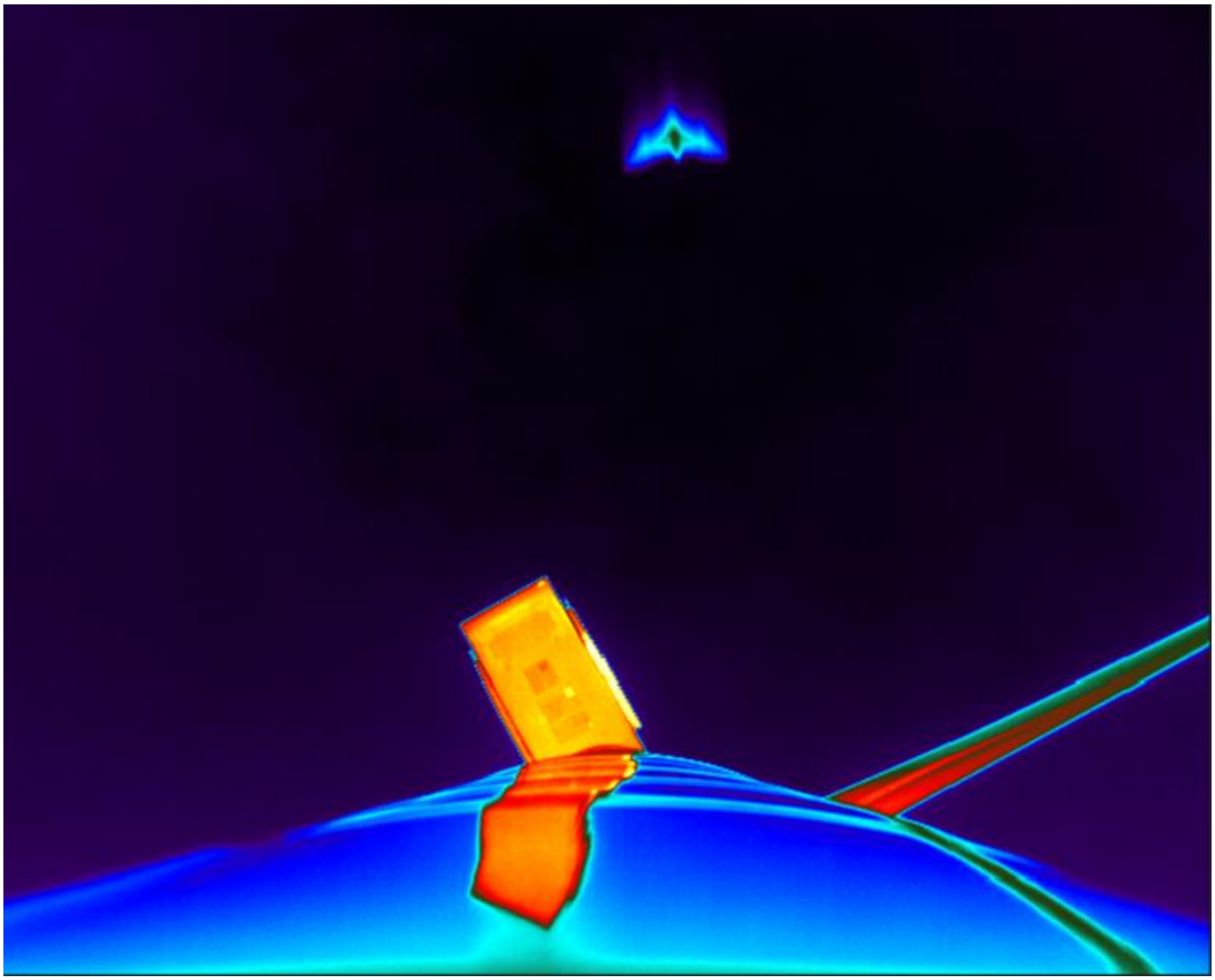
Research Goals for Studying Bat Behavior at the Wind Turbine-scale



Thermal image of a bat flying near a wind turbine. Courtesy of Sara Weaver.

BWEC bats and wind energy cooperative

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Contents

Bats and Wind Energy Cooperative

The Bats and Wind Energy Cooperative (BWEC) is an alliance of experts from government agencies, private industry, academic institutions, and non-governmental organizations that cooperate to develop and disseminate solutions to measure and mitigate the impact of wind turbines on bats, while maintaining the ability to develop and operate wind energy facilities in a competitive and cost-effective manner.

Acknowledgements

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Introduction

Understanding the causes of why bats approach and interact with wind turbines may provide more efficient means of monitoring and mitigating impacts (Cryan and Barclay 2009). Mortality monitoring continues to be a useful method to quantify the impact of wind turbines on bats. However, searching for carcasses can be expensive to implement, and the results lack the temporal scale necessary to determine when and under what conditions collisions occur. Moreover, standard mortality monitoring conducted at land-based wind energy facilities is not possible for offshore wind energy development. Precise data on the behavior bats exhibit near wind turbines and on collisions are necessary to develop and advance strategies that meet renewable energy generation and conservation goals.

There is increasing evidence that some species of bats are attracted to wind turbines. Studies using thermal videography have documented bats approaching the tower, nacelle, and blades (Horn et al. 2008, Ahlén et al. 2009, Cryan et al. 2014). Several plausible attraction hypotheses have been introduced but none have been confirmed or disproven with conclusive evidence (Kunz et al. 2007, Cryan and Barclay 2009), in part because it is challenging to detect, observe and track bat movements. In addition, there is limited information on basic bat behavior and physiology to understand what drives their responses to environmental cues. These responses may vary by species, landscape or habitat conditions, and turbine dimensions, or interact with one another in unpredictable ways.

Advancing research to monitor bat interactions with wind turbines can improve technology-based monitoring approaches, which may be more cost-effective for land-based and essential for offshore wind energy development. It can also provide information which may improve minimization strategies. For example, the specific timing and conditions when collisions occur may reduce the amount of time curtailment is implemented or provide information on how bats respond to different deterrent technologies. Advances in technologies such as thermal cameras, acoustic detectors, telemetry, and radar combined with innovations in machine learning and artificial intelligence makes studying bat behavior at wind turbines increasingly feasible.

As research progresses, it is important to articulate the goals that will enhance our understanding of how bats perceive wind turbines. At the Bats and Wind Energy Cooperative (BWEC) 2018 Science Meeting, several priorities for understanding bat behavior at the wind-turbine or wind energy-facility scales were established (BWEC 2019). One of these priorities was to develop a list of research questions for behavioral studies. The need to better understand bat behavior was reiterated at the State of the Science and Technology for Minimizing Impacts to Bats from Wind Energy workshop, convened in November 2019 (Hein and Straw 2021). In January 2020, the National Renewable Energy Laboratory, on behalf of the BWEC, organized a forum with subject matter experts (Table 1) to discuss next steps for research pertaining to bat and wind turbine interactions.

The participants discussed several research questions related to the available technology used to study bat behavior, the behavior of bats flying near wind turbines, the conditions when collisions occur, and improving the effectiveness of minimization strategies. Most activities presented below are centered at the turbine-scale, though some may require facility-scale monitoring. Some of these data may already be available from previous studies but can be analyzed differently (e.g., using more reliable machine-learning algorithms) or combined with other datasets to increase samples size. For new studies, it is important to select sites with greater species diversity, and relatively high bat activity and mortality.

Table 1. Names and affiliations of participants in the January 2020 forum.

Name	Affiliation
Kenny Breuer	Brown University
Aaron Corcoran	University of Colorado-Colorado Springs
Paul Cryan	U.S. Geological Survey
Shifra Goldenberg	Smithsonian Conservation Biology Institute
Marcos Gorresen	Hawai'i Cooperative Studies Unit-University of Hawaii, Hilo
Ty Hedrick	University of North Carolina
Cris Hein	National Renewable Energy Laboratory
Brogan Morton	Wildlife Imaging Systems
Brad Romano	Invenergy, Inc.
Michael Schirmacher	Bat Conservation International
Bethany Straw	U.S. Geological Survey (formerly National Renewable Energy Laboratory)
John Yarbrough	National Renewable Energy Laboratory

The participants primarily focused on the use of thermal cameras as the most practical technology for recording bat interactions at the turbine-scale. Other technologies, such as acoustic detectors, telemetry, and radar, can be used in combination with cameras to provide additional information. During the expert forum, research questions regarding equipment and analysis tools, behavior, mortality, and evaluating minimization strategies were transformed into four broad research goals:

1) Advance technology, methods, and analysis tools for behavioral research studies,
2) Characterize bat behavior at the wind-turbine-scale,
3) Characterize bat collision with wind turbines (e.g., time of night, conditions, and location along the blades where collisions occur), and
4) Evaluate the effectiveness of strategies to reduce bat mortality at wind turbines.

The participants did not rank goals by species, priority, or timeline as this likely varies by region, facility, and stakeholder group. For example, efforts to understand the behavior of threatened and endangered species, or those being considered for listing under the Endangered Species Act, may take precedence over non-listed migratory tree-roosting bats in certain scenarios, whereas reducing mortality of migratory tree-roosting bats may be a priority in other situations. The goals, subgoals, and activities are individually described, but several can be incorporated in any study or addressed simultaneously. Examples include:

1) Species identification: The need to assess species-specific differences is essential to differentiate behaviors among species that are vulnerable to collisions or the presence of threatened or endangered species. Identifying species or species groups is listed as a subgoal but should be a component of all studies.
2) Assessing behavior and mortality: Research focused on behavior is separate from those centered on mortality, but in some situations, both can be examined during the same study. Moreover, when evaluating the effectiveness of a minimization strategy, information on behavior can be simultaneously collected to provide greater insight as to how bats are responding to the strategy.
3) Combining multiple technologies: Although each technology provides useful information, there are limitations and biases associated with their use. Pairing technologies, such as acoustic detectors and thermal cameras, can help to overcome the constraints of an individual technology.

4) Capturing individuals: Several activities may require the capture of individuals, which provides the opportunity to secure radio- or GPS-tags. The live capture of bats also provides an opportunity for taking blood and tissue samples (e.g., biopsy, hair, or guano), which may help examine physiological aspects associated with behavior and risk.

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Research Goal 1: Advance technology, methods, and analysis tools for behavioral research studies

The first research goal focuses on improving the technologies, methodologies and analytical tools for field studies using cameras, including sub-goals and activities to develop guidance for setting up equipment and to accelerate data processing and analysis of video data using machine learning algorithms (Table 2). Of these, one of the more urgent needs is automated detections, classifications (i.e., bat, bird, insect, non-biological target), and flight tracks. One of the main barriers to using thermal video cameras is the amount of time it takes to process and analyze data. Fully automating the analysis reduces cost, quantifies the measure of classification confidence, and produces results in a timely manner. Moreover, it is likely more accurate, in terms of reducing rate of missed detections, compared to human processing and analysis.

Table 2. Goals, sub-goals, and activities to improve data collection and analysis of video monitoring studies.

Goal	Sub-Goal	Activities	Notes related to activities
Advance technology, methods, and analysis tools for behavioral research studies	Fully automate video detections, classifications, and flight tracks	Develop standards for a central repository and public access of video data	To assist machine learning target classification and establish classification accuracy
		Enhance existing video software for 2D and 3D analysis using machine learning algorithms	To make processing and analysis more efficient and accurate
		Develop real-time video analysis capabilities to inform turbine operations	To help expedite reporting and decision making for curtailment Cameras provide a wider field of view compared to acoustic detectors and can detect bats that may not be echolocating
	Standardize field methods for setting up equipment, reporting, and transmitting data	Develop guidance for setting up equipment and reporting	To provide comparability among studies and reduce having to 'reinvent the wheel' Guidelines should detail equipment specifications (e.g., camera type, pixel resolution, illuminator intensity), camera placement (e.g., camera height, distance from turbine), and turbine specifications (e.g., hub height, blade length)
		Sync clocks between acoustic detectors and thermal cameras	To improve pairing video observations to recorded echolocation calls and assist in identifying species-specific behaviors
		Develop guidance for camera equipment required for research vs. monitoring	To determine what equipment is appropriate for a given study Research equipment may be more precise/expensive than what is needed for monitoring
		Develop capabilities for to communicate with technologies and transmitting data offsite	To reduce site visits for monitoring equipment or collecting data

Research Goal 2: Characterize bat behavior at the turbine-scale

The second goal aims to quantify bat behavior near wind turbines to help answer fundamental questions of how and why bats approach these structures. Based on existing data, it is apparent that some individuals alter course to approach and spend time near wind turbines, in some cases investigating the tower, nacelle, and blades. Knowing what factors are associated with these interactions may optimize existing or inspire new minimization strategies. Subgoals and activities are designed to, 1) relate bat presence and activity with weather conditions, turbine operations, and spatial features, 2) assess species-specific behavioral traits, 3) determine whether bats habituate to wind turbines, 4) estimate the distance at which bats become interested, and 5) investigate potential attraction hypotheses (Table 3).

Table 3. Goals, sub-goals, and activities to characterize bat behaviors at the wind turbine-scale.

<table>
<tr><th>Goal</th><th>Sub-Goal</th><th>Activities</th><th>Notes</th></tr>
<tr><td rowspan="5">Characterize bat behavior at the turbine- or facility-scale</td><td rowspan="2">Relate bat video observations with spatial, temporal, operational, and weather conditions</td><td>Use video observations to compare bat behavior among seasons and latitude</td><td>To compare behavior among seasons when bats are active (i.e., from spring through fall), and assess whether there are differences in latitude (Canada vs. Texas) within a species</td></tr>
<tr><td>Relate video observations with weather and operational data from wind turbines and nearby meteorological towers

Use GIS to classify landscape conditions at various scales</td><td>To quantify specific timing and conditions interactions and collisions occur

Weather and operational data should be on as fine a scale as possible (e.g., 10 min)</td></tr>
<tr><td rowspan="3">Investigate potential attraction hypotheses (Note: the attraction hypotheses listed here are represent a few examples and are not intended to be an exhaustive list. See Kunz et al. 2007 and Cryan and Barclay 2009 for additional hypotheses)</td><td>Use cameras to compare behavior at wind turbines, other vertical structures (e.g., meteorological towers, solitary tall trees), and open-air space</td><td>To assess whether bats perceive wind turbines as potential roosts

Onsite investigation for actual evidence of roosting (e.g., guano or presence of bats) can be used</td></tr>
<tr><td>Use cameras to examine response by bats to recorded turbine or anemometer noise at vertical structures (e.g., trees, meteorological towers, or non-operating wind turbines) or open airspace to control conditions (i.e., no noise)</td><td>To assess whether turbine noise attracts bats</td></tr>
<tr><td>Compare insect activity and foraging rate of bats at wind turbines to open airspace</td><td>To assess whether wind turbines represent potential foraging areas

Foraging can be determined by feeding buzzes using acoustic detectors or by flight behaviors (e.g., rapid turns/rolls) using cameras. Insect activity can be estimated by radar or insect traps</td></tr>
</table>

		Investigate if attraction hypotheses vary by landscape or habitat conditions	To assess whether bats perceive wind turbines as roosts in areas with fewer trees Onsite investigation for actual evidence of roosting (e.g., guano or presence) also can be used To assess whether insect abundance is higher in agricultural settings compared to forests. Compare insect activity and bat foraging activity between habitat types
	Assess species-specific behaviors	Pair acoustic and video data or use several high-definition cameras	To identify observations to the species level and assess differences in behavior Requires reliable syncing of detectors and cameras, and confidence in species ID
		Use video data to quantify morphometrics of species	To determine whether species-specific flight profiles can be identified Record flight behavior of different species using a flight cage or areas where bats are active and can be identified
	Determine whether bats habituate to wind turbines	Use telemetry to track individual movement patterns within a wind energy facility	To investigate how bats move within a wind energy facility and if individuals continually approach the same turbine (or set of turbines) Requires advances in tags (i.e., light enough for smaller species and capability to transmit data without having to recapture individuals) to track bat flight
		Use thermal cameras to monitor bat activity at treatment and control conditions	To assess how bats respond to the presence/absence of a tall structure when all other conditions are equal A large crane or other retractable structure can be used as a surrogate for turbines. Raise (treatment) or lower (control) the crane during a randomized schedule to compare bat activity
	Estimate the distance bats alter direction to interact with wind turbines	Combine camera array and radar data to monitor changes in movement pattern near wind turbines or use telemetry data	To quantify the distance a bat may perceive a wind turbine as a potential resource The most appropriate distance measure may depend on species of interest, etc.

Research Goal 3: Characterize bat collisions with wind turbines

The third research goal centers on characterizing mortality events. This includes identifying, 1) where strikes occur along the blades, 2) what conditions exist when strikes occur, and 3) how best to record collisions (Table 4). Although studies investigating collision events may also assess behavior, these studies may require additional cameras to capture the entire rotor-swept area (RSA), higher resolution cameras to confidently identify strikes, alternative camera placements (e.g., installed on the wind turbine focused outward to detect falling objects), or additional technologies (e.g., strike detectors). Some of the activities can be combined with strike indicator sensors.

Table 4. Goals, subgoals, and activities for characterizing bat collisions with wind turbines.

Goal	Sub-Goal	Activities	Notes
Characterize bat collisions with wind turbines	Identify if there are specific locations bat collisions occur	Use cameras to visualize the entire blade length with enough resolution to confirm strikes	To assess the location along the blades and height above ground (e.g., are collisions occurring mostly below the nacelle or above) where collisions occur Data could be paired with strike detection systems to provide more information on collisions
	Relate bat collisions with spatial, temporal, operational, and weather conditions	Use cameras to determine the timing and conditions when strikes occur	To assess when interactions and/or collisions occur and whether conditions from video data are similar to those observed from existing acoustic and mortality data Next day mortality monitoring may be required to confirm mortality events and species identification
		Use cameras and acoustic detectors to relate postconstruction bat activity, by species, if possible, with collision risk to determine whether a relationship exists	To assess whether conditions of high bat activity and mortality are the same. For example, does high bat activity increase collision risk? Are there behaviors that increase collision risk (e.g., bats chasing one another)?
		Use cameras and 3D analysis to examine flight trajectories that lead to collisions	To assess whether the flight trajectory of a bat helps to understand what it was doing prior to the collision and direction the bat was approaching the wind turbine (e.g., leeward)
		Use cameras to evaluate bat collision risk in relation to RPM and turbulence	To assess whether RPM or turbulence influence bat behavior and risk. In addition, relate bat interactions with wind turbines when energy is being produced vs. not being produced.
	Assess the effectiveness of camera position to quantify mortality	Compare feasibility of quantifying mortality using different camera placements	To examine the effectiveness of camera placements, including 1) pointed up toward the RSA, 2) down toward the ground, 3) along the length of the blade, or 4) a combination of placement options

Research Goal 4: Evaluate the effectiveness of strategies to reduce bat mortality at wind turbines

The fourth research goal intends to evaluate the effectiveness of minimization strategies. Mortality monitoring is the most effective approach to quantify differences among control and treatment conditions. However, that methodology cannot offer insight into why the strategy is effective or not. Thus, supplementing mortality monitoring with behavioral studies can provide a more complete assessment of the effectiveness of a strategy. Behavior studies can 1) examine how bats respond to different deterrent stimuli, 2) provide insight on placement for deterrents, 3) evaluate whether bats habituate to deterrents, and 4) potentially improve smart curtailment strategies (Table 5). It is important to report on the performance of the technology being validated. The technology specifications (e.g., decibel level, placement) and performance (i.e., did it operate as per the specifications throughout the study period) are integral to the evaluation of the technology.

Table 5. Goals, subgoals, and activities to evaluate the effectiveness of strategies to reduce bat mortality at wind turbines.

Goal	Sub-Goal	Activities	Notes
Evaluate the effectiveness of strategies to reduce bat mortality at wind turbines	Examine how bats respond to deterrent stimuli	Use cameras to compare presence, behavior (e.g., distance of response), and collisions among deterrent treatments	To obtain additional data to support mortality monitoring on the effectiveness of different treatments
	Assess placement options for deterrents	Compare effectiveness of different deterrent configurations to reduce bat mortality	To assess where collisions occur along the length of the blades and what decibel level is needed to achieve deterrence
	Evaluate potential habituation to deterrents	Use cameras to quantify how bats respond to the long-term exposure from deterrent stimuli at flight cages, ponds, and wind turbines	A flight cage can monitor species-specific habituation; a pond may offer long-term effect of individuals that visit a location night after night; and a wind turbine can provide data on potential changes in the effectiveness of deterrents in reducing mortality
	Evaluate the effectiveness of deterrent and curtailment strategies	Compare effectiveness of combined strategies (i.e., curtailment + deterrents) to curtailment only and deterrent only treatments	To determine whether there is a synergistic effect when combining low wind speed curtailment (e.g., 4.0 m/s) + deterrents, or whether using deterrents during certain conditions and curtailment during others is effective
	Assess whether cameras are an effective technology for smart curtailment	Compare the effectiveness of using thermal cameras and acoustic detectors to inform turbine operations	To compare the effectiveness of smart curtailment decisions between cameras and acoustic detectors. Camera- and acoustic detector-based treatments can be compared to a blanket curtailment strategy Evidence suggests bats do not always echolocate or only use low-intensity echolocation that may not be detected by the relatively small cone of reception of acoustic detectors