U.S. OFFSHORE WIND SYNTHESIS OF ENVIRONMENTAL EFFECTS RESEARCH

BAT AND BIRD INTERACTIONS WITH OFFSHORE WIND FARMS

MAIN TAKEAWAYS

- There is limited information on the risks to bats and birds from offshore wind turbines in North America, making it difficult for decision makers to site and operate wind farms that minimize potential collision risk and behavioral changes while maximizing wind energy production.
- Existing data from North America and Europe indicate that bats, particularly migratory tree-roosting species, approach and interact with land-based wind turbines, increasing their susceptibility to collisions. These interactions may also occur at offshore wind turbines. For some seabirds, such as terns and gulls, there is concern about potential collision risk. Other species, such as gannets and razorbills, may avoid or be displaced by wind farms.
- Monitoring bat and bird interactions at offshore wind turbines will require a combination of approaches, such as visual surveys, radar, cameras, strike indicators, tracking devices, and acoustic detectors, to determine species composition, assess behavioral changes, and detect collisions.
- Collision risk models may be an important tool for predicting collision risk for birds. The models are useful in comparisons across wind farms, wind turbine types, or species. They require specific data for different categories of birds (e.g., body size, flight height, and flight speed), avoidance behavior, and turbine characteristics, but the underlying assumptions are difficult to validate.
- Factors that may result in avoidance or attraction, such as lighting, wind turbine characteristics, turbine spacing, and proximity to high-use areas, should be considered when siting offshore wind farms.
- Minimization strategies that have successfully reduced bat and raptor collisions at land-based wind farms, such as curtailment and deterrents, need to be validated for offshore bat and bird species and modified to withstand the harsh marine environment.

Please visit **Tethys** to view the literature reviewed to inform the development of this research brief.

TOPIC DESCRIPTION

Offshore wind (OSW) energy development may represent a new risk to bats and birds using the airspace off the U.S. Atlantic and Pacific Coasts. The risks may include collision mortality or behavioral changes, such as avoidance and attraction. Given the limited OSW deployment in the United States, potential risk can be initially evaluated based on information from interactions of bats and birds with OSW turbines in Europe, known offshore movement patterns of bats and birds, and land-based wind farms in the United States. Worldwide, studies at OSW farms have reported no bat fatalities and only a handful of bird fatalities, but data are limited. The lack of information stems from the absence of a practical approach to measure collision-related mortality in an offshore setting.

Specifically for the United States, uncertainty also stems from limited OSW deployment to date and a scarcity of information on baseline activity patterns and behavioral responses of species potentially vulnerable to collision and/or behavioral changes.

Across the United States and Canada, hundreds of thousands of bats are killed by land-based wind turbines each year. Of the 45 species of bats occurring in these two countries, 22 are represented in fatalities at land-based wind farms. Three species—all long-distance migratory tree-roosting bats, including eastern red bats, hoary bats, and silver-haired bats (Figure 1)—constitute 78% of reported fatalities, with hoary bats making up nearly 38%. Given estimates for future wind energy

> In North America, information regarding interactions of bats and birds with offshore wind turbines is limited, making it difficult for decision makers to site and operate wind farms to minimize collision risk and behavioral changes while maximizing wind energy production.

Figure 1. *The silver-haired bat is a common migratory bat found across North America. Photo by Cris Hein, National Renewable Energy Laboratory.*

development, the fatality rate at land-based wind farms, and low reproductive potential, population models indicate that at least one species, the hoary bat, could become extinct by 2050 if sufficient mitigation measures are not implemented.

More than 300 species of birds (mostly songbirds) have been reported as fatalities at land-based wind farms across the United States. The annual estimated mortality is in the hundreds of thousands. Species of concern for collision mortality at OSW turbines include gulls and jaegers. Some resident and migrating species may avoid entering or passing through OSW farms, whereas other species have shown attraction. Conditions such as prey availability, weather, time of day, visibility, and wind farm configuration may influence avoidance rates and the extent of movement around the wind farm.

MAIN RISKS & EFFECTS

Bats

Within a wind farm, the greatest risk for bats is being struck by fast-moving turbine blades. Bats rarely collide with stationary structures such as buildings, communications towers, and nonoperating wind turbines. In addition, growing evidence indicates mortality from barotrauma, or lethal exposure to pressure variations that occur around wind turbine blades, is unlikely to be a significant contributor to bat mortality.

Collision risk for some species of bats may be greater because of their apparent attraction to wind turbines. There are several hypotheses on why bats approach and interact with wind turbines, including the influence of the surrounding landscape and habitat, prey distribution, environmental conditions, physical presence of the wind turbines, and physiological phenomena (Table below). It remains unclear whether these or potentially other factors apply to OSW development; however, if bats exhibit attraction behaviors in response to OSW farms as they do at land-based wind farms, the risk of collision may increase.

In the United States, bat fatalities at land-based wind farms are associated with certain conditions. They occur only at night, predominately over a 3-month period from mid-July to mid-October, and primarily during relatively low wind speeds (e.g., less than 5 meters per second [m/s], or 11 miles per

Attraction hypotheses for bats and land-based wind farms.

Adapted from Kunz et al. 2007, Cryan and Barclay 2009, and Guest et al. 2022.

INFLUENCE	ATTRACTION HYPOTHESIS
Landscape and habitat	Bats may be attracted to certain landscape features in the vicinity of wind farms, such as forest habitat or water. Bats may also perceive wind turbines as potential roosting or mating habitat.
Prey distribution	Bats may be attracted to insect prey that aggregate in the vicinity of wind turbines.
Environmental conditions	Environmental conditions, such as low wind speed and temperature changes, may aggregate bats in the vicinity of wind turbines.
Physical presence	Bats may be attracted to the lights or rotation and sound of spinning turbine blades.
Physiological phenomena	Bats may be unable to detect the movement and speed of rotating wind turbine blades or become disoriented due to the electromagnetic fields. Wind flow patterns from wind turbines may resemble that of tall trees.

> Several hypotheses may explain why bats approach and interact with wind turbines, including the influence of surrounding landscape and habitat, prey distribution, environmental conditions, physical presence of the wind turbines, and physiological phenomena.

hour [mph]). Studies investigating bat activity and movement offshore have reported lower overall activity levels but similar patterns relative to season and weather conditions. Along the Atlantic Coast, at least seven species have been recorded offshore, including the three migratory tree-roosting bats. Flight heights recorded offshore range from near sea level to more than 200 meters (m) (656 feet [ft]) above sea level. Historic observations have reported bats as far as 2,000 kilometers (km) (1,243 miles [mi]) from shore, but more recent recordings indicate presence ranging from 5 to 130 km (3 to 81 mi) and 17 to 42 km (10 to 26 mi) using acoustic detectors and aerial digital surveys, respectively. Limited data exist for bat occurrence along the Pacific Coast, but hoary bats are known to migrate offshore and use coastal islands near California as stopover locations. In Europe, bat activity at OSW farms has been detected during seasonal migration, with most activity occurring closer to the coast. In a study using acoustic detectors both on turbine platforms (17 m/56 ft above sea level) and at nacelle height (97 m/318 ft above sea level), the majority of bat activity was recorded at the lower elevation on platforms, with only 10% of detections occurring at nacelle height.

Similar seasonal activity patterns observed in land-based and offshore acoustic monitoring studies and the predominance of long-distance migratory species detected offshore suggest that seasonal (e.g., late summer) and weather (e.g., lower wind speeds and warmer temperatures) patterns of fatality may be comparable onshore versus offshore. Whether the magnitude of risk or factors associated with attraction are similar at land-based and OSW farms remains unknown.

Behavioral Responses of Birds to Wind Farms

- **Avoidance:** An action taken by a bird to prevent interaction with the infrastructure of a wind farm.
- **Macroavoidance:** Response to the presence of the wind farm, resulting in a redistribution of birds outside the wind farm perimeter.
- **Mesoavoidance:** Response to the presence of individual turbines or turbine rows, resulting in a redistribution of birds within the wind farm.
- **Microavoidance:** Response to the rotor-swept area or blades of a wind turbine, considered to be a last-second action to avoid collision.
- **Displacement:** Limiting the normal use of an area within or adjacent to a wind farm, such as resting, roosting, or foraging habitat.
- **Barrier Effect:** Occurs where a wind farm alters the flight behavior of a bird and prevents it from accessing an area. This results in the bird taking an alternate route around the wind farm and thus expending additional energy.

Birds

Hundreds of species of birds use the offshore environment, including shorebirds, wading birds, pelagic birds, and migratory songbirds. Activity for some species may increase during seasonal migration, but resident species will use the same area during their entire lifecycle, including breeding and nonbreeding seasons. Risk to birds from OSW turbines may occur day or night, depending on the movement patterns of the species.

Birds may adjust their behavior in response to wind farms, which has the potential to affect their survival or reproductive success. Avoidance can occur at multiple scales, including macroavoidance (avoiding the entire wind farm), mesoavoidance (avoiding turbines or rows of turbines), and microavoidance (avoiding the rotor-swept area). Two terms associated with macroavoidance are "displacement" and "barrier effects." Displacement occurs when birds alter their normal use of the habitat, whereas barrier effects occur when birds alter their normal flight path or altitude to move around the entire wind farm. These behaviors may limit foraging and could increase energy use during migration or commuting between breeding colonies or foraging areas. Microavoidance can be considered an escape mechanism or a last-second flight maneuver to avoid collision.

In Europe, avoidance behaviors have been observed in several diving species, such as Razorbills and Northern Gannets. Along the Atlantic and Pacific Coasts of the United States, calculations for displacement vulnerability suggested that species groups, including loons, sea ducks, grebes, and alcids, may exhibit avoidance behaviors. Individual-based models may be a useful tool in exploring the potential avoidance effects of OSW development on factors such as body mass, productivity, and fatality. One benefit of individual-based models is they scale up to population-level impacts to consider the cumulative impact within the range of a population. One study developed models for Northern Gannets (Figure 2) at wind farms in the English Channel and North Sea. The model simulations suggested that the wind farms would need to be 10 times larger or located in more highly used areas to have a population-level effect.

Figure 2. *The Northern Gannet is a seabird found along the U.S. Atlantic coast and in Europe and northern Africa.*

Other species may be attracted to wind farms, including Great Cormorants and Lesser Black-backed Gulls, which may increase the likelihood of bird interactions with wind turbines. Attraction may be associated with potential new roosting opportunities. In Europe, Great Cormorants and Greater Black-backed Gulls use turbine platforms to roost, particularly along the edge of wind farms. The presence of wind turbines can also create new habitat, which is often called the reef effect. New hard substrates like turbine foundations are colonized by marine organisms, which then increases the presence of fish prey for some bird species. Northern Gannets, a species considered vulnerable to collision, exhibit both avoidance and attraction behaviors. A study in the North Sea observed 89% of the GPS-tagged Northern Gannets avoided OSW farms, but 11% frequently entered the farms when foraging and commuting.

Species considered vulnerable to collision risk are known to roost on artificial structures or spend a high percentage of their flight time at the height of the rotor-swept zone. Spinning turbine blades can strike birds as they pass through the rotor-swept area; however, unlike bats, birds also collide with stationary structures. The likelihood of colliding with the static components of wind turbines (i.e., the tower, nacelle, or nonrotating blades) increases during low-visibility conditions. In Europe, recorded offshore collision events include an unidentified songbird, a common eider, a black-legged kittiwake, and five gulls. In the United States, seabirds along the Atlantic Coast that are thought to be at potential risk for collision include gulls, phalaropes, cormorants, jaegers, and skuas (Figure 3). On the Pacific Coast, terns, gulls, jaegers, skuas, cormorants, and pelicans are some species predicted to have elevated collision risk. Many species of birds potentially affected by OSW energy are already in decline and the potential adverse effects of wind turbines on some species may compound low productivity and delayed breeding. This means that any additional mortality, albeit small, could have population-level impacts for some species. The potential effect on rare and long-lived species, such as albatross, remains unknown. In general, mortality on songbirds at land-based wind farms is considered relatively low, particularly compared to other sources of mortality, and large information gaps remain as to the potential effects of OSW on songbirds.

Figure 3. *The Double-crested Cormorant is a seabird found on both the Atlantic and Pacific Coast. Photo by Jeremy Hynes.*

MONITORING, MODELING, & MITIGATION

Monitoring

Collecting baseline data prior to OSW development is necessary to understand the normal behavior, distribution, and movement patterns of bats and birds. During and after construction, monitoring data collected at the OSW farm can be compared to baseline data to determine whether changes exist. Boat surveys, high-definition aerial surveys, radar surveys, and telemetry can provide data on large-scale movement patterns and be used to assess the abundance, distribution, behavior, passage rates, flight speed, and flight height of bats and birds offshore. These data, combined with information on the wind farm layout and specifications, can be used to develop collision risk models (CRMs).

Because few mortality monitoring studies have occurred at OSW farms, data on collision events are rare. Carcass searches and the use of associated statistical tools to estimate mortality at land-based wind farms are not possible at OSW farms. Therefore, observing behavioral interactions and collision events offshore requires remote-sensing technologies. Currently, there are no commercially available, validated technology or suite of technologies that can quantify mortality at OSW turbines, but several systems are undergoing validation studies. For example, strike indicators paired with thermal cameras (Figures 4 and 5) and acoustic detectors are designed to record real-time collision events and collect information about the taxon (i.e., bat or bird) or species (i.e., hoary bat or eastern red bat). Because data are collected in real time, observations and collision events can be related to weather and operational conditions that could be used to inform potential curtailment strategies.

As new technologies are developed and used offshore, it is important to understand the benefits and drawbacks of different sensors for monitoring bat and bird interactions. Several steps are required to validate the efficacy of sensors that are either in use or under development:

> Monitoring bat and bird interactions with offshore wind turbines will require a combination of approaches to determine species composition, assess behavioral changes, and detect collisions.

- Articulate the biases associated with sensor technologies. The biases of detection technologies used with OSW turbines should be clearly described to improve interpretation of the results. For example, bats may not always echolocate when commuting, which may affect occupancy and activity estimates developed from acoustic monitoring studies.
- Communicate the technical specifications for sensor technologies to turbine manufacturers and operators so the technologies can be safely integrated with the OSW components. These specifications should describe (1) where the monitoring equipment will be installed on the wind turbine, (2) what the power requirements are to operate the equipment, and (3) whether the technology needs to receive and transmit data.
- Validate the technologies at land-based wind farms prior to implementing them offshore. Ensure the technologies are suitable for the harsh marine environment.

Each available monitoring technology has strengths and weaknesses, but combining multiple technologies can help overcome the limitations of an individual technology. Single-sensor and multisensor technologies are currently being evaluated or used at operational wind farms, (Table on page 7).

Sample of remote-sensing technologies to detect bat and bird interactions under evaluation or in use at operational wind farms.

SINGLE-SENSOR TECHNOLOGIES	MULTI-SENSOR TECHNOLOGIES
VARS[a]: near-infrared cameras	**WT-Bird:** accelerometer impact sensors and near-infrared cameras
DTBird: visual or thermal cameras	**ATOM[b]:** thermal cameras, visual cameras, and acoustic microphones
DTBat: thermal cameras or acoustic detectors	**Wind Turbine Sensor Unit:** accelerometers and contact microphone impact sensors, visual and infrared cameras, and acoustic microphones
ID-Stat: acoustic impact sensor	**MUSE[d]:** horizontal radar and thermal or visual cameras
ACAMS[c]: stereo-optic visual cameras with fisheye lenses	**TSVA[e]:** stereo thermal cameras and acoustic microphones
B-finder: thermal camera	
ThermalTracker: thermal camera (Figure 5)	

[a]VARS = visual automatic recording system; [b]ATOM = acoustic and thermographic offshore monitoring system; [c]ACAMS = aerofauna collision avoidance monitoring system; [d]MUSE = MUlti-SEnsor (formerly known as TVADS); [e]TSVA = thermal stereo vision application.

Examples of Commonly Used Monitoring Methods

- **Acoustic detectors**: record the vocalizations of bats within approximately 40 m (131 ft) and birds within 100 m (328 feet). The range of detection will vary based on the frequency of vocalization (i.e., lower frequency sounds travel farther), intensity, and orientation of the animal to the microphone. Data can be used to identify species or species groups, characterize seasonal and temporal activity patterns at a local scale, and relate such patterns to weather and wind turbine operational conditions.
- **Boat surveys:** record observations of individual animals along transects. Birds flying or on the surface are included. The field of view may extend several hundred meters (yards) but will vary based on each observer or the binoculars used. Data can be used to determine presence, density, behavior, and flight height.
- **High-resolution digital aerial surveys:** collect imagery from fixed-wing aircraft surveys over large distances (e.g., a wind energy facility and surrounding area). Surveys are conducted during daylight hours and require high-visibility conditions. Analysis can provide species abundance and distribution.
- **Cameras:** provide observations of animals within the field of view. Visual and thermal cameras are used to record data for animals active during the day or night, respectively. The field of view will vary based on the type of camera, lens, and positioning on the turbine. Cameras can be positioned on the tower pointing up toward the blades or out toward the water, and on the rotor pointing along the length of the blades. Data can be used to assess behavioral interactions (e.g., attraction or avoidance) between bats or birds and wind turbines. Cameras can often distinguish between birds and bats but are generally not able to identify species.
- **Radar:** tracks moving objects from a few to several hundred kilometers (or miles) away from a wind turbine, depending on the type of radar technology (e.g., antenna type, power of the radar signal, and radar wavelength). Data on flight height, flight direction, flight speed, and passage rates are recorded. Most radar technologies cannot distinguish between bats and birds, and some may not be able to detect smaller animals.
- **Strike indicators:** record collision events using sensors installed along the length of each blade. Sensors can include microphones and accelerometers. Data can be used to determine the timing of collisions, size of the object striking the blade, and where along the blade the collision occurred. Indicators cannot identify the type of animal (bird or bat) or species colliding with the blade.
- **Telemetry:** provides information on movement patterns of tagged animals over time. Automated radio telemetry requires specialized receiving stations to record the presence of tagged individuals within a few to several kilometers (miles). Radio tags are small enough to use on most bats and birds. Satellite telemetry does not require receiving stations, but the weight of the tags limits their use to larger species and/or shorter tracking duration. Data can be used to identify flight paths, movement corridors, and high-use areas.

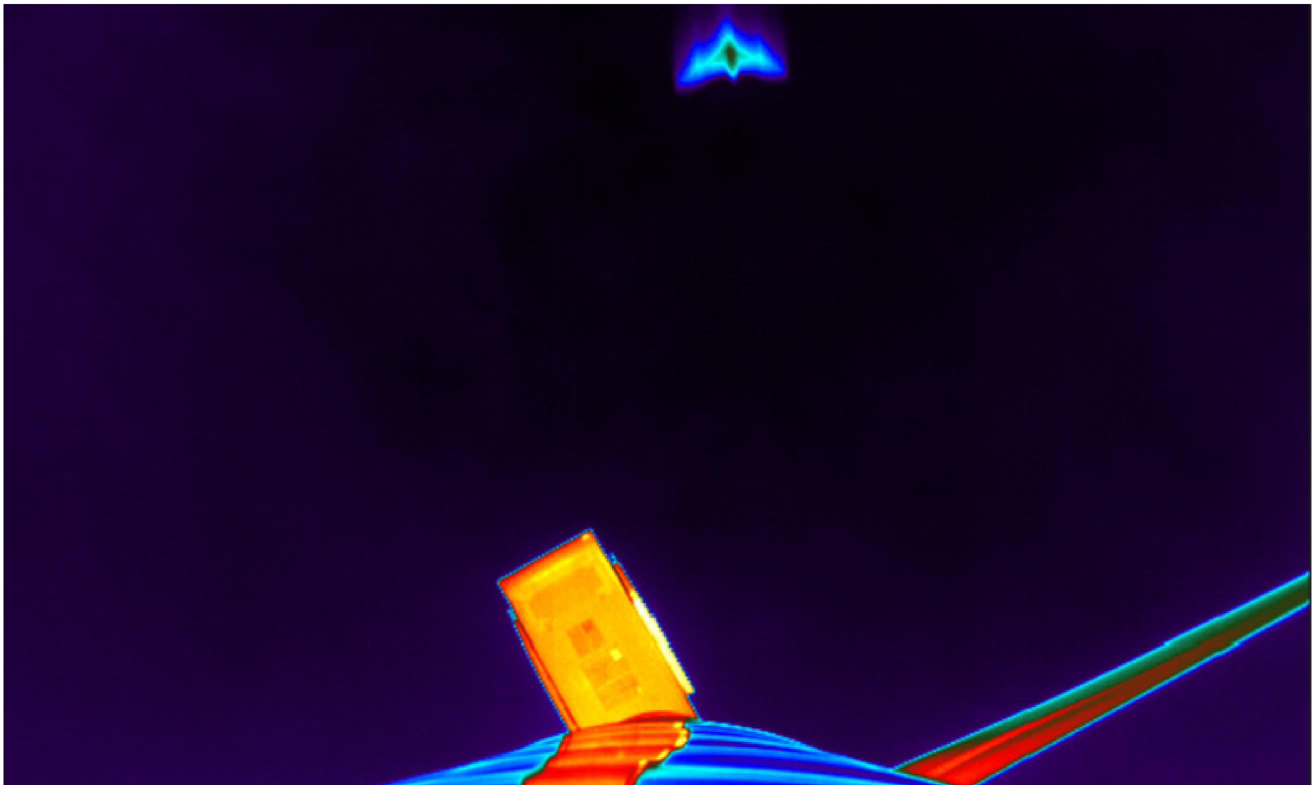

Figure 4. *Thermal image of a bat flying near a land-based wind turbine. Photo from Sara Weaver, Bowman Consulting.*

Figure 5. *ThermalTracker camera system for monitoring bats and birds at wind farms. Photo from Pacific Northwest National Laboratory.*

Modeling

Systematic carcass surveys are necessary to estimate mortality at land-based wind farms, but are not possible for OSW farms. In Europe, where OSW energy has been deployed for decades, bird carcasses have been reported, yet no systematic surveys have been conducted. CRMs can be developed to predict risk and inform potential exposure. Relative to OSW, these models have been developed only for marine birds.

CRMs use data on the physical description of the species (e.g., body size and wingspan) and how the animal behaves around wind turbines (e.g., avoidance, flight height, flight speed, and activity periods). Bird surveys are used to describe the number of birds passing through a region and the distribution of their flight height, speed, and patterns. Characteristics of the wind farm and turbines (e.g., blade length and rotor speed) and site conditions (e.g., geography and weather) are included to estimate the number of bird collisions during a monthly or annual cycle (Figure 6). The model predicts the probability that an animal will be in the rotor-swept area of a wind turbine as the blade passes through, then applies a species-specific avoidance rate to the interactions to determine the number of instances where an individual animal will be in that location instead of avoiding it. CRMs are flexible in scale and have been used to estimate population-level impacts at a regional scale or fatalities of a particular species at a proposed wind farm.

Several CRMs are available, but the most widely used is the Band model, which was published in 2012 and later updated to include methods for quantifying uncertainty. CRMs are particularly useful in a relative sense to compare results among species or OSW farms. In the Belgian North Sea, a wind farm zone comprising nine farms and 399 turbines used CRMs to estimate 70 fatalities per year; the highest estimated fatalities were for Greater and Lesser Black-back Gulls. It is important to note that absolute numbers derived from CRMs should be interpreted with caution, given the uncertainties of the input variables.

CRMs are sensitive and can vary dramatically with small changes in the input data and underlying assumptions. For example, a change from 0.98 to 0.99 for the avoidance rate can decrease estimated collision by half for seabirds. Improvements to CRMs continue, with one study reporting that the use of GPS-derived flight speed rather than a generic value reduced the predicted number of collisions.

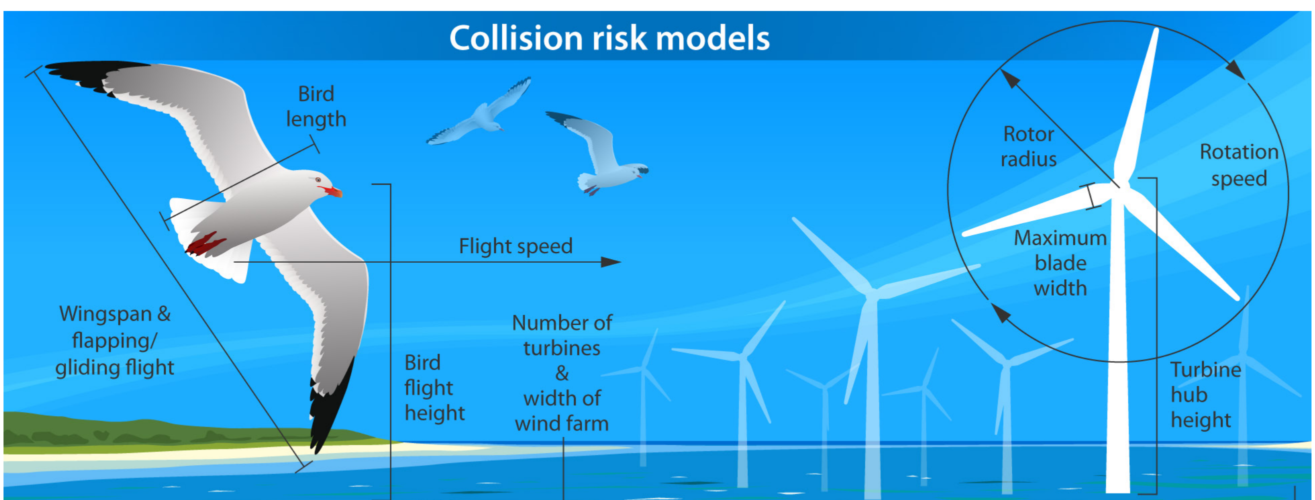

Figure 6. *Parameters used in collision risk models. Graphic by the National Renewable Energy Laboratory. Modified from Cook and Masden 2019.*

Mitigation

Developing cost-effective approaches to mitigate impacts will be necessary if OSW farms present a significant risk to bats and birds. Mitigation includes avoidance, minimization, and compensatory measures. A comprehensive knowledge of the species presence, use patterns, and ecological drivers behind spatial distribution and behavioral interactions with wind turbines is essential in making informed siting decisions that maximize avoidance. Siting facilities away from high-use areas may help reduce impacts. Considering the size and shape of the wind farm and wind turbine spacing may also reduce displacement and barrier effects. Minimizing lighting and limiting perching opportunities for birds are known to decrease potential attraction for some species.

Minimization strategies to reduce collisions, such as curtailment of wind turbine operations and deterrents, are being studied at land-based wind farms (Figure 7). Curtailment for bats has proven effective during low-wind conditions. However, if OSW farms are in regions with relatively high average wind speeds (for example, >10 m/s, or 22 mph), and risk of bat collision is low, then curtailment may not be necessary. There are promising results using targeted smart curtailment to reduce Golden Eagle and Griffon Vulture mortality, but the effectiveness of curtailment for other species of birds, including those using the offshore environment, is not well studied. One challenge to implementing curtailment is the loss of energy production from the wind turbines, but there are ongoing efforts to optimize curtailment (e.g., basing it on real-time detections and weather conditions) to make it more cost-effective.

Alternatively, deterrents allow wind turbines to operate normally with no impact to energy production. Visual deterrents, including the use of ultraviolet light or painting a single turbine blade black, may alert flying animals to the presence of wind turbines. Audible noise deterrents for birds typically are not successful, as individuals can become habituated to the sound. Ultrasonic deterrents mounted on the nacelle of wind turbines have mixed results for deterring bats and more research is needed to demonstrate consistent reductions in mortality. One of the challenges of using ultrasound is projecting the signal far enough to dissuade bats from approaching wind turbines, which becomes increasingly challenging as blade length increases. Given the longer blade length for OSW turbines, blade-mounted deterrents may help

Figure 7. *Deterrent technologies are one potential minimization strategy to keep bats and birds from approaching wind turbines. Graphic by the National Renewable Energy Laboratory.*

emit sound throughout the entire rotor-swept area. Before implementation, deterrent technologies need to be modified to operate in the harsh offshore environment, and the effectiveness of the method must be validated for offshore species through experimental studies.

Compensation for impacts is the last option and is used for offsetting the impact on a species. Compensatory measures often are designed to create or restore habitat for species affected by wind farms, including areas where breeding, nesting, or foraging occurs. Compensation may be achieved by addressing other natural or anthropogenic effects on populations, such as expanding protected areas, reducing predation, enhancing prey abundance or availability, or removing invasive species.

Minimization Strategies Developed For Land-based Wind Energy

Curtailment

Curtailment for wildlife involves feathering the wind turbine blades (i.e., adjusting the angle of the blades parallel to the wind) and increasing the cut-in speed of the turbine (i.e., the wind speed at which the turbine blades begin to spin and produce energy) to prevent turbine rotors from spinning during periods of risk.

Understanding when species interact with and collide with wind turbines can inform when to implement curtailment. For example, bat mortality only occurs at night and tends to be highest during lower wind speeds in late summer and early autumn. Based on those data, a hypothetical curtailment scenario could be to feather the turbine blades and raise the cut-in speed to 5 m/s (11 mph) between July 15 and September 30. Smart curtailment strategies can use site-specific bat activity data or additional weather parameters (e.g., temperature) to alter turbine operations based on specific local conditions, thereby reducing the amount of curtailment and associated energy loss. Several approaches that use either human observers or camera systems have been studied to curtail turbines according to the presence and close proximity of eagles and vultures.

Deterrents

Another minimization strategy is to install wildlife deterrents to generate sound or visual cues that disrupt the animal's normal behavior or flight path near a wind turbine. The frequency of the sound is an important aspect. For birds, a sudden audible (e.g., <20 kilohertz [kHz]) sound might be startling, but there are limited data demonstrating effectiveness because in most cases birds habituate to the noise. Some technologies to deter birds only generate a sound when the bird is in close proximity. Lasers and strobing lights have shown success for deterring birds but may also result in attraction or other behavioral/physiological changes. For bats, an ultrasonic (e.g., >20 kHz) sound might interfere with their sonar and be disorienting. The intensity of the sound is also important. The sound must travel far enough for the animal to interact with it and be deterred before entering the rotor-swept area. This can be difficult for ultrasound because higher frequency sounds travel shorter distances. Existing deterrent technologies are installed on the nacelle or tower of the wind turbine, but blade-mounted deterrents are under development. Blade-mounted deterrents can extend the range of the sound being projected.

The effectiveness of deterrents using ultraviolet light is being investigated to reduce bird and bat interactions with wind turbines. Painting a single blade a dark color to make the structure more noticeable has also been explored at a land-based wind farm; the results were promising but not definitive.

KNOWLEDGE GAPS & RESEARCH NEEDS

Given the lack of OSW deployment along the U.S. Atlantic and Pacific Coasts, it is difficult to assess the degree of collision risk and behavioral changes that wind turbines present for bats and birds. While wind turbine technologies and bat and bird species may vary among countries and coastlines, sharing lessons learned from national and international collaborations will improve technologies and methodologies for collecting baseline data, improving CRMs, and monitoring risks at OSW farms. Addressing these issues in the early phases of OSW deployment will help determine whether mitigation approaches are necessary and assist with planning for future projects. At a high level, there are several primary research needs:

1. **Collect** additional baseline data, including offshore bat and bird abundance, distribution, movements, flight height, and flight speeds to estimate the potential exposure and decrease uncertainty for CRMs
2. **Assess** attraction or avoidance behaviors to understand the scale and associated mechanisms, such as the reef effect, and determine whether these changes negatively affect survivorship or reproduction
3. **Quantify** collision risk and validate and improve CRMs
4. **Develop and Validate** potential mitigation options to reduce risk.

Bats

Research from land-based wind farms indicates certain species of bats appear to be attracted to wind turbines and that spinning blades represent a substantial risk. Further, data showing that activity patterns of bats offshore resemble those documented on shore suggest that the timing and conditions of mortality may be similar. However, data are limited regarding the spatial distribution (e.g., distance from shore), abundance (e.g., number of bats) and species using the offshore environment. Moreover, it is not clear whether the factor(s) that attract bats to land-based wind turbines apply offshore. Collecting data about baseline activity and movement patterns at potential OSW sites will help assess potential risk, but understanding bat activity around operational OSW farms and quantifying mortality is essential in determining whether wind turbines pose a significant risk to bats (Figure 8).

Birds

Hundreds of species of birds reside or migrate along the U.S. Atlantic and Pacific Coasts. Species groups such as gulls, terns, pelicans, jaegers, and skuas may be vulnerable to colliding with wind turbines based on their size and flight behavior. Migratory songbirds and shorebirds may also be at risk due to their presence offshore during certain times of

Figure 8. *The hoary bat is a migratory tree-roosting species found across North America and known to fly along the Atlantic and Pacific Coasts. Photo by Cris Hein, National Renewable Energy Laboratory.*

the year. Other species groups, including loons, sea ducks, grebes, and alcids, may exhibit avoidance behaviors at various scales. Understanding which species may be attracted to OSW turbines or farms is also important, as well as determining what the cause of the attraction is and whether the attraction relates to risk. Refining the lists to acquire more species-specific data will help narrow down which species to focus on. Understanding bird collision risk and behavioral effects will require collecting additional baseline data (e.g., activity patterns, distribution, flight height, and flight speed).

For collision risk, model accuracy needs to be validated using collision data after OSW farms are constructed. The development of remote-sensing technologies is necessary to quantify collision risk and behavioral effects, preferably at the species level. Collecting these data from new or operational OSW farms will allow stakeholders to make informed decisions regarding the appropriate mitigation measures.

*For more information on the literature reviewed to develop this Research Brief, visit: **Tethys***

NATIONAL RENEWABLE ENERGY LABORATORY

Pacific Northwest NATIONAL LABORATORY

U.S. OFFSHORE WIND SYNTHESIS OF ENVIRONMENTAL EFFECTS RESEARCH