Raptor Monitoring and Minimization Technologies

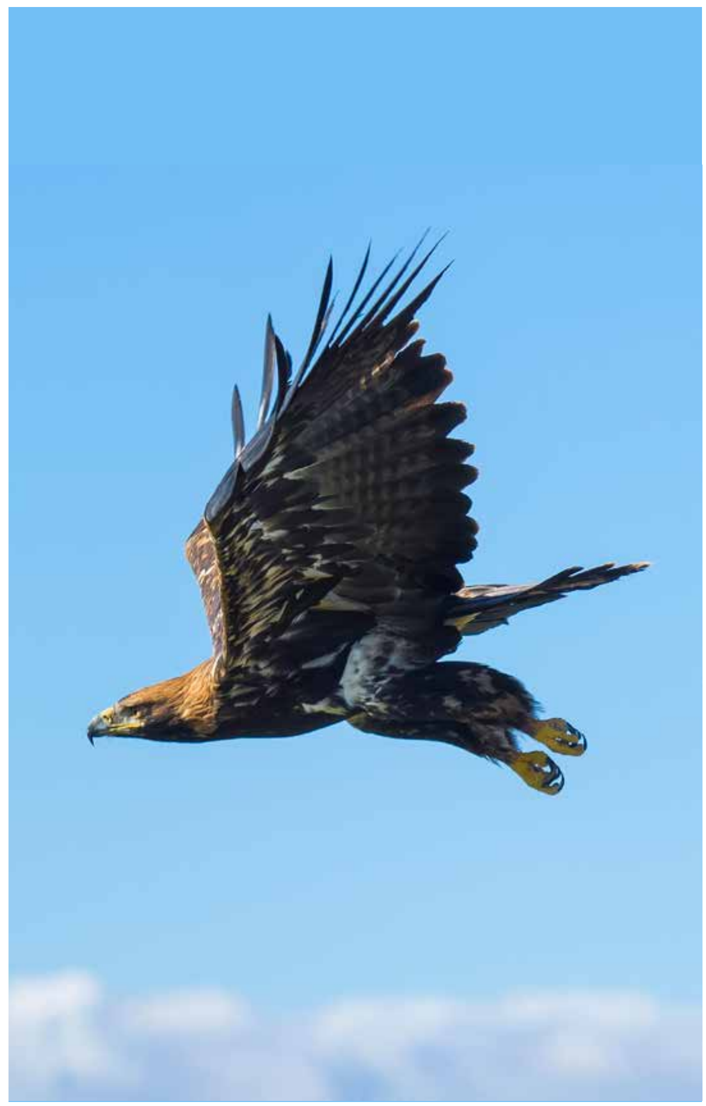
In June 2023, the International Energy Agency Wind Task 34—Working Together to Resolve the Environmental Effects of Wind Energy (WREN)—organized a forum to discuss monitoring and minimization strategies used to study raptor interactions with wind energy facilities. The forum included experts in raptor movement and behavior, minimization measures, technology validation, and wind energy development from four countries. The experts represented a range of international stakeholder groups including private industry, financial institutions, government agencies, nonprofit organizations, and wildlife consultants. This educational brief summarizes the discussion during the forum and written comments from additional participants who could not attend the live event. Relevant literature was used to provide additional context when needed.

INTRODUCTION

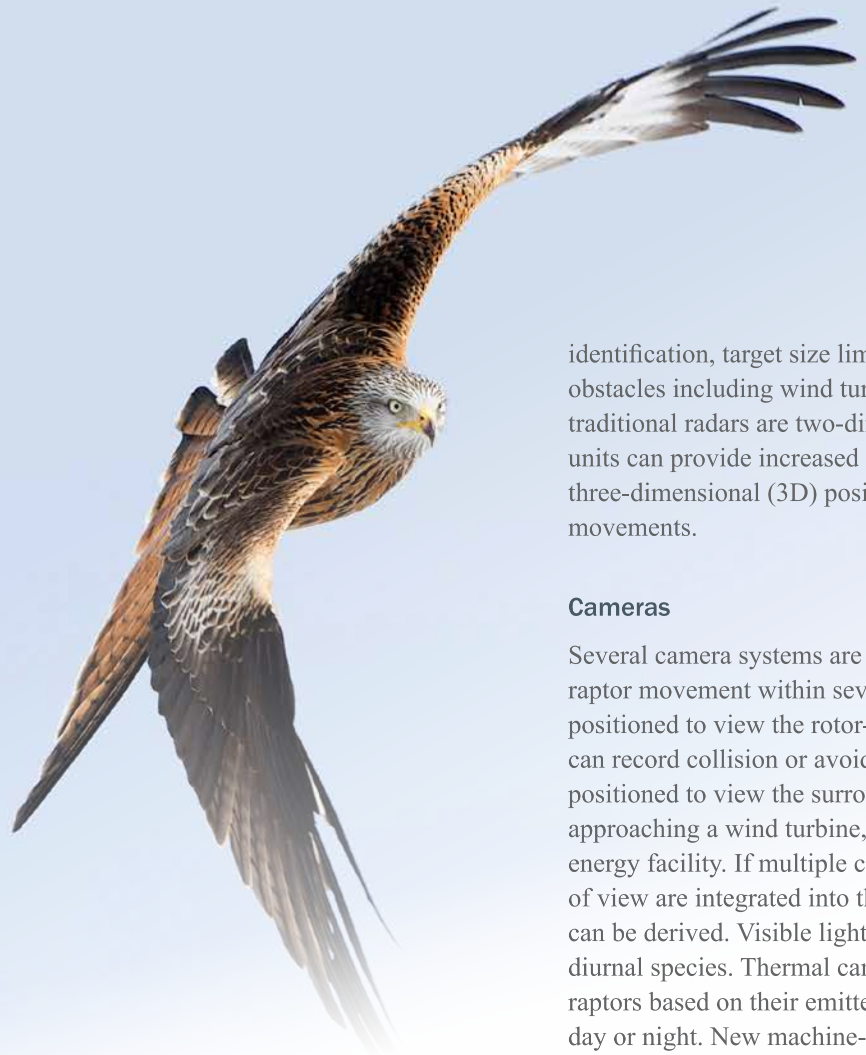
Wildlife monitoring at wind energy facilities allows researchers to observe and assess the potential impact of wind turbines on species, such as raptors, while minimization measures reduce the severity of these impacts. Historically, human-based monitoring was used to identify, count, and track raptor movement at proposed and operating wind energy facilities and remains an important tool. More recently, technologies—including radar, camera-based systems, and global positioning system (GPS) tags—have become feasible alternatives. Many of the technologies used in monitoring studies are also used to inform minimization measures, including curtailment and deterrents. Given their importance and increased use, it is worth highlighting some commonly used technologies, their benefits, and limitations.

TRADITIONAL MONITORING METHODS

The primary field method of monitoring raptors at wind energy facilities has relied on ground-based surveys performed by trained human observers, sometimes referred to as biomonitors. Fixed-point or transect count surveys are used to collect information on species of interest and can occur during pre- and postconstruction settings. Once a wind energy facility is operational, systematic carcass searches— performed by humans or dogs—are conducted around wind turbines and associated infrastructure to document raptor fatalities resulting from collisions. Nest surveys can also be conducted to locate areas with high raptor activity (that is, nest locations and flight paths to and from the nest). This survey approach also allows active nests to be spatially buffered from disruptive activities such as construction. The exact application, frequency, and duration of these surveys depend on a variety of factors, including objective, seasonality, risk, country, and legal requirements.



Golden Eagle flying in the sky. *Getty Images*



Red Kite in flight against blue sky. *Getty Images*

MONITORING TECHNOLOGIES

To complement or replace biomonitor surveys, technologies can be used for monitoring. Following are examples of technologies used to quantify presence, movement patterns, and collision events of raptors. Each technology has unique strengths and limitations, and combining technologies is one way to overcome some limitations and obtain comprehensive data. For example, the combination of cameras and strike detection systems may provide species-specific information on the collision event that is not possible with strike detection systems alone.

Radar

Radar units can detect and track the movements of birds in real time and provide data on bird density, flight height, flight speeds, passage rates, and behavior. Avian radars have a range of about 5 to 15 kilometers. Meteorological radars have larger ranges (up to 50 kilometers) but cannot monitor individual movement. Radar constraints include limited species identification, target size limitations, and interference from obstacles including wind turbines, and weather. Although most traditional radars are two-dimensional, sophisticated radar units can provide increased spatial information, including three-dimensional (3D) positioning and tracking of individual movements.

Cameras

Several camera systems are available to identify and track raptor movement within several hundred meters. Cameras positioned to view the rotor-swept area of wind turbines can record collision or avoidance events, whereas cameras positioned to view the surrounding area can record raptors approaching a wind turbine, wind turbine string, or wind energy facility. If multiple cameras with overlapping fields of view are integrated into the same system, 3D information can be derived. Visible light cameras are used to monitor diurnal species. Thermal cameras allow researchers to monitor raptors based on their emitted heat signatures during either the day or night. New machine-learning algorithms can improve species identification based on color patterns, size, and flight characteristics. Artificial-intelligence-based workflows also improve the massive data storage needs associated with continuous video monitoring by retaining only video files that contain the species of interest.

Lidar

Lidar devices emit rapid pulses of light and measure the return time to provide high-resolution 3D information on targets. The data can be used to track individual birds within the field of view. Lidar alone cannot distinguish among species.

Radio Telemetry and GPS Tags

Radio telemetry and GPS tags are secured to individual animals to track their movement over time. These data can be used to determine flight corridors and high-use areas as well as potential avoidance behavior. The data collected are limited by the number of tagged individuals, which may not reflect the dynamics and use of the population at large. The use of GPS tags can be tailored to specific research inquiries; for example, units can be programmed to give more frequent updates to track meso- or microscale movements close to turbines. Alternatively, geofencing can be used to delineate spatial zones of interest to trigger data collection within those areas.

White-tailed eagle *(Haliaeetus albicilla)* soaring across the sky. *Getty Images*

Strike Detection Systems

These systems are installed on the blades of wind turbines and use sound or vibration sensors to record the exact timing of collision events with turbine blades. They require calibrations to remove the normal noise and vibrations of moving turbine blades. Used in isolation, strike detection systems cannot provide species-specific information on the collision event.

MINIMIZATION TECHNOLOGIES

Several technologies that reduce raptor collisions with wind turbines focus on either slowing the rotational speed of wind turbines when raptors are nearby, often referred to as curtailment, or deterring raptors from approaching wind turbines. For curtailment, radar-based systems may inform operations when large numbers of birds pass through an area, such as during migration. Thresholds can be established for passage rates so that when the threshold (e.g., 200 birds/hour/1 kilometer) is reached, it triggers curtailment for all or a portion of a wind energy facility. Camera-based systems focus on one or a few individuals and may trigger operations when birds are near a wind turbine. Deterrent systems that use cameras operate similarly; however, rather than curtailing wind turbines when a raptor is nearby, they inform a sensor to emit an audio or visual stimulus to alter the bird's flight path away from the wind turbine. Deterrent systems may issue more than one stimulus if a bird continues to approach a wind turbine. Multiple camera systems are required per wind energy facility, and cameras can be installed on the wind turbine or as stand-alone units. Camera-based systems often use machine-learning algorithms for species identification to issue orders (curtail/deter) only when sensitive species are present. The algorithms are programmable to set the confidence level (e.g., 95% vs. 75% confidence) in detecting the target species to balance error rates, operational considerations, and conservation objectives.

CHALLENGES TO VALIDATION

Although rigorous scientific validation is crucial to ensure the accuracy, reliability, wind turbine compatibility, and effectiveness of any of these technologies, several challenges can complicate this process. There are inherent difficulties to *in situ* research at wind energy facilities, where the primary goal of the facility is energy production rather than research. Variables outside the control of the researcher can interrupt data coverage, such as weather events or required turbine maintenance.

There can be additional logistical hurdles regarding reliable connectivity and power sources. The placement and use of some audible deterrent systems may be affected by surrounding land use and sensitivities of the local community. Experimental design and treatment application may be constrained so that minimization strategies may be applied only during certain seasons (that is, minimization strategy applied for a season and then control period for the following season), which inhibits the ability to compare control and treatment data during the same time and conditions.

These technology systems are generally validated against reference data collected from human observers to evaluate consistency and accuracy. However, human detections contain different biases that can make calibrating the error of the technology system difficult. In addition, there is an inherent difference in effectiveness between human monitoring and technology systems (that is, limited searcher efficiency vs. 360° camera coverage). Moreover, some systems are designed primarily for real-time decision-making and have limited data collection and storage capabilities, which can make post-hoc validation or assessments of effectiveness difficult. Finally, because collision events are statistically rare, sample sizes and trials may need to be particularly large to have adequate usable data to evaluate the statistical effectiveness. However, larger sample sizes increase the cost of validation studies and in some cases may be cost-prohibitive.

RESEARCH RECOMMENDATIONS

Several strategies can help facilitate more effective validation of monitoring and minimization technologies:

- Cross-validation of technologies can increase accuracy, for example, validating radar systems using GPS-tagged birds. However, when combining technologies, care should be taken to appropriately coordinate data collection (e.g., ensuring that the time stamp of each system is synced) and to account for biases with each method within the analysis. Studies that use a combination of human verification plus the position of a known target can effectively control for error. Objects such as drones can be used as surrogates to increase sample size and aid in validation; however, to be effective, these objects should reflect the biological target as closely as possible in size, reflectivity, and flight characteristics. One alternative is to use more common species as surrogates to supplement the response variable, although the use of surrogates depends on the experimental design and context.

Black Eagle soaring across the sky. *Getty Images*

- Evaluating and validating new technologies requires extensive coordination among the technology developers, wind turbine manufacturers, wind energy developers and operators, and wildlife agencies. Successful integration of wildlife monitoring technologies with wind turbines and wind energy facilities is complex. The technologies must be compatible with energy plant safety and cybersecurity specifications of the facility. In addition, regulatory agencies should consider granting facilities freedom from liability to conduct validation studies to help expedite research.

- The experimental design of validation studies should be as rigorous as possible. Units of measurement must reflect the inference so that they are made at the correct level. Standardizing reporting measures will further increase comparability among studies.

- The results of validation studies should be transparent to ensure that follow-on work can advance the research and development of the technology.

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For more information on WREN, visit https://tethys.pnnl.gov/about-wren

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