Bald eagle in flight. *Getty Images*

Raptors and Land-Based Wind Energy in the United States

Introduction

Wind energy is a critical element of a sustainable energy future; however, like many other energy resources, its development can have negative impacts on wildlife, including many avian species. Impacts to birds can be either direct through collision with wind turbine blades, or indirect through habitat loss from displacement or land use change. The associated infrastructure may pose additional hazards such as collisions with vehicles and electrocution from overhead distribution lines (Drewitt and Langston 2006; Smith and Dwyer 2016).

Some species of raptors are more vulnerable to collisions due to their flight patterns, physiology, and behavior. Many raptor species rely significantly on soaring flight, which is dependent on air currents. Unfortunately, these same air currents are often suitable for wind energy development, leading to an increased risk of collisions with wind turbines (Barrios and Rodriguez 2004; Péron et al. 2017). Additionally, the vision of raptors is more suited for focusing on distant objects, potentially diminishing their awareness of closer obstacles in their immediate vicinity, especially during hunting (Martin 2011; May et al. 2020). Moreover, raptors tend to have delayed sexual maturation and long life spans with relatively low reproductive capacity, resulting in populations that are slow to recover from additive mortality (Beston et al. 2016).

Raptors at Risk

There are reported collision fatalities from wind energy facilities for many species of raptors in North America. Species that use open landscapes, such as grasslands and deserts, are more likely to encounter wind turbines than forest-dwelling species. Rather than solely focusing on individual mortality events, it is important to consider species vulnerability to population-level impacts from wind energy. A 2021 study looking at the potential for population-level impacts from wind turbine collision for 14 raptor species suggests that barn owls (*Tyto alba*), ferruginous hawks (*Buteo regalis*), golden eagles (*Aquila chrysaetos*), American kestrels (*Falco sparverius*), and red-tailed hawks (*Buteo jamaicensis*) had higher potential to experience population-level impacts compared to the other species studied (Diffendorfer et al. 2021).

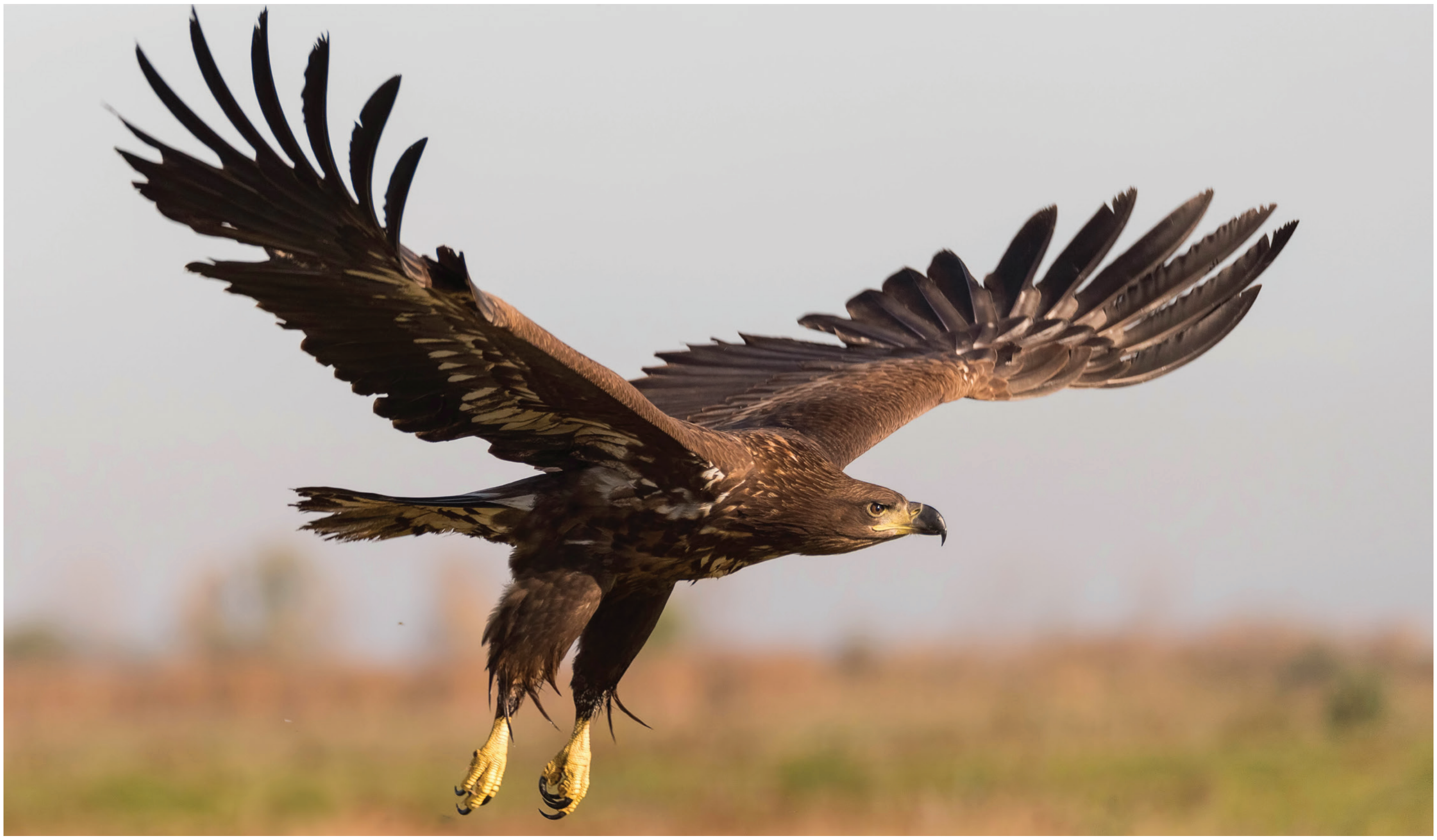
Impacts to eagle species are of particular interest due to high concern for eagle conservation and strong legal protections in the United States accorded by the Bald and Golden Eagle Protection Act and the Migratory Bird Treaty Act. Golden eagles appear to be more vulnerable to turbine collision mortality than bald eagles (*Haliaeetus leucocephalus*), even after accounting for variation in wind energy facility occurrence within their respective ranges. Although most modern facilities experience either zero or few eagle fatalities over their multidecade operational life, a few facilities in the Altamont Pass Wind Resource Area in California have documented relatively high levels of collision in part due to the extremely high densities of breeding golden eagles in the region (Smallwood and Thelander 2008; Wiens and Kolar 2021).

Our understanding of indirect impacts, such as displacement from an area occupied by a wind energy facility, is limited. Often, accurately quantifying this type of impact requires research over large areas and long study periods to collect the necessary data (Drewitt and Langston 2006). One type of methodology used is the before-after control-impact (BACI) study design, wherein researchers compare data collected before and after construction of a facility, in addition to comparing data collected at the project area to those collected at a reference, or control area, to assess the degree of impact. It is important to study these impacts for each raptor species of interest because species vary in their sensitivity to disturbance/displacement impacts. For example, red-tailed hawk abundance near a wind energy facility in Wisconsin returned to preconstruction levels after 8 years, whereas American kestrel abundance did not (Dohm et al. 2019).

Raptor Monitoring

Monitoring across the various phases of development is essential to understanding a given project's potential risk to raptors. Preconstruction surveys establish a baseline for local bird communities and identify the presence of any species of concern (U.S. Fish and Wildlife Service [FWS] 2012). These surveys may involve fixed-radius point counts, migration counts, prey surveys, communal roost surveys, and nest surveys and monitoring. Developers are encouraged to incorporate the results of nest surveys into micrositing efforts to avoid placing wind turbines near nests of sensitive raptor species (FWS 2022). Raptor nests identified near areas of ground disturbance or construction activity are buffered to minimize disturbance impacts and monitored if construction occurs concurrent with the breeding season (Murgatroyd et al. 2021). Some elements of construction may be delayed or altered to lessen impacts to nesting individuals. The FWS recommends that postconstruction mortality monitoring be conducted during the first year or two after a facility is operational. These studies typically involve searching for carcasses within established plots around wind turbines. The intensity, timing, duration, number of wind turbines included, search interval, and frequency of these surveys depend on the objectives of the monitoring and on site-specific metrics, including information from the preconstruction assessments (Huso and Dalthorp 2014). Raw carcass counts are typically adjusted based on the results of searcher efficiency and carcass persistence trials in addition to other corrections, which account for various sources of bias inherent in mortality estimation and are necessary to produce accurate fatality estimates (Reyes et al. 2016). In instances where impacts to raptors are greater than anticipated, additional studies can be undertaken to identify the root cause of the issue and test the effectiveness of remedial measures. These may involve the use of cameras or tracking technologies (e.g., GPS or radiotelemetry tags) to monitor movement and behavior at the turbine or landscape scale, respectively (McClure et al. 2021a).

American kestrel. *Getty Images*



Golden eagle. *Getty Images*

Mitigation Strategies

Reducing risk to raptors should follow the mitigation hierarchy, which includes actions to avoid, minimize, and compensate fatalities (Dempsey et al. 2023). These actions can take place during different phases of the project life cycle. Avoidance of high-quality raptor habitat during initial project planning is the most cost-effective way to limit risk. Site planners can use desktop and preconstruction field data to identify and avoid areas of high raptor nesting density, historic and active nest sites, winter roost locations, and concentrated prey resources (FWS 2012). Avoidance can result in micro- or macro-siting changes, including changing the boundary of the project or relocating or removing individual turbines, respectively. For example, if a frequent-movement corridor (e.g., travel from communal roost to a concentrated food resource) is identified within the planned site, wind turbines can be moved away from the corridor to reduce the chance of collision. Layouts can also be adjusted to increase the open space between wind turbines and wind turbine strings to allow for more evasive flight maneuvers (Hanssen et al. 2020; May et al. 2015). Wind energy facilities with new, larger wind turbines can have lower densities and increased spacing between wind turbines than previous generations. New computer models that simulate eagle behavior may help predict the likely flight paths of birds based on topography and wind data (Sandhu et al. 2022).

Construction activities, including the associated noise, lighting, vehicles, and habitat disturbance, can also impact local raptors. These activities can be difficult to avoid and minimize but only represent temporary disturbances. To help alleviate impact, activities should be sited away from sensitive habitats as much as possible, and, for certain species, avoidance of construction activity near active nests during crucial stages of the breeding season is strongly recommended (FWS 2012). For example, developers must observe seasonal restrictions and temporary disturbance buffers regarding the use of heavy machinery near bald eagle nests (FWS 2007). Educating construction crews about possible wildlife conflicts, including response and reporting measures as well as minimization measures, is critical for reducing raptor impacts. Employing wildlife consultants on-site to monitor sensitive raptor resources is another useful strategy.

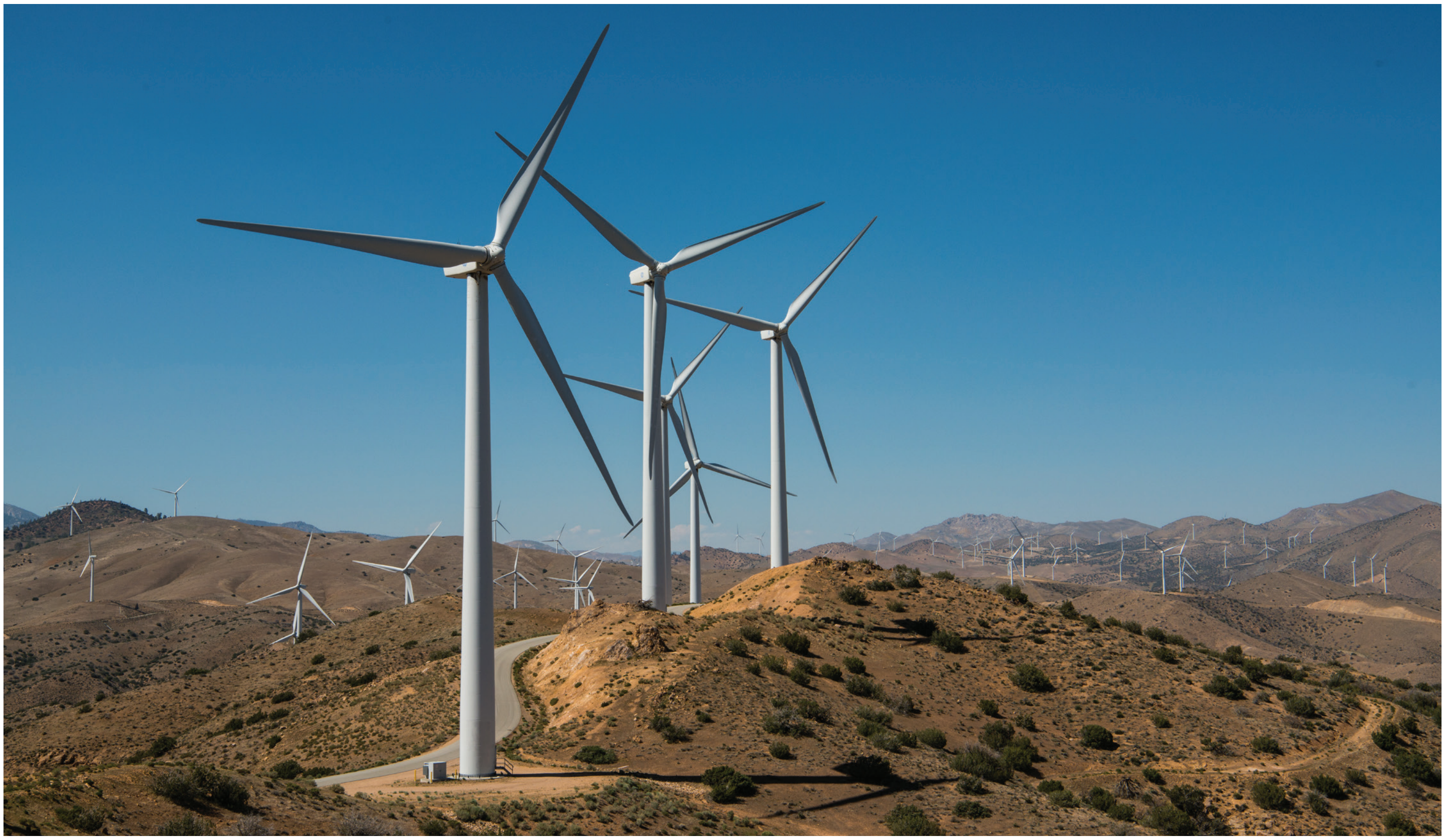
Impacts that cannot be avoided can be minimized through a variety of strategies. For example, attractant removal aims to reduce raptor activity near the project area by reducing perching and food resources availability (Alison et al. 2017). Other strategies like curtailing wind turbines, or slowing the rotational speed of the blades, during high-use periods (e.g., during migration) can be effective. In addition, human observers or radar technologies can be used to record periods of high activity to inform seasonal curtailment. Active GPS tracking of sensitive species, such as California condors (*Gymnogyps californianus*) and golden eagles, may be employed to inform wind energy operators when a bird enters a facility. There are additional approaches to inform curtailment decisions, including using human observers, cameras, or radar that detect, identify, and track individual birds as they approach wind turbines. In most cases, the observations are used to curtail a small subset of wind turbines when raptors are nearby (McClure et al. 2021b, 2022). An alternative strategy being explored is to emit audible deterrent signals as a raptor approaches to alter the birds' flight path away from the wind turbine (Terrill et al. 2018). Minimization strategies can also rely on information related to the sensory perception of raptors. For example, flashing white strobe lights may reduce the risk of collision compared to the more standard red constant illumination (Cook et al. 2011; Gehring et al. 2009; Marques et al. 2014).

Another potential approach is to paint a single wind turbine blade black to potentially make it more visible to birds (May et al. 2020).

Any impact to raptors that cannot be limited through avoidance or minimization must be compensated for or offset by actions that reduce raptor mortality from other sources or increase raptor conservation. Avenues of compensatory mitigation developed for eagles include power pole retrofitting to prevent electrocution, lead ammunition abatement programs to prevent lead poisoning, and roadkill removal to reduce vehicle collisions (Allison et al. 2017; Londsorf et al. 2022; McTee et al. 2023).

Decommissioning and repowering represent additional opportunities to reduce risk. If a single turbine is identified as particularly hazardous because of design or placement, managers can choose to remove it. When the wind energy facility is ready for decommissioning or repowering, the placement of wind turbines should be evaluated to minimize future wildlife impacts. Replacing smaller wind turbines with fewer, larger, and more efficient ones may reduce collision risks (Dahl et al. 2015), although a recent study shows that the relative energy production of a site may be a better predictor of collision risk than wind turbine size alone (Huso et al. 2021).

Red-tailed hawk in flight. *Getty Images*



Pine Tree Wind and Solar Farm is part of the National Renewable Energy Laboratory's 100% Renewable Energy Study. *Photo by Dennis Schroeder, NREL 50710*

Areas for Future Research

- Use technological advancements to fill raptor natural history gaps and continue to increase understanding of raptor interactions with wind turbines.
- Validate existing collision risk models to improve their performance on the target species and expand their applicability to other species and additional scenarios.
- Evaluate the deployment of wind energy in new regions with raptor species that have not yet interacted with wind turbines.
- Explore alternative monitoring technologies, such as drones or strike detectors, to estimate collision risk.
- Explore the layout options for wind energy facilities and wind turbine design options to decrease collision risk for raptors.
- Validate the effectiveness of detection and deterrent systems to reduce collision risk.
- Advance machine-learning algorithms for detecting, identifying, and tracking raptors that help inform curtailment and deterrent strategies.
- Verify the effectiveness of compensation measures for protected species.
- Publish study results and make data publicly available for large-scale analyses.

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For more information, visit

https://www.nrel.gov/wind/eco-wind.html

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