be detrimental to species of conservation concern and those with declining populations such as Barn Owls (*Tyto alba*) in Canada (Bishop and Brogan 2013).

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Raptor–vehicle collisions are dependent on many factors. Traffic volume and prey availability in grassy verges are predictors of raptor distributions and subsequent raptor–vehicle collisions along roadways (Planillo et al. 2015, Sumasgutner et al. 2021). Speed limits, road width, and surrounding landscapes also influence collision risks (Gagné et al. 2015). For example, DeVault et al. (2014) found that flight initiation distance of Turkey Vultures (*Cathartes aura*) nearly doubled as vehicle speed increased from 30 to 90 kph. Collision rates between vehicles and Barred Owls (*Strix varia*) in North Carolina were higher on roads with higher speed limits and along roads through more suitable habitats (Gagné et al. 2015). The surrounding landscape, specifically the degree of urbanization, may also impact collision rates (Hager 2009, Panter et al. 2022). A study from England and Wales found that the probability of raptor–vehicle collisions was greater in less urbanized environments (Panter et al. 2022). However, evidence from the USA and Canada reported vehicle collisions affect urban and exurban raptors (Hager 2009), indicating patterns likely differ across species and landscapes.

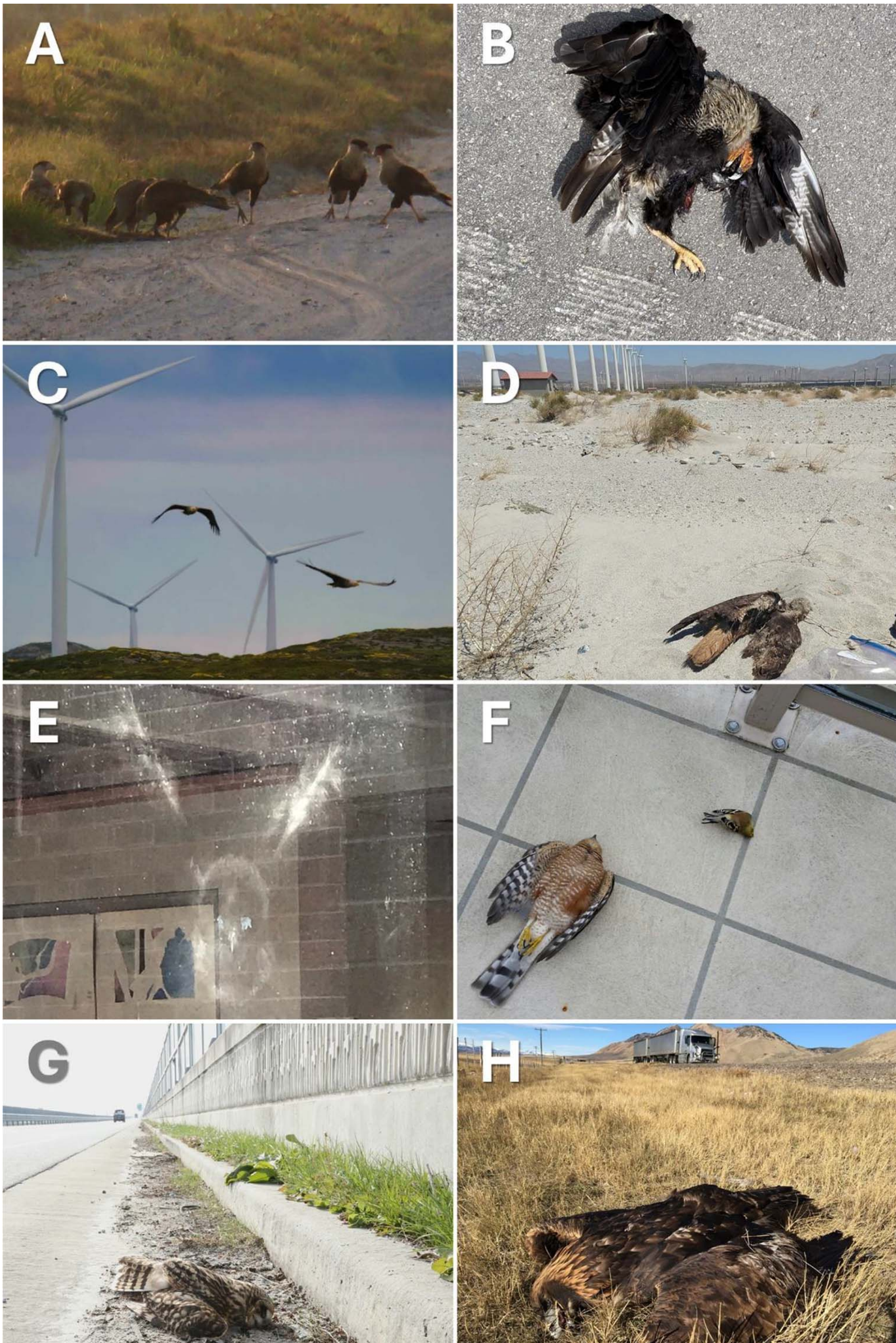
How raptors use the environment close to transportation networks also influences collision risk (Dwyer et al. 2018). Raptors that feed on roadkill and roadside garbage are more susceptible to vehicle collisions (Fig. 1A–B; Lambertucci et al. 2009, Sumasgutner et al. 2021, Slater et al. 2022). Despite this, little is known about the population-level impacts of vehicle collisions on raptors across large demographic, temporal, and spatial scales.

Human-related mortality is a major limiting factor for some raptor populations (Donázar et al. 2016, Šálek et al. 2023), with human-caused raptor mortality increasing over the past century (De Pascalis et al. 2020). Raptors that collide with vehicles experience higher mortality rates than those impacted by other anthropogenic factors (Kadlecova et al. 2022). McCabe et al. (2022) found that immature Snowy Owls (*Bubo scandiacus*) were more likely to be killed by vehicle collisions than adult birds in North America and suggested that if raptor–vehicle collisions occur more often in suboptimal habitats, negative density-dependent population effects may persist. Little is known about population effects on other raptor species. However, across 15 raptor species in the UK, vehicle collisions were the cause of death in 28% of recovered banded birds between 2002 and 2019 (Hanmer and Robinson 2021). Similarly, approximately 11% of raptor band recoveries in the USA from 1920s–2000s were due to vehicle collisions, a percentage that increased markedly over time (Lutmerding et al. 2012).

Wind Turbine Collisions. Windmills have existed for centuries but were not reported to affect birds until the advent of electrical power-generating wind turbines and subsequent installation of large numbers of turbines in relatively small areas. Raptors are more vulnerable to collisions with wind turbines than other avian groups and are more likely to suffer population-level consequences (Watson et al. 2018). Collision risk is highly variable and is related to complex relationships among landscapes, wind conditions, species abundance, time of year, and species-specific behaviors (Barrios and Rodríguez 2004, Schuster et al. 2015, Watson et al. 2018).

Griffon Vulture (*Gyps fulvus*) fatalities in Tarifa, Spain have been linked to topography and wind conditions (Barrios and Rodríguez 2004). Vultures were more likely to be killed by turbines located in areas of poorer updraft where they may spend more time circling to gain altitude (Barrios and Rodríguez 2004). Furthermore, Griffon Vulture fatalities throughout Spain were positively correlated with the species' abundance (Carrete et al. 2012). In Norway, White-tailed Eagle (*Haliaeetus albicilla*) fatalities at the Smøla wind facility have been linked to siting of the facility within an area of very high breeding density and siting of some turbines near a communal roost (Fig. 1C; Watson et al. 2018). In Germany, White-tailed Eagle fatalities were positively correlated with nesting habitat and wind turbine density but not with nest density (Heuck et al. 2019). The Altamont Pass Wind Resource Area (APWRA) is notorious for causing numerous fatalities of Golden Eagles (*Aquila chrysaetos*), Red-tailed Hawks (*Buteo jamaicensis*), American Kestrels (*Falco sparverius*), and Burrowing Owls (*Athene cunicularia*), among many other species (Smallwood and Thelander 2008). Within the facility, some turbines are more likely to kill raptors than others, with particularly dangerous turbines associated with high prey abundance, high breeding density of raptors, high density of nonbreeding raptors, and topography supporting low-altitude flight (Schuster et al. 2015, Watson et al. 2018).

Certain flight behaviors and flight activities are also thought to increase risk. For example, species that engage in kiting while foraging appear to be at increased risk of collision. The Red-tailed Hawk (Fig. 1D), American Kestrel, Eurasian Buzzard (*Buteo buteo*), Eurasian Kestrel (*Falco tinnunculus*), Nankeen Kestrel (*Falco cenchroides*), and Brown Falcon (*Falco berigora*) all share similar flight strategies while foraging that put them at higher risk of collision (Watson et al. 2018). Similarly, birds that frequently engage in territorial flights or social interactions in flight are at higher risk of collision than those that do not (May et al. 2011).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Population-level effects from collision fatalities have been documented for some species. In Spain, a decline in the population of the endangered Egyptian Vulture (*Neophron percnopterus*) was linked to collisions with turbines (Carrete et al. 2009). High adult mortality resulted in an increase in breeding subadult Golden Eagles within the APWRA (Wiens and Kolar 2021), with effects extending to the continental population (Katzner et al. 2016). Moreover, both Red Kites (*Milvus milvus*) and Eurasian Buzzards suffer population-level consequences from wind turbines in Germany (Grünkorn et al. 2016).

Window Collisions. More studies exist on bird–building collisions than perhaps any other collision source. Birds collide with windows because they do not perceive glass as humans do. Instead, birds perceive clear glass as an open passageway and mirrored glass as a continuation of habitat (Fig. 1E; Klem 1979). Though most bird–building collision studies focus on songbirds, numerous studies from rehabilitation and veterinary clinics around the world report raptor–building collisions as a top cause of admissions (Neese et al. 2010, Thompson et al. 2013, Smith et al. 2018, Panter et al. 2022) with numerous raptors documented, including various falcon ($n = 6$), hawk ($n = 13$), and owl ($n = 15$) species. Klem (1979) reported *Accipitridae* (hawks, eagles, and kites) among the top ten bird families most prone to window collisions in the USA and Canada. Because buildings with glass windows are present nearly everywhere humans live, this indiscriminate source of death poses a threat to raptors globally, though some species are more vulnerable to window collisions than others.

Particular hunting strategies also contribute to greater risk of window collisions by some raptors. Species that habitually pursue prey at high speeds through restricted areas, such as Cooper's Hawks (*Accipiter cooperii*) and Eurasian Sparrowhawks (*Accipiter nisus*), are particularly vulnerable to window collisions (Klem 1981, Dwyer et al. 2018). For example, Newton et al. (1999) found collisions were among the top two causes of death of Eurasian Sparrowhawks in the UK. Millsap et al. (2024) found collisions with human-made objects, especially windows and vehicles, were the greatest cause of death in urban Cooper's Hawks in New Mexico, regardless of age.

Raptors occupying urban environments may be more vulnerable to window collisions than rural raptors because of the greater density of buildings in urban areas. Although large buildings such as skyscrapers cause the greatest number of bird collisions per building, the vast numbers of residential homes across urbanized landscapes collectively pose a far greater risk (Loss et al. 2015). This risk is compounded as many homeowners maintain bird feeders in their yards, putting both feeder birds and nonfeeder birds at greater risk of window collisions (Kummer et al. 2016). Hager (2009) found that building collisions affected 45% of urban raptor species in the USA and Canada and were the top source of mortality for Sharp-shinned Hawks (*Accipiter striatus*; Fig. 1F), Cooper's Hawks, Merlins (*Falco columbarius*), and Peregrine Falcons (*Falco peregrinus*), with potential for population-level effects. Similarly, Panter et al. (2022) found urban raptors in England and Wales were 2.5 times more likely to be admitted to rehabilitation centers due to building collisions compared to raptors living in rural areas.

Window collisions can cause challenges in protecting species of conservation concern in urban areas, as seen in the reintroduction of the Peregrine Falcon in the USA and Canada following their steep decline during the second half of the 1900s. In 1990, window collisions were reported to pose "a serious threat to the successful reintroduction of this species in urban environments" (Klem 1990). Although window collisions have continued to be reported as a leading cause of death and injury in reintroduced Peregrine Falcons, especially young birds (Sweeney et al. 1997, Gahbauer et al. 2015), their successful reestablishment suggests these deaths may be compensatory or too infrequent to overcome current population growth rates.

←

Figure 1. Raptor collisions with anthropogenic obstacles are a global conservation concern. (A) Crested Caracaras (*Caracara cheriway*) foraging on a vehicle-struck mammal along a road edge in southern Florida, USA. Photo J. Dwyer; (B) A Crested Caracara (*Caracara cheriway*) killed by a collision with a vehicle in southern Texas, USA. Photo H. Bullock; (C) White-tailed Eagles (*Haliaeetus albicilla*) transiting a wind farm in west-central Norway. Photo T. Katzner; (D) Red-tailed Hawk (*Buteo jamaicensis*) killed by collision with a wind turbine in central California, USA. Photo US Geological Survey; (E) Barred Owl (*Strix varia*) impact smear on a window in Kansas, USA. Photo K. Anton, Johnson County Community College Bird Collision Study, www.youtube.com/watch?v=FgZcnaOI_-A; (F) Sharp-shinned Hawk (*Accipiter striatus*) and Lesser Goldfinch (*Spinus psaltria*) killed in collisions with a window in Vancouver, Canada. Photo J. Dodson; (G) Short-eared Owl (*Asio flammeus*) killed in collision with either a vehicle or a glass highway sound barrier in South Korea. Photo K. Young-Jun; (H) Golden Eagle (*Aquila chrysaetos*) likely killed by a vehicle collision but lying below a distribution power line, which can also cause collision mortality, in Wyoming, USA. Photo E. Fairbank.

Other Collision Sources. There are many other sources of collision-related fatalities in raptors. These include, but are not limited to, collisions with aircraft, communication towers, fences, highway sound barriers (Fig. 1G), and overhead power lines (Fig. 1H; Molina-López et al. 2011, Simon et al. 2020, Cococcetta et al. 2022). In some cases, such as when glass sound barriers or power lines are placed along highways, it can be difficult to identify whether a bird was killed or injured by a window collision, power line collision, or vehicle collision.

Of these other collision sources, aircraft are among the most studied for raptors (Blackwell and Wright 2006, Washburn et al. 2015, 2021). Collisions between birds and aircraft have consequences for both wildlife and humans (Washburn 2018) and thus differ from most other collision sources. Airfields attract raptors that forage in open areas and species that roost or perch on the ground, e.g., Snowy Owl and Bald Eagle (*Haliaeetus leucocephalus*). In the USA, 16 of 19 owl species and 28 of 34 diurnal raptor species have been struck by aircraft (Federal Aviation Administration 2023). Among the top 20 bird species that are considered most dangerous to military aircraft and human life, seven species are medium- to large-bodied raptors (Pfeiffer et al. 2018). Although most collisions between aircraft and raptors occur near the ground (<150 m above ground) on approach, taxi, or take-off, collisions may occur anywhere that aircraft and birds occupy the same space (Dolbeer 2006).

SOLUTIONS AND RESEARCH NEEDS

Vehicle Collision Solutions. The impacts of vehicle collisions on raptor populations remain speculative, yet strategies to mitigate raptor–vehicle collisions have been attempted. Using flight diverters, fencing, and hedging to redirect raptors above and away from roadways may reduce raptor–vehicle collisions (Kociolek et al. 2015, Dwyer et al. 2018). In Spain, poles positioned along roadways (spaced 1–2 m apart for forest raptors and 3 m apart for soaring raptors) shifted flight paths of some raptor species but with mixed effects (Zuberogoitia et al. 2015). Attaching orange and white flags to the poles induced a stronger avoidance response (Zuberogoitia et al. 2015), especially for forest-dwelling raptors, suggesting that flagged poles may reduce the number of raptor–vehicle collisions along key sections of transportation networks. Monochromatic light-emitting diodes targeted at avian photoreceptors have been used to deter Red-tailed Hawks from approaching baited lures at a banding station positioned in a mowed grassy area in an open field (Foss et al. 2017). Individuals exposed to lights were more than five times more likely to abort than those who approached an unlit control station surrounded by dense shrubs and low trees (Foss et al. 2017). This experiment was designed to reduce raptor–aircraft strikes but could be applied to reduce raptor–vehicle collisions on roads and railways.

Managing roadsides to make them less attractive to birds by modified right-of-way mowing regimes and vegetation management could reduce raptor–vehicle collisions (Jacobson 2005, Kociolek et al. 2015). However, in this era of anthropogenic change, only small patches of isolated habitat remain untouched by the ecological influences of roads (Coffin 2007), and deterrence management of roadside habitats may have profoundly negative population impacts due to the loss of food availability and foraging habitat (Hindmarch et al. 2017). Recent research has recommended that roadkilled carcasses should be relocated away from roadways, reducing the risk of flushing, which often results in collisions between vehicles and scavenging species, such as Golden Eagles (Slater et al. 2022, Lonsdorf et al. 2023).

Successful mitigation and prevention of raptor–vehicle collisions is largely dependent on the species involved, technique employed, and scale at which efforts are implemented. Future research should attempt to identify key collision hotspots through time and space, exploring the impacts on broader raptor populations. Innovation of new tools to mitigate raptor–vehicle collisions should be the focus of researchers, governing bodies, and organizations responsible for the safety of wildlife and people across global transportation networks. Future studies should aim to identify any further population-level effects of vehicle collisions on raptors across age and taxonomic groups.

Wind Turbine Collision Solutions. Because fatalities and predicted fatalities at wind energy facilities can decrease energy production and impede development, there is much interest in reducing collisions between wind turbines and raptors, especially threatened and endangered species. Solutions can occur either before or after construction. Pre-construction solutions include landscape management and siting individual turbines or entire facilities in low-risk areas, e.g., low-use, low prey abundance, etc., (Allison et al. 2017, Garcia-Rosa and Tande 2023). To guide pre-construction efforts to minimize fatalities, sensitivity or risk maps have been produced for some species and regions (Miller et al. 2014, Murgatroyd et al. 2021, Wallace et al. 2024). When poorly sited projects result in high numbers of fatalities, post-construction mitigation measures can reduce fatalities (McClure et al. 2022).

Laws and regulations also can reduce fatalities. In the USA, mitigation may be required under regulations governing incidental take (US Fish and Wildlife Service [USFWS] 2021, 2024). When laws have been violated (e.g., incidental take without a permit), mitigation measures have been enforced, leading to reductions in fatalities (US Department of Justice 2013, McClure et al. 2022).

Post-construction solutions include repowering, curtailment (i.e., shutdown) of individual turbines, and blade painting. Early-generation wind turbines are smaller, lower to the ground, and have faster spinning blades than newer turbines. Thus, repowering (i.e., replacing smaller, lower production turbines with larger, higher production turbines) is a potential solution to decrease high mortality rates for some species (Smallwood and Karas 2009).

Temporary, informed curtailment of turbines has also been used to mitigate fatalities. Informed curtailments may be done by human observers or automated systems that detect, identify, and track raptors and curtail turbines (Marques et al. 2014). Reports from human observers have reduced soaring bird mortality by 62% and vulture mortality by 92% in Spain (Ferrer et al. 2022). In Wyoming, an automated curtailment system decreased eagle fatalities by 85% and outperformed human observers (McClure et al. 2021, 2022). Performance of these types of systems, however, may vary regionally, suggesting that further study is needed (Duerr et al. 2023).

Blade painting, such as painting one blade or striping blades with black paint, increases visibility to flying birds and may be effective in reducing collisions. Blade painting at the Smøla wind energy facility reduced collisions by 70%, with the greatest reductions for raptors (May et al. 2020). That said, more studies are needed to better understand the effect of blade painting.

Preventing raptor fatalities at wind energy facilities is challenging, and more research on the effectiveness of mitigation tools is needed. Further, avoiding siting wind farms in high-risk areas and using systems, including artificial intelligence, to reduce fatalities is of the utmost importance, given the considerable expansion of wind energy expected over the coming decades.

Window Collision Solutions. Practical solutions to prevent bird–window collisions include the use of bird-friendly glass and building designs. Several companies offer bird-friendly glass and products to apply to existing glass surfaces to prevent collisions. American Bird Conservancy maintains an online database of available products with ratings of their effectiveness in preventing window collisions in songbirds (American Bird Conservancy 2024). Multiple studies have demonstrated the effectiveness of fritted glass and glass treated with decals applied in tight grid patterns in mitigating window collisions in non-raptorial birds (Sheppard and Phillips 2015, De Groot et al. 2022). Incorporating bird-friendly architectural designs such as decorative grilles that break up expanses of glass can also reduce bird–window collisions (Sheppard and Phillips 2015). Although ultraviolet-treated glass has proven marginally effective in reducing songbird collisions, it would likely make no difference in raptor collisions, as raptors have low sensitivity to ultraviolet radiation (Håstad and Ödeen 2014). Raptor-specific studies are needed to empirically determine whether visual markers on glass reduce raptor–window collisions. We suspect that differences in the mechanisms behind raptor collisions and songbird collisions may limit the effectiveness of such markers in mitigating raptor–window collisions.

Proximity of bird feeders and vegetation to windows have proven to be important predictors of window collisions in non-raptorial birds (Klem et al. 2004, Kummer et al. 2016). However, drivers of window collisions may be different for raptors, particularly those that pursue prey at high speeds. Such raptors typically utilize their lateral visual field while pursuing prey, only switching to frontal vision when seizing prey, meaning they may not recognize potential collision sources ahead until they are too close to avoid a collision (Martin 2011). Although Klem et al. (2004) found that placing feeders <1 m away from windows greatly reduced collision fatalities in non-raptorial birds, Boal and Mannan (1999) found that feeders placed near windows put Cooper's Hawks at high risk of fatal window collisions while in pursuit of feeder birds. This risk is compounded by the tendency of raptors to return to bird feeders due to high densities of easily captured prey (Klem 1981). Future research should aim to identify factors that predict raptor–window collisions and determine effective mitigation strategies.

Other Collision Sources Solutions. As with wind turbines, strategically planning overhead power line routes and communication tower placement to avoid migratory corridors and areas of high concentrations of vulnerable species can significantly mitigate raptor collisions and incidental take (Bernardino et al. 2018, D'Amico et al. 2019). To further minimize raptor collisions with power lines and guy wires of towers, visual markers can be installed on wires to make them more visible to birds, particularly in areas with large concentrations of raptors (Slater et al. 2020). Placing markers on fences has been shown to reduce fence collisions among some grouse (*Phasianidae*) and may also be effective in reducing raptor collisions (Van Lanen et al. 2017).

Currently, airports institute hazard management programs and implement science-based management to decrease the presence of birds and other wildlife on airfields (Cleary and Dolbeer 2005, DeVault et al. 2013). Programs that use multiple mitigation strategies based on the biology of "problem species" are most effective in reducing raptor–aircraft collisions (Washburn 2018). Most-used methods include translocation of raptors, prey management, hazing, and lethal removal, yet further study is needed to assess the efficacy of these methods in deterring raptors in various locations (Washburn et al. 2021). Integrating other strategies into management plans could further decrease raptor–aircraft collisions. Examples include displaying visual stimuli with eyespot patterns and looming movement to deter raptors at airfields (Hausberger et al. 2018) and, in areas where soaring raptors are problematic, mapping the strongest thermals and adjusting aviation routes to avoid these areas (Novoselova et al. 2020).

As a leading professional society for raptor researchers and raptor conservationists, the RRF is dedicated to the accumulation and dissemination of scientific information about raptors, and to resolving raptor conservation concerns (RRF 2021). Raptor collisions with built environments remain an ongoing conservation concern, presenting a global threat to raptor populations. Based on the science summarized here, mitigating the factors associated with raptor collisions with human-made structures and vehicles will allow long-term co-occurrence of raptor populations with human populations.

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LITERATURE CITED

Allison, T. D., J. F. Cochrane, E. Lonsdorf, and C. Sanders-Reed (2017). A review of options for mitigating take of Golden Eagles at wind energy facilities. Journal of Raptor Research 51:319–333. doi:10.3356/JRR-16-76.1.

American Bird Conservancy (2024). Glass collisions: Products and solutions database. American Bird Conservancy, The Plains, VA, USA. https://abcbirds.org/glass-collisions/products-database/.

Arnold, E. M., S. E. Hanser, T. Regan, J. Thompson, M. Lowe, A. Kociolek, and J. R. Belthoff (2018). Spatial, road geometric and biotic factors associated with Barn Owl mortality along an interstate highway. Ibis 161:147–161. doi:10.1111/ibi.12593.

Barrios, L., and A. Rodríguez (2004). Behavioural and environmental correlates of soaring-bird mortality at on-shore turbines. Journal of Applied Ecology 41:72–81. doi:10.1111/j.1365-2664.2004.00876.x.

Bernardino, J., K. Bevanger, R. Barrientos, J. F. Dwyer, A. T. Marques, R. C. Martins, J. M. Shaw, J. P. Silva, and F. Moreira (2018). Bird collisions with power lines: State of the art and priority areas for research. Biological Conservation 222:1–13. doi:10.1016/j.biocon.2018.02.029.

Bishop, C. A., and J. M. Brogan (2013). Estimates of avian mortality attributed to vehicle collisions in Canada. Avian Conservation and Ecology 8:2. doi:10.5751/ACE-00604-080202.

Blackwell, B. F., and S. E. Wright (2006). Collisions of Red-tailed Hawks (*Buteo jamaicensis*), Turkey Vultures (*Cathartes aura*), and Black Vultures (*Coragyps atratus*) with aircraft: Implications for bird strike reduction. Journal of Raptor Research 40:76–80. doi:10.3356/0892-1016(2006)40[76:CORHBJ]2.0.CO;2.

Boal, C. W., and R. W. Mannan (1999). Comparative breeding ecology of Cooper's Hawks in urban and exurban areas of Southeastern Arizona. Journal of Wildlife Management 63:77–84. doi:10.2307/3802488.

Bullock, K. L., G. Malan, and M. D. Pretorius (2011). Mammal and bird road mortalities on the Upington to Twee Rivieren main road in the southern Kalahari, South Africa. African Zoology 46:60–71. doi:10.3377/004.046.0118.

Carrete, M., J. A. Sánchez-Zapata, J. R. Benítez, M. Lobón, and J. A. Donázar (2009). Large scale risk-assessment of wind-farms on population viability of a globally endangered long-lived raptor. Biological Conservation 142:2954–2961. doi:10.1016/j.biocon.2009.07.027.

Carrete, M., J. A. Sánchez-Zapata, J. R. Benítez, M. Lobón, F. Montoya, and J. A. Donázar (2012). Mortality at wind-farms is positively related to large-scale distribution and aggregation in Griffon Vultures. Biological Conservation 145:102–108. doi:10.1016/j.biocon.2011.10.017.

Cleary, E. C., and R. A. Dolbeer (2005). Wildlife Hazard Management at Airports: A Manual for Airport Personnel, Second Ed. US Department of Agriculture, National Wildlife Research Center, Washington, DC, USA.

Cococcetta, C., T. Coutant, T. Collarile, A. Vetere, F. Di Ianni, and M. Huynh (2022). Causes of raptor admission to the Wildlife Rehabilitation Centre in Abruzzo (central Italy) from 2005–2016. Animals 12:1916. doi:10.3390/ani12151916.

Coffin, A. W. (2007). From roadkill to road ecology: A review of the ecological effects of roads. Journal of Transport Geography 15:396–406. doi:10.1016/j.jtrangeo.2006.11.006.

D'Amico, M., R. C. Martins, J. M. Álvarez-Martínez, M. Porto, R. Barrientos, and F. Moreira (2019). Bird collisions with power lines: Prioritizing species and areas by estimating potential population-level impacts. Diversity and Distributions 25:975–982. doi:10.1111/ddi.12903.

De Groot, K. L., A. G. Wilson, R. McKibbin, S. A. Hudson, K. M. Dohms, A. R. Norris, A. C. Huang, I. B. J. Whitehorne, K. T. Fort, C. Roy, J. Bourque, and S. Wilson (2022). Bird protection treatments reduce bird-window collision risk at low-rise buildings within a Pacific coastal protected area. PeerJ 10:e13142. doi:10.7717/peerj.13142.

De Pascalis, F., M. Pannucio, G. Bacaro, and F. Monti (2020). Shift in proximate causes of mortality for six large migratory raptors over a century. Biological Conservation 251:108793. doi:10.1016/j.biocon.2020.108793.

DeVault, T. L., B. F. Blackwell, and J. L. Belant (Editors) (2013). Wildlife in Airport Environments: Preventing Animal-Aircraft Collisions through Science-Based Management. Johns Hopkins University Press, Baltimore, Maryland, USA.

DeVault, T. L., B. F. Blackwell, T. Seamans, S. L. Lima, and E. Fernández-Juricic (2014). Effects of vehicle speed on flight initiation by Turkey Vultures: Implications for bird-vehicle collisions. PLoS ONE 9:e0087944. doi:10.1371/journal.pone.0087944.

Dolbeer, R. A. (2006). Height distribution of birds recorded by collisions with civil aircraft. Journal of Wildlife Management 70:1345–1350. doi:10.2193/0022-541X(2006)70[1345:HDOBRB]2.0.CO;2.

Donázar, J. A., A. Cortés-Avizanda, F. A. Fargallo, A. Margalida, M. Moleón, Z. Morales-Reyes, R. Moreno-Opo, J. M. Pérez-García, J. A. Sánchez-Zapata, I. Zuberogoitia, and D. Serrano (2016). Roles of raptors in a changing world: From flagships to providers of ecosystem services. Ardeola 63:181–234. doi:10.13157/arla.63.1.2016.rp8.

Duerr, A. E., A. E. Parsons, L. R. Nagy, M. J. Kuehn, and P. H. Bloom (2023). Effectiveness of an artificial intelligence-based system to curtail wind turbines to reduce eagle collisions. PLoS ONE 18:e0278754. doi:10.1371/journal.pone.0278754.

Dwyer, J. F., S. Hindmarch, and G. E. Kratz (2018). Raptor mortality in urban landscapes. In Urban Raptors: Ecology and Conservation of Birds of Prey in Cities. (C. W. Boal and C. R. Dykstra, Editors). Island Press, Washington, DC, USA. pp. 199–213.

Dykstra, C. R. (2018). City lifestyles: Behavioral ecology of urban raptors. In Urban Raptors: Ecology and Conservation of Birds of Prey in Cities (C. W. Boal and C. R. Dykstra, Editors). Island Press, Washington DC, USA. pp. 18–35.

Federal Aviation Administration (2023). Federal Aviation Administration Wildlife Strike Database. Version 4.2.11. US Department of Transportation, Federal Aviation Administration, Washington, DC, USA. https://wildlife.faa.gov/.

Ferrer, M., A. Alloing, R. Baumbush, and V. Morandini (2022). Significant decline of Griffon Vulture collision mortality in wind farms during 13-year of a selective turbine stopping protocol. Global Ecology and Conservation 38:e02203. doi:10.1016/j.gecco.2022.e02203.

Foss, C. R., D. J. Ronning, and D. A. Merker (2017). Intense short-wavelength light triggers avoidance response by Red-tailed Hawks: A new tool for raptor diversion? The Condor 119:431–438. doi:10.1650/CONDOR-16-230.1.

Gagné, S. A., J. L. Bates, and R. O. Bierregaard (2015). The effects of road and landscape characteristics on the likelihood of a Barred Owl (*Strix varia*)-vehicle collision. Urban Ecosystems 18:1007–1020. doi:10.1007/s11252-015-0465-5.

Gahbauer, M. A., D. M. Bird, K. E. Clark, T. French, D. W. Brauning, and F. A. McMorris (2015). Productivity, mortality, and management of urban Peregrine Falcons in northeastern North America. Journal of Wildlife Management 79:10–19. doi:10.1002/jwmg.803.

Garcia-Rosa, P. B., and J. O. G. Tande (2023). Mitigation measures for preventing collision of birds with wind turbines. Journal of Physics: Conference Series 2626:e012072. doi:10.1088/1742-6596/2626/1/012072.

Grünkorn, T., J. Blew, T. Coppack, O. Krüger, G. Nehls, A. Potiek, M. Reichenbach, J. von Rönn, H. Timmermann, and S. Weitekamp (2016). Prognosis and assessment of bird collision risks at wind turbines in northern Germany (PROGRESS). Federal Ministry for Economic Affairs and Energy (BMWi), Berlin, Germany.

Hager, S. B. (2009). Human-related threats to urban raptors. Journal of Raptor Research 43:210–226. doi:10.3356/JRR-08-63.1.

Hanmer, H. J., and R. A. Robinson (2021). Incidence of road mortality in ringed raptors and owls: A spatial analysis. BTO Research Report 733. British Trust for Ornithology, Thetford, UK.

Håstad, O., and A. Ödeen (2014). A vision physiological estimation of ultraviolet window marking visibility to birds. PeerJ 2:e621. doi:10.7717/peerj.621.

Hausberger, M., A. Boigné, C. Lesimple, L. Belin, and L. Henry (2018). Wide-eyed glare scares raptors: From laboratory evidence to applied management. PLoS ONE 13:e0204802. doi:10.1371/journal.pone.0204802.

Hernandez, C. L., S. C. Oster, and J. L. Newbrey (2018). Retrospective study of raptors treated at the Southeastern Raptor Center in Auburn, Alabama. Journal of Raptor Research 52:379–388. doi:10.3356/JRR-17-16.1.

Heuck, C., C. Herrmann, C. Levers, P. J. Leitão, O. Krone, R. Brandl, and J. Albrecht (2019). Wind turbines in high quality habitat cause disproportionate increases in collision mortality of the White-tailed Eagle. Biological Conservation 236:44–51. doi:10.1016/j.biocon.2019.05.018.

Hindmarch, S., J. E. Elliott, S. McCann, and P. Levesque (2017). Habitat use by Barn Owls across a rural to urban gradient and an assessment of stressors including, habitat loss, rodenticide exposure and road mortality. Landscape and Urban Planning 164:132–143. doi:10.1016/j.landurbplan.2017.04.003.

Jacobson, S. L. (2005). Mitigation measures for highway-caused impacts to birds. US Department of Agriculture, Forest Service, Washington, DC, USA.

Kadlecova, G., E. Voslarova, and V. Vecerek (2022). Diurnal raptors at rescue centres in the Czech Republic: Reasons for admission, outcomes and length of stay. PLoS ONE 17:e0279501. doi:10.1371/journal.pone.0279501.

Katzner, T. E., D. A. Nelson, M. A. Braham, J. M. Doyle, N. B. Fernandez, A. E. Duerr, P. H. Bloom, M. C. Fitzpatrick, T. A. Miller, R. C. E. Culver, L. Braswell, and J. A. DeWoody (2016). Golden Eagle fatalities and the continental-scale consequences of local wind-energy generation. Conservation Biology 31:406–415. doi:10.1111/cobi.12836.

Klem, D., Jr. (1979). Biology of collisions between birds and windows. Ph.D. dissertation. Southern Illinois University, Carbondale, IL, USA.

Klem, D., Jr. (1981). Avian predators hunting birds near windows. Proceedings of the Pennsylvania Academy of Sciences 55:90–92.

Klem, D., Jr. (1990). Bird-window collisions: Mortality and prevention. Journal of Field Ornithology 61:120–128.

Klem, D., Jr., D. C. Keck, K. L. Marty, A. J. Miller Ball, E. E. Niciu, and C. T. Platt (2004). Effects of window angling, feeder placement, and scavengers on avian mortality at plate glass. Wilson Bulletin 116:69–73. doi:10.1676/0043-5643(2004)116[0069:EOWAFP]2.0.CO;2.

Kociolek, A., C. Grilo, and S. Jacobson (2015). Flight doesn't solve everything: Mitigation of road impacts on birds. In Handbook of Road Ecology (R. van der Ree, D. J. Smith, and C. Grilo, Editors). John Wiley and Sons, Hoboken, NJ, USA. pp. 281–289.

Kummer, J. A., E. M. Bayne, and C. S. Machtans (2016). Use of citizen science to identify factors affecting bird-window collision risk at houses. Ornithological Applications 118:624–639. doi:10.1650/CONDOR-16-26.1.

Lambertucci, S. A., K. L. Speziale, T. E. Rogers, and J. M. Morales (2009). How do roads affect the habitat use of an assemblage of scavenging raptors? Biodiversity and Conservation 18:2063–2074. doi:10.1007/s10531-008-9573-3.

Lonsdorf, E. V., J. S. Gerber, D. Ray, S. J. Slater, and T. D. Allison (2023). Assessing carcass relocation for offsetting Golden Eagle mortality at wind energy facilities. Journal of Wildlife Management 87:e22478. doi:10.1002/jwmg.22478.

Loss, S. R., T. Will, and P. P. Marra (2015). Direct mortality of birds from anthropogenic causes. Annual Review of Ecology, Evolution, and Systematics 46:99–120. doi:10.1146/annurev-ecolsys-112414-054133.

Lutmerding, J. A., M. Rogosky, B. Peterjohn, J. McNicoll, and D. Bystrak (2012). Summary of raptor encounter records at the Bird Banding Lab. Journal of Raptor Research 46:17–26. doi:10.3356/JRR-11-LUTM.1.

Maphalala, M. I., A. Monadjem, K. L. Bildstein, B. Hoffman, and C. Downs (2021). Causes of admission to a raptor rehabilitation centre and factors that can be used to predict the likelihood of release. African Journal of Ecology 59:510–517. doi:10.1111/aje.12851.

Marques, A. T., H. Batalha, S. Rodrigues, H. Costa, M. J. R. Pereira, C. Fonseca, M. Mascarenhas, and J. Bernardino (2014). Understanding bird collisions at wind farms: An updated review on the causes and possible mitigation strategies. Biological Conservation 179:40–52. doi:1016/j.biocon.2014.08.017.

Martin, G. R. (2011). Understanding bird collisions with man-made objects: A sensory ecology approach. Ibis 153:239–254. doi:10.1111/j.1474-919X.2011.01117.x.

May, R., T. Nygård, E. L. Dahl, O. Reitan, and K. Bevanger (2011). Collision Risk in White-tailed Eagles: Modelling Kernel-based Collision Risk using Satellite Telemetry Data in Smøla Wind-power Plant. NINA Report 692. Norwegian Institute for Nature Research, Trondheim, Norway.

May, R., T. Nygård, U. Falkdalen, J. Åström, Ø. Hamre, and B. G. Stokke (2020). Paint it black: Efficacy of increased wind turbine rotor blade visibility to reduce avian fatalities. Ecology and Evolution 10:8927–8935. doi:10.1002/ece3.6592.

McCabe, R. A., J.-F. Therrien, K. Wiebe, G. Gauthier, D. Brinker, S. Weidensaul, D. Reid, F. I. Doyle, K.-O. Jacobsen, T. Aarvak, I. J. Øien, et al. (2022). Density-dependent winter survival of immatures in an irruptive raptor with pulsed breeding. Oecologia 198:295–306. doi:10.1007/s00442-021-05057-9.

McClure, C. J. W., B. W. Rolek, M. A. Braham, T. A. Miller, A. E. Duerr, J. D. McCabe, L. Dunn, and T. E. Katzner (2021). Eagles enter rotor-swept zones of wind turbines at rates that vary per turbine. Ecology and Evolution 11:11267–11274. doi:10.1002/ece3.7911.

McClure, C. J. W., B. W. Rolek, L. Dunn, J. D. McCabe, L. Martinson, and T. E. Katzner (2022). Confirmation that eagle fatalities can be reduced by automated curtailment of wind turbines. Ecological Solutions and Evidence 3:e12173. doi:10.1002/2688-8319.12173.

Miller, T. A., R. P. Brooks, M. Lanzone, D. Brandes, J. Cooper, K. O'Malley, C. Maisonneuve, J. Tremblay, A. Duerr, and T. Katzner (2014). Assessing risk to birds from industrial wind energy development via paired resource selection models. Conservation Biology 28:745–755. doi:10.1111/cobi.12227.

Millsap, B. A., K. K. Madden, and R. K. Murphy (2024). Causes of death of female Cooper's Hawks from an urban setting in New Mexico, USA. Journal of Raptor Research 58:1–14. doi:10.3356/JRR-23-00022.

Molina-López, R. A., J. Casal, and L. Darwich (2011). Causes of morbidity in wild raptor populations admitted at a wildlife rehabilitation centre in Spain from 1995–2007: A long term retrospective study. PLoS ONE 6:e24603. doi:10.1371/journal.pone.0024603.

Murgatroyd, M., W. Bouten, and A. Amar (2021). A predictive model for improving placement of wind turbines to minimise collision risk potential for a large soaring raptor. Journal of Applied Ecology 58:857–868. doi:10.1111/1365-2664.13799.

Neese, M. R., J. Seitz, J. Nuzzo, and D. J. Horn (2010). Cause of admittance in raptors treated at the Illinois

Raptor Center, 1995–2006. Journal of Wildlife Rehabilitation 30:17–20.
Newton, I., I. Wyllie, and L. Dale (1999). Trends in the numbers and mortality patterns of sparrowhawks (*Accipiter nisus*) and kestrels (*Falco tinnunculus*) in Britain, as revealed by carcass analyses. Journal of Zoology 248:139–147.
Novoselova, N. S., A. A. Novoselov, A. Macarrão, G. Gallo-Ortiz, and W. R. Silva (2020). Remote sensing applications for abating aircraft–bird strike risks in southeast Brazil. Human–Wildlife Interactions 14:8. doi:10.26077/3z5d-eb31.
Panter, C. T., S. Allen, N. Backhouse, E. Mullineaux, C.-A. Rose, and A. Amar (2022). Causes, temporal trends, and the effects of urbanization on admissions of wild raptors to rehabilitation centers in England and Wales. Ecology and Evolution 12:e8856. doi:10.1002/ece3.8856.
Pfeiffer, M. B., B. F. Blackwell, and T. L. DeVault (2018). Quantification of avian hazards to military aircraft and implications for wildlife management. PLOS ONE 13: e0206599. doi: 10.1371/journal.pone.0206599.
Planillo, A., S. Kramer-Schadt, and J. E. Malo (2015). Transport infrastructure shapes foraging habitat in a raptor community. PLoS ONE 10:e0118604. doi:10.1371/journal.pone.0118604.
Raptor Research Foundation (RRF) (2021). About Us. https://raptorresearchfoundation.org/about/history/.
Šálek, M., M. Bažant, P. Klvanõa, Z. Vermouzek, and R. Václav (2023). Historical changes in mortality patterns of diurnal and nocturnal raptors in the Czech Republic, Central Europe: 1913–2017. Biological Conservation 282:110073. doi:10.1016/j.biocon.2023.110073.
Schuster, E., L. Bulling, and J. Köppel (2015). Consolidating the state of knowledge: A synoptical review of wind energy's wildlife effects. Environmental Management 56:300–331. doi:10.1007/s00267-015-0501-5.
Sheppard, C., and G. Phillips (2015). Bird-friendly Building Design, Second Ed. American Bird Conservancy, The Plains, VA, USA.
Simon, K. L., D. A. Best, J. G. Sikarskie, H. T. Pittman, W. W. Bowerman, T. M. Cooley, and S. Stolz (2020). Sources of mortality in Bald Eagles in Michigan, 1986–2017. Journal of Wildlife Management 84:553–561. doi:10.1002/jwmg.21822.
Slater, S. J., J. F. Dwyer, and M. Murgatroyd (2020). Conservation Letter: Raptors and overhead electrical systems. Journal of Raptor Research 54:198–203. doi:10.3356/0892-1016-54.2.198.
Slater, S. J., D. M. Maloney, and J. M. Taylor (2022). Golden Eagle use of winter roadkill and response to vehicles in the western United States. Journal of Wildlife Management 86:e22246. doi:10.1002/jwmg.22246.
Smallwood, K. S., and B. Karas (2009). Avian and bat fatality rates at old-generation and repowered wind turbines in California. Journal of Wildlife Management 73:1062–1071.
Smallwood, K. S., and C. Thelander (2008). Bird mortality in the Altamont Pass Wind Resource Area, California. Journal of Wildlife Management 72:215–223.
Smith, K. A., G. D. Campbell, D. L. Pearl, C. M. Jardine, F. Salgado-Bierman, and N. M. Nemeth (2018). A retrospective summary of raptor mortality in Ontario, Canada (1991–2014), including the effects of West Nile Virus. Journal of Wildlife Diseases 54:261–271. doi:10.7589/2017-07-157.
Sumasgutner, P., R. Buij, C. J. W. McClure, P. Shaw, C. R. Dykstra, N. Kumar, and C. Rutz (2021). Raptor research during the COVID-19 pandemic provides invaluable opportunities for conservation biology. Biological Conservation 260:109149. doi:10.1016/j.biocon.2021.109149.
Sweeney, S. J., P. T. Redig, and H. B. Tordoff (1997). Morbidity, survival and productivity of rehabilitated Peregrine Falcons in the upper Midwestern U.S. Journal of Raptor Research 31:347–352.
Thompson, L. J., B. Hoffman, and M. Brown (2013). Causes of admissions to a raptor rehabilitation centre in KwaZulu-Natal, South Africa. African Zoology 48:359–366. doi:10.3377/004.048.0220.
US Department of Justice (2013). Utility Company Sentenced in Wyoming for Killing Protected Birds at Wind Projects. US Department of Justice, Washington, DC, USA. Last updated 3 April 2024. https://www.justice.gov/opa/pr/utility-company-sentenced-wyoming-killing-protected-birds-wind-projects.
US Fish and Wildlife Service (USFWS) (2021). Regulations Governing Take of Migratory Birds; Revocation of Provisions. US Department of the Interior, Fish and Wildlife Service, Washington, DC, USA. https://www.federalregister.gov/d/2021-21473.
US Fish and Wildlife Service (USFWS) (2024). Permits for Incidental Take of Eagles and Eagle Nests. US Department of the Interior, Fish and Wildlife Service, Washington, DC, USA. https://www.federalregister.gov/d/2024-02182.
Van Lanen, N. J., A. W. Green, T. R. Gorman, L. A. Quattrini, and D. C. Pavlacky, Jr. (2017). Evaluating efficacy of fence markers in reducing Greater Sage-Grouse collisions with fencing. Biological Conservation 213:70–83. doi:10.1016/j.biocon.2017.06.030.
Wallace, Z., B. Bedrosian, J. Dunk, D. W. LaPlante, B. Woodbridge, B. Smith, J. L. Brown, T. Lickfett, K. Gura, D. Bittner, R. Crandall, et al. (2024). Predicting the spatial distribution of wintering Golden Eagles to inform full annual cycle conservation in western North America. PLoS ONE 19:e029734. doi:10.1371/journal.pone.0297345.
Washburn, B. E. (2018). Human-raptor conflicts in urban settings. In Urban Raptors: Ecology and Conservation of Birds of Prey in Cities (C. W. Boal and C. R. Dykstra, Editors). Island Press, Washington DC, USA. pp. 214–228.
Washburn, B. E., M. J. Begier, and S. E. Wright (2015). Collisions between eagles and aircraft: An increasing problem in the airport environment. Journal of Raptor Research 49:192–200. doi:10.3356/rapt-49-02-192-200.1.
Washburn, B. E., C. K. Pullins, T. L. Guerrant, G. J. Martinelli, and S. F. Beckerman (2021). Comparing management programs to reduce Red-tailed Hawk

collisions with aircraft. Wildlife Society Bulletin 45:237–243. doi:10.1002/wsb.1177.

Watson, R. T., P. S. Kolar, M. Ferrer, T. Nygård, N. Johnston, W. G. Hunt, H. A. Smit-Robinson, C. J. Farmer, M. Huso, and T. E. Katzner (2018). Raptor interactions with wind energy: Case studies from around the world. Journal of Raptor Research 52:1–18. doi:10.3356/JRR-16-100.1.

Wiens, J. D., and P. S. Kolar (2021). Golden Eagle Population Surveys in the Vicinity of the Altamont Pass Wind Resource Area, California, 2014–21. US Department of the Interior, US Geological Survey, Reston, VA, USA. doi:10.3133/ofr20211107.

Zuberogoitia, I., J. del Real, J. J. Torres, L. Rodríguez, M. Alonso, V. de Alba, C. Azahara, and J. Zabala (2015). Testing pole barriers as feasible mitigation measure to avoid bird vehicle collisions (BVC). Ecological Engineering 83:144–151. doi:10.1016/j.ecoleng.2015.06.026.

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