Collision Risk Modeling – A Tool for Assessing Risks to Raptors at Wind Energy Facilities

In January 2022, the International Energy Agency Wind Task 34—Working Together to Resolve the Environmental Effects of Wind Energy (WREN)—organized a forum to discuss aspects of raptor collision risk with wind turbines. The forum included experts in raptor biology and physiology, collision risk modeling, wind energy development, and atmospheric scientists from seven countries. They represented a range of international stakeholder groups including academia, government agencies, national laboratories, and wildlife consultants. This educational brief summarizes the discussion during the forum and written comments from those who could not attend. Relevant literature was used to provide additional context when needed.

INTRODUCTION

For several species of raptors, such as golden eagles *(Aquila chrysaetos),* griffon vultures *(Gyps fulvus)* and white-tailed eagles *(Haliaatus albicilla)*, collision risk with wind turbines continues to be a concern among stakeholders. These concerns include the potential population-level impact related to collisions, compliance with regulatory mechanisms for protected species, and the ability to generate renewable energy. To make siting and operational decisions, stakeholders require some level of certainty of the risk associated with a proposed project. Understanding this risk, in part, requires species-specific data on raptors and how they perceive and interact with wind farms or individual wind turbines. Collision risk models (CRMs) are a tool, often used in environmental impact assessments, that can provide estimates of risk relative to specific turbines or an entire wind farm. However, questions associated with the uncertainty in CRM estimates remain.

RAPTOR FLIGHT BEHAVIOR AND PHYSIOLOGY

Certain species of raptors have behavioral or physiological traits that make them more susceptible to wind turbine collisions. Understanding these traits will improve CRMs and our overall understanding of collision events. For example, knowing the head position (i.e., looking forward or looking downward) and eye movement of a raptor in flight may provide insight on some collision events. Research shows that birds have blind spots in front and above their heads when they are tilted downward. Thus, a raptor flying toward or within a wind farm with its head tilted downward may not see wind turbines directly in front of it. Data also show that species move their eyes while in flight to increase their perception of the surrounding environment. Both the size of the blind spots and frequency of eye movement varies among species. For example, golden eagles have larger blind spots and move their eyes less often than bald eagles *(Haliaeetus leucocephalus)*. Species with larger blind spots and less eye movement may be more vulnerable to collisions.

A golden eagle launches off a platform near wind turbines. *Photo by Dennis Schroeder, National Renewable Energy Laboratory*

It remains unclear how often raptors change their head position or move their eyes while in flight, but such movements may be related to prey availability and the presence of other birds. An area with high prey availability may increase the amount of time a raptor is focused on the ground rather than looking forward. Thus, prey density may be an early indicator of risk for a proposed wind farm. The presence of avian competitors or other species of birds (e.g., those that exhibit mobbing behavior toward raptors) can also affect whether an individual is aware of its surroundings or is exhibiting aggressive or evasive behaviors that could lead to risk. Interactions with other species may be difficult to quantify at a proposed site, but it may be possible to assess alertness or species awareness of different raptor species under natural conditions or controlled environments to determine whether this can be used to predict collision risk.

Seasonal changes in flight behavior may also contribute to risk. Raptors often take advantage of updrafts to provide lift. Updrafts can be generated by rising temperatures (thermal updrafts) or by landscape features (orographic updrafts), both of which allow an individual to achieve greater height without expending energy. Thermal updrafts are more common during summer and are generated when the air near the ground heats up and rises. Orographic updrafts are generated when a steep increase in slope (e.g., a hill or ridge) directs wind upward. Raptors generally use orographic updrafts during fall, winter, and spring when there are fewer thermal updrafts. Because wind farms may be sited along ridgelines for favorable wind conditions, these sites can increase interactions if raptors use the ridgelines to achieve higher altitudes during certain times of the year (e.g., during migration).

Other factors may also influence the use of certain habitat features or landscape conditions. Identifying these factors early may reduce risk. For example, suitable nesting sites are high-use areas that often require setback from any development. Current setback distances are often based on expert opinion, but these distances may not be appropriate or necessary. Refining data related to habitat use can improve setback distances to reduce risk.

Research investigating the hearing and vision capabilities of raptors may contribute to risk minimization strategies. Knowing the optimal hearing range and frequency patterns that raptors respond to can help in the development of audible deterrent technologies that dissuade raptors from approaching wind turbines. Similarly, understanding how raptors respond to visible light and color can lead to making turbines more noticeable, which may increase avoidance behaviors of raptors near wind turbines. Although avoidance can reduce direct mortality from collisions, this behavior can also be associated with a loss of habitat and resource access, which may negatively impact raptor populations, especially if the avoidance behavior is observed across larger spatial scales.

WHAT ARE COLLISION RISK MODELS AND HOW ARE THEY USED?

CRMs calculate the probability of a collision occurring given a set of specific characteristics of the wind farm (e.g., layout and number of turbines), wind turbines (e.g., turbine size and rotor speed; Figure 1), and the species of interest (e.g., body size and flight speed). There are several CRMs available, and the appropriate one to use may depend on the unique set of circumstances of the wind farm and the species known to occur in the area. In other words, a CRM that performs well for one wind farm may not work for another.

CRMs can be used to predict risk at different spatial scales, such as the wind farm, a string of wind turbines, or a single wind turbine. CRMs also can be developed during different times of the year, such as during migration or the summer breeding season. Additionally, CRMs can assess risk at an existing wind farm, providing insight on when and why collisions occur. Thus, depending on their use, CRMs can help inform mitigation measures, such as avoiding areas of relatively higher risk, changing turbine operations during periods of high risk, or managing habitat or prey species to reduce risk or draw individuals away from a wind farm to a more favorable area.

CHALLENGES WITH COLLISION RISK MODELS

Despite their promise, CRMs have several limitations or biases. Some models are sensitive to certain parameters, such as the avoidance rate, meaning that the estimate of collisions can change dramatically with only small variations in the input

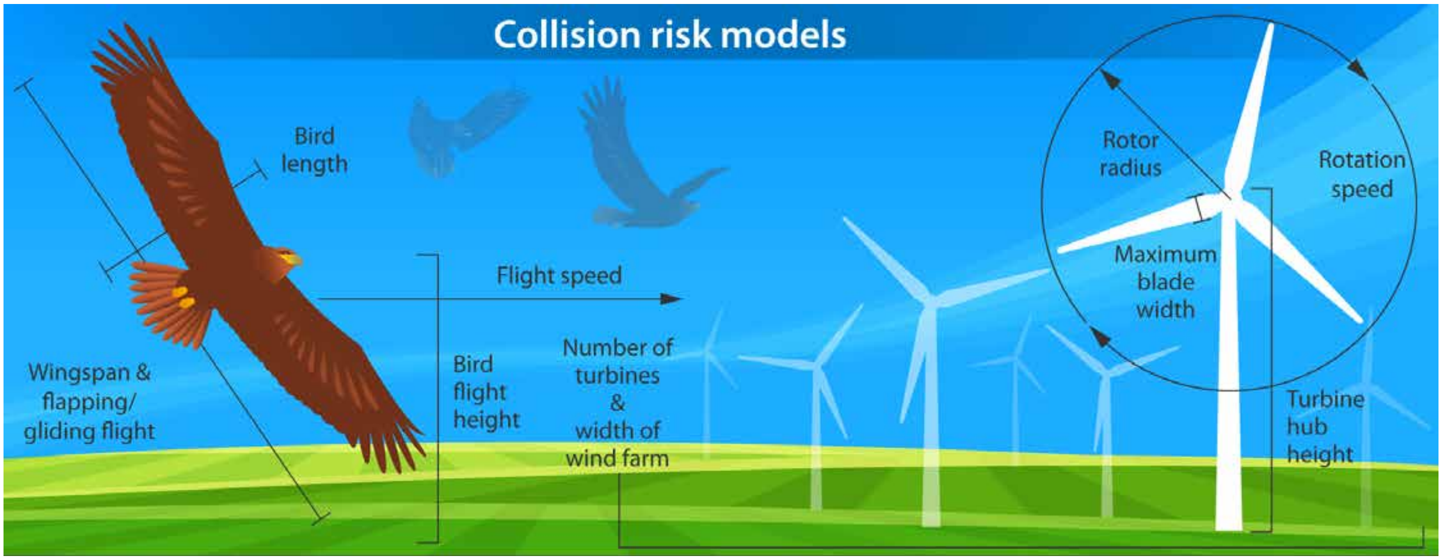

Figure 1. Parameters often used in collision risk models. *Graphic by the National Renewable Energy Laboratory; modified from Cook and Masden 2019*

Models could help reduce collision risk of griffin vultures, like this one. *Photo from iStock 1078410696*

data. Certain models overcome this sensitivity by incorporating uncertainty in lieu of a point estimate, while other models may elect to use alternate, less sensitive parameters. For example, the Hammer model of collision risk considers a more nuanced understanding of flight approach angle but excludes any avoidance parameters. Model uncertainty and data deficiency represent two other limitations. For many species, the necessary input data may be lacking because it is too difficult or expensive to collect. In cases where input data do not exist for a species of interest, surrogate species can be used. However, differences between the species of interest and the surrogate species, such as behavior, body size, and flight characteristics, will increase the uncertainty in the model.

The interest in consistency and comparability among sites can be a challenge for the use of CRMs. Given that there is currently no “one-size-fits-all” model, requirements to use a specific CRM for a company, agency, or species may not provide the best outcome. Rather, using a CRM that incorporates the site- and species-specific variables will improve model performance and help meet the objectives of the project. Many models require site-specific information on bird activity, species composition, and species abundance through field-based avian use surveys in fixed-radius plots. The type and quantity of data needed for accurate site characterization vary depending on a range of species, spatial, and temporal factors. For example, birds migrating through a uniform landscape might require less data collection than a known foraging area with complex topography.

Although there is a concerted effort to improve data input for CRMs to increase their predictive capabilities and reduce uncertainty, there are limited data on model validation. Most studies report on the results from a CRM, but rarely follow up with field studies to assess the performance of the model. Model validation studies require comparing the estimated mortality predicted by the model with actual mortality collected during standard post-construction mortality monitoring. CRMs with a Bayesian framework can incorporate appropriately collected post-construction mortality data if they become available to reduce uncertainty and increase the accuracy of the collision probability parameters.

IMPROVING KEY BEHAVIORAL PARAMETERS FOR COLLISION RISK MODELS

Several parameters in CRMs are easy to quantify, such as the blade length and rotor speed of a wind turbine, or the wingspan and body length for a species of bird. Behavioral characteristics, such as flight speed and avoidance, can be difficult to obtain and are often unknown for most species of birds. CRMs also tend to be sensitive to these behavioral parameters; thus, most of the research to improve models estimates and reduce uncertainty focus on bird behavior.

Flight speed can vary depending on the behavior of the bird, which can be influenced by time of day, wind speed, and habitat. The speed a bird is moving, such as during commuting or foraging, as it interacts with a wind turbine will influence the CRM. Collecting flight speed data has been challenging, but advances in technology such as radar and radiotracking have improved our ability to quantify flight speed more accurately. More certainty in this parameter can result in substantial changes in CRMs, as one study showed a 10%–16% decrease in predicted collisions with improved flight speed data.

Another common behavioral parameter is avoidance, or the rate of birds taking evasive action to avoid colliding with a wind turbine. For example, an avoidance rate of 99% indicates that 99% of birds are expected to avoid collision. Avoidance is difficult to quantify and requires direct observation of species interactions with human-made structures. Historically, avoidance rates were conducted during good visibility conditions (i.e., during daylight in clear weather), but this behavior likely varies based on weather, time of day, and season. Remote sensing technologies (e.g., radar and infrared cameras) may provide a means to collect avoidance rate data during times when visual observations are not possible.

TECHNOLOGIES TO QUANTIFY AND REDUCE RISK

Visual observations of raptors provide a wealth of information on nest locations, flight behavior, and movement patterns. Remote sensing technologies can further advance our understanding of raptor interactions with wind farms and wind turbines. To better understand the timing and conditions of collisions, sensor technology for installation on wind turbine blades is currently being developed and validated. Collision sensors offer the ability to get specific timing of collision events. The timing of a collision, combined with temporal, spatial, operational, and weather data can inform researchers on the circumstances when these events occur. Combining collision sensors with video cameras can provide species-specific information that can be used to refine CRMs.

Camera systems can record raptor flight behavior and interactions with wind turbines to help us understand avoidance behavior. With respect to reducing risk, cameras can be paired with deterrent technologies to initiate an alert sound when a raptor approaches a wind turbine. Cameras also can be used to inform curtailment strategies, such that wind turbines only curtail when a raptor is nearby.

Several technologies, such as radar, lidar, radiotelemetry, and GPS tags, can provide movement information, such as flight height, flight speed, and migratory pathways across a range of scales, including local, regional, and international scales. These data can be combined with landscape and atmospheric conditions that might explain behavior and land use relative to habitat and meteorological conditions.

A white-tailed eagle soaring. *Photo from iStock 1078410696*

Although technologies offer useful data, it is necessary to understand and articulate their limitations. In many cases, these limitations can be overcome by combining multiple technologies. It is also important for technology providers, researchers, and wind energy developers to engage early and often on the proper use and integration of technologies at the wind farm. This includes knowing where the technologies will be located on the wind turbine or within the facility, how the technology will be powered, and how data will be collected on site or transmitted to an off-site location.

CONCLUSION

A better understanding of how the basic biology and ecology of raptors impact their interactions with wind turbines is warranted. This can be achieved through existing and new approaches to monitoring behavior at various scales. Increased use of technologies can improve our understanding of parameters that are difficult to quantify, such as flight speed and avoidance, but that are influential in model results. Decades of research have provided useful information regarding raptor interactions with wind turbines. Yet there are opportunities to improve and build on existing data that optimize siting and operational decisions to meet our energy production and conservation goals.

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