FINAL TECHNICAL REPORT

ULTRASONIC BAT DETERRENT TECHNOLOGY

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1.0 EXECUTIVE SUMMARY

The project objective was to advance the development and testing of an Near commercial bat-deterrent system with a goal to increase the current GE deterrent system effectiveness to over 50% with broad species applicability. Additionally, the research supported by this program has provided insights into bat behavior and ultrasonic deterrent design that had not previously been explored. Prior research and development had demonstrated the effectiveness of a commercial-grade, air-powered, ultrasonic bat deterrent to be between 30-50% depending upon the species of bat. However, the previous research provided limited insight into the behavioral responses of bats in the presence of ultrasonic deterrent sound fields that could be utilized to improve effectiveness.

A unique bat flight room was utilized to observe the behavioral characteristics of bats in the presence of ultrasonic sound fields. Behavioral testing in the bat flight facility demonstrated that ultrasonic sounds similar to those produced by the GE deterrent influenced the activities and behaviors, primarily those associated with foraging, of the species exposed. The study also indicated that continuous and pulsing ultrasonic signals had a similar effect on the bats, and confirmed that as ultrasonic sounds attenuate, their influence on the bats' activities and behavior decreases. Ground testing at Wolf Ridge Wind, LLC and Shawnee National Forest assessed both continuous and pulsing deterrent signals emitted from the GE deterrent system and further enhanced the behavioral understanding of bats in the presence of the deterrent.

With these data and observations, the existing 4-nozzle continuous, or steady, emission ultrasonic system was redesigned to a 6-nozzle system that could emit a pulsing signal covering a larger air space around a turbine. Twelve GE 1.6-100 turbines were outfitted with the deterrent system and a formal three-month field study was performed using daily carcass searches beneath the 12 turbines. Additionally, a unique 3D bat flight path visualization system was utilized to monitor for and identify any changes in bat activity caused by the operation of the deterrent system. Both the carcass search and flight path visualization data indicated that the pulsed deterrent system was effective, but not more effective, than the steady system tested in prior years. However, an unanticipated byproduct of the pulsing system was the emission of intermittent water vapor from the deterrent devices due to the air compression process that powered the devices. This water vapor may have altered the ultrasonic signal and obscured the results in an unknown way. While a qualitative analysis of the effect of the water vapor on the deterrent signal had indicated there was not dramatic change in the expected ultrasonic signal, it was not possible to conclusively determine if the pulse signal would have been more effective in the absence of the water vapor. A mid-season installation of a desiccant system was performed and the dataset divided into two groups to account for the change. Prior to the system change, the deterrent was not effective (-22%) at reducing eastern red bat fatalities and effective (38%) for the non-eastern red bat species, combined. After the installation of the desiccant system, the pulsed deterrent system showed similar results, although not statistically significant, with a point estimate effect of 23% for eastern red bats and 54% for the other combined bat species.

2.0 ACCOMPLISHMENTS

Project Goals and Objectives

Beginning in 2013, General Electric (GE) and California Ridge Wind Energy (CRWE) began testing an ultrasonic bat deterrent device at an operating wind farm in Illinois. For these tests, 20 GE 1.6-100 wind turbines were outfitted with a GE deterrent device. Based on this development independent of the scope of the DOE program, the GE deterrent device effectiveness at reducing bat fatalities was estimated to be approximately 30% when all species were considered and over 50% when Eastern red bats (*Lasiurus borealis*) were excluded from the data. These experiments indicated that, while the device was effective, additional information on bat behavior in the presence of ultrasonic sound was needed to refine the device and/or the deployment strategy and increase its effectiveness.

The behavioral and farm test research conducted under the DOE project was designed to build upon the previous research results by methodically gathering data that could be used to improve the efficacy of the device signal, as well as the placement of deterrent devices on the turbine. The project objectives were to improve the effectiveness of the deterrent device deployment to better than 50% reduction in bat mortality, using behavioral studies focused on refinement of the device signal (amplitude and/or frequency) and/or deployment strategy (more devices, strategic placement). The DOE research culminated in a 2016 study of a redesigned turbine-mounted deterrent system at the California Ridge Wind Energy facility that incorporated the deterrent design and deployment insights learned from the behavioral studies.

Technical Approach and Accomplishments Summary

The technical approach included the following research activities and accomplishments. Additional details for each research objective are provided later in the report.

1) **Explore the behavioral response of bats to continuous and pulsed ultrasonic signals in a specially constructed bat flight room (Milestones 1.2.1, 1.2.2)** Using a bat flight room (9 meters [m] by 6 m by 3 m), Texas Christian University explored the behavioral response of wild-caught bats presented with a variety of ultrasonic signals. The signal variety was chosen specifically to determine the range of acoustic characteristics (amplitude and frequency) that can be effectively and practically used to deter bats of different species away from an area. Behavioral testing in the bat flight facility demonstrated that ultrasonic sounds similar to those produced by the GE deterrent influenced the activities and behavior, primarily those associated with foraging, of the species tested. The study also indicated that bats had a similar response to both continuous and pulsing ultrasonic signals, and confirmed that as ultrasonic sounds attenuated, their influence on the bats' activities and behaviors decreased. Additionally, even though the statistical power of the results were not very high, the behavior of bats calling at both high and low frequencies appeared to be influenced by the presence of the deterrent signal.

2) **Conduct ground testing to support the findings of the behavioral responses observed in the flight room and increase the team's understanding of species-dependent responses to various deterrent pulsing duty cycles in a natural environment (Milestones 2.1.1, 2.2.1, 2.1.2, 2.2.2).** Ground testing of a single ultrasonic deterrent that emitted both continuous and pulsing signals was conducted at Wolf Ridge Wind, LLC and Shawnee National Forest. At Wolf Ridge the behavior of bats at three paired wind turbines

and cattle ponds was explored. The focus of the Shawnee National Forest testing was to investigate activity-level response at a location where *Myotis* were known to be present.

At Wolf Ridge, the deterrent significantly reduced bat activity at a reference distance of 10 m but the effectiveness appeared to decrease at greater reference distances (e.g., 20 and 30 m). The deterrent also appeared to minimize the number of trials with greater than 8 bat passes. No difference in bat activity was found among 3 deterrent treatments: constant on, one sec pulse followed by one sec silence, and one second pulse followed by two sec silence.

The Shawnee results confirmed that certain deterrent signals reduced bat activity, with the constant signal significantly deterring bats out to 20-30 m. The pulsing signal results were inconclusive, very likely due to the pulse signal dynamics (1 sec pulses spaced by 3 sec silence) acting in concert with the narrowness of the study area. Sixty four percent of the bats passing through the study area during the pulsing treatments did so during a “pulse off” or silent period between deterrent pulses.

In 2016, a second ground test was conducted at Wolf Ridge to test the effectiveness of the redesigned deterrent signal across spring, summer, and early fall. In comparison to previous tests, this study was conducted at ponds only (to increase the sample size of bats). Bat activity was significantly lower during the deterrent trials compared to the silent control periods, with no difference in effectiveness observed between the continuous and pulsed deterrent signals or among seasons.

3) **Use thermal imaging to assess bat behavior and activity data at deterred and control turbines (Milestone 4.1.1)**. In 2015, evaluation of bat flight paths from thermal imaging video collected at deterrent and control turbines had improved our understanding of bat behavior around operational turbines. By mapping multiple bat flight paths, it was possible to determine where in the turbine airspace and how bats are flying and if bats are altering their flight paths around turbines in response to deterrent signals.

   Analysis of the 2015 thermal imaging data showed the number of bat passes was reduced 57% within ~20 m of the deterrent system (Attachment H). This information was used to refine the placement of deterrents on turbines in 2016. In 2016, the thermal imaging study evaluated bat behavior around deterrent and control turbines fitted with the redesigned deterrent system. Similar to the 2015 study, the 2016 study found the number of bat passes was reduced more than 50% within ~20 m of the deterrent system (Attachment K).

4) **Redesign the existing deterrent system to increase the probability of effectiveness (Millstones 3.2.1, 4.1.2).** Previous tests have been limited to four deterrent devices per turbine based on availability of a steady air supply from the compressor units. To increase the airspace treated by the deterrent system, the air supply from the compressors was pulsed, allowing for six deterrent nozzles to be deployed from the same compressor capacity as the four-nozzle system. Additionally, high frequency coverage was enabled due to a dynamic change in a high frequency tone emitted as a natural byproduct of the pulsing deterrent. Blade mounted deterrents were considered during Phase I of the project, but the added complexity and expense made them impractical and they were considered too high risk given the effectiveness of the stationary mounted devices. The final configuration included four deterrent nozzles installed on the turbine tower and two deterrent nozzles installed on the rear of the nacelle; all deterrents emitted a pulsed signal.

5) **Conduct a farm test in 2016 to assess percent reduction in estimated bat mortality using the newly optimized devices and/or deployment strategy (Milestones 5.1.1, 6.2.1).** Twelve turbines were outfitted with the redesigned deterrent systems. Daily carcass searches were performed beneath all 12 turbines to estimate the effectiveness of the deterrent in

reducing bat mortality, Randomized control and treatment turbine groups were alternated in 6-day blocks and dogs were used to maintain a searcher efficiency of over 90%.

Full field testing of the redesigned pulsed deterrent system was initiated in July 2016. As the field testing progressed into September, it appeared the redesigned pulse system was not performing to the same level of effectiveness as the continuous operation system had during the prior three years of testing. However, field observations indicated that water vapor was intermittently emitting from the pulsed deterrent nozzles during operation which could have been impacting the deterrent effectiveness. To determine whether removing the water vapor would increase the deterrent effect, air-water separators were installed on the pulsing systems on four turbines to remove the moisture from the lines. The remaining eight turbines were reconfigured to a 5-nozzle continuous signal deterrent system, as it leveraged the deterrent system components that were in place and still allowed for testing of a yet-to-be-tried system configuration. Even though there was a risk that there would not be enough data in the remaining test weeks to draw firm conclusions, GE believed it was important to test these modifications since there would not be another opportunity to collect data until 2017.

The results of the final analysis indicated that:

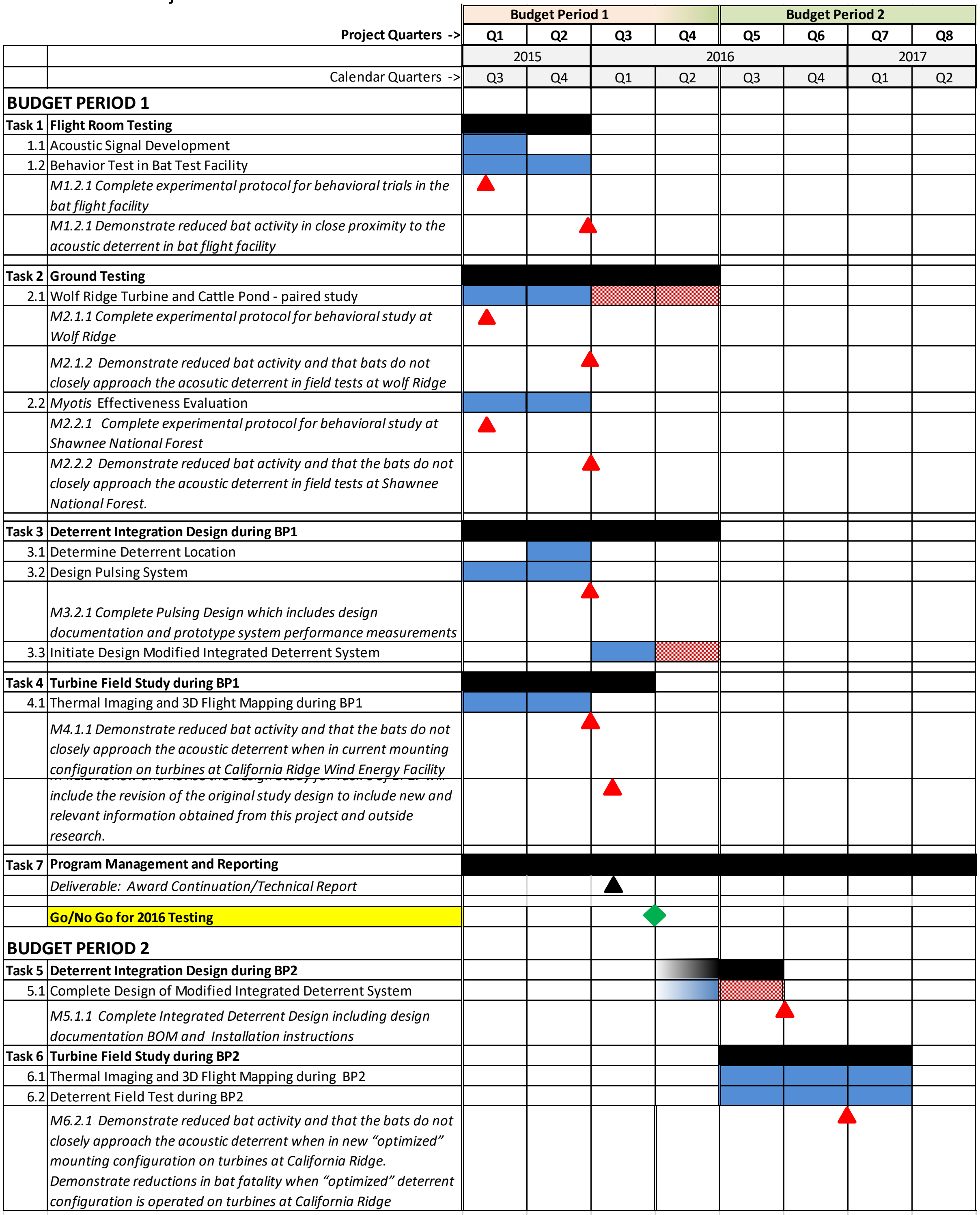
- The pulsed deterrent system was effective at reducing bat fatalities for species other than eastern red bats both before (38% reduction in bat fatalities) and after (54%) the air/water separators were installed. The early indications of low performance may have been skewed by a high proportion of Eastern red bats in the early season carcass pool.
- Eastern red bat fatalities were not reduced by the pulsed deterrent prior to nor after retrofitting the systems with the air/water separators.

Conclusions

According to the balance of the results of ground-based testing, the pulsed-deterrent system was of similar effectiveness as the continuous-emission system tested in prior years. The results of the carcass monitoring//field test further indicated there was no advantage to the added cost and complexity of a 6-nozzle pulsed system over the simpler, 4-nozzle constant system tested in previous studies. However, it was not possible to conclusively determine if the pulsed deterrent system would have been more effective than the 4-nozzle constant system had the water vapor been absent throughout the entire field test.

3.0 PROJECT ACTIVITIES

The Overall Project Plan and Schedule are shown below.



		Budget Period 1				Budget Period 2			
	Project Quarters ->	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**
		2015		2016				2017	
	Calendar Quarters ->	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
BUDGET PERIOD 1									
Task 1	**Flight Room Testing**	■	■						
1.1	Acoustic Signal Development	🟦							
1.2	Behavior Test in Bat Test Facility	🟦	🟦						
	M1.2.1 Complete experimental protocol for behavioral trials in the bat flight facility	▲							
	M1.2.1 Demonstrate reduced bat activity in close proximity to the acoustic deterrent in bat flight facility		▲						
Task 2	**Ground Testing**	■	■	■	■				
2.1	Wolf Ridge Turbine and Cattle Pond - paired study	🟦	🟦	▨	▨				
	M2.1.1 Complete experimental protocol for behavioral study at Wolf Ridge	▲							
	M2.1.2 Demonstrate reduced bat activity and that bats do not closely approach the acosutic deterrent in field tests at wolf Ridge		▲						
2.2	*Myotis* Effectiveness Evaluation	🟦	🟦						
	M2.2.1 Complete experimental protocol for behavioral study at Shawnee National Forest	▲							
	M2.2.2 Demonstrate reduced bat activity and that the bats do not closely approach the acoustic deterrent in field tests at Shawnee National Forest.		▲						
Task 3	**Deterrent Integration Design during BP1**	■	■	■	■				
3.1	Determine Deterrent Location		🟦						
3.2	Design Pulsing System	🟦	🟦						
	M3.2.1 Complete Pulsing Design which includes design documentation and prototype system performance measurements		▲						
3.3	Initiate Design Modified Integrated Deterrent System			🟦	▨				
Task 4	**Turbine Field Study during BP1**	■	■	■					
4.1	Thermal Imaging and 3D Flight Mapping during BP1	🟦	🟦						
	M4.1.1 Demonstrate reduced bat activity and that the bats do not closely approach the acoustic deterrent when in current mounting configuration on turbines at California Ridge Wind Energy Facility		▲						
	include the revision of the original study design to include new and relevant information obtained from this project and outside research.			▲					
Task 7	**Program Management and Reporting**	■	■	■	■	■	■	■	■
	Deliverable: Award Continuation/Technical Report			▲					
	Go/No Go for 2016 Testing				◆				
BUDGET PERIOD 2									
Task 5	**Deterrent Integration Design during BP2**				■	■			
5.1	Complete Design of Modified Integrated Deterrent System				🟦	▨			
	M5.1.1 Complete Integrated Deterrent Design including design documentation BOM and Installation instructions					▲			
Task 6	**Turbine Field Study during BP2**					■	■	■	
6.1	Thermal Imaging and 3D Flight Mapping during BP2					🟦	🟦	🟦	
6.2	Deterrent Field Test during BP2					🟦	🟦	🟦	
	M6.2.1 Demonstrate reduced bat activity and that the bats do not closely approach the acoustic deterrent when in new "optimized" mounting configuration on turbines at California Ridge. Demonstrate reductions in bat fatality when "optimized" deterrent configuration is operated on turbines at California Ridge						▲		

Started 2015 ground testing later than planned due to delayed NEPA approvals

- Requested no-cost extension of BP1 to allow for additional ground testing due to late start
- Added 2 weeks additional field testing at Cal Ridge to address issues with deterrents

"Go" decision approval in June 2016 based on results of 2015/16 lab and ground testing

The following sections summarize highlights of the project activities. Detailed information is provided in the milestone reports in Attachments A through K.

3.1 FLIGHT ROOM TESTING (TASKS 1.1, 1.2)

Activities and Accomplishments

In this task, the response behavior of bats to a range of acoustic signals was evaluated in a specially constructed bat flight room. Full details of the related tasks and results are provided in Attachments A and B. A set of ultrasonic signals were used that varied in frequency, amplitude, pulse rate, and interval. The behavioral responses of the bats to each type of signal was evaluated and results were used to determine the range of amplitude and frequency characteristics that can effectively and practically be used, and ultimately provide insights into the field application of the GE deterrent.

Using a bat flight room (~9 m by 6 m by 3 m), Texas Christian University explored the behavior of wild-caught bats when presented with 9 different ultrasonic signals using an Avisoft Bioacoustics simulator. These signals included four deterrent treatments (silence – as a control, constant on, 1 sec pulse followed by 1 sec silence, 1 sec pulse followed by 2 sec silence) and three different distances were simulated. These signals were designed to represent the maximum sound at reference distances of approximately 12 m, 18 m, and 30 m from the GE deterrent. The actual deterrent could not be used in the flight room because of the size of the room relative to the product deterrent acoustic field. Therefore, acoustic signals scaled to the size of the room were simulated and thereby similar to the actual frequencies and amplitudes a bat would experience near an actual wind turbine.

The bats used by TCU in this study were captured from local parks in and around Fort Worth using mist nets. Captured bat species included eastern red (*Lasiurus borealis*) and evening (*Nycticeius humeralis*) defined as high frequency bats which echolocate at frequencies >35 kHz, and Mexican free-tailed (*Tadarida brasiliensis*) bats, a low frequency bat, which echolocates at frequencies <35 kHz. Once bats had acclimated to the flight facility and were actively flying at night, an Avisoft Bioacoustics simulator was used to play the signals. The behavioral responses of the bats to each type of signal were recorded using two Canon XA20 camcorders. An AR125 Ultrasonic bat detector from Binary Acoustic Technology was also placed in the flight facility to record acoustic activity during the silence and experimental trials. Both video and acoustic data files were then reviewed and analyzed to assess whether and how the activity patterns and behavior of the bats varied with each signal played compared to when they were not played (i.e., silence). All video data were analyzed using Studiocode video analysis software (version 5, Studiocode Business Group, Sydney, AU) and all acoustic data were analyzed using Sonobat Bat Call Analysis Software (version 3.04).

For the analysis, the presence/absence of bats was recorded in the focal area within each paired video (i.e., front and side videos combined) at 10 second intervals (hereafter referred to as a snapshot), for a total of 30 snapshots per 5 minute video (including the last 5 minutes of the 10 minute silence prior to the experimental trials, and the trials themselves). We then calculated the proportion of snapshots with bats present for the silence period and each experimental trial, which we used as a measurement of bat activity. Three dependent variables (presence/absence, behavior type, and call type) were compared against the three independent variables: duty cycle (continuous, 1 s pulse, and 2 s pulse), distance (12 m, 18 m, and 30 m), and species using ANOVAs, where $\alpha = 0.05$. If a significant difference was found between the duty cycles, then Tukey's post-hoc test was performed to determine the source of the variation. For acoustic data, the proportion of calls belonging to each echolocation call type (searching, foraging, feeding buzz, communication) was calculated. Fisher's exact test was then used to compare call data from the three duty cycles with call data during silence. This comparison allowed us to determine whether the ultrasonic signal significantly influenced the acoustic activity of bats in the facility. Note that as the flight facility is a controlled environment, bats may not conduct behaviors that are representative of those in wild. For instance, the bats' ability to move away from the deterrent is restricted.

Specific objectives

- To evaluate the behavioral responses of bats to each type of signal in order to determine the range of acoustic characteristics (amplitude and frequency) that can effectively and practically be used to deter bats from an area.

- To inform where and how many GE deterrents can be placed on wind turbines to minimize bat fatalities.

A total of 245 behavioral trials were conducted from July 11 to September 25, 2015, were used in the analysis.

Presence/absence*: Silence vs. deterrent comparison*

Among high frequency bats (i.e., bat species with echolocation call frequencies >35 kHz) activity appeared higher during the silence than when the deterrent was played across all reference distance categories (Fig. 1 A-C), although this pattern was not statistically significant due to high variance in activity during silent periods. In comparison, for the low frequency bat species (<35 kHz), a decrease in activity was observed at the 30-m reference distance category and an increase was seen at both the 12-m and 18-m reference distance categories (Fig. 1 D-F). Again this pattern was not statistically significant.

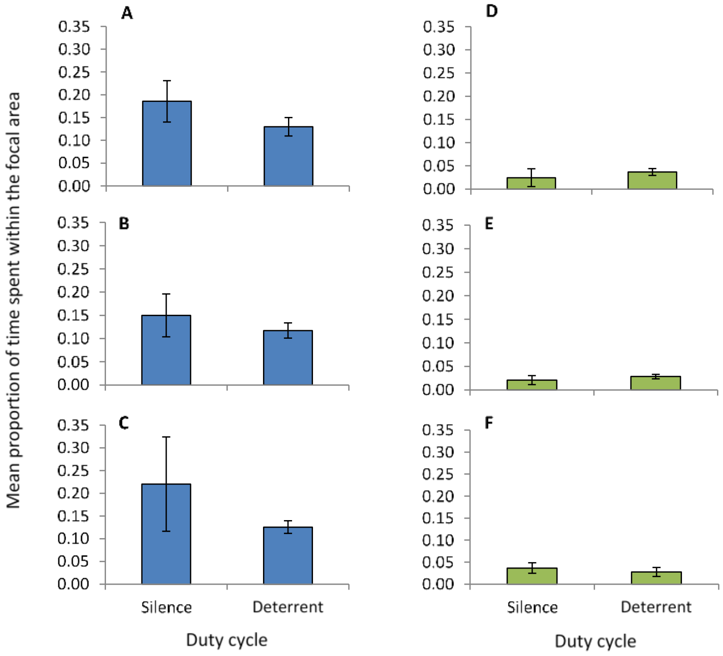


Figure 1: Mean ± SE proportion of time bats spent within the focal area during silence and with the deterrent on (continuous, 1 s pulse, 2 s pulse). *For high frequency species shown in blue, (A****)*** *shows bat presence when an acoustic signal was played at a reference distance equivalent to 12 m, (B) 18 m, and (C) 30 m. For low frequency bats shown in green, (D) shows bat presence when an acoustic signal was played at a reference distance equivalent to 12 m, (E) 18 m, and (F) 30 m*.

Duty cycle and reference distance category comparison

Across the three duty cycles and the three reference distance categories, no statistically significant differences were observed in the proportion of time both high and low frequency bats spent in the focal area.

Behavioral data

Specific behaviors (i.e., foraging, drinking, chasing and passing) exhibited by the bats were also identified. Activity rates and behavior during trials were evaluated to determine if signal characteristics (such as distance and duty cycle) significantly affected the bats. TCU found that ultrasonic sounds influenced certain bat activities and behavior, such as foraging. In particular, while high frequency bats would actively fly while the signals were playing, foraging activity and efficiency decreased (Fig. 2).

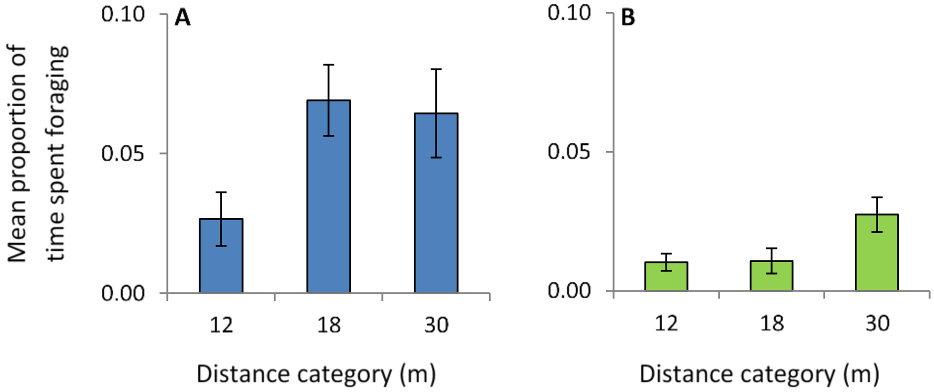


Figure 2: Mean ± SE proportion of time spent foraging by eastern red bats (A) and evening bats (B) across the three reference distance categories (12 m, 18 m, 30 m) when the deterrent was on.

Trials also confirmed that as ultrasonic sounds attenuated, as the bats' activities and behavior were influenced with distance from the source of the sound. We also noted this influence to be species specific. For example, foraging behavior among eastern red bats was significantly lower at 12 m than at 18 m and 30 m, while evening bats foraged at both 12 and 18 m significantly less than at 30 m (Fig. 2). Finally, TCU did not find significant differences in activity patterns and behaviors across duty cycles suggesting that deterrents could be pulsed and remain effective.

Accomplishments include:

Completion of the behavioral trials in the bat flight room.

Completion of Milestone 1.2.2 – Demonstrate reduced bat activity in close proximity to the acoustic deterrent in the bat flight facility.

Departure from Plan and Why

No departures from plan were made.

Key Conclusions, learnings, and application

As presence/absence of bats and bat behavioral patterns did not vary among the different duty cycles, it was concluded that deterrents could be pulsed at the tested intervals and remain effective.

These results and recommendations were used to inform the Turbine Field Study in 2016.

3.2 GROUND TESTING (Tasks 2.1, 2.2)

3.2.1 WOLF RIDGE

Activities and Accomplishments

We tested the effective range of the deterrent and associated avoidance behaviors of bats near turbine towers and cattle ponds at Wolf Ridge in 2015. Full details of the related tasks and results are provided in Attachments C and D. This ground testing was conducted to further assess the findings of the detailed behavioral responses observed in the flight room and increase our understanding of species-dependent responses to various deterrent pulsing duty cycles in a natural environment. Using high-definition video cameras and night vision technology, we recorded bat activity at paired cattle ponds and turbine towers concurrently with the deterrent off, on, and pulsing. In addition, we placed ultrasonic bat detectors in proximity to the cattle ponds and turbines during the night vision surveys to record acoustic bat activity. Testing cycled through a series of acoustic signal treatments (e.g. control (deterrent off), continuous (deterrent on), and pulsed treatments which vary in pulse duration and interval). Using video analysis software, we determined the number of bats present during each treatment and documented levels of activity with the deterrent placed at 3 distances (10m, 20m, and 30m) from the focal observation point. We analyzed bat calls recorded at the survey sites using bat call analysis software to confirm species presence.

We surveyed paired turbine and pond locations on 33 nights from 17 August to 28 September 2015. We had a 10-min silence period between treatments to allow any treatment effect to diminish and bat activity to return to normal prior to beginning the next trial. The order in which the deterrent treatments were played was randomly determined for each survey night. Within a survey night, the paired turbine tower and pond locations received the same treatments in the same order, and the set of 4 treatments was played twice. Within each trial, we counted the number of bat passes within the focal area and characterized behavior during each pass (passing, foraging, chasing, reversal, or drinking). We also recorded acoustic activity using bat detectors, and reviewed these files to identify the calls to species (where possible) and to further characterize behavior (commuting, searching, foraging, feeding, and social calls).

In total, we detected 447 bat passes in 448 10-min experimental trials. We used these data to answer 3 main questions:

1. Did the GE prototype deterrent device reduce bat activity at water sources and wind turbine towers?

Overall bat activity was highly variable with 68% of the deterrent trials yielding zero bat passes, whereas 4% of the deterrent trials contained 41% of the total bat passes. Of the 448 trials, only 9 trials had ≥8 bat passes, and these high bat activity events occurred only at ponds during control trials or with the deterrent operating at 30 m (See Milestone 2.1.2). This finding suggests that the deterrent may be preventing high activity events from occurring when operating at 10 or 20 m from the focal observation point at ponds. We also compared bat activity during the control trials (pooled across all survey nights) to the deterrent trials at three distances. We observed a 70% reduction in mean bat passes at 10 m at ponds with the deterrent on compared to the control (Milestone 2.1.2). We observed a similar pattern in a reduction in bat passes at turbines when the deterrent was on at 10 m and 20 m, but the differences were not significant, likely due to the low overall number of bat passes seen at turbines (n = 74 passes). If the rates of reduction in bat passes observed during the deterrent treatments, especially at 10 m, translates into similar rates of fatality reduction at wind turbines, then this deterrent is effective at reducing bat mortality.

2. Did bat activity and behavior vary with deterrent treatment?

We found no difference in bat activity among the 3 deterrent treatments at 10 and 20 m from ponds or 10 and 20 m from turbine locations at Wolf Ridge (See Attachment D for full details). Therefore, the results were an indication that the pulsing deterrent could be effective for field application. Pulsing the deterrent reduces the air required for each nozzle, thereby allowing additional emitters to be placed on a given turbine without increasing the demand for compressed gas and the associated infrastructure.

3. Did bat activity vary with distance from the deterrent source?

The mean number of bats observed per trial was 50% higher at 20 m than 10 m, and 202% higher at 30 m than 10 m at ponds (Table 1; See Attachment D for full details). We found a similar trend in reduction of bat activity at 10 m compared to 20 or 30 m from the turbine towers, although the difference was not statistically significant, likely due to the low number of bats and high variability in bat activity at turbines. Nevertheless, these trends suggest that the effectiveness of the deterrent likely attenuates with distance; thus, increasing the number of emitters deployed on individual turbine towers will increase sound coverage within and near the rotor-swept zone. Without additional engineering changes, alternative placement options include placing emitters on the nacelle and along the tower.

Table 1. The mean percent change in the number of bat passes detected with distance from ponds and turbines at Wolf Ridge in 2015. N = number of 10-min trials.

Ponds					**Turbines**				
Variable	**N**	**Mean Bat Passes**	**% Change vs. 10m**	**St. Dev**	**Variable**	**N**	**Mean Bat Passes**	**% Change vs. 10m**	**St. Dev**
10m	53	0.74	-	1.48	10m	50	0.12	-	0.39
20m	58	1.10	50%	1.53	20m	58	0.22	87%	0.53
30m	59	2.22	202%	3.14	30m	59	0.59	394%	1.50

In summary, ground testing in 2015 demonstrated that the deterrent significantly reduced bat activity at a reference distance of 10 m from the focal point of observation, but that the effectiveness appeared to decrease at greater reference distances (e.g., 20 and 30 m). The deterrent also appeared to minimize large pulses in bat activity, which could be promising for deterrent effectiveness at reducing bat fatalities at wind turbines. We found no difference in bat activity among the 3 deterrent treatments: constant on, one sec pulse followed by 1 sec silence, and one second pulse followed by 2 sec silence. This finding suggests that a pulsing deterrent maintains its effectiveness in a manner similar to a constant deterrent. Since the pulsing feature is necessary to increase the number of deterrents driven by a single compressor, this is an important finding as it leads to an opportunity to increase the number of deterrents deployed on a single turbine.

Accomplishments include:

Completion of the ground tests at Wolf Ridge Wind.

Completion of Milestone 2.1.2. – Demonstrate reduced bat activity and that bats do not closely approach the acoustic deterrent in field tests at Wolf Ridge.

Departure from Plan and Why

We made no departure from the plan in 2015.

In 2016, the research team added two additional rounds of deterrent testing at Wolf Ridge. The ground testing that took place from April to June was designed to evaluate how bats would respond to the redesigned deterrent system (scheduled to be tested at California Ridge starting in July 2016). The ground testing that took place from July to September (funded by TCU – outside the scope of the DOE award) was designed to determine how bats would respond to the deterrent during the fall migratory season. This fall season coincides with the highest bat fatality rates observed at Wolf Ridge during fatality searches completed in previous years, and thus we felt it was important to gather data from this time of year. In total, we conducted deterrent testing on 50 nights between April 1 and September 17, 2016 at 3 cattle ponds. Because our bat detection rates were much higher at ponds in 2015, we conducted the 2016 deterrent trials at ponds only to maximize the number of bats we could potentially observe. The deterrent signals that we tested in 2016 had a higher initial manifold pressure (increased to 85 psi) to reduce the frequency of the deterrent narrowband tone signal to approximately 40-48 kHz, a frequency range in which two abundant bat species at this site echolocate. This was accomplished by ramping the pressure in the pulsed signals to allow the frequency of the ultrasonic narrowband tone to vary, thereby increasing the amplitude of sound in the 40-48 kHz range. We also used thermal cameras instead of night vision cameras to record bat activity in our surveys.

In total, we recorded 492 bat passes during 601 10-minute trials during 81 pond nights in 2016. As we found no significant difference in bat activity between the redesigned deterrent signals (continuous on and pulsed signals with ramped pressure), we pooled the deterrent treatments for subsequent analysis. Bat activity was significantly reduced when the deterrent was playing compared to the control periods (Fig. 3). The results from these ground tests revealed that the deterrent significantly reduced bat activity at ponds, with reduction rates ranging from 72-91% compared to the control. The deterrent also changed bat flight behavior, with bats demonstrating significantly less complex foraging flight and more simple passing flight during deterrent tests compared to the control (Fig. 4). We found no difference in the effectiveness of the pulsing deterrent treatments, nor did we find a difference in effectiveness among seasons (spring, summer, and early fall).

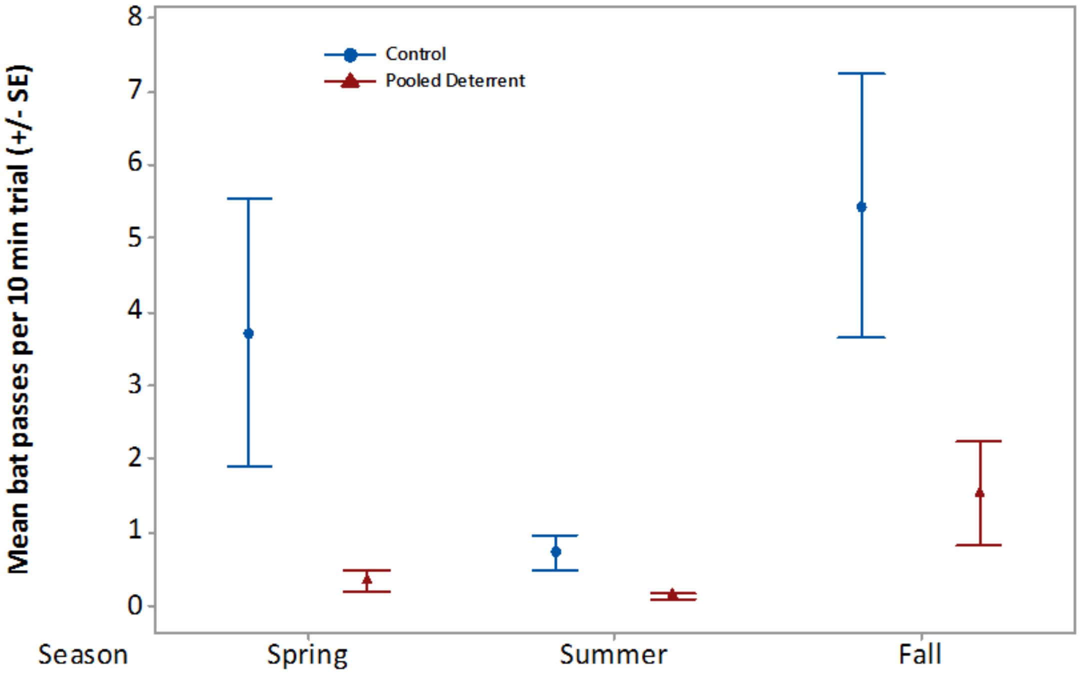


Figure 3. Mean ± SE the number of bat passes per 10-min trial observed during deterrent testing at cattle ponds at Wolf Ridge in 2016.

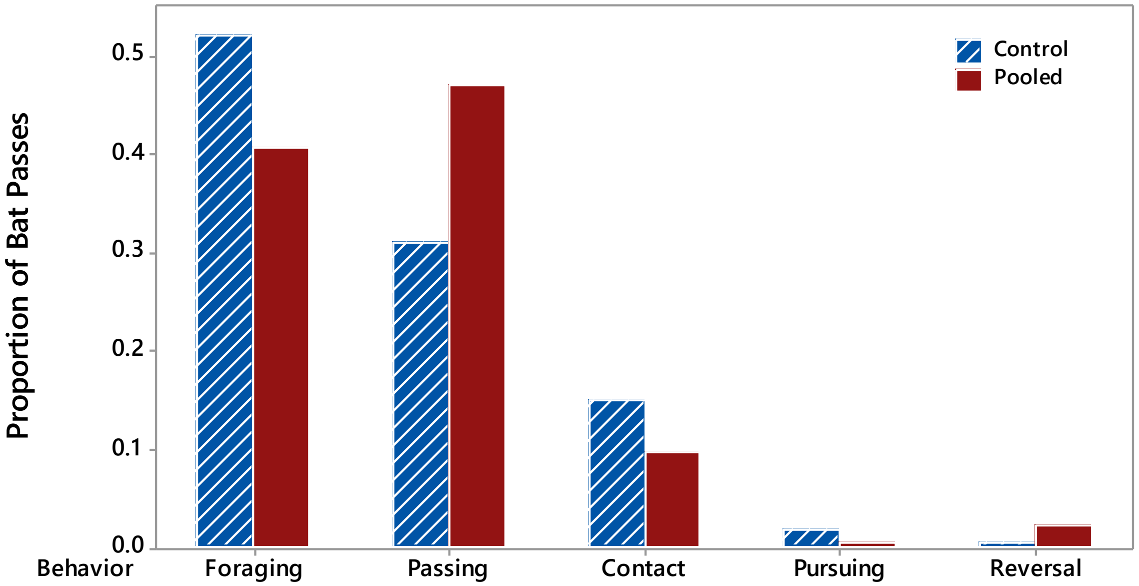


Figure 4. Relative frequency of different bat behaviors observed during control periods (n = 296 passes in 150 trials) and deterrent testing (n = 190 passes in 451 trials) at Wolf Ridge in 2016.

Key Conclusions, Learnings, and Application

Bat activity was lower during the deterrent trials compared to the silent control periods, although the difference was only statistically significant in 2016. We found no difference in bat activity among the continuous and pulsed acoustic signals, suggesting that pulsed signals may be as effective at reducing bat activity as continuous signals. This finding indicated that it was possible to redesign the deterrent system so that >2 emitters can be connected to a single air compressor, thereby potentially increasing the number of emitters deployed on wind turbine towers to increase the extent of airspace near the rotor swept zone that can effectively be covered by the acoustic deterrent signal. The deterrent also changed bat flight behavior, with bats exhibiting significantly fewer complex foraging flight paths and significantly more simple, straight-line flight paths during deterrent tests compared to control periods. Although the reduction in effectiveness with distance that we observed is a challenge with the current technology, acoustic deterrents, such as the GE devise tested here, show promise as an effective impact mitigation strategy.

3.2.2 SHAWNEE NATIONAL FOREST

Activities and Accomplishments

The testing of constant and pulsed deterrent signals under Task 2.2 was performed between August 20 and September 24, 2015 at the Shawnee National Forest in southern Illinois. Full details of the related tasks and results are provided in Attachment E. The objective of this study was to observe the effect of the constant and pulsed deterrent signals on bats, particularly those of the *Myotis* genus. The study was performed in the Oakwood Bottoms section of the Shawnee National Forest because it was reported and later confirmed to have populations of *Myotis* bats.

Tests were conducted using a random block design, where a silent (control), constant, and pulsed (1 second on, 1 second off) signal were emitted in randomly-ordered individual 10-minute test periods separated by 10-minute rest periods. Each iteration of 3 test periods was termed a “block” of testing. During a 10-minute test period the bat activity was recorded using two night-vision enabled video cameras and an ultrasonic acoustic recorder placed approximately 30 m from the deterrent nozzle. The night vision cameras were placed perpendicular to one another so that bat passes could be classified to 3 distance zones (0-10 m, 10-20 m, and 20-30 m). The bat passes recorded in the videos were used to quantify bat activity within each zone during each treatment. Species composition and the presence/absence of eastern red bat (*Lasiurus borealis*) and *Myotis* bats were determined by using bat call analysis software to manually review the acoustic recordings collected during each 10-minute test period at an acoustic detector placed at approximately 30 m from the deterrent nozzle.

The bat activity recorded by the video cameras was used to test for treatment, distance zone, and treatment-by-distance zone effects in a Generalized Linear Model (GLM) based on a Poisson error structure and a logit link; differences were assessed using an Analysis of Deviance (ANODEV) test. In addition, the eastern red bat and Myotis bat presence/absence data were analyzed using a separate GLM based on Bernoulli error structure and a logit link; deterrent effects were assessed using an ANODEV test.

A total of 79, 3-signal blocks were completed. Half (37) of these did not have any bat passes recorded, and 2 others were excluded because of equipment malfunctions during one or more of the 10-minute test periods. A total of 170 bat passes were recorded in the remaining 40 blocks. The acoustic detector recorded 1,763 bat call sequences during the 10-minute test periods, of which 623 could be identified to species.

Departure from Plan and Why

The original plan was to use the acoustic recordings to assign species to individual bat passes throughout the study. Due to the difficulty in recording calls from every bat observed in the study area, we revised the analysis plan to best use the acoustic data we had collected. The difficulty in recording all bats with the acoustic detector was created by the need to place the detector at the far end of the study area so the acoustic recordings were not obscured by the operation of the deterrent, which was detectable on the microphone. We also recorded few *Myotis* bats, so analyzing treatment effects by distance was not feasible with the small sample size. Thus, the acoustic data analysis was further modified to compare presence/absence of *Myotis* bats in each 10-minute period. Last, we revised our analysis to include presence/absence of eastern red bats because this species was indicated as having a weak behavioral response to the signal in testing under Task 1 and during past field tests of the deterrent.

Key Conclusions, learnings, and application

Bat Pass (video) Results:

Bat activity, or the number of passes made by bats, was reduced when the constant deterrent signal was played. In contrast to the Wolf Ridge ground study, the pulse signal did not appear to affect bat activity. However, we believe these results were confounded by other factors explained below such that the pulsing results from the Shawnee study are inconclusive. For the constant deterrent signal, bat activity was reduced by 93.75% (SE 6.92%) in the 0-10 m distance zone, 6.90% (SE 26.76%) in the 10-20 m distance zone, and 39.13% (SE 22.18%) in the 20-30 m distance zone (Table 2, below). A likely explanation for the decrease in deterrence in the 10-20 m zone under the constant deterrent signal is that the study area was T-shaped as it included a road intersection in the 10-20 m zone. It is possible that the foliage around the intersection had blocked the signal from full emission, and that bats were able to enter the study area in this zone without a gradual exposure to the treatment signal. The narrowness of the study area (<10 m) coupled with the intermittent pattern of the pulse signal could have caused the apparent ineffectiveness of the pulsed signal. This notion is supported by the fact that 64% (n=29) of the bats recorded during the pulse signal test periods entered or completely passed through the study area during the quiet portion of the pulsed duty cycle.

Table 2. Estimated deterrent effects on bat counts, standard errors, and P-values associated with a test of beneficial deterrent effect.

Treatment	Zone	Deterrent Effect %	SE %	*P*-value
Pulsing	0–10 m	18.75	32.61	0.2829
Constant		93.75	06.92	<0.0001
Pulsing	10–20 m	03.45	27.50	0.4501
Constant		06.90	26.76	0.3983
Pulsing	20–30 m	17.39	27.53	0.2640
Constant		39.13	22.18	0.0393

Bat Acoustic Results:

A majority of the 623 recorded bat call sequences were from big brown bat (*Eptesicus fuscus,* 34%) and eastern red bat (28%) species; *Myotis* bats only comprised 4% of the 623 bat calls recorded (Attachment E), but were recorded during 31 of the 40 blocks. The presence of eastern red and *Myotis* bats did not appear to be influenced by either of the deterrent signals. This result is not entirely surprising because the presence/absence acoustic data were of lower resolution than the bat activity (video) data and the microphone was placed at the far end of the study area, so smaller deterrent effects, if any, would have been difficult to detect. These data are not sufficient to draw conclusions to differentiate the deterrent effectiveness towards high frequency bats compared to low frequency bats.

In summary, the findings of task 4.1 indicate that deterrent effectiveness decreases as distance increases from the deterrent emission source. They also support use of a constant deterrent signal, and indicate that deterrent system configuration should consider the shape of the targeted environment and avoid creating “deterrent signal dead-zones” where bats are allowed to approach the targeted airspace because the deterrent signal is blocked by obstructions. The results of the pulsed signal tests were inconclusive; future studies should consider the study area when selecting pulse duty (on/off) cycles. Additionally, future studies attempting to focus on species-specific effects through use of bat acoustic detection equipment should consider the use of multiple microphones to encompass the study area or an analysis that quantifies call count data.

3.3 DETERRENT DESIGN AND INTEGRATION (Tasks 3.1, 3.2, 3.3, 5.1)

Activities and Accomplishments

During the course of the program, the GE deterrent system that had been successfully tested from 2013 to 2015 was modified based on learnings and concepts developed during the DOE program. The system originally was a 4-nozzle system operated with constant signal, but was modified for the 2016 test season to be a 6-nozzle system operated with pulsed signal. The studies in the program indicated that there was potential for increasing the effectiveness by providing wider acoustic coverage with additional emitters. However, since the air capacity of the compressors was limited, the only way to operate more emitters was to pulse the system. During the development of the pulsed system, an inherent benefit observed during lab testing was that as the system discharged during each pulse, there was a strong tone (referred to as the narrowband tone) that swept from 42 kHz to 53 kHz. It was hoped that this additional frequency content would increase the deterrent effectiveness against Eastern red bats, which had been resistant to the deterrent signal in prior studies. During the lab test, a pulsing duty cycle of 3 sec on and 3 sec off was determined optimal for spanning the maximum frequency range and reaching the target operating pressures accounting for the necessary time to recharge the system after each pulse. Full details of the pulsing system, related tasks, and results are provided in Attachments G and J.

For the field test, 12 wind turbines were equipped with the deterrent system. The systems were operated daily according to the study design plan. Operating pressures were monitored regularly to ensure proper operation of the system. While there were some minor anomalies noted on occasion, the systems all worked mechanically as expected without any failures.

Departure from Plan and Why

There were two departures of note from the original plan.

The first was an adjustment to the pulsing duty cycle different than the planned 3 sec on, 3 sec off cycle developed in the lab. This planned duty cycle was developed based on the system dynamics in the lab where it took 3 seconds to discharge from approximately 72 psi down to 42 psi and then another 3 seconds to charge the system again. However, when the lab system was installed in the field there was a variation across the 12 turbines in the amount of time it took the system to discharge that ranged from approximately 4.9 sec to 7.9 sec. All systems were charged and ready to pulse again after 3 sec. While it would have been possible to control all the systems to discharge over 3 sec, they each would have then ended with a different final pressure which would have affected the range of frequency sweep for the narrowband tone. It was decided that rather than have varying frequency emissions, it was better for each turbine to have slightly different emission times.

The second departure was a result of unexpected water vapor spraying from the emitters. Mid-way through field testing, the site team noticed short bursts of water vapor coming from the nozzles during very first part of the pulse. This water vapor had not been observed during the prototype testing. Apparently due to the humidity and temperature of the site conditions, water condensation was occurring during the air compression. Since the water could have an effect on the ultrasonic emission, the team needed to find a way to limit the vapor emissions and account for it for the study analysis.

The team's solution mid-study was to incorporate air-water separators as a retrofit. Due to supplier limitations, it was only possible to procure air-water separators for 4 systems and only install them for approximately the last 3 weeks of the test. Change made to the study design in the 2nd half of the test to account for the hardware modification as described in the subsequent section describing the 2016 Turbine Field Study (Tasks 6.1, 6.2).

Key Conclusions, learnings, and application

An engineering team was sent to the site in an attempt to determine the effectiveness of the air-water separators and to assess the acoustic impact of the water vapor. Both of these tasks proved to be very challenging given the nature of the deterrent installation at high elevation external to the tower with no way to directly access in-situ during operation. The only way to determine the effectiveness of the air-water separators was by observation and the only way to measure the acoustics was by inserting a microphone through the tower in a position near the emitter and therefore only qualitative assessments could be made.

The air-water separators were observed to be effective in that a considerable amount of water was accumulated in the collection system. However, it was also noted from the ground that occasional vapor was still emitted; presumably from resulting water that had built up in the extensive hosing system during the first 2 months of the test. Additionally, the acoustic measurements were difficult to evaluate because of the uncontrolled location of the microphones relative to the emitters, atmospheric conditions, and inability to control the intermittent water vapor pulses. However, the team could qualitatively determine that the ultrasonic acoustic signature was approximately as expected even with the water vapor, although the amplitude of the tonal frequencies may have been diminished relative to the lower frequency broadband. This may have been a byproduct of the measurement location or increased atmospheric attenuation of the higher frequencies compared to the lower frequencies. Even with the measurement uncertainties, it was clear that ultrasonic emissions were still being produced from the emitters and the acoustic signature was not a dramatic departure from expectation. As will be shown in the field study results, the final 2016 field data analysis indicated similar levels of deterrent effectiveness compared to the prior year results which further corroborated that the water vapor did not dramatically alter the deterrent effectiveness. Unfortunately, it is not possible to conclusively determine if the deterrent system would have been even more effective had the water vapor not been present. For similar future testing, the air-water separators would be designed into the system from the beginning.

Overall, the pulsing system retrofit added complexity and cost without apparent significant statistical improvement in effectiveness based on the data analysis described in subsequent section covering the 2016 Turbine Field Study (Tasks 6.1, 6.2).

3.4 2015 THERMAL IMAGING STUDY (Task 4.1)

Activities and Accomplishments

Under Task 4.1, bat activity in the airspace surrounding two wind turbines at the California Ridge Wind Energy Facility in east-central Illinois was recorded using two pairs of thermal video cameras (See Attachment H). The objective of this study was to assess if the GE prototype deterrent system deterred bats from using the turbine airspace and was performed concurrently with a separate deterrent study using a constant deterrent signal from a 4-nozzle system in 2015.

The deterrent system was deployed on the tower of each turbine, with two nozzles oriented north and two nozzles oriented south at approximately 26 and 50 meters (m) below the nacelle. Nightly deterrent operation was assigned randomly between the turbines, so on any given night the deterrent system on one turbine was operable while the deterrent system on the other turbine was silent. If a deterrent system was assigned to operate, the deterrent system was configured to emit a constant deterrent signal. A constant signal was tested in this subtask because the pulse system was still being refined and assessed under Tasks 1—3. Attachment H provides a thorough description of the deterrent treatment design.

Two cameras were deployed beneath each of the turbines to record nightly bat activity between August 23 and September 4, 2015. The raw video was reviewed using a semi-automated software program designed to detect small moving objects. After the video from each camera was reviewed for bat activity, the bat observations recorded by each camera were checked for a companion observation at the other camera from the same turbine. The flight paths of bats observed in both cameras (the model space, see Figure 3 Attachment H) at a turbine were reconstructed using Computer Aided Design (CAD) software. The distance to the nearest deterrent system nozzle was either estimated (bat in one camera only) or measured (bat in both cameras) and recorded for each bat. The time spent in the field of view was also recorded for each bat observed in both cameras at a turbine.

The two turbines selected for this study had a different configuration of flashing red Federal Aviation Administration (FAA) aviation warning lights; one turbine was equipped and the other was not. This configuration was only realized after the test had started and was not intended to be a test variable. Thus, the data analysis considered the data from each turbine separately; the turbines were referred to as “FAA-lit” or “FAA-unlit”, but the analysis was not able to control for FAA lighting and thus lighting and turbine location are confounded. Four primary metrics were analyzed: the mean time observed in the model space, the mean minimum approach distance, the total number of bats observed (bat counts) in any camera, and the bat counts within the model space only. To determine whether the presence of bats within the model space was influenced by the operation of the deterrent, the proportion of total bats able to have their flight paths reconstructed was also analyzed.

The mean time in view and mean minimum approach distances were analyzed using a Generalized Linear Model (GLM) based on a normal error and log-link, weighted by sample size.

The bat count data were analyzed using a GLM based on a Poisson error and log-link structure. The proportion of bats with reconstructed flight paths was analyzed using a GLM based on a binomial error and log-link.

Departure from Plan and Why

Prior to initiating the study, we had not anticipated the need to analyze the data from each turbine separately. In order to isolate the deterrent effects from the uncontrolled variable (FAA lighting), we analyzed the data from the two turbines separately. The results don't necessarily indicate that the FAA lights alone were a confounding factor, as this was not a controlled variable; rather, the conditions at each turbine location differed and so the data for each treatment/location combination were considered separately. For ease of reporting the results, we referred to each turbine as whether it had or lacked FAA lights.

Key Conclusions, learnings, and application

Deterrent operation reduced the mean time bats spent within the model space, which was within approximately 20 m from the turbine tower (Tables 1 and 2 of Enclosure 1 of Attachment H). Bats spent the least amount of time (2.65 sec, $\widehat{\mathrm{SE}}$ = 0.58 sec) at the turbine with no FAA lights when the deterrent system was on, and the most time in view (4.75 sec, $\widehat{\mathrm{SE}}$ = 0.77 sec) at the turbine with FAA lights when the deterrent system was off.

The mean minimum approach distance results were variable; bats at the turbine location with the FAA lighting had the expected response, staying further from the turbine when the deterrent system was operating than when it was off. No effect was observed at the turbine without FAA lighting.

The bat counts within the model space (within approximately 20 m of the turbine) were 56.24% ($\widehat{\mathrm{SE}}$ = 8.37%) lower when the deterrent system was operating than when it was not operating (P = 0.0439). The total bat counts, including those bats observed beyond the model space, was also reduced by 20.69% ($\widehat{\mathrm{SE}}$ = 7.13%), although unlike the within-model space result, this was statistically nonsignificant (P = 0.5931).

The analysis of the subset of bats with modeled flight paths determined the operation of the deterrent system had influenced whether bats flew into the model space. This analysis also indicated that the time in view results within the model space were similarly influenced by the deterrent signal, thus the results are only applicable to bats within the model space and cannot be generalized to all bats in the vicinity of turbines.

In summary, we determined that, when the deterrent system is emitting a constant signal, bats stayed farther from the studied turbines, and when they did approach closely, they did so for a shorter time. Also useful to future research were the lessons learned regarding study design. We recommend selecting turbines in close proximity and in identical configuration to one another in order to minimize the outside influence of uncontrollable factors.

3.5 2016 TURBINE FIELD STUDY (Tasks 6.1, 6.2)

Activities and Accomplishments

Task 6, the 2016 Turbine Field Study during BP2, included 2 tasks: task 6.1 – Thermal Imaging and 3D Flight Mapping during BP2 and task 6.2 – Deterrent Field Test during BP2 (See Attachment K). Task 6 was performed at the California Ridge Wind Energy Facility in east-central Illinois. Task 6 was successfully performed, with modifications. The revised (pulsing) GE prototype deterrent system used in Task 6 included 6 nozzles per turbine; two on the rear of the nacelle, oriented up and down, and four on the turbine tower. The tower-mounted deterrent nozzles were oriented north and south at approximately 26 and 50 meters (m, 85 and 164 feet [ft]) below the nacelle. Nightly deterrent operation was assigned randomly between the 12 study turbines, so on any given night half of the deterrent systems were operable while the remainder were off (silent/control). Treatment assignment groups were reassigned every six days; with each group performing each treatment, deter/treatment or silent/control, for three consecutive days before switching.

Between July 31 and September 11, 2016, all 12 deterrent systems, when assigned to operate, were programmed to emit a pulsing signal of 4.9 to 7.9 sec on and 3 sec off. During this period, the team learned that the deterrents were regularly emitting water vapor, and preliminary results of task 6.2, the carcass monitoring study, suggested the deterrent effectiveness was reduced from what was expected. Therefore, the team redesigned the study's treatment groups to test a possible solution to the perceived water vapor issue. (However, it was later determined in the final analysis that the early observations of lower effectiveness was skewed towards a disproportionately large presence of Eastern Red bats in the first part of the season compared to the second part of the season.) Between September 24 and October 11, 2016, the deterrent systems on four turbines were refined to include air/water separators that extracted condensation from the deterrent systems. The remaining eight deterrent systems not outfitted with air/water separators were reconfigured to a five-nozzle system that emitted a constant signal. Note that the five-nozzle constant system in 2016 is in contrast to the prior 4-nozzle system tested in 2013-2015 in that the addition of the fifth nozzle lowered the operating pressure such that the ultrasonic amplitude from the five-nozzles was less than the four-nozzle system. In collaboration with the DOE, the research team felt it was better to configure the remaining turbines without the air/water separator in this way with the hope of gaining insight into yet another potential deterrent configuration even though the data would be sparse. The eight constant-emission systems continued to follow the six-day treatment assignment routine while the four pulse-emission systems emitted deterrent signal every night. Attachment K provides a thorough description of the deterrent treatment design.

<u>Task 6.1 –Thermal Imaging and 3D Flight Mapping during BP2</u> – The objective of the study was to determine whether a turbine-mounted deterrent system could reduce bat activity near, reduce time spent by bats in the vicinity of, and increase approach distance to, the deterrent system in a turbine airspace environment. This study used two pairs of thermal video cameras deployed beneath each turbine to record the bat activity in each turbine's airspace. The deterrent systems on these two turbines were programmed to perform opposite treatments, i.e. a silent control at one turbine and the programmed deterrent signal at the other throughout the study period. For the first half of the study (July 31—September 11), the deterrent systems emitted a pulse signal and for the second half (September 24—October 11), they were programmed to emit a constant signal. In response to the lessons learned in Task 4.1 – The 2015 Thermal Imaging Study, the study was performed at adjacent turbines with no FAA lighting.

The thermal video cameras were programmed to record bat activity between 20:00 and 00:00 each night. Bat flights were identified in the video using a semi-automated review process. The video from a pair of cameras was time-synchronized to calculate the total time each bat was viewable in the camera system and to prepare the video segments for flight path reconstruction. The minimum approach distance of each bat was obtained through a partial reconstruction of its flight path using Computer Aided Design (CAD) software (See Figures 4 and 5 in Attachment K for examples). Deterrent effectiveness was modeled with Generalized Linear Models (GLM) of the total number of bat passes, the time in view data, and the bat pass counts by approach distance category. For visual comparison of any distance effects on the tested signals, smoothed response curves were fitted to the counts and associated 95% confidence intervals of bat passes in each approach distance category.

Task 6.2 – Deterrent Field Test during BP2 – Task 6.2 was designed to measure the effectiveness of the redesigned deterrent system through a carcass monitoring program that was aligned with the three-day treatment blocks (Attachment K). During the carcass monitoring program, daily searches were performed by human and dog searchers. Searches were conducted within 60 m radius circular cleared plots centered beneath each of the 12 study turbines. In addition, calibration (detection efficiency) trials were performed over 12 separate trials and a total of 142 bat carcasses that were randomly placed throughout the searched area. The counts of bat carcasses from each treatment group in each three-day period were used to determine deterrent effectiveness through a GLM in which the accompanying turbine operations and treatment covariates were added. The bat count data were analyzed in three groups: all bat species combined, eastern red bat (*Lasiurus borealis*), and non-eastern red bat species.

Departure from Plan and Why

The emission of water vapor from the turbine nozzles was identified during the testing performed in August 2016. The frequency of emission appeared to be consistent, although the volume of water being emitted was immeasurable and presumed to vary based on outside conditions, such as ambient air temperature and relative humidity. The study design was subsequently revised to allow the research team an opportunity to understand whether the results of the carcass monitoring were being confounded by the presence of the water vapor. Air/water separators were available for four deterrent systems, so the deterrent treatment design was modified to gather treatment data under pulsing conditions every night at the four turbines with the air/water separators and use the remaining eight turbines to test whether a five-nozzle deterrent system emitting a constant signal might be effective at reducing bat activity/fatalities. The remaining eight turbines were divided into two treatment groups of four turbines each, following the same six-day treatment block design as during the first half of the study. The revised study design was performed between September 24 and October 11, 2016.

Key Conclusions, learnings, and application

Task 6.1 –Thermal Imaging and 3D Flight Mapping during BP2 – Both the pulse and constant signals affected bat activity in the turbine airspaces. Relative to the activity observed under silent/control conditions, total bat activity was reduced 32.8% ($\widehat{\mathrm{SE}}$ =0.1%) under the pulse signal and 60.0% ($\widehat{\mathrm{SE}}$ = 11.8%) under the constant signal emitted by the five-nozzle system, although the reduction observed under the pulse signal was not statistically significant ($p = 0.0623$) while the reduction under the constant signal was significant (0.0141; Attachment K). Due to the testing of each signal independent of the other, relative comparisons between the signal are limited to a qualitative assessment only and temporal differences could not be accounted for. In addition to the overall bat activity being reduced when the deterrent was operating, the time spent by bats in the camera system field of view was also reduced. Compared to the data collected under silent/control conditions, bats spent an average of 50.9% ($\widehat{\mathrm{SE}}$ =7.1%) less time in view under the pulse signal and 43.4% ($\widehat{\mathrm{SE}}$ =30.5%) less time in view under the constant signal. Although the two signals appeared to reduce the time spent in view by bats, the results obtained for the pulse signal were statistically significant ($p < 0.001$) while the results for the constant signal were not ($p= 0.230$; Attachment K).

The effectiveness of the pulse and constant deterrent signals decreased as distance from the nozzles increased. Both signals greatly reduced (> 50%) bat activity within approximately 20 m (64 ft) of the nozzles, beyond which the effectiveness consistently declined (Figure 5). The constant signal reached zero effectiveness between 35 and 40 m (115 and 131 ft), while the pulse signal reached zero effectiveness between approximately 25 and 30 m (82 and 98 ft; Figure 5).

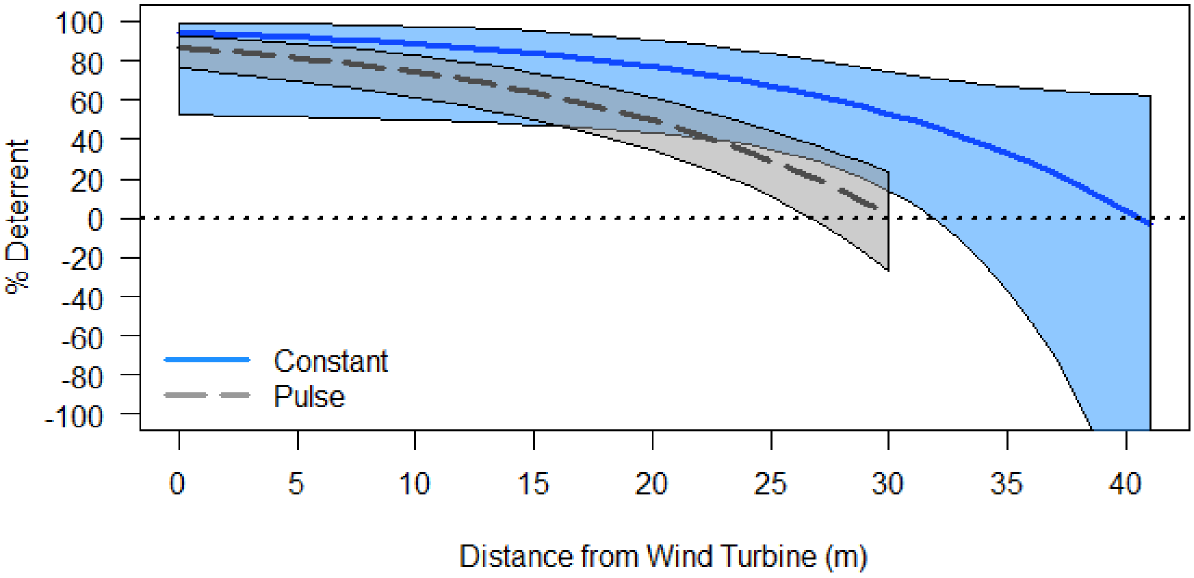


Figure 5. Comparison of the two fitted response models of the % deterrent effect as a function of distance from the turbine-mounted deterrent system for constant and pulse signals tested in 2016. *[The blue line and shaded area (95% confidence interval) represent the estimated effectiveness of the 5-nozzle constant system and the black dashed line and gray shaded area (95% confidence interval) represent the estimated effectiveness of the 6-nozzle pulse system.]*

<u>Task 6.2 – Deterrent Field Test during BP2</u> – During the carcass monitoring study, the pulse signal did not appear effective at reducing eastern red bat fatalities, but did appear to be effective at deterring other bat species. Because the study was split into two halves the data collected in both halves was relatively sparse and led to wide variance on the effectiveness estimates (Attachment K).

In the first half of the study, where only the pulse signal without air/water separators was tested against a silent control, 227 bat carcasses, including 153 eastern red bat carcasses and 74 non-eastern red bat carcasses were counted and carcass detection probability was estimated to be 94.69% ($\widehat{SE}$ =2.78%). Non-eastern red bat species primarily included hoary (*Lasiurus cinereus*) and silver-haired (*Lasionycteris noctivagans*) bats.

The deterrent system was ineffective at reducing fatalities of eastern red bats (-22.51% [$\widehat{SE}$ =19.94%]; p = 0.521). However, the pulse signal neared effectiveness at deterring the other bat species (37.97% [$\widehat{SE}$ =14.78%]; p = 0.107) (Table 16 in Attachment K).

Due to the late timing in the bat migration season and the relatively short remaining test window the sample sizes in the second half of the study, after the air/water separators were installed, were small. The dataset included 52 carcasses (20 eastern red bat and 32 non-eastern red bat). This limited our ability to draw conclusions of treatment effects in the second half. The detection probability during the second half of the study remained high, at 93.81% ($\widehat{SE}$ = 3.53%).

During the second half of the study, the effectiveness of the pulse signal on eastern red bats and non-eastern red bats appeared to improve, but results were not statistically significant (p > 0.050; Figure 6a). Therefore, it is difficult to ascertain if the results of the systems with the air/water separators were truly better than the early season results when the water vapor was present. There is the possibility the effectiveness of the deterrent against all species could have been better overall had the water vapor not been present. The results for the five-nozzle constant system were similar to those of the pulse signal; again, they were not statistically significant ($p > 0.050$; Table 3).

In summary, deterrent effectiveness in reducing bat *activity* was high (> 50%) within 20 m (66 ft) of the nozzles, regardless of whether the system was emitting a constant signal from four or five nozzles, or a pulse signal from six nozzles. This pattern of high reductions in bat activity out to approximately 20 m (66 ft) is consistent with the results observed during Tasks 1 and 2, as well as other research (Attachments B-F, H, and K).

The results of task 6.2 indicated that, consistent with the results of testing on a four-nozzle constant system in prior years, the pulse signal was ineffective at reducing eastern red bat fatalities and was effective at reducing fatalities of non-eastern red bat species (Figure 6a). Insufficient data were gathered to draw conclusions on the effectiveness of the five-nozzle constant signal deterrent system in reducing bat fatalities. However, it is plausible the five-nozzle system could provide similar effectiveness to a four-nozzle constant system when one considers the results of Tasks 4.1 and 6.1, which showed similarly high deterrence of bat activity within 20 m of the nozzles for both the four- and five-nozzle systems. Further testing is required to confirm whether an increase in the number of nozzles emitting a constant signal from one system is similarly or proportionally *more* effective at reducing bat fatalities than the original four-nozzle system, which has yielded reductions of approximately 30% overall and over 50% for non-eastern red bat species combined.

The research team concluded that there is not enough apparent improvement in the pulsed system (based on these data) to warrant the increased system complexity required to pulse the deterrent signal in its current form (See Figure 6b), and thus effort should be invested in optimizing a system that emits constant signals. No changes to the overall study designs of the thermal video analysis or the turbine field study/carcass monitoring program are suggested at this time.

Table 3. Summary of acoustic deterrent effects on carcass counts obtained during task 6.2. *[Standard errors are reported in parentheses, and represent the precision of the sample point estimate. During the 1st half, no air/water separators were installed on the deterrent systems. In the 2nd half of the study, the four turbines with air/water separators were assigned to perform the pulse treatment every night; their data was compared to the carcass data collected under different sets of four of the remaining turbines that were programmed to operate as silent controls in three-day blocks.]*

Study	Bat Species Group	Signal Treatment	
		Pulse	Constant
1st half	All	1.71% (13.05%)	N/A
	ERB	–22.51% (19.94%)	N/A
	Non-ERB	37.97% (14.78%)*	N/A
2nd half	All	42.50% (20.81%)*	10.96% (28.19%)
	ERB	23.24% (41.48%)	26.25% (39.83%)
	Non-ERB	54.03% (38.62%)	1.56 % (38.63%)

[a] ERB = eastern red bat

*Significantly different from zero ($P \leq 0.05$), one-tailed. The one-tailed test was used because our null hypothesis (H_o) was: Deterrent system does not reduce bat fatalities at wind turbines (i.e., $x \leq$ 0% effective), and our alternate hypothesis (H_a) was: Deterrent system effectively reduces bat fatalities (i.e., $x > 0\%$ effective) at wind turbines. The directionality of our hypothesis dictates appropriate use of a one-tailed test of significance.

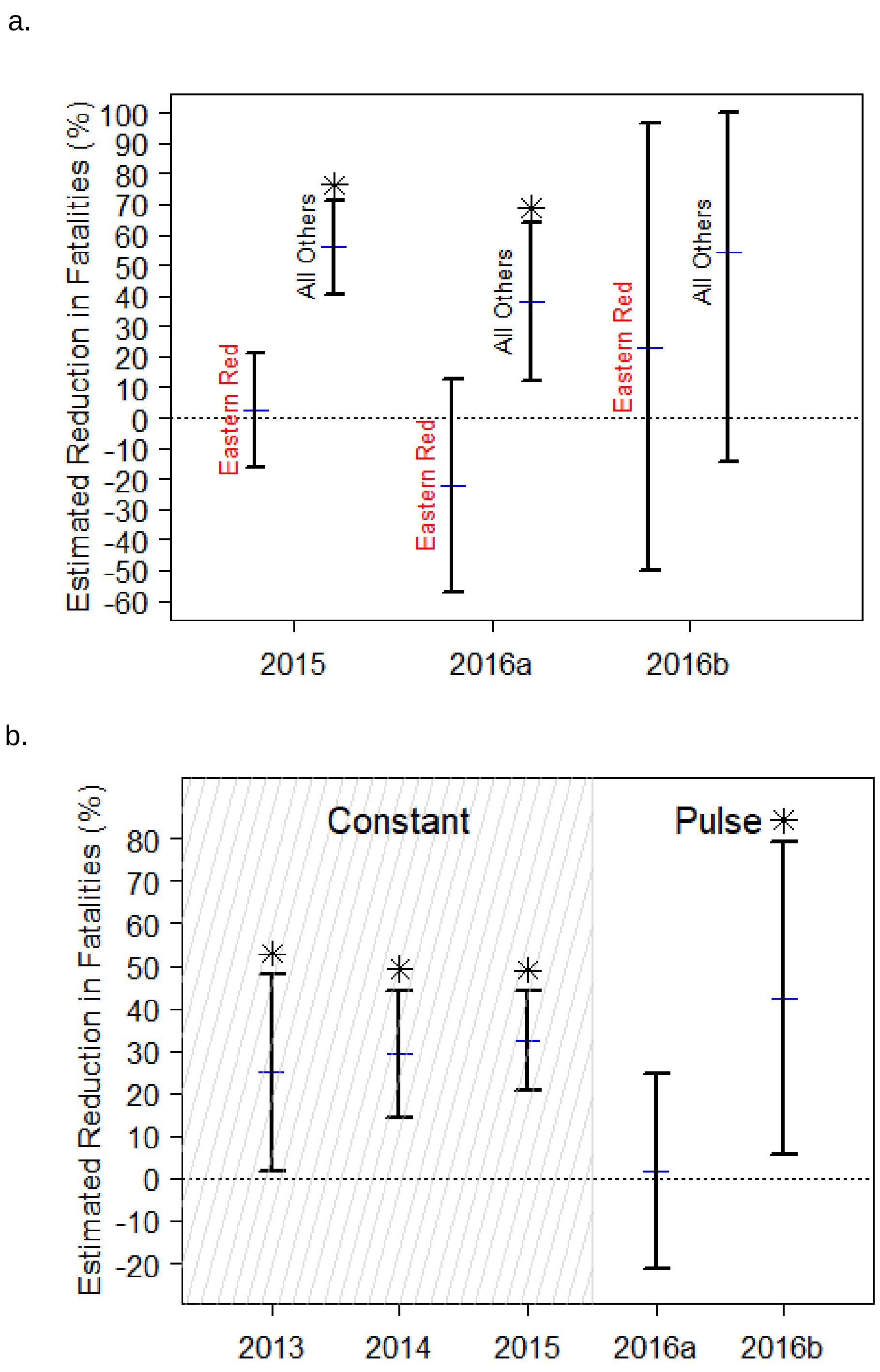


Figure 6. Estimated mean reduction in fatalities of (a) eastern red bat and all other bat species and (b) all bat species combined for the GE deterrent system deployed on wind turbines at the California Ridge Wind Energy Facility in Illinois, 2013—2016. Error bars represent 90% confidence interval estimates. Zero (dotted line) indicates no effect. Asterisk (*) indicates significant reduction at α = 0.05, one-tailed. 2013 based on an asymptotic Z-distribution, subsequent years and test results based on a T-distribution. Results of 5-nozzle constant emission signal tested in 2016 are not plotted due to insufficient sample size. 2013—2015 results retrieved from Shoener and Skalski (2016), referenced in Attachment K.

4.0 PRODUCTS DEVELOPED

Presentations at Scientific Meetings:

Bennett VJ, CT Lindsey, BC Cooper, C Granthon, and AM Hale. 2017. Bat behavior in response to ultrasonic signals: implications for reducing mortality at wind turbines. 97th Annual Meeting of the American Society of Mammalogists, Moscow, ID.

Lindsey CT, AM Hale, and VJ Bennett. 2017. Assessing changes in bat activity in response to an acoustic deterrent – implications for decreasing bat fatalities at wind facilities. The Wildlife Society's 24th Annual Conference, Albuquerque, NM. (*Upcoming: Sept. 23-27*).

Bennett VJ, CT Lindsey, BC Cooper, C Granthon, and AM Hale. 2017. Bat behavior in response to ultrasonic signals: implications for reducing mortality at wind turbines. 47th Annual Meeting of the North America Symposium for Bat Research, Knoxville, TN. (*Upcoming: Oct. 22-28*).

Theses and Publications:

Lindsey CT. 2017. Assessing changes in bat activity in response to an acoustic deterrent – implications for decreasing bat fatalities at wind facilities. M.S. Thesis, Texas Christian University. (*In preparation for submission to PeerJ for publication*).

5.0 ATTACHMENTS

Milestone Reports	Title / Task Description	ATTACHMENT
M1.2.1	Complete experimental protocol for behavioral trials in bat flight facility	**A**
M1.2.2	Demonstrate reduced bat activity in close proximity to the acoustic deterrent in the bat flight facility	**B**
M2.1.1	Complete experimental protocol for behavioral study at Wolf Ridge	**C**
M2.1.2	Demonstrate reduced bat activity and that bats do not closely approach the acoustic deterrent in field tests at Wolf Ridge	**D**
M2.2.1	Complete experimental protocol for behavioral study at Shawnee National Forest	**E**
M2.2.2	Demonstrate reduced bat activity and that the bats do not closely approach the acoustic deterrent in field tests at Shawnee National Forest	**F**
M3.2.1	Complete Pulsing Design which includes design documentation and prototype system performance measurements	**G**
M4.1.1	Demonstrate reduced bat activity and that the bats do not closely approach the acoustic deterrent when in current mounting configuration on turbines at California Ridge Wind Energy Facility	**H**
M4.1.2	Review and Revise the Design Study for Task 6 of BP2: will include the revision of the original study design to include new and relevant information obtained from this project and outside research.	**I**
M5.1.1	Complete Integrated Deterrent Design including design documentation BOM and Installation instructions	**J**
M6.2.1	Quantify differences in bat passes and approach data between silent control periods and periods when a new redesigned mounting configuration on turbines at California Ridge is operated. Compare between bat carcass counts under silent control conditions and when the redesigned deterrent configurations are operated on turbines at California Ridge.	**K**

ATTACHMENT A

Milestone M1.2.1

DE-EE0007035
General Electric Company
Ultrasonic Bat Deterrent Technology

Task 1 – Flight Room Testing (M1-M6)

Task Summary:

This task is designed to evaluate the response behavior of bats to a range of acoustic signals in a specially constructed bat flight room. A set of ultrasonic signals will be developed that vary in frequency, amplitude, pulse rate, and interval. In a bat flight room located at Texas Christian University, these signals will be presented to wild-caught bats using an Avisoft Bioacoustics simulator. The behavioral responses of the bats to each type of signal will be evaluated and results will be used to determine the range of amplitude and frequency characteristics that can effectively and practically be used, and ultimately where and how many GE deterrents can be placed on turbines.

Subtask 1.1 – Acoustic Signal Development (M1-M3)

Subtask Summary: Using the known frequency characteristics of the deterrent device, GE will design a playlist of various acoustics waveforms with specific frequency content that will be used to systematically evaluate the response of bats. It is expected that broadband and tonal frequencies ranging from approximately 20 kHz to 100 kHz will be developed. Both steady and pulsed signals will be developed. The waveforms will be provided as input files for the Avisoft simulator. Additionally, GE will use special high frequency response microphones to measure and document the acoustic field in the flight room.

Subtask 1.2 – Behavior Testing in Bat Flight Facility (M1-M6)

Subtask Summary: Using a bat flight room (~ 17 m by 10 m by 3 m), the team will explore the behavior of bats when presented with the variety of ultrasonic signals designed in Subtask 1.1. Once bats have acclimated to the flight facility and are actively flying at night, an Avisoft Bioacoustics simulator will be used to play the variety of ultrasonic signals designed in Subtask 1.1. The behavioral responses of the bats to each type of signal will be recorded (e.g. closest approach to the sound source, mean distance from sound source, etc.).

Objectives

This study is designed to determine how bats respond to the GE Prototype deterrent device using acoustic waveforms developed in subtask 1.1. Using wild-caught bats in a flight facility, we will compare levels of bat activity with four deterrent treatments (control – no sound, constant on, 1 sec pulse followed by 1 sec silence, 1 sec pulse followed by 2 sec silence). We hypothesize (H_A) that the activity and presence of bats in close proximity to the deterrent device will depend on exposure to sound emitted by the deterrent. The null hypothesis (H_0) is that activity and presence of bats is independent of exposure to sound emitted by the deterrent.

Field Methods and Bat Flight Facility

The bats used in this study will be captured from local parks in and around Fort Worth using mist nets. Captured bats will therefore be representative of local species, and will likely include eastern red (*Lasiurus borealis*) and evening (*Nycticeius humeralis*) bats. Mist nets are commonly used to capture live bats (Fig. 1). In any given mist net session, several mist nets (triple-high and single 6-12 m length monofilament nets from Avinet Inc., Dryden, NY) will be set up and opened 10 minutes before dusk, weather permitting, and remain open for up to 3 hours, which represents the period of peak local bat activity. Each net will be monitored continuously from an appropriate distance, and physically checked at no more than 10 minute intervals. After removal from the net, the bats will be placed in a cloth sack and taken to a secure temporary carrier, with the exception of bats that have been identified to be 1) pregnant, 2) lactating, 3) carrying young, or 4) federally endangered (note that no federally endangered bats are known to currently reside in north-central Texas). In these instances, such individuals will be released as quickly as possible. Note that all personnel involved with mist netting will have had the rabies pre-exposure vaccination series and be wearing bite-proof gloves when handling bats.

Fig. 1. Triple-high mist nets at select locations around Fort Worth.

At the end of the mist netting session, or when up to 6 individuals have been caught, bats will be transported to the flight facility (see Fig. 2 below) as quickly as possible. The bats will remain in the facility for a limited amount of time (approximately 4 weeks), after which time they will be returned to the wild at the site where they were captured. Note that each individual bat successfully tested in the flight facility will represent an independent sampling unit. The goal is to successfully test approximately 15-30 individual bats through a series of trials within the 3 month survey period (July to September 2015). During this time, we will strive to sample a representative number of males and females from each species; however, this is ultimately dependent on our capture success.

Note that for mist netting surveys and housing bats in the flight facility we have an Institutional Animal Care and Use Protocol (IACUC permit #14-01) in place. An approved protocol is required by federal regulations in order to use animals in research, teaching, and testing under the Health Research Extension Act (HREA) and key amendments to the Animal Welfare Act (AWA).

The flight facility is a stand-alone structure approximately 9 m by 6 m by 3 m (Fig. 2). Conditions within the facility will be kept similar to the natural environment; no visible artificial lights will be used during the behavioral studies, and researchers will only use headlamps pre- and post-surveys. A series of mesh covered windows will ensure that temperature and humidity inside the facility are comparable to outside conditions (Fig. 3). Reflective sheets will be placed on the roof and misting fans may be used to ensure that the temperature inside the tent does not exceed the temperature outside the tent. Bats will be checked three times during the day (around 8 am, 12 pm, and 4 pm) to ensure their health and safety, and additional checks will be conducted in inclement weather.

Fig. 2. Flight facility.

Fig. 3. Mesh covered windows allow natural ambient conditions within the flight facility.

Within the facility, bats will be provided with a shallow water tray (2 m x 1 m x 1.5 cm) positioned in the center of the facility along with roosting opportunities (such as soft puppy carriers, carpeted cat houses, and tree branches; Fig. 4). As the flight facility contains a limited number of flying invertebrate prey items, a light trap will be ran outside to attract moths, flies, and beetles, which will then be retrieved and released into the facility. In addition, when the bats stop flying in the evening, their diet will be supplemented with approximately 3 – 5 mealworms (larval *Tenebrio molitor*) covered in vitamin powder (1/16 teaspoon pure CoQ-10 powder and 2 tsp Vionate powder; Lollar 2010). If foraging opportunities are limited during the night, more mealworms will be provided. Water will be available at all times, and the tray will be replenished on a daily basis.

Fig. 4. Roosting opportunities provided for the bats within the flight room.

Experimental Trials

In order to test a range of ultrasonic signals, a series of playlists will be created consisting of acoustic signals developed in subtask 1.1. The acoustic signals are representative of the amplitude and frequency range of sounds at approximately 10 m, 20 m, and 30 m from the deterrent source. At each distance category, one signal will be a constant sound, whereas the other signals will be the deterrent sound pulsed at two different duty cycles (1 second on followed by 1 second off and 1 second on followed by 2 seconds off). The acoustic signals will be played using an Avisoft Bioacoustics UltraSoundGate Player 116 (frequency range 1 – 180 kHz) from a laptop in the flight facility, which will be connected to an ultrasonic dynamic speaker Vifa (± 6 dB, 20 – 100 kHz). The speaker will be attached to the boom arm of an AiRR 200 mic stand at a height of 1.5 m, and positioned 1 m from the center of the water tray (Fig. 5).

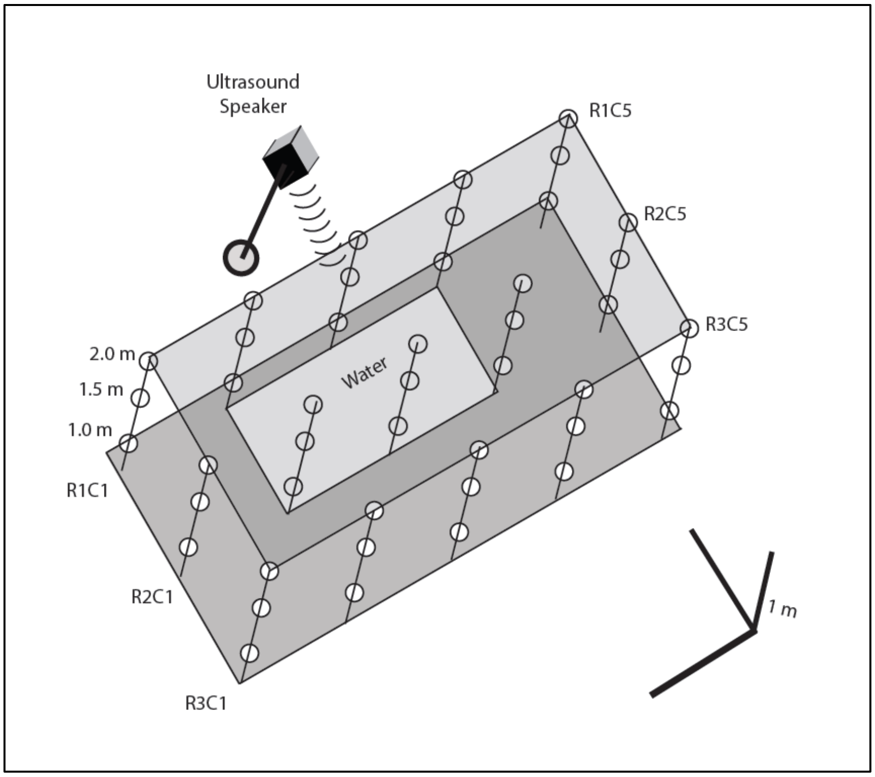


Fig. 5. 3-Dimensional representation of the 4 m x 2 m x 2 m cuboidal study area including the 2 m x 1 m water tray, and the ultrasound speaker; R# = row number, C# = column number. Distance markings (white circles) are positioned 1 m apart horizontally, and 0.5 m apart vertically.

For each set of up to six bats housed in the facility at one time, experimental trials will be conducted over a period of 3 nights, following an initial acclimation period of approximately 1-3 days, during which time bats are expected to drink and forage as they normally would in the wild. Each night, acoustic signals for only a specific distance category (approximately 10 m, 20 m, and 30 m) will be played and the order in which they are played over the 3-day period will be random. The experimental trial for a given night will begin when at least one bat emerges from its day roost and begins to fly within the facility. During the first 10 minutes, no acoustic signal will be played and this period will provide a baseline of bat activity. After the initial 10 minutes, a playlist consisting of acoustic signals (10 30-sec sound files concatenated to produce sound for 5 minutes) developed in subtask 1.1 will then be played. The acoustic signals within the playlist will be in random order and each 5 minutes of sound will be followed by 5 minutes of silence. The trial will continue for up to 3 hours (primary activity period for bats), or until all bats have finished their foraging bouts. At least two technicians will be present during each survey night.

We will use 2 Canon XA20 camcorders (Canon Inc., Melville, NY) placed against the edge of two perpendicular sides of the flight facility, with their fields of view centered on a 4 m x 2 m x 2 m cuboidal area surrounding the water tray (see Fig. 5 above) to record bat behavior and activity. Within the field of view, we will also place 1.0 m distance markers on the walls of the flight facility to aid analysis (see Fig. 6; see analysis section below). For the entirety of the survey period, both cameras will be placed in the same location with the same tripod height each night (predetermined to gain the best field of view of the area). These cameras will be turned on in unison at the start of the initial 10 minute observation period and at the beginning of each 5 minute treatment period. Thus the cameras will be turned off in unison at the end of the 10 minute observation period and end of each 5 minute treatment period. Once cameras start recording, a technician will verbally announce the time, date, and playlist ID number. Subsequently, a technician will start the playlist on the computer, while verbally indicating the beginning of a recording period.

Fig. 6. Front and side views of the cuboidal study area within the flight facility. Distance markers on the walls are 1.0 m apart to aid in data analysis.

The camcorder videos will be saved as MP4 files onto SD cards within the camcorder, and at the end of each night the data will be transferred to external hard drives for analysis. As back-up, we will also record the general behavior of each bat with Olympus Digital Voice Recorders (WS-SIOM). Note that none of the cameras have color capability; therefore, individual bats will be coated with combinations of non-toxic pink, green, orange, blue, purple, and yellow ECO Pigments (Day-Glo Color Corp, Cleveland, OH; Fig. 7,) on their backs. Researchers will use UV flashlights to identify individual bats as they fly into the field of view.

Fig. 7. Evening bat (*Nycticeius humeralis*) marked with blue ECO Pigment.

Data Management and Analysis

All videos will be processed with Studiocode (version 5, Studiocode Business Group, Sydney, AU), and videos from front and side views will be stacked. Within the program, a previously designed code window will be used to identify and indicate specific activities and position of the bats during the trials, with help from markings on the walls of the flight facility. Videos will then be surveyed for flying bats, and the presence or absence of bats within the cuboidal study area will be recorded (see Fig. 5 above). Periods where bats are present within the study area will then be further examined, and bat activity will be identified (i.e., foraging, drinking, resting, and passing).

ATTACHMENT B

Milestone M1.2.2

DE-EE0007035
General Electric Company
Ultrasonic Bat Deterrent Technology

This document presents the results of Subtask 1.2 and the completion of Milestone 1.2.2.

> ***Milestone 1.2.2 – Demonstrate reduced bat activity in close proximity to the acoustic deterrent in the bat flight facility***

EXECUTIVE SUMMARY

Behavioral testing in the bat flight facility demonstrated that ultrasonic sounds equivalent to those produced by the GE deterrent influenced the activities and behavior of the species tested, primarily foraging behavior. Our study also appeared to indicate that continuous and pulsing ultrasonic signals had a similar effect on the bats, and confirmed that as ultrasonic sounds attenuate, their influence on the bats' activities and behavior decrease.

Task 1 – Flight Room Testing (M1-M6)

Task Summary:

This task was designed to evaluate the response behavior of bats to a range of acoustic signals in a specially constructed bat flight room. A set of ultrasonic signals were developed that varied in frequency, amplitude, pulse rate, and interval. In a bat flight room located at Texas Christian University, these signals were presented to wild-caught bats using an Avisoft Bioacoustics simulator. The behavioral responses of the bats to each type of signal was evaluated and results were used to determine the range of amplitude and frequency characteristics that can effectively and practically be used, and ultimately provide insights into where and how many GE deterrents can be placed on turbines.

Subtask 1.1 – Acoustic Signal Development (M1-M3)

Subtask Summary: Using the known frequency characteristics of the deterrent device, GE and TCU designed various acoustics waveforms with specific frequency content that was used to systematically evaluate the response of bats. Broadband and tonal frequencies ranging from approximately 20 kHz to 60 kHz were developed. Both steady and pulsed signals were produced. The waveforms were provided as input files for the Avisoft simulator.

Subtask 1.2 – Behavior Testing in Bat Flight Facility (M1-M6)

Subtask Summary: Using a bat flight room (~ 17 m by 10 m by 3 m), TCU researchers explored the behavior of bats when presented with the variety of ultrasonic signals designed in Subtask 1.1. Once bats had acclimated to the flight facility and were actively flying at night, an Avisoft Bioacoustics simulator was used to play the signals. The behavioral responses of the bats to each type of signal will be recorded.

Objectives

This study was designed to determine how bats respond to the GE Prototype deterrent device using acoustic waveforms developed in subtask 1.1. Using wild-caught bats in a flight facility, we compared levels of bat activity with four deterrent treatments (silence – as a control, constant on, 1 sec pulse followed by 1 sec silence, 1 sec pulse followed by 2 sec silence). We hypothesize (H_A) that the activity and presence of bats in proximity to the deterrent device will depend on exposure to sound emitted by the deterrent. The null hypothesis (H_0) is that activity and presence of bats is independent of exposure to sound emitted by the deterrent.

Methods

The bats used by TCU in this study were captured from local parks in and around Fort Worth using mist nets. Captured bat species included eastern red (*Lasiurus borealis*), evening (*Nycticeius humeralis*), and Mexican free-tailed (*Tadarida brasiliensis*) bats. The bats were taken to a customized flight facility, where we conducted a series of experimental trials once the bats had acclimated. Since the flight room was not large enough to encompass the entire expected range of area affected by the jet deterrent, a simulated deterrent signal was developed and played through the Avisoft simulator. However, due to differences in the actual frequency response and directivity of the Avisoft transducer compared to the jet source, an exact representation of the jet deterrent sound field could not be replicated and there are some differences in the ultrasonic signal that the bats experienced in the flight room compared to what they would experience in the field. The Avisoft transducer directivity places the maximum sound generation directly in front of the transducer and the sound quickly drops off on either side, while the actual jet deterrent has a more uniform directivity around the jet axis. Therefore, the simulated signals were developed such that the sound directly in front of the transducer in the location of the camera viewing area represented the maximum sound from the deterrent at reference distances of approximately 12 m, 18 m, and 30 m from the jet deterrent. Nine ultrasonic signals, developed in Subtask 1.1., were used in the experimental trials. At each reference distance category, three ultrasonic signals were produced, one signal was a constant sound (hereafter referred to as continuous), whereas the other signals were deterrent sound pulsed at two different duty cycles (1 second on followed by 1 second off, hereafter referred to as 1 s pulse, and 1 second on followed by 2 seconds off, hereafter referred to as 2 s pulse).

We used two Canon XA20 camcorders to record the activity of bats during a 5 minute period of silence prior to the experimental trials and during the trials themselves. The camcorder videos were saved as MP4 files and were then reviewed and analyzed. We also placed an AR125 Ultrasonic bat detector from Binary Acoustic Technology in the flight facility to record all acoustic activity during the silence and experimental trials. The wav. files collected in these surveys were used in our analysis described below.

We analyzed all video data using Studiocode video analysis software (version 5, Studiocode Business Group, Sydney, AU). First, we recorded the presence and absence of bats in the focal area within each paired video (i.e., front and side videos combined) at 10 second intervals (hereafter referred to as a snapshot), for a total of 30 snapshots per 5 minute video (including the last 5 minutes of the 10 minute silence prior to the experimental trials, and the trials themselves). We then calculated the proportion of snapshots with bats present within the focal area for the silence period and each experimental trial, which we used as a measurement of bat activity. This presence/absence data was considered to be the first of three dependent variables used in the statistical analysis described below.

Second, we analyzed bat behavior in the videos. We were able to identify three distinct in-flight behaviors; passing, foraging, and chasing. Passing behavior was defined as a straight-line flight through the field of view, whereas foraging behavior was defined as a zigzagging flight path during which the bats changed direction multiple times through the field of view. We identified chasing behavior, as the name implies, when one bat followed another bat closely. For every video, we recorded each behavior exhibited and duration. Once all videos had been analyzed, we used Studiocode output to measure the time spent exhibiting each behavior, and calculated their proportion relative to the total time the bat was flying. This behavioral data represents the second dependent variable used in our statistical analysis below.

Finally, we used acoustic data to further analyze bat activity during the trials and silence. For each acoustic wav. file recorded, we identified (where possible) one of four specific echolocation call types: searching, foraging, feeding buzz, and communication. We defined searching calls as a loud call followed by a soft call, occurring at regular intervals which correspond to the bats' wing beats, and which represent the bat turning its head from side to side, searching for prey. Foraging was characterized as a series of calls getting closer and closer together. These calls occurred at irregular intervals, during and between wing beats, and were produced as the bat got closer to its prey. In the event that a bat successfully captured a prey item, a foraging call was typically followed by a feeding buzz. In this echolocation call type, the calls were characterized by a distinct change in frequency. Finally, we determined communication calls to be lower in frequency than any of the other call types and these were commonly produced when the bats were stationary. Once all acoustic files had been analyzed, we calculated the proportion of files associated with each behavior relative to the total number of files extracted. This acoustic data represented the third and final dependent variable used in the statistical analysis described below.

For statistical analysis, we compared our three dependent variables (presence/absence, behavior type, and call type) against three independent variables: duty cycle (continuous, 1 s pulse, and 2 s pulse), distance (12 m, 18 m, and 30 m), and species. Two species categories were determined based on preliminary examination of the data, which revealed that species with echolocation calls >35 kHz showed similar trends in activity and behavior, compared to bats with echolocation calls <35 kHz. Therefore, we grouped species into two categories, high frequency and low frequency, unless otherwise stated in the analysis. For all video analysis (presence/absence and behavior type), the proportion of time spent either within the focal area, or doing a particular behavior, was averaged within each duty cycle and transformed using an arcsine square root transformation, to meet the assumptions of the following statistical tests.

First, we grouped the transformed values of presence/absence data from all three duty cycles and compared them to the equivalent presence/absence data during silence. This comparison allowed us to determine whether the acoustic signals (hereafter referred to as the deterrent) significantly influenced the presence of bats in the focal area. We used an analysis of variance (ANOVA) to compare the presence/absence data for both species categories and for all three reference distance categories separately. We then compared the presence/absence data between the three duty cycles using an ANOVA, for both species categories, and for all three reference distance categories together. For this test and all following tests, $\alpha = 0.05$. If a significant difference was found between the duty cycles, then a Tukey's post-hoc test was performed to determine the source of the difference.

Second, for each behavior (unless otherwise stated), we grouped the data from all three duty cycles and compared them to the equivalent data during silence. This comparison allowed us to determine whether the acoustic signals (hereafter referred to as the deterrent) significantly influenced the different types of behavior exhibited by the bats in the focal area. We used an ANOVA to compare behavior for both species categories and for all three reference distance categories separately. We then compared the transformed values for each behavior between the three duty cycles using an ANOVA, for both species categories, and for all three reference distance categories together. For this test and all following tests, $\alpha = 0.05$. If a significant difference was found between the duty cycles, then Tukey's post-hoc test was performed to determine the source of the variation.

For all acoustic data, we calculated the proportion of calls belonging to each echolocation call type (searching, foraging, feeding buzz, communication). We grouped the call data from all three duty cycles and compared it to the equivalent data during silence. This comparison was done using a Fisher's exact test, for both species categories, and for all three reference distance categories separately. This comparison allowed us to determine whether the deterrent significantly influenced the acoustic activity of bats in the facility. We then compared the number of calls from each of the three duty cycles with expected values using a Chi-square test (χ^2), for both species categories, and for all three distance categories separately. If significant differences were found, then each value's contribution to the Chi-square was considered to determine the source of the variation. Finally, to determine whether the effective range influenced the bats' acoustic activity within the facility, we compared behavioral data between the three reference distance categories for both species categories separately. For this comparison, we also used a Chi-square test. In addition, we included in the analysis the effect of external variables, such as date and set of bats, to determine if these independent variables could be influencing our results (e.g., the occurrence of seasonal changes in environmental conditions and bat behavior).

Results

A total of 245 behavioral trials were conducted from July 11 to September 25, 2015. Three species of bat were brought into the flight facility; 6 (3 female; 3 male) eastern red bats (*Lasiurus borealis*), 44 (23 female; 21 male) evening bats (*Nycticeius humeralis*), and 12 (11 female; 1 male) Mexican free-tailed bats (*Tadarida brasiliensis*). A total of 3 (2 female; 1 male) eastern red bats and 18 (5 female; 13 male) evening bats were not used in the trials because they were either used in the preliminary testing period to fine-tune our methodology or they did not acclimate to the flight facility.

Of the total number of videos recorded, we were able to analyze 237 trials successfully. Five trials were disregarded because they were conducted on a day the bats had not fully acclimated to the flight facility, as a result we repeated the survey day and these second set of trials were used instead. For two trials, the SD card became full mid-trial ending the recording, which could not be used in our analysis and in the last video that we disregarded, the IR lights were not turned on in error resulting in the video being too dark to analyze. Preliminary analysis of the data confirmed that external independent variables, such as date and set of bats, did not have a notable influence and were therefore not included in any of the further analysis and results.

Presence/absence

We were able to record presence/absence data for all three species involved in the trials: eastern red, evening, and Mexican free-tailed bats. Note that eastern red and evening bats have call frequency >35 kHz and were subsequently grouped into the high frequency species category, whereas Mexican free-tailed bats represented the low frequency species for the following analysis.

Silence vs. deterrent comparison

Comparing the proportion of time the bats were present within the focal area during the silence against the deterrent, there appeared to be a trend among the high frequency bat species. For these bats, activity was higher during the silence than when the deterrent was played across all reference distance categories (Fig. 1 A-C). A similar pattern was only seen at the 30 m reference distance category for the low frequency bat species, although the pattern was reversed in the 12m and 18 m reference distance categories (Fig. 1 D-F).

The ANOVA to compare the presence/absence data among the silence and deterrent confirmed that the differences observed in the proportion of time spent in the focal area were not statistically significant (Table 1).

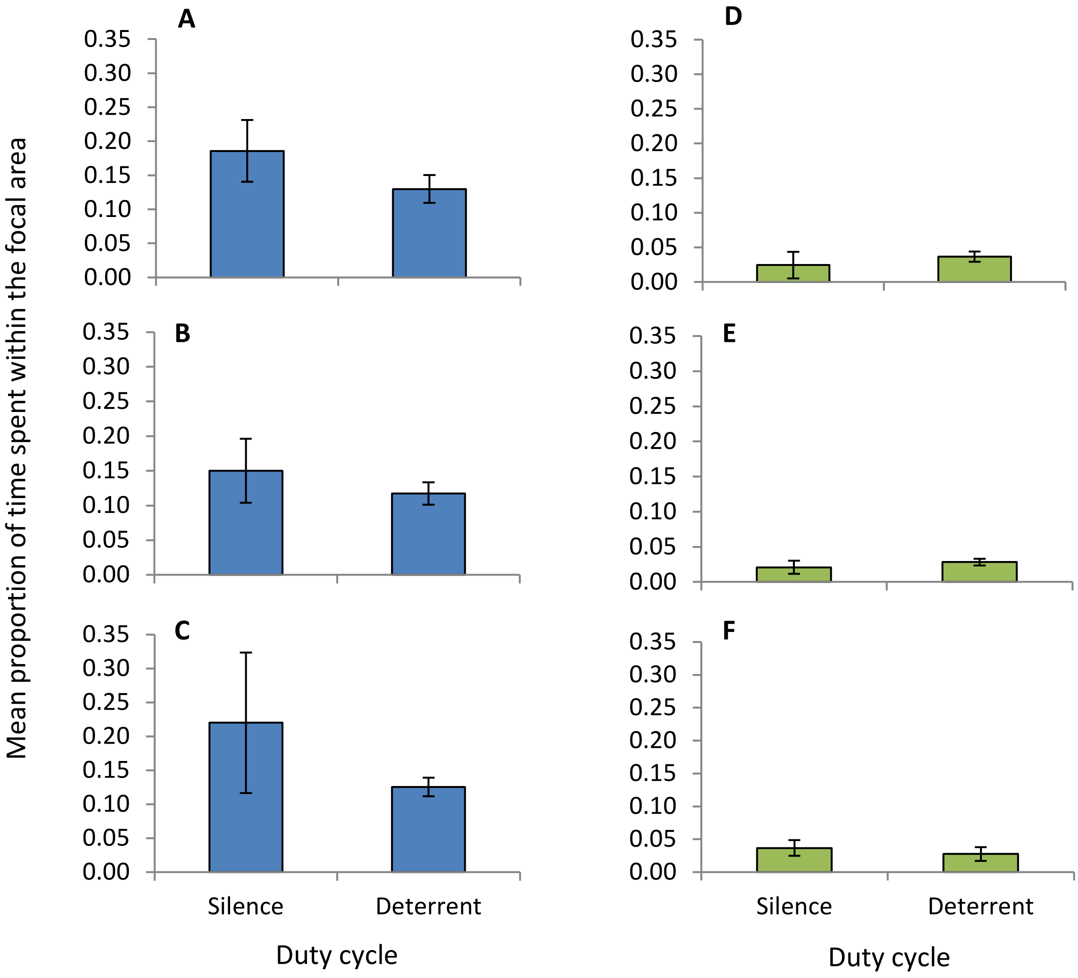


Figure 1: Mean ± SE proportion of time bats spent within the focal area during silence and with the deterrent on (continuous, 1 s pulse, 2 s pulse). For high frequency species, (A) shows bat presence when an acoustic signal was played at a reference distance equivalent to 12 m, (B) 18 m, and (C) 30 m. For low frequency bats, (D) shows bat presence when an acoustic signal was played at a reference distance equivalent to 12 m, (E) 18 m, and (F) 30 m.

Table 1: ANOVA results showing the proportion of time bats spent in the focal area* between the silence and the deterrent for both species categories (high and low frequency bats) and for all three reference distance categories (12 m, 18 m, 30 m) separately.

	Reference distance (m)	df	F-value	P-value
High frequency species	12	1,49	1.890	0.176
	18	1,49	0.380	0.543
	30	1,53	1.240	0.271
Low frequency species	12	1,24	0.240	0.631
	18	1,26	0.090	0.763
	30	1,24	0.810	0.377

df = degrees of freedom. *data were transformed prior to analysis.

Duty cycle and reference distance category comparison

Comparing the proportion of time the bats spent within the focal area where the deterrent was played across the three duty cycles and the three reference distance categories, we observed slight differences for both high and low frequency bats. The ANOVA comparing the presence/absence data among the duty cycles and the reference distance categories confirmed that the differences between continuous, 1 s pulse, and 2 s pulse, and the differences between 12 m, 18 m, and 30 m were not statistically significant (Table 2). Note that an interaction between reference distance category and duty cycle was also not significant and was therefore not included in the final analysis.

Table 2: ANOVA results for the comparison of the proportion of time bats spent within the focal area* between the three duty cycles (continuous, 1 s pulse, 2 s pulse) and the three reference distance categories (12 m, 18 m, 30 m), for both species categories (high and low frequency bats).

	Factor	df	F-value	P-value
High frequency species	Reference distance	2	0.49	0.614
	Duty cycle	2	1.44	0.241
	Error	132		
Low frequency species	Reference distance	2	1.05	0.355
	Duty cycle	2	0.60	0.553
	Error	66		

df = degrees of freedom. *data were transformed prior to analysis.

Behavioral data

We were able to record behavioral data for two species involved in the trials: eastern red and evening bats. We observed passing, foraging, and chasing behavior during the trials; however, we only used foraging behavior in the analysis. As foraging efficiency relies heavily on the bats being able to echolocate effectively, it was determined to be the preferred behavior to best estimate the deterrent's influence. Preliminary analysis also revealed that the aforementioned high frequency species exhibited different behavioral patterns. We therefore proceeded to analyze the two species separately. We were not able to collect behavioral data for Mexican free-tailed bats since they did not behave as naturally in the flight facility as the other two species (e.g., we did not observe foraging in Mexican free-tailed bats).

Silence vs. Deterrent comparison

Comparing bat behavior between the silence and the deterrent, we observed that eastern red and evening bats spent more time foraging during the silence than during the deterrent at 12 m and 30 m, but not at 18 m (Fig. 2). Nevertheless, these differences were not statistically significant using ANOVA tests (Table 3).

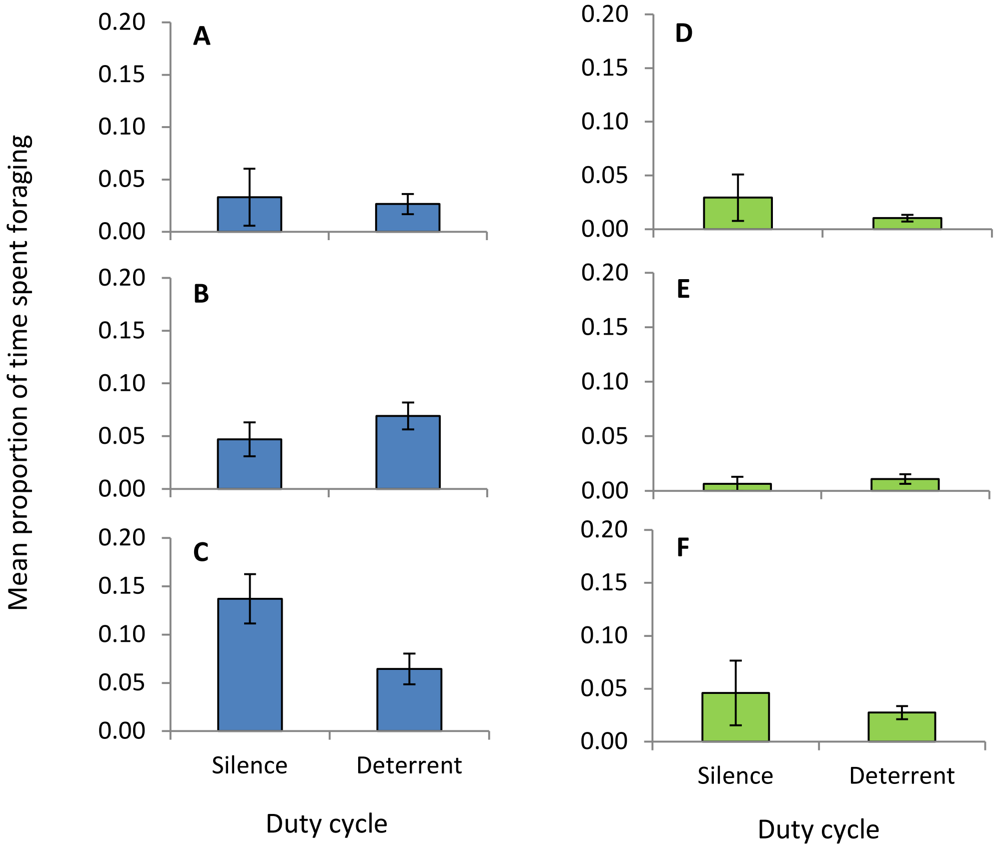


Figure 2: Mean ± SE proportion of time spent foraging during the silence period and when the deterrent was on (continuous, 1 s pulse, 2 s pulse). For eastern red bats, (A) shows foraging behavior when an acoustic signal was played at a reference distance equivalent to 12 m, (B) 18 m, and (C) 30 m. For evening bats, (D) shows foraging behavior when an acoustic signal was played at a reference distance equivalent to 12 m, (E) 18 m, and (F) 30 m.

Table 3: ANOVA results for the proportion of time spent foraging* during the silence and during the deterrent treatments for eastern red and evening bats across all three reference distance categories (12 m, 18 m, 30 m).

Species	Reference distance (m)	df	F-value	P-value
Eastern red bat (*Lasiurus borealis)*	12	1,12	0.180	0.677
	18	1,12	0.150	0.709
	30	1,13	2.360	0.148
Evening bat (*Nycticeius humeralis*)	12	1,32	1.750	0.195
	18	1,30	0.020	0.903
	30	1,34	0.250	0.617

df = degrees of freedom. *data were transformed prior to analysis.

Duty cycle and reference distance category comparison

Comparing foraging behavior across the three duty cycles and the three reference distance categories, we observed slight differences for both eastern red and evening bats. The results from the ANOVA tests revealed that the observed differences in foraging between the duty cycles were not statistically significant, whereas we found significant differences between the reference distance categories for both bat species (Table 4). Tukey post-hoc tests for these differences revealed that evening bats foraged more at 30 m than the other reference distance categories (Fig. 3). Tests were not conclusive for eastern red bats, even though we found a 50% reduction in foraging at 12 m compared to the other reference distance categories (Fig. 3). Note that an interaction between reference distance category and duty cycle was also not significant and was therefore not included in the final analysis.

Table 4: ANOVA results for the comparison of the proportion of time spent foraging* among the three duty cycles (continuous, 1 s pulse, 2 s pulse) and the three reference distance categories (12 m, 18 m, 30 m) for two bat species (eastern red and evening bats).

	Factor	df	F-value	P-value
Eastern red bat (*Lasiurus borealis)*	Reference distance	2	3.40	**0.046**
	Duty cycle	2	0.34	0.717
	Error	32		
Evening bat (*Nycticeius humeralis*)	Reference distance	2	5.20	**0.007**
	Duty cycle	2	0.23	0.796
	Error	84		

df = degrees of freedom. *data were transformed prior to analysis.

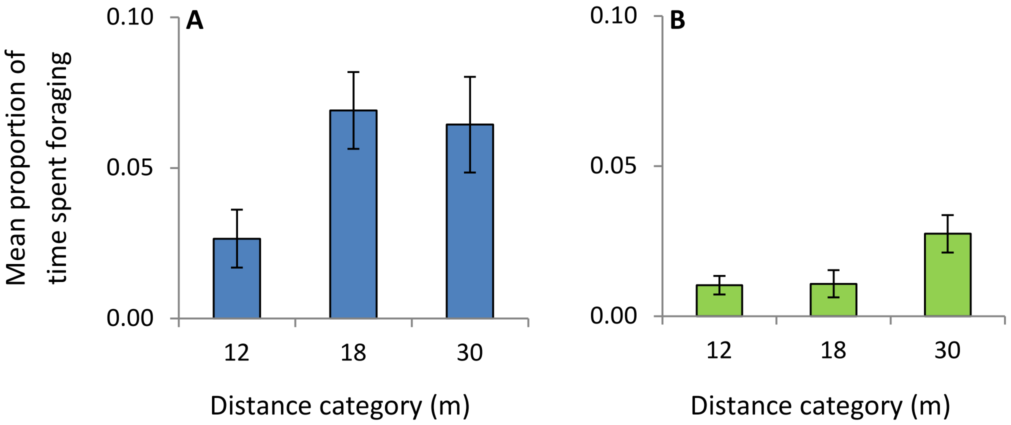


Figure 3: Mean ± SE proportion of time spent foraging by eastern red bats (A) and evening bats (B) across the three reference distance categories (12 m, 18 m, 30 m) when the deterrent was on.

Acoustic data

We were able to collect acoustic data for two species involved in the trials: evening and Mexican free-tailed bats. We successfully identified searching, foraging, feeding buzz, and communication calls; however, preliminary analysis revealed that not all calls were commonly made by both species (e.g., evening bats rarely emitted communication calls), and across both species feeding buzzes were infrequent, especially in Mexican free-tailed bats. We therefore proceeded to analyze these species separately and were not able to include feeding buzzes in our statistical analysis.

Silence vs. Deterrent comparison

Comparing call types between the silence period and when the deterrent was on, we observed a trend towards less searching and more foraging during the silence in all reference distance categories for evening bats, while we noticed the opposite trend for Mexican free-tailed bats (Table 5). Using Fisher's exact test, we found these trends were statistically significant for searching and foraging in all reference distance categories for evening bats, but only for searching and foraging at 18 m for Mexican free-tailed bats (Table 5).

Table 5: Fisher's exact test results for the comparison of the proportion of bat call types (searching, foraging, or communication) recorded during silence and when the deterrent was on for two bat species (evening and Mexican free-tailed bats) across all three reference distance categories (12 m, 18 m, 30 m).

Species	Behavior	Reference distance (m)	Total # calls	# calls in silence	# calls with deterrent	P-value
Evening bat (*Nycticeius humeralis*)	Searching	12	2141	789	1352	**<0.001**
		18	569	345	224	**0.002**
		30	2971	957	2014	**<0.001**
	Foraging	12	393	245	148	**<0.001**
		18	108	82	26	**0.003**
		30	924	450	474	**<0.001**
Mexican free-tailed bat (*Tadarida brasiliensis*)	Searching	12	653	165	488	0.111
		18	828	226	602	**0.004**
		30	656	179	477	0.304
	Foraging	12	244	54	190	0.540
		18	272	50	222	**0.004**
		30	140	28	112	0.058
	Communication	12	36	2	34	**0.008**
		18	4	1	3	1.000
		30	8	6	2	**0.006**

For Mexican free-tailed bats, we also observed more communication calls while the deterrent was playing compared to the silence at 12 m and less communication calls when the deterrent was playing at 30 m (Fig. 4). Fisher's exact test revealed these trends were significant (Table 5).

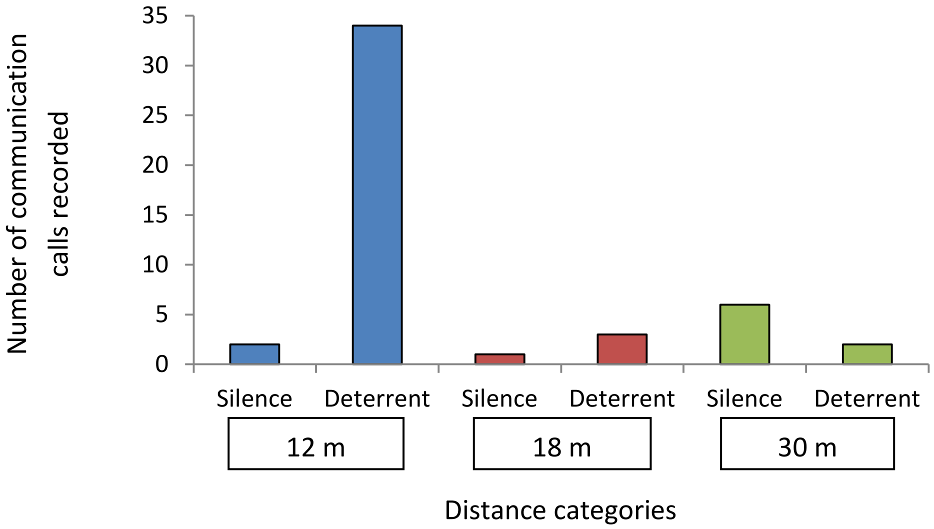


Figure 4: Number of communication calls exhibited by Mexican free-tailed bats during the silence period and when the deterrent was on, compared across the three reference distance categories (12 m, 18 m, and 30 m).

Duty cycle comparison

Comparing bat behavior across the three duty cycles, we found that values were very similar for evening bats across all cycles, except for searching and foraging at 30 m. At 30 m, we observed that more time was spent searching and less time was spent foraging during the continuous cycle compared to the other cycles. Chi-square tests revealed that these results were significantly different from expected values (Table 6).

For Mexican free-tailed bats, we observed that they spent more time searching and less time foraging during the 1 s pulse duty cycle than during the other cycles across all three reference distance categories. The proportional difference between searching and foraging was highest at 12 m and lowest at 30 m. Chi-square tests revealed that these results were significantly different from expected at 12 m (Table 6). In contrast, communication calls for this species were found to be lower during the 2 s pulse than during the other cycles at 12 m. This was confirmed as significantly different by a chi-square test (Table 6).

Table 6: Chi-square test results for the comparison of bat call types (searching, foraging, or communication) between the three duty cycles (continuous, 1 s pulse, 2 s pulse) for two bat species (evening and Mexican free-tailed bats) at all three reference distance categories (12 m, 18 m, 30 m).

Species	Behavior	Reference distance (m)	Number of calls				$\chi^2_{\text{df = 2}}$	P-value
			Total	Continuous	1 s pulse	2 s pulse		
Evening bat (*Nycticeius humeralis*)	Searching	12	1352	499	475	378	0.03	0.985
		18	224	8	84	132	-	-
		30	2014	873	729	412	59.85	**<0.001**
	Foraging	12	148	54	50	44	0.261	0.878
		18	26	1	8	17	-	-
		30	474	113	235	126	61.19	**<0.001**
Mexican free-tailed bat (*Tadarida brasiliensis*)	Searching	12	488	151	187	150	14.18	**0.001**
		18	602	311	197	94	4.314	0.116
		30	477	153	128	196	0.357	0.837
	Foraging	12	190	76	41	73	17.72	**<0.001**
		18	222	113	62	47	4.033	0.133
		30	112	36	27	49	0.425	0.808
	Communication	12	34	16	14	4	6.788	**0.034**
		18	3	1	1	1	-	-
		30	2	0	1	1	-	-

χ^2 = Chi-square test. df = degrees of freedom.
- For some categories, expected values were too low to meet the assumptions of the statistical test.

Reference distance category comparison

Comparing bat behavior using call types between the three reference distance categories when the deterrent was played, we observed that searching behavior was lower and foraging higher at 30 m for evening bats. In contrast, we noticed that searching behavior was higher and foraging was lower at 30 m for Mexican free-tailed bats. This trend was supported by a chi-square test (Table 7). We also observed higher communication calls at 12 m than at the other two reference distances (Fig. 5). Fisher's exact test revealed that this difference was significant (Table 7).

Table 7: Chi-square test results for the comparison of the frequency of bat call types (searching, foraging or communication) while the deterrent was playing across the three reference distance categories (12 m, 18 m, 30 m) for two bat species (evening and Mexican free-tailed bats).

		Number of calls					
Species	Behavior	Total	12 m	18 m	30 m	$\chi^2_{df=2}$	P-value
Evening bat (*Nycticeius humeralis*)	Searching	3590	1352	224	2014	65.99	**<0.001**
	Foraging	648	148	26	474	65.52	**<0.001**
Mexican free-tailed bat (*Tadarida brasiliensis*)	Seaching	1567	488	602	477	25.37	**<0.001**
	Foraging	524	190	222	112	14.03	**0.001**
	Communication	39	34	3	2	51.50	**<0.001**

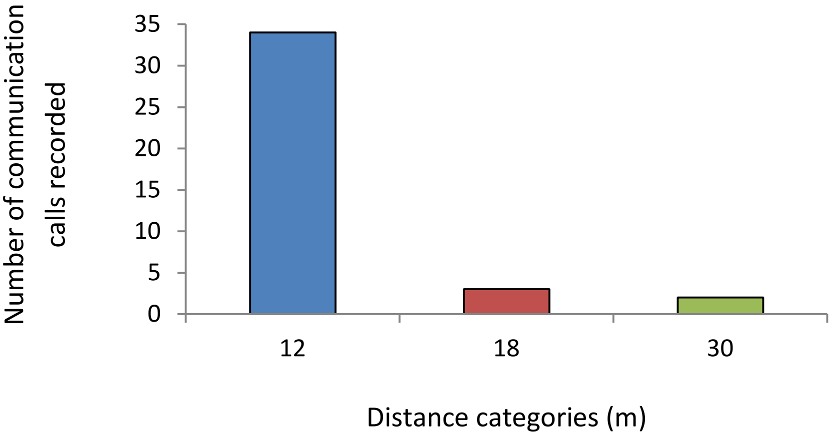


Figure 5: Number of communication calls exhibited by Mexican free-tailed bats while the deterrent was played across the three reference distance categories (12 m, 18 m, and 30 m).

Finally, we explored how often feeding buzzes were emitted by bats during silence and when the deterrent was on. We observed that at 12 m, the number of feeding buzzes emitted by evening bats decreased by 50% when the deterrent signal was played (Fig. 6). In contrast, we noted that the number of feeding buzzes emitted by evening bats at 30 m appeared to be similar to the number of feeding buzzes emitted during silence. Not one feeding buzz was emitted at 18 m. Furthermore, as sample sizes of this behavior were low, we were unable to conduct a statistical analysis on these data.

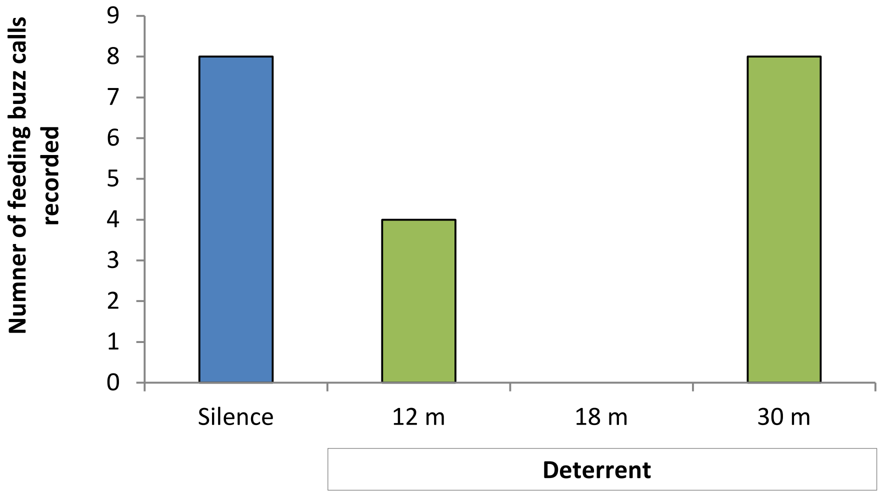


Figure 6. Number of feeding buzz calls exhibited by evening bats during the silence and while the deterrent was playing across the three reference distance categories (12 m, 18 m, and 30 m).

Discussion

Throughout our study, we observed a distinct difference in the types of behaviors undertaken by high frequency bats in comparison to low frequency bats, whether ultrasonic sounds were playing or not. This difference is most likely due to the ecology of the species involved. For example, Mexican free-tailed bats, a low frequency species (with a base echolocation frequency of approximately 25 kHz), are adapted to very open habitats in which their longer wing spans enable them to fly at height and large distances in pursuit of swarms of invertebrate prey (Ammerman et al. 2012). In the confines of a flight room, this type of foraging strategy is restricted, so it is not surprising that few of our Mexican free-tailed bats attempted to forage. Furthermore, their low frequency echolocation was not well-suited to the cluttered flight room environment, and might explain why they showed less flying activity than the other two species. In contrast, both evening and eastern red bats are adapted to foraging in or near cluttered environments (Ammerman et al. 2012), so we observed both these species readily flying and foraging in the flight room soon after being placed in the facility.

Despite inter-species differences, our results showed that general activity levels were very similar whether the ultrasonic signals were off or on. In other words, the bats were flying, or at least active, regardless of the deterrent being played. However, when we explored the different types of behavior the bats were exhibiting in more detail, we observed that high frequency bats foraged less when the ultrasonic signals were playing. This pattern was also supported by our acoustic data, as we recorded fewer foraging calls during the experimental trials in comparison to the silence. Activities such as foraging are very reliant on echolocation, providing the bat with detailed information. When a bat is pursuing a prey item, it needs to know the distance to the prey, its velocity, and the direction in which the prey is moving (Altringham 1998). Without such information, prey capture becomes inefficient and potentially energetically costly. In natural circumstances, when foraging becomes inefficient, then a bat will leave that area and move to another more successful foraging site (Bunkley 2015; Berthinussen & Altringham 2012). In the flight room, the bats did not have the option to leave the area, but one alternative would be to reduce foraging efforts. The decrease in foraging when the ultrasonic signals were playing, therefore, suggests that these sounds were deterring the high frequency bats from being able to forage effectively. In turn, our results indicate that the GE deterrent is likely to make it difficult for high frequency bats, such as evening and eastern red bats, to forage or conduct other activities that rely on detailed echolocation information (e.g., drinking and coming in to land). In contrast, passing, searching, commuting, and potentially migration do not require such detailed acoustic information for their successful execution. These activities are, therefore, able to be undertaken by high frequency bats with the deterrent playing. Ultrasonic signals of higher amplitude within frequency ranges used by these species may be a way to mask the echolocation calls produced during such activities and therefore cause bats to avoid areas in proximity to the deterrent. Unfortunately, we were unable to test signals with higher amplitude in the flight facility as the speakers used would be overloaded. We recommend a modification to the frequency range covered and increased amplitude at higher frequencies would improve the effectiveness of the current GE prototype deterrent.

As previously mentioned, Mexican free-tailed bats were not able to effectively forage in the flight room. Nevertheless, this species was active during the trials and more frequently emitted communication calls while the ultrasonic signals were playing. These communication calls appeared to be very similar to distress calls that bats emit when they are, for example, caught in mist nets. The presence of these acoustic calls indicates that Mexican free-tailed bats responded negatively to the ultrasonic signals. Again, in natural conditions the bats would have left and/or avoided the area, suggesting that for this and other low frequency species, the GE deterrent would be effective. Given the characteristics of the ultrasonic signals created in subtask 1.1. this may not be surprising. The portion of the signal with the highest amplitude falls within the frequency range of our low frequency bats (20-35 kHz). At these higher amplitudes, the deterrent should be able to mask any echolocation calls emitted by such species, including the hoary (*Lasiurus cinereus*), big brown (*Eptesicus fuscus*), and silver-haired (*Lasionycteris noctivagans*) bats. In other words, all activities should be hindered by the deterrent, not just those activities that rely on receiving detailed information from returning echoes, such as foraging. Thus, our flight room experiment suggests that the GE deterrent should prevent low frequency bats from coming into close proximity to it.

Another important finding from our experiment is that the effect of the ultrasonic signals did not appear to vary between continuous and intermittent pulsed duty cycles across all our trials or among species. More specifically, these results suggest that the ultrasonic signal from the GE deterrent can be pulsed for 1 second every 3 seconds to remain effective. The advantage of pulsing the deterrents would to allow engineers to place more deterrents on a single turbine as multiple devices can be operated off of one air compressor.

Finally, our results confirmed that the responses of bats to the ultrasonic signals varied with distance. Across all our trials and species, we found that the bats were more active when the 30 m reference distance signal was being played compared to the 12 m reference distance.

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ATTACHMENT C

Milestone M2.1.1

DE-EE0007035
General Electric Company
Ultrasonic Bat Deterrent Technology

Task 2 – Ground Testing (M1-M6)

Task Summary: The deterrent ground testing task is the second phase of determining key deterrent characteristics needed to increase its effectiveness in an operating wind farm. This task is designed to evaluate the effective range of the deterrent device using new information from the flight room tests to broadcast the optimal sound(s), and to evaluate the deterrent effect on different species, including *Myotis* species. Based on the results of Task 1, a series of acoustic signals including continuous sound and pulsed sound that vary in duration and inter-pulse interval will be tested in the field. Ground testing will take place at two locations. At Wolf Ridge a paired study will be conducted with the deterrent near turbine towers and cattle ponds. The objective is to determine if there are changes in how bats respond to the deterrent while flying near a turbine as compared to a water source. The second location will be near a *Myotis* bat colony in the Shawnee National Forest.

Subtask 2.1 – Wolf Ridge Turbine and Cattle Pond – paired study (M1-M6)

Subtask Summary: The effective range of the deterrent and associated avoidance behaviors of bats will be tested near turbine towers and cattle ponds at Wolf Ridge. This ground testing will be conducted to support the findings of the detailed behavioral responses observed in the flight room and increase our understanding of species-dependent responses to various deterrent pulsing duty cycles in a natural environment. Using high-definition video cameras and night vision technology, bat activity will be recorded at a cattle pond and turbine tower concurrently with the deterrent off, on, and pulsing. In addition, ultrasonic bat detectors will be placed in proximity to the cattle ponds and turbines during the night vision surveys to record acoustic bat activity. Testing will cycle through a series of acoustic signal treatments (e.g. control (deterrent off), continuous (deterrent on), and pulsed treatments which vary in pulse duration and interval). Using video analysis software, we will determine if bats were present during each treatment, document levels of activity by counting the number of bats and time spent in the field of view, and estimate minimum distance to the deterrent. The bat acoustic calls recorded will be used to confirm species presence at the survey sites using bat call analysis software.

Objectives

This study is designed to determine if the GE Prototype deterrent device successfully deters bats from water sources and wind turbine towers at a wind facility in the southern Great Plains. We will compare levels of bat activity at these two locations with four deterrent treatments (control – no sound, constant on, 1 sec pulse followed by 1 sec silence, 1 sec pulse followed by 2 sec silence). We hypothesize (H_A) that the presence of bats will depend on exposure to sound emitted by the deterrent. The null hypothesis (H_0) is that the presence of bats is independent of exposure to sound emitted by the deterrent. The paired study design will further allow us to compare bat presence and activity at a known resource (i.e., water source) to presence and activity at wind turbine towers.

Study Site

We will conduct this study at Wolf Ridge Wind, LLC (Wolf Ridge) located in north-central Texas (N 33° 43’ 53.538”, W 97° 24’ 18.186”). This wind facility consists of 75 1.5-MW GE wind turbines (Fig. 1) and has been the focus of ongoing research on the direct and indirect impacts of wind turbines on birds and bats since 2009. Six bat species are known to be present at this site: *Lasiurus borealis*, *Lasiurus cinereus*, *Lasionycteris noctivagans*, *Perimyotis subflavus*, *Nycticeius humeralis*, and *Tadarida brasiliensis*.

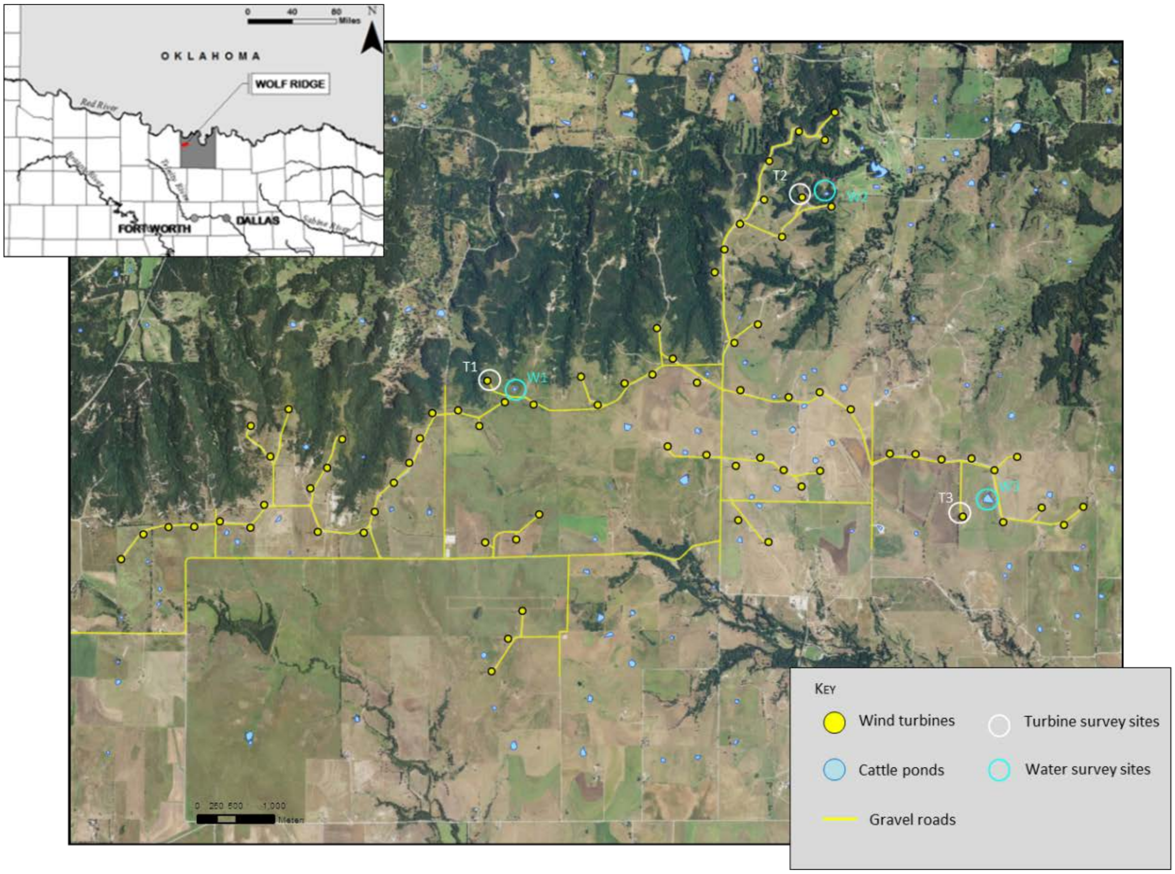

Fig. 1. Map illustrating the locations of wind turbines and cattle ponds at Wolf Ridge Wind, LLC.

Survey Methods

Surveys will be conducted at three pairs of wind turbines and cattle ponds at Wolf Ridge (see Fig. 1) from August 17 through September 30, 2015. Weather permitting, we will survey bat activity on approximately 24 nights during this period, although the total number of nights may be adjusted due to overall levels of bat activity or limitations due to storms.

We will monitor bat activity near wind turbine towers and at cattle ponds with the deterrent at 3 distances (10 m, 20 m, and 30 m) from the focal observation point. Comparing bat activity at these three distances will allow us to determine if bat presence and activity depends on proximity to the deterrent (e.g., is the device effective at deterring bats over a distance of 30 m, which is within the range of the length of a turbine blade). The deterrent placement will be the same at both locations within a single survey night and will be rotated across survey nights during the study period. Within a single survey night the four treatments (deterrent off, deterrent on, 1 second on 1 second off, 1 second on 2 seconds off), each 10 minutes in length, will be conducted in random order with a 10 minute silent period between treatments. Surveys will begin approximately 30 minutes before sunset and will continue up to 3 hours after sunset (the primary activity period for bats). The order and the timing of the treatments will be the same at both locations within a single survey night.

Fig. 2. Photograph of deterrent

At the specified distance from the focal observation point at the deterrent will be placed on a tripod. Air pressure to operate the deterrent will be provided by connecting six compressed nitrogen tanks to a single supply hose via a custom manifold. Two video cameras mounted on tripods will be placed at each survey location. Sony DCR-SX45 cameras in daylight mode will be used for the first 30 minutes of each survey period, followed by SONY HDR-PJ710 cameras with ATN-NVM4 night vision scopes for the remainder of the night. The cameras will be at 90 degrees from each other and focused at the same focal point. The GPS location of each camera has been predetermined using GIS to ensure consistent recording setups. Daylight cameras will be placed 10 meters from the focal point near the edge of the pond, whereas night vision cameras will be placed 20 meters from the focal point (to obtain the same field of view). Supplemental light will be provided for each night vision camera by using external tripod-mounted infrared lights. Two infrared lights will be mounted on tripods and placed approximately 10 m behind each cameras and at 45 degrees to the side so that a shadow is not cast by the camera and tripod.

Fig. 3. Photograph of deterrent set up at wind turbine.

An AR-125 bat detector and recorder will also be deployed near the focal point of the camera to record echolocation calls from bats that are inside the video frame. The acoustic detector will record for the entire monitoring period.

At least 2 technicians will be present at each survey location (pond and turbine) each study night. Video recordings will be started simultaneously on both cameras at each location, so that the videos can later be synchronized for video analysis. A night vision/acoustic recording data form will be completed each night describing weather conditions (temperature, wind speed, wind direction, relative humidity, barometric pressure), recording times and details, and any additional notes. All electronic equipment will be removed from the area after each sampling night. Surveys will only be conducted on nights with relatively calm winds and no precipitation.

Data Management and Analysis

The team will analyze the videos using Studiocode video analysis software, first by confirming bat presence during each treatment at each distance from the focal observation point. Second, we will document level of activity (i.e., number of bats and time spent in the field of view) for each treatment type and distance. Finally, the team will identify specific types of behavior exhibited by the bats (including foraging, passing, and drinking). The bat acoustic calls recorded will be used to confirm species presence at the survey sites using SonoBat v. 3.03 bat call analysis software.

ATTACHMENT D

Milestone M2.1.2

DE-EE0007035
General Electric Company
Ultrasonic Bat Deterrent Technology

This document presents the results of Subtask 2.1 and the completion of Milestone 2.1.2.

> ***Milestone 2.1.2 – Demonstrate reduced bat activity and that bats do not closely approach the acoustic deterrent in field tests at Wolf Ridge.***

Executive Summary

We examined the behavior response of bats to acoustic signals produced by the GE ultrasonic bat deterrent at paired cattle ponds and wind turbine tower locations at Wolf Ridge, LLC in 2015. Deterrent testing during 33 survey nights from August-September demonstrated that the deterrent significantly reduced bat activity at a reference distance of 10 m from the focal point of observation, but that the effectiveness appeared to decrease at greater reference distances (e.g., 20 and 30 m). The deterrent also appeared to minimize large pulses in bat activity, which could be promising for deterrent effectiveness at reducing bat fatalities at wind turbines. We found no difference in bat activity among the 3 deterrent treatments: constant on, one sec pulse followed by 1 sec silence, and one second pulse followed by 2 sec silence. This finding suggests that it will be possible to redesign that deterrent system so that >2 emitters can be connected to a single air compressor, thereby potentially increasing the number of emitters deployed on wind turbine towers to increase the extent of airspace near the rotor swept zone that can effectively be covered by the acoustic deterrent signal.

Task 2 – Ground Testing (M1-M6)

Task Summary: The deterrent ground testing task is the second phase of determining key deterrent characteristics needed to increase its effectiveness at an operating wind farm. This task was designed to evaluate the effective range of the deterrent device using new information from the flight room tests to broadcast the optimal sound(s), and to evaluate the deterrent effect on different species, including *Myotis* species. Based on the results of Task 1, a series of acoustic signals including continuous sound and pulsed sound that varied in duration and inter-pulse interval were tested at two locations. At Wolf Ridge, we conducted a paired study with the deterrent near turbine towers and cattle ponds. The objective was to determine if there were changes in how bats respond to the deterrent while flying near a turbine as compared to a water source. The second location was near a *Myotis* bat colony in the Shawnee National Forest (see Milestone 2.2.2).

Subtask 2.1 – Wolf Ridge Turbine and Cattle Pond – paired study (M1-M6)

Subtask Summary: We tested the effective range of the deterrent and associated avoidance behaviors of bats near turbine towers and cattle ponds at Wolf Ridge. This ground testing was conducted to support the findings of the detailed behavioral responses observed in the flight room and increase our understanding of species-dependent responses to various deterrent pulsing duty cycles in a natural environment. Using high-definition video cameras and night vision technology, we recorded bat activity at a cattle pond and turbine tower concurrently with the deterrent off, on, and pulsing. In addition, we placed ultrasonic bat detectors in proximity to the cattle ponds and turbines during the night vision surveys to record acoustic bat activity. Testing cycled through a series of acoustic signal treatments (e.g. control (deterrent off), continuous (deterrent on), and pulsed treatments which vary in pulse duration and interval). Using video analysis software, we determined if bats were present during each treatment and documented levels of activity with the deterrent placed at 3 distances (10m, 20m, and 30m) from the focal observation point. We used the recorded bat calls to confirm species presence at the survey sites using bat call analysis software.

Objectives

This study was designed to determine if the GE Prototype deterrent (deterrent) device successfully deters bats from water sources and wind turbine towers at a wind facility in the southern Great Plains. We compared levels of bat activity at these two locations with four deterrent treatments (control – no sound, constant on, 1 sec pulse followed by 1 sec silence, 1 sec pulse followed by 2 sec silence). We hypothesized (H_A) that the presence of bats would depend on exposure to sound emitted by the deterrent. The null hypothesis (H_0) is that the presence of bats is independent of exposure to sound emitted by the deterrent. The paired study design will further allow us to compare bat presence and activity at a known resource (i.e., water source) to presence and activity at wind turbine towers.

This document presents the results of Subtask 2.1 and acts as **Milestone 2.1.2**, intended to demonstrate reduced bat activity in close proximity to the acoustic deterrent near wind turbine towers and cattle ponds. (Month 6 of BP1)

Study Site

We conducted this study at Wolf Ridge Wind, LLC (Wolf Ridge) located in north-central Texas (N 33° 43’ 53.538”, W 97° 24’ 18.186”). This wind facility consists of 75 1.5-MW GE wind turbines (Fig. 1), and has been the focus of ongoing research on the direct and indirect impacts of wind turbines on birds and bats since 2009. Six bat species are known to be present at this site: *Lasiurus borealis*, *Lasiurus cinereus*, *Lasionycteris noctivagans*, *Perimyotis subflavus*, *Nycticeius humeralis*, and *Tadarida brasiliensis*.

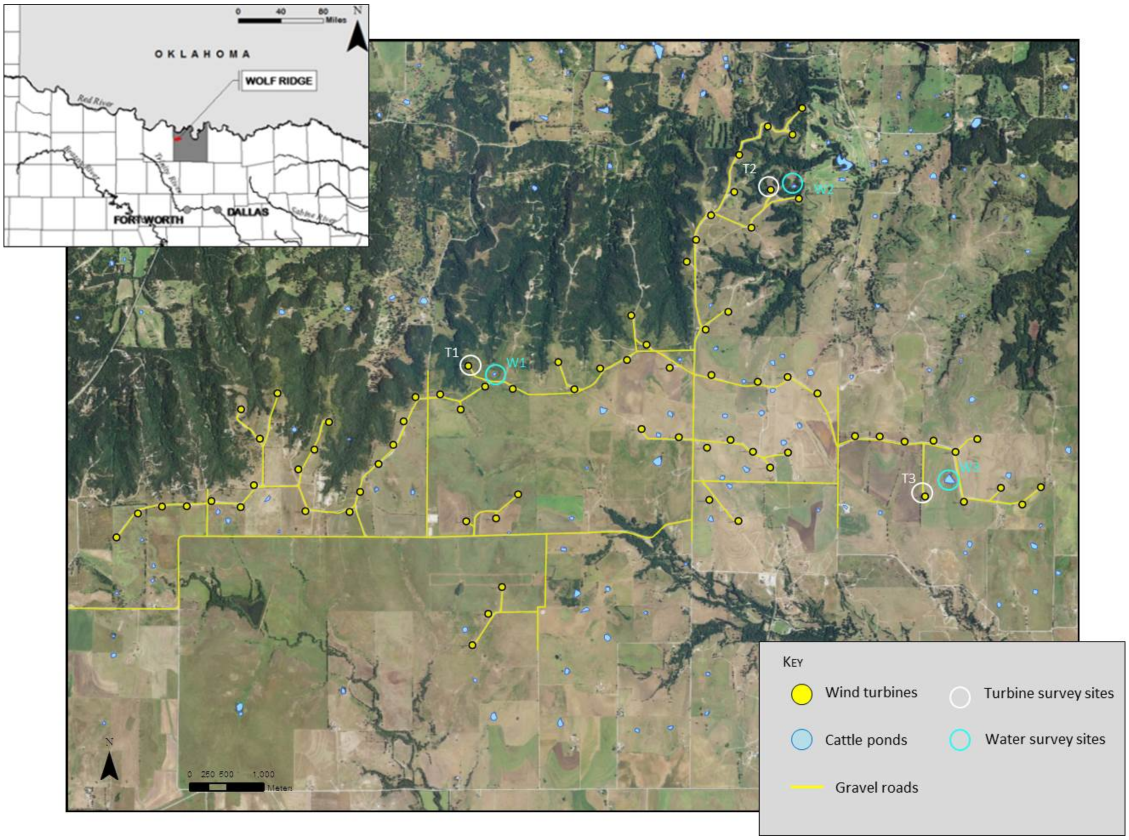

Figure 1. Map of the study area and survey locations within Wolf Ridge Wind, LLC in north-central Texas.

Methods

We used a paired study design to compare the deterrent treatment effect near turbine towers and cattle ponds. This study design would allow us to determine if bats respond differently to the deterrent while flying near a water source (i.e., a known resource where bats rely on echolocation for drinking and foraging activities) compared to a turbine tower. We conducted surveys at 3 turbines (T24, T39, and T63), each with a nearby pond (n = 3 ponds). The pond at T24 was located 288 meters (m) east of the turbine, the pond at T39 was located 247m east of the turbine, whereas the pond associated with T63 was located 330m to the northeast of the turbine (Fig. 1). Surveys rotated among the 3 paired sites.

The pneumatic deterrent tested during this study operates by releasing compressed nitrogen through a specially designed nozzle. Compressed nitrogen was supplied to the acoustic deterrent through high-pressure hoses that connected to a set of compressed nitrogen tanks; a control box was used to start and stop the flow of nitrogen and to vary the deterrent treatment. We established a focal point at each survey location that remained the same throughout the treatments. As the water level at ponds fluctuated over the season, we adjusted the focal point slightly over the course of the survey period so that it remained over the water. The focal point at the turbines was located 5 m in front of the turbine door, whereas the focal point at the ponds was over the water at 5 m from the pond edge. We placed the acoustic deterrent 2 m above the ground on a tripod and oriented it horizontally toward the focal point. To determine the effective range of the deterrent, the deterrent placement rotated among 3 distances (10, 20, or 30 m from the focal point) across survey nights. Only a single distance was tested at both the turbine and pond location each survey night. The deterrent treatments lasted

10 min and consisted of a silent “Control” with no deterrent, “On” with the deterrent on continuously at a constant pressure, “Pulse 1” with the deterrent pulsing for 1 sec on and 1sec off (0.5 Hz, 50% duty cycle), and “Pulse 2” with the deterrent pulsing on for 1 sec on and 2 sec off (0.3 Hz, 30% duty cycle).

We deployed a pair of high-definition video cameras at each site to record bat activity. Sony HDR-PJ790V cameras in daylight mode were used for daylight videos (i.e., the first 2 trials beginning at sunset; see below). We used the same cameras mounted with ATN-NVM3 night vision scopes for night videos (i.e., all subsequent trials within the survey nights). Daylight cameras were placed 7 m from the focal point, whereas night vision cameras were placed 18.5 m from the focal point. These setups provided the same 10 m wide field of view at the focal point. One camera was placed in-line with the deterrent, while the other was offset 90° to the side. The videos recorded by the two cameras overlapped in an approximately 10 m wide focal area, centered on the focal point (Fig. 2). The resulting focal areas were 5-15, 15-25, and 25-35 m from the deterrent, respectively, for the 10, 20, and 30 m tests. Supplemental light was provided for each night vision camera with two tripod-mounted infrared lights. The infrared lights were placed to provide the best lighting for each setup, generally 10 m behind the cameras, and at 45° degrees to the side. The lights were oriented to cross at the focal point to optimize bat detection.

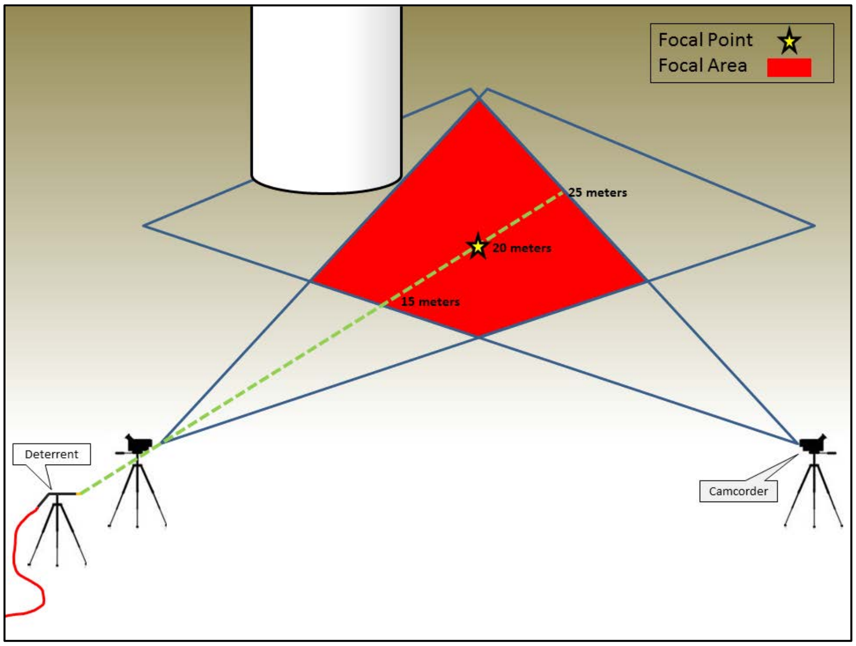

Figure 2: Diagram of equipment setup at a turbine site for the 20 m tests (not to scale).

Each survey night consisted of deterrent testing at a turbine and adjacent pond. Trials began at sunset and continued for 2.5 hours. As ambient light levels were too high to use the night vision scopes during the first 2 trials of each survey night, we used the video cameras in daylight mode to record bat activity. The night vision scopes were mounted to the cameras for the following 6 trials, for a total of 8 trials per survey night. Video recording began just prior to starting the deterrent treatment and continued for the entire deterrent test (10 min). We had a 10 min silence period between treatments to allow any treatment effect to diminish and bat activity to return to normal prior to beginning the next trial. The order in which the deterrent treatments were played in each trial was randomly determined for each survey night. Within a survey night, the paired turbine tower and pond locations received the same treatments in the same order, and the set of 4 treatments was played twice.

We used Studiocode video analysis software to synchronize videos and assess bat activity for each trial (version 5, Studiocode Business Group, Sydney, AU). A bat pass was confirmed when a bat was visible in the video from both cameras at the same time, meaning the bat was in the focal area. Two independent reviewers watched each paired video trial and documented bat passes. We reviewed all bat passes documented by one or both reviewers to confirm or refute the presence of a bat, and then only confirmed bat passes were used in subsequent analyses. Bats visible from only one angle were not included in the analysis because we considered them to be outside the focal area. After a bat pass was identified, we characterized the behavior of the bat into 1 of 5 categories: “Passing” - a bat made changes in flight direction 0-1 times within the field of view; “Foraging” - a bat made 2 or more changes of flight direction while within the field of view; “Chasing” - one bat followed the flight path of another bat; “Reversal” – a bat entered the field of view and reversed direction before leaving the field of view; and “Drinking” - a bat made contact with the surface of a pond. We then analyzed these behaviors for differences between deterrent treatments and between habitat type (pond vs. turbine).

In addition, we placed AR-125 ultrasonic bat detectors in proximity to the cattle ponds and turbines during the night vision surveys to record acoustic bat activity. The acoustic detector recorded for the entire monitoring period. We processed recordings with Sonobat call analysis software. Each recording was manually reviewed to identify the call to species (where possible) based on echolocation call characteristics. It is important to note that species identification using only acoustic recordings can be imperfect due to the overlapping acoustic repertoires of different bat species. Because a single bat may trigger the detector multiple times during a single flight past a detector, a file containing bat calls was grouped with the next file if it also contained calls and occurred ≤6 seconds after the first file, this process was repeated until there was >6 seconds between recording files. This resulted in single bat passes that contained several separate files; files >6 seconds apart were considered different passes. The recordings were also assessed to characterize the behavior of each bat based on the pattern of the recorded calls within a single pass: “Commuting” - calls were consistently spaced in time with consistent amplitude; “Searching” - calls were consistently spaced in time with changing amplitude; “Foraging” – calls were inconsistently spaced over time and had increasing frequency and slope; “Feeding” – call was characteristic of a feeding buzz with many calls per second; and “Social calls” – calls were of lower frequency with inconsistent duration and inconsistent timing. For bat passes containing multiple files, we assessed each call file separately for behavior because acoustic behaviors can and do often change during a single bat pass. For example, a bat may progress quickly from searching to foraging to a feeding buzz during a single pass.

We used Minitab v. 17 statistical software to analyze the data collected during this study ($\alpha = 0.05$). Due to the large numbers of zeroes and lack of normality in our response variables, we were generally unable to analyze the data using standard parametric tests. Instead, we used the non-parametric Kruskal-Wallis test as an alternative to ANOVA, followed by Mann-Whitney tests when appropriate.

Results and Discussion

Summary – We surveyed paired turbine and pond locations on 33 nights from 17 August to 28 September 2015. We did not observe any bats in the first daylight video sessions, likely because ambient light conditions were still too high and bats may have not yet emerged from their day roosts. Thus, these sets of trials were excluded from the analysis. The second daylight video and all night video sessions were included in the analysis. One of the 33 survey nights ended early due to adverse weather, although we included the trials completed earlier that evening in the analysis. Intermittent problems with recording equipment also resulted in a few trials being excluded from the analysis. In total, we recorded and detected 447 bat passes from high-definition video in 448 10 min experimental trials (Table 1).

Table 1. Number of experimental trials conducted for each deterrent signal type at pond and turbine locations at Wolf Ridge Wind, LLC from 17 August to 28 September 2015.

Turbine				**Pond**			
Signal Type		Total Trials	Bat Passes	Signal Type		Total Trials	Bat Passes
Duty Cycle	Distance (m)			Duty Cycle	Distance (m)		
Control	10	18	9	Control	10	19	72
Control	20	19	5	Control	20	19	23
Control	30	18	6	Control	30	18	44
On	10	16	1	On	10	18	20
On	20	20	5	On	20	20	13
On	30	20	10	On	30	20	50
1 sec pulse	10	18	2	1 sec pulse	10	18	9
1 sec pulse	20	18	1	1 sec pulse	20	18	22
1 sec pulse	30	19	20	1 sec pulse	30	19	50
2 sec pulse	10	16	3	2 sec pulse	10	17	10
2 sec pulse	20	20	7	2 sec pulse	20	20	29
2 sec pulse	30	20	5	2 sec pulse	30	20	31
Total		**222**	**74**	**Total**		**226**	**373**

Video Analysis –Bat activity was highly variable, with 303 (68%) of the deterrent trials yielding zero bat passes while 18 (4%) of the deterrent trials contained 183 (41%) of the total bat passes. Relatively low bat activity, averaging approximately one video bat pass per trial, likely contributed to the difficulty in analyzing this dataset and discerning differences among treatments, if they exist. Passive acoustic detectors present at the Wolf Ridge site (data not shown here) provided relative levels of bat activity (recordings per microphone-night) within the wind resource area prior to and throughout the deterrent study (Fig. 3). Bat activity recorded by the passive detectors during the deterrent study was generally much lower than the level of activity captured by the detectors from the beginning of June and into July (Fig. 3). The weather experienced during the spring and summer in this part of Texas was highly unusual, likely due to the strong “el niño” effect, with large amounts of rainfall in spring and very little rainfall during the summer months. Bat abundance, and therefore activity levels during July, August, and September were likely lower at this study site than what we have observed in previous years (Bennett and Hale, unpubl. data).

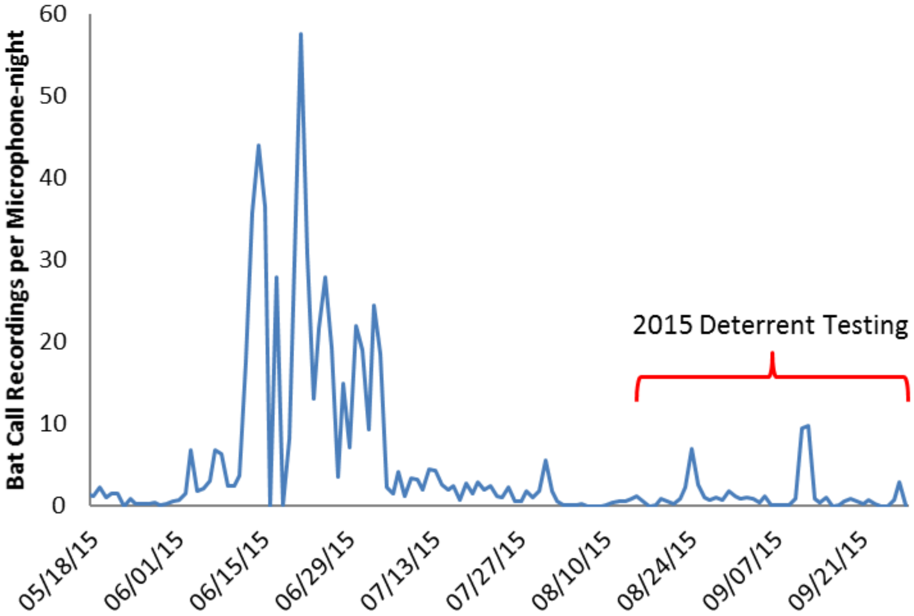

Fig. 3. Acoustic bat activity (number of bat call recordings per microphone-night) recorded from passive acoustic detectors at Wolf Ridge Wind, LLC from June-September 2015.

As only a single distance was tested in any given survey night, we first compared bat activity among control nights to better understand variation in bat activity and how this might affect the interpretation of the results on the on the different distance nights. As we found no significant difference in bat activity among the control trials (10, 20, and 30 m survey nights) at ponds (Kruskal-Wallis test: H = 1.48, df = 2, P = 0.48) or turbine locations (Kruskal-Wallis test: H = 3.02, df = 2, P = 0.22), we proceeded to compare bat activity among the deterrent treatments at the 3 distances.

Bat activity during our survey period was highly sporadic, with most activity occurring on only a few nights. Of the 448 trials, only 9 trials had ≥8 bat passes documented. These 9 trials contained 128 (29%) of the bat passes, while only representing 2% of the total number of trials. Interestingly, these high activity trials occurred only at ponds and with the deterrent operating at 30 m or during control trials (Fig. 4). This finding suggests that the deterrent may be preventing these high activity events from occurring when operating at 10 or 20 m from the focal observation point at ponds. This finding may be important, as bat fatality at many wind farms is also highly variable within the fall migratory season. If the deterrent is also effective at minimizing these pulses in activity from occurring near wind turbines, then bat mortality may be significantly reduced when they are deployed.

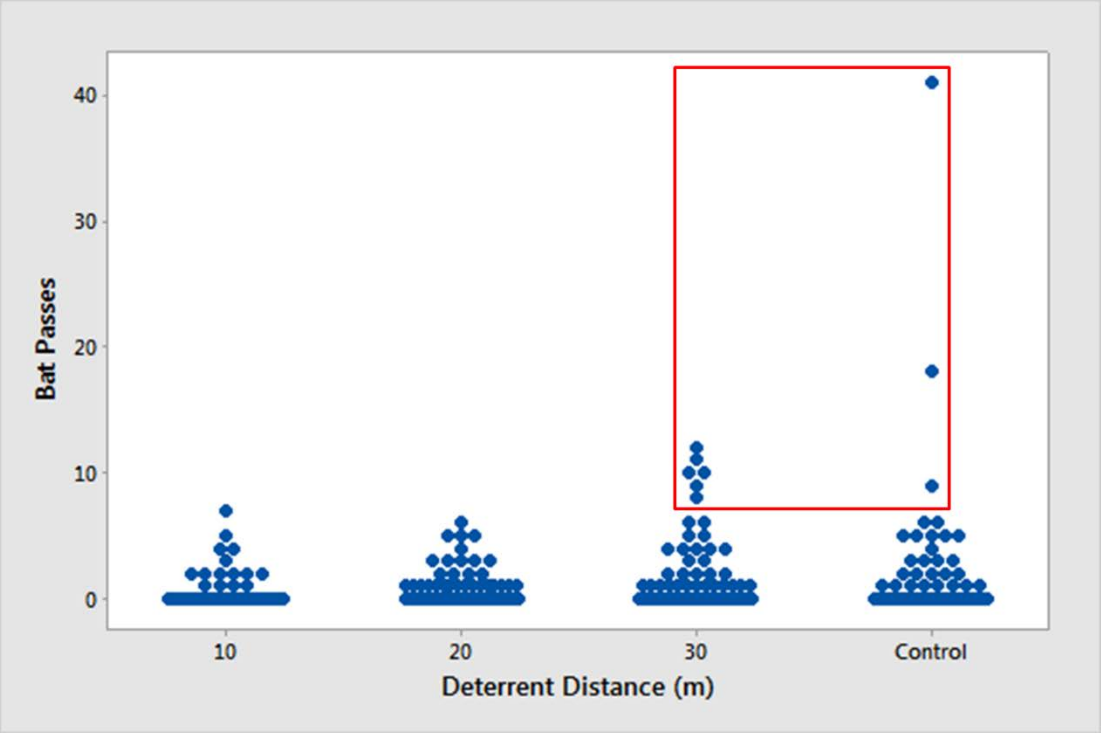

Fig. 4. Number of bat passes observed with the deterrent on (pooling continuous, 1 sec pulse, and 2 sec pulse treatments) and during the control trials at three distances from the focal observation point at ponds. The red rectangle encompasses the trials with $\geq$8 bat passes within a 10-min period.

To determine whether the deterrent was effective in reducing overall levels of bat activity, we compared the control trials (pooled across all survey nights) to the 3 deterrent distances. We observed a 70% reduction in mean bat passes at 10 m at ponds with the deterrent on compared to the control (Table 2, Fig. 5). Using a Mann-Whitney U test, this difference was significant at $\alpha = 0.05$ (Control: n = 56 trials, Deterrent 10 m: n = 53 trials, W = 3437.5, P = 0.014). At 20 and 30 m at ponds, we also observed a reduction in mean activity compared to the control (20 m = 56% reduction, 30 m = 11% reduction), although the differences were not significant with the Mann-Whitney U tests (Control: n =56 trials, Deterrent 20 m: n = 58 trials, W = 3328.0, P = 0.51; Control: n = 56 trials, Deterrent 30 m: n = 59 trials, W = 3118.5, P = 0.45). We observed a similar pattern in a reduction in bat passes at turbines when the deterrent was on at 10 m and 20 m, but the differences were not significant (P > 0.05 in both cases), likely due to the low overall number of bat passes seen at turbines (Table 3, Fig. 6). In contrast we detected a 63% increase in bat passes at turbines with the deterrent at 30 m compared to the control, but again the difference was not significant (Control: n = 55 trials, Deterrent 30 m: n = 55 trials, W = 3117.0, P = 0.71). If the rates of reduction in bat passes observed during the deterrent treatments, especially at 10 m, translated into similar rates of fatality reduction at wind turbines, then this deterrent may be as effective at reducing bat mortality as curtailing wind turbines at low wind speeds (i.e., up to 5.0 or 5.5 m/s).

Table 2. Mean ± SE bat passes detected during the control trials and with the deterrent on (pooling continuous, 1 sec pulse, 2 sec pulse) at 3 distances at pond locations at Wolf Ridge.

Variable	N	Mean Bat Passes	% Change vs. Control	SE Mean	St. Dev	Min.	Q1	Median	Q3	Max.
Control	56	2.482	-	0.809	6.057	0	0	0.5	3	41
10m	53	0.736	-70%	0.204	1.483	0	0	0	1	7
20m	58	1.103	-56%	0.201	1.53	0	0	1	1.25	6
30m	59	2.22	-11%	0.409	3.141	0	0	1	4	12

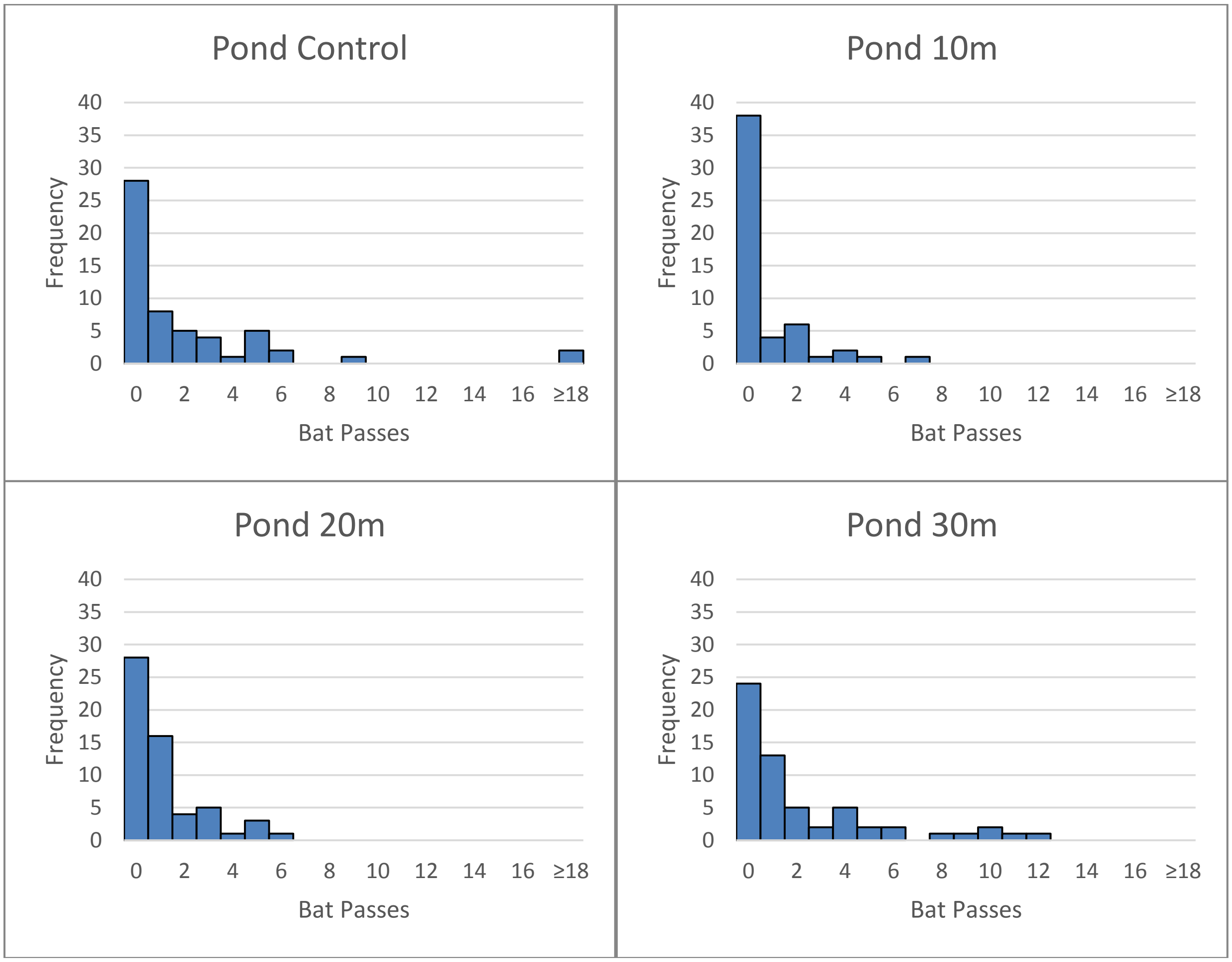

Fig. 5. The number of bat passes detected in videos during control and deterrent treatments (continuous, 1 sec pulse, and 2 sec pulse combined) at 3 distances at ponds at Wolf Ridge in 2015.

Table 3. Mean ± SE bat passes detected during the control trials and with the deterrent on (pooling continuous, 1 sec pulse, 2 sec pulse) at 3 distances at turbine locations at Wolf Ridge.

Variable	N	Mean Bat Passes	% Change vs. Control	SE Mean	St. Dev	Min.	Q1	Median	Q3	Max.
Control	55	0.364	-	0.123	0.91	0	0	0	0	5
10m	50	0.12	-67%	0.055	0.385	0	0	0	0	2
20m	58	0.2241	-38%	0.07	0.531	0	0	0	0	2
30m	59	0.593	63%	0.195	1.498	0	0	0	0	6

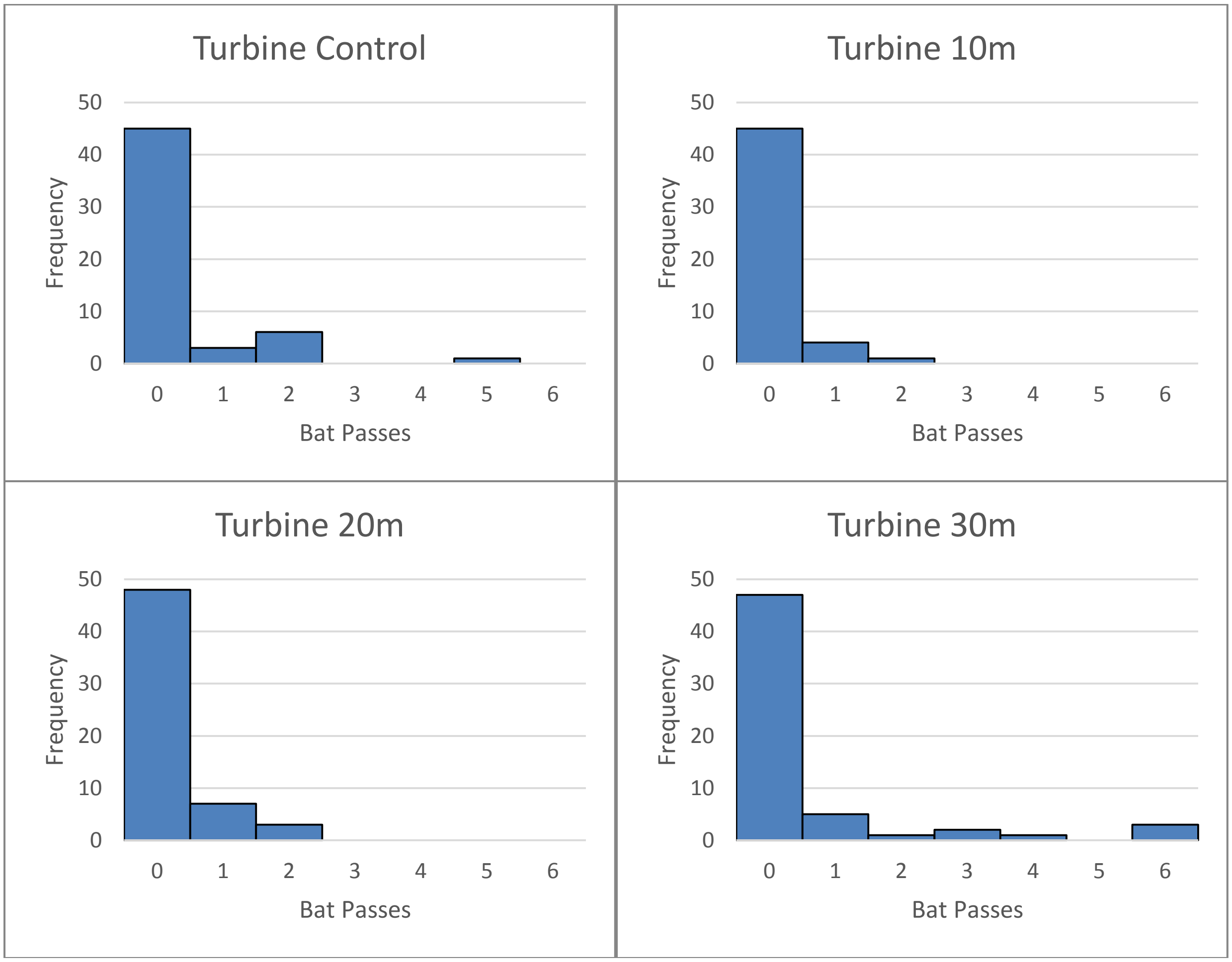

Fig. 6. The number of bat passes detected in videos during control and deterrent treatments (continuous, 1 sec pulse, and 2 sec pulse combined) at 3 distances at turbines at Wolf Ridge in 2015.

To test for changes in the effectiveness of the deterrent with distance, we pooled the three deterrent treatments for each distance (10, 20, and 30 m). The mean number of bats observed per trial was 50% higher at 20 m than 10 m, and 202% higher at 30 m than 10 m at ponds (Table 4; Kruskal-Wallis test: H = 11.27, df = 2, P = 0.004). Comparing the deterrent at each pair of distances at the ponds, we found a significant difference between the 10 m (n = 53 trials) and 30 m (n = 59 trials) distances (Mann Whitney U test: W = 2485.0, P = 0.001) and the

10 m and 20 m distances(n = 58 trials) (Mann Whitney U test: W = 2654.0, P = 0.037), but not between the 20 m and 30 m distances (Mann Whitney U test: W = 3156.5, P = 0.13). We therefore conclude that the deterrent appears to be more effective at reducing bat activity at 10 m than at 20 to 30 m from the ponds (Fig. 7).

Similarly, mean bat passes increased by 87% at 20 m and 394% at 30 m when compared to 10 m at the turbines, although the difference was not significant (Table 4; Kuskal-Wallis test: H = 2.66, df = 2, P = 0.26). This lack of significance was likely due to the low number of bats and high variability in bat activity at turbines. Nevertheless, these trends suggest that the effectiveness of the deterrent likely attenuates with distance, and a deterrent placed at the nacelle may not deter bats near the tips of the blades (i.e., 40 m away). Thus, alternative placement options, particularly along the tower, should be considered.

Table 4. The mean percent change in the number of bat passes detected with distance at ponds and turbines at Wolf Ridge in 2015.

Ponds					Turbines				
Variable	N	Mean Bat Passes	% Change vs. 10m	St. Dev	Variable	N	Mean Bat Passes	% Change vs. 10m	St. Dev
10m	53	0.74	-	1.48	10m	50	0.12	-	0.39
20m	58	1.10	50%	1.53	20m	58	0.22	87%	0.53
30m	59	2.22	202%	3.14	30m	59	0.59	394%	1.50

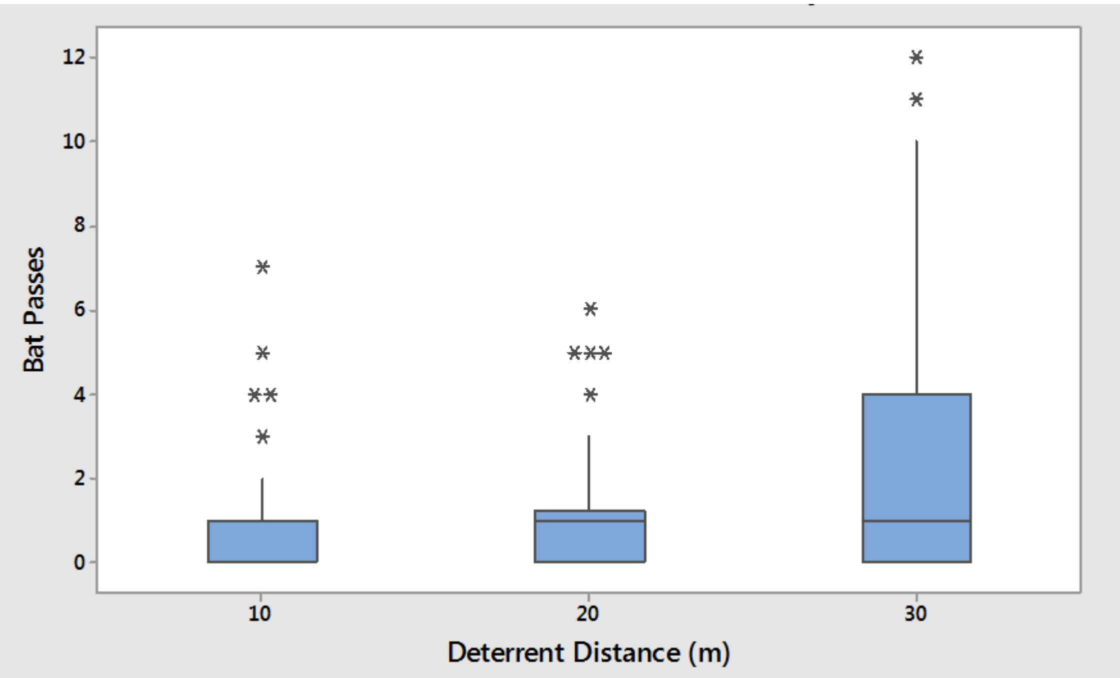

Fig. 7. Distribution of the number of bat passes observed with the deterrent on (continuous, 1 sec pulse, and 2 sec pulse pooled) across 3 distances at ponds at Wolf Ridge Wind, LLC in 2015.

We found no difference in bat activity between the 3 deterrent treatments (continuous, 1 sec pulse, and 2 sec pulse) at 10 and 20 m from ponds (Fig. 8; Kruskal-Wallis test: H = 0.08, df = 2, P = 0.96) or 10 and 20 m from turbine locations (data not shown; Kruskal-Wallis test: H =

2.09, df = 2, P = 0.35) at Wolf Ridge. Compared to the “continuous on” treatment, the 1 sec pulse uses 50% less compressed gas and the 2 sec pulse uses 66% less compressed gas. Pulsing the deterrent reduces gas consumption, and if deterrent efficiency remains the same, it may allow additional deterrent systems to be utilized on a given turbine without increasing the demand for compressed gas and the associated infrastructure.

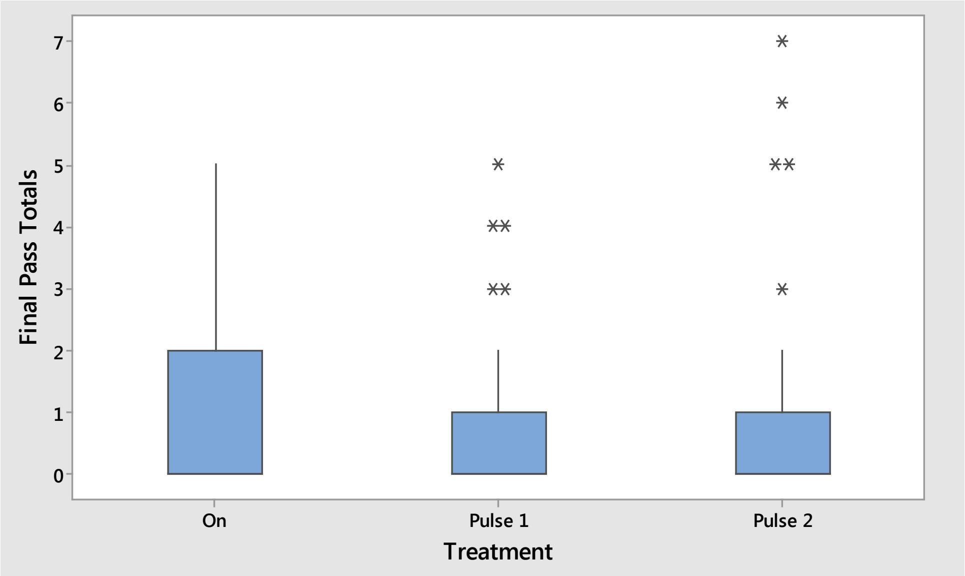

Fig. 6. Distributions of the number of bat passes observed during 3 deterrent treatments (10 and 20 m distances pooled together) at ponds at Wolf Ridge Wind, LLC in 2015.

Video Behavioral Analysis – Most bats seen in the videos were foraging and passing at ponds and turbine locations at Wolf Ridge. We observed chasing, reversal and drinking in only 1-7% of the bat passes. Bats were foraging (characterized by two or more changes of flight direction) significantly more often at ponds (40%) than at turbine locations (27%) (Fisher’s exact test: P = 0.036; Fig. 9). As differences in in-flight behavior could affect how bats respond to the deterrent, we also looked for differences in behavior among the deterrent treatments and the control. We found that the proportion of each behavior was not significantly different between the deterrent treatments (continuous, 1 sec pulse, and 2 sec pulse pooled) and the control (Fisher’s exact test: P > 0.05 in all cases; Fig. 10). Thus, our data indicate that the deterrent may not affect the behavior of bats that enter the focal area of observation (i.e. come close to the deterrent). It is important to note, however, that if bats are avoiding the deterrent by reversing direction prior to entering the focal observation (which is limited in size), we would not have detected those occurrences. Therefore, our study may actually underestimate the influence of the deterrent on behavior of individual bats.

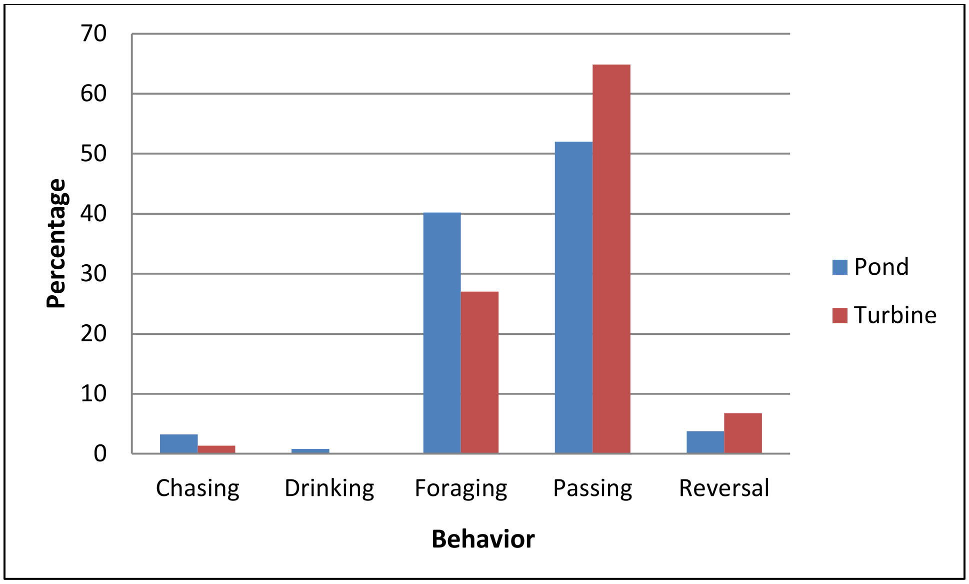

Fig. 7. Proportion of each behavior observed at ponds and turbines from video analysis at Wolf Ridge Wind, LLC in 2015.

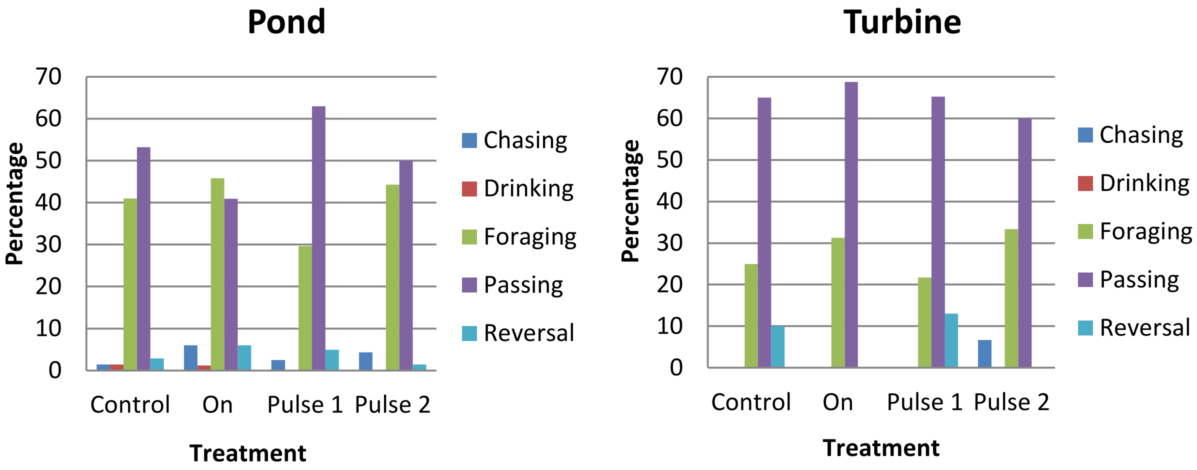

Fig. 8. Percentage of each behavior observed during the control and deterrent treatments at ponds and turbines at Wolf Ridge Wind, LLC in 2015.

Acoustic Analysis - As seen in the video analysis, more bat calls were recorded at pond locations than at turbines (Fig. 11). Also similar to the video analysis, bat acoustic activity was also highly variable among survey locations and nights during the deterrent trial period (Fig. 11). Nevertheless at ponds, the number of acoustic bat passes was correlated with the number of video passes we observed (r = 0.574, n = 32, P = 0.001). Due to the low number of bat detections (visual and acoustic) at turbines, we were unable to explore this relationship at those locations.

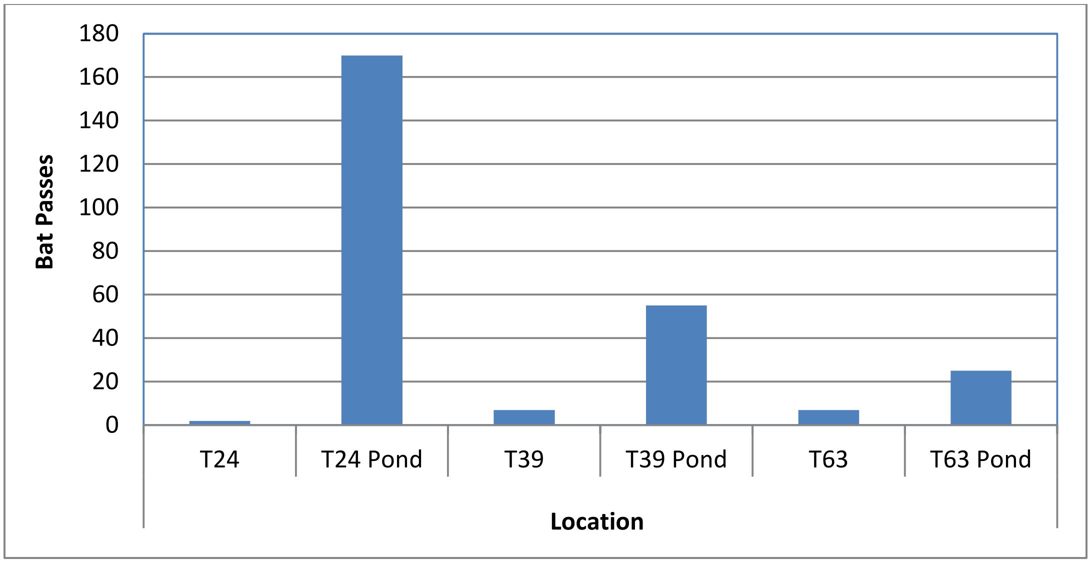

Fig. 9. The number of acoustic bat passes, by location, collected during deterrent testing at Wolf Ridge Wind, LLC in 2015.

Although the number of acoustic bat passes was much higher at ponds (n = 250) than turbines (n = 16), the distribution of bat calls was similar for most species (Table 5). Analysis of acoustic calls showed that an unknown bat species, suspected to be in the genus *Myotis* based on its call characteristics, accounted for 25% of the calls at the ponds and only 6% of the calls at the turbines. *Myotis* bats are not known to occupy this region of Texas, and additional research would be necessary to verify the species identification. Although the Wolf Ridge study site was selected, in part, because of the presence of multiple species of tree bats (hoary bats, eastern red bats, and silver-haired bats), we did not detect any hoary bat calls at our survey locations. This could be because hoary bats were echolocating at altitudes beyond the range of our ground-based detectors or because their numbers were lower than in previous years due to the weather patterns and/or other unknown factors. An additional field season of deterrent testing at Wolf Ridge could reveal hoary bat-deterrent interactions and provide additional information regarding the effectiveness of the acoustic deterrent at reducing bat activity. This data would be important, due to the high proportion of hoary bat fatalities reported at wind farms across North America (Arnett and Baerwald, 2013).

Table 5. Percentage of acoustic calls recorded by species at ponds and turbines at Wolf Ridge Wind, LLC.

Common Name	**Scientific Name**	**Habitat Type**	
		Pond	**Turbine**
Evening Bat	*Nycticeius humeralis*	35%	38%
Eastern Red Bat	*Lasiurus borealis*	16%	25%
Tri-colored Bat	*Perimyotis subflavus*	16%	19%
Unknown Myotis	*Myotis* spp.	25%	6%
Silver-haired Bat	*Lasionycteris noctivagans*	3%	6%
Mexican Free-tailed Bat	*Tadarida brasiliensis*	0%	6%
Hoary Bat	*Lasiurus cinereus*	0%	0%
Unknown	n/a	5%	0%

ATTACHMENT E

Milestone M2.2.1

DE-EE007035
General Electric Company
Ultrasonic Bat Deterrent Technology

Subtask 2.2 – Shawnee National Forest – *Myotis* efficacy study (M1-M6)

Summary

The study conducted at the Shawnee National Forest in southern Illinois is intended to complement the subtask 2.1 study by performing a similar protocol in a distinctly different habitat with a bat community that partially overlaps in terms of species composition. The testing will be conducted over a known foraging or drinking resource such as a small pond, wetland, or field. Following the same general study design as subtask 2.1, the testing will cycle through a series of acoustic signal treatments (e.g. continuous (deterrent on), and pulsed treatments which vary in pulse duration and interval). Data will be reviewed using video analysis software. Counts of bats during each test period, their use of the viewable airspace (in distance), and general behaviors will be recorded by the reviewer. Species composition of the study area will be compiled using bat acoustic monitoring systems and a bat call analysis software.

Objectives

The primary objective of Subtask 2.2 is to assess if the GE Prototype deterrent (Device) successfully deters all bats, including *Myotis* bat species. The secondary objective is to fully describe the deterrent distance effect of the Device. We hypothesize (H_a) that the presence of *Myotis* (and also other bats) within the study area is dependent on exposure to sounds emitted by the Device. The null (H_0) hypothesis is that presence of *Myotis* bats is independent on exposure to sounds emitted by the Device.

Study Site

Due to the emphasis of comparing the effects of the device on *Myotis* versus all other bat species, extensive effort and coordination were placed into finding suitable field sites with regular visitation by *Myotis* and other bats. In 2014, the US Fish and Wildlife Service (USFWS) and Illinois Department of Natural Resources (IDNR) staff provided useful insight in potential locations, strongly recommending the Middle Fork of the Vermilion River watershed and the Shawnee National Forest, in southern Illinois, as places where bat diversity was high. The Shawnee National Forest proved to be the more promising and practical location. Therefore, access was pursued and granted in April of 2015. The study is limited to areas along Centerline Road, which is a 3 mile long gated roadway flanked by several borrow ponds. An assessment of the prospective study areas along Centerline Road will be completed prior to initiating sampling. This assessment will include: 1) discussion with park biologists to obtain prior survey input (i.e. data from mist-net sampling) to define areas with increased numbers of Myotis bats that are greater than 500 feet from known *Myotis* roosts, 2) desktop survey of the net locations and immediate area to identify potentially suitable study locations, and 3) visual/acoustic survey of potential study locations in order to determine which of the previously-identified areas will be most suitable both in terms of number of bats and study equipment deployment.

Sampling Methods

The study area will be surveyed up to 24 separate nights throughout the study period; per the conditions placed upon the study by the DOE, USFWS, and USFS, no more than 5 consecutive nights will be sampled

The Device will be placed on a tripod 10 m from the study area during each sampling night. Air pressure for the device operation will be provided by connecting 6 compressed nitrogen tanks to a single supply hose via a custom manifold. Using reflective markers, the sampling area will be visually divided into 10 meter (m) increments in order to provide an approximate pass distance framework for each bat observation. Two infrared sensitive cameras (Sony® Handycam SR12) outfitted with night-vision monoculars and up to 8 infrared floodlights will be placed to cover as much of the airspace within the study area as possible. One camera will monitor an area between 10 and 20 m from the Device; the second camera system will monitor from 20-30 m. A Petterson® D500x acoustic detector will be used to passively collect bat calls and confirm Device operation during each sampling night. At least 2 technicians will be present each study night; one technician will operate the Device while the other will monitor the cameras to ensure they are functioning properly. While the survey markings for each piece of equipment will likely remain until the end of the season, all electronic equipment will be removed from the area after each sampling night.

Once the study setup is completed, nightly sampling will commence either half an hour before sunset or after the first bat has been sighted in the area, whichever occurs later. Bat activity has been demonstrated as greatest for the first 5 hours after sunset, and is thought to exhibit a non-linear pattern (Hayes 1997, Kunz 1973). Therefore, within each sampling night, the experimental sequence will be repeated twice, utilizing approximately 2 total hours. The study design will operate 10 minute (min) treatment periods separated by 10 minute “rest” periods. The order of treatments will be assigned randomly in each experimental iteration. Treatments consist of a horizontal orientation with constant emission, a 1 sec 50% duty cycle (1 sec on, 1 sec off), and a 1 sec 33% duty cycle (1 sec on, 2 sec off).

Meteorological conditions such as temperature, wind speed, wind direction, relative humidity, and barometric pressure will be recorded with a Kestrel weather meter every half hour. Sampling will only occur on nights with appropriate weather conditions for bat activity (i.e. relatively calm winds, no precipitation, temperatures above 10˚C (50˚F), etc.).

Data Management and Analysis

We will process raw video using motion-detection software (i.e Briefcam), to initially determine whether each file contains possible bat passes. Video files containing probable bat passes will be reviewed manually using Windows Media Player and VLC Media Player. The reviewer will watch each of the files and note the amount of time into the file that a bat or unidentified object (hereafter “target”) passed through the field of view. Additionally, the elapsed time of each observation, bat behavior notes, the number of passes through each distance band, and other notes on the video will be recorded in an electronic spreadsheet. The bat pass information will be organized by treatment period for further statistical processing.

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ATTACHMENT F

Milestone M2.2.2

DE-EE0007035
General Electric Company
Ultrasonic Bat Deterrent Technology

This document presents the results of Subtask 2.2 and the completion of Milestone 2.2.2

> ***Milestone 2.2.2 – Demonstrate reduced bat activity and that the bats do not closely approach the acoustic deterrent in field tests at Shawnee National Forest.***

Executive Summary

The purpose of the 2015 ground-based study was to observe the effect the deterrent had on bats, specifically any *Myotis* species, while the device cycled through a series of acoustic signal treatments (e.g. continuous and pulsed treatments). Testing was conducted at Oakwood Bottoms, a forested parcel located within Shawnee National Forest in southern Illinois. This location was recommended by biologists at the U.S. Fish and Wildlife Service, the Illinois Department of Natural Resources, and the U.S. Forest Service as a location with strong populations of *Myotis* bats.

Twenty four nights were surveyed between August 20, 2015 and September 24, 2015. Two to 3 technicians managed the field equipment setup including a deterrent device and air tanks, 2 video cameras outfitted with night vision monoculars, and 2 acoustic detectors. Video cameras captured 2 separate views of the scene during treatment periods. Raw video data was reviewed for individual bat passes. Counts of bats during each test period, distance and flight direction to the deterrent, and general behaviors were recorded by the reviewer. Bat count data within each of 3 distance zones (0-10 meters [m], 10-20 m, and 20-30 m) were tested for deterrent effects. Species composition of the study area was compiled using bat acoustic detectors and bat call analysis software. Eastern red bat (*Lasiurus borealis*) and *Myotis* presence was manually confirmed for each treatment period; this data was used to test for species effects.

A total of 623 calls from eight species were identified by an automated classifier. Big brown bat (*Eptesicus fuscus*) and eastern red bat were the most commonly detected species. Little brown bat (*Myotis lucifugus*) was the only *Myotis* species positively identified during the automated analysis; it comprised 4% of the total bat calls. *Myotis* bats were present during 31 of the 40 treatments used for analysis, as determined through the additional manual review of bat calls recorded during each treatment period.

Milestone 2.2.2 was successfully achieved; the results confirmed certain deterrent signals reduced bat activity, with the constant signal significantly deterring bats out to 20-30 m. The pulsing signal results were inconclusive, very likely due to the pulse signal length (1 sec) acting in concert with the narrowness of the study area. Sixty four percent of the bats passing through the study area during the pulsing treatments did so during a “pulse off” or silent period between deterrent pulses. A nonsignificant reduction in species-specific activity was detected, with nonsignificance attributed to the far distance of the acoustic microphone and/or because the data resolution was limited to species presence/absence.

Objectives

The primary objective of Subtask 2.2 was to assess if the GE Prototype deterrent (Device) successfully deters all bats, including *Myotis* bat species. The secondary objective was to fully describe the deterrent distance effect of the Device. Milestone 2.2.2 states the experimental protocol for the behavioral study at Shawnee National Forest was to be conducted. We hypothesized (H_a) that the presence of *Myotis* (and also other bats) within the study area was dependent on exposure to sounds emitted by the Device. The null (H_0) hypothesis was that presence of *Myotis* bats is independent of exposure to sounds emitted by the Device.

Study Site

The Shawnee National Forest is located in the Shawnee Hills of Southern Illinois and consists of approximately 265,600 acres of federally managed lands (Figure 1). Much of what is now the Shawnee National Forest had been heavily exhausted farmland until it was acquired by the U.S. Forest Service during the 1930's. Restoration of the land has been ongoing successfully since it was obtained and is now home to several different bat species. The Shawnee National Forest has identified 15 caves that many of the cave bat species will use as hibernacula over the winter months (McCreedy et al. 2004).

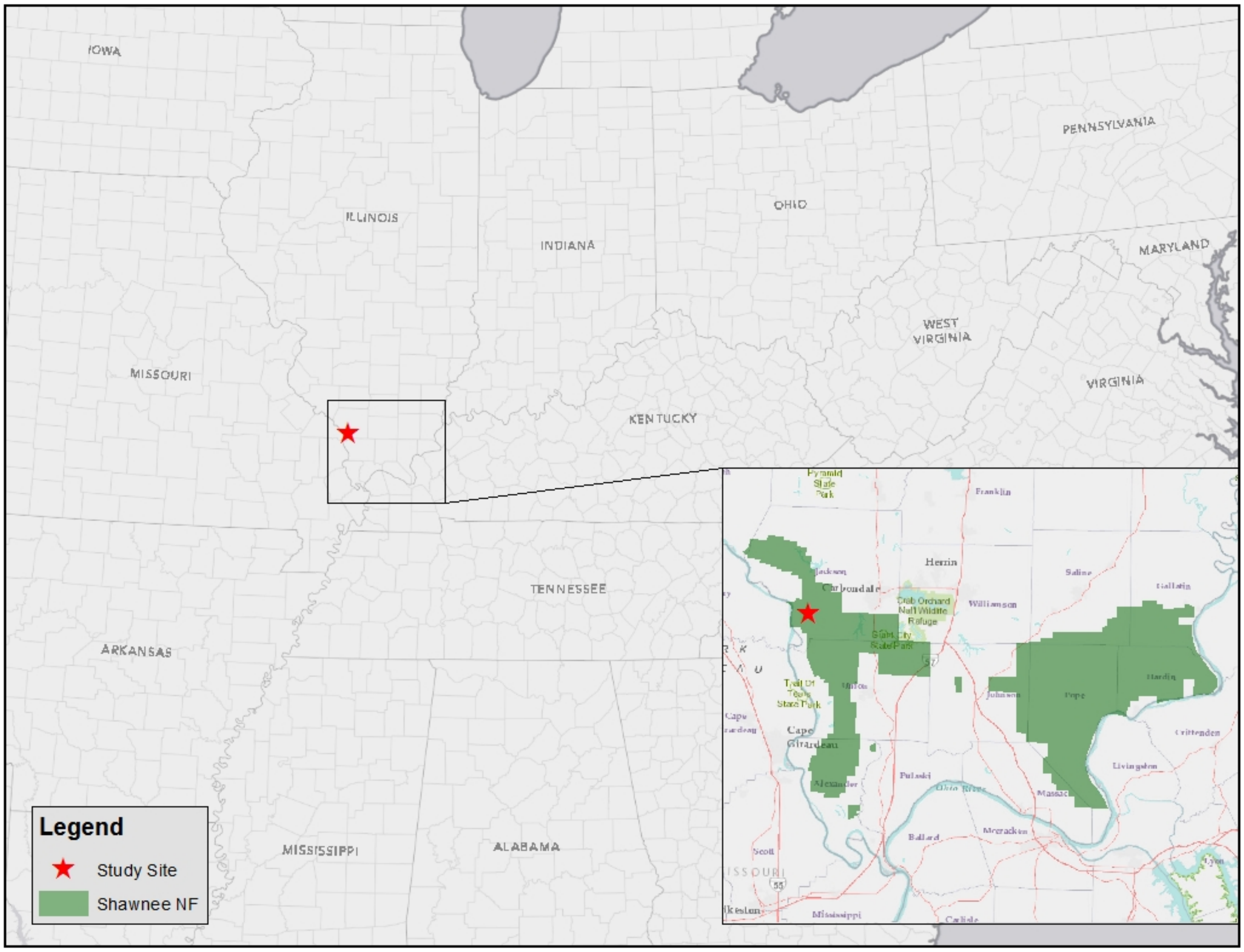


Figure 1. Location of the study within the Shawnee National Forest

Oakwood Bottoms is a bottomland forest located within the Shawnee National Forest in Jackson County, Illinois. The forest is dominated by oak-hickory tree species but also has remnant stands of pine species, which were used to help stabilize the soil during the beginning of the forest's restoration (Brandt et al. 2014). Restoration that has taken place from the 1960's up until the present has resulted in the construction of the Greentree Reservoir system which includes approximately 680 acres of wetland habitat within four wetland areas, 200 acres of timber stand improvement, and 250 acres of reforestation (Ducks Unlimited 2016).

The Oakwood Bottoms vicinity is known to harbor large numbers of Myotis bats during the summer months (Chad Deaton, USFS, Pers. Communication). The study was limited to areas along Centerline Road, a 3 mile long gated roadway flanked by several borrow ponds. An assessment of prospective study areas along Centerline Road was completed prior to initiating sampling. *Myotis* presence was confirmed by technicians on August 18,' 2015 and August 19, 2015 through use of a Pettersson® D500x and a Wildlife Acoustics® EchoMeter Touch at 2 different locations along the road. Of the two sites, a length of gravel driveway situated next to a highly vegetated pond was selected.

Study Setup

Each night, the device was placed on a tripod at one end of the study area (Figure 2). Distance markers crafted out of sections of foam tubing and reflective tape were placed on the ground at 0, 10, 20, and 30 meters from the device (Figure 5). Two infrared sensitive cameras (Sony® Handycam SR12) outfitted with night vision monoculars (ATN NVM14-3) were utilized to record the study scene. Camera A was placed perpendicularly to the direction the device was facing and Camera B was placed facing directly towards the deterrent at the edge of the study scene (Figures 3-5). Depending on natural light availability, up to 6 infrared floodlights were used to illuminate the study area. Two acoustic detectors were set to automatically record bat activity during each of the study nights. The Echometer Touch was placed by one of the technicians 30 meters from the device and the Pettersson was mounted on a tripod 10 meters from the device with the microphone approximately 1.5 meters off the ground, pointed at a 45 degree upward angle. Technicians monitored the operation of each video camera and the device throughout the entire study. All equipment, aside from stakes marking equipment placements, was removed from the area after each sampling night.

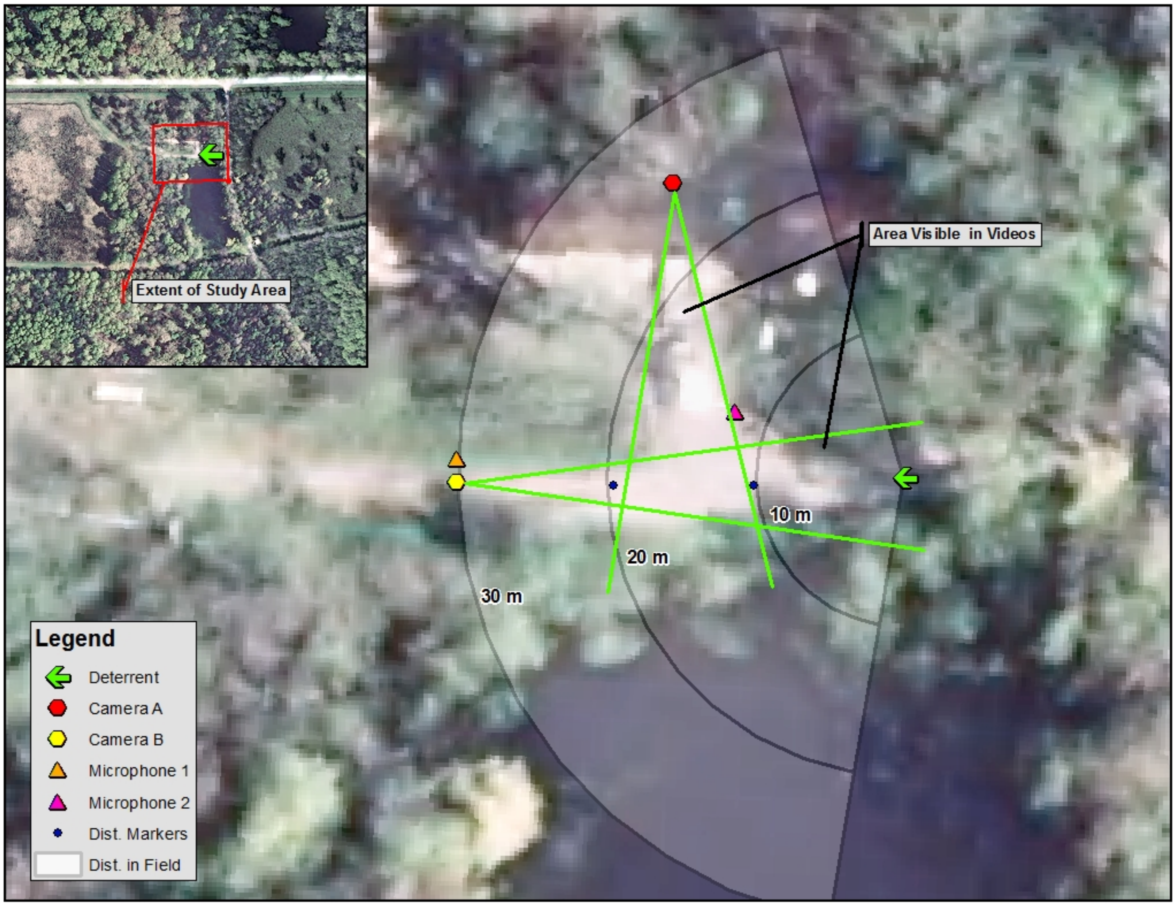


Figure 2. Diagram of the study area at Oakwood Bottoms

Figure 3. View of the study area from behind the deterrent location

Figure 4. View of the study area from Camera A

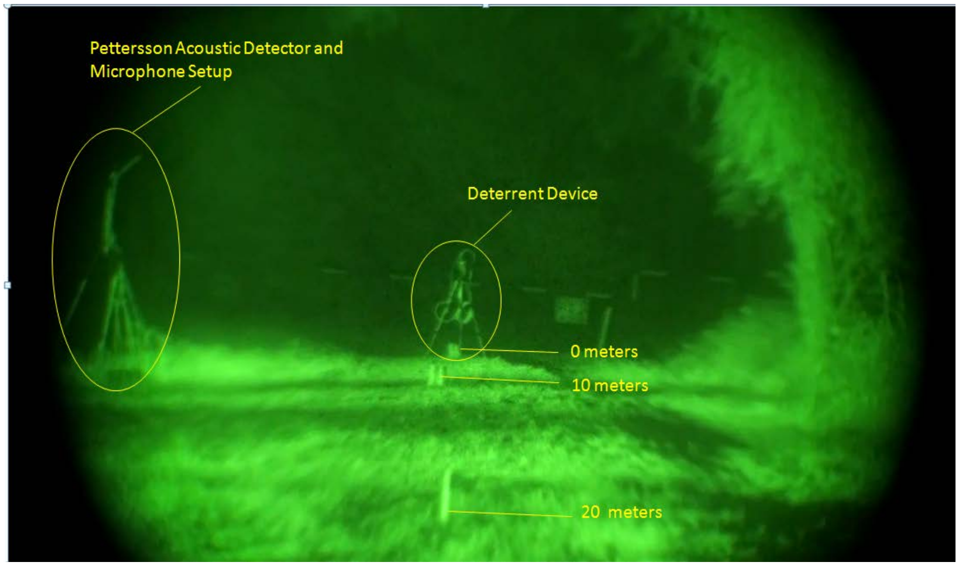


Figure 5. View of the study area from Camera B

Sampling Methods

Sampling was conducted over 24 evenings between August 20 and September 24. Sampling was performed for no more than 3 consecutive nights after which at least one rest night was given to the study area. Nightly sampling began once the first bat was detected and concluded 3 hours after sunset. The technician stationed at Camera A was in charge of operating the deterrent, following random-order pairs of treatments. Treatments included a constant emission, a 1 sec 50% duty cycle (1 sec on, 1 sec off), and a silent control. Each night typically had 4 samples of 3 10-minute treatments separated by 10 minute rest periods. A full night of testing took 3 hours and 40 minutes to complete.

Meteorological conditions including temperature, wind speed, wind direction, relative humidity, and barometric pressure were recorded during each treatment using a Kestrel® weather meter approximately every 20 minutes. Sampling only occurred on nights with appropriate weather conditions for bat activity (i.e. relatively calm winds, no precipitation, temperatures above 10˚C (50˚F), etc.).

Data Management and Analysis

Video files were reviewed using Windows Media Player. The reviewer watched each video, noting the amount of time into the file that a bat or unidentified object (hereafter "target") passed through the field of view. This information, along with the elapsed time of each observation, bat behavior notes, the number of passes through each 10 m distance band, direction of flight relative to the deterrent (toward, away, perpendicular), and other notes on the video were recorded in an electronic spreadsheet. Bats were assigned to one or more 10 m zones by comparing their position in both cameras. For instance, a bat passing through 10-20 m was generally detected on both Camera A and B.

Each target was characterized by an initial observer and then reviewed by at least 1 other to ensure proper identification. This assignment was completed visually, with observers referencing object size, apparent speed, wing beat patterns, and position in the frame. Both observers needed to agree that the target was a bat for it to be characterized as such. If a disagreement between the observers occurred, a third observer was called upon to make a determination.

Assignment of each bat to a treatment was completed using the time of observation relative to the times recorded on the field trial log. Since the cameras did not embed a time stamp in the video files, the time of file creation and total elapsed time for each file was paired with the elapsed time information for each bat. This information was then converted into an actual time of observation for each bat. Based on the time of observation compared to the treatment log for the respective night, each bat was assigned to the proper treatment period. The raw bat count data were tallied for each distance band within each treatment period. Because of the orientation of the study area (Figure 2), the 10-20m data was revisited and those bats flying perpendicular to the deterrent were removed from consideration.

Acoustic data was processed using Sonobat™ ver. 3.2. The data from the Echometer Touch was used in analysis, as it was placed far from the deterrent and was more likely to provide unbiased acoustic data during all samples. Once the entire season's acoustic data was processed using batch classifiers, those calls recorded during each 10 minute sampling event were manually reviewed to confirm proper assignment of eastern red bat (*Lasiurus borealis*) and *Myotis* to the respective files. The acoustic data was used to describe the bat community present during the study period and to determine presence/probable absence of eastern red bats and *Myotis* species during each treatment.

The bat count data were analyzed using a generalized linear model (GLM) based on a Poisson error structure and log-link. The experimental design was analyzed as a randomized block design with treatments (3), distance zones (3), and interactions (4) of the form

$$\ln y_{ijk} = \alpha + \beta_i + \tau_j + D_k + \tau D_{jk} + \epsilon_{ijk}$$

where

y_{ijk} = bat count for the *i*th block $(i = 1, \cdots, 40)$, *j*th treatment $(j = 1, \cdots, 3)$, and *k*th distance class $(k = 1, \cdots, 3)$

α = baseline,

β_i = effect of the *i*th block $(i = 1, \cdots, 40)$;

τ_j = effect of the *j*th treatment $(j = 1, \cdots, 3)$;

D_k = effect of the *k*th distance class $(k = 1, \cdots, 3)$;

τD_{jk} = interaction between the *j*th treatment and *k*th distance class;

ε_{ijk} = random error term.

Analysis of deviance (ANODEV) was used to test for treatment, zone, and treatment-by-zone interactions. Generalized likelihood methods were used to account for overdispersion, and *F*-tests were used to test for effects. Variance estimates were also adjusted for overdispersion. Treatment-by-zone interactions were expected if distance classes were far enough for sound attenuation and treatment effects were to be encountered in the nearfield.

For each 10-min trial, the presence or absence of *Myotis* spp. or eastern red bats was recorded. The presence/absence data were in reference to the entire study area, not the different distance zones. Hence, these data were analyzed using a GLM based on a Bernoulli error structure and logit-link using the response model

$$\ln\left(\frac{p}{1-p}\right) = \alpha + \beta_i + \tau_j + \varepsilon_{ij}$$

where

p = proportion;

α = baseline;

β_i = effect of the *i*th block $(i = 1, \cdots, 40)$;

τ_j = effect of the *j*th treatment $(j = 1, \cdots, 3)$;

ε_{ij} = random error term.

Analysis of deviance was used to test for treatment effects according for overdispersal based on *F* –tests. Variance estimates were also adjusted for overdispersal.

Results

A total of 1,763 bat passes were recorded during the study. High frequency bats comprised 58% (n=1,025) of the total bat pass count. Not every bat call was classified to species by the batch attribute algorithms; 623 calls were identifiable to species. Big brown bat (*Eptesicus fuscus*) was the most commonly detected bat species (34%), followed by eastern red bats at 28%. Little brown bat (4%) was the only *Myotis* species positively classified during the batch processing (Figure 6).

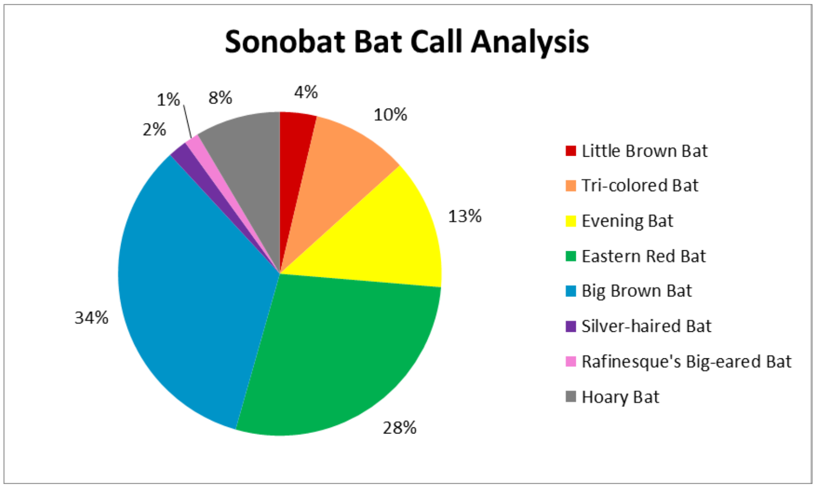


Figure 6. Species composition recorded on Echometer Touch detector placed 30 m from deterrent

A total of 79 sampling periods were completed. Of these, half (n=37) did not have any bats observed during video review. Two others were excluded because temporary equipment malfunctions caused one or more of the treatment periods to fall short of 10 minutes. The 170 bat passes recorded in the remaining 40 samples were used in bat pass analysis (Table 1). Most bats only passed through the study area once (58.33%) or twice (23.31%, Table 2).

Table 1. Summary of bat passes recorded during the 40 sample periods used in statistical analysis

	0-10 m	10-20 m	20-30 m	Total
Constant	1	27	14	42
Pulsing	13	28	19	60
Control	16	29	23	68

Table 2. Counts of treatment periods with n bat passes per treatment

	0-10 m			10-20 m			20-30 m		
Count	**Constant**	**Pulsing**	**Control**	**Constant**	**Pulsing**	**Control**	**Constant**	**Pulsing**	**Control**
0	75	69	71	62	62	61	72	64	67
1	3	6	7	6	10	12	4	9	6
2	1	2		6	2	5	1	4	4
3		2	1	2	4	1		2	1
4				2	1		2		1
5									
8				1					

The ANODEV found significant treatment effects ($P = 0.0617$) and significant zone-by-treatment interactions ($P = 0.0251$) (Table 3). Examination of the individual effects found that at the 0–10 m distance zone, the pulsating treatment was not significantly better than the control ($P = 0.2829$) with an estimated deterrent effect of 0.1895 ($\widehat{\text{SE}} = 0.3261$). However, the constant treatment was significantly better than the control ($P < 0.001$) with an estimated deterrent effect of 0.9375 ($\widehat{\text{SE}} = 0.0692$). In other words, the constant sound treatment deterred 93.75% of the bats within 0–10 m (Table 3).

The significant zone-by-treatment interaction existed because a treatment effect was found within the 0–10 m and 20–30 m zones but not the 10–20 m zone (Table 4). In zone 2 (i.e., 10–20 m), the mean bat counts were nearly identical between treatments (Figure 7). In zone 3 (i.e., 20–30 m), the constant sound treatment was significant once again ($P = 0.0393$) but not the pulse treatment ($P = 0.2640$) (Figure 7).

Two potential causes for the apparent ineffectiveness include: 1) signal attenuation due to the physical shape of the study area and/or 2) some signal fluctuation in the 10-20 m zone. To elucidate whether the nonsignificance in the 10-20 m zone was caused by the study area, all instances of bats passing perpendicular to the data was removed from the analysis. It was hypothesized that bats transiting the road intersection were prevented from exposure to the noise produced by the device by the vegetation bordering either side of the access roads and the pond edge (see Figure 2). Once these perpendicular-traveling bats were removed, the data from 10-20 m agreed with the results observed in the 0-10 and 20-30 m zones. At 10-20 m, the pulse sound was not effective ($p=0.5357$); however, the constant sound was now significantly effective ($p<0.001$) at deterring bats (Figure 8). The deterrent was effective at reducing bat passes by 40.0%, when bats did not fly perpendicular to the deterrent.

One explanation for the non-significant effects of the pulsing sound is that bats were able to enter the study area during the silent portion of each pulse. To assess this, the 45 bat observations taken during pulse treatments were reviewed. Of the 45 bats, 29 entered or completely passed through the study area while the deterrent was silent. In 3 instances the deterrent sounded as the bat entered the scene and the bat reversed or changed course to exit the study area.

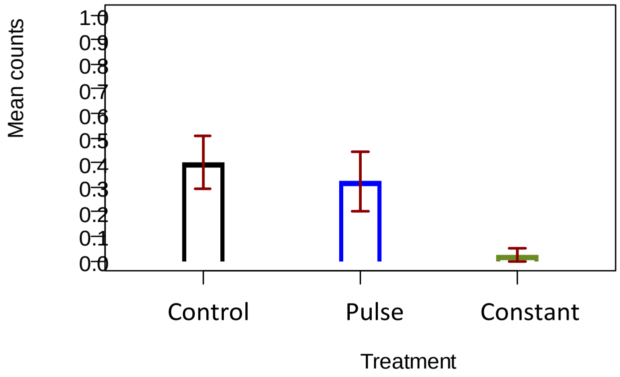
Table 3. Analysis of deviance (ANODEV) table for bat counts by treatment, zone, and block. Analysis based on a generalized linear model with Poisson error structure and log-link.

	DF	Deviance	Mean Dev.	*F*	*P*(>F)
Total$_C$	359	489.6074			
Block	39	82.9651	2.1273		
Zone	2	26.6452	13.3226	11.5319	<0.0001
Treatment	2	6.4954	3.2477	2.8111	0.0617
Treatment x Zone	4	13.0527	3.2632	2.8246	0.0251
Error	312	360.4491	1.1553		

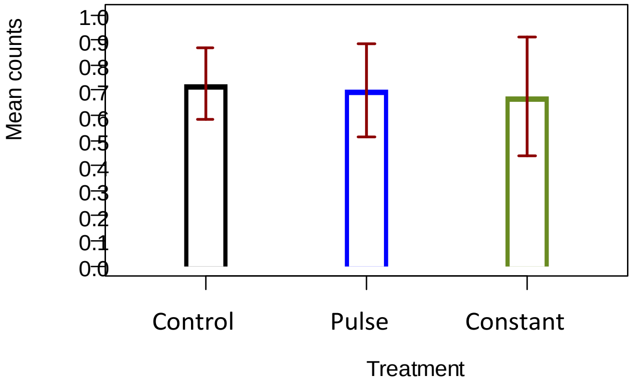
Table 4. Estimated deterrent effects on bat counts, standard errors, and *P*-values associated with a test of beneficial deterrent effect.

Treatment	Zone	Deterrent Effect	SE	*P*-value
Pulsating	0–10 m	0.1875	0.3261	0.2829
Constant		0.9375	0.0692	<0.0001
Pulsating	10–20 m	0.0345	0.2750	0.4501
Constant		0.0690	0.2676	0.3983
Pulsating	20–30 m	0.1739	0.2753	0.2640
Constant		0.3913	0.2218	0.0393

Zone 0–10 m



a. Zone 10–20 m



b. Zone 20–30 m

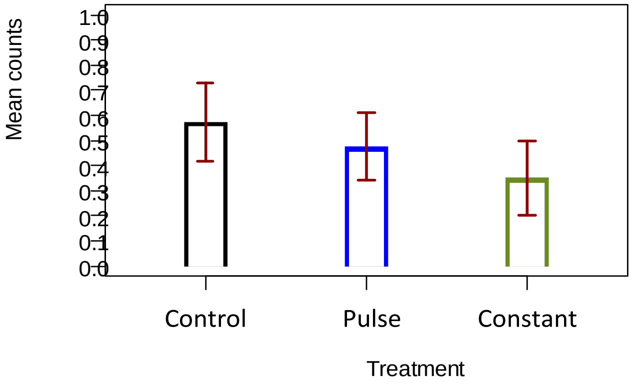


Figure 7. Mean bat passes per trial by treatment and zones, i.e., a) 0–10 m, b) 10–20 m, and c) 20–30 m. Bars indicate ±1 standard error about the mean.

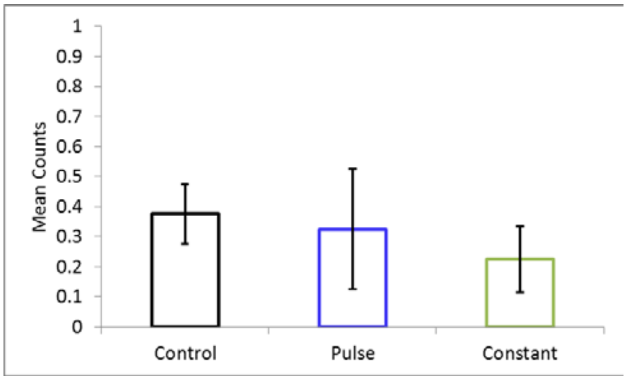


Figure 8. Mean bat passes per trial by treatment in the 10–20 m zone, after adjusting for study area influence. Bars indicate ±1 standard error about the mean.

Species effects were tested using the *Myotis* and eastern red bat presence/absence data. No significant effect for either the constant or pulsating treatments was found in the presence/absence data for either *Myotis* spp. (*P* = 0.3245, Table 5) or eastern red bats (*P* = 0.4941, Table 6). Graphs of the observed proportion of trials with bat presence indicate some decline in value with the constant sound treatment, but the differences are not significant (Figure 9).

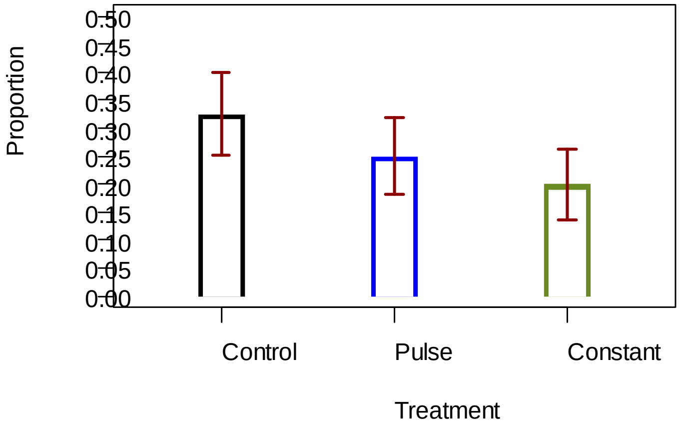
Table 5. Analysis of deviance (ANODEV) table for the presence/absence of *Myotis* spp. as a function of block and treatment effects. Analysis based on a generalized linear model with Bernoulli error structure and logit-link.

	DF	Deviance	Mean Dev.	*F*	*P*(>F)
Total_C	119	137.1135			
Block	39	49.2746	1.2635		
Treatment	2	2.4988	1.2494	1.1420	0.3245
Error	78	85.3401	1.0941		

Table 6. Analysis of deviance (ANODEV) table for the presence/absence of eastern red bats as a function of block and treatment effects. Analysis based on a generalized linear model with Bernoulli error structure and logit-link.

	DF	Deviance	Mean Dev.	*F*	*P*(>F)
Total_C	119	152.7634			
Block	39	61.1054	1.5668		
Treatment	2	1.6420	0.8210	0.7114	0.4941
Error	78	90.0160	1.1541		

Myotis spp.



a. Eastern red bats

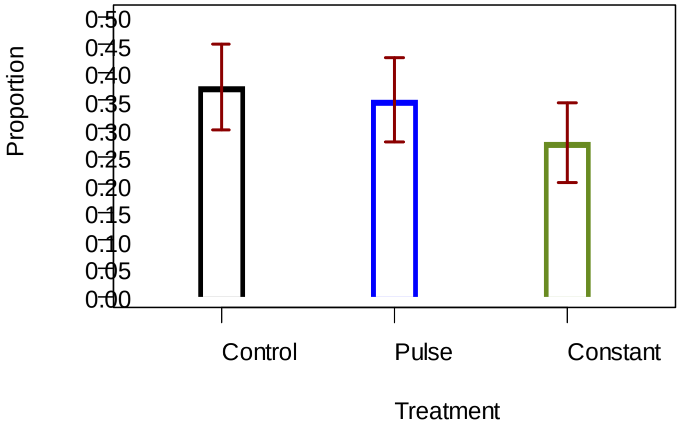


Figure 9. Observed proportion of trials with the presence of a) *Myotis* spp. or b) eastern red bats by treatment. Bars indicated ±1 standard error.

Discussion

The results of the field testing in Subtask 2.2 have shown that Milestone 2.2.2, “Demonstrate reduced bat activity and that the bats do not closely approach the acoustic deterrent in field tests at Shawnee National Forest”, has been satisfied. The device has a graded effectiveness to 20-30 m during the constant signal; a 93.75% efficacy at 0-10 m reduces to a 39.13% reduction at 20-30 m. Szewczak (2011) suggested effective ranges of approximately 20 m for acoustic bat deterrents. There is some reservation in knowing the exact extent of the constant sound treatment effect, because no difference in bat counts was detected at the intermediate zone of 10–20 m during the initial analysis. The increase in bat passes through the 10-20 meter zone, along with observations of bat behavior by the technicians, suggests that the bats utilize this area as a through-way to access the pond. Since many of the bats that flew through this zone generally took a straight path and did not spend time within the study area or appear to be foraging, it is possible the deterrent had no effect on these particular bats at all. It may also be possible the bats were shielded from the sound emitted by the device until they were straight in front of it. Fan et al. (2010) determined that arrangements of vegetation can be used to attenuate high frequency (> 10kHz) sounds.

Because of this perceived effect, the bat passes recorded as crossing the study area were removed from the 10-20m zone and the data was re-analyzed. Once these bats were removed from consideration, the constant signal was determined to be effective at deterring bats. This result confirms that the original result was obfuscated by bats that were only once briefly exposed to the deterrent signal.

The pulsing signal had no significant effect, due to the narrowness of the study area interacting with the length of the silence in the pulse cycle (Figure 3). This reason was supported by the observation that 64.44% of the bats passed through the study area between deterrent pulses. In future deterrent deployments, care should be taken to align the length of silent periods with the targeted deterrence area to ensure that bats cannot pass through it while the deterrent is silent.

This study did not find statistical significance in any species-specific effects as have been observed in other research. The Task 1.2 research, which performed deterrent tests on captive bats in a flight room facility, found that different bat species altered their behavior in different ways during deterrent tests. Eastern red bats, for example, did not alter their physical activity, but reduced the number of foraging calls they made, whereas Mexican free-tailed bats (*Tadarida brasiliensis*) were not at all physically active during deterrent tests.

Carcass tests during real-world application of acoustic deterrents also demonstrated species-specific effectiveness. The 2015 carcass monitoring at the California Ridge Wind Energy Facility determined that eastern red bats were not deterred from collision with operating turbines (Romano et al. 2015). Arnett et al. (2013) also found differences in deterrence effects by species. This contradiction between the bat count analysis and the presence/absence analysis might be due to the following possible reasons:

a. Presence/absence data (i.e., 0, 1 data) are less informative than count data, which indicate both the presence/absence and the quantity of bats.

b. The presence/absence data cover the entire study area (i.e., 0–30 m), which includes zones 10–20 m where bat counts were found not to differ between treatments. Hence, the treatment effects may be diluted when the response is over the entire area.

In conclusion, the constant signal was effective at deterring a bat community including *Myotis* species out to 20-30 m. The pulsing signal results were inconclusive due to the preponderance of bats passing through the area while the deterrent was cycled off. Future deterrent placements and/or ground based studies should be cognizant of the pulse signal spacing relative to the focal deterrence area. Last, no species effects were observed for eastern red bats and *Myotis* species, but this was due to the less informative data collected at distance to the deterrent. Future studies attempting to focus on species effects should consider call count data or a different study layout.

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ATTACHMENT G

Milestone M3.2.1

DE-EE0007035
General Electric Company
Ultrasonic Bat Deterrent Technology

This document presents the results of Subtask 3.2 and the completion of Milestone 3.2.1.

> ***Milestone 3.2.1 – Complete Pulsing Design which includes design documentation and prototype system performance measurements (Month 6 of BP1)***

EXECUTIVE SUMMARY

In Task 3, the objective was to utilize all of the available information from other project tasks to redesign the deterrent for increased effectiveness. One key learning that came from the 2015 carcass study, that was performed external to the DOE program, was that the redeployed deterrent was approximately 30% effective against all bat species and 56% effective for all pooled species once Eastern Red bats were removed from the data. This finding, along with other information learned from the DOE project tasks indicated that the overall effectiveness could be improved by increasing the number of deterrents on the nacelle and tower and by altering the ultrasonic emissions in a way that would be more effective at deterring Eastern Red bats. With these two goals in mind, the GE Team designed a pulsing deterrent system that allows up to eight deterrents to be powered by the existing compressors. Additionally, the pulsed system can tune the acoustic emissions to a wider frequency range. In this way, it is believed that both objectives of increasing the deterrent coverage with more deterrents and more effectiveness against Eastern Red bats can be achieved. However, there is a dependency of the tuned frequency range to the number of deterrents that can be operated. Therefore, the final design was determined to locate two deterrent nozzles on the tower at each of the 3rd and 4th tower decks as well as two on the rear of nacelle. The team has designed the deterrent to emit the appropriate acoustic signal covering broadband (0-30kHz) and the high frequency region of 42 kHz- 53 kHz. The final design will run the 6 nozzles on a 50% duty cycle of 3 seconds on, 3 seconds off. The system is directly integrated into the turbine controller with existing spare channels. The simplicity of design ensures system functionality and reliability for turbine installation of the 2016 DOE testing.

Task 3 - Deterrent Integration Design

Task Summary: Tasks 1-2 studied the behavioral response to continuous and intermittent (pulsing) acoustic signals produced by the deterrents in a controlled flight room and several field locations. Armed with the results of these tasks, the next step is to determine the best deterrent location on the turbine, design the deterrent to emit the appropriate acoustic signal in that location, and integrate the deterrent into the wind turbine machine architecture in a manner that would ensure system functionality and reliability.

Subtask 3.1 – Determine Deterrent Location (M3-M6)

Subtask Summary: Interpret data from prior behavioral studies (Tasks 1, 2, and 4.1) to understand bats' response to the type (continuous, pulsed), proximity, and directionality of acoustic sound produced by the deterrent. Optimize the behavioral response and acoustic properties into a set of proposed locations with multiple options (such as nacelle, tower, and blade locations) so that the design team can balance the cost / benefit ratio of the system with the available funds.

Subtask 3.2 – Design Pulsing System (M1-M6)

Subtask Summary: The current deterrent arrangement is limited to four individual deterrents that can be powered by the compressor system. The deterrents are operated with a steady airflow, but more deterrents could be operated from a single compressor if they were pulsed. Since it is anticipated that more deterrents are going to be needed than the current four, GE will begin the design work early in BP1 to engineer a pulsing deterrent system. The objective of this task is to design and test the necessary valve and control system required to pulse the deterrents with a variety of duty cycles. Component level design of the pulsing system includes the air supply system, pressure regulation system, pressure delivery system, and pressure monitoring system design to ensure automated, stable and reliable operation for the life of the system in the machine with minimal operational maintenance.

Introduction

Prior to the DOE grant, GE had been developing the deterrent system and performing field trials for effectiveness in reducing bat mortality at an operational wind farm. Carcass studies were performed with the deterrent installed on twenty 1.6-100 turbines in 2013, 2014, and 2015. Each year the deterrents were moved to different locations, but produced the same acoustic signal. The first year, four deterrents were installed on the front of the nacelle; the second year two were installed on the back of the nacelle and two on the tower; and the fourth year all four were installed on the tower. An interesting result from the three year study is that each year indicated on average about 30% reduction in bat carcass counts against all bat species combined despite the deterrents being located at different positions. However, if Eastern Red bats are excluded from the carcass data, the deterrent effectiveness significantly increases to approximately 56%. These results indicate that the deterrent effectiveness could be increased by placing more deterrents on the turbine and even more if the deterrent had greater effectiveness towards Eastern Red bats. These two objectives have been a major thrust of the DOE research and specifically of the GE task to redesign the acoustic deterrent.

Each of these objectives presents technical obstacles that need to be overcome in order to increase the deterrent effectiveness. The current GE deterrent design is a constant steady acoustic emission from the specially designed nozzle that generates ultrasonic sound based on the principles of jet acoustics. Two compressors in the tower provide air supply to the deterrent nozzle jets. A jet produces sound as a function of the ratio of supply pressure to ambient pressure. The sound amplitude increases exponentially as a function of the jet velocity which is determined by the jet operating pressure ratio. Additionally, the emitted frequency content is a function of the jet diameter and pressure ratio. By selecting the proper jet size and pressure ratio, the amplitude and frequency content can be controlled.

The deterrent nozzle is designed to produce broadband ultrasonic sound between 10-25 kHz in the range of “low frequency” bat species such as the hoary and silver haired bat while also producing a discrete tone in the range of “high frequency” bats typical of the Myotis species near 50 kHz. In the field of jet acoustics, this discrete tone is called a “screech” tone. The exact frequency of the screech tone is determined by the jet size and operating pressure. Figure 1 shows the deterrent frequency spectrum operating at a steady supply pressure measured approximately 10 m from the deterrent.

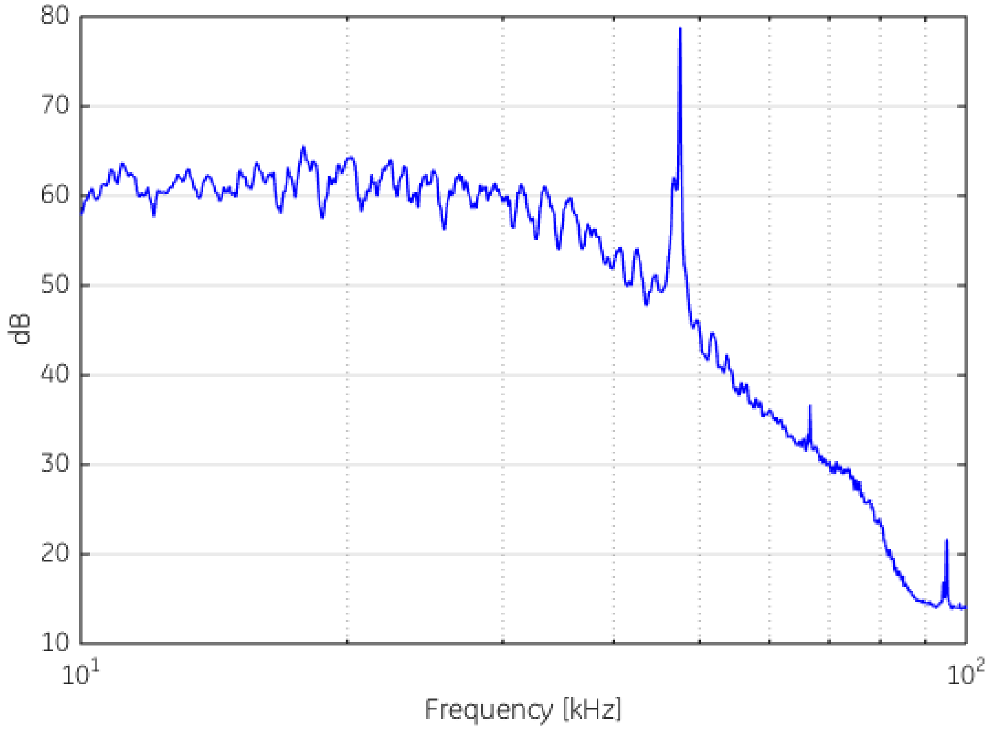

Figure 1. Frequency verses amplitude of acoustic signal output

The first technical obstacle to the redesign objectives is that in order to increase the number of deterrents beyond the four that are currently being supplied by two compressors, the nozzle air flow would need to be pulsed such that more nozzles could be operated at the necessary pressure ratio. This creates an engineering challenge of designing a pulsed system that meets the required operation and creates a biological challenge that now there would be a short period of time where the bats would not hear the ultrasonic sound. All behavioral and field testing to date has been performed with a steady air jet so the deterrent signal was constantly present. The GE system would need to be modified to include on/off valves as well as account for the dynamics of the pressure system and its effects on the ultrasonic emission as the air was turned on and off.

The second obstacle associated with targeting more effectiveness against Eastern Red bats requires that the deterrent acoustic frequency range be changed to generate more energy in the Eastern Red calling frequencies. Based on learnings from Task 1.2 in the TCU flight room, it became clear that the original deterrent signal has a dip in the emission amplitude between 30-45 kHz which is the frequency range where Eastern Reds echolocate. Therefore, in order to be effective against Eastern Red bats, it is necessary to increase the ultrasonic signal in that frequency range. As will be seen, tuning the deterrent frequency is a challenge because of the significant system interactions and dependencies such that it is not possible to easily achieve all of the desirable frequencies simultaneously.

Due to all the factors associated with the objectives of increasing the number of deterrents and modifying the emitted frequency range, the GE Team was challenged with finding a way to pulse the jets and maintain effectiveness against all desired species. This milestone report summarizes the work that was performed and the final configuration that was selected for the 2016 field study.

Selection of Final Deterrent Configuration

The other projects tasks were designed to provide information enabling a redesign of the deterrent to be more effective and also provide guidance on where the deterrents should be placed for the 2016 field trial. As a summary, the following recommendations and observations from other project tasks and related work have provided GE with learnings that influenced the redesign described in this report.

- Flight room experiments suggest that the GE deterrent creates ultrasonic emission that is effective at preventing “low frequency” bats, such as sliver haired and hoary, and “high frequency” bats such as the Myotis species from coming into close proximity of deterrent, but effectiveness against Eastern Red bats could be improved by modifying the frequency range covered and increase amplitude in the 30kHz-45kHz range (Task 1.2)
- The Wolf Ridge turbine and pond ground study indicated no difference in bat activity between the steady and pulsing deterrent treatments which indicates that pulsing can be utilized on a given turbine (Task 2.1). Unfortunately, due to the late start of the ground test work waiting on the NEPA approval, there was not time to fully explore all of the pulsing parameters of interest or to test the final deterrent configuration.
- The Shawnee ground test suggest that to ensure maximum coverage, deterrent devices should be placed within 30-40 m of one another (Task 2.2)
- Thermal imaging video results show that the vast majority of bat activity is below the nacelle. (Task 4.1)
- The results from the 2013, 2014, and 2015 field test work indicate that more deterrents placed on the tower and nacelle could increase the deterrent effectiveness.

Based on the above learnings, the project team decided that there is still significant opportunity to increase the deterrent effectiveness with nacelle and tower deterrents only. Blade mounted deterrents were considered, however the cost of the associated rotating system would be significantly higher than the deterrents mounted on stationary turbine components. Additionally, there was no evidence that rotating blade mounted deterrents would be more effective than stationary deterrents. Therefore, the blade mounted concept was dropped in favor of mounting more deterrents on the tower and nacelle. As will be shown, in the subsequent analysis, six nozzles appears to be a good configuration for the pulsed system and therefore the decision was made to install two deterrents on the nacelle and four on the tower for the 2016 field trial study. Given the apparent range of the deterrents, this configuration would cover the entire tower region plus additional coverage near the nacelle region.

Hardware Description

GE built a full scale deterrent system in the lab to accurately monitor and test the deterrent nozzle system to be applied to the 2016 turbine installation. The test rig used existing field components with added mechanical valve control to create a pulsing signal output. A GE test controller was used to actuate valves, control pressure regulators, and record pressure sensor readings. Figure 2 shows a picture of the system and components.

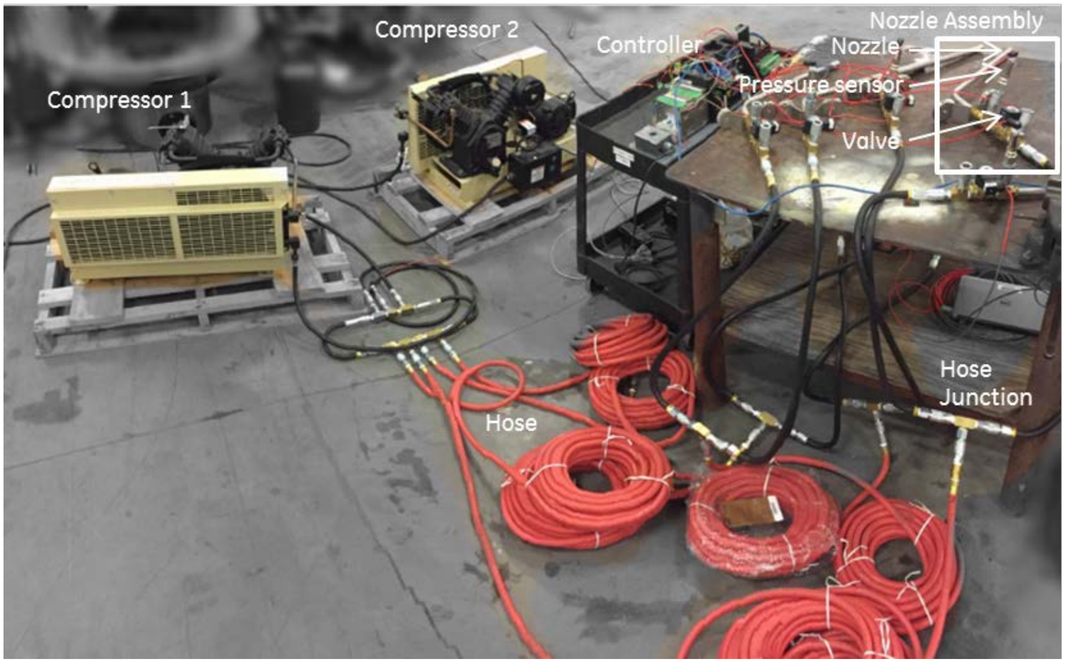

Figure 2. Full test rig configured in GE test facility. See Figure 3 for zoom in on nozzle assembly

The design includes a manifold loop to balance air flow to the output lines which would route to different sections of the turbine. Management of these hose lines is a key learning in order to achieve the desired acoustic emission. The system pressure accumulation relies on the dynamics of the full size hose lengths. These lengths come from the architecture of the turbine. The system was optimized using full scale hose lengths which, in the end, limit duty cycle and cycle time of the pulsing as it take time to build up pressure in the hose lines. The hose lines act as accumulators for the air supplied to nozzles and create a buffer such that when the valve is opened it takes some time for the nozzle to reach a steady output pressure while the pressure in the hose lines balances. Balancing the lines is necessary to provide consistent flow to individual nozzles. Therefore, when the system is pulsed it creates a dynamic that is based on the build-up and release of pressure at the nozzles. When the valve is opened, the nozzle is at maximum pressure and the hose volume results in a release of pressure. Since the nozzle acoustic emission is a direct function of nozzle pressure, this system dynamic of releasing the pressure causes the acoustic emission to also vary over time. Then when the valve is closed the hoses begin to build up pressure again until the valve is opened. Therefore, the pressure of the system that initially drives the nozzles is a function of how long the valves are closed between openings. As will be shown in the next section, this pulsing dynamic was used in the design of the deterrent operation to create frequencies in the range of the Eastern Red bat while still maintaining the higher frequencies needed to target Myotis species.

Figure 3 shows a picture of the entire ultrasonic emitter assembly. Valves are attached to the assembly in addition to a pressure sensor housing, the pressure sensor, nozzle chamber and nozzle cap. The nozzle is machined with a specially designed hole where compressed air is released to produce the desired acoustic signal output.

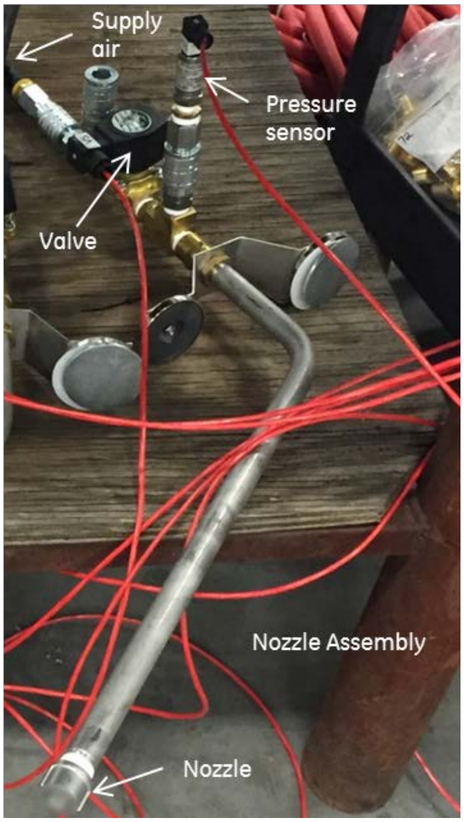

Figure 3 First image is an example of test rig nozzle assembly: valve (V5) and nozzle connection with pressure sensors (PS6). Nozzle is located at tip end of assembly.

The system is capable of testing any combination of nozzles (0-8), on/off operation, and sequencing of nozzles including duty cycle and varied combination of valves for evaluation. Test recordings were collected and consisted of regulator commands, valve commands, and pressure measurements over time along with acoustic emission.

Testing Results

The aim of system testing was to develop a better understanding of the design as well as the full capability of pulsing. Many different configurations were evaluated based on factors such as maximum pressure at valve opening, minimum pressure at valve closing, acoustic emission, duty cycle, and number of nozzles. Recall that the pulsing concept was introduced with the primary intent of allowing more nozzles to be utilized. However, through the course of the testing, it was observed that the entire system dynamic that led to a gradual rise and fall in pressure could also be used to control the acoustic output in a manner that gave flexibility in the frequency range emitted by the deterrent. This behavior can be used to better tailor the ultrasonic emission to target Eastern Red bats while still maintain the higher frequencies needed to target Myotis species. As described in the introduction, the broadband and tonal acoustic emission is strongly related to the nozzle pressure. Therefore, a great deal of time was spent understanding the relationship between the pressure pulsing dynamic and acoustic emission. Eventually GE was able to design a system such that the pulsing allows for sweeping through a wider pressure range to create a signal that will acoustically target more species.

After a series of intermediate test trails, the final phase of development was to optimize the pulsing configuration in the full scale system. Figure 4 shows representative dynamic results from this phase, showing optimization of the design based on accumulation time and pressure design targets for the needed acoustic signal frequencies. Each line on the graph represents a different configuration of the number of nozzles or duty cycle. It is seen that the pressure range through which the nozzle operates is a function of both duty cycle and the number of nozzles. With these relationships documented, the last step to selecting a final configuration was to correlate these pressures with the acoustic emission.

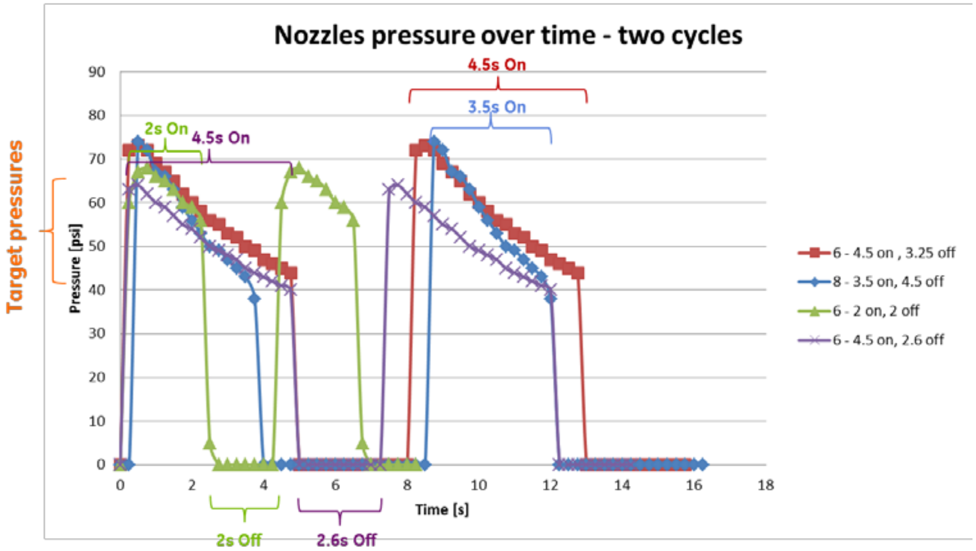

Figure 4 Plot shows four pressure curves over time in all nozzles for various configurations. Selected configurations are shown to help meet target pressure range.

It was observed that the frequency range of the broadband jet characteristic did not change significantly over the operating pressure range. However, significant change was seen in the jet screech frequency as the pressure changed. Figure 5 shows the acoustic spectrum of the jet run at several different steady operating pressures. When the pulsing system dynamic causes the operating pressure to sweep from high to low pressure, the resulting acoustic emission will change according the curves shown in Figure 5. Therefore, it can be inferred from the pressure ranges shown in Figure 4 that when the valve opens, the pressure will be at its highest level, the broadband noise amplitude will be at its highest level, and the screech tone will be at its lowest frequency. As the pressure in the system falls, the broadband noise amplitude will begin to reduce, and the screech frequency will increase. In this way, the redesigned GE ultrasonic deterrent is capable of generating a wider range of frequencies that should be able to deter a wider range of bat species.

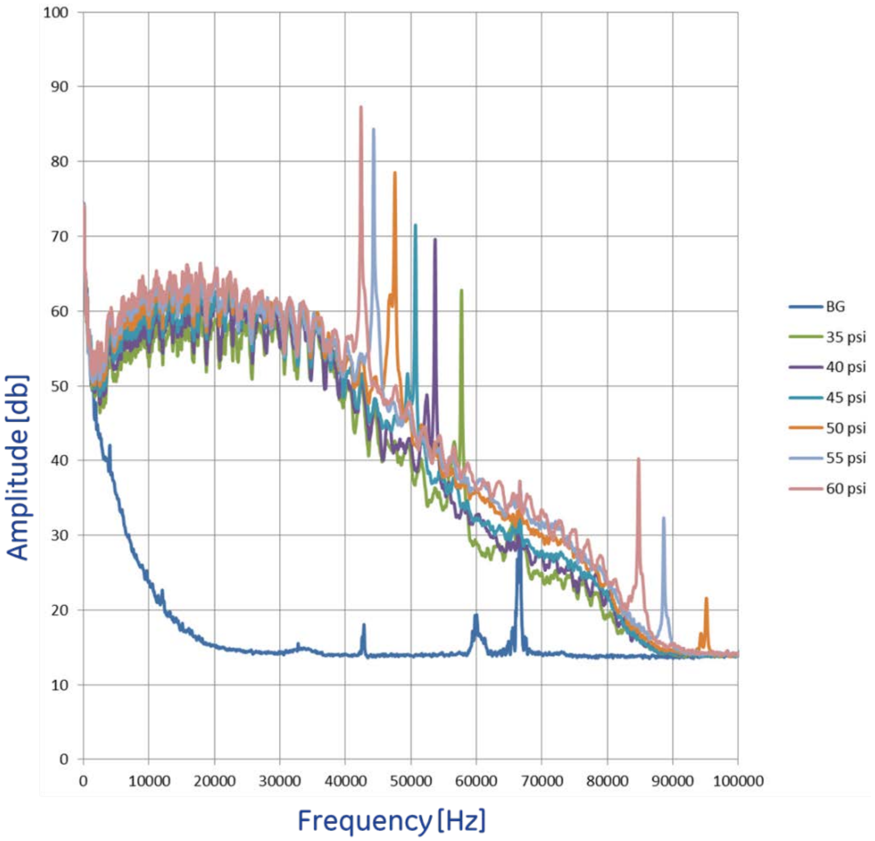

Figure 5 Frequency vs. amplitude of signal out of nozzle seen at discrete nozzle operating pressures

The main limitation of the system is that the entire frequency range of interest isn't able to be fully realized because of the relationship between nozzle pressure and screech frequency. Figure 6 shows the relationship between the screech frequency and deterrent nozzle operating pressure for three different configurations with different number of nozzles. It is seen that the frequency asymptotically approaches a minimum value near 42 kHz at very high pressures and a maximum near 55 kHz at low pressures.

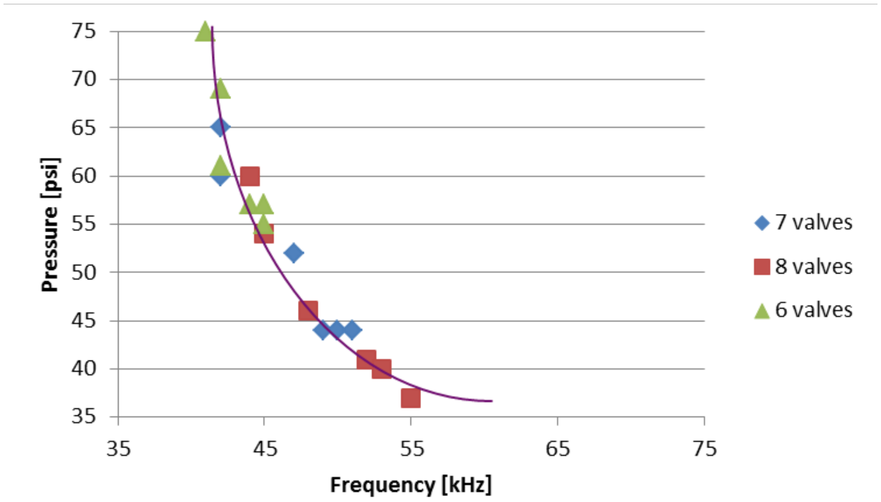

Figure 6 Relationship between nozzle supply pressure and acoustic output

Based on the information as described to this point, a deterrent configuration of 6 nozzles with a duty cycle of 3 seconds on and 3 seconds off was selected. Measurements were made to verify the acoustic emissions of this configuration and the spectrograms are shown in Figure 7. Colors in the spectrogram represent the sound amplitude. For reference, the figure on the left is the original deterrent signal and the figure on the right is the pulsing deterrent signal. In the original deterrent, the dark red line, representing very high sound amplitude, is the jet screech frequency and is horizontal because the frequency does not change over time. In the redesigned pulsing deterrent, the dark red line representing the screech tone is seen to sweep through a frequency range of approximately 42.5 kHz to 53 kHz during the time period when the deterrent is operating.

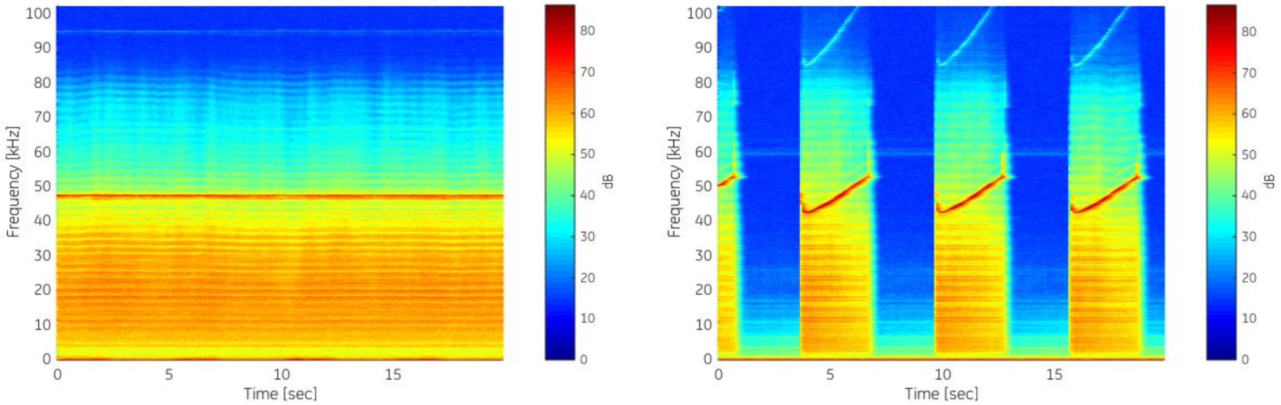

Figure 1. Acoustic signal output over time. Left: original static signal with four nozzles. Right: pulsing signal with 6 nozzles.

Figure 8 shows the time averaged frequency spectrum of the final configuration compared to the frequency spectrum of the original deterrent. The additional high frequency content is generated as the operating pressure sweeps down and the deterrent produces frequencies within targeted species range. It is believed that the redesigned deterrent signal will be more effective at deterrent bats including the Eastern Red bats.

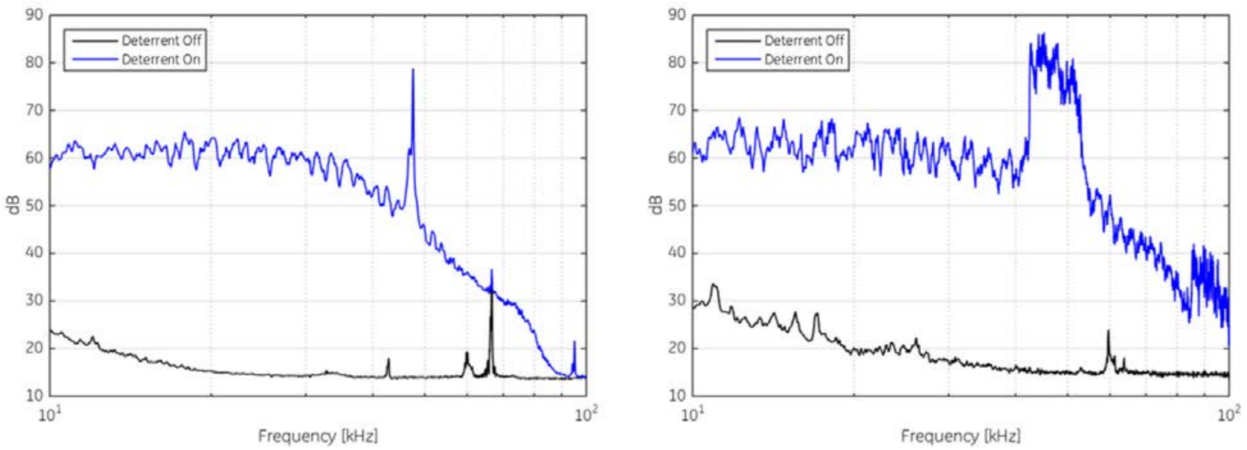

Figure 2. Acoustic signal output overlay of all signals over time to see total coverage at 10m. Note background noise of room when deterrent is off in black. Left: original static signal with four nozzles. Right: pulsing signal with 6 nozzles.

Final Design Recommendations

Based on field studies, system performance characteristics, and considerations of hose length in order to provide a balanced air supply, the team recommends a deterrent system with 2 nozzles on 3rd and 4th tower deck, and rear of nacelle. This design will reach acoustic frequency targets, provide signal coverage radially around close proximity of turbine, and fit within design architecture, as well as provide reliable and repeatable design in time for the 2016 installation and within the estimated project budget.

ATTACHMENT H

Milestone M4.1.1

DE-EE0007035
General Electric Company
Ultrasonic Bat Deterrent Technology

This document presents the results of Subtask 4.1 and the completion of Milestone 4.1.1:

> ***Milestone 4.1.1 – Demonstrate reduced bat activity and that the bats do not closely approach the acoustic deterrent when in current mounting configuration on the turbines at California Ridge Wind Energy Facility***

Executive Summary

Subtask 4.1 was completed at the California Ridge Wind Energy Facility in Champaign and Vermilion Counties, Illinois. The study objective was to determine whether a turbine tower-mounted 4-deterrent system could deter bats from the turbine tower. Two turbines were each fitted with the 4-deterrent system. Deterrents were oriented north and south, a pair each on the tower at ~26 and ~50 meters (m) below the nacelle. On each night, one turbine was assigned to a "deter" treatment and the other to a "silent" treatment. The "deter" turbine had its deterrent system enabled and emitting sound, and the "silent" turbine had its deterrent system disabled and silent. Two thermal cameras were placed beneath each turbine; they recorded bat activity between 18:00 and 06:00 from August 23 to September 4. Raw video was processed using a surveillance software program that detects small moving objects. The total number of bat passes within the field of view of each camera was initially recorded. The flight paths for a subset of bats that were observed simultaneously in both cameras' fields of view (the "model space"[1]) were reconstructed using Computer Aided Design (CAD) software. The flight path for each bat connected the CAD mapped points in time from the bat's initial entry into model space, through the closest approach point to the tower, and to the last observed location of the bat before exiting the model space. The flight path data was then used to calculate the approach distance to the nearest deterrent and the total time spent in model space. All flight paths were compiled into separate deter and silent CAD models, which were visually compared.

The number of bat passes was reduced 57.28% within ~20 m of the deterrent system. Bat approach distances to the nearest deterrent were ~4 m farther from deterrents when the deterrents were operating. Effects were visible in the distance histogram, with a right-skewed distribution of the number of bat passes peaking at 5-10 m from a deterrent under silent conditions and a less-right skewed distribution peaking at 15-20 m under deterrent conditions.

Time spent within the model space was similar under both silent (deterrent off) and deter conditions. Although the proportion of bats spending less than 10 seconds in the model space was similar for both deter and silent conditions, the maximum time spent by any bat under deter conditions was 14.4 seconds; while under silent conditions was 33.5 seconds.

In summary, Milestone 4.1.1 was successfully achieved, as we demonstrated bats were both reduced in number and dispersed farther in distance from the turbine when deterrents were

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[1] "Model space" was defined as the irregularly-shaped volume of space bounded by the intersections of the edge planes of the pyramidal fields of view of the two cameras.

operated, confirming the deterrent is effective. A demonstrated deterrent field of 5-20 m indicates that configuration of deterrents can be further refined to maximize coverage of risk areas.

Objectives

The objective of Subtask 4.1 was to assess if the GE Prototype deterrent (Device) deters bats from using the turbine airspace. Milestone 4.1.1 specifically states “Demonstrate reduced bat activity and that the bats do not closely approach the acoustic deterrent when in current mounting configuration on the turbines at California Ridge Wind Energy Facility”.

We hypothesized (H_a) that the noise created by the Device caused bats to avoid the airspace near the turbine. The null (H_0) hypothesis was that the activity (number, minimum approach distance, time spent) of bats was independent of Device operation.

Study Site

Thermal cameras were deployed at the California Ridge Wind Energy Facility (CRWEF), located in Champaign and Vermilion Counties, Illinois. It is owned by California Ridge Wind Energy LLC and consists of 134 1.6 megawatt (MW) turbines distributed across approximately 168 square kilometers (km, Fig. 1). The wind farm is located approximately 16 km Northwest of Danville, IL and approximately 32 km from Champaign, IL along State Route 49 North. The study area mostly contains agricultural land with sparsely distributed oak-hickory wood lots. The Middle Fork River runs along the eastern side of the wind farm; the river is approximately 3.2 km from the nearest turbine at its closest point. This river provides wildlife habitat in the form of temperate deciduous forest interspersed with tallgrass prairie. Night-time thermal video monitoring was performed at two turbines randomly selected from 20 deterrent-equipped CRWEF turbines with above-average carcass counts recorded from wildlife monitoring in 2014 (Fig. 1).

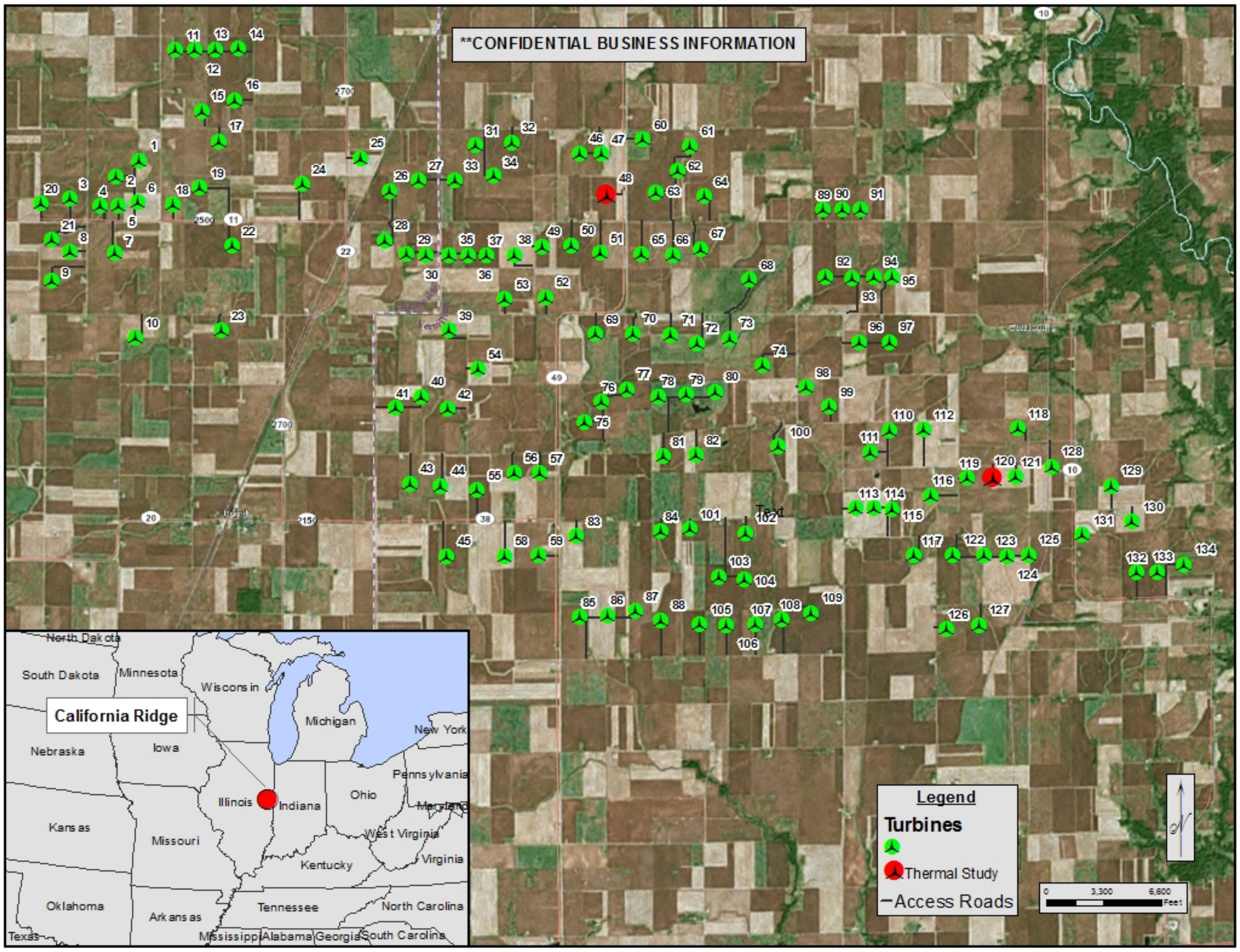


Figure 1. Map depicting Subtask 4.1 study locations within the California Ridge Wind Energy Facility

Sampling Methods

Three AXIS Q1922-E and 1 AXIS Q1932-E Thermal Network Cameras with a lens focal length of 19 mm (F 1.0) and a horizontal angle of 32 degrees were used to record bat images. Two cameras were placed at the base of each selected turbine, with identical camera orientations and upward angles at each turbine. One camera was placed 34 m southwest of the turbine and the second was placed 30 m to the northeast of the turbine (Fig. 2). Fully adjustable survey tripods with leveling heads (tribachs) and a custom designed tilting bracket were used as a camera platform. Cameras were rotated upward, with the nacelle centered at the top of each field of view. The cameras were set to record images in high definition using a view called “Fire and Ice” at 30 frames per second (fps). Camera systems were visited once every 3 days to retrieve video files, synchronize the camera timestamps, and perform an inspection of the camera system.

Figure 2. Thermal camera placement at base of Turbine 120

Each camera was connected to a power-over-Ethernet (POE) switch via Ethernet cables and networked to a single laptop computer housed in the base of the turbine tower. Both cameras from a single location were managed using Axis Communications Camera Management software (management software). The management software was used to program the recording schedule, synchronize the camera time stamps to the computer time registry, and fine tune each camera view during set-up. Nightly video data were stored on portable network hard drives.

Four deterrents were mounted on each turbine. The upper deterrents were placed approximately 26 m below the nacelle and the lower pair was mounted approximately 56 m below the nacelle. Deterrent pairs were oriented north and south, approximately 180 degrees apart.

Deterrent treatment application was randomly assigned, and followed a 3-day rotation schedule. That is, the deterrent-on “treatment” (deter) was in effect at the assigned turbine for 3 days, and then the assignment switched to the “silent treatment (deterrent off, “silent”). After a 6-day iteration, the initial “deter” turbine was again randomly selected. Both turbines assigned to the deterrent study were programmed to begin operations at the factory default cut-in wind speed of 3.0 m/s. Turbines were fully feathered below 3.0 m/s. Deterrents were programmed to operate from 18:00 to 06:30 on the deter turbine.

Data Management and Analysis

Data were transferred from the field network to a dedicated external hard drive where it was organized by date and camera number. Videos were saved as .asf files from the cameras and were then converted to .avi files with Freemake Video Converter. Each video was then split using AVISplit into 4 smaller videos for processing.

Only nights with complete files from all 4 cameras were processed. The raw footage for each night was reviewed using BriefCam Syndex FS, a commercially available surveillance software that identifies moving objects from recorded video and provides a condensed video synopsis of the detected objects. The user can then refine the synopsis to select for specific object types using pre-set program filters (e.g. by Speed, Size, Color, etc.) on a slider bar. A complete synopses typically included clips of thousands of “objects”, such as bats, birds, insects, aircraft, spinning turbine rotors, nacelle shifts, and clouds. The program works by linking the condensed object clips to the original video so that each object can be individually selected on the synopsis screen for viewing of the object event in its entirety on an adjacent screen.

To eliminate unwanted objects, the pre-set program filter of “Size” was used. “Size” refinement was limited to the 5 smallest object categories that each individual synopsis produced. The time duration for each of these Size categories varied from approximately 30 seconds to 4 minutes of playback time. Every object detected in the first 3 categories was individually selected and the original event of that object was reviewed in full at 2x speed. Size categories 4 and 5 were reviewed at 2x speed but only objects that presented as small and fast moving across the screen were selected for full review. During this process, each small, fast-moving object was either eliminated (clouds, spinning blades, nacelle cone, etc.) or classified as bat, bird, unknown bat/bird, or unidentified object. The timestamp, basic observation notes, and general object location were also recorded and subsequently used by the team of secondary reviewers.

After the fifth Size category was reviewed, the observer reselected a known bat observation and used the “Similarity” filter tool to obtain a refined synopsis of objects similar to the selected bat for review. The refined synopsis was then viewed for any new objects not recorded previously.

All recorded objects were reviewed in their entirety by a second reviewer using standard video player software. The review process included confirmation or correction of object type (bird, bat, etc.) from the first reviewer, beginning and ending timestamps, and any behavioral notes (e.g. “pass through blade”). Object type classification was determined from the visual cues of object shape, size, flight style, speed (judged by perceived position vs. number of frames in observation), and wing beat patterns. We omitted non-bat objects from further datasets.

Video files from both cameras were then time-synchronized to determine which bat observations were recorded on both cameras. Although the Axis camera management software was used to synchronize the cameras periodically during recording, asynchrony still occurred. Time synchronization was performed by reviewing the nacelle direction data for each turbine, finding times in the evening where a movement was recorded, and then identifying the first frame in which the movement occurred in each camera. Asynchrony was generally determined to be 0.2 to 2.6 seconds [sec] between cameras.

After time synchronization, bat passes from both cameras at each station were compiled into a combined dataset that eliminated duplicate observations from individual cameras for bats observed on both cameras at the same time. Bats in this file were observed on 1 or both cameras at each of the 2 turbines.

A study area model for test turbines 48 and 120 was created to scale in Computer Aided Design (CAD) software. The model (including deterrent locations) was informed by calibration measurements taken in the field and technical diagrams and specifications of the turbine model. Model space was generally within 30 meters (m) of the deterrent system, while the total viewable space extended to approximately 70 m (Fig.3).

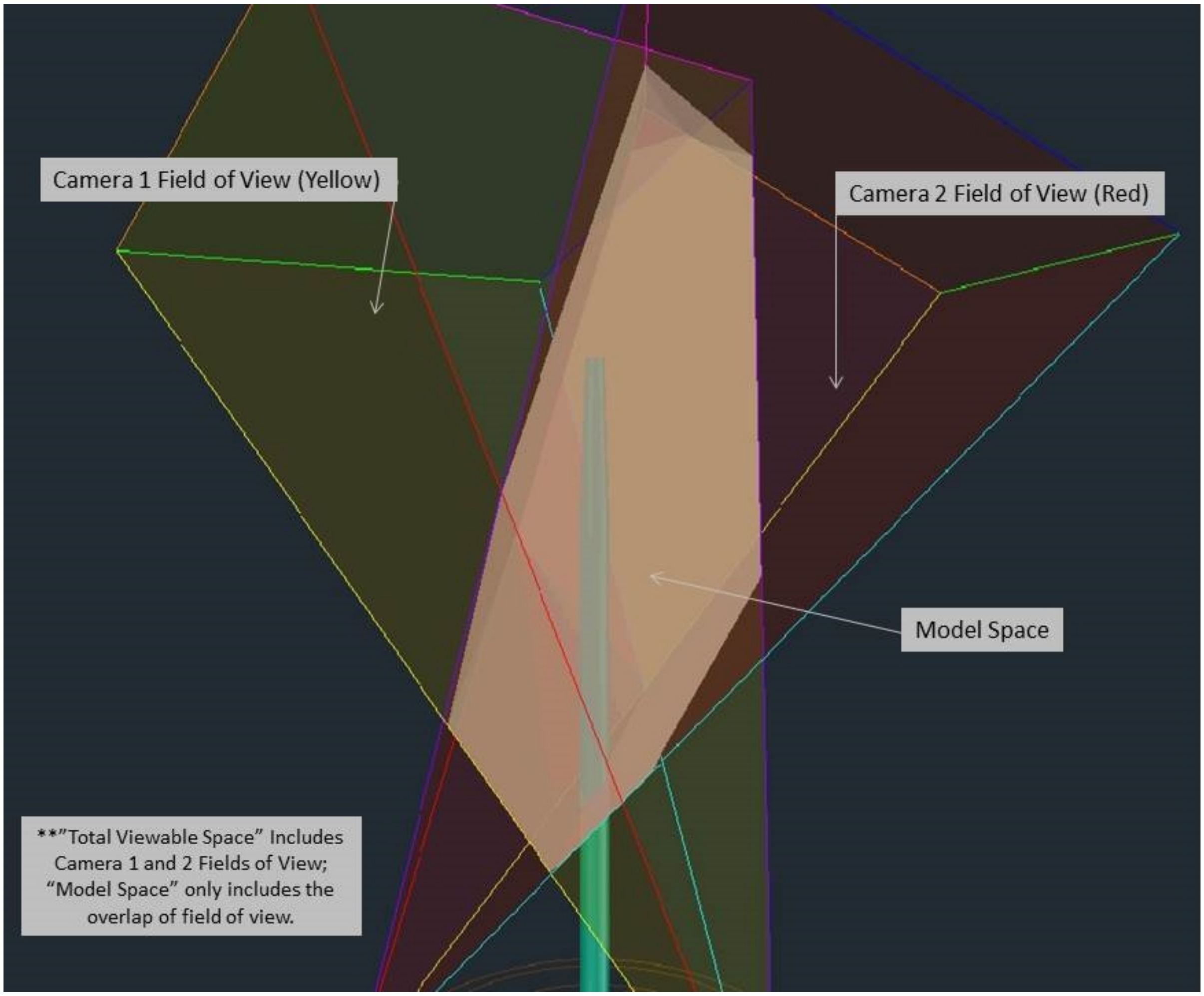


Figure 3. Diagram of camera fields of view at nacelle height. Camera 1 field of view (FOV) is the yellow polygon, Camera 2 FOV is red, and the model space is the tan area of FOV overlap.

The bat count data from the total viewable space and the smaller model space were used to analyze for differences in bat activity. The flight path for each bat was reconstructed within the model space using triangulation of its position within pairs of time-synchronized still images extracted from the videos. Images were extracted for an average of 4-6 key locations throughout an observation, including those associated with its entry and exit from the model space, and major turns in the flight path. Once a flight path was reconstructed, e.g. Fig. 4, the distance to the nearest deterrent was recorded; this represented the bats "minimum approach distance" to the 4-deterrent system. Lastly, the total time spent within the model space was recorded for each flight path. Mean and median nightly minimum-approach distances to a deterrent were calculated, as were mean and median flight path times. These data, along with total number of bat passes and number of modeled bat passes were used in statistical analysis of deterrent effects.

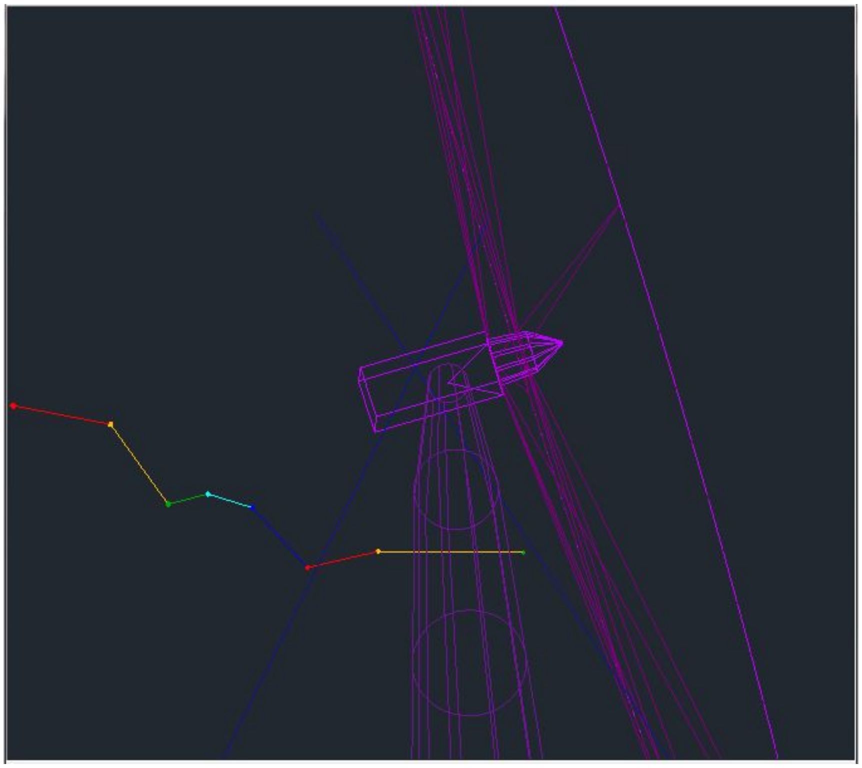


Figure 4. Sample of bat flight path modeled in the turbine airspace

Data analysis methodology will be provided in a separate report. The outcomes of tests of statistical significance for the results presented herein will also be presented in the statistical report.

Results

A total of 565 bat passes were observed on 8 nights of video recorded between August 23 and September 4. Of these, 147 bat passes were recorded by both cameras, and their flight paths within model space could be reconstructed.

Bat activity by number of passes recorded was reduced 16.55% within the total viewable space when the deterrents were operating. On average, 32.13 (SE ± 10.09) bat passes were observed under deter conditions each night and 38.50 (SE ± 9.19) bat passes were observed under silent conditions each night (Fig.5).

Bat activity was reduced 57.28% within the smaller model space. In this space, an average of 5.50 (SE ± 1.79) bat passes were observed under deter conditions, while 12.88 (SE ± 3.89) were observed under silent conditions (Fig. 5).

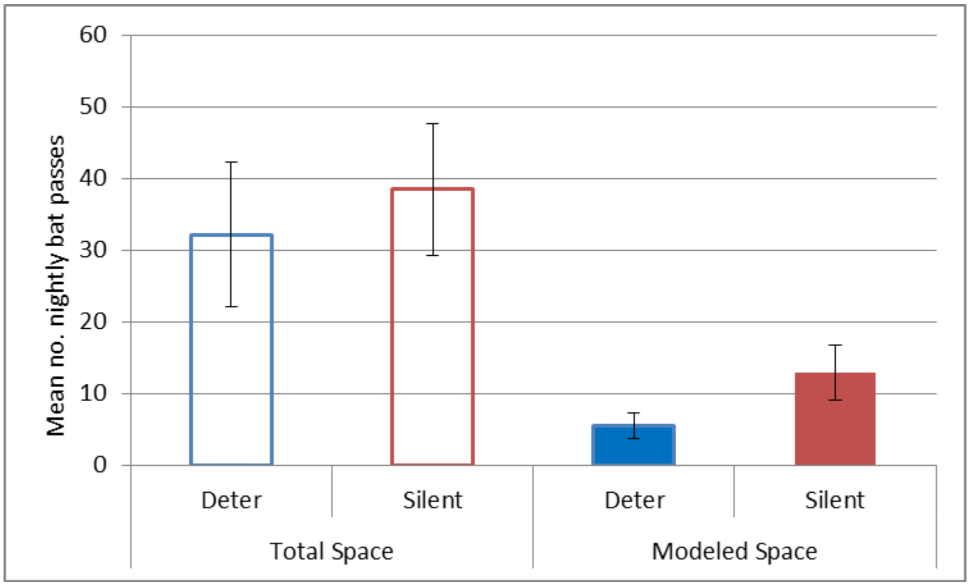


Figure 5. Mean number of nightly bat passes collected during 8 nights of monitoring study turbines under deter and silent conditions.
Error bars are ± 1 Standard Error.

Mean minimum approach distances were 3.6 m farther under deter conditions compared with the silent conditions. Bats approaching deterrents under silent conditions had a mean minimum approach distance of 13.9 m (SE ± 1.15 m). Under deter conditions, mean minimum approach distance was 17.5 m (SE ± 1.57 m).

Median approach distances were similar to mean distances. Median minimum approach distances were 15.8 m under deter conditions and 10.0 m under silent conditions, for a difference of 5.8 m.

A histogram of number of bat passes by minimum approach distance was used to assess bat activity by approach distance. The peak of distribution for closest approach distance under silent conditions was at 5-10 m (n=29). The peak of distribution for closest approach distance under deter conditions was estimated to be 15-20 m (n=12), indicating that bat activity was farther from the turbine airspace when deterrents operated (Fig. 6).

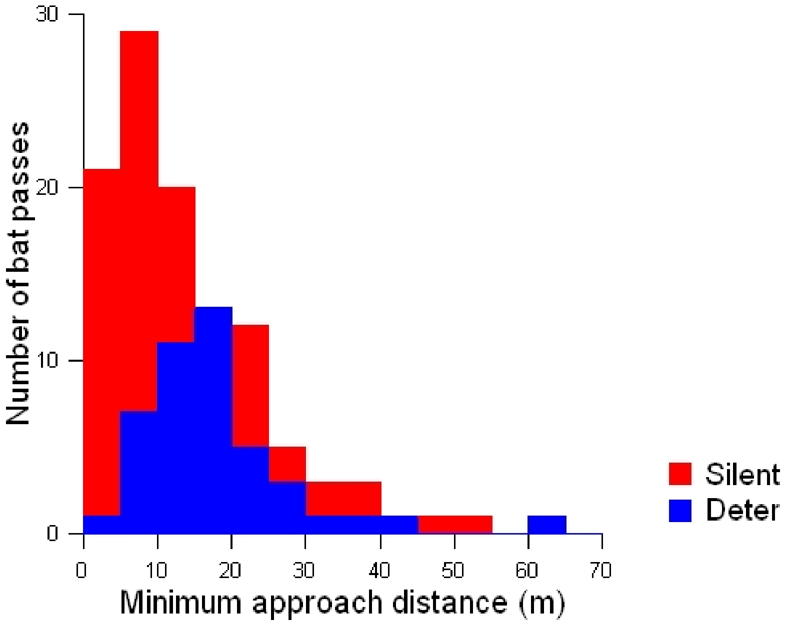


Figure 6. Histogram depicting number of bat passes by minimum approach distance (in m) under deter and silent conditions

We also tested for differences in time spent by bats within the model space under deter and silent conditions. Under deter conditions, bats spent a mean 2.8 (SE±0.47) seconds (s) in the model space. Under silent conditions, bats spent a mean 4.3 s (SE±0.58). On any given night, bats spent 1.1 s more to 5.1 s *less* time in model space under deter conditions.

Median time spent in modeled space differed less (1.0 s) than mean time spent. Under deter conditions, median time spent was 2.0 s, while under silent conditions the median time spent was 3.0 s.

A histogram of the number of bat passes by second was created to compare distributions of time spent by bats within the model space under deter and silent conditions (Fig. 7). Although the histogram proportions were similar between the deter and silent conditions, the longest time spent in model space by any bat was 14.40 s under deter conditions, while it was 33.51 s under silent conditions.

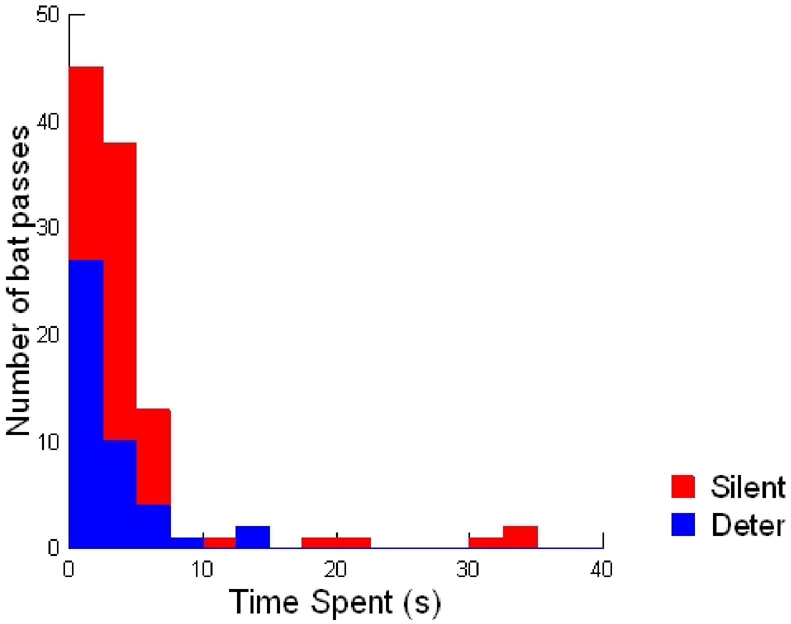
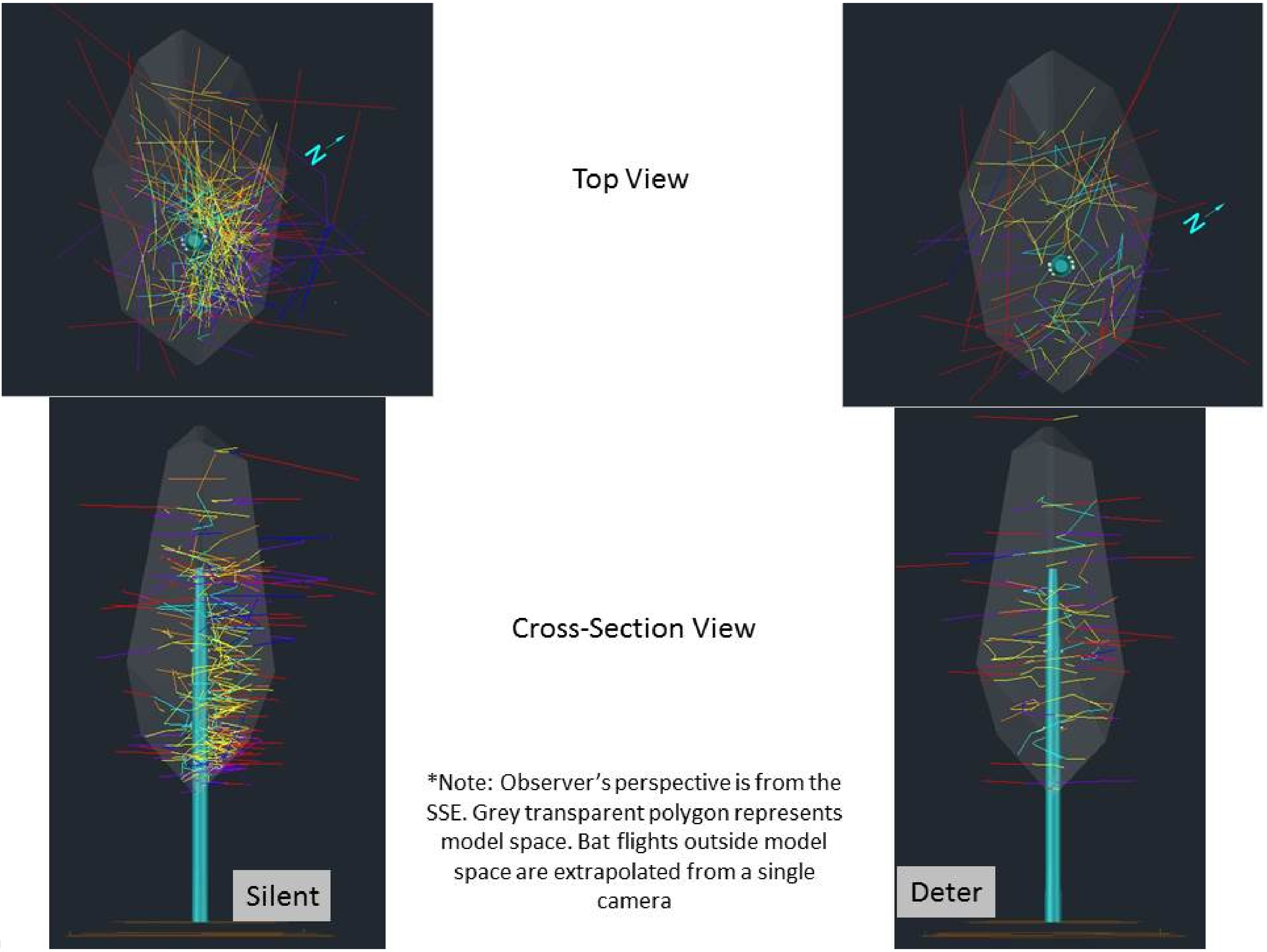


Figure 7. Histogram of number of bat passes by time spent (s) in model space under deter and silent conditions.

Finally, we compiled the constructed flight paths under deter and silent conditions into a single model of the turbine airspace for each condition. Diagrams of the CAD model illustrate how the flight paths, thus approach and time data, were distributed in space (Fig. 8). Bats approaching a turbine under silent conditions regularly appear to concentrate their flights very near the tower structure, often approaching the tower from the downwind side. Flight paths during silent conditions appeared to be distributed throughout the model space. Under deter conditions, bats avoided a pocket of airspace around each deterrent; close approaches to the tower structure only occurred far from the deterrent locations. For example, under deter conditions, bats continued to approach the tower near nacelle height where deterrents were not present.



*Note: Observer's perspective is from the SSE. Grey transparent polygon represents model space. Bat flights outside model space are extrapolated from a single camera

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Figure 8. Top and cross section views of modeled bats around a representative "silent" and "deter" turbine.

Discussion

Milestone 4.4.1, “Demonstrate reduced bat activity and that the bats do not closely approach the acoustic deterrent when in current mounting configuration on the turbines at California Ridge Wind Energy Facility”, was successfully achieved by the thermal camera study.

Three distinct deterrent effects were observed during the thermal imaging and 3-D flight mapping. First, the deterrent is effective out to approximately 20 m, with a 57.28% reduction in the number of bat passes when the deterrents are operating. The effect was visible in the top view of the deterrent image plotted in Figure 8. This effective range is consistent with that reported for prior acoustic deterrents discussed in Szewczak (2011) and Szewczak and Arnett (2007).

Second, there appears to be a gradient to the deterrent effect. The number of bat passes under deter and silent conditions are more comparable at greater distances (see Fig. 6). Bat passes within the total viewable space are not as reduced as the subset within the model space (16.55% vs. 57.28%), which is much closer to the deterrent.

Finally, regardless of whether or not bats are exposed to the deterrent sound, they spend similar lengths of time within the model space. The model space represents an irregularly shaped zone that accounts for overlapping camera views, and as such, will include both those bats that fly by a tower from a distance and those that approach and spend time in the airspace near a tower. Nevertheless, bat collision risk is still reduced because while the deterrents are operating, fewer bats approach the tower, and those that do tend to stay further away.

Bats may be at higher risk near the tower because collision with the blade may occur if they approach the rotor swept zone too closely when they are near the tower. It has been hypothesized that bats approach the tower because there is a resource there, such as food, water, roost habitat or for mating (Cryan and Barclay 2009, V. Bennett and A. Hale, TCU, Pers. Communication). We observed only one instance where a bat skimmed near the tower wall (in a silent period), and a considerable number of flight loops and chase flights. These observations may be consistent with one or some of the proposed “attractive resource” hypotheses, since both flight loops and chases are behaviors indicative of foraging or territoriality (Ahlen et al; Giuggioli et al 2015). The skimming behavior could indicate either drinking or gleaning (V. Bennett pers. communication).

Fewer bat passes were observed when deterrents were operating, which indicates the deterrent device does deter bats from approaching near the tower. However, some bats were still spending considerable time in the airspace, especially on the downwind side of the tower. This is consistent with the hypothesis that bats are attracted to the downwind airspace because of the presence of a valuable resource. This resource may still be attracting some bats even when they are deterred from approaching the tower. Generally, a vortex is generated behind the spinning turbine blades, but this vortex creates a lower velocity wake downwind of the nacelle (Xie and Archer 2014). This wake area may be the attractive resource the bats are using, with food or mates, for example, as secondary resources that can be found in this attractive wake area. However, it should be noted that the downwind wake of an operating turbine is not in itself a risky area, as it is far from the spinning rotors. Preventing bats from approaching near the turbine while they are using the wake should be a priority in deterrent design.

In summary, this study further demonstrates acoustic deterrents are effective at reducing bat activity out to approximately 20 meters. To ensure maximum coverage, deterrent devices should be placed within 30-40 m of one another and oriented to prevent bats from entering the rotor field from either upwind or downwind.

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Cryan, P and Barclay, R. 2009. Causes of bat fatalities at wind turbines: hypotheses and predictions. *Journal of Mammalogy*90(6): 1330-1340.

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ATTACHMENT I

Milestone M4.1.2

This document presents the results of Milestone 4.1.2 …..

Milestone M4.1.2 – *Review & Revise Design Study for Task 6 of Budget Period 2*

Task 6 – Turbine Field Study during BP2 (M10-M18)

Task Summary and Details

This task will evaluate how bats interact with deterrents mounted on an operating wind turbine. The evaluation includes: 1) a thermal imaging study and 2) a formal carcass study. In 2016, 12 turbines will be outfitted with a re-designed deterrent system. Two of the turbines will be monitored with a thermal camera system to document the 3-dimensional flight paths of bats flying in proximity to turbine-mounted deterrents.

Subtask 6.1 – Thermal Imaging and 3D Flight Mapping during BP2 (M13-M18)

Subtask Summary: The objective of the thermal imaging camera study is to assess bat behavior and activity within the airspace surrounding the re-designed deterrent system. For this task, 2 pairs of thermally-sensitive cameras will be deployed at 2 turbines; they will record the bat activity around these turbines each evening in the late summer and fall. On any given night, one of the turbines will be assigned to have operational deterrents; the other will act as a control (deterrents off). The video data from these cameras will be synchronized and calibrated, which allows for the 3-dimensional mapping of bats observed on both cameras utilizing Computer Aided Design (CAD) software. This process will allow the research team to better understand the mechanics behind the deterrent's effectiveness using spatial analysis of the mapped flight paths during treatment and control periods and quantify behavioral data collected during the observations. It may also be possible to apply the behaviors to the spatial environment, which would allow for an assessment of potential changes in behavior by bats near the deterrent field.

Subtask Details:

The objective of this research is to characterize changes in the spatial use of airspace around a wind turbine when a deterrent system is operating. Thermal imaging surveillance cameras will be arrayed around the base of 2 turbines at the California Ridge Wind Energy Facility. Both turbines will be equipped with the most current configuration of the acoustic deterrent system for that respective year.

Four (4) AXIS Q1922-E Thermal Network Cameras will be used to record activity at each of 2 turbines selected for their high bat fatality rates. The cameras will be positioned 40-60 m from the turbine base to achieve acceptable resolution and field of view; the angle of placement will be optimized utilizing a modeling of the field of view of each camera relative to a 3-dimensional scale-replica of the wind turbine.

Through the management software, the cameras will be programmed to record video data from 1800 hours through 0700 hours the following day. The cameras will be set to record the images in high definition using a view called "Fire and Ice" at 30 frames per second, and automatically download video files to a data drive mounted to the network. This video will be reviewed as it is collected.

Raw footage from each night will be initially processed using Briefcam Syndex FS, commercially available forensic video analysis software (www.briefcam.com). Briefcam Syndex FS is a standalone software product that allows the user to input multiple recorded videos for offline processing. The output product is a combined video synopsis of short length of all moving objects identified during analysis.

These synopses are typically 20 minutes long and, initially, have detected moving objects ranging from 1000 to over 4000 potential targets. The moving objects in each synopsis video include bats, birds, insects, aircraft, spinning turbines, nacelle shifts, and clouds. The unwanted objects, which include all non-biological targets, typically are displayed later in a synopsis and for a longer duration. Small and fast objects such as birds, bats or insects are usually presented within the first 30 seconds of the synopsis. To filter the unwanted objects out and capture the majority of small objects on first view, the observer will review each synopsis file for at least 4 minutes. All target objects observed will be isolated and a time stamp start and end will be recorded during the initial review. If a target is observed, the observer will further refine the output synopsis with tools which select for similar objects and then by refining for objects by size, speed, and various combinations of both. Basic data of file length, overall video quality, and whether or not there were identified targets will be recorded in a camera data log. This basic data will be used as a reference by the team of target reviewers; the goal of this process is to increase the efficiency of the review team and ensure that no video clips are missed.

Following review of each night of video, all videos with potential bat targets will be reviewed in their entirety by a second technician whom is blind to the deterrent operation conditions. Videos will be played using VideoCleaner (www.videocleaner.com) or VLC Media Player (www.videolan.org), open source video player software capable of editing footage (e.g. slow the frames, clip observations, etc.). Observers will watch the entire length of each video at normal speed during the initial review and then, if necessary, slow the footage to better view the target for full characterization. Target objects will be classified as bats, birds, or unidentified objects.

A subset of the bats observed during this process will be observable from both camera vantage points. Because the cameras will be synchronized and calibrated to each scene, the 2-dimensional trajectories of a single bat observed on both cameras can be combined into a 3-dimensional, scale drawing of the flight path. The process essentially involves a “visual telemetry” using Computer Aided Design software to draw the visible space, turbine, and, eventually, each bat flight in space. The modeling of the airspace and turbine is made possible through precise measurements of camera placement, calibration of the field of view using an object of known dimension, and inputting the camera specifications (e.g. lens distortion) to account for bias created by the equipment and study scene. After the scene is calibrated, synchronized frames are paired and an infinite-length line is drawn from each camera’s perspective to the bat. The intersection of this line (plus known error inputs from the model generation) gives us certainty that the bat was at exactly that location in space. By duplicating this process using multiple paired frames, the flight path of each bat can be reconstructed (Figure 1). These modeled paths will be used to measure the approach direction and minimum approach distance to each viewable deterrent nozzle; total time spent within the model space will also be recorded. This information will be paired with the total bat pass counts for further analysis. This type of analysis was successfully completed in 2014 and 2015.

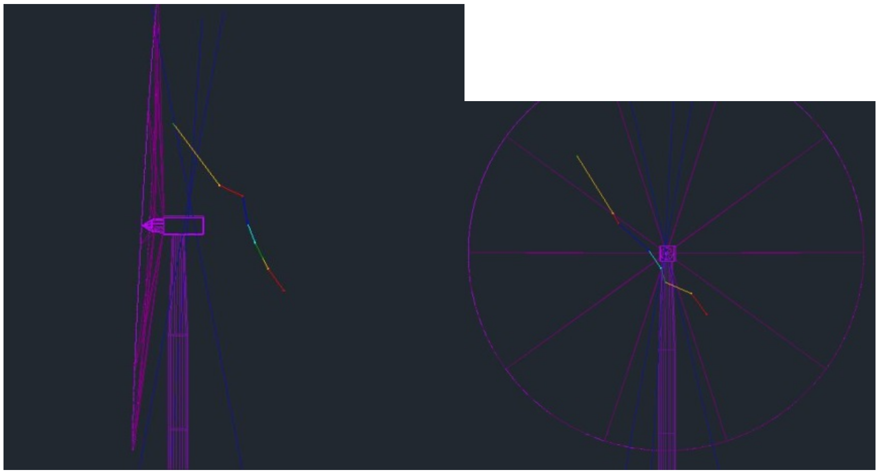

Figure 1. 3D model of bat flight path, side view and rear view.

Subtask 6.2 – 2016 Deterrent Field Test During BP2 (M9-M18)

Subtask Summary: The objective of a 2016 deterrent effectiveness study is to define whether the redesigned deterrent system identified during the above research provides an increase in absolute efficacy when the device is installed and utilized in a commercial setting. Deterrents will be installed on twelve turbines in the anticipated optimal configuration, determined through a synthesis of the results of the prior tasks. The effectiveness of the redesigned deterrent system will be assessed during the fall of 2016 using a treatment-control design similar to prior studies of this nature. During the treatments, human and dog and handler teams will be regularly canvassing 60-meter plots centered on the 12 turbines, searching for bat carcasses. The raw carcass counts will be calibrated using data from a known set of carcasses, commonly referred to as a “bias trial”, placed in a manner that the search teams are blind to the trials. To complete the assessment of deterrent value, the tabulated and adjusted carcass counts will be fitted to a Generalized Linear Model, which will include appropriate turbine operation and meteorological covariates.

Subtask Details:

The study turbines will be selected from a set of 20, which have been monitored for bat carcasses annually between 2013 and 2015. The carcass retrieval data from these turbines will be reviewed and the turbines with highest apparent bat fatality rates will be selected for this study.

The operations of each turbine within the study will be pre-programmed to follow a schedule determined prior to the onset of the monitoring. Operations will be scheduled to occur nightly, between the hours of 18:00 and 06:30. Turbines assigned to the deterrent study will be programmed to begin operations at the factory default cut-in wind speed of 3.0 m/s (6.7 mph) whether they were assigned to treatment or control groups. The treatment group in this set will be programmed to begin operations of the deterrents within the nightly timeframe. Deterrents will be mounted on all study turbines in a consistent manner, determined through a review of the data collected in other facets of this proposed research.

The selection of treatment and control turbines will be centered on a 6-day block design. Within each 6-day period, the turbines in each study will be randomly divided into treatment and control groups of equal size. For the initial 3 days of the block, the groups will operate per the parameters of their assignment (e.g. treatment or control). In the second 3 days (days 4, 5, and

6), the assignments switched, and treatment turbines will become control turbines, or vice versa. The process will be repeated for each 6-day block.

A schedule of searches will be arranged to follow the 3-day sub-rotation within the study blocks. Human search teams will search all plots on the first day of each 3-day rotation. Dog and handler teams, whom have been demonstrated to provide a higher level of carcass detection, will be utilized (Matthews et al. 2013) to search days 2 and 3 of each 3 day study period. The inclusion of this pattern of searches was designed around maximizing carcass detectability and minimizing bleed-through of carcasses from treatment to control or control to treatment assignments. It is imperative that carcasses be accurately assigned to treatment or control; otherwise the results will be confounded by design inadequacies.

Sixty-meter (60 m) radius search plots will be established beneath each of the monitored turbines. Plot boundaries will be marked with wooden survey stakes to aid in proper coverage by the dog and handler teams. Plots will be mowed and sprayed with herbicide in an effort to maximize carcass detectability. The search conditions in each plot encompassing the selected turbines will be defined and mapped by condition at the end of the search period.

When a searcher discovers a carcass, the searcher/dog handler will flag its location using a roll of flagging or a pin flag and then continue searching until the entire plot had been surveyed. This ensures that each plot is searched thoroughly and at a consistent rate. After the plot is completely searched, the carcass will be bagged using gloves or by inverting the collection bag. All carcasses will be collected using this method as a safety precaution and to reduce the possible human scent bias for those carcasses later used in trials. The bags will be labeled with the unique identification number assigned to the carcass. Carcasses will be handled in accordance with the IDNR Scientific Permit and the IDNR Permit for Possession of Endangered or Threatened Species. A laser rangefinder (Nikon ProStaff 550 or similar) will be used to determine the distance to the turbine, and an azimuth to the tower will be taken with a compass. This information, along with time, weather data, transect number, and visibility class will be recorded. Carcasses will be stored in a freezer at the site's maintenance facility.

A total of 180 individual trial carcasses will be placed in order to determine searcher efficiency during the monitoring season. Trials will be placed to target single, 3-day periods, with a subset of the allotted carcasses placed before each day. So, if a 3-day period is targeted with 30 carcasses, 10 will be placed before day 1, 10 before day 2, and 10 before day 3. Carcass distribution among the visibility classes will vary per turbine to reflect site conditions. All visibility classes will be tested, and distribution will generally reflect the amount of each visibility class present within the plots.

Trials will be unannounced and will be placed near dusk after daily searches are completed. A combination of toe, wing, or finger clipping was used to mark the carcasses in a way that is discreet such that handlers are not influenced by finding trial carcasses. Trials will be placed 12-24 hours prior to a targeted search in an attempt to best simulate the conditions of actual bird/bat kills, as well as to minimize scavenging of trial carcasses. Any carcasses recovered by the dog crews will be collected and checked for identifying marks by the trial placement manager. In preparing the tests, all carcass distances and azimuths will be generated using the Excel random number function before arriving at the wind farm to avoid bias. Carcasses will be tossed into the air to determine position (face up or face down, wings in/wings out, etc.), simulating a bird or bat falling from the turbine.

ATTACHMENT J

Milestone M5.1.1

This document presents the completion of Milestone 5.1.1:

Milestone 5.1.1: Complete Integrated Deterrent Design including Design Documentation BOM and Installation Instructions

Design Documentation BOM

List of deterrent system materials used in 2016 deterrent installation in Budget Period 2 of DE-EE0007035. This is the full bill of materials for the bat deterrent pulsing design:

1. Valve and nozzle assembly
    a. 6 - ½" stainless steel nozzle cap and pipe
    b. 6 - ½" valves and solenoids assembly
    c. 6 - GE section specific mounting bracket
    d. Various ½" tee, ½" hose, and fittings (couples and barbs) to compressor manifold
    e. Various ½" tee, ½" hose and fittings (couples and barbs) need between tower sections
        i. Rear of Nacelle, 3rd deck, 4th deck
2. Controller electrical
    a. Relays for signal to valve and nozzle assembly
    b. Power for relay box and compressors
    c. Digital signals for compressor
3. Tower electrical – valve relay drive
    a. Digital signal to send down tower
    b. Power to send down tower
    c. Added protection to signal coming out of turbine
4. Compressor
    a. 2 - 400V/3 Phase /60Hz/50C compressors
    b. Connected air supply via manifold to nozzle assemblies
    c. Includes 120psi check valve
    d. ½" piping Air-water separator mounted to compressor

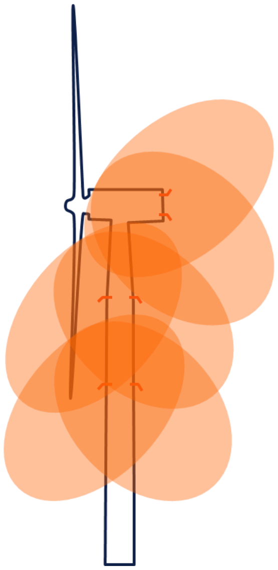

***Figure 1.** Representation of turbine nozzle locations on with turbine. Orange clouds represent deterrent signal regions. For full signal acoustic detail see Milestone 3.2.1*

Figure 2 is a photo of installed nozzles at California Ridge wind farm. Circled locations show where the nozzles are installed from the outside of the wind turbine. An overview of material installation locations can be seen in Figure 3. Hose and harness connections also appear in this figure.

***Figure 2**. Photo of installed nozzle on tower section platform from outside of wind turbine*

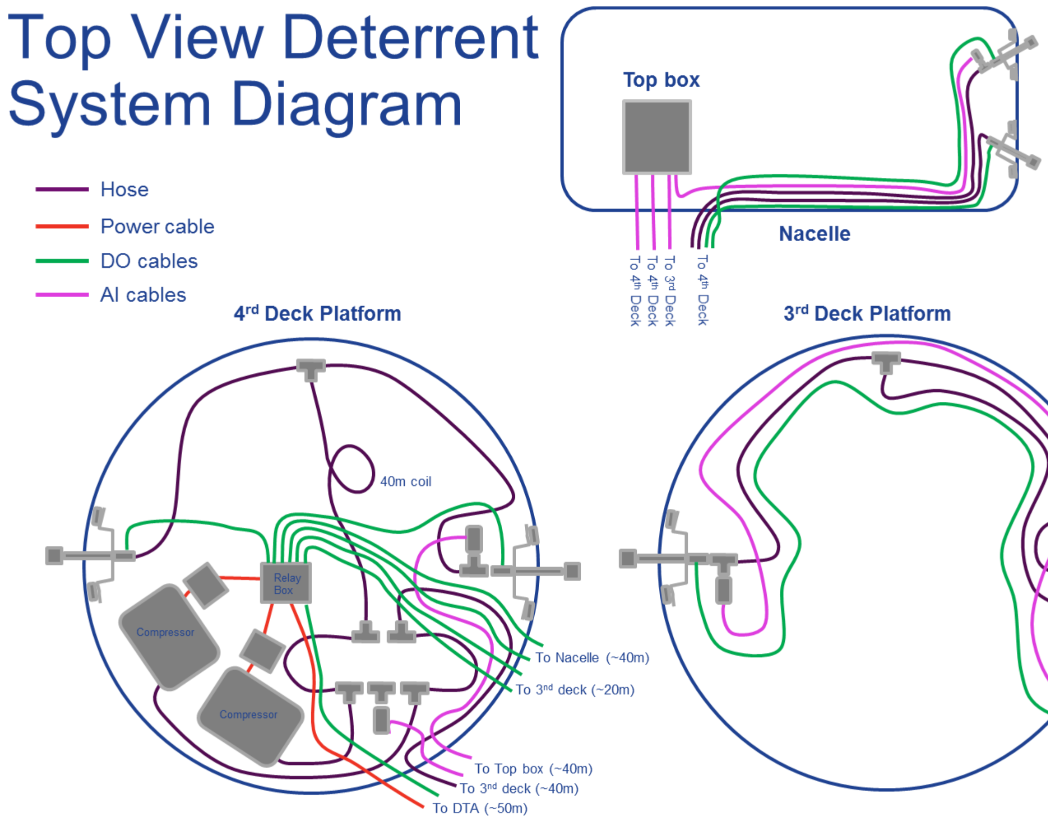

Figure 3. *System diagram of bat deterrent: top view showing design. Both compressors are located on the 4th deck with the relay control cabinet. From relay box, signals are sent out to each valve near a nozzle assembly. Figure also shows nacelle and 3rd deck nozzles.*

Installation Instructions

This section includes the installation instructions. The installation is done at each location in the wind turbine for install of the bat deterrent system. Note that the process assumes related safety protocol and training for entering and climbing a wind turbine generator. The material will be lifted up tower into a defined location using turbine hoist. This install uses pre-assembled parts to reduce field installation.

The following are general guidelines for installation:

1. Assemble components for pre-install inspection
   a. Preassembled valve and nozzle assemblies
   b. Hose with necessary sealed fittings
   c. Compressors
      i. compressor oil
      ii. Compressor electrical box and power connection
   d. Drill and drill bit
      i. Small hole tower drill procedure

    e. Top box retrofit electrical kit (including required breakers, relays, terminals, and ferruled wiring)

2. Perform team safety review for the following:

    a. Drilling
    b. Working at heights
    c. Electrical work
    d. Hand tools
    e. Hoist and lifting
    f. LOTO
    g. Basic turbine startup and shutdown
    h. Troubleshooting for turbine model

3. Locate compressors on tower deck

    a. Reassemble compressors
    b. Mount to deck
    c. Make electrical connections
    d. Run power cable

4. Top box and Electrical retrofit

    a. Perform connection in top box
    b. Route cable down tower through drip loop (NOTE: remember to make electrical connection need for nacelle nozzles)

5. Install Nozzles in nacelle as follows:

    a. Drill holes in nacelle according to small hole procedure (composite saw bit)
    b. Mount valve and nozzle assembly bracket to nacelle (hand tools)
    c. Connect hosing to nozzle
    d. Connect cabling to valve assemble and pressure sensor
    e. Route pressure sensor cabling to topbox
    f. Route Hose assembly and Valve cabling downtower for future connections

6. Install tower nozzle and electrical as follows:

    a. Feed additional hose and cables harnesses in bundle through nacelle drip loop Route and secure down tower
    b. Route cables and hose to 4th deck
    c. Make appropriate hose connections to compressor manifold
    d. Make appropriate cable connections to relay box
    e. Follow tower small hole drill procedure, placing 2 holes 2ft above tower deck at 180 degrees apart (avoid power cables, ladder and any other existing turbine components)
    f. Mount valve and nozzle assembly bracket to nacelle

   g. Make hose connection connections to valve and nozzle assembly and compressor manifold
   h. Make electrical connections to valves assembly and relay box
   i. Clean up the deck by routing hose and cables and making sure all components are secured to the deck and verify that no hoses are twisted or kinked.
   j. Run cables and hose to 3rd deck
   k. Follow tower small hole drill procedure, placing 2 holes 2ft above tower deck at 180 degrees apart (avoid power cables, ladder and any other existing turbine components)
   l. Mount valve and nozzle assembly bracket to nacelle
   m. Make hose connection connections to valve and nozzle assembly and compressor manifold
   n. Make electrical connections to valves assembly
   o. Clean up the deck by routing hose and cables and making sure all components are secured to the deck and verify that no hoses are twisted or kinked.

7. Start up and verify system as follows

   a. Upload bat deterrent control software
   b. Enable digital out parameters and remaining control channels
   c. Turn on compressors with valves open to check compressor connections
   d. Turn on pulsing to check dynamics and pressure
   e. Tune pulsing duration to meet pressure specification (65-40psi target range)
   f. Run system to confirm performance
   g. Set variables for automated control during DOE testing (pulse duration, compressor time on and off, turbine schedule)

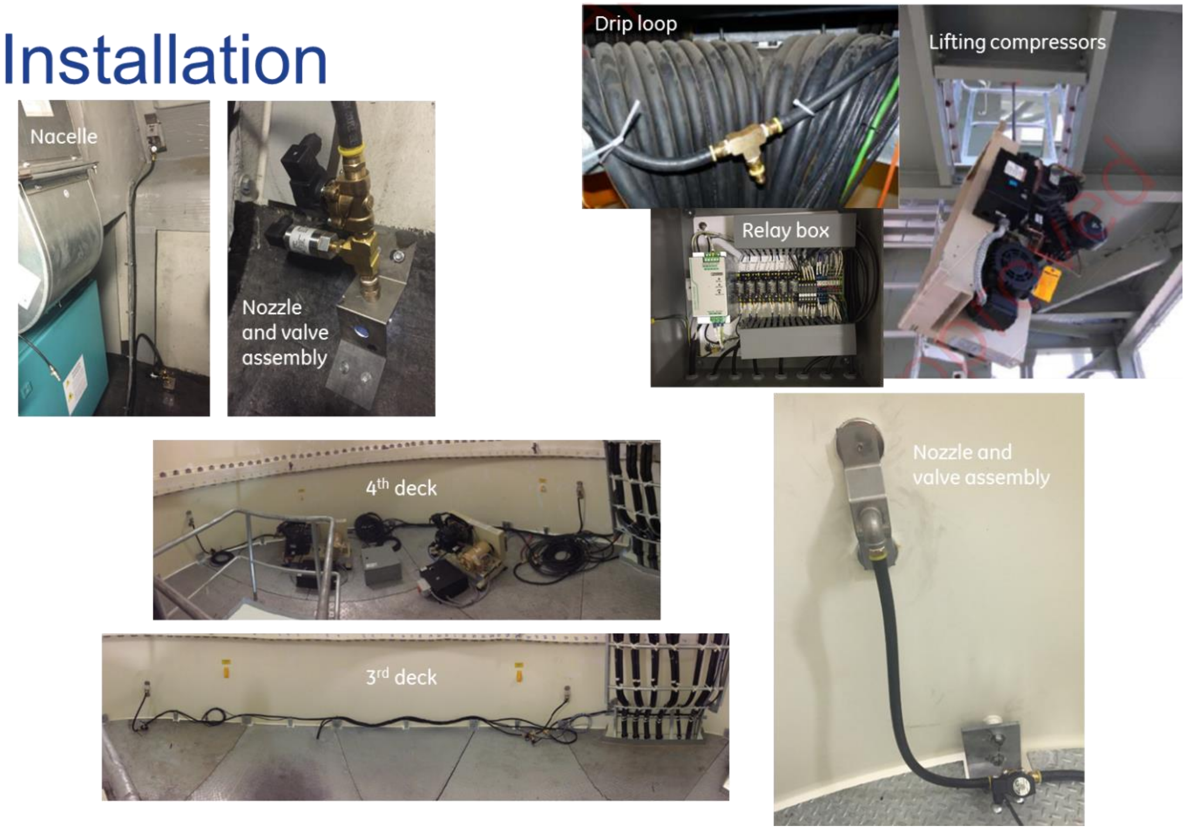

***Figure 4**. Photos from installation. Bat deterrent material installed in full scale industrial wind turbine environment. Most hardware, fitting, compressors and electrical cabinets all exist up tower on turbine tower decks and remaining equipment exists inside wind turbine nacelle.*

ATTACHMENT K

Milestone M6.2.1

DE-EE0007035
General Electric Company
Ultrasonic Bat Deterrent Technology

This document presents the results of Subtasks 6.1 and 6.2 and the completion of Milestone 6.2.1.

Milestone 6.2.1

Demonstrate reduced bat activity and that the bats do not closely approach the acoustic deterrent when in new "optimized" mounting configuration on turbines at California Ridge. Demonstrate reductions in bat fatality when "optimized" deterrent configuration is operated on turbines at California Ridge. (Month 15 of BP2)

Executive Summary

Under the US Department of Energy grant DE-EE0007035, a prototype ultrasonic-frequency acoustic deterrent was tested in 2016 at the California Ridge Wind Energy Facility (CRWEF) in Champaign and Vermilion Counties, Illinois. CRWEF is owned by California Ridge Wind Energy, LLC, and consists of 134 1.6 MW General Electric (GE) turbines with 100-meter (m; 394 foot, ft) monopole towers and 100 m (394 ft) rotor diameters. The habitat surrounding the CRWEF is dominated by agriculture fields that are dissected by a matrix of oak-hickory woodlots and shelterbelts, grassy swales, and homesteads. Deterrent systems were installed on 12 CRWEF turbines and set to operate with no (control), constant, or pulse signals following a 6-day randomized block schedule between the evening of July 31 and morning of October 11, 2016.

In each 6-day block, the 12 turbines were randomly divided into treatment groups of equal size; after operating under the assignment for 3 nights, the treatment groups changed (i.e. control group became pulse group and vice versa) then operated for another 3 nights. Turbine groups were re-randomized in each 6-day block. The 2 turbines used in Subtask 6.1, Thermal Imaging and 3D Flight Mapping during BP2, were always assigned to opposite groups so bat activity data were collected under control conditions at one of the turbines each night.

Due to the discovery of water vapor being emitted from the pulse deterrent systems, the study was split into 2 halves. During the first half, between July 31 and Sept. 11 (6, 6-day blocks), the pulse signal was tested against a silent control. The pulse signal was emitted from a 6-nozzle system that covered the airspace behind the nacelle and along the tower. The pulse signal included a 4.9 to 7.9 second deterrent signal followed by a 3.0 second silent period. For the Sept. 24 and Oct. 11 half of the study, air/water separators intended to reduce or eliminate the water vapor emissions were installed on 4 pulse signal systems. The remaining 8 deterrent systems were retrofitted to a 5-nozzle constant signal system. The 4 pulse systems were set to operate every night while systems on the 8 remaining turbines were divided into constant signal and control groups that continued to follow the 6-day randomized block design. Due to the division of the study period, analysis precision was low. Thus, results of the constant signal under Subtask 6.1 and all results of Subtask 6.2 should be considered to represent general patterns in effectiveness.

The objective of Subtask 6.1 was to determine whether a turbine-mounted deterrent system could reduce bat activity near, reduce time spent by bats in the vicinity of, and increase

approach distance to, the deterrent system at 2 turbines. The pulse signal was tested in the first half of the study and the constant signal during the second half. In each half, both turbines contributed an equal number of nights to each treatment group (i.e., pulse/constant vs. control).

Two pairs of thermal video cameras were placed beneath 2 turbines and set to simultaneously record bat flights at both locations between 20:00 and 00:00. Bat flights were identified in the raw video using a semi-automated review process. The video from both cameras at a turbine were time-synchronized to calculate the total time each bat was observed. To assign each bat to the appropriate approach distance bin, each bat's flight path was partially reconstructed in a scale simulation created using Computer Aided Design (CAD) software. Deterrent effectiveness was modeled from total bat passes, the time in view data, and bat counts by distance bin using Generalized Linear Models (GLM). The total bat passes observed were reduced 32.83% and 60% under pulse and constant signals, respectively. Time spent in the camera field of view was significantly lower (50.9%) under pulse signal relative to the control and was also lower (43.4%) under the constant signal, although this result was not significant. Both deterrent signals were >45% effective within 20 m [66 ft] of the deterrent system, but became less effective beyond this distance. Reductions in bat activity and the observed distance effects were similar to those observed in Tasks 1, 2, 4.1, and other research (Szewczak 2011).

Subtask 6.2 included a carcass monitoring program conducted between August 1st and October 11, 2016 at all 12 study turbines; the objective of the program was to demonstrate the effectiveness of the redesigned (i.e,. pulse) system in reducing bat fatalities. Daily carcass monitoring was conducted by human and dog searchers within 60 m (197 ft) radius plots centered beneath the 12 turbines. Carcass detection probability was estimated from recovery data obtained during 12 tests that used 142 bat carcasses placed randomly throughout the plot areas. Searches and calibration trials were aligned with the 3-day halves of the 6-day study blocks.

The bat carcass recovery probability for the first study half was 94.69%, and 93.81% during the second half. Because detection probability was so high and introduced greater variability to the raw counts than had existed inherently, deterrent effectiveness was modeled from the unadjusted raw bat carcass counts using a GLM in which turbine operations and treatment covariates were added. Carcass data were analyzed in the following species groups: all bat species, eastern red bat (*Lasiurus borealis*), and non-eastern red bat species.

The pulse system was ineffective (1.71%) in reducing all-bat species fatalities during the first half of the study and effective (42.50%) during the second half of the study. The pulse signal was effective for non-eastern red bats in both halves of the study (37.97 and 54.03%, respectively), and ineffective for eastern red bats in both halves (-22.51% and 22.24%, respectively). This effectiveness profile was similar to the effectiveness observed under the constant signal system tested by Shoener and Skalski (2016), which found an effectiveness of 56.06% on non-eastern red bats and no effectiveness on eastern red bats. The 5-nozzle constant deterrent system appeared to be ineffective at reducing bat fatalities for any species group, though reduction estimates were not precise and sample sizes were small.

In summary, Milestone 6.2.1 was successfully achieved, as we demonstrated bats were dispersed further from the turbine and also that non-eastern red bat fatalities were reduced when the "optimized" pulse signal system was operated at CRWEF. Specifically, the results confirmed the pulse deterrent signal was highly effective (>45%) out to approximately 20 m (66 ft), and that the pulse signal reduced fatalities of non-eastern red bats but not fatalities of eastern red bats. The effectiveness in reducing bat fatalities of the 6-nozzle pulse signal system tested in this study was similar to that of the 4-nozzle constant signal system tested in 2015 (Shoener and Skalski 2016). The disparity between the consistent effectiveness documented in Task 6.1 (bat activity) and the varied effectiveness documented in Task 6.2 (carcass counts) may be attributed to incomplete displacement of bats from the rotor swept area (high reductions in bat activity out to approximately 20 m (66 ft) and declines in effectiveness along the remaining 30 m (164 ft) of the rotor radius) and/or differences in species-specific responses to the deterrent signal, possibly indicated by the differing reductions in bat fatalities for eastern red bats vs. non-eastern red bats exhibited in Task 6.2.

Background

The California Ridge Wind Energy Facility (CRWEF), owned by California Ridge Wind Energy LLC, is located in Champaign and Vermilion Counties, Illinois. It consists of 134 GE 1.6-megawatt (MW) turbines with 100-meter (m, 394-foot [ft]) towers and 100 m (394 ft) rotor diameters. This report presents the results of research conducted under US Department of Energy grant DE-EE0007035 to test the effectiveness of prototype ultrasonic-frequency acoustic deterrents designed to minimize bat fatalities at wind energy facilities.

At present, the only accepted method of reducing bat fatalities at wind facilities is to alter turbine operations, usually raising the minimum wind speeds at which the rotors begin turning (referred to as cut-in speed) from a recommended minimum cut-in (usually 3.0 to 3.5 meters/second [m/s]) to some higher wind speed. Formal studies have repeatedly demonstrated the effectiveness of this strategy (Young et al. 2013, Arnett et al. 2013, Arnett et al. 2010, Baerwald et al. 2009). However, these strategies decrease turbine energy output and may increase turbine operation costs. Since 2007, the use of acoustic deterrents to reduce the direct impacts of wind turbines on bats has been considered and some research has been conducted (Szewczak and Arnett 2007, Horn et al. 2008, Arnett et al. 2013). Results of these studies have been variable, yet consistently promising. If acoustic deterrents are able to improve or provide comparable reductions to bat impacts while maintaining power generation capability and decreasing operating costs, then they will provide an attractive alternative for minimizing the direct impact of wind turbine operation on bats.

According to a recent study conducted by Bat Conservation International (BCI), turbines equipped with acoustic deterrents reduced bat collisions by up to 51%; however, these results were inconclusive, because deterrent efficacy was estimated to be between -2 and 64% (Arnett et al. 2013). To assess the effectiveness of the deterrent system prototype developed by General Electric Power and Water (GE), Western EcoSystems Technology, Inc. (WEST) designed and conducted an initial study at CRWEF from July 15, 2013, to September 30, 2013. In this study, 4 deterrent nozzles were mounted on the 4 corners of the nacelles of 20 turbines, just behind the rotors. The prototype GE acoustic deterrents used in the research included an air compressor that forced high pressure ambient air through a nozzle, emitting a broad-band (white noise) sound up to 37 kilohertz (kHz) and a tone at approximately 47 kHz (Figure 1a), mostly covering the echolocation frequency range of North American bat species.

The results from the 2013 study demonstrated an approximate 25% reduction in the all-bat species fatality estimates at deterrent turbines compared to the estimates from the control turbine group (Gruver et al. 2014). Gruver et al. (2014) suggested that the lower-than-expected effectiveness of the deterrent system might be attributed to unanticipated deterrent sound attenuation caused by the higher wind speeds at nacelle height and/or the sounds emitted from operation of the turbine.

In a follow-up study performed in 2014 at CRWEF, the 4-nozzle system was adjusted to 2 nozzles deployed on the tower, approximately 26 m (85 ft) below the nacelle, and 2 nozzles deployed on the rear of the nacelle, one oriented upward and one downward. Using a 6-day rotating treatment block design and 16 turbines, all-bat species fatalities were estimated to be reduced by 29.25% when deterrents were operating. In addition to the carcass study, a concurrent thermal camera study of bat activity at a focal CRWEF deterrent turbine demonstrated bats more often utilized the airspace downwind of and below the nacelle.

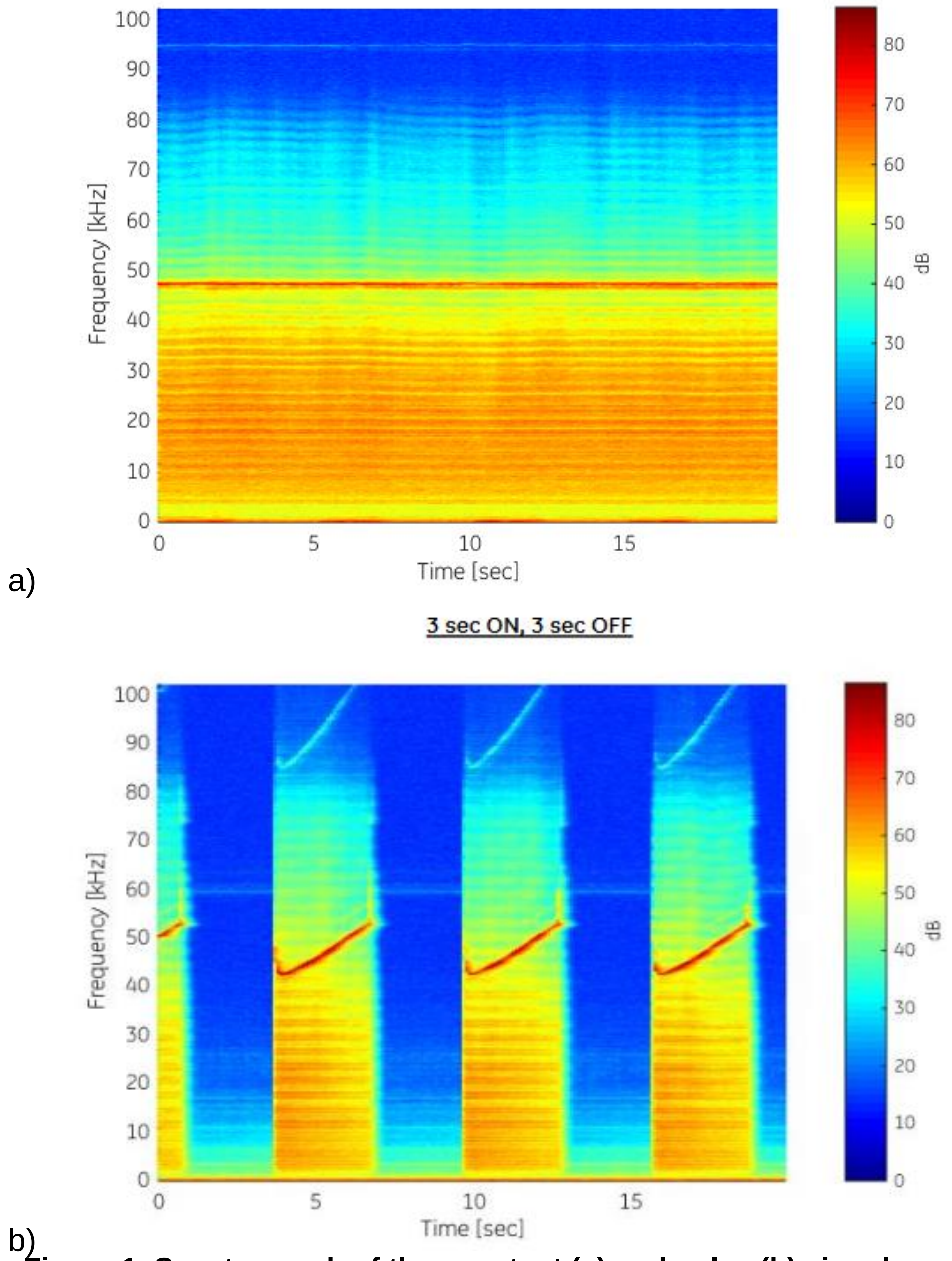

Figure 1. Spectrograph of the constant (a) and pulse (b) signals emitted from the deterrent system. Dark red line indicates the tone, the orange from c. 10-37 kHz represents the broad-band noise.

In response to the indication that bats more often utilize the airspace downwind and below the nacelle, the deterrent array was readjusted and another study was performed at CRWEF in 2015. The revised deterrent system deployed on each turbine included 2 pairs of nozzles mounted on each turbine tower; one pair was 26 m (85 ft) and another pair 50 m (164 ft) below nacelle height. Nozzles in each pair were mounted approximately 180 degrees from one another. We predicted this new array would provide a greater broadcast of the deterrent noise over the lower rotor swept area and would result in further improvement of the deterrent at reducing all-bat species fatality estimates.

The results of the 2015 study indicated deterrent operation reduced all-bat species fatalities by 32.5%. Separate deterrent estimates were also calculated for eastern red bat (*Lasiurus borealis*, -2.48%) and all other bat species (56.06%), indicating the deterrent was ineffective for eastern red bats and effective for other bat species. The disparity in deterrent effectiveness on fatalities of eastern red bat, a high-frequency (>35 kHz) echolocator, and the other bat species (predominantly low-frequency [<35 kHz] echolocators) may be attributed to a number of factors including differences in species physical sensitivity to the deterrent signal, gaps in coverage of the full range in echolocation frequencies, or behavioral differences in species use of the airspace surrounding the turbine (e.g., foraging vs. curiosity). Also, the similarity in effectiveness of the 4-nozzle prototype deterrent system deployed in 3 different configurations across 3 prior years indicated additional nozzle placements may be necessary to increase the effectiveness of an acoustic deterrent.

Ground-based tests of the pulse signal strategy, performed under Tasks 1 and 2 of this grant, indicated bats may be deterred by a pulse signal. Thus for Task 6, the deterrent system was redesigned to emit sound in pulses. By pulsing the air through the deterrent system, we were able to maintain the broad-band noise below 37 kHz and modulate the ~47 kHz tone through a range of frequencies between 45 and 70 kHz, thus potentially increasing the coverage of the echolocation frequencies used by the high-frequency bat group (i.e., eastern red bat and *Myotis* species). The pulse signal was emitted from the deterrent systems for an average 6.9 seconds (range 4.9 to 7.9 seconds) spaced by a 3.0 second period of silence as the system recharged (Figure 1b). The pulse strategy also allowed for deployment of 6 nozzles in a single deterrent system, increasing airspace coverage. In addition to the 4 nozzles mounted on the tower, with identical positioning to the system tested in 2015, 2 were added to the rear of the nacelle.

Objectives

The objective of Subtask 6.1 was to assess if the redesigned deterrent system deterred bats from using the turbine airspace. Under this objective, we hypothesized lower numbers of bats would be observed for shorter periods of time and at greater distances when deterrent systems operated. The null hypothesis would be that bat activity would be similar in number and spatial use whether the deterrent system was operating or was silent.

The objective of Subtask 6.2 was to determine whether the redesigned deterrent system reduced bat fatalities at wind turbines. We hypothesized the redesigned deterrent system would reduce all-bat species fatalities at CRWEF test turbines. The null hypothesis was that the level of all-bat species fatalities would not change when the deterrent systems were operating. We also hypothesized that emission of a pulse signal would reduce eastern red bat fatalities. The null hypothesis was that the pulse signal would not reduce eastern red bat fatalities at CRWEF test turbines. Last, we hypothesized that the redesigned deterrent system would be also be effective at reducing non-eastern red bat fatalities. The null hypothesis was that the pulse signal would be ineffective at reducing non-eastern red bat fatalities.

Study Site

CRWEF is approximately 18 kilometers (km; 11 miles, mi) east to west, and approximately 10 km (6 mi) north to south (Figure 2). CRWEF is located approximately 16 km (10 mi) northwest of Danville, IL, and approximately 32 km (20 mi) from Champaign, IL, along State Route 49 North. The landscape surrounding CRWEF is dominated by cultivated agriculture interspersed with sparsely distributed oak-hickory wood lots and homesteads. The Middle Fork River, a tributary of the Vermilion River, runs along the eastern edge of CRWEF and is approximately 3 km (2 mi) from the nearest turbine. This river provides a diversity of wildlife habitat in the form of deciduous forest interspersed with tallgrass prairie and wetlands (IDNR 2005).

Methods

Turbine and Deterrent Selection and Operation

A subset of 12 of the 20 CRWEF turbines used for prior deterrent research was selected for study under Task 6 (Figure 2). Turbines used in the study included: 24, 27, 32, 48, 51, 67, 88, 96, 109, 112, 117, and 120. Subtask 6.1, Thermal Imaging and 3D Flight Mapping during BP2, was performed at Turbines 112 and 120 because they were near one another, were surrounded by similar agricultural landscape, and lacked US Federal Aviation Administration (FAA) aviation safety lighting.

Study turbine and deterrent system operations were pre-programmed to a prescribed operating schedule between 17:30 and 07:00 each night. All study turbines were programmed to begin operations at the factory default cut-in wind speed of 3.0 m/s (6.7 mph), below which rotors were fully feathered to avoid more than 3 rotations per minute. A 6-day block design was used to determine deterrent system operations during testing (Table 1). Within each 6-day period, the turbines were randomly assigned to deter and control groups of equal size. During the initial 3 nights of each block, deterrent systems on the turbines in each group operated according to the assigned parameters (e.g., deter or control). In the second 3 nights, the assignments switched. This assignment/operation process was repeated for each 6-day block. To be able to compare deterrent effect on a nightly basis in Subtask 6.1, Turbines 112 and 120 were always assigned to opposite groups.

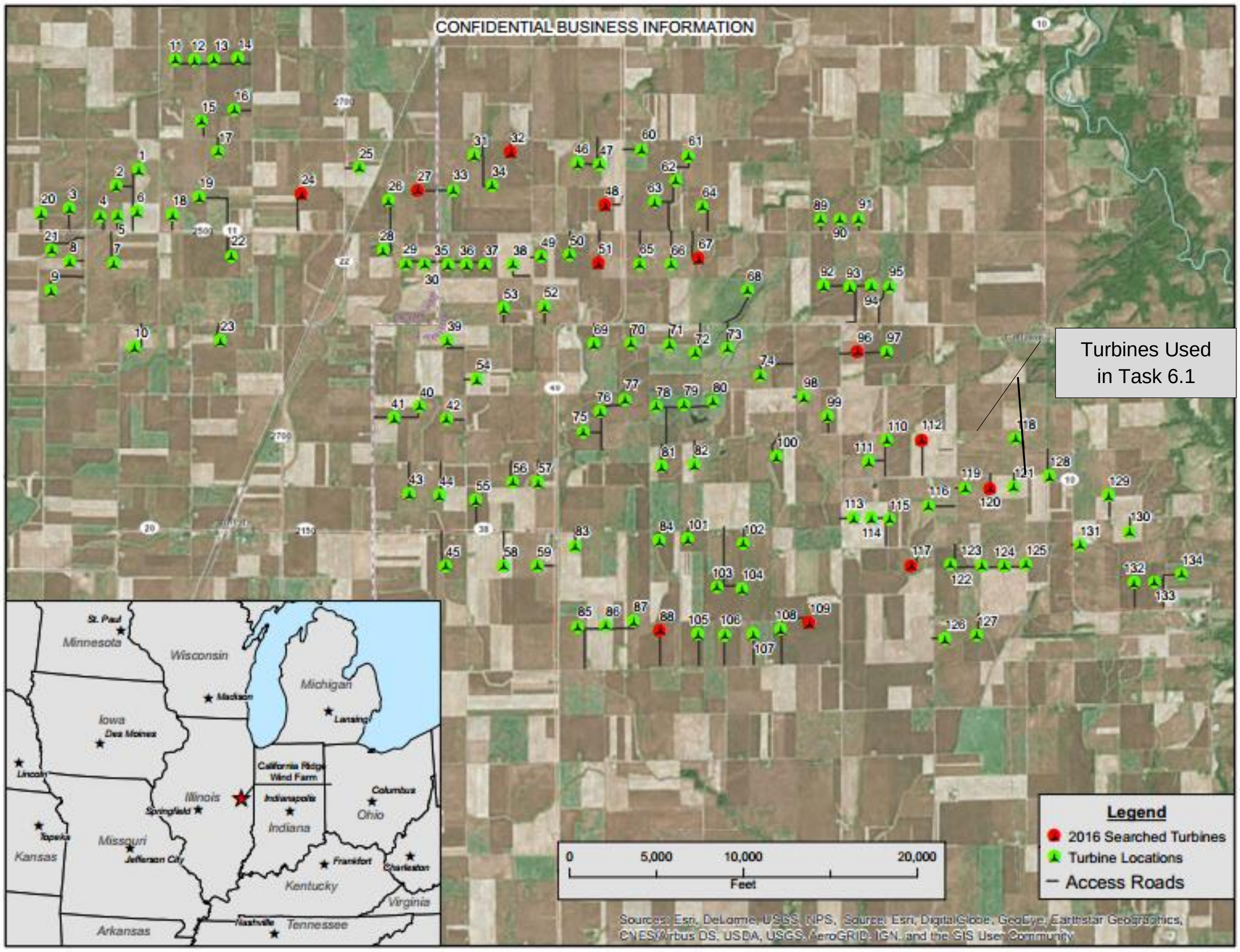

Figure 2. Map depicting Task 6 study locations within the California Ridge Wind Energy Facility in Champaign and Vermilion Counties, Illinois.

Table 1. Sample Treatment (T) Assignment

Study Block	Days	Turbine							
		A	B	C	D	E	F	G	H
1	1-3	T			T		T		T
	4-6		T	T		T		T	
2	1-3		T		T	T	T		
	4-6	T		T				T	T
i	1-3		T	T			T	T	
	4-6	T			T	T			T

The 2016 study period was divided into 2 halves due to the discovery of a consistent and unintended water emission from the pulse system. During the first half of the study, between July 31 and September 11, the pulse signal and a silent control were tested.

Condensation within the deterrent compressor system and/or lines was identified as one potential cause of the unintended water vapor emissions. The GE engineering team identified a viable solution involving the installation of an air/water separation unit in the deterrent compressor system. Suppliers could immediately provide enough air/water separation units for installation on 4 deterrent systems. For the second half of the season, between September 24 and October 11, the deterrent systems were modified and the study resumed. Four deterrent systems were retrofitted with the air/water separators; these 4 systems were configured to operate on every study night of the second half. The installation of the air/water separator unit did not change the frequency, amplitude, or duration of the acoustic signal from within the variability recorded for the systems prior to the installation. The deterrent systems on the remaining 8 study turbines were reconfigured to emit a constant signal from 5 nozzles, one on the nacelle (rear, oriented down) and 2 pairs on the tower using the same orientation described previously. Due to the addition of a 5th nozzle, the constant signal was emitted at lower amplitude than the average achieved across the systems from prior years. These 8 turbines were divided into 2 groups (constant signal and control) following the 6-day block design used during the first half of the study.

Subtask 6.1 – Thermal Imaging and 3D Flight Mapping During BP2

Field Data Collection

Three AXIS Q1922-E and 1 AXIS Q1932-E Thermal Network Cameras with a lens focal length of 19 mm (F 1.0) and a horizontal angle of view of 32 degrees were used to record bat images. Two cameras were placed at Turbines 112 and 120, with identical camera orientations in each system. One camera was placed 54 m (177 ft) northwest of the turbine and the second was placed 54 m (177 ft) to the southeast of the turbine (Figure 3). Fully adjustable survey tripods with leveling heads (tribachs) and a custom designed tilting bracket were used as a camera platform. The camera were pointed at each other, then tilted up about 50-52 degrees to put the middle set of deterrents near the center of view. The cameras were set to record images in high definition using a pre-programmed display called “Fire and Ice” at 30 frames per second (fps).

Figure 3. Thermal camera placement at base of Turbine 120

Each camera was connected to a power-over-Ethernet (POE) switch via Ethernet cables and networked to a single laptop computer housed in the base of the turbine tower. The Axis Communications Camera Management software was used to program the recording schedule, synchronize the camera time stamps to the computer time registry, and fine tune each camera view during set-up. Video data from each station were written to portable network hard drives. Camera systems were visited once every 3 days to retrieve video files, re-synchronize the camera timestamps, and perform an inspection of the camera system hardware. Video was collected on most nights between July 31 and October 11, 2016. Due to the consistently high level of bat activity and budget/time constraints, video from 16 nights was reviewed and used in subsequent data analysis of the effect of the pulse (1st study half) and constant (2nd study half) signals on bat activity.

Data Management and Analysis

Video data was transferred from the portable hard drives to a dedicated external hard drive where it was organized by date and camera number. Videos were saved as .asf files from the cameras and were then converted to .avi files and clipped down to the focal 4-hour time block from 20:00:00-00:00:00 using Freemake Video Converter Version 4.1.9.

Only nights with complete 4-hour files from all 4 cameras were processed. The raw footage for each night was reviewed using BriefCam Syndex FS, commercially available surveillance software that identifies moving objects in recorded video and provides a condensed video synopsis of the detected objects. A complete synopsis typically included thousands of “objects”, such as bats, birds, insects, aircraft, spinning turbine rotors, nacelle movements, and clouds. The video reviewer reduced the number of objects shown in a synopsis by applying pre-set program filters (e.g. by Speed, Size, Color, Similarity) to the complete synopsis. Filter categories provided by the software were relative to the objects identified in the complete synopsis. In other words, the midpoint setting of the Size filter would retrieve the objects 50% smaller than the largest object in that video file. After applying filters, the reviewer then viewed all objects meeting the refinement criteria, navigated to an object in the original video by clicking on the object in the synopsis screen, and completed the review.

For this project, the pre-set program filter of “Size” was used to conduct the initial refinement. “Size” refinement was limited to the 5 smallest object categories detected in an individual synopsis. Every object detected in the first 3 categories was individually selected and the original event of that object was fully reviewed at 2x speed. “Size” categories 4 and 5 were reviewed at 2x speed but only objects that presented as potential bats (i.e. small and fast moving) were selected for full review. The reviewer then used the “Similarity” filter tool to obtain a refined synopsis. The “Similarity” tool prompts the reviewer to provide representative bat observations within the complete synopsis and searches the rest of the detected objects for those that are similar in pixel size, shape, and movement. The reviewer provided several representative bat observations (i.e. a bat moving in the foreground and then one in the background) and then reviewed the refined synopses for any new objects not found in the “Size” filter review.

Each small, fast-moving object was either eliminated (insects, clouds, spinning blades, nacelle cone, etc.) or classified as bat, bird, unknown bat/bird, or unidentified object by the reviewer. Object type classification was determined from the visual cues of object shape, size, flight style, speed (judged by perceived position vs. number of frames in observation), and wing beat patterns. The timestamp, basic observation notes, and general object location were also recorded. To aid the relocation of each object through the review process, it was assigned to one of 4 field of view quadrants, using the tower as a y-axis, and beginning with quadrant 1 in the top left, moving left to right and top to bottom sequentially.

The video files and data collected on all objects recorded by the initial reviewer were then processed by two other reviewers using the freely available video player software, VirtualDub. The two other reviewers provided consensus on the object type (bird, bat, etc.), quadrant, and beginning or ending timestamps.

Although the Axis camera management software was used to synchronize the cameras periodically during recording, asynchrony on the order of 0.2 to 4.0 seconds between cameras still occurred from one night to the next. To accurately assign view time and approach distance to each bat and subsequently tally the number of bat passes for each night, the video files from both cameras needed to be time-synchronized. Time synchronization was performed by reviewing the nacelle orientation data from each turbine, finding times in the evening where a movement was recorded, and then identifying the first frame in which the movement occurred in each camera. The timestamps for observations from one camera were adjusted to synchronize with the matching timestamp from the other camera. The bat pass data from both cameras at each station were compiled into a combined dataset, and duplicate observations eliminated. Bats in this file were observed on 1 or both cameras at each of the 2 turbines. The beginning and ending time stamps for each bat observation were calculated (in seconds, s) from the synchronized timestamps by subtracting the earliest observed timestamp in both cameras from the latest observed timestamp in both cameras.

The turbine and deterrent positions, camera locations, and the camera fields of view were modeled to scale in Computer Aided Design (CAD) software for both study turbines (Figure 4). The scale model space was informed by physical measurements taken in the field by a surveyor supplemented by technical diagrams and specifications of the turbine and camera models.

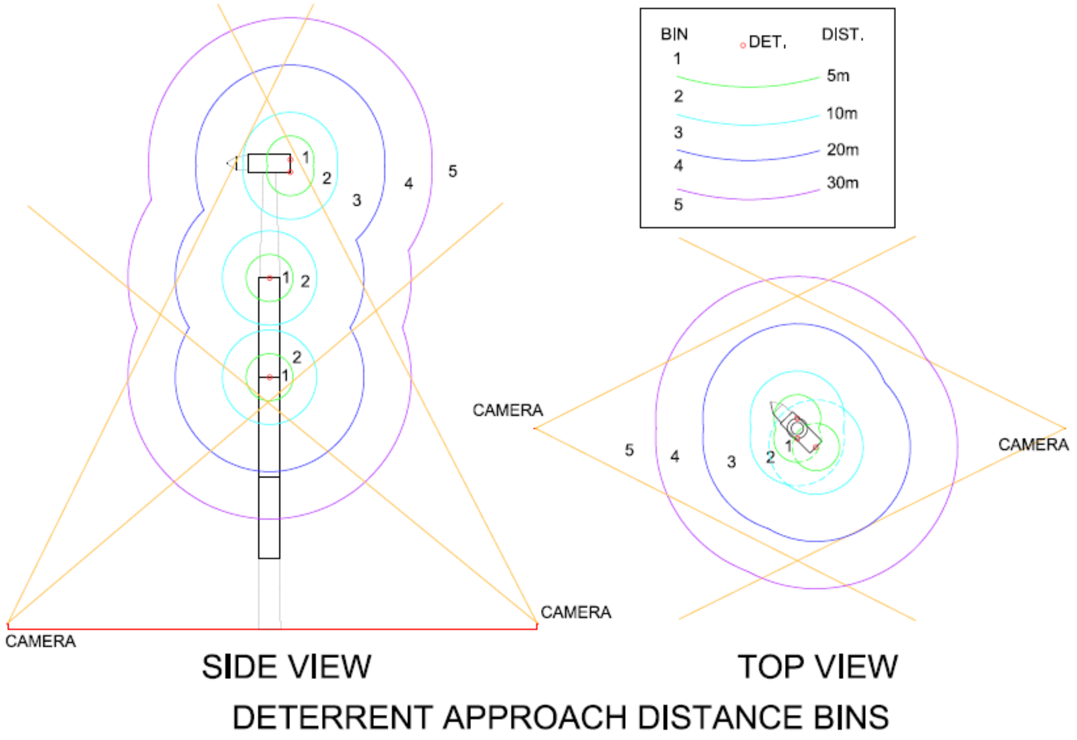

Figure 4. Diagram of model space, camera fields of view, and approach distance bins. Camera field of view is bounded in yellow lines.

The flight location of each bat observed in both cameras was partially reconstructed within the model space using triangulation of its position from pairs of time-synchronized still images extracted from the videos where the bat was detected in both cameras (Figure 5) or by estimating its nearest possible approach distance by manual review of the observation characteristics (e.g., on the near side of the field of view overlap, etc.) using partial modeling vectors and visualization in the model. Once a flight path was reconstructed, the minimum possible distance to the nearest deterrent was calculated. Every observed bat was assigned to an approach distance bin (Figure 5) encompassing the estimated or calculated approach distance. Approach distance bins included 0.0-5.0 m (0.0-16.0 ft), 5.1-10.0 m (16.1-33.0 ft), 10.1-20.0 m (33.1-66.0 ft), 20.1-30.0 m (66.1-99.0 ft), or 30.1+ m (99.1+ ft).

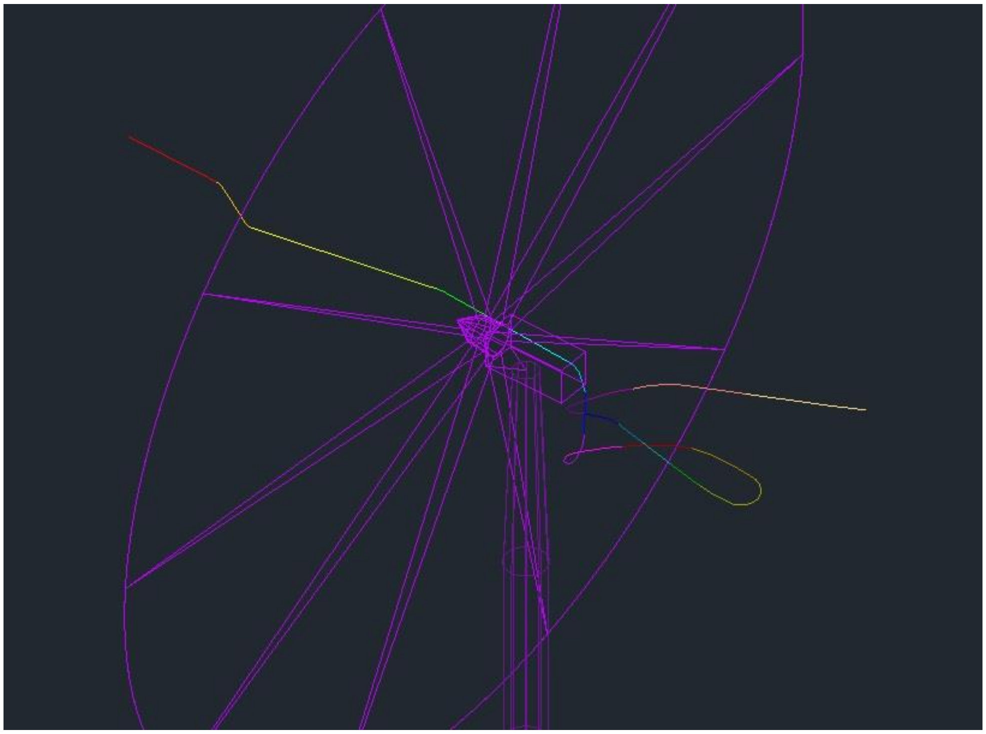

Figure 5. Example of bat flight path modeled in CAD. Each different color in the path is 1 second of flight within model space

Statistical Analysis

Eight nights of video from the first half of the study were used to estimate the effectiveness of the pulse system and 8 from the second half of the study were used to estimate the effectiveness of the constant system. In each study half, both turbines were assigned to operate (deter) or not operate (control) an equal number of nights. Direct comparison between data sets collected in the first and second halves of the study were not performed because the study periods, and thus pulse and constant signal treatments, were separated in time.

The data collected during the first (pulse vs. control) and second (constant vs. control) halves of the study were analyzed using the same methods. Generalized linear models (GLM) were used to analyze the bat count data, assuming a Poisson error structure and log-link. The overall bat counts by treatment by night were analyzed using a two-way classification of trial-night-by-treatment of the form

$$\ln y_{ij} = \beta_0 + \beta_i + \tau \qquad (1)$$

where

y_{ij} = bat count for the *j*th treatment $(j = 1{,}2)$ in the *i*th block $(i, \cdots, 8)$;

β_0 = baseline;

β_i = *i*th block effect;

τ = treatment effect.

Using a GLM with a normal error structure and log-link, bat flight durations were compared between control and deter conditions during both study halves.

With approach distance information, the analysis also examined the relationship between the degree of deterrent effect and proximity to the nozzles of the turbine-mounted deterrent system. Deterrent effects as a function of distance bin from the turbine-mounted deterrent system were modeled as a linear relationship on the log-scale, where

$$\ln y_{ij} = \beta_0 + \beta_i + \tau + \beta_1 d + \beta_3 (d \times \text{treatment}),$$

where *d* is distance from the nearest deterrent nozzle on the wind turbine. The GLM analyses did not use the 28 September data because no bats were observed at either the control or treatment turbine. In all tests, significance was assessed at the P ≤ 0.10 level.

Subtask 6.2 – Deterrent Field Test during BP2 (Carcass Monitoring)

Search Schedule

Daily searches were conducted from August 1st to October 11th. Clearing searches were conducted within all plots before the study began in order to remove any bat carcasses that had fallen prior to August 1st.

The search schedule was aligned with each 3-day half of the 6-day study block rotations. Search crews included human searchers, as well as dog and handler search teams provided by Conservation Canines, a biological research group associated with the University of Washington[1]. A combination of the human search teams and the dog and handler teams were used to maximize carcass detection probability, minimize bleed-through of carcasses from treatment to control or control to treatment assignments, and ultimately to minimize the potential to assign carcasses to the wrong treatment.

Human searcher teams were scheduled to search day 1 of every 3-day study block. A dog and handler team searched on days 2 and 3 of each 3-day rotation. Both the human searcher and dog and handler teams are hereafter referred to as “searcher(s),” unless otherwise specified.

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[1] Address: Conservation Canines, Center for Conservation Biology, Box 351800 University of Washington Seattle, WA 98195-1800.

Search Plots, Plot Condition Classes, and Habitats

A 60 m (197 ft) radius circular search plot was established beneath each turbine (Figure 6). Plots were marked with staked circular transects spaced approximately 5 m (16 ft) apart. To maximize carcass detection, plots were periodically mowed and raked. Despite intensive plot maintenance, plot conditions varied across the season, so plot condition classes for placed and found carcasses (including both actual carcasses and searcher efficiency/carcass removal trials) were determined at the time of placement and recovery (Figure 7).

The plot condition classes identified within the survey areas were defined as follows:

> **Class 1** (easy): Bare ground (i.e., gravel pad/access road, bare dirt) 90% or greater; all ground cover sparse and 15 centimeters (cm, 6 inches [in]) or less in height.
>
> **Class 2** (moderate): Bare ground 25% - 90%; all ground cover sparse and 15 cm (6 in) or less in height.
>
> **Class 3** (difficult): Bare ground 25% or less; ground cover ranging in height up to 31 cm (12 in).

The ground cover within plots included gravel roads and turbine aprons, bare topsoil with sparse vegetation, and perennial grasses or herbaceous vegetation, wheat/rye crops, mowed corn, or mowed soybeans of varying density and heights. The grasses and wheat/rye crops were intentionally planted within search plots in order to fix soil nutrients and prevent erosion while the study was performed. Throughout the season, many plots had begun regenerating crops or weeds and some areas had been periodically covered by pools of water or eroded by runoff.

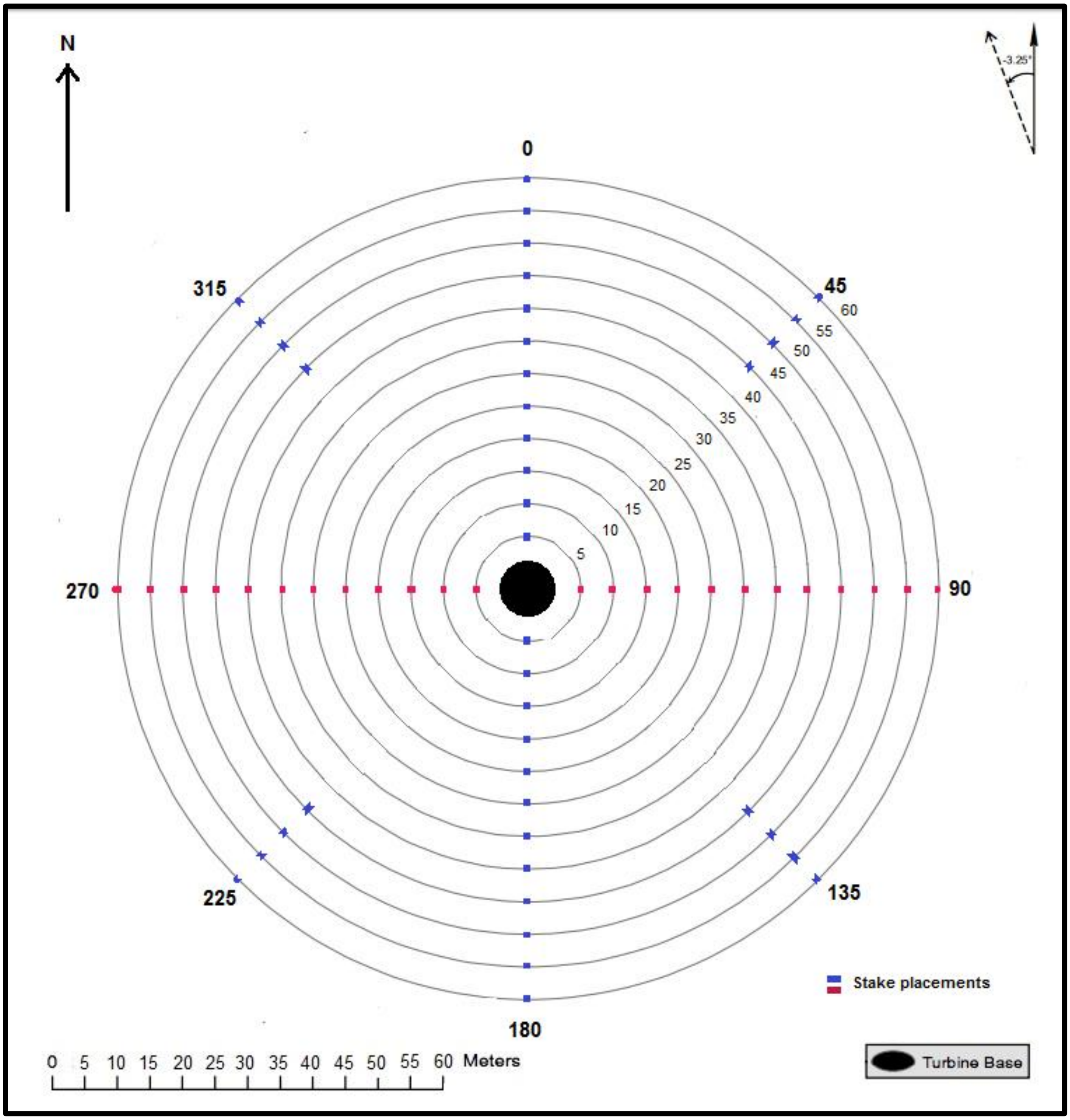

Figure 6. Plot diagram showing stake placements at both 45 and 90 degree azimuths around turbine. Stakes were placed every 5 m (16 ft) and were marked with alternating colors to assist with visibility and lane consistency when searching.

Figure 7. Plot photos exemplifying variety of conditions and plot condition classes. Clockwise from top left shows plots with dense chaff and leftover crop debris (Class 3), plots with grasses and agricultural weeds (Class 2-3), plots showing areas of bare ground mixed with dense vegetation (Class 1-2), or plots that were cleared and some corn or weedy plants are regenerating (Class 1-2).

Search Methods

Human searchers were assigned to search in pairs. One searcher began searching around the turbine base while the other searcher began at the first (5 m, 16 ft) transect. Searches proceeded outward; with the search team following concentric transect pairs (e.g., 0, 5 m and 10, 15 m transects). Search direction (clockwise, counter-clockwise) was alternated according to the calendar day.

When a plot was searched by a dog and handler team, the handlers would determine the predominant wind direction, if any, prior to starting. They would then station the dog downwind or upwind from the plot in response to the wind and plot conditions. Upon starting a search, the handler generally used a back-and-forth walking pattern to guide the dog at an angle into or with the prevailing wind. The dog was usually allowed to freely roam while searching for carcass scent.

The location of each discovered bat carcass was marked with a pin flag or flagging tape and the searcher(s) would finish searching the plot, ensuring each plot was searched thoroughly and at a consistent rate. After photographs and field data were collected, bat carcasses were bagged and labeled with a unique identification number, then retained in an on-site freezer. Human searchers used a laser rangefinder (Nikon ProStaff 550 or similar) to determine the distance to the turbine, and a compass to determine azimuth to the turbine tower. Dog handlers used a Columbus V-900 Bluetooth GPS Data Logger to mark their search path and to document carcass locations. This information, along with species, number of days old (1, 2, 3, or 4+ days old), age (adult/juvenile), sex (male/female), time discovered, weather conditions, and plot condition class, was recorded electronically.

Incidental carcasses were defined as those found outside of the search plot boundaries, those found within a plot but outside of a scheduled search (e.g., during plot maintenance or by wind farm personnel), or those determined to be from a prior 3-day search period (i.e., a 3 day old carcass found on day 1 of a search sequence). Incidental carcasses were excluded from statistical analysis.

Calibration Trial Placements

Calibration trials were used to assess the ability of searchers to detect bat carcasses during the study. These trials were designed to account for both scavenging and searcher efficiency. Bat species used in calibration trials included hoary bat (*Lasiurus cinereus*), silver-haired bat (*Lasionycteris noctivagans*), eastern red bat (*Lasiurus borealis*), and big brown bat (*Eptesicus fuscus*). Only entire carcasses in good condition (i.e., not severely decayed or damaged) were used.

Calibration trial carcasses were placed to target 12, 3-day search rotations. Up to ten carcasses were placed on a single trial day, with a total of 10-18 carcasses placed within a targeted 3-day search rotation. Trials were unannounced and set up near dusk after daily searches were complete. Carcasses were marked discreetly to keep searchers blind to the trials. When preparing the tests, all carcass distances and azimuths were generated using the Excel random number function. Carcasses were tossed into the air to determine position (face up or face down, wings in/wings out, etc.), simulating a falling carcass. Nitrile or latex gloves were worn at all times while handling and preparing the carcasses.

All searchers were tested in proportion to the number of days they searched. For example, searchers who searched multiple times per week were tested more frequently than searchers who searched less than once per week. Carcass distribution among the plot condition classes varied for each turbine, generally reflecting the amount of each plot condition class present at that specific turbine.

Carcasses placed before any of the 3 targeted search days were either found by searchers, scavenged, or remained unfound. The trial placement manager examined every carcass recovered by searchers during a trial and checked them for identifying marks. The manager also checked the location of any trial carcasses that had not been recovered to determine whether they had been scavenged. Carcasses that could not be relocated by the trial manager after the third day of searches were recorded as scavenged. Any trial carcasses still present after the end of the 3-day block were retrieved by the calibration trial manager.

Statistical Analysis

The raw carcass counts of the numbers of non-incidental bats collected on days 1, 2, and 3 of the 3-day trials were converted to estimates of bat fatality using data from calibration trials and maximum likelihood estimation. If any turbine search was missed during a 6-day block, the data collected from the respective turbine was excluded from the analysis for that study block. Thus, bat count and covariate data from each turbine were considered for inclusion on a block-by-block basis. The carcass data collected during the second half of the season under the pulse signal treatment were aligned and pooled according to the 3-day trial periods for analysis.

The carcass recovery data were pooled across all counted control or treatment turbines within a 3-day trial when estimating total bat fatality. Standard errors were computed based on the inverse Hessian of the likelihood models. The result was that for every 6-day test block, 2 control and 2 treatment estimates of bat fatality were calculated along with their standard errors. This procedure was used to analyze deterrent effectiveness on all bats, eastern red bats alone, and pooled data for non-eastern red bat species.

For illustrative purposes, both the raw carcass counts and the bat fatality estimates were used as dependent variables in subsequent tests of treatment effects because of the high detection probability observed throughout the study.

The shift between human and dog and handler teams during the 3-day deterrent trials required a multiphase calibration trial to account for imperfect search detection in the estimation of total bat fatality. The multiphase calibration trial was performed by the following:

Let N_1 be the number of fresh bat carcasses “seeded” the evening before day 1 of the trials. Then x_{11}, x_{12}, and x_{13} are the number of bat carcasses recovered from this release on days 1, 2, and 3, respectively. They have expected values:

$$E(x_1) = N_1 R_1 p_1 = N_1 \theta_1 \tag{1}$$

$$E(x_2) = N_1 R_2 (1 - p_1) p_2 = N_1 \theta_2 \tag{2}$$

$$E(x_3) = N_1 R_3 (1 - p_1)(1 - p_2) p_3 = N_1 \theta_3 \tag{3}$$

where

R_i = carcass retention probability to day i,

p_1 = conditional probability of a human crew recovering the bat carcass on day 1 after seeding before day 1,

p_2 = conditional probability of a dog and handler team recovering the bat carcass on day 2 after seeding before day 1,

p_3 = conditional probability of a dog and handler team recovering the bat carcass on day 3 after seeding before day 1.

Let N_2 be the number of fresh bat carcasses seeded after day 1 but before day 2 of the trials. Then x_{22} and x_{23} are the numbers of bat carcasses retrieved on days 2 and 3 of the trial with expected values:

$$E(x_{22}) = N_2 R_1 p_2 = N\theta_4 \tag{4}$$

$$E(x_{23}) = N_2 R_2 (1 - p_2) p_3 = N\theta_5. \tag{5}$$

Finally, let N_3 be the number of fresh bat carcasses seeded after day 2 but before day 3 of the trials. Then x_{33} is the number of bat carcasses retrieved by the dog and handler team on day 3 with expected value:

$$E(x_{33}) = N_3 R_1 p_3 = N_3 \theta_6. \tag{6}$$

Now consider a three-day trial at the wind turbines. Let the number of dead bats recovered be denoted as d_1, d_2, and d_3 for days 1–3, respectively. Searches on day 1 was conducted by human crews and the searches on days 2 and 3 were conducted by a dog and handler team. The expected values of the d_i are as follows:

$$E(d_1) = D_1 R_1 p_1 = D_1 \theta_1 \tag{7}$$

$$E(d_2) = D_1 R_2 (1 - p_1) p_2 + D_2 R_1 p_2 = D_1 \theta_2 + D_2 \theta_4 \tag{8}$$

$$\begin{aligned} E(d_3) &= D_1 R_3 (1 - p_1)(1 - p_2) p_3 + D_2 R_2 (1 - p_2) p_3 + D_3 R_1 p_3 \\ &= D_1 \theta_3 + D_2 \theta_5 + D_3 \theta_6 \end{aligned} \tag{9}$$

where D_i = number of bat fatalities on day $(i = 1, \cdots, 3)$.

The daily recovery counts from the calibration trials can be modeled as a product of multinomials. The carcass counts during a 3-day turbine trial can be modeled as a product of Poisson distributions. The joint likelihood model can then be written as follows:

$$L = \binom{N_1}{\vec{x}_1} \theta_1^{x_{11}} \theta_2^{x_{12}} x_3^{x_{13}} (1 - \theta_1 - \theta_2 - \theta_3)^{N_1 - x_{11} - x_{12} - x_{13}}$$

$$\cdot \binom{N_2}{\vec{x}_2} \theta_4^{x_{22}} \theta_5^{x_{24}} (1 - \theta_1 - \theta_4)^{N_2 - x_{22} - x_{23}}$$

$$\cdot \binom{N_3}{\vec{x}_{33}} \theta_6^{x_{33}} (1 - \theta_6)^{N_3 - x_{33}}$$

$$\cdot \frac{e^{-D_1 \theta_1} (D_1 \theta_1)^{d_1}}{d_1!}$$

$$\cdot \frac{e^{-(D_1 \theta_2 + D_2 \theta_4)} (D_1 \theta_2 + D_2 \theta_4)^{d_2}}{d_2!}$$

$$\cdot \frac{e^{-(D_1 \theta_3 + D_2 \theta_5 + D_3 \theta_6)} (D_1 \theta_3 + D_2 \theta_5 + D_3 \theta_6)^{d_3}}{d_3!} \tag{10}$$

Using method-of-moments based on Equations (8–10), the daily mortalities can be estimated as follows:

$$\widehat{D}_1 = \frac{d_1}{\widehat{\theta}_1} \tag{11}$$

$$\widehat{D}_2 = \frac{d_2 - \widehat{D}_1\widehat{\theta}_2}{\widehat{\theta}_4} \tag{12}$$

and

$$\widehat{D}_3 = \frac{d_3 - \widehat{D}_1\widehat{\theta}_3 - \widehat{D}_2\widehat{\theta}_5}{\widehat{\theta}_6}. \tag{13}$$

The total estimated fatalities over the 3-day trial is then estimated as:

$$\widehat{D} = \widehat{D}_1 + \widehat{D}_2 + \widehat{D}_3. \tag{14}$$

Numerical methods were used to estimate $\widehat{D}$ and its associated variance.

Treatment effects were estimated from the bat counts and/or the estimates of total bat fatality using generalized linear models (GLMs), based on a log-link and normal error. This basic response model was of the form:

$$\hat{y}_{ijk} = \mu \cdot \beta_i \cdot \tau \cdot \mathrm{OP}_{ijk} \cdot \epsilon_{ijk} \tag{15}$$

where

$\hat{y}_{ijk}$ = estimate of bat fatality for the *i*th block $(i = 1, \cdots, B)$, *j*th treatment ($j =$ 1 for control, 2 for treatment,), and *k* replicate $(k = 1, 2)$;

μ = baseline value for control in block 1, replicate 1;

β_i = block effect $(i = 1, \cdots, B)$;

τ = treatment effect;

OP_{ijk} = total turbine operating hours for the *i*th block $(i = 1, \cdots, B)$, *j*th treatment $(j = 1, 2\ )$, and *k* replicates $(k = 1, 2)$;

ϵ_{ijk} = random error term.

The natural log of turbine operating hours (ln) was used as an offset to adjust for variation in operating hours within a trial. The response model (1) corresponds to a randomized block experimental design with within-block replication of two treatments. In essence, this analysis is comparing the rate of bat fatalities per turbine operating hour between treatments. Adjustment for turbine operating hours had little effect on results because numbers were similar between treatments.

Tests of treatment effects were based on analysis of deviance (ANODEV) and asymptotic *F*-tests. In all tests, significance was assessed at the $P \leq 0.10$ level. Treatment effects were compared by total bat, eastern red bat and non-eastern red bat groups. The relative effect of the treatment compared to the control was estimated by $\hat{\tau}$ in the GLM. Letting $\hat{\tau}$ be the log-linear estimate of the treatment effect from the fitted GLM, the back-transformed value is:

$$\hat{\theta} = e^{\hat{\tau}}$$

with estimated variance:

$$\widehat{\mathrm{Var}}(\hat{\theta}) = \mathrm{Var}(\hat{\tau}) \cdot e^{2\hat{\tau}}.$$

The reduction in bat fatalities due to the treatment was then estimated by $1 - \widehat{\theta} \times 100\%$.

Results

Subtask 6.1 – Thermal Imaging and 3D Flight Mapping during BP2

Pulse Signal during the First Half of the Study

The analysis of the thermal video data during the first half of the study found that the pulse signal had a significant effect on the total number of bats that passed into the field of view. Over the 8 nights, 198 bats were observed during control and 133 bats observed during the pulse signal for an empirical estimate of overall deterrent effect of 0.3283 (Tables 2 and 4). Analysis of deviance (ANODEV) found the deterrent effect to be 32.83% ($\widehat{\mathrm{SE}}$ =0.0753) effective (Table 3).

Analysis of time in field of view data found that the pulse signal significantly reduced the length of time bats spent in the field of view. Bats spent a mean 9.8 s ($\widehat{\mathrm{SE}}$ =0.7 s) in view under control conditions and 4.9 s ($\widehat{\mathrm{SE}}$ =0.5 s) when the deterrent system emitted a pulse signal. This led to a relative reduction in bat flight time of 50.9% ($\widehat{\mathrm{SE}}$ =7.1%), which was statistically significant (P<0.001, Figure 8).

Using the midpoints of the distance bins (note midpoint of the farthest bin set at 35 m [115 ft]), the ANODEV found the deterrent effect to be log-linear in form, declining with distance from the turbine-mounted deterrent system (Tables 4 and 5). The fitted model estimated an 87% deterrent effect at the deterrent nozzles, declining to 0 at approximately 30.1 m (98.7 ft) (Figure 9). The fitted model for the deterrent effect (DE) as a function of distance was

$$\mathrm{DE} = 1 - \mathrm{e}^{-2.0214+0.0670\mathrm{d}}$$

where the intercept has a standard error of 0.3021 and the slope, a standard error of 0.0109.

Table 2. Bat counts by date and treatment from thermal camera studies at control and pulse signal treatments, July 31 –September 11, 2016.

	Signal Treatment	
Date	**Control**	**Pulse**
7/31	65	46
8/1	36	18
8/2	16	2
8/3	22	27
9/8	9	10
9/9	0	0
9/10	8	6
9/11	42	24
Total	**198**	**133**

Table 3. Analysis of deviance for bat counts using a Poisson error structure and log-link.

Source	DF	DEV	MDEV	*F*	*P*-value
Total$_{COR}$	13	175.3869			
Blocks	6	147.7846	24.6308	10.0162	0.0065
Treatment	1	12.8477	12.8477	5.2245	0.0623
Error	6	14.7546	2.4591		

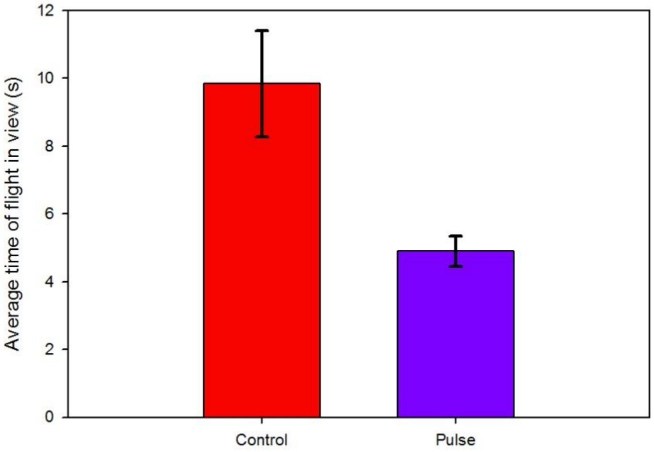

Figure 8. Average time in field of view for control and pulse treatments. The pulse signal resulted in a statistically significant relative reduction in time in field of view of 50.9% ± 7.1% (*P* <0.001).

Table 4. Bat counts by distance bin (in meters from the deterrent nozzle) for control (C) and pulse signal treatment (T), pooled over trial nights and empirical estimates of deterrent effect.

	Distance Bin (m)					
Signal Treatment	**0–5**	**6–10**	**11–20**	**21–30**	**30+**	**Total**
C	30	37	42	17	72	198
T	1	7	22	26	77	133
Estimated deterrent effect	0.967	0.811	0.476	-0.529	-0.069	0.328

Table 5. Analysis of deviance for bat counts by distance (D) using a Poisson error structure and log-link.

Source	DF	DEV	MDEV	*F*	*P*-value
$\text{Total}_{\text{COR}}$	69	468.5756			
Blocks	6	147.7846	24.6308	8.3221	< 0.0001
Treatment	1	12.8477	12.8477	4.3409	0.0415
D	1	88.2187	88.2187	29.8070	< 0.0001
D × treatment	1	42.1447	42.1447	14.2397	0.0004
Error	60	177.5799	2.9597		

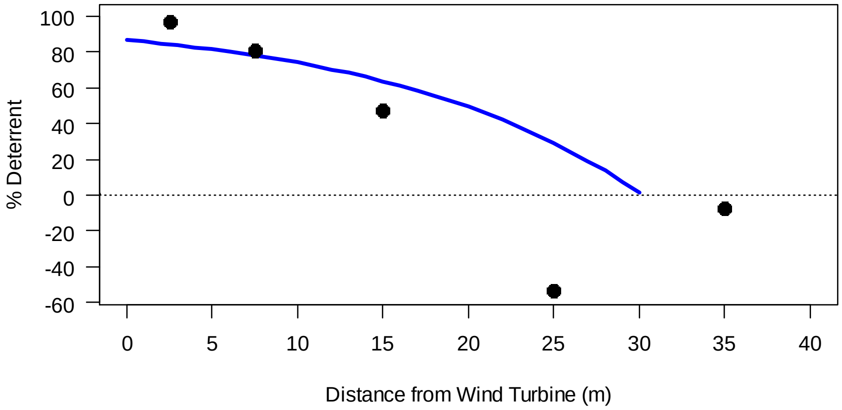

Figure 9. Fitted curve for % deterrent effect produced by the pulse signal as a function of distance from turbine-mounted deterrent system

Constant Signal during the Second Half of the Study

The analysis of the thermal video data during the second half of the study found that a constant signal significantly reduced the number of bats passing into the field of view. Over the 8 nights, 40 bats were observed during control and 16 bats observed during the constant signal for an empirical estimate of overall deterrent effect of 0.60 ($\widehat{\mathrm{SE}}$ =0.1183, Tables 6 and 7). ANODEV found the deterrent effect to be statistically significant (P = 0.0141, Table 8).

Analysis of time in the field of view data found that the constant signal appeared to reduce the length of time bats spent in the field of view. Bats spent a mean 8.1 s ($\widehat{\mathrm{SE}}$ =1.6 s) in view under control conditions and 4.9 s ($\widehat{\mathrm{SE}}$ =1.3 s) when the deterrent system emitted a constant signal. This led to a relative reduction in bat flight time of 43.4% ($\widehat{\mathrm{SE}}$ =30.5%), however, it was not statistically significant (P=0.230, Figure 10).

Similar to the ANODEV of distance effect of the pulse signal, the ANODEV of the constant signal found the deterrent effect by distance to be log-linear in form, declining with distance from the turbine-mounted deterrent system (

Table , Figure 11). Noting the thermal camera data to be sparse, particularly near the deterrent nozzles, the fitted model estimated a 100% deterrent effect at the tower, declining to 0 at approximately 40.5 m (132.9 ft) (Figure 11). The fitted model for the deterrent effect (DE) as a function of distance was

$$\mathrm{DE} = 1 - \mathrm{e}^{-2.900+0.0715\mathrm{d}}$$

where the intercept has a standard error of 1.099 and the slope, a standard error of 0.0356.

Table 6. Bat counts by date and treatment from thermal camera studies at control and constant signal treatments, September 26–October 6, 2016.

	Signal Treatment	
Date	**Control**	**Constant**
9/26	9	3
9/27	1	0
9/28	0	0
9/29	10	3
9/30	1	3
10/1	8	4
10/3	2	1
10/6	9	2
Total	**40**	**16**

Table 7. Bat counts by distance bin (in meters from nearest deterrent nozzle) for control (C) and constant signal treatment (T), pooled over trial nights and empirical estimates of deterrent effect.

	Distance Bin (m)					
Signal Treatment	**0–5**	**6–10**	**11–20**	**21–30**	**30+**	**Total**
C	1	5	9	9	16	40
T	0	0	2	3	11	16
Estimated deterrent effect	**1.0**	**1.0**	**0.778**	**0.667**	**0.312**	**0.600**

Table 8. Analysis of deviance for total bat counts using a Poisson error structure and log-link.

Source	DF	DEV	MDEV	*F*	*P*-value
Total$_{COR}$	13	39.5684			
Blocks	6	23.5025	3.9171	4.3206	0.0491
Treatment	1	10.6263	10.6263	11.7209	0.0141
Error	6	5.4397	0.9066		

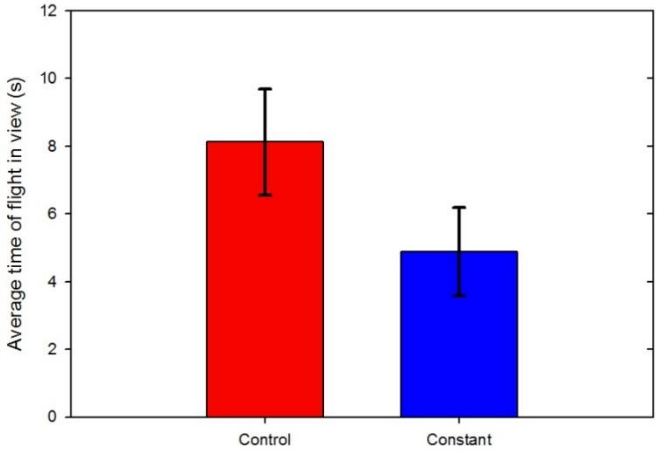

Figure 10. Average time in field of view for control versus constant experiment. The constant signal resulted in a relative reduction in time in field of view of 43.4% ± 3.05%, however this effect was not statistically significant (*P* = 0.230).

Table 9. Analysis of deviance table for bat counts by distance (D) using a Poisson error structure and log-link.

Source	DF	DEV	MDEV	*F*	*P*-value
Total$_{COR}$	69	117.3597			
Blocks	6	23.5025	3.9171	5.0567	0.0003
Treatment	1	10.6263	10.6263	13.7179	0.0005
D	1	31.7825	31.7825	41.0294	< 0.0001
D × treatment	1	4.9708	4.9708	6.4170	0.0139
Error	60	46.4777	0.7746		

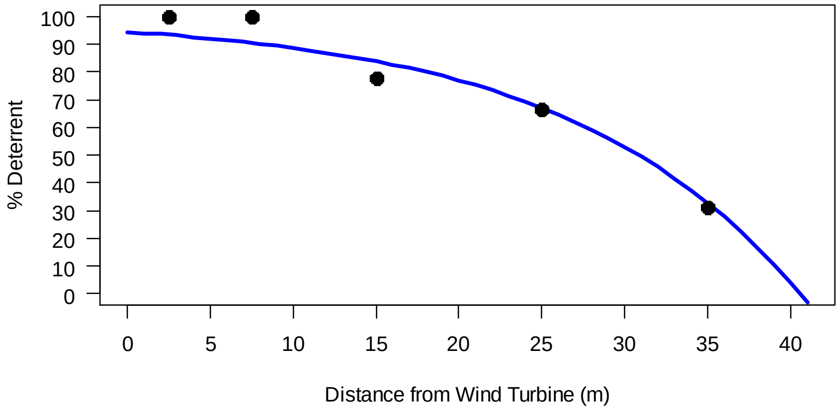

Figure 11. Fitted curve for % deterrent effect produced by the constant signal as a function of distance from turbine-mounted deterrent system.

Pulse versus Constant Signal Effectiveness

Using the fitted deterrent curves for the pulse (first half) and constant (second half) signal trials, response models were compared graphically using asymptotic 95% confidence intervals (Figure 12). The fitted curve for the pulse signal is lower in magnitude and shorter in distance than the fitted curve for the constant signal. The pulse signal appears to asymptote to 0% effectiveness nearer the deterrent nozzles (~26-30 m [85-99 ft]) than the constant (~33-41 m [99-134 ft]). However, the 95% confidence intervals for the two curves appreciably overlap, indicating no significant difference between the two response models.

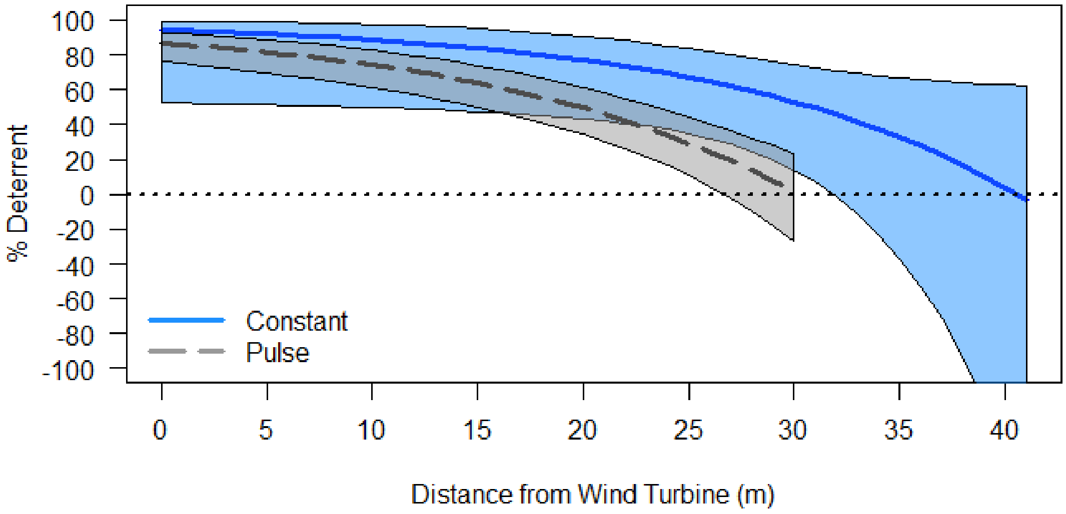

Figure 12. Comparison of the two fitted response models of the % deterrent effect as a function of distance from the turbine-mounted deterrent system for constant and pulse signals.

Subtask 6.2 – Deterrent Field Test during BP2 (Carcass Monitoring)

Calibration Trials

One hundred and forty-two (142) bat carcasses were distributed over 12 3-day calibration trials split into the first and second halves of the study because it was believed that the searcher efficiency of the human search crew improved over time (Tables 10 and 11). The raw carcass count data was used to obtain maximum likelihood estimates of probabilities of carcass recovery for each day of deposition (Tables 12 and 13). Assuming bat deposition during the deterrent trials was uniform during the calibration trials, the overall recovery probability for bats in the first half of the study was 94.69% ($\widehat{\mathrm{SE}}$ =2.78%), and during the second half of the study, 93.81% ($\widehat{\mathrm{SE}}$ = 3.53%).

Table 10. Numbers of bat carcasses placed and recovered during a 3-day calibration trial of searcher efficiency for the first half of the deterrent study. Day 1 consisted of a human search team; days 2 and 3, a dog and handler search team.

		Recoveries		
	Placed	**Day 1**	**Day 2**	**Day 3**
Day 1	48	9	35	2
Day 2	22	--	18	4
Day 3	17	--	--	15

Table 11. Numbers of bat carcasses placed and recovered during a 3-day calibration trial of searcher efficiency for the second half of the deterrent study. Day 1 consisted of a human search team; days 2 and 3, a dog and handler search team.

		Recoveries		
	Placed	**Day 1**	**Day 2**	**Day 3**
Day 1	35	13	17	2
Day 2	10	--	7	3
Day 3	10	--	--	9

Table 12. Estimated probabilities $(\hat{\theta})$ of carcass recovery by day for carcasses placed during calibration trials conducted on the first half of the deterrent study, along with associated standard errors. Day 1 consisted of a human search team; days 2 and 3, a dog and handler search team.

		$\hat{\theta}$	
	Day 1	**Day 2**	**Day 3**
Day 1	0.1875 (0.0563)	0.7292 (0.0641)	0.0417 (0.0288)
Day 2		0.8182 (0.0822)	0.1818 (0.0822)
Day 3			0.8823 (0.0781)
Overall $\hat{\theta}$ = 0.9469 (0.0278)			

Table 13. Estimated probabilities $(\hat{\theta})$ of carcass recovery by day for carcasses placed during calibration trials conducted on the second half of the deterrent study, along with associated standard errors. Day 1 consisted of a human search team; days 2 and 3, a dog and handler search team.

		$\hat{\theta}$	
	Day 1	**Day 2**	**Day 3**
Day 1	0.3714 (0.0817)	0.4857 (0.0845)	0.0571 (0.0392)
Day 2		0.7000 (0.1449)	0.3000 (0.1449)
Day 3			0.9000 (0.0949)
Overall $\hat{\theta}$ = 0.9381 (0.0353)			

Pulse Signal Effect during the First Half of the Study

Six 6-day test blocks were performed during the first half of the study using a pulse signal and a silent control. The number of turbines included within each block ranged from 5 to 12. Due to unrelated site power outages during block 3, randomization did not occur. During block 3, all 5 turbine deterrent systems were operated as controls for 3 days and then as pulse signals during the following 3 days.

The overall carcass detection probability was >90% in 2016. This meant that adjustments to the raw carcass counts were small, but standard errors for the adjustments always exceeded the adjustments themselves. For example, the average adjustment for eastern red bat carcasses was 0.4290, while the average standard error was 2.4686, suggesting more noise was added to the data when the bias corrections were made. Therefore, the raw counts were used in all subsequent statistical analyses of treatment effects.

During the first half of the experiment, 227 bat carcasses of all species were recovered; this included 113 at control turbines and 114 at pulse signal treatment turbines. These carcass counts provide a first approximation to an estimate of overall deterrent effectiveness across all bat species of -0.89%; or, in other words, a slight increase in mortality due to the acoustic treatment. The GLM analysis, which used the raw carcass counts and took into account differences in turbine operating hours during the test blocks, produced an estimate of 1.71% reduction ($\widehat{\mathrm{SE}}$ = 13.05%) in mortality. The treatment effect was not significantly different from zero (i.e., no deterrent effect) (*P* =0.9472) (Table 14).

Table 14. Analysis of deviance (ANODEV) for bat carcasses under control and pulse signal treatments. The generalized linear model (GLM) was based on Poisson error and ln-link. The natural log of turbine operating hours was treated as an offset.

Source	DF	DEV	MDEV	*F*	*P*-value
$\mathrm{Total}_{\mathrm{COR}}$	21	89.4266			
Blocks	5	34.7006	6.9401	1.9026	0.1809
Treatment	1	0.0168	0.0168	0.0046	0.9472
Block × treatment	5	18.2314	3.6463	0.9996	0.4653
Error	10	36.4777	3.6478		

During the first half of the study, 153 eastern red bat carcasses were collected; 68 were collected under control conditions and 85 under the pulse signal treatment. These raw counts produced an estimated deterrent effect of –25.0% (i.e., acoustic treatment increased the mortality rate). The GLM analysis, which used the raw carcass counts and adjusted for turbine operating hours, estimated a negative deterrent effect of –22.51% ($\widehat{\mathrm{SE}}$ = 19.94%) (i.e., acoustic treatment increased the mortality rate). However, this estimate was not significantly different from zero (*P* = 0.5207) (Table 15).

Adjustment for detection probability produced estimates of eastern red bat fatality of 72.63 ($\widehat{\mathrm{SE}}$ = 9.04) under control and 90.67 ($\widehat{\mathrm{SE}}$ = 10.00) under the pulse signal treatment. It appears the pulse signal treatment had no deterrent effect on eastern red bats.

Table 15. Analysis of deviance (ANODEV) for eastern red bat carcasses under control and pulse signal treatments. The generalized linear model (GLM) was based on Poisson error and ln-link. The natural log of turbine operating hours was treated as an offset.

Source	DF	DEV	MDEV	*F*	*P*-value
$\text{Total}_{\text{COR}}$	21	95.6698			
Blocks	5	48.2819	9.6564	2.7350	0.0825
Treatment	1	1.5640	1.5640	0.4430	0.5207
Block × treatment	5	10.5169	2.1034	0.5957	0.7046
Error	10	35.3071	3.5307		

Carcass counts from bat species other than eastern red bat were pooled in a separate analysis of deterrent effects. The other bat species encountered included big brown bat, hoary bat, silver-haired bat, tri-colored bat, evening bat, and unknown bat species[2] (Table 16). During the first half of the study, raw carcass counts of 45 and 29 were found at control and pulse signal treatment turbines, respectively. These raw counts produce an estimated deterrent effect of 35.6%. The GLM analysis, which used the raw carcass counts and adjusted for turbine operating hours, produced a deterrent estimate of 37.97% ($\widehat{\text{SE}}$ = 14.78%). This estimate was near significantly different from zero (*P* = 0.1068) (Table 17).

Adjustment for detection probability resulted in similar fatality estimates of 47.67 ($\widehat{\text{SE}}$ = 7.15) and 30.46 ($\widehat{\text{SE}}$ = 5.67) for control and pulse signal treatments, respectively.

Table 16. Numbers of non-eastern red bat species carcasses found under control and pulse signal treatments during the first half of the study.

		Signal Treatment	
Common name	**Scientific name**	**Control**	**Treatment**
Big brown bat	*Eptesicus fuscus*	1	3
Hoary bat	*Lasiurus cinereus*	29	20
Silver-haired bat	*Lasionycteris noctivagans*	14	4
Indiana Myotis	*Myotis sodalis*	0	0
Tri-colored bat	*Perimyotis subflavus*	0	1
Evening Bat	*Nycticeius humeralis*	1	0
Unknown Bat		0	1
	Total	**45**	**29**

Table 17. Analysis of deviance (ANODEV) for non-eastern red bat carcasses under control and pulse signal treatments. The generalized linear model (GLM) was based on Poisson error and ln-link. The natural log of turbine operating hours was treated as an offset.

Source	DF	DEV	MDEV	*F*	*P*-value
$\text{Total}_{\text{COR}}$	21	38.4665			
Block	5	11.7650	2.3530	1.7930	0.2020
Treatment	1	4.1205	4.1205	3.1398	0.1068
Block × treatment	5	9.4577	9.4577	1.4414	0.2907
Error	10	13.1234	1.3123		

Pulse and Constant Signal Effects during the Second Half of the Study

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[2] Due to damaged condition of specimen, species was unable to be confirmed.

It became apparent during the initial half of the experiment that the pulse signal was not having the desired deterrent effect. Instead of continuing that experiment, the study was quickly redesigned to include a comparison of a constant signal in addition to control and pulse signals and to include air/water separators on the pulse signal systems. Only 3 test blocks were performed of this new treatment configuration before the end of the study. The small sample sizes, however, resulted in treatment comparisons that should be viewed as more qualitative than quantitative.

During the second half of the study, 52 bat carcasses were found, distributed 21, 19, and 12 between control, constant, and pulse treatments, respectively. These values estimate relative deterrent effects of 9.5% and 42.9% for constant and pulse signals, respectively. The GLM analysis, which used the raw carcass counts and adjusted for turbine operating hours, estimated relative deterrent effects of 10.96% ($\widehat{\text{SE}}$ = 28.19%) and 42.50% ($\widehat{\text{SE}}$ = 20.81%) for constant and pulse signals, respectively. The two treatment effects were not statistically different from zero (Table 18).

Table 18. Analysis of deviance (ANODEV) for bat carcasses under control, constant, and pulse signal treatments. The generalized linear model (GLM) was based on Poisson error and ln-link. The natural log of turbine operating hours was treated as an offset.

Source	DF	DEV	MDEV	*F*	*P*-value
Total$_{\text{COR}}$	17	28.0577			
Block	2	15.7527	7.8763	8.4822	0.0085
Treatment	2	2.6058	1.3029	1.4031	0.2948
Block × treatment	4	1.3420	0.3355	0.3613	0.8302
Error	9	8.3572	0.9286		

Twenty eastern red bat carcasses were found during the second half of the study, distributed 8, 6, and 6 between control, constant, and pulse signals respectively. Relative deterrent effects of 26.3% and 21.9% for constant and pulse signals, respectively, were calculated. The GLM analysis, which used the raw carcass counts and adjusted for turbine operating hours, estimated relative deterrent effects of 26.25% ($\widehat{\text{SE}}$ = 39.83%) and 23.24% ($\widehat{\text{SE}}$ = 41.48%) for constant and pulse signals, respectively. Treatment effects were not significantly different from the controls (*P* = 0.8461) (Table 19).

Adjusting for detection probability, eastern red bat fatality estimates were 8.44 ($\widehat{\text{SE}}$ = 3.01), 6.22 ($\widehat{\text{SE}}$ = 2.55), and 6.59 ($\widehat{\text{SE}}$ = 2.70) for control, constant, and pulse signal treatments, respectively.

Table 19. **Analysis of deviance (ANODEV) for eastern red bat carcasses under control, constant, and pulse signal treatments. The generalized linear model (GLM) was based on Poisson error and ln-link. The natural log of turbine operating hours was treated as an offset.**

Source	DF	DEV	MDEV	*F*	*P*-value
Total$_{\text{COR}}$	17	15.4525			
Block	2	2.4755	1.2378	1.0939	0.3756
Treatment	2	0.3852	0.1926	0.1702	0.8461
Block × treatment	4	2.4076	0.6019	0.5319	0.7159
Error	9	10.1841	1.1316		

Across the non-eastern red bat species, the numbers of carcasses recovered during the second half of the study were 13, 13, and 6 for control, constant, and pulse signal treatments, respectively (Table 20). The species included in this assessment were: big brown bat, hoary bat, silver-haired bat, and Indiana bat. The raw bat counts produced estimates of relative deterrent effects of 0% and 53.8% for constant and pulse signals, respectively. The GLM analysis, which used the raw carcass counts and adjusted for turbine operating hours, produced estimates of relative deterrent effects of 1.56% ($\widehat{\mathrm{SE}}$ = 38.62%) and 54.03% ($\widehat{\mathrm{SE}}$ = 22.69%) for constant and pulse signals, respectively. These values are not statistically different (*P* = 0.1336) from the controls (Table 21).

Adjusting for detection probability, non-eastern-red bat fatality estimates were 14.18 ($\widehat{\mathrm{SE}}$ = 3.96), 13.88 ($\widehat{\mathrm{SE}}$ = 3.87), and 6.35 ($\widehat{\mathrm{SE}}$ = 2.60) for control, and constant, and pulse signal treatments, respectively.

Table 20. Numbers of carcasses found for non-eastern red bat species under control, pulse, and constant signal treatments during the second half of the study.

		Signal Treatment		
Common name	**Scientific name**	**Control**	**Pulse**	**Constant**
Big brown bat	*Eptesicus fuscus*	1	0	1
Hoary bat	*Lasiurus cinereus*	1	0	0
Silver-haired bat	*Lasionycteris noctivagans*	11	5	12
Indiana Myotis	*Myotis sodalis*	0	1	0
Tri-colored bat	*Perimyotis subflavus*	0	0	0
Evening Bat	*Nycticeius humeralis*	0	0	0
Unknown Bat		0	0	0
	Total	**13**	**6**	**13**

Table 21. Analysis of deviance (ANODEV) for non-eastern red bat carcasses under control, constant, and pulse signal treatments. The generalized linear model (GLM) was based on Poisson error and ln-link. The natural log of turbine operating hours was treated as an offset.

Source	**DF**	**DEV**	**MDEV**	***F***	***P*-value**
$\text{Total}_{\text{COR}}$	17	27.4387			
Block	2	15.6803	7.8402	11.8906	0.0030
Treatment	2	3.3482	1.6741	2.5390	0.1336
Block × treatment	4	2.4759	0.6190	0.9388	0.4841
Error	9	5.9342	0.6594		

Summary of 2016 Deterrent Signal Effectiveness

Only 2 of the deterrent effectiveness tests were significantly different than zero, and due to the few blocks included in either half of the study, deterrent effectiveness estimate precision was low (Table 22). Nevertheless, the results suggest the 6-nozzle pulse system was effective at deterring low-frequency bats from the turbine, especially after the installation of the air/water separators. The pulse signal appears to be ineffective at deterring eastern red bats, however the variances on effectiveness are wide for both study halves. The 5-nozzle constant signal system was ineffective in reducing bat fatalities; however, the results are likely inconclusive due to small sample size.

Table 22. Summary of acoustic deterrent effects. (Standard errors in parentheses).

Study	Bat Species Group	Signal Treatment Pulse	Constant
1st half	All	1.71% (13.05%)	N/A
	ERB	–22.51% (19.94%)	N/A
	Non-ERB	37.97% (14.78%)*	N/A
2nd half	All	42.50% (20.81%)*	10.96% (28.19%)
	ERB	23.24% (41.48%)	26.25% (39.83%)
	Non-ERB	54.03% (38.62%)	1.56 % (38.63%)

[a]ERB = Eastern red bat
*Significantly different from zero ($P \leq 0.05$)

Discussion

Milestone 6.2.1 – "*Demonstrate reduced bat activity and that the bats do not closely approach the acoustic deterrent when in new "optimized" mounting configuration on turbines at California Ridge. Demonstrate reductions in bat fatality when "optimized" deterrent configuration is operated on turbines at California Ridge. (Month 15 of BP2)*", was achieved by the Task 6 studies. Pulse and constant signals were tested against a silent control using both video records of bat flight activity and counts of bat carcasses beneath the test turbines. Both tested deterrent signals were found to be effective at reducing bat activity in the vicinity of the turbines; and the pulsed signal was effective at reducing the number of both non-eastern red bat (in the first half of the study) and all-bat (in the second half of the study) carcasses, but not effective at reducing the number of eastern red bat fatalities.

It is necessary to note several limitations affecting the interpretation of study results.

Throughout the study, water vapor was emitted from the pulsing system; this was immeasurable and may have confounded our ability to isolate pulse signal effectiveness, although field testing of the deterrent signal suggested the vapor did not alter or inhibit acoustic signal transmission. Because of the installation of air/water separators, the planned study period was divided, with the first half of the study covering the usual peak of bat migration (Aug-Sept) at temperate latitudes (Hein and Schirmacher 2016) while the second half of the study occurred after the usual peak (late Sept-Oct). This division of the Subtask 6.2 data reduced analysis precision because sample sizes were affected.

Deterrents were effective in reducing bat activity around and displacing bat activity from the study turbines. The pulse and constant signals did not differ significantly in their effect on bat activity across distance and time.

A notable distance effect was observed under both the pulse and constant signals; both signals were highly effective out to approximately 20 m (66 ft) from the nozzles, where bat passes were reduced by 47.6% and 77.8% respectively. Beyond 20 m (66 ft), effectiveness steadily declined. Finding that both acoustic deterrent signals were effective out to 20 m (66 ft) was consistent with the findings from Task 4.1, the bat activity study in 2015, which found a significant reduction in the number of bat passes within 20 m (66 ft) of the turbine-mounted deterrent system when a constant signal was emitted. This effective range is also consistent with the results from several ground-based deterrent studies, including those of Tasks 1 and 2 of this grant and Szewczak (2011) and Szewczak and Arnett (2007). Because the amplitude of acoustic signals attenuates with distance, and several studies have indicated reduced effectiveness beyond 20 m (66 ft), there may be optimal signal amplitude for bat deterrence that occurs within this distance and, to extend effectiveness, similar amplitude must be achieved at greater distances.

Bats exposed to either pulse or constant deterrent signals spent between 50.9% (pulse) and 43.4% (constant) less time within model space than those observed when deterrents were off. The results for the constant signal were nonsignificant, presumably due to sparse data. The Subtask 6.1 time in the field of view analysis results contrast with the results of Task 4.1, the 2015 thermal imaging study, which found that regardless of whether or not bats were exposed to the deterrent sound, they spent similar lengths of time within the model space. This discrepancy is attributed to improvements in the Subtask 6.1 study design, which, by using 2 turbines with identical configurations, similar surroundings and alternating the treatments between the 2 turbines, reduced biases associated with location and turbine configuration.

Shoener and Skalski (2016) found the constant deterrent signal was ineffective (-2.48%) at reducing eastern red bat fatalities. In Subtask 6.2, deterrent ineffectiveness on eastern red bats was observed for the pulse deterrent signal (-22.51% and 22.24% in the 1st and 2nd study halves, respectively). Thus, the hypothesis that a pulse signal would be effective at deterring eastern red bats was rejected.

The pulse signal effectiveness of 37.97% (1st half) and 54.03% (2nd half) for the non-eastern red bat group was similar to the effectiveness (56.06%) of the constant signal tested in 2015 (Shoener and Skalski 2016). Thus, the hypothesis that a pulse signal would be effective at deterring non-eastern red bat species was accepted.

The 5-nozzle constant signal system tested during the 2nd half of the study was ineffective at deterring all bats, eastern red bats, and non-eastern red bats. This result differed from the consistent effectiveness observed for a constant signal tested over 3 years of prior study at CRWEF (Shoener and Skalski 2016, Gruver et al. 2014). This conflict in results is most likely attributed to insufficient data, but may also be attributed to the weakening of the signal due to the addition of a 5th nozzle in the system. Confirmation of the 5-nozzle deterrent system effectiveness or ineffectiveness requires further study.

Even though the current study demonstrated reductions in bat activity within 20 m (66 ft) of the deterrents, this effectiveness does not equate to similar reductions in bat fatalities. This apparent disparity may be due a number of factors, including species response to the deterrent signal or the low deterrent effectiveness at the distal ranges of the rotor swept area where rotors carry the greatest speed, have the smallest physical signature, and presumably are most difficult for bats to detect.

In summary, this study further demonstrates the GE prototype acoustic deterrent is greatly effective at reducing bat activity out to approximately 20 m (66 ft). It also demonstrates the 2016 pulse signal is similar in effectiveness to the prior constant signal systems, in that it is ineffective at reducing eastern red bat fatalities, and is effective at reducing non-eastern red bat fatalities. The results for the 5-nozzle constant signal system were insufficient to draw conclusions and require further study. To understand why reductions in bat activity do not translate into similar reductions in bat fatality under the same deterrent system, further research would be required. Potential improvements to the deterrent system design that warrant testing include: adjusting and testing a broad-band constant signal that overlaps the echolocation range of high-frequency bat species such as eastern red bats, redesigning the pulse system to be free of water vapor emission in order to confirm that lack of effectiveness for eastern red bats was not due in some way to the water vapor emission, and designing and testing of a constant signal system with more than 4 nozzles that emits a louder deterrent signal.

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