Final Technical Report

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EXECUTIVE SUMMARY

There is still a great need for the development of mitigation strategies that are economically viable and can be used alone or in combination with other options (e.g., operational minimization, acoustic deterrents) to ensure that bat fatalities are effectively reduced at wind facilities across the U.S. Our goal was to develop a wind turbine tower coating that:

1. bats show little or no interest in approaching
2. can be applied to currently deployed wind turbine towers and to towers as they are constructed
3. is economically feasible to produce and apply, and
4. ultimately contributes to a reduction in bat mortality at utility-scale wind facilities.

The development of a texture coating is based on the water misperception hypothesis and the acoustic mirror effect, both of which relate to how echolocating bats identify resources in the wild. Previous research has shown that bats will repeatedly try to drink from smooth surfaces because they misperceive them to be water. Similarly, previous research has shown that detection of prey by bats can be facilitated by smooth backgrounds, such as water surfaces and leaves.

Wind turbine tower monopoles are large, smooth surfaces and numerous studies have reported bats making close investigative approaches at turbine tower surfaces that are suggestive of drinking and foraging behavior. We therefore hypothesized that water misperception and foraging activity could be contributing to bat-wind turbine fatalities by increasing the amount of time that bats spend in or around the rotor-swept zone. We designed a series of experiments to characterize how wild-caught bats interact with smooth and texture-treated surfaces in a controlled, enclosed environment. We used the results of these experiments to develop a texture coating that was applied to two operational wind turbine towers. We then surveyed bat activity at smooth and texture-treated wind turbine towers over one season.

We conducted 64 behavioral trials in a flight facility from 10 June to 25 September 2015 and an additional 76 behavioral trials from 9 June to 30 August 2016. The first set of trials showed that while bats did make contact with smooth surfaces, they did not make contact with textured surfaces. We ascertained that bat activity occurred at 0 to 1 m distances from surfaces, suggesting that the bats (used in this study) may need to be this close to a surface to accurately discern its texture. For the second set of trials, in which we tested a specifically developed texture coating, bats showed a >40% reduction in activity within 1 m of the textured surfaces in comparison to the smooth surfaces.

Following these controlled experiments, we conducted field tests at Wolf Ridge Wind, LLC. For this field study, our goal was to apply the texture coating that was developed and tested in the flight facility experiments to the midsection of 3 turbine monopoles (i.e., from 10 m above ground up into the rotor-swept zone). During the texture coating application we were only able to complete the application to 2 of the turbine towers during the allotted time period, which was limited due to budgetary constraints. Furthermore, the texture coating application was challenging and the material usage on the first tower was higher than it should have been, resulting in a texture coating that did not match the coating specifications from the previous experimental surfaces. Not knowing how this variation in texture coating could potentially impact bat behavior, we conducted bat activity surveys at both texture-treated towers and 2 nearby control towers (n = 2 turbine tower pairs), over 55 nights from 24 June to 22 September,

2017. All species of bats known to be present at the site were detected in the video recordings and in the acoustic recordings at these turbine towers. We found no significant differences in overall numbers of bats observed and levels of acoustic activity at the smooth and texture-treated towers. When we analyzed the experimental pairs separately, however, we found that a greater proportion of the close range bat activity within Pair 1 occurred at the texture-treated tower and that much of this activity could be attributed to foraging behavior. In contrast at turbine Pair 2, we observed no difference in the proportion of close range bat activity between the smooth and texture-treated tower, with no clear differences in behavior at the two tower types. When we examined acoustic bat activity at the tower pairs separately, we found species-specific differences in activity that differed between the smooth and texture-treated towers within the pairs. For example, hoary bat acoustic activity was significantly higher at the texture-treated tower in Pair 1, but significantly lower at the texture-treated tower in Pair 2. Given the observational nature of the field test, our limited sample size (2 turbine pairs), variation in the texture-coating between the 2 turbine pairs, and different patterns of bat activity observed at the 2 turbine pairs, inferences from this one field test are limited at best.

In conclusion, the results from the flight facility experiments were promising (i.e., we observed a significant decrease in bat activity at smooth compared to texture-treated surfaces); however, due to coating installation and application challenges prior to our field test, we were unable to collect sufficient information to understand how these coatings affect bat activity at operational wind turbine towers. We recommend that further observations should be made at these towers before concluding whether or not a texture coating could be an effective mitigation strategy.

During this study, we made substantial improvements in understanding how bats interact with wind turbine towers and identifying behaviors that may put them at increased risk of colliding with rotating blades. Furthermore, we have a much better idea of what it would take to apply a coating to turbine towers, both in the operational and manufacturing stages. The identification and development of a texture coating that reduces bat activity in the immediate vicinity of wind turbine towers has the potential to become standard mitigation. The results from the flight facility experiments, in particular, suggest that water misperception may be a contributing factor to bat-wind turbine mortality by increasing the amount of time bats spend in close proximity to the smooth tower surfaces. Although the results from the field test are inconclusive, the lessons learned will be informative for future research into turbine surface materials that are readily differentiated from water and may alter how bats perceive wind towers. Thus, the outcomes of this research project may have a significant impact on wind energy operators, wind developers, and OEMs by contributing to future impact mitigation strategies. In future research we will test new ideas to improve the development, application, and evaluation of this mitigation technique.

ACCOMPLISHMENTS

Project Objective: The overall objective of this project was to develop a wind turbine tower coating that:

1. bats have little or no interest in approaching (i.e., wind turbine towers are not perceived or misperceived to be a resource)
2. can be applied to operational wind turbine towers or incorporated into the manufacturing stage of wind turbine towers,
3. is economically feasible to produce and apply, and
4. when tested, effectively reduces bat activity at operational wind turbines, and therefore bat mortality.

Project Goals:

- Test the behavioral responses of bats to smooth and textured surfaces in a vertical orientation in a flight facility.
- Develop a textured coating that can interrupt the smooth surface of a wind turbine tower currently deployed in the field.

Overall Accomplishments: Based on a series of behavioral trials conducted in a bat flight facility, we were able to develop a wind turbine tower coating that bats would have little interest in approaching. We further tested this texture coating in flight facility and confirmed that in a controlled environment that bats showed less interest in the textured surface than smooth painted surfaces, and they made little to no contacts with the surface.

Following these studies, we were able to develop an effective study design in which bat behavior at operational wind turbine towers could be recorded and analyzed. Two wind turbines were coated with the texture following a carefully developed application plan. Finally, we successfully undertook field surveys for 3 months during the peak migration period of bats to assess how bats respond to these texture-treated turbines. Results show promise, but also highlight the importance of applying the coating correctly.

Task 1. Testing behavioral response of bats to textures in flight room (Months 1-6)

Task objective: Test the behavioral responses of bats to smooth and textured surfaces in a flight facility.

Subtask 1.1: Make textured surfaces for flight facility (Month 1)

i. Major activities

We created a variety of surfaces with types and grades of texture that are discernibly different from smooth surfaces and from each other, and do not compromise the integrity of the paint. These textured treatments were then be applied to individual steel plates and presented to wild-caught bats in the flight facility as part of Subtask 1.2.

ii. Specific objectives

To create a variety of surfaces with types and grades of texture that are discernibly different from smooth surfaces and from each other, and do not compromise the integrity of the paint.

iii. Significant results, including major findings, developments or conclusions (positive or negative)

We created four surfaces that vary in their grade of texture that were then applied to individual steel plates.

iv. Key outcomes, milestones and other achievements

- The creation of four texturized surfaces that presented to wild-caught bats in the flight facility as part of Subtask 1.2.
- Milestone 1.1 – Completed written specifications of texture treatments for metal plates in the bat flight facility. Appendix A.
- Subtask 1.1 was COMPLETED in Q1.

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

i. Major activities

Bat drinking and bat foraging behavior trials – in a flight facility we conducted two experiments in which we used wild caught bats to observe and record whether bats attempted to drink and forage from different surface types, including painted surface, curved painted surface, and four texturized surfaces created in Subtask 1.1.

ii. Specific objectives

- To analyze the responses of wild-caught bats when presented with a variety of smooth and textured surfaces (treatments produced in Subtask 1.1) in a bat flight facility.
- To determine rate of approach, closest distance of approach, and activities exhibited by the bats toward each treatment.
- To compare the results of each treatment and assess which treatments (i.e., grade and type of texture) bats showed little or no interest in approaching.
- To inform the development of a textured coating that can be applied to wind turbines in (Task 2)

iii. Significant results, including major findings, developments or conclusions (positive or negative)

Bat drinking behavior trials – We found that bats made contact with smooth treatment surfaces, but not with the textured surfaces. We also found that as texture particle size increased so did the number of bat passes (straight-lined flight across the treatment surface). On further investigation, we determined that this relationship was strongly associated with gap distance between particles. Finally, we ascertained that all bat passes occurred at 0 to 1 m distances from the treatment surfaces, suggesting that the bats (used in this study) may need to be this close to a surface to accurately discern its texture.

Bat foraging behavior trials – We found that the bats could switch their foraging strategy and glean prey from surfaces equivalent to a wind turbine tower. We noted that eastern red bats gleaned more readily and successfully than evening bats, indicating that there were species-specific differences. Bats were also able to glean off the texture with the largest particle sizes, but this may have been an artifact of gap distance between particles (see bat drinking trials). Finally, we recorded more bat passes in close proximity to textured treatment surfaces with the larger particle sizes (as opposed to making contact), which is similar to our findings in the bat drinking trials.

iv. Key outcomes, milestones and other achievements

- Completion of bat drinking and foraging behavior trials.
- Milestone 1.2.1 – Completion of experimental protocol for the behavioral trials in the bat flight facility. Appendix A.
- Completion of the analysis of the data collected in the drinking and foraging behavioral trials in the bat flight room.
- Milestone 1.2.2 – Completion of documented report detailing a significant difference in bat activity in close proximity to textured surfaces compared to smooth surfaces in the bat flight facility to the DOE and NextEra Energy Resources. Appendix B.
- Subtask 1.2 was COMPLETED in Q2 2015.

Task 1 Accomplishments: As per the objective, we were able to test the behavioral responses of bats to smooth and textured surfaces in a flight facility. Our experiment effectively demonstrated that bats do not contact textured surfaces as they did smooth. We also determined that the particle size and distance between particles (gap distance) influenced rate of approach and these findings were integral in informing the development of a textured coating that could be applied to wind turbines as part of Task 2.

Task 1 was COMPLETED in Q2 2015.

Task 2: Texture coating development, field study design, and application plan (Months 1-9)

Task objective: Develop a textured coating that can disrupt the smooth surface of wind turbine tower surfaces.

Subtask 2.1: Texture coating development (Months 1-7)

i. Major activities

We worked with an outside company (Duromar Inc.) to create technical specifications that are the design basis for a texture treatment for wind turbine towers. The selection of the final, single coating that was tested in Budget Period 2 was based on the results of the behavioral trials and on an analysis of the feasibility and financial costs of applying the treatment.

ii. Specific objectives

- To develop a wind turbine tower surface treatment based on the results from Task 1.
- To select a single surface treatment to test in the field.
- To provide technical specifications that will be the design basis for a coating treatment for wind turbine towers.

iii. Significant results, including major findings, developments or conclusions (positive or negative)

NextEra identified and approached a coating manufacturing company, Duromar, Inc. to begin the coating development process. Duromar is an industrial coating developer/supplier to the power industry and provides coatings specifically for wind turbine towers and blades. We worked closely with Duromar to create technical specifications that are the design basis for a texture treatment that can be applied to wind turbine towers. Based on 1) the results of the behavioral trials (Subtask 1.2) and 2) an analysis of the feasibility and financial costs of applying the treatment, the team designed and selected a single coating that was tested in Budget Period 2.

iv. Key outcomes, milestones and other achievements

- Development and selection of a single coating treatment that were applied to wind turbines at Wolf Ridge as part of Task 3 and tested in bat activity surveys in Tasks 4 and 6.
- Milestone 2.1 – Selection of a single coating including complete written technical specifications of texture treatment to be applied to operational turbine towers at Wolf Ridge. See Appendix C. Note: The information in Appendix C is protected data and will be released to the public on 1/31/2023.
- Subtask 2.1 was COMPLETED in Q1 2016.

<u>Subtask 2.2: Field study design (Months 4-8)</u>

i. Major activities

We developed a field study design protocol based in part on our existing behavioral survey protocol that we refined over the past several years at Wolf Ridge, and on the feasibility study conducted as part of Task 4. The protocol describes the survey methods for conducting bat activity surveys using a suite of technologies including high-definition cameras, night-vision technology, acoustic bat detectors, and thermal imaging cameras at wind turbine tower surfaces. We also provide a justification for the number of turbines included in the study based on an analysis of the anticipated effect size, observed activity at the site, and feasibility of the study design.

ii. Specific objectives

The goal of this subtask was to complete an experimental protocol to evaluate bat activity and behavior at control and texture-treated wind turbines.

iii. Significant results, including major findings, developments or conclusions (positive or negative)

A protocol was developed using night-vision technology and thermal imaging cameras, bat activity and behavior will be recorded at ~3 turbine pairs (control and texture-treated) for approximately 50-65 survey nights during the fall migration period of bat (July to September). The protocol also proposed the use of video analysis software to determine if bats are present during the paired activity surveys, estimate time spent in the field of view (i.e., in close proximity to the wind turbine tower), and document levels of activity by counting the number of bats and types of behavior exhibited.

iv. Key outcomes, milestones and other achievements

- Completion of a study design for surveying bat activity at control and treatment wind turbines at Wolf Ridge.
- Milestone 2.2 – Complete study design for surveying bat activity at control and treatment wind turbines at Wolf Ridge. See Appendix D.
- Subtask 2.2 was COMPLETED in Q1 2016.

<u>Subtask 2.3: Texture coating application plan (Months 8-9)</u>

i. Major activities

We prepared a written plan of action for the application of the tower coating at Wolf Ridge. The plan details how the texture coating developed and selected in Subtask 2.1 will be applied to wind turbines at Wolf Ridge in Task 5. This plan of action identified the selected treatment and control turbine towers, the paint supplier, and the contractor who would apply the treatment at Wolf Ridge. This plan provided an organizational framework for the application process and a detailed time schedule.

ii. Specific objectives

To develop a plan of action for the application of the tower coating at Wolf Ridge.

iii. Significant results, including major findings, developments or conclusions (positive or negative)

The written plan of action was developed collectively by the TCU principal investigators, the research team at NextEra Energy Resources, the coating supplier (selected by NextEra Energy Resources), and the site lead at Wolf Ridge.

<u>Coating supplier and contractor for application</u>:

We identified the coating supplier and contractor for applying the treatment. The cost of applying the texture treatment to the entirety of 10 turbines (as originally planned) significantly exceeded the available funds for coating application. We estimated that Task 5 would require at least $424,243 more in funding than we had available. We therefore developed as part of this subtask estimated costs for the original 10 treated turbines, a down-scaled version with 5 treated turbines, and a revised option in which we proposed applying the coating to 3 turbines only at mid-tower height.

<u>Turbine selection</u>:

We identified 5 wind turbine pairs for possible inclusion in the bat activity surveys based on the following criteria:

- observed bat activity in previous years (we selected turbines with higher known bat activity levels to increase the power of our study);
- uncluttered survey area (turbines have little vegetation within the survey area which facilitates equipment setup); and
- location within the wind farm (the selected turbines are distributed across the wind resource area).

Of these 5 pairs, we proposed that 3 would be selected for inclusion in the study. Within each turbine pair, one turbine was randomly assigned to receive the texture treatment and the other turbine served as the control.

iv. Key outcomes, milestones and other achievements

- Completion of a written plan of action for the application of the tower coating to selected wind turbine towers at Wolf Ridge.
- Milestone 2.3 – Complete a written plan of action for the application of the tower coating to selected wind turbine towers at Wolf Ridge. See Appendix E.
- Subtask 2.3 was COMPLETED in Q1 2016.

Task 2 Accomplishments: As per the objectives of Task 2, we selected a single texture treatment that can be applied to towers that have already been manufactured and placed in the field. We wrote a field study design protocol for monitoring bat activity at control and treatment turbines, and wrote a specific plan of action for applying this treatment to selected turbines at Wolf Ridge in Budget Period 2.

Task 2 was COMPLETED in Q1 2016.

<u>Task 3: Behavioral study in flight facility – part II (Months 11-16)</u>

i. Major activities

We conducted an experiment in a bat flight facility in which we documented the responses of wild-caught bats presented with the texture coating developed in Task 2. Vertical surface trials were conducted to assess bat behavior at surfaces that are oriented in a way that is most similar to the wind turbine towers that free-flying bats encounter in the wild.

ii. Specific objectives

To assess bat behavior at the texture coated surfaces (developed in Task 2) that are oriented in a way that is most similar to the wind turbine towers that free-flying bats encounter in the wild.

iii. Significant results, including major findings, developments or conclusions (positive or negative)

iv. We found that both eastern red and evening bats made significantly more passes at the smooth surfaces compared to the texture coated surface. We also noted that these significant results were driven by the number of passes made at surfaces on the first night when the bats were released into the flight facility (i.e., these first trials were conducted when the bats were completely naïve about their environment). These results demonstrate that when bats have no knowledge of their surroundings they make more passes and therefore show more interest in smooth surfaces than at texture-treated surfaces. Similarly, while we only saw eastern red bats contact a surface twice, both times at a smooth surface, we believe that this low number of contacts was due to the vertical height of the flight facility limiting their ability to approach the surfaces effectively. In contrast, evening bats that appear to require less room to approach the surfaces, made significantly more contacts on smooth surfaces compared to the texture-treated surfaces.

v. Key outcomes, milestones and other achievements

- Milestone 3.1 – Complete experimental protocol for the behavioral trials in the bat flight facility. See Appendix F.
- Completion of behavioral study in flight facility using texture coating developed in Task 2.
- Milestone 3.2 – Complete documented report detailing bat behavior in close proximity to the commercially developed texture coating in the bat flight facility for evaluation by DOE and TCU. See Appendix G. Note: The information in Appendix G is protected data and will be released to the public on 1/31/2023.

Task 3 Accomplishments: As per our objective, we effectively assessed bat behavior at smooth and texture coated surfaces in the flight facility. Our study demonstrated that bats showed less interest in the texture coating developed in Task 2 than in smooth surfaces similar to wind turbine tower surfaces that they would encounter in the wild. These results contributed to the decision to proceed with Tasks 5 and 6.

Task 3 was COMPLETED in Q4 2016.

Task 4: Feasibility study - bat activity surveys at operational wind turbines at Wolf Ridge (Months 11-16)

i. Major activities

We conducted a field test in which bat activity was surveyed at 3 pairs of operational wind turbine towers (selected in Subtask 2.3) at Wolf Ridge Wind, LLC. For this feasibility study, we set out to ensure that bat activity could be effectively recorded. We, therefore, varied the set-up of equipment in the field, primarily the thermal cameras, to establish an optimal position for these cameras. Another undertaking of the feasibility study was to explore how best to analyze the video data.

ii. Specific objectives

The goal of this feasibility study was to inform and refine the survey protocol for Task 6.

iii. Significant results, including major findings, developments or conclusions (positive or negative)

From the feasibility study, we determined that by refining the thermal camera set-up, we were able to establish that the most effective equipment set-up for detecting bat activity around turbine tower surfaces. We also ascertained that creating a key that guided the identification of flying objects recorded in the video footage, their behavior, and their position near the turbine tower surface would provide a user-friendly and repeatable method for data processing. A total of 8 behaviors were defined: passing, reversing, looping, foraging, skimming, sweeping, colliding and gleaning. We further classified these behaviors into three categories based on proximity to the turbine tower surface: contact/close contact, close-range (≤1 m from the surface), and far-range (>1 m from the surface).

Based on the results of the feasibility study, we determined that:

- Bat activity across the survey period (i.e., the fall migration period) yielded sufficient bat observations to effectively undertake a paired treatment study at the wind resource facility.
- The timing of the nightly survey effort was appropriate.
- Bat activity at specific turbine sites did not vary within paired turbines. This similarity in activity provided strong support for our proposed paired study design at Wolf Ridge (Task 6), as it indicated that we would be able to demonstrate the effectiveness of texture-treated turbines among the paired turbine sites selected.
- We determined that both the type and frequency of behavior appeared to vary with distance from the turbine surface and that these differences appeared to be associated with turbine tower interaction. Specifically, contact and close contact and close-range behaviors tended to be more dependent on interactions with the turbine tower surface, whereas far-range activity by bats appeared independent of the turbine tower surface.

i. **Key outcomes, milestones and other achievements**

- Milestone 4.1 – Complete experimental protocol for the feasibility study. See Appendix H.
- Milestone 4.2 – Complete activity surveys at operational wind turbines at Wolf Ridge and provide a documented report detailing bat behavior in close proximity to operational wind turbines at Wolf Ridge to the DOE and NextEra Energy Resources. See Appendix I.

Task 4 Accomplishments: As per the objective, our feasibility study and the completed report (Deliverable 4.2) contributed to the modification of the protocol for bat activity surveys at control and texture-treated wind turbines at Wolf Ridge as part of Task 6. Furthermore, our findings emphasize the importance of separating bat activity and behavior into distance categories, as we would expect that the application of the texture treatment to turbine towers would most likely only reduce contact, close contact, and close-range bat activity.

Task 4 was COMPLETED in Q4 2016.

<u>Task 5: Application of coating treatment to turbines at Wolf Ridge (Months 20-22)</u>

i. Major activities

We conducted field tests to assess effective application methods and determine the time required for adhesives to cure, which dictates timing of various stages of the application process. Based on these tests, TCU, NextEra Energy, Duromar, and third party contractors formalized a plan for the application of the coating treatment on 3-5 operational wind turbine towers at Wolf Ridge. The texture coating was then successfully applied to 2 operational wind turbine towers at Wolf Ridge.

ii. Specific objectives

The goal of this task was to apply a single coating developed in Task 2 and tested in Task 3 to the exterior tower surface of a sub-section of approximately 3-5 selected wind turbine towers.

iii. Significant results, including major findings, developments or conclusions (positive or negative)

Application of the texture coating to wind turbine towers at Wolf Ridge was undertaken from 19th to 23rd June 2017.

The goal of the texture-coating application was to apply a texture that had the same specifications as the experimental surfaces that were used in the flight facility experiments (i.e., same thickness of adhesive base coat and top coat and the same density of both the large and small beads). Although we had several practice sessions on the ground, the application crew had difficulty with the application process while up-tower. Despite our best efforts and constant involvement during the application process, the coating on the first tower did not match our specifications. Most importantly the material usage for the adhesive base layer was higher than expected and it appeared that the resulting base layer was thicker than we had intended it to be. A consequence of having a thick base layer is that the smaller beads would “sink” into the material rather than resting on top of the coating. Before proceeding to the application on the second tower, we again repeated the practice sessions on the ground. The coating when applied to the second tower did meet our expectations and importantly, the material usage for the adhesive base layer was consistent with the experimental surfaces we had created for the flight facility experiments (i.e., both the small and large beads were sitting on the surface of the base layer). At that time, we did not know if or how the differences in application would impact the outcome of our study. As both tower surfaces were texture-treated, we stayed with our original plan to observe bat activity at both treated towers.

During the allotted time (5 days) for the coating application, we were only able to complete 2 of the 3 turbine towers. The mobilization and demobilization of the equipment for tower preparation, texture-coating application, and top-coat application was much more extensive than anticipated and added considerably to the overall application time. Furthermore, the heat index was quite high during the week and the work crew had to take numerous breaks to prevent dehydration and over-heating. The crew worked from sunset to sunrise for the first 4 days, and faced the threat of a lightning stand-down on day 5. Although we considered the application process to be successful overall, we did fall short of our stated goal of treating 3-5 turbine towers, and the coating application was different between the two towers.

ii. Key outcomes, milestones and other achievements

- Milestone 5 – Completion of report detailing the application of the texture treatment. See Appendix J.

Task 5 Accomplishments: The texture coating was applied to 2 wind turbine tower sections at Wolf Ridge. On these 2 towers, the texture application was completed according to the application plan, including tower surface preparation prior to application.

We were then able to proceed to the Task 6 bat activity surveys, which we conducted at both pairs of turbine towers.

Task 5 was COMPLETED in Q2 2017.

Task 6: Bat activity surveys at control and texture-treated turbine towers at Wolf Ridge (Months 17-28)

iii. Major activities

Following the results of the feasibility study conducted in Task 4, TCU delivered to the DOE a refined experimental protocol for conducting the proposed bat activity surveys at control and texture-treated wind turbines at Wolf Ridge from June through September 2017. TCU then conducted baseline activity surveys at three sets of paired turbines at Wolf Ridge prior to the application of the texture coating. Following the texture coating application in Task 5, TCU conducted behavioral surveys at the two sets of paired (one texture-treated and one control) operational wind turbines at Wolf Ridge.

iv. Specific objectives

The goal of this field study was to determine if the texture coating developed in Task 2 and tested in Task 3 successfully reduced bat activity in close proximity to wind turbine towers at a wind facility in the southern Great Plains.

v. Significant results, including major findings, developments or conclusions (positive or negative)

From May 20 to June 18, baseline bat activity surveys at three sets of paired turbines at Wolf Ridge were conducted on a total of 17 nights, each pair was surveyed at least 5 times prior to the application of the texture coating (June 19-23, 2017). In this time, 740 10 min trials were recorded.

From June 24 to September 22, 2017, a second set of behavioral surveys were undertaken at two sets of paired turbines (one texture-treated and one control). These surveys were conducted for a total of 55 nights; 28 nights at turbines 23 and 25, and 27 nights at turbines 60 and 63. Note that surveys were partially undertaken on 4 of the survey nights due to weather constraints. Thus, a total of 2545 10-minute trials were recorded.

vi. Key outcomes, milestones and other achievements

Milestone 6.1 – Written experimental protocol for the bat activity surveys at Wolf Ridge to the DOE. See Appendix K.

Milestone 6.2 – Complete spreadsheet detailing bat behavior in close proximity to control and texture-treated wind turbine towers at Wolf Ridge to the DOE and NextEra Energy Resources.

Task 6 Accomplishments: As per our objective, we successfully completed field surveys at paired turbines to determine if bat behavior varied between texture-treated and smooth wind turbine towers. The video and acoustic data collected in this task were analyzed as part of Task 7.

Task 6 was COMPLETED in Q4 2017.

Task 7: Data analysis and final reporting (Months 22-30)

i. Major activities

For this task, we analyzed of the all video files and acoustic data collected to assess bat activity at control and treatment turbines. At this point we were unable to perform a formal cost-benefit analysis of the texture-coating process as there did not appear to be a significant reduction in bat activity at the texture-treated towers in the field test. The high-cost of the prototype-level experiment we performed cannot realistically be scaled up to a future application at this time. Prior to investing in a market transformation plan, more research is needed to fully understand how bats respond to the two textured surfaces that we applied to the wind turbine towers.

ii. Specific objectives

Our objectives were to quantify the effectiveness of the surface treatment at reducing bat activity at wind turbines tower surfaces, and provide an economic assessment of the cost of i) retrofitting existing turbines that are currently operational, and ii) incorporating the texture treatment at the tower manufacturing or wind turbine installation phase. Given the inconclusive nature of the results from the first field test (see below), we conclude that more research is needed to fully understand how bats respond to texture-treated surfaces on wind turbine towers prior to developing a market transformation plan.

iii. Significant results, including major findings, developments or conclusions (positive or negative)

The results of the final flight facility experiment with the vertical test surfaces (Task 3) showed a significant reduction in bat activity (measured as the number of passes within 1 m and contacts) at texture-treated compared to smooth surfaces. The results of this experiment clearly indicated that a texture coating might be an effective mitigation strategy at reducing close-range bat activity at wind turbine tower surfaces, which in turn could lead to a reduction in the amount of time bats spend within the rotor-swept zone of wind turbines.

The results of the field test (Task 7) were inconclusive, however, perhaps due in part to one of the tower coatings (the first tower coated in Pair 1) not being applied to our specifications.[1] The small number of towers that we were able to observe presented another challenge when interpreting the results of the field test.

[1] The adhesive base layer was applied at a thickness greater than what was on our experimental surfaces in the flight facility, causing the small beads to sink into the base layer rather than to stay up on the surface.

In our original plan, our goal was to observe bat activity at 5 pairs of turbine towers (i.e., a representative sample of 5 turbine pairs at a wind facility consisting of 75 turbines). Due to the costs of the application, we were not surprised to find out that we had to scale our study down to just 3 turbine pairs. At the time of the application, however, we were only able to complete the texture application on 2 towers and we had serious concerns that the first tower was not completed to our original specifications. As we were unsure how this variation in application may or may not impact bat behavior (as both towers were still texture-treated), we made the decision to go ahead and survey bat activity at both tower pairs. In total our sample size was reduced to 2 turbine pairs, but only one of which met our coating specifications. Thus, we modified the statistical analysis as described in our study protocol.

Using general liner models (GLM) with turbine nested within pairs, we found no significant differences in overall numbers of bats observed (number of bats observed per hour) or in levels of acoustic activity recorded (number of calls per survey night) between the two turbine pairs, or at the smooth and texture-treated towers within pairs. When we analyzed the tower pairs separately using either a paired t-test or Wilcoxon signed rank test (our response variable was the difference in the number of bats observed or the number of calls recorded), we again found no relationship between overall bat activity and the texture treatment. When we looked at bat activity by proximity to the tower surfaces, bat activity by behavior category, and species-specific acoustic activity using Fisher's exact tests, however, differences between the smooth and texture-treated surfaces within each turbine pair became apparent.

At Pair 1, we observed:

- A greater proportion of passing and foraging behavior by bats >2 m from the texture-treated tower (this increase in activity may be independent of the tower coating).
- A greater proportion of close range activity at the texture-treated tower, which included foraging flight patterns and gleaning and skimming activity at the tower surface (this increase in activity could be due to the tower coating).
- No difference in acoustic activity at the smooth and texture-treated tower for eastern red bats.
- Higher acoustic activity for hoary bats and silver-haired bats at the texture-treated tower.
- Lower acoustic activity for tricolored bats, canyon bats, and evening bats at the texture-treated tower.

At Pair 2, we observed:

- A lower proportion of foraging behavior by bats >2 m from the texture-treated tower (this decrease in activity may be independent of the tower coating).
- A higher proportion of passing behavior <2 m from the texture-treated tower.
- No contact or close contact with the tower surface at either the smooth or texture-treated tower.

- No difference in acoustic activity at the smooth and texture-treated tower for eastern red bats.
- Lower acoustic activity for hoary bats and silver-haired bats at the texture-treated tower.
- Higher acoustic activity for tricolored bats at the texture-treated tower.

Given the observational nature of the field test, our limited sample size (2 turbine pairs), variation in the texture-coating between the 2 turbine pairs, and different patterns of bat activity observed at the 2 turbine pairs, we recommend that additional survey work should be conducted at these turbine towers before determining whether or not a texture coating could be an effective mitigation strategy.

Given the challenges we faced during the field test, together with no apparent reduction in bat activity at the texture-treated towers, we were unable to perform a formal cost-benefit analysis of the texture-coating process at this time. The lessons learned from the texture coating application process would lead us to take a different strategy if we were given another opportunity to test a texture coating on operational wind turbine towers in the future.

To retrofit operational turbine towers with a coating that has a uniform texture and is consistently and reliably replicated and economically feasible to apply, we envision that the coating would need to be manufactured on the ground as a film, wrap, or laminate that could be quickly applied to the tower monopoles. To manufacture a turbine tower with a uniformly textured surface, we envision that this could readily be accomplished during the painting stage. Alternatively, the texture could be applied to the base layer of steel or concrete.

Given the lower level of technology readiness of this project, we cannot justify the creation of a market transformation plan at this time. Rather, more research would be needed to fully understand 1) how bats are responding to the coatings that are now present on two turbine towers, and 2) how the properties of potential future coating alternatives could impact bat behavior.

iv. Key outcomes, milestones and other achievements

Milestone 7 – Complete summary of effectiveness of treatment at reducing bat activity (analysis compares activity at control and treatment turbines), without the anticipated cost estimates to retrofit existing wind turbine towers with the texture treatment or market transformation plan. A full summary is included in this final technical report.

Task 7 Accomplishments: As per our objective, we successfully completed the analysis of the video and acoustic data collected to determine if bat behavior varied between texture-treated and smooth wind turbine towers.

Task 7 was COMPLETED in Q4 2017.

Project Schedule & Milestones						**DE-EE0007033**
SOPO Task Number	**Title / Task Description**	**Task Completion Date**				**Progress Notes**
		Original Planned	**Revised Planned**	**Actual**	**Percent Complete**	
1.1	**Make Textured Surfaces for Flight Facility**	Sep-2015		Sep-2015	100%	
	M1.1 Develop texture treatments for metal plates/mock wind turbine tower	Jul-2015		Aug-2015	100%	M1.1 milestone submitted 8/19/15 (Q1 2015)
1.2	**Behavioral Study in Flight Facility**	Dec-2015		Dec-2015	100%	
	M1.2.1 Complete experimental protocol for the behavioral trials in the bat flight facility	Jul-2015		Aug-2015	100%	M1.2.1 milestone submitted 8/19/15 (Q1 2015)
	M1.2.2 Demonstrate difference in bat activity in close proximity to textured surfaces compared to smooth surfaces in the bat flight facility	Jan-2016		Jan-2016	100%	M1.2.2 milestone submitted 1/27/16 (Q1 2016)
2	**Texture Coating Development**	Mar-2016		Mar-2016	100%	
	M2.1 Selection of a single coating including complete written specifications of texture treatment to be deployed on turbine towers at Wolf Ridge	Feb-2016		Feb-2016	100%	M2.1 milestone submitted 2/29/16 (Q1 2016)
	M2.2 Complete study design for behavioral surveys at control and treatment wind turbines at Wolf Ridge.	Feb-2016		Feb-2016	100%	M2.2 milestone submitted 2/29/16 (Q1 2016)
	M2.3 Plan of action for the application of the tower coating to wind turbine towers at Wolf Ridge.	Mar-2016		Mar-2016	100%	M2.3 milestone submitted 3/29/16 (Q1 2016)
3	**Behavioral study in flight facility**	Oct-2016		Dec-2016	100%	

	M3.1 Complete experimental protocol for the behavioral trials in the bat flight facility	May-2016		Jun-2016	100%	M3.1 milestone submitted 6/20/16 (Q2 2016)
	M3.2 Completed survey and documented report detailing bat behavior in close proximity to texture coating in flight facility.	Nov-2016		Dec-2016	100%	M3.2 milestone submitted 12/29/2016 (Q4 2016)
4	**Feasibility study**	Oct-2016		Oct-2016	100%	
	M4.1 Complete experimental protocol for feasibility study	May-2016		Jun-2016	100%	M4.1 milestone submitted 6/20/16 (Q2 2016)
	M4.2 Completed survey and documented report detailing bat behavior in close proximity to operational wind turbines.	Oct-2016		Oct-2016	100%	M4.2 milestone submitted 10/28/16 (Q4 2016)
5	**Application of Coating to Turbines at Wolf Ridge**	Apr-2017		Jul-2017	100%	
	M5 Application of coating to approximately 3-5 wind turbine towers at Wolf Ridge	Apr-2017		Jul-2017	100%	M5.milestone submitted 7/31/2017 (Q2 2017)
6	**Activity Surveys at Control and Treatment Turbines at Wolf Ridge**	Oct-2017		Oct 2017	65%	
	M6.1 Complete experimental protocol for activity surveys	Nov-2016		Nov-2017	100%	M6.1 milestone submitted 11/22/16 (Q4 2016)
	M6.2 Completed field data spreadsheet	Oct-2017		Oct-2017	100%	M6.2 milestone submitted 10/31/17 (Q4 2017)
7	**Data Analysis & Final Reporting**	Dec-2017		May-2018	100%	Final Scientific/Technical Report 05/01/18; Revision 07/24/18

SUMMARY OF PROJECT ACTIVITIES

Task 1. Testing behavioral response of bats to textures in flight room

The expected outcome of Task 1 was to describe how bats respond to smooth and textured surfaces with a range of texture treatments in a controlled environment. We predicted that increasing the level of texture on the painted surfaces would reduce the time bats spend in close proximity to those surfaces in comparison to smooth surfaces (i.e., surfaces equivalent to wind turbine tower surfaces). Our primary objective was therefore to identify a type and level of texture that bats in the flight room exhibit little or no interest in approaching. The results of this part of our study were intended to then be used in Task 2 to aid the development of a paint additive(s) or other applique that can be effectively and economically applied to existing and proposed wind turbine towers.

To develop a wind turbine tower coating that bats have little or no interest in approaching, we assessed how wild-caught bats responded to a range of treatment surfaces that varied in the type and grade of texture in a controlled custom-made flight facility. We created a total of 5 discernibly different test surfaces, including a smooth surface similar to the surface of a wind turbine tower, 3 textured surfaces with increasing texture grade (i.e., we increased the size of particles added to the paint without compromising the integrity of the paint), and an applique (intended to interrupt a smooth painted surface; see Appendix A; Fig. 1).

Figure 1: Range of experimental surface textures (including one applique) that were used in the flight facility testing in 2015.

We presented these treatment surfaces to eastern red bats (*Lasiurus borealis*), the species of bat that comprised the majority of fatalities at a nearby wind facility, and evening bats (*Nycticeius humeralis*). We then observed and recorded how these bats responded to the surfaces in two different experimental trials: 1) bat drinking behavior trials in which we investigated whether bats attempted to drink from the different surfaces; and 2) bat foraging behavior trials, in which we explored whether the bats could capture prey items from each surface type. See Appendix A and B for full details on protocols and results respectively.

For the bat drinking behavior trials, we covered a water tray with the 5 aforementioned treatment surfaces, as well as curved control treatment to represent a wind turbine tower section. To effectively record all behavior near and at the water tray, we set up two Canon XA20 camcorders (Canon Inc., Melville, NY) at a 90 degree angle from one another with their field of view centered on the water tray. In addition, we used a Fastec IL4 100 high-speed mono imaging camera (South Central Imaging, Ltd., Westfield, IN) with a 17 mm lens (f 0.95) and two 850 nm Infrared LED Light Bars (Larson Electronics LLC, Kemp, TX) to capture high definition images of bats interacting with the treatment surfaces.

We processed all videos in Studiocode (version 5, Studiocode Business Group, Sydney, AU) and analyzed each video to estimate 4 response variables:

1. number of contacts with the treatment surface or number of drinking events at the water tray;
2. number of passes (a straight flight path parallel to the surface or water tray) across the treatment surface or water tray (this value includes the number of contacts with each treatment surface and drinking events at the water tray);
3. closest approach to a treatment surface by each bat during a pass; and
4. time until a bat first approaches each treatment surface or the water tray.

The 64 behavioral trials conducted from 10 June to 25 September 2015 revealed that bat behavior varied with surface type. At the treatment surfaces, we recorded bats making contact (drinking attempts and touches with their body) with 3 of the 6 surfaces: the control, curved control, and applique treatment surfaces. Thus, bats did not contact the textured treatment surfaces (Fig. 2). These results demonstrate that bats did not come into contact with textured surfaces as they would smooth surfaces. Note that the majority of the applique treatment is a smooth surface (Fig. 1).

We found that the number of passes (straight-line flight at a height of <1 m over the treatment surface) increased with texture gradient (ANOVA, $F_{2,447}$ = 144.11, P<0.001, Fig. 3). On further analysis, we found that there was a strong relationship between number of passes per bat and mean gap size of each treatment surface (Pairwise post-hoc Tukey test = P<0.001). These results suggest that gap size between particles is an important property that influences bat activity patterns and interest in a surface. We also observed that the majority of passes occurred within 0.5 m of each treatment surface. These results suggest that bats need to be in close proximity (<0.5 m) to a surface to gather detailed sensory information about that surface, and they may be making more passes at surfaces with larger gap sizes to gather more information (i.e., interest in a surface increases with gap size). Thus, to develop an effective texture coating that bats show little or no interest in approaching, gap sizes between particles should be kept to a minimum.

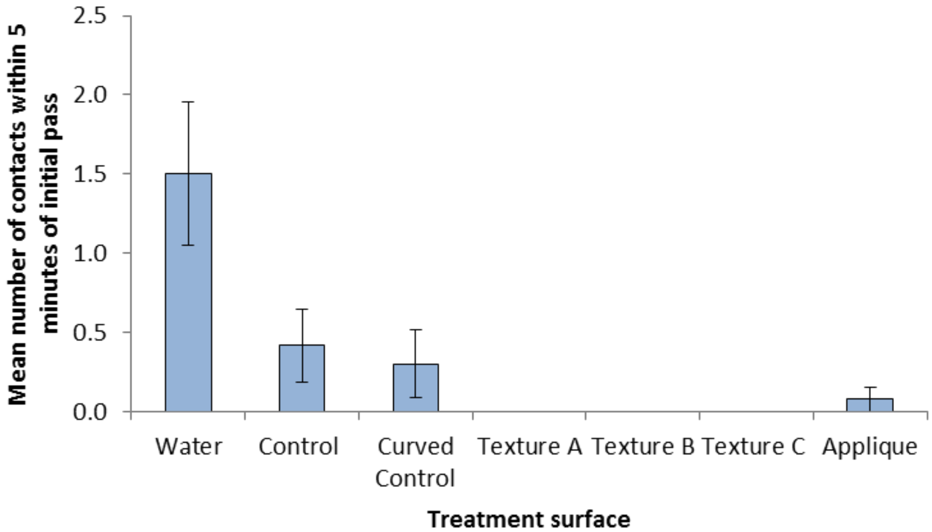


Figure 2: Mean ± SE number of contacts made at each treatment surface and number of drinking events at the water tray within 5 minutes of the bats' initial pass with standard error.

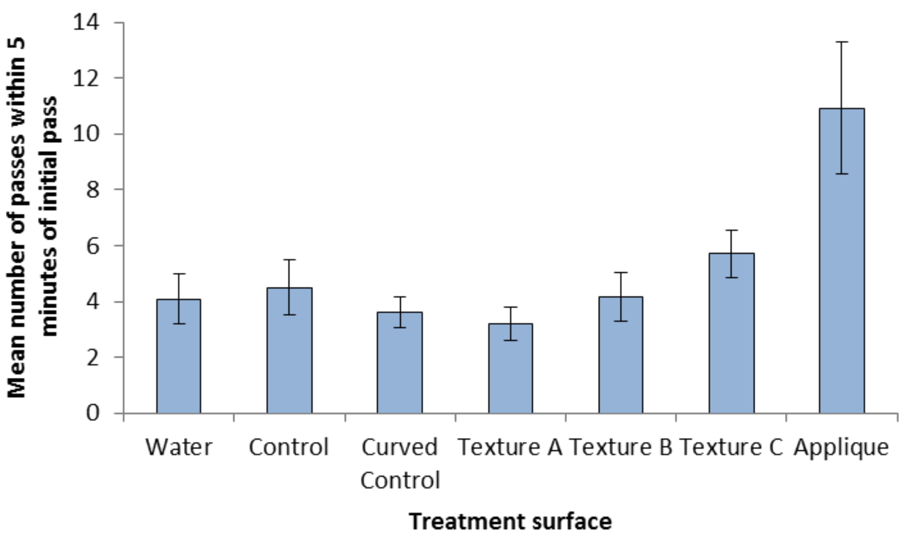


Figure 3: Mean ± SE number of passes made within 5 minutes of the bats' initial pass across the treatment surface.

For bat foraging behavior trials, we suspended prey items (e.g., mealworms) against the surface of a mock turbine tower section and first explored whether bats could capture prey from smooth surfaces similar to wind turbine towers. Then, if the bats were able to capture prey from this control surface, we presented the bats with the textured surfaces to determine if prey removal rate varied from the control surface. Again, we used two Canon XA20 camcorders at a 90 degree angle from one another with their field of view centered on the mock turbine tower section. We analyzed each video to determine three response variables: 1) number of successful gleans, 2) number of gleaning attempts, and 3) closest approach to mealworms. A successful glean was defined as the removal of a mealworm from a treatment surface and a gleaning attempt was defined as a bat making contact with the mealworm or the treatment surface within 0.25 m from the mealworm, but did not result in the removal of the mealworm.

From 1 July 1 to 29 September 2015, 54 behavioral trials including eastern red and evening bats presented with control, Texture C, and applique treatment surfaces were successfully analyzed. Despite having a relatively low sample size, we found that the bats could switch their foraging strategy and glean prey from surfaces equivalent to a wind turbine tower (Fig. 4). We noted that eastern red bats gleaned more readily and successfully than evening bats, indicating that there were species-specific differences. Bats were also able to glean off Texture C (with the largest particle sizes), but this may have been an artifact of gap distance between particles (see bat drinking trials).

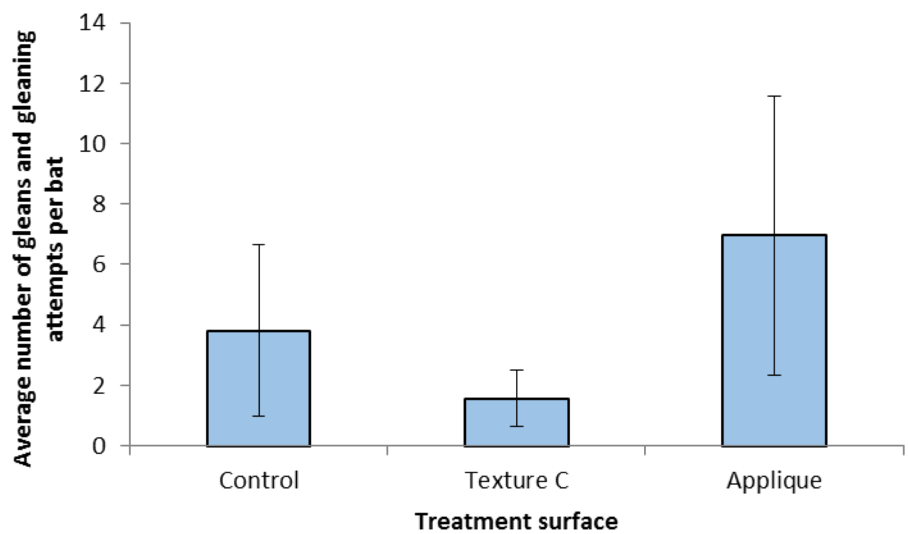


Figure 4: Mean ± SE number of gleans and gleaning attempts at each treatment surface.

Finally, we recorded more bat passes in close proximity to the textured treatment surface in comparison to control and applique surfaces, providing further support for our findings in the bat drinking trials.

Based on these results of this trials and additional work conducted as part of an playback experiment, we concluded that coating that 1) bats have little or interest in approaching, 2) could be applied to operational wind turbine towers or incorporated into the manufacturing stage of wind turbine towers, and 3) was economically feasible to produce and apply, would have to have the following characteristics:

- Multiple sized particles,
- Densely textured surface (i.e., only small gaps between particles),
- Non-natural shaped particles, such as spheres,
- Lightweight particles and base compound, and
- Light colored particles and base compound.

One clear restriction of this experiment was that while we were able to gather detailed information regarding the various surface treatments (flat and curved) in a horizontal position over the water tray, we were unable to evaluate the behavioral response of bats to smooth and textured surfaces in a vertical orientation during the drinking trials due to the experimental setup in the flight facility. Task 3 addresses this issue by testing the texture coating developed in Task 2 below in a vertical orientation.

Finally, unlike the drinking behavior trials, we had not conducted preliminary experiments prior to conducting the foraging behavior trials. The result was that much of the survey period involved determining how we could set-up the equipment and conduct the trials efficiently. For example, we established that the number of bats flying in a single trial influenced how we could effectively record the bats' responses at each treatment surface being tested and how we could analyze the data. Subsequently, we were unable to gather sufficient data on the prey capture rates at the various treatment surfaces to make strong inferences regarding this dependent variable. Nevertheless, the lessons learned in this survey period are important as they provide essential information on survey techniques and experimental setups to inform future bat foraging behavior trials.

Task 2: Texture coating development, field study design, and application plan

The expected outcome of Task 2 was 1) to develop and ultimately select a single turbine tower coating, 2) complete a field study design protocol to assess bat activity at control and treatment turbines, and 3) develop a detailed plan of action for applying the coating to 3-5 turbine towers at Wolf Ridge.

Texture coating development

NextEra identified and approached a coating manufacturing company, Duromar, Inc. to begin the coating development process. Duromar is an industrial coating developer/supplier to the Power Industry and provides coatings specifically for wind turbine towers and blades. They provide products for both manufacturing and repair applications. Over several months, we worked closely with Duromar to create technical specifications that were the design basis for a texture treatment that could be applied to wind turbine towers (Fig. 5). Based on 1) the results of the behavioral trials (see Appendix B) and 2) an analysis of the feasibility and financial costs of applying the treatment, the team designed and selected a single coating (see Appendix C) that was tested in Task 3 (in the flight facility) and in Task 6 on operational wind turbine towers at Wolf Ridge Wind, LLC in north central Texas.

Figure 5: Preparing a test surface for the flight facility experiments.

Field study design

We developed a field study design protocol to evaluate bat activity and behavior at control and texture-treated wind turbines. The research team considered that the behavioral studies we proposed under this task were superior alternatives to the fatality study outlined in our original application. Our rationale behind this decision was based on increasing evidence that bats are interacting with wind turbine towers, blades, and nacelles and while not all of the causal mechanisms behind these interactions are known or well-understood, undoubtedly behavior at wind turbines puts bats at risk of colliding with rotating blades. Measuring bat activity would therefore directly demonstrate whether the texture coating effectively reduces the probability of collisions with blades, whereas fatality searches would indirectly show the same effect, albeit diluted by external variables (such uncertainty associated with estimating search efficiency and carcass persistence rates). Additionally, a detailed behavioral study showing how bats approach and maneuver around turbine towers provides important insights into the extent of surface treatment that is necessary to reduce bat activity near and within the rotor swept zone (i.e., it may be unnecessary to coat the entire turbine tower).

Thus, the protocol for our proposed field study was based on 1) our existing behavioral survey protocol that has been refined over the past several years at Wolf Ridge and 2) cost estimates that we obtained for applying the texture coating treatment to a selection of operational wind turbines at Wolf Ridge. The protocol describes the survey methods for conducting bat activity surveys using a suite of technologies including high-definition cameras, night-vision technology, acoustic bat detectors, and thermal imaging cameras at wind turbine tower surfaces. We also provided a justification for the number of turbines included in the study based on an analysis of the anticipated effect size, observed activity at the site from previous surveys, and proposed study design (Appendix D).

Given the technology readiness level of this project, we determined that the best next step was to attempt to apply the texture coating to a sub-section of 3 turbine towers at which we conduct a comprehensive behavioral study to compare bat activity between paired control and texture-treated turbines at Wolf Ridge. Prior to executing this study in its entirety in 2017, we conducted a feasibility study from July through September 2016, using the protocols developed in this current task. Based on the results of this feasibility study, we then revised the field study design protocols (see Task 4 below).

Texture coating application plan

For the texture coating application plan, we established that applying the texture to a small number of turbines would require the following steps: 1) mobilize and provide manpower to the site; 2) stop operation and secure the selected turbines, including the rotor lock; 3) set up application equipment and method of turbine tower access; 4) pressure wash tower sections to be coated and allow to dry; 5) apply coating to tower surfaces using airless spray equipment and allow cure time; 6) remove application and access equipment; and 7) unlock and restart the turbines.

The plan of action also identified the selected treatment and control turbine towers, the paint supplier, and the contractor who would apply the treatment at Wolf Ridge. The written plan of action was then developed collectively by the TCU principal investigators, the research team at NextEra Energy Resources, the Duromar coating supplier, and the site lead at Wolf Ridge (see

Appendix E). This plan provided an organizational framework for the application process and a detailed time schedule. The earliest start date for the application process proposed was April 1, 2017 with a target completion date of June 15, 2017.

As part of this task, we estimated the cost of applying the texture treatment to 5 turbines towers as proposed. We found the costs significantly exceeded the available funds for coating application by $424,243 more in funding than we had available. Based in part on the cost estimates, we proposed that the best next step was to apply the texture coating to a sub-section of 3 turbine towers, with the texture extending from 10 m above ground to mid-tower height, just within the rotor swept zone (Fig. 6). The final texture application plan reflects these proposed revisions to our original study design that was only possible with an additional budgeted $82,922 in cost share (cash) from NextEra as Task 6 was expected to cost $145,922. The final cost of the coating application was $43,497 over this budget, and this difference was paid for by NextEra (total cost share $126,419).

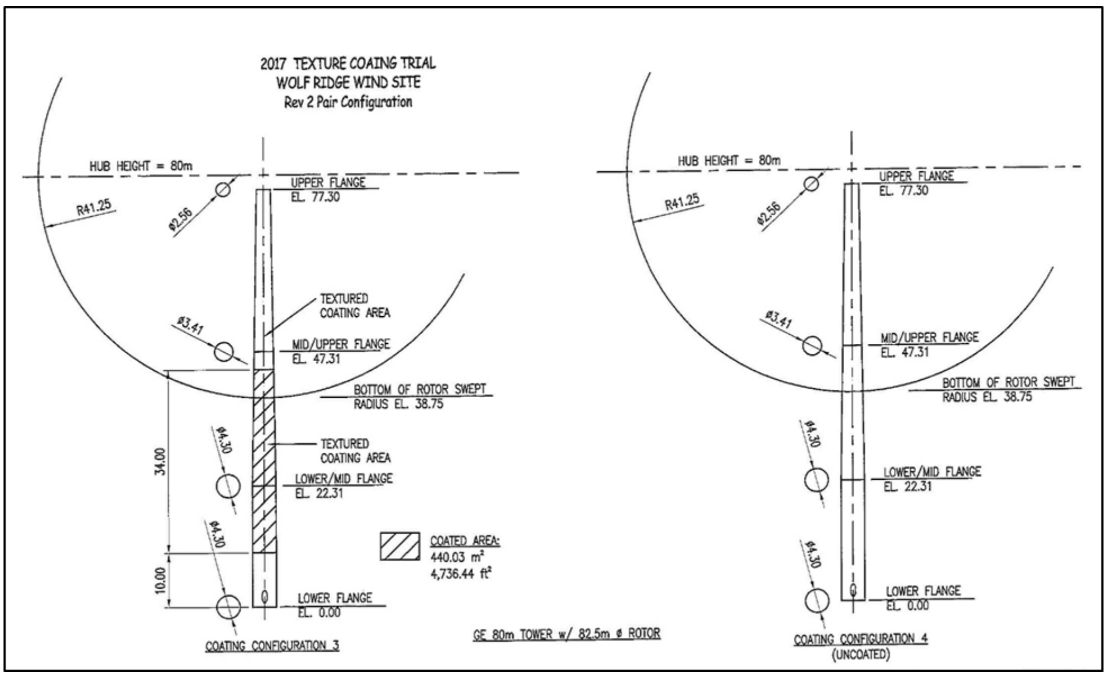


Figure 6: Revised application plan for texture-coating wind turbine towers at Wolf Ridge.

We identified 5 wind turbine pairs for possible inclusion in the bat activity surveys based on the following criteria: observed bat fatality and activity in previous years (we selected turbines with higher known bat fatality and activity levels to increase the power of our study); bat fatality and activity was similar within pairs; uncluttered survey area (turbines have little vegetation within the survey area which facilitates equipment setup); and location within the wind farm (the selected turbines are distributed across the wind resource area). Of these 5 pairs, 3 were selected for inclusion in the study.

Within each turbine pair, one turbine was randomly assigned to receive the texture treatment and the other turbine served as the control. As the texture treatment cannot be rotated among turbines during the course of the study, this paired approach also allowed us to control for some of the inherent variation in bat activity that we have observed among turbines over the past 4 years of surveys at Wolf Ridge.

Task 3: Behavioral study in flight facility – part II

The expected outcome of Task 3 was to verify that bats in the flight room exhibited reduced activity (as evidenced by number of passes and contacts) at surfaces treated with the coating developed in Task 2 compared to smooth surfaces similar to wind turbine towers. Thus, we conducted an experiment in which we recorded the responses of wild-caught bats when presented with the texture coating (developed in Task 2) in a controlled flight facility setting (Fig. 7). A full description of the methodology is provided in Appendix F. The rationale for choosing the single texture coating for further testing was based on the behavioral response of bats to testing in Task 1.

Figure 7: Inside view of the experimental set-up in the 2016 flight facility.

During the Task 3 trials, bats caught in mist netting surveys were released in the flight facility and observed during their acclimation period (nights 1-4). Within the flight facility there were 2 sets of flat metal plates (approx. 2 m by 2 m) mounted vertically on the facility walls: smooth painted plates and texture-treated plates (using the coating developed in Task 2). In addition to these flat surfaces, we also placed a curved vertical structure (approximately 3 m tall, nearly reaching from the floor to ceiling, with the curvature of an 80-m turbine tower 40 m above ground) near the center of the flight facility. One side of this curved structure was smooth painted, whereas the other side was texture-treated. All bat behavior within the flight facility was recorded with digital voice recorders (human observers dictated the bats' behavior) and high-definition video recorders. The flight facility was illuminated with infrared lighting and individual bats were identified using UV-reflective powder. We used video analysis software to quantify bat activity at each surface type.

From June 9 to August 30, 2016, a total of 76 behavioral trials were conducted with eastern red and evening bats (see Appendix G). These trials revealed that bat behavior again varied with surface type. Overall, we found that the number of passes (straight-line flight within <1 m of the treatment surface) was higher at the smooth painted surfaces than at the texture-treated surfaces. Moreover, we found that the magnitude of the difference was species-specific (Fig. 8). Among eastern red bats, which are one of the three most commonly found bat species in post-construction fatality monitoring studies in North America, we recorded a 68% reduction in the average number of passes at the textured surfaces compared to smooth surfaces (paired t-test: t = -7.05, df = 8, P <0.001). For the evening bats, we observed a 43% reduction in passes at the textured surfaces compared to smooth surfaces (t = -4.33, df = 21, P <0.001).

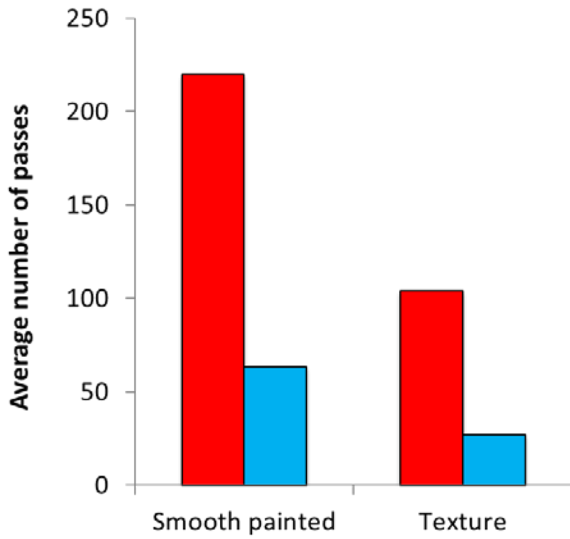


Figure 8: Average number of passes recorded at smooth painted and texture-treated surfaces by eastern red bats (in red) and evening bats (in blue) in a flight facility.

On further analysis, we found that both bat species tended to show more interest (i.e., make more passes) at the treatment surfaces they were presented with on their first night in the flight facility, when the surfaces and enclosure were novel to them. These results suggest that bats may be most at risk from turbine-collisions when they are not familiar with their surroundings, as would be the case for bats that are migrating (such as the eastern red bat) when they encounter operational wind turbines. Our results demonstrated that the texture-treated coating we developed has the potential to reduce migratory bat interest in novel smooth surfaces, such as wind turbine towers, thereby reducing overall collision risk.

In contrast to passing behavior, the number of contacts with the treatment surfaces were much lower than the number of close passes (Fig. 9). Bats are known to investigate a surface by making a number of passes over the surface prior to making contact, this includes water when drinking, in addition to selecting roosting and landing sites. It is therefore not surprising that the number of close passes by bats outnumbered contacts with the experimental surfaces. Among the contacts that were recorded, we again observed a species specific difference. Of the 16 eastern red bats used in our behavioral trials, only 2 contacts were recorded at the smooth surfaces by 2 different individuals (Fig. 9). We did not observe any contacts by eastern red bats with the texture-treated surfaces during this study.

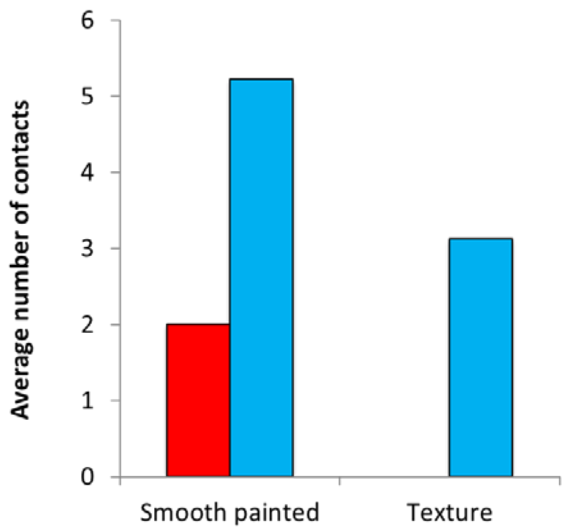


Figure 9: Average number of contacts recorded at smooth painted and texture-treated surfaces by eastern red bats (in red) and evening bats (in blue) in a flight facility.

For eastern red bats, the limited number of contacts observed at vertical surfaces (compared to the previous flight facility experiments with horizontal surfaces in Task 1) may simply have been due to limitations imposed by the flight facility ceiling on eastern red bat flight maneuverability. In Task 1, the bats had ~4 m on either side of the water tray to maneuver, whereas in Task 3 they only had 0.7 m or less at the ceiling end of the vertical experimental surfaces. Thus, if flight facility height had not restricted eastern red bat movement, we might have observed contact rates similar to previous experiments.

Compared to eastern red bats, evening bats made more contacts with the treatment surfaces in the flight facility (Fig. 9). We recorded 37 contacts overall on smooth surfaces and 27 on texture-treated surfaces, with individuals tending to make multiple contacts within a single trial. On average, we observed a 40% reduction in the number of contacts made by evening bats at the texture-treated surfaces compared to the smooth surfaces, which was similar in magnitude to the reduction seen in passes for this species (Fig. 8 & 9). Thus overall, we found the texture-treatment reduced bat activity in proximity. Based on these results, we concluded that the next step would be to test the texture-coating on operational wind turbine towers.

<u>Task 4: Feasibility study - bat activity surveys at operational wind turbines at Wolf Ridge</u>

The expected outcome of Task 4 was to: 1) refine the field study design proposed in Task 2 to maximize detection of bat activity at wind turbine surfaces, and 2) determine a method of analysis that would allow us to comprehensively discern differences in bat activity between texture-treated and smooth wind turbine tower surfaces (see Appendices H and I). A formal statistical analysis of the data gathered in Task 4 was not an expected outcome of this task.

For the field study design, we selected five pairs of wind turbines that would be suitable to include in the 2017 field test based on bat carcass counts in previous post-construction fatality monitoring (2009-2014) and levels of acoustic bat activity recorded in prior seasons. At these selected turbines, bat fatality and acoustic activity had been consistently higher than at other turbines, and within each pair, the levels of fatality and acoustic activity were similar. During this task we also optimized survey timing and fine-tuned our equipment set-up. From July to mid-August 2016, we conducted bat behavioral surveys at 3 of the 5 pairs of operational wind turbines at Wolf Ridge Wind, LLC using a combination of night vision technology, thermal cameras, and acoustic bat detectors. The results of these surveys confirmed that bats were active near the tower surfaces of these turbines and that bat activity within each turbine pair was comparable (Fig. 10).

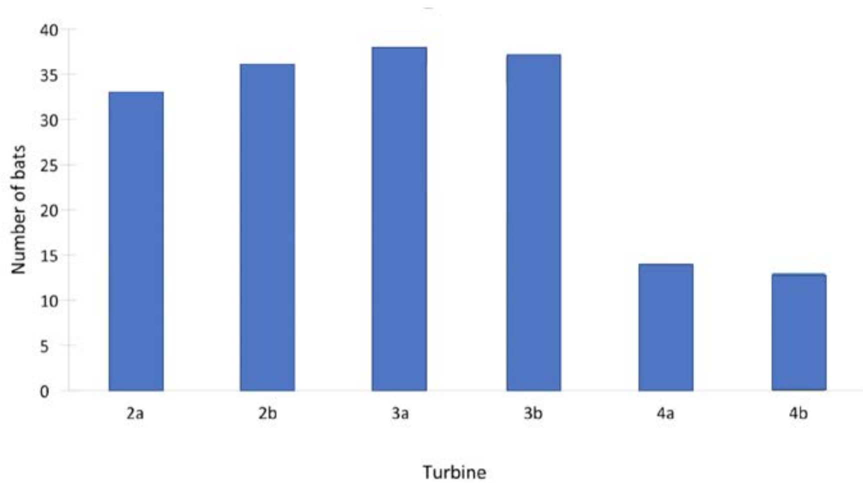


Figure 10: Number of bats observed at wind turbines in video surveys conducted during the feasibility study at Wolf Ridge Wind, LLC. Turbines in each pair are labelled as “a” or “b”. Using chi-square goodness-of-fit tests, we found no significant difference in bat activity between wind turbines within each of the 3 pairs (*P* = 0.72, 0.91 and 0.85, respectively).

Based on the number of bats observed and the number of acoustic bat calls recorded during this short observation period, we felt that it was worthwhile to proceed with Tasks 5 and 6 in 2017, i.e., that we could reasonably expect to gather enough data to evaluate the effectiveness of the texture-treatment at reducing bat activity in close proximity to wind turbine towers in the 2017 field test. Furthermore, by examining both video observations and recorded acoustic bat activity across survey nights, we determined that the timing of the nightly survey effort was appropriate to capture bat activity during the fall migratory season at Wolf Ridge.

Finally, while the night vision and acoustic set-up remained the same across the survey season, we modified the position and field of view of the thermal camera set-up to maximize bat detections at turbine sites. By refining the thermal camera set-up, we were able to establish that the most effective equipment arrangement for detecting bat activity around turbine tower surfaces would be to have a night vision set-up and thermal camera set-up together at both the leeward and windward sides of the turbine tower (Fig. 11).

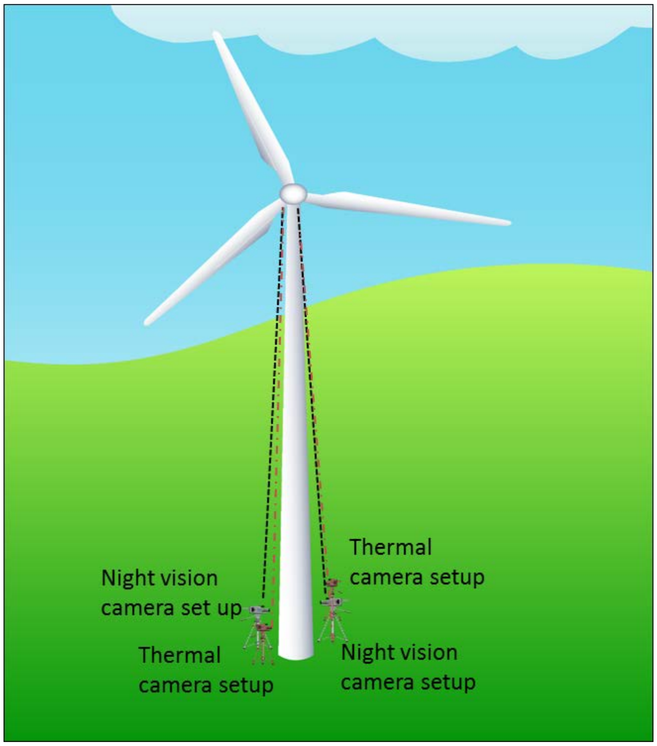


Figure 11: Image depicting the proposed night vision and thermal camera set-ups for bat behavioral surveys at wind turbine tower surfaces in Task 6 at Wolf Ridge Wind, LLC.

For data analysis, we quantified the number of bats present during the activity surveys and documented the types of behavior exhibited by bats in close proximity to turbine towers using video analysis software. We ascertained that creating a “Classification Key” to guide the identification of flying objects recorded in the video footage, as well as to characterize their behavior and position relative to the turbine tower surface, would provide a user-friendly and repeatable method for data processing. Thus, using the key, we were able to systematically identify objects as bats, possible bats, and non-bats. We also defined 8 distinct types of behavior exhibited by the bats in proximity to turbine towers. The behaviors were then further characterized by the bats’ proximity to the turbine tower. For this process, we defined three distance categories: 1) contact/close contact, in which bats made contact or close contact (<0.2 m) with the tower surface; 2) close-range, in which either the reflection of the bat appeared on the turbine tower surface indicating the bat was within close proximity to the surface or the distance of the bat from the surface could be estimated as <2 m using distance markers (i.e., the flange) on the turbine tower; and 3) far-range, which included all other bats observed at distances >2 m from the turbine tower.

By processing the bats recorded in the feasibility study with this key, we affirmed that certain behaviors were more likely to be associated with turbine tower surfaces than others (i.e., all contact/close contact behaviors). Typically these surface-associated behaviors involved bats interacting with the turbine tower, such as skimming, sweeping, colliding, and gleaning. We therefore considered these behaviors high risk as the bats were interacting with the tower surface rather than just passing through the area. Similarly, any close range bat activity could be construed as interest in the tower surfaces, which in turn could lead to contact/close contact behaviors. We reasoned that if the texture-treatment created a surface that bats showed little or no interest in approaching, we would expect to observe: 1) little or no reduction in the far-range behaviors that happen independent of the tower surface; 2) a reduction in close-range behaviors involving the tower surface; and 3) a significant reduction in contact and close contact behaviors.

Task 5: Application of coating treatment to turbines at Wolf Ridge

The expected outcome of Task 5 was to alter the surface of a subset of wind turbine towers (hereafter referred to as treatment or texture-treated turbines) at Wolf Ridge so that the acoustic properties of the treated tower surfaces no longer resembled a smooth surface. Thus, we set out to apply the texture coating developed in Task 2 to wind turbine towers (expected range: 3-5 towers) currently installed at an operational wind facility (Wolf Ridge Wind, LLC) between February to April 2017. We used the technical specifications provided in Task 2 (Appendix E) and applied the texture as shown in Fig. 6 (see process in Fig. 12). The application, however, did not occur in the spring because of a combination of constraints including equipment availability, personnel availability, and weather conditions. By April, all materials and labor had been sourced, but due to high average wind speeds from April into early June, we had to delay application until the week of June 19, 2017. While this delay was a setback to the planned schedule, it did not impact our data collection, as the peak bat activity season (i.e., fall migration, see also results from feasibility study: Appendix I) does not typically start until early July at our study site.

Figure 12: Texture coating application to a wind turbine tower at Wolf Ridge Wind, LLC in 2017.

Our field application plan was also designed to apply the tower coating to 3 turbine towers within a period of 5 full working days; however, we only successfully applied the texture coating to 2 turbine towers. Due to rental agreements for the large pieces of equipment (e.g., Bronto lift truck, spay equipment, etc.), the plan was constrained to a single mobilization effort. Thus, once the tower application process began on Monday June 19th, we lost ½ working day due to a lightning stand-down. In addition, time was lost due to several breaks each day that were necessary to prevent dehydration and fatigue of the field personnel, and somewhat longer than anticipated mobilization, de-mobilization, and application times. As a result in the 5-day application period, we were only able to successfully apply the texture coating to 2 turbine tower sections. Unfortunately, the costs to deploy the equipment and personnel to Wolf Ridge for a second time to apply the coating to a third tower were well beyond the reach of our approved research budget. We, therefore, made no plans to return to Wolf Ridge to apply the texture coating to a third tower at a later date.

Nonetheless, we were able to apply the texture-coating to two turbine towers (Task 5) and at the time of application considered this process a success, especially given the uncertainty of trying a new field application for the first time at an operational wind facility. Our goal in Task 6 was to compare bat activity at paired control and texture-treated towers and we concluded that this would still be possible with a reduced sample size of 2 turbine pairs. Furthermore, as bat activity is highly variable from one night to the next (as has been seen in previous years at our site and at many others), we considered that observing bat activity at two pairs of towers on as many nights as possible during the 2017 field season would represent an acceptable alternative to three pairs, in that we would still be able to estimate the difference in bat activity (if one exists) between the texture-treated and smooth turbine towers. Full details of this task are provided in Appendix J).

<u>Task 6: Bat activity surveys at control and texture-treated turbine towers at Wolf Ridge</u>

The expected outcome of Task 6 was to determine how free-flying bats responded to the texture coating on operational wind turbines from May through September 2017. This time period includes the fall migratory season of tree bats (July – September) and corresponding peaks in bat fatality rates at wind turbines across North America. For this task, we used the protocols described in Appendix K, in which we used a combination of high-definition video cameras with night vision technology along with thermal cameras and acoustic detectors to record bat activity at paired turbine towers at Wolf Ridge Wind, LLC.

Due to a delay in the application of the texture coating, we proceeded to monitor bat activity at 3 pairs of wind turbine towers initially selected in Task 2 (Appendix D) that were part of the sub-set of turbines surveyed in Task 4 (Appendix I) from late spring through early summer. Thus from May 20 to June 18, 2017, we conducted baseline bat activity surveys at these 3 turbine pairs on 17 nights. During this time period, each pair was surveyed at least 5 times prior to the application of the texture coating (June 19-23, 2017; Table 1), and 740 10-min trials were recorded on the video cameras (Table 2). After the texture coating was applied, we conducted bat activity surveys at just 2 pairs of turbines from June 24 to September 22, 2017, for a total of 55 survey nights (Table 1). Within each of these pairs, one turbine was texture-treated in Task 5 (Appendix J) and one was a smooth control. During this time period, each pair was surveyed at least 27 nights (Table 1), collecting a total of 2,545 10-minute trials recorded on the video cameras (Table 2). Using video analysis software and the Classification Key developed in Task 4 (Appendix I), we identified 1,030 confirmed bats and 693 possible bats on thermal and night vision video recordings (Table 2).

Table 1: Number of survey nights at each turbine location at Wolf Ridge Wind, LLC from May through September 2017. The texture coating was applied June 19-23.

Turbine Pair	Turbine ID	Number of survey nights prior to texture coating	Number of survey nights after texture coating
1	23 (smooth)	5	28*
	25 (texture-treated)	5	28*
2	60 (smooth)	6	27
	63 (texture-treated)	5	27
3	39 (smooth)	6	---
	40 (texture-treated)	6	---

*One survey night was excluded from subsequent analyses because only 1 10-min trial was completed successfully that night.

Table 2: Total number of 10-min trials and the number of bat-like objects (includes bats, possible bats, and non-bats from the Classification Key) observed during surveys conducted prior to and after the texture coating application at turbine towers at Wolf Ridge Wind, LLC in 2017. The texture coating was applied June 19-23.

	Prior to texture application (n = 735 10-min trials)*	Post texture application (n = 2,545 10-min trials)
Number of trials with bat-like objects	309 (41% of trials)	763 (30% of trials)
Number of bat-like objects	624	1,732
Number of bats†	30	1,000
Number of possible bats†	287	406
Number of non-bats†	307	326

* an additional 3 10-min trials were not reviewed; † based on the Classification Key

In acoustic surveys, a total of 1,215 bat acoustic calls were recorded (Fig. 13) during the May to September survey period in 2017. We detected all seven bat species known to be present at the study site: eastern red bat (n = 370 calls), hoary bat (n = 214 calls), silver-haired bat (n = 77 calls), canyon bat (n = 8 calls), evening bat (n = 325 calls), tri-colored bat (n = 209 calls), and Mexican free-tailed bat (n = 12 calls). The first three species listed, the migratory tree bats, represent the species most commonly found in fatality searches at wind energy facilities in the U.S. and Canada.

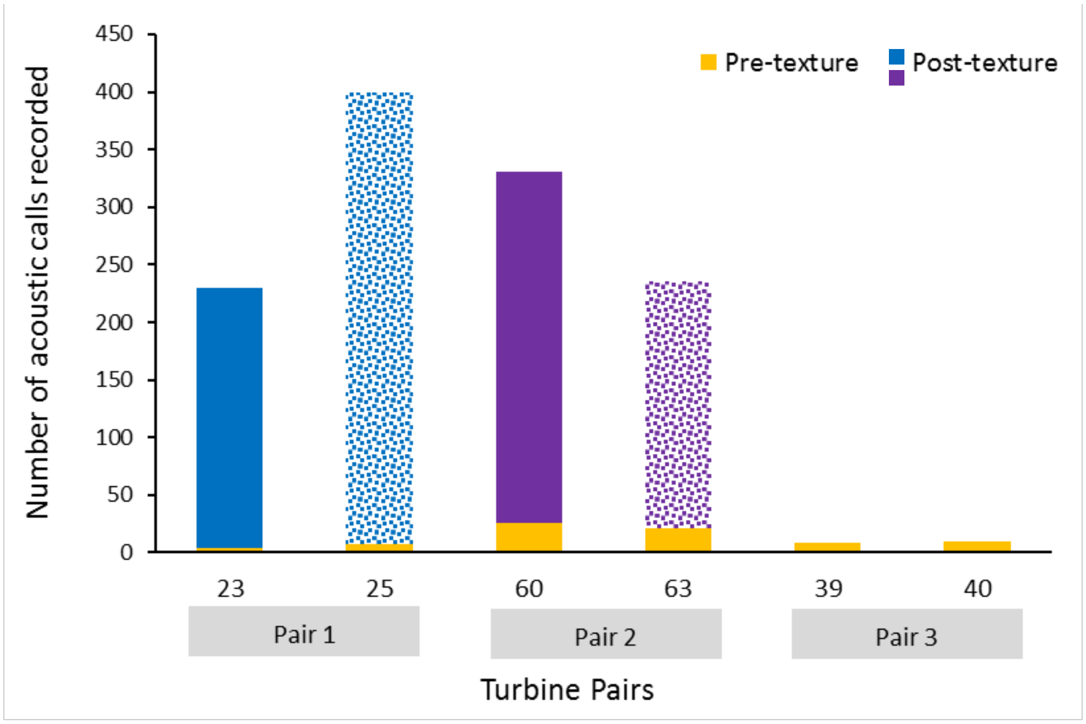


Figure 13: Number of bat acoustic calls recorded at each turbine from May 20 to September 22, 2017 at Wolf Ridge Wind, LLC in 2017. The texture coating was applied June 19-23. In the post-texture period, the solid fill indicates the smooth tower and the patterned fill indicates the texture-treated tower with Pair 1 and Pair 2.

Task 7: Data analysis and final reporting - Bat activity at smooth and texture-treated turbine towers

Video surveys at wind turbines

Overall levels of bat activity - Prior to conducting a formal analysis of the confirmed bats and possible bats (based on the Classification Key) at smooth and texture-treated turbines, we first generated graphs to allow us to visually compare the activity patterns of both observation categories at each turbine within Pairs 1 and 2 across the survey period (Fig. 14). Note that we excluded Pair 3 from this exercise due to the small number of survey nights (all of which occurred prior to the texture coating application). As the possible bat observations showed a similar pattern of temporal variability at each turbine as the confirmed bat observations (see Fig. 14), we decided that the possible bat observations likely represented real bats, and thus, we included them in all subsequent analyses.

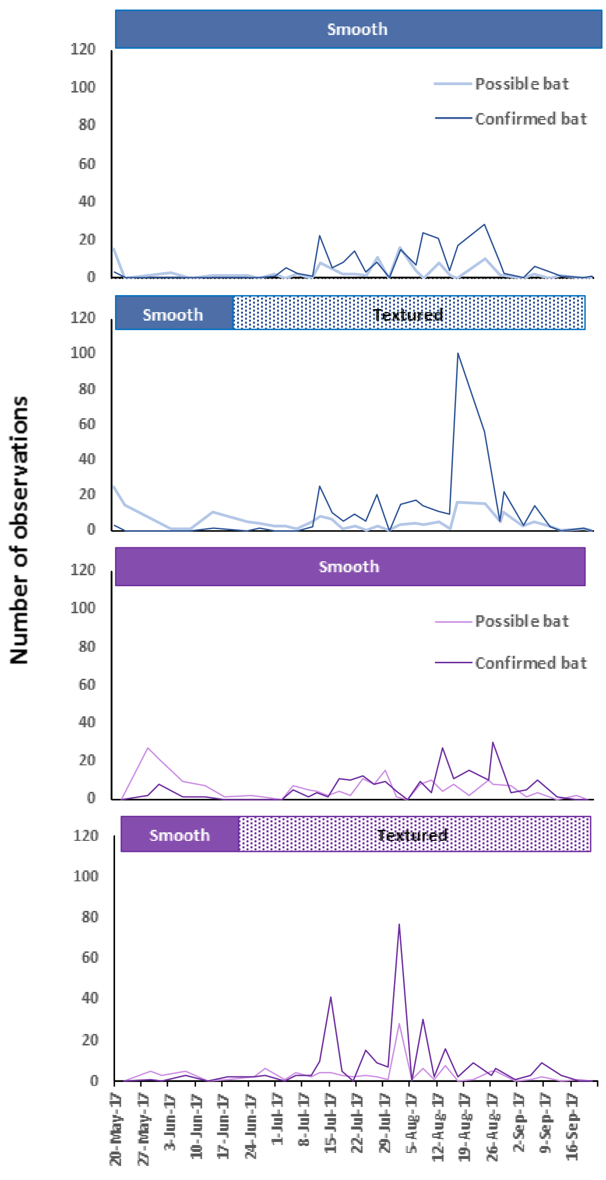


Figure 14: Number of flying objects categorized as 'confirmed bat' and 'possible bat' observations at each turbine in Pair 1 and Pair 2 over the course of the survey period at Wolf Ridge Wind, LLC in 2017. The data for Pair 1 are shown in blue, whereas the data for Pair 2 are shown in purple. The colored bars above each graph indicate the surface of the turbine tower at the corresponding time.

Prior to the texture treatment, we conducted bat activity surveys to estimate baseline bat activity levels at the focal turbines. Over the six turbines we surveyed, the combined mean number of confirmed bats and possible bats observed per hour ranged from 2.2 to 7.9 (n = 5 or 6 survey nights per turbine; Fig. 15). These results were consistent with the findings of the feasibility study. Furthermore, as bat migration and peak activity levels occur later in the season (i.e., from July to September), the observed relatively low levels of activity during this early season period was as expected. Using a GLM with turbine nested within pairs, we found that bat activity levels did not differ among the three turbine pairs we surveyed ($F_{2,3} = 0.26$, $P = 0.77$). For Pairs 1 and 2, we did not detect a significant difference in bat activity between the turbines within each pair (Pair 1 paired t-test: t = -1.97, df = 4, P = 0.12; Pair 2 paired t-test: t = -1.36, df = 4, P = 0.25). Within Pair 3, however, bat activity levels were significantly higher at turbine 40 than at turbine 39 (Paired t-test: t = -2.96, df = 5, P = 0.031).

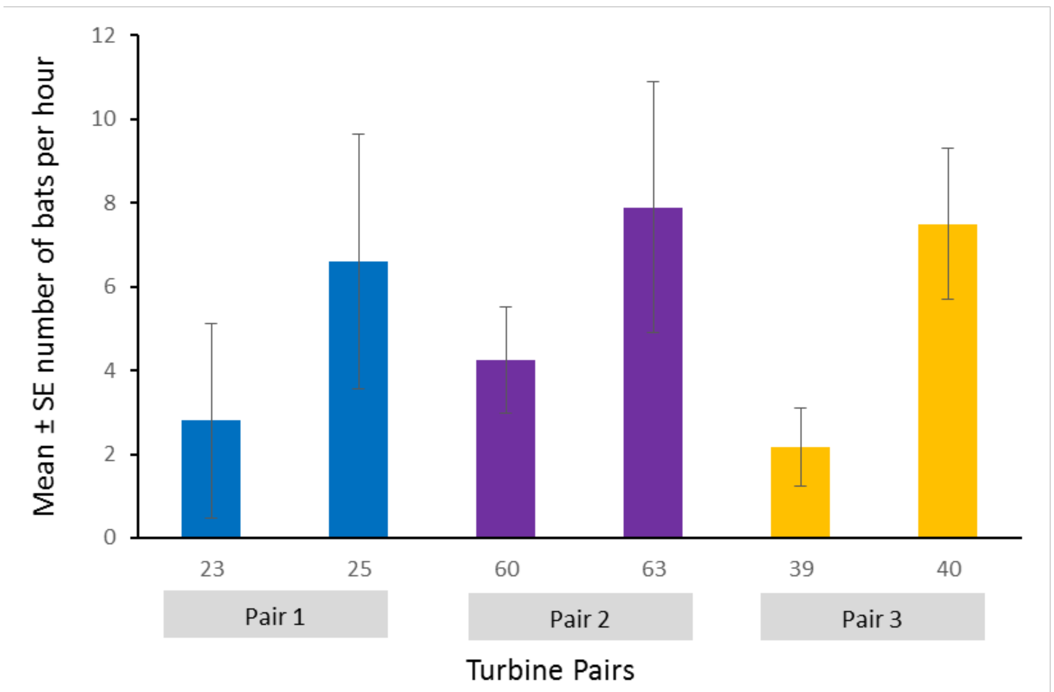


Figure 15: Mean ± SE number of bats (including possible bats) observed per hour in behavioral surveys at three pairs of wind turbine towers prior to the texture coating application (May 20 to June 18, 2017) at Wolf Ridge Wind, LLC. (n = 5 or 6 survey nights per pair). There was no significant difference in bat activity (number of bats and possible bats observed per survey night) among the surveyed pairs.

From June 24 to September 22, 2017 (after the texture treatment was applied), the mean combined number of bats and possible bats observed per hour ranged from 5.3 to 8.5 at the four turbines we surveyed (n = 27 survey nights per turbine; Fig. 16). As this later time period has been associated with peaks in bat activity and fatality in previous studies, it is not surprising that the mean levels of bat activity were higher during this period compared to earlier in the season. Using a GLM with turbine nested within pairs, we found that bat activity levels (using the ln + 1 transformation) did not differ between the two turbine pairs we surveyed ($F_{1,2}$ = 0.02, P = 0.88). For Pair 1, we did not detect a significant difference in bat activity between the turbines for this pair (Wilcoxon signed rank test: W = 126.50, n = 27 survey nights, P = 0.136). Similarly for Pair 2, we also failed to detect a significant difference in bat activity between the turbines (Wilcoxon signed rank test: W = 122.50, n = 26 survey nights, P = 0.182).

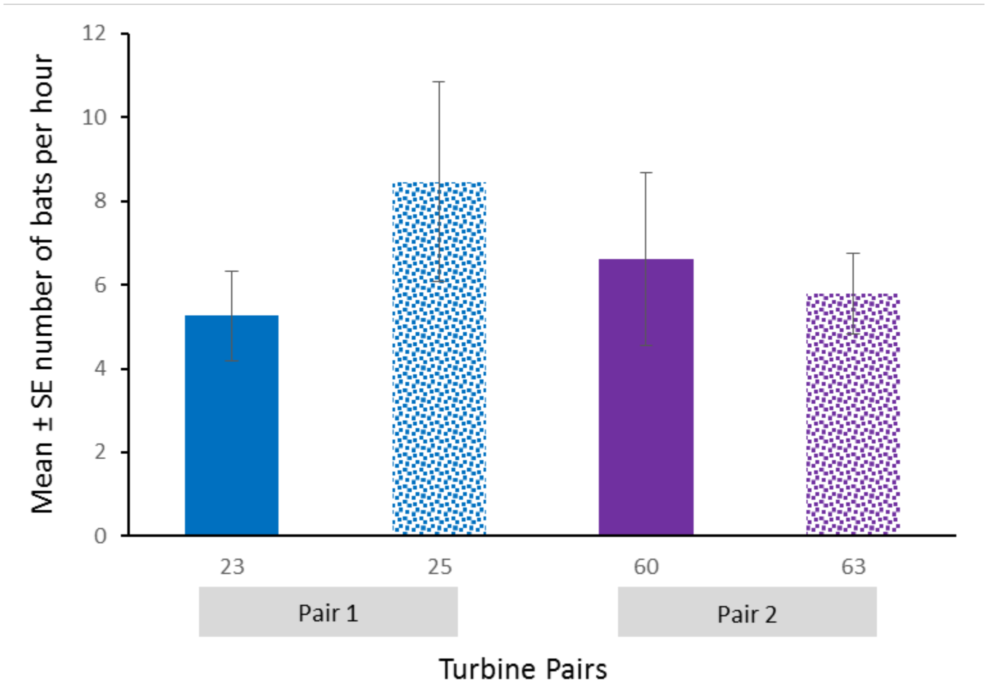


Figure 16: Mean ± SE number of bats (including possible bats) observed per hour in behavioral surveys at two pairs of wind turbine towers after the texture coating application (June 24 to September 22, 2017) at Wolf Ridge Wind, LLC. (n = 27 survey nights per pair). There was no significant difference in bat activity (number of bats and possible bats observed per survey night) between the surveyed pairs.

Given that the first texture-treated tower (in Pair 1) did not match our coating specifications (see Task 5) but the texture-treated tower in Pair 2 did, we cannot be confident that the texture coating on the two experimental towers was the same or would be perceived in the same manner by echolocating bats. In all subsequent analyses, we therefore summarize the findings for Pair 1 and Pair 2 separately.

Bat activity by distance to the turbine tower surfaces - Although we detected no significant difference in overall bat activity at the smooth and texture-treated turbines (Fig. 16), this result is not surprising as we had predicted that the texture treatment would not impact bat activity in the "far range" distance category, but rather that it would be associated with fewer bats in the close range and contact/close contact categories. Of the bats and possible bats that we observed at Pair 1 and Pair 2, 72% of the activity (1,170 of 1,623 observations) was in the far range category, followed by close contact, and then by contact/close contact (Fig. 17 & 18). Due to the small number of contact/close contact observations in the survey period (n = 9), we combined this category with close contact (i.e., <2 m from the tower surface) observations in subsequent analyses to evaluate differences in bat activity in close proximity to the tower surface (n = 453 close and contact/close contact observations at the two tower pairs).

Prior to the texture coating application (May 20 to June 18, 2017), the observed proportion of close range bat activity (including contact/close contact) did not differ between the two towers within each pair (Fisher's exact test: P = 1.000 in both cases; Fig. 17). Among the four towers, the proportion of bat activity that was <2 m from the tower surface ranged from 0.036 to 0.114 during this early part of the survey period.

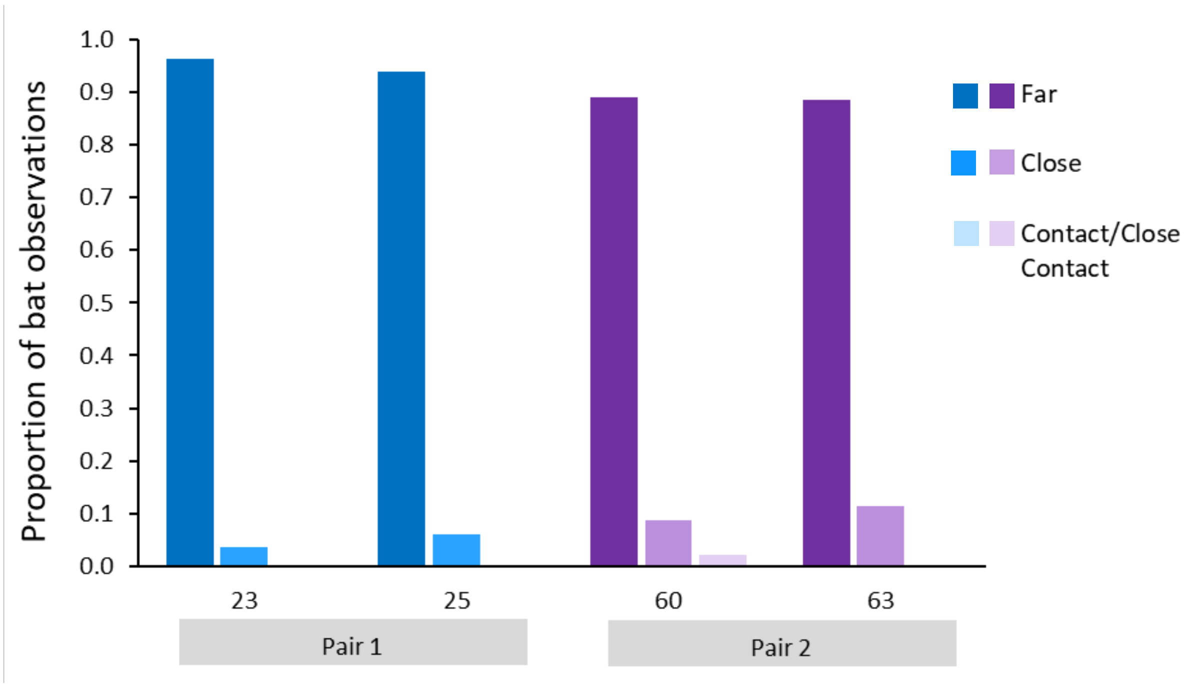


Figure 17: Proportion of bat observations (including possible bats) that were categorized as far, close, and contact/close contact at turbine towers surveyed prior to the texture coating application (May 20 to June 18, 2017) at Wolf Ridge Wind, LLC. (n = 5 or 6 survey nights per pair).

Following the texture coating application, however, we did detect a significant difference in the proportion of bat activity that occurred in close proximity to the tower (i.e., close and contact/close contact) within Pair 1 (Fisher's exact test: $p_{smooth} = 0.254$, $p_{textured} = 0.363$, P= 0.002; Fig. 18). This result was contrary to our original prediction that bat activity would be lower in close proximity to the texture-treated tower. In contrast for turbine Pair 2, we found no significant difference in the proportion of bat activity that occurred in close proximity to the tower (i.e., close and contact/close contact) (Fisher's exact test: $p_{smooth} = 0.301$, $p_{textured} = 0.288$, P= 0.734; Fig. 18). This result did not support our hypothesis that bat activity would be lower in close proximity to the texture-treated tower.

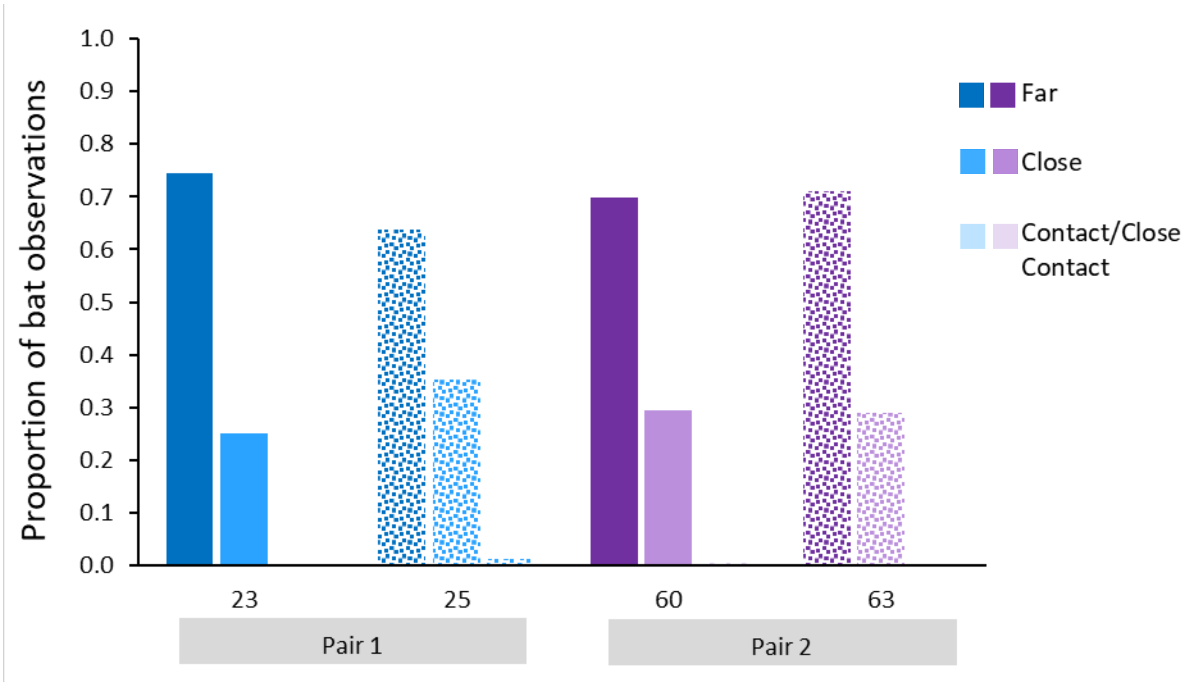


Figure 18: Proportion of bat observations (including possible bats) that were categorized as far, close, and contact/close contact at turbine towers surveyed after the texture coating application (June 24 to September 22, 2017) at Wolf Ridge Wind, LLC. (n = 27 survey nights per pair).

At each of the four surveyed turbines, we observed an increase in the proportion of bat activity in close proximity to the tower surface in the late summer and early fall compared to the early summer survey period (Fisher's exact tests: $P < 0.008$ in all cases). From July through September, the proportion of bat activity that was <2 m from the tower surface ranged from 0.254 to 0.363. As this increase in close activity occurred at both the smooth and texture-treated tower surfaces, it is likely that this change in how bats were interacting around the towers was independent of the texture coating.

Bat behavior at smooth and texture-treated turbine towers – For each of the confirmed bat and possible bat observations summarized above in the post-texture survey period, we also ascribed one of seven behaviors based on characteristics of the flight pattern (passing, foraging, reversal, looping, chasing, gleaning, skimming). Most of the bats, both close to the tower surfaces as well as farther away (>2 m) were passing or foraging in the immediate vicinity of the wind turbine towers, with fewer observations of bats reversing direction or engaging in complex, looping flight patterns (Fig. 19 & 20).

We used a series of Fisher's exact tests to determine if the observed proportions of the behaviors within each distance classification differed between the smooth and texture-treated tower within each pair (significant findings presented in Table 3). For Pair 1 (coating not applied to specifications), we observed a significantly greater proportion of bats foraging both close and far from the texture-treated tower compared to the smooth tower, and a significantly lower proportion of bats passing far from the texture-treated tower compared to the smooth tower.

Consistent with these observations, we also observed a significantly greater proportion of bat gleaning and skimming activity at the texture-treated tower surface compared to the smooth tower. Taken together, these behaviors revealed more foraging activity by bats on and around the texture-treated tower within this pair. For Pair 2 (coating applied to our specifications), we observed a significantly lower proportion of foraging bats far from the tower surface at the texture-treated tower compared to the smooth tower, and significantly higher proportion of passing bats close to the texture-treated tower compared to the smooth.

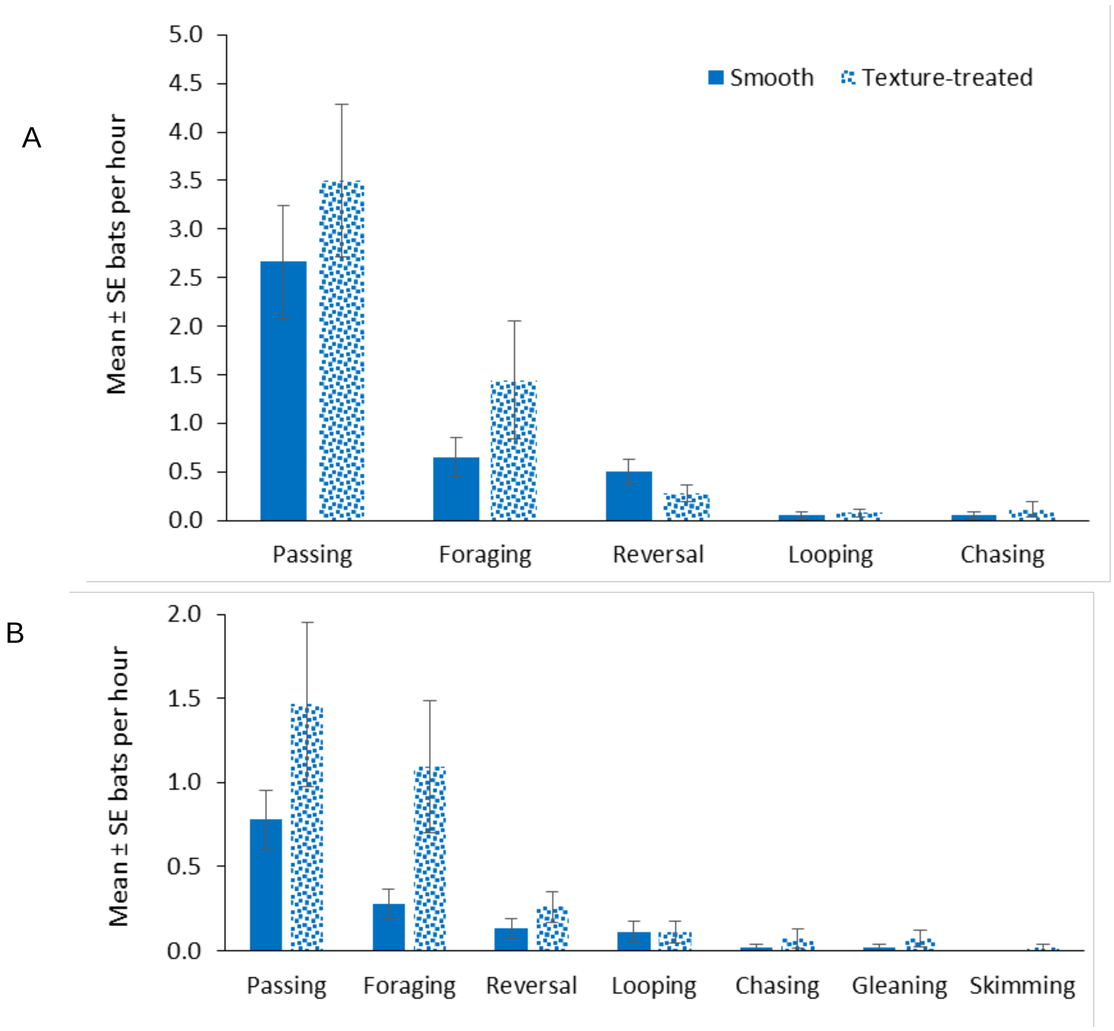


Figure 19: Mean ± SE number of bat observations (including possible bats) per hour categorized by behavior that occurred (A) far from the tower surface (>2 m) and (B) close to the tower surface (<2 m) at the smooth and texture-treated turbines in Pair 1 at Wolf Ridge Wind, LLC from June 24 to September 22, 2017. (n = 27 survey nights).

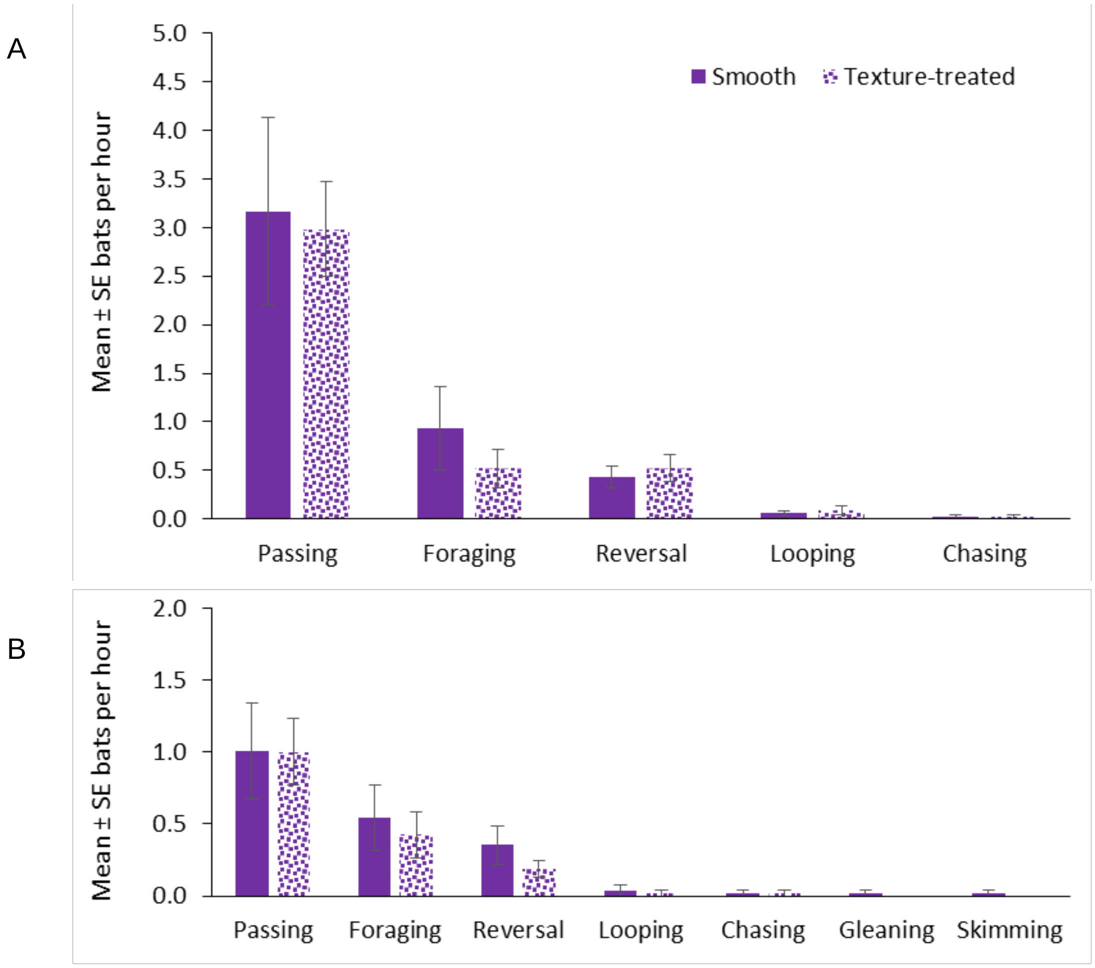


Figure 20: Mean ± SE number of bat observations (including possible bats) per hour categorized by behavior that occurred (A) far from the tower surface (>2 m) and (B) close to the tower surface (<2 m) at the smooth and texture-treated turbines in Pair 2 at Wolf Ridge Wind, LLC from June 24 to September 22, 2017. (n = 27 survey nights).

Table 3: Summary of significant differences in the proportion of bats assigned to different behavior categories within close and far distance categories at the smooth and texture-treated turbines surveyed from June 24 to September 22, 2017 at Wolf Ridge Wind, LLC. (n = 27 survey nights at each pair). p-hat is the observed proportion of bats within the given distance category (far >2 m; close <2 m) exhibiting that behavior at each turbine.

Turbine Pair 1				
Behavior	Smooth p-hat	Texture-treated p-hat	Fisher's exact test P-value	Direction of difference at texture-treated tower
Passing far	0.507	0.414	<0.001	lower
Foraging far	0.123	0.171	0.003	higher
Foraging close	0.053	0.129	<0.001	higher
Gleaning/Skimming	0.004	0.011	0.038	higher
Turbine Pair 2				
Behavior	Smooth p-hat	Texture-treated p-hat	Fisher's exact test P-value	Direction of difference at texture-treated tower
Foraging far	0.139	0.089	0.009	lower
Passing close	0.082	0.173	<0.001	higher

Finally, it was not possible to evaluate whether or not the texture-treatment led to a reduction in behaviors that were specifically associated with turbine towers, such as skimming, sweeping, colliding, and gleaning, as we only recorded one instance of gleaning prior to the texture coating application. We would consider these behaviors to increase the risk of collision if they cause bats to spend more time in and near the rotor-swept zone. In the post-texture application survey period, we recorded 8 total contact events: 2 skimming (one at the smooth tower and one at the texture-treated tower in Pair 1), and 6 gleaning events. Of the latter, 2 gleans were recorded at smooth towers (23 and 60, one in each pair), one was below the texture-treatment on 25 (i.e., <10 m above ground, Pair 1), and 3 were on the texture-treatment on 25 (Pair 1). Although contact activity was low across all the turbines, no contact or close contact was observed at the texture-treated turbine within Pair 2. In contrast, more contacts were observed at the texture-treated compared to the smooth tower in Pair 1.

Acoustic surveys at wind turbines

We recorded 1,215 acoustic calls from seven bat species from May 20 to September 22, 2017 at the Wolf Ridge wind energy facility (Fig. 13 & 21). These acoustic data were collected in conjunction with the previously described video surveys at wind turbines, and provide valuable insights into species-specific bat activity levels – which is currently not possible from video surveys of bats at wind turbines. In the pre-texture survey period, we recorded 2.4 ± 2.7 (SD) acoustic calls per turbine night (n = 32). After the texture coating application was completed, we recorded 10.5 ± 13.4 (SD) acoustic calls per turbine night (n = 108). These findings are consistent with the video surveys, indicating that peak bat activity took place from July to September at this wind energy facility. During the pre-texture period, four bat species were recorded at the focal turbines: eastern red bat (n = 21 calls), silver-haired bat (n = 27 calls), tricolored bat (n = 4 calls), and the evening bat (n = 25 calls). After the texture coating was applied, we recorded seven bat species at the focal turbines: eastern red bat (n = 349 calls), hoary bat (n = 214 calls), silver-haired bat (n = 50 calls), tricolored bat (n = 205 calls), canyon bat (n = 8 calls), evening bat (n = 300 calls), and the Mexican free-tailed bat (n = 12 calls).

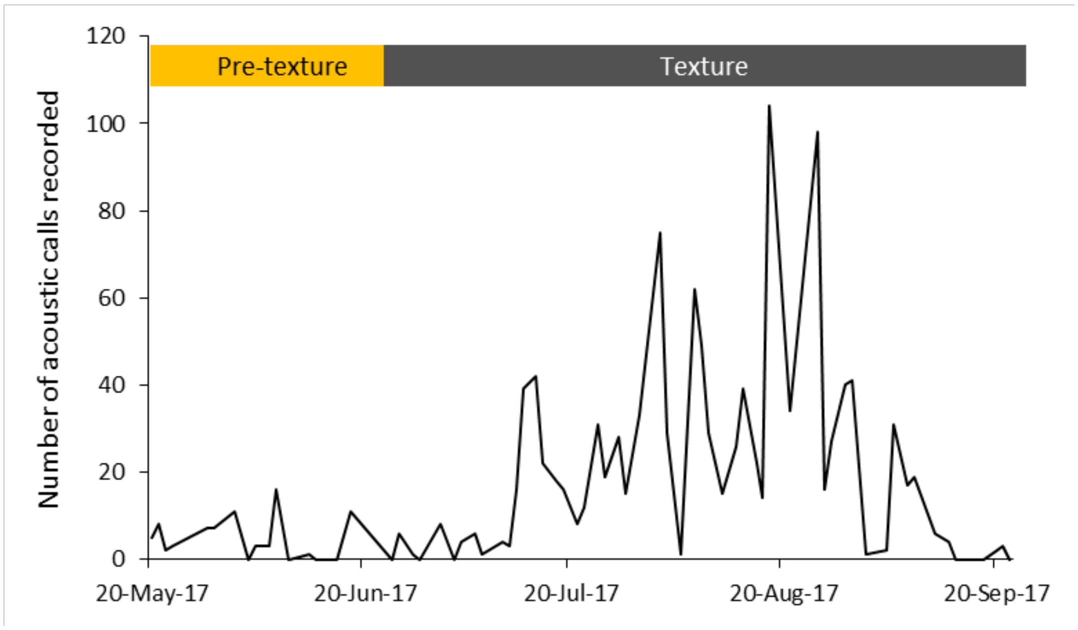
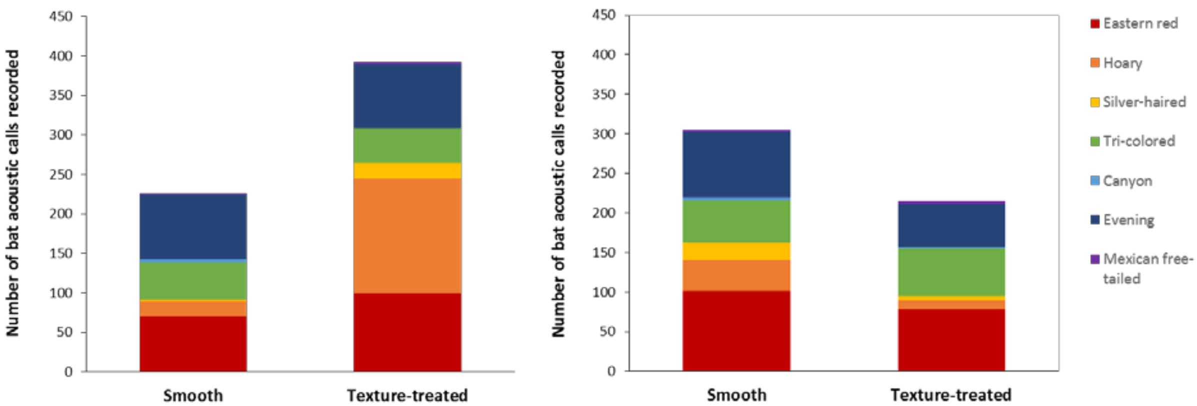


Figure 21: Number of acoustic bat calls recorded from May 20 to September 22, 2017 at focal wind turbines at Wolf Ridge Wind, LLC. The texture coating application was completed June 19-23.

Using a GLM with turbine nested within pairs, we found no significant difference in acoustic bat activity (for all bat species combined) among the three turbine pairs we surveyed during the pre-texture period ($F_{2,3}$ = 3.19, P = 0.06). Nor did we detect a difference in acoustic bat activity between turbines within each pair (Pair 1 paired t-test: t = -0.58, df = 3, P = 0.60; Pair 2 paired t-test: t = 0.58, df = 5, P = 0.59; Pair 3 paired t-test: t = --0.23, df = 5, P = 0.83).

In the survey period after the texture coating was applied, we also found that acoustic bat activity (for all bat species combined) did not differ between the two turbine pairs we surveyed (GLM with turbine nested within pairs: $F_{1,2}$ = 0.00, P = 0.99). Within Pair 1, we did not detect a significant difference in bat activity between the turbines (Wilcoxon signed rank test: W = 77.50, n = 23 survey nights, P = 0.068). Similarly for Pair 2, we also failed to detect a significant difference in bat activity between the turbines (Wilcoxon signed rank test: W = 149.50, n = 21 survey nights, P = 0.244).

When we look at the acoustic activity by species of bat, there appeared to be differences in the proportion of calls by different species at the smooth and texture-treated turbines within each pair in the post-texture application survey period (Fig. 22). We used a series of Fisher's exact tests to determine if the observed proportions of acoustic calls recorded for each species differed between the smooth and texture-treated turbine within each pair (Table 4). When we look at the migratory tree bats (eastern red bat, hoary bat, and silver-haired bats), we see differences in the relationship between the texture treatment and acoustic activity. In the eastern red bat, we found no relationship between the texture treatment and the proportion of recorded activity at either turbine pair. In contrast for the hoary bat and silver-haired bat, we saw opposite patterns at the two tower pairs, with significantly higher activity at the texture-treated tower in Pair 1 and significantly lower activity at the texture-treated tower in Pair 2. For the remaining 4 bat species, the results were mixed: we found either no relationship or significantly lower activity at the texture-treated tower in Pair 1, and either no relationship or significantly higher activity at the texture-treated tower in Pair 2.



Pair 1 – Texture application did not meet coating specifications

Pair 2 – Texture application met coating specifications

Figure 22: Number of acoustic bat calls recorded by species at smooth and texture-treated paired wind turbines from June 24 to September 22, 2017 at Wolf Ridge Wind, LLC.

Table 4: Results of Fisher's exact tests to determine if the proportion of calls recorded by each species differed between the smooth and texture-treated turbine within each pair. Data are from surveys conducted from June 24 to September 22, 2017 at Wolf Ridge Wind, LLC.

	Pair 1		**Pair 2**	
Bat species	P-value	Direction of difference at texture-treated tower	P-value	Direction of difference at texture-treated tower
Eastern red	0.112	---	0.455	---
Hoary	< 0.001	higher	0.004	lower
Silver-haired	0.01	higher	0.02	lower
Tricolored	0.001	lower	0.005	higher
Canyon	0.048	lower	1.00	---
Evening	< 0.001	lower	0.615	---
Mexican free-tailed	1.00	---	0.455	---

In summary, the results from this field test were inconclusive and did not support our hypothesis that a texture treatment on the wind turbine tower monopoles would lead to a reduction in bat activity in close proximity to the turbine tower surfaces. Specifically, we predicted that the texture-treated surface would result in: 1) little or no reduction in the far-range behaviors that happen independent of the tower surface; 2) a reduction in close-range behaviors involving the tower surface; and 3) a significant reduction in contact and close contact behaviors. The results show mixed results for prediction 1, no support for prediction 2, and no support for prediction 3. Although 25-35% of the observed bat activity at each tower was <2 m from the surface, only 8 of these observations involved bats contacting or making close contact the tower surfaces. These observations represent 0.46% of all bat activity, which is less than we have observed in previous studies, which makes it exceedingly difficult to fully evaluate prediction 3.

At Pair 1 we observed: a greater proportion of passing and foraging behavior by bats >2 m from the texture-treated tower (this increase in activity may be independent of the tower coating); a greater proportion of close range activity at the texture-treated tower, which included foraging flight patterns and gleaning and skimming activity at the tower surface (this increase in activity could be due to the tower coating); no difference in acoustic activity at the smooth and texture-treated tower for eastern red bats; higher acoustic activity for hoary bats and silver-haired bats at the texture-treated tower; and lower acoustic activity for tricolored bats, canyon bats, and evening bats at the texture-treated tower.

At Pair 2 we observed: a lower proportion of foraging behavior by bats >2 m from the texture-treated tower (this decrease in activity may be independent of the tower coating); a higher proportion of passing behavior <2 m from the texture-treated tower; no contact or close contact with the tower surface at either the smooth or texture-treated tower; no difference in acoustic activity at the smooth and texture-treated tower for eastern red bats; lower acoustic activity for hoary bats and silver-haired bats at the texture-treated tower; and higher acoustic activity for tricolored bats at the texture-treated tower.

We speculate that the contrasting findings related to bat behavior and species-specific acoustic activity between the turbine pairs could be due to the difference in the texture coating application at Pair 1. The material usage for Turbine 25 (Pair 1) was higher than it should have been, resulting in a texture coating that did not match the coating specifications developed from the experimental surfaces in the bat flight facility. It is possible that this previously untested texture coating could have altered the texture of the tower monopole in such a way that it became attractive to bats or facilitated foraging close to the tower surface. Another possibility is that hoary bats and silver-haired bats, in particular, were responding to variation in some other variable that we were not able to quantify. For example, there could have been an eruption in a preferred prey item that occurred near Pair 1 and that this difference in prey availability had a stronger impact on overall bat activity than did the difference in the surfaces on the wind turbine towers. Thus, further surveys would be required to understand the different levels of bat activity that we observed at the two turbine pairs. If however, the same opposing patterns in activity between our texture-treated turbines is observed in subsequent years of study, it is likely to demonstrate the importance of applying the coating application exactly as specified in the flight facility experiments. As the coating was applied manually to the turbines in this field test, it is likely that variation during the coating application could occur; however, we would not anticipate this to be a problem once the system of application becomes automated.

As overall bat activity patterns during the field test were inconsistent with previous acoustic surveys conducted over 5 years at this site, we speculate that some bats (hoary and silver-haired bats, in particular) could have been responding to some other variable(s) that we were not able to quantify. Thus, further surveys would be necessary to confirm if bats are responding to this texture treatment or if it has no effect on activity at wind turbine towers.

Acknowledgment

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DE-EE0007033
General Electric Company
Texturizing Wind Turbine Towers to Reduce Bat Mortality

Task 1 – Testing behavioral response of bats to textures in flight room (M1-M6)

Task Summary:

Task 1 is divided into two Subtasks. Subtask 1.1 involves the production of a range of test surfaces that vary in the type and grade of texture. In Subtask 1.2, we will then explore how wild-caught bats respond to each textured surface, as well as a smooth painted surface, in a controlled behavioral experiment.

In preliminary testing in 2014, we found that increasing the level of texture in wind turbine paint increased the distance of closest approach by bats to horizontal painted metal surfaces in a bat flight facility. Increasing the level of texture also decreased the time bats spent in close proximity to those surfaces. In this study, we will determine how wild-caught bats respond to smooth and textured surfaces on a mock wind turbine tower section.

Subtask 1.1 – Make textured surfaces for flight facility (Month 1)

Subtask Summary: We propose to create types and grades of texture that are discernibly different from smooth surfaces and from each other, and do not compromise the integrity of the paint. At this stage, we will work closely with a coating specialist identified by our research partner NextEra Energy Resources (NEER) to ensure that the coatings we test in the flight facility can be developed and applied to wind turbine towers.

Subtask 1.2 – Behavioral study in flight facility (Months 1-6)

Subtask Summary: We propose to record the responses of wild-caught bats when presented with a variety of smooth and textured surfaces (treatments produced in Subtask 1.1) in a bat flight facility. From this study, we will determine rate of approach, closest distance of approach, and activities exhibited by the bats towards each treatment. We will compare the results of each treatment and assess which treatments (i.e., grade and type of texture) bats showed little or no interest in approaching.

Objectives

Our primary objective is therefore to identify a type and level of texture that bats in the flight room exhibit little or no interest in approaching. The results of this part of our study will then be used in Task 2 to aid the development of a paint additive(s) or other applique that can be effectively and economically applied to existing and proposed wind turbine towers. We hypothesize (H_A) that increasing the level of texture on the painted surfaces will reduce the time bats spend in close proximity to those surfaces in comparison to smooth surfaces (i.e., surfaces equivalent to wind turbine tower surfaces). The null hypothesis (H_0) is that activity and presence of bats is independent of texture.

Deliverable 1.1.2 Report detailing how we created the textured surfaces

Textured Surfaces for Flight Facility

For this experiment, we will use a series of metal plates with a variety of painted and textured surfaces (hereafter referred to as treatment surfaces, Fig. 1) that can be attached to a mock wind turbine tower section or placed over a water tray. The initial selection of treatment surface is based on preliminary behavioral trials and analysis of spatial and temporal characteristics of echoes from synthetic bat calls played at different surfaces in a sound treated room in 2014. We will use paint-ready, 26 gauge galvanized steel plates (2.5 m x 1 m) and apply paint with rollers to create all treatments. For the painted treatment, we will use two coats of Intergard 345 and a topcoat of Interthane 990, the same primer and finish paint coating, used on General Electric wind turbine towers deployed at operational wind facilities. To create 3 different grades of texture, we will use sand of 3 distinct grain sizes: 600-850 microns (Fine texture, Sand 1), 850-1180 microns (Intermediate texture, Sand 2), and 1400-2000 microns (Coarse texture, Sand 3). For plates with these textures, the second coat comprised 2 cups of sand to ½ gallon of Intergard 345. An additional texture treatment will consist of an applique intended to interrupt a smooth painted surface. This applique will be 12.7 mm tall x 19 mm wide x 1 m long strips of Tight Fit Foam Tape (Ace Hardware) and will be positioned at 0.5 m intervals along the length of the vertical axis of the plate. These treatments will then be presented to wild-caught bats in the flight facility as part of Subtask 1.2.

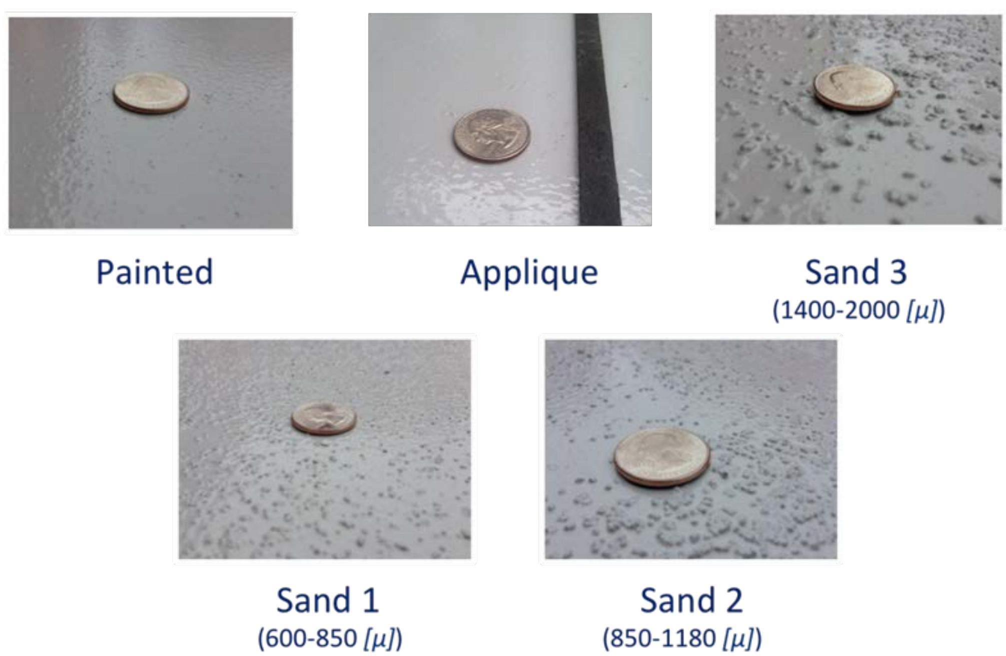

Fig 1: Range of surface textures including one applique that will be used in the initial round of behavioral testing in 2015.

Deliverable 1.2.1 Experimental protocol for behavioral trials in the bat flight facility

Field Methods and Bat Flight Facility

The individual bats used in this experiment will be wild-caught from select locations in north-central Texas including the Wolf Ridge wind farm and local parks in and around Fort Worth (i.e., in close proximity to the existing bat flight facility; Fig 2, see mist netting permit in appendix 1). Captured bats will therefore be representative of local species and include eastern red (*Lasiurus borealis*) and hoary (*Lasiurus cinereus*) bats that comprise the highest number of fatalities at Wolf Ridge.

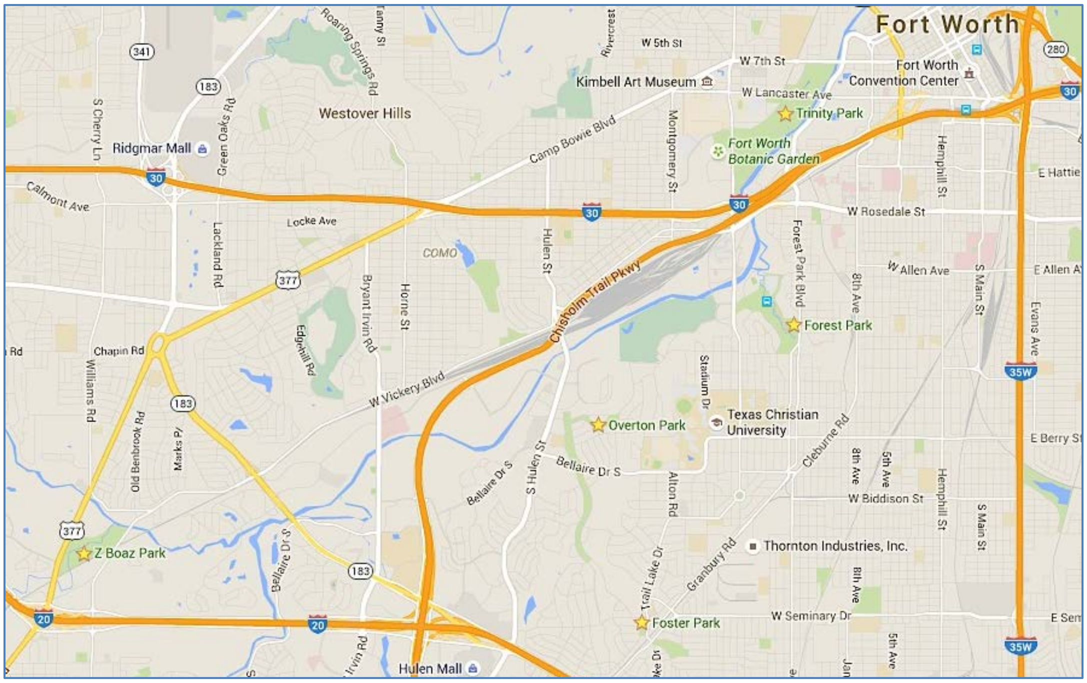

Fig 2: Locations (yellow stars) of Fort Worth local parks that are included in our mist netting permit (Left to right: Z Boaz Park, Overton Park, Foster Park, Trinity Park, Forest Park).

At select locations, where we have identified frequent bat activity, we will put up mist nets, a commonly used approach to catch bats (Fig. 3). These mist nets (triple-high and single 6-18 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 3 hours after dusk, as this represents the primary activity periods of local bats. Each net will be monitored continuously from an appropriate distance and physically checked at no more than 10 minute intervals. From the net, the bats will be placed in a cloth sack and taken from the net to a secure temporary carrier, with the exception of bats that have been identified during removal from the net 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 individuals will be taken away from the mist nets and 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. 3: Images of triple high mist netting locations before nets are opened.

At the end of the trapping session or when up to 8 bats have been caught, we will transport the bats to the flight facility (see below). The bats that are housed in the flight facility will only be used in the experiment for a limited amount of time (< 4 weeks) and will then be released back at their site of capture. Note that each individual bat successfully tested in the flight facility represents an independent sampling unit. Our goal is to successfully survey approximately 15-30 individual bats within the 3 month survey period (July to September 2015). In this time, we will strive to sample a representative cross-section of males and females from each species; however, this is ultimately dependent on our trapping 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; see appendix 2) 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 building approximately 14.6 m by 8.5 m (Fig. 4). Hoary bats (the largest species in the area) require a minimum flight area of 23.04 m^2 (Lollar 2010); therefore, we selected a larger flight facility to provide sufficient room for maneuverability. As we want the bats in the flight facility to behave as naturally as possible, conditions within the facility will be kept similar to the bats' natural environment. Subsequently, no visible artificial lights will be used during the behavioral surveys and researchers will only use headlamps pre- and post-trials. Similarly, the temperature and humidity within the facility will be similar to the conditions outside the tent, using a series of mesh covered windows to ensure appropriate ventilation (Fig. 4). The conditions within the facility will also be monitored and we will check on the bats throughout the day to ensure their health and safety. Checks will be conducted at approximately 8 am, 12 pm, and 4 pm, and additional checks will be conducted in increment weather.

Fig. 4: Outside view of flight facility with custom made screen windows.

<u>Flight Facility set-up:</u> In order to effectively collect data, we will divide the facility into two rooms (8.5 m by 7.3 m) using a mesh screen partition (Fig. 5). In one half, we will conduct bat drinking behavior trials, and in the other side we will conduct bat foraging behavior trials. Preliminary surveys in 2014 showed that eastern red, evening, and Mexican free-tailed bats flew unhindered in a 7.3 m x 8.5 m flight area. The minimum flight area for bats with a wingspan between 30-35 cm (all species in the study area besides the hoary bat) is 12.96 m^2 (Lollar 2010). Thus when a hoary bat is caught, we will remove the mesh screen partition.

Fig. 5: Inside view of flight facility. The facility is split into two rooms by a mesh divider. A shallow water tray is centered in each room. The treatment surfaces are covered by camouflage netting which is seen in the lower right corner of the image.

A custom made shallow galvanized steel water tray (2 m x 1 m x 1.5 cm) will be centered in each room. The inside of each tray is coated with EMI5005 RTV Food Grade Adhesive Silicone Sealant (EMI Supply Inc., Monroe NC) to prevent rusting and zinc leaching into the water. Species-specific roosting opportunities will be provided. Soft puppy carriers and carpeted cat houses will be provided for cavity-dwelling species (evening, tri-colored, and Mexican free-tailed bats), and grouped branches in tree stands will be provided for tree-dwelling species (eastern red, hoary, and silver-haired bats; Fig. 6; Lollar 2010).

Fig. 6: Roosting opportunities provided for the bats within the flight room.

Textured surfaces will be kept under camouflage hunting netting until they are used in trials (Fig. 5). In addition, two custom-made "to scale" sections of a wind turbine tower (to which the surface treatments will be attached; Fig. 7) will be used in each side of the facility. These tower sections represent the curvature of GE wind turbine towers at mid-tower height (approximately 40 m), which falls within the rotor swept zone and where the blades are moving the fastest. The model turbine tower section will be placed over the water tray during bat drinking behavior trials and on a stand that is 1.2 m tall so that the tower section is centered within the bats' flight space during bat foraging behavior trials.

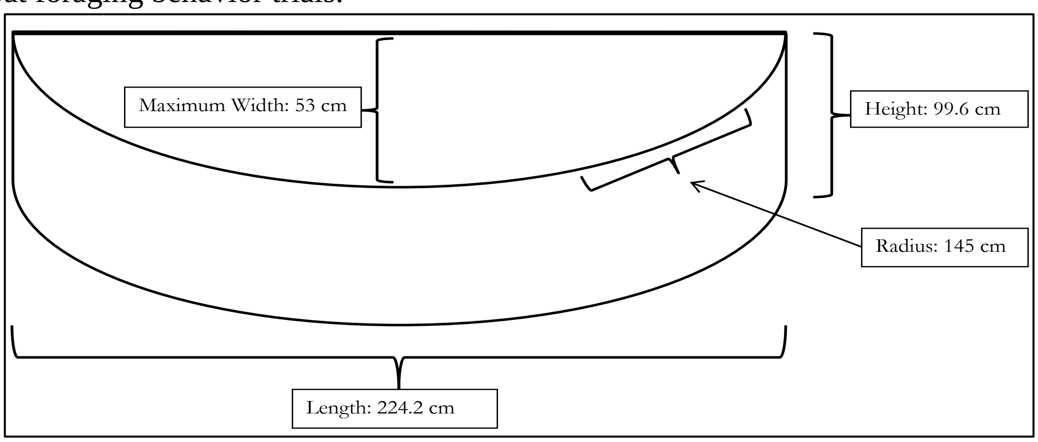

Fig.7: Specifications of the custom-made fiberglass wind turbine tower section that will be placed in the bat flight facility.

<u>Care of bats:</u> The experimental trials will not begin until the bats have acclimated to the flight facility, which includes flying, voluntarily drinking from the water tray, and foraging activity. Preliminary surveys in 2014 revealed that this process takes approximately 1-3 days. Bats generally emerge from roosting sites and fly for no more than a few hours at dusk, in which time they drink and forage for invertebrate prey. As the flight facility does contain a limited number

of flying invertebrate prey items, we run a light trap outside the flight facility. Moths, flies and beetles will be retrieved from the light traps and released into the flight facility on a nightly basis. In addition, when the bats stop flying in the evening, we will supplement their diets with mealworms (larval *Tenebrio molitor*) covered in vitamin powder (1/16 tsp. Bulk Supplements Pure Coenzyme Q10 (COQ10) to 2 tsp. Miracle Care Vionate Vitamin Mineral Powder; Lollar 2010). As previously mentioned, environmental conditions will be monitored throughout the day. During the 4 pm check on high temperature days, we will offer the bats water by holding a pipette up to their mouths.

Finally, in order to identify individual bats in the flight facility during trials and while checking on the bats during the day, we will coat their backs with combinations of non-toxic pink, green, orange, blue, purple, and yellow ECO Pigments (Day-Glo Color Corp, Cleveland, OH; Fig. 8, see appendix 3) during the 4 pm check.

Fig. 8: Evening bat (*Nycticeius humeralis*) marked with blue ECO Pigment.

Bat drinking behavior trials – In these trials, we will identify a treatment surface that bats show little or no interest in approaching. The treatment surfaces comprise the textured surfaces that were created in Subtask 1.1 (control; fine, intermediate, and coarse sand; and applique). During the trials we will present the bats with the various treatment surfaces and record behavior at each surface to identify interest.

From preliminary surveys, we found that when a bat showed interest in a surface or was preparing to drink, the bats would make straight line flight paths across the longest extent of the surface (known as a pass, Fig 9); and generally, the bat would make several passes over the surface before contacting the water or treatment surface. Contact with the surface occurs when the bats touch the surface with a body part (e.g., tongue, wings, feet, uropatagium, etc.).

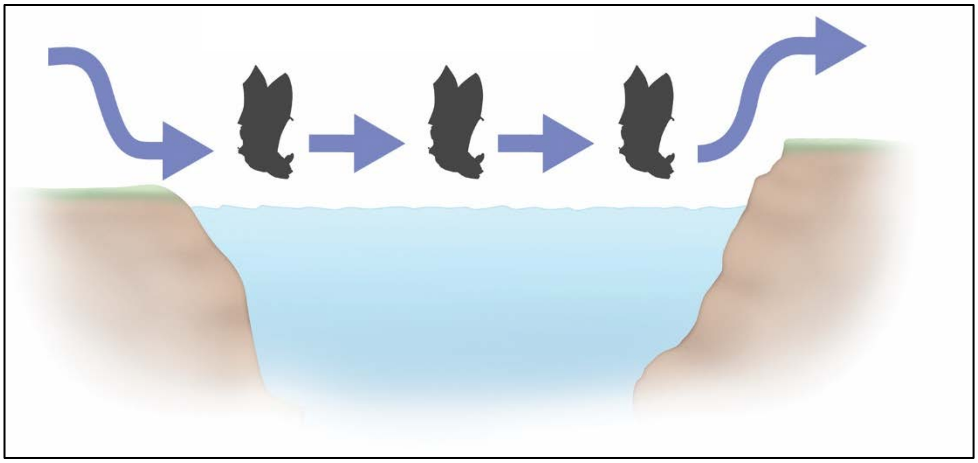

Fig. 9: Illustration of straight line flight path across a water source.

Once bats have acclimated to the flight facility, trials will be initiated at dusk as soon as the bats emerge from their day roosts. Treatment trials will not be conducted on odd days (Table 1), as on these days bats will have access to the water tray when they emerge from their day roosts; and if bats do not drink during the trial on the odd days, the water will remain uncovered on subsequent nights until we observe bats drinking from the water tray again. This schedule will ensure that the bats obtain sufficient water and is recommended for the health and safety of the bats while in captivity.

Table 1: Representative schedule for bat drinking behavior trials.

Day	Stage	Treatment	Details
1-3	1	Bat acclimates to flight facility	*If bat does not freely drink from the water tray we will release the bat on day 4.*
			The order of surfaces are randomly selected for each set of bats
4	2	Control	Painted smooth surface (equivalent to turbine tower surface)
6		Texture (A)	Fine texture (Sand 1)
8		Texture (B)	Intermediate texture (Sand 2)
10		Texture (C)	Coarse texture (Sand 3)
12		Texture (D)	Applique
14		Curved Control	Painted smooth surface attached to custom-made fiberglass wind turbine tower section
15			*Bat released on day 15*

From preliminary surveys in 2014, we found that bats drink shortly after emergence (within 10-20 minutes) from their day roosts. Thus, each bat drinking behavior trial will last approximately 20 minutes from the bats' emergence. On treatment nights, the water tray will be covered with the treatment surface before the bats emerge. We will place a 3.0 m x 1.2 m aluminum plate over the water tray and cover it with camouflage netting. Then we will place the treatment surface on top of the camouflage netting aligning the treatment surface with the edge of the aluminum sheet (Fig. 10). On nights with the curved control treatment, the fiberglass wind turbine tower section will be placed on top of the camouflage netting, and we will place the smooth painted treatment surface across the turbine (Fig. 10).

Fig. 10: Placement of treatment surfaces over the water tray. The left image shows the treatment surface aligned with the right edge of the aluminum plate and camouflage netting over the water tray. The right image shows the treatment surface being placed on top of the turbine tower section.

During each treatment trial, the water tray will remain covered until we have observed an individual bat making passes and/or contact. We will then remove the surface from the water tray 10 minutes after we have observed passes and/or contact. If no passes and/or contact occur, we will uncover the water at the end of the 20 minute trial. When the treatment surface is removed, we will add water to the tray to replenish any that spilled over the sides when the treatment surfaces were added and removed.

To effectively record all behavioral and activities near and at the water tray, we will place 2 Canon XA20 camcorders (Canon Inc., Melville, NY) at a 90 degree angle from one another with their field of view centered on the water tray (see Fig. 11). Within the field of view, we will also place 0.5 m distance markers on the walls of the tent to aid analysis (see analysis section below). The side view camera (Fig. 12) will be placed 3 m away from the edge of the water tray, and the front view camera (Fig. 13) will be 3.15 m from the end of the water tray. For the entirety of the survey period, both cameras will be placed in the same location with the same tripod height each night (side view: 1.25 m, front view: 0.5 m). These cameras will be turned on in unison at the start of each treatment trial and turned off at the same time at the end of each treatment trial. The camcorder videos will be saved as MP4 files on to SD cards within the camcorder, and at the end of each night the data will be transferred to external hard drives for analysis. At a minimum, two technicians will be present in the flight room during each behavioral trial.

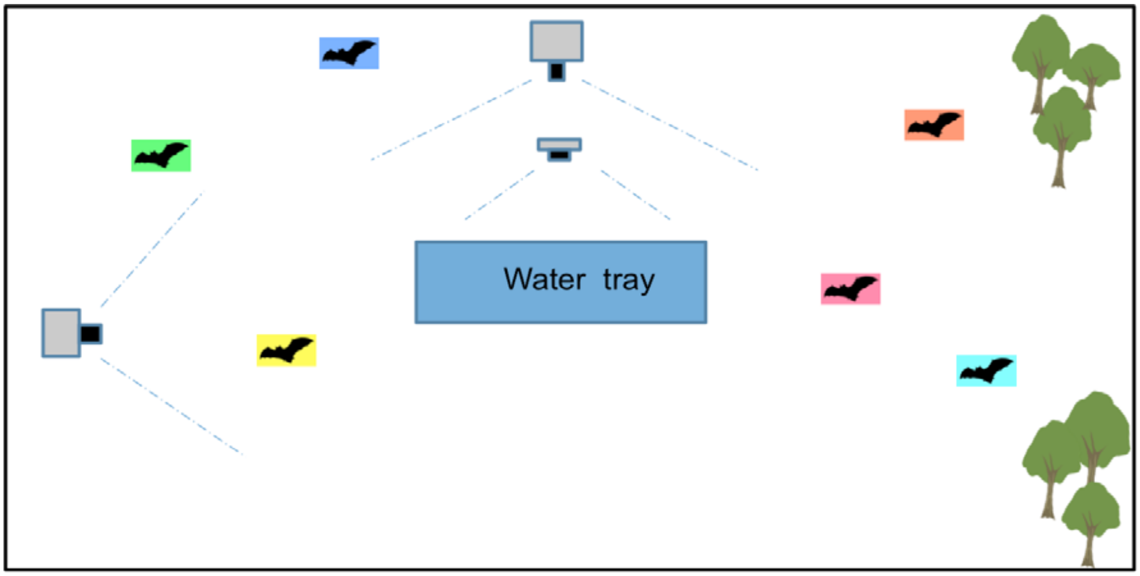

Fig. 11: Aerial representation of bat flight facility. Two Canon XA 20 camcorders will be placed at right angles from each other on tripods, and the Fastec IL4 high speed mono imaging camera will be placed at ground level to record bat contact with the surface.

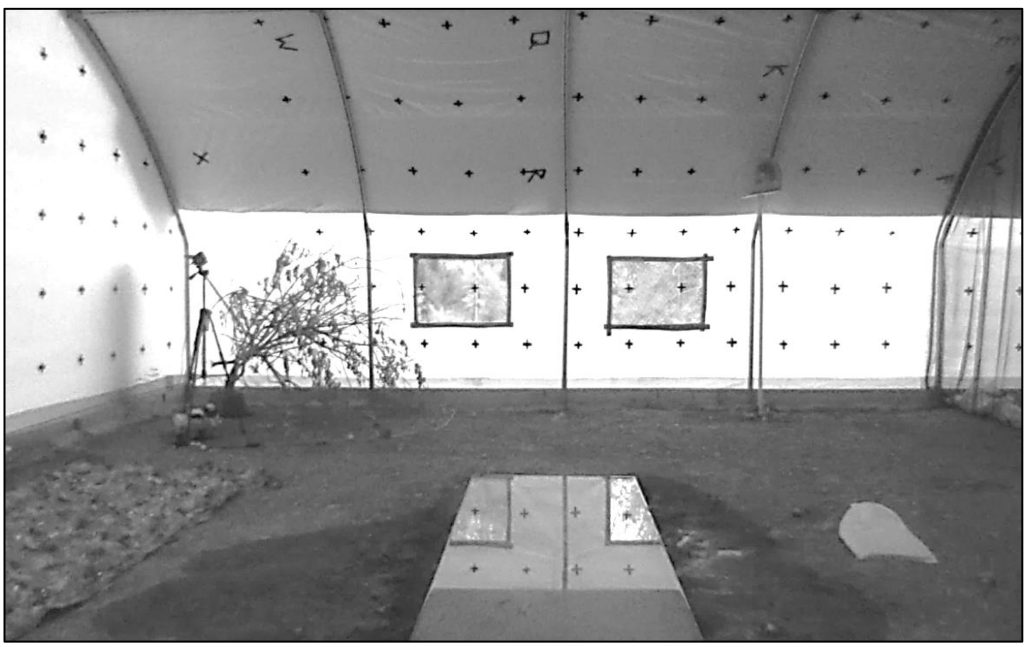

Fig. 12: Canon XA20 camcorder side view of flight room. The side view captures the water tray showing position of the bats over the surface.

In addition, we will use a Fastec IL4 100 high speed mono imaging camera (South Central Imaging, Ltd., Westfield, IN) with a 17 mm lens (f 0.95) and 850 nm Infrared LED Light Bars (Larson Electonics LLC, Kemp, TX) to observe and record bat activity in low light conditions at the water trays and treatment surfaces (Fig. 14). The high speed camera placement will be adjusted each night to obtain the best close up image for each treatment surface (i.e. straight surfaces versus curved surfaces; see Fig. 10).

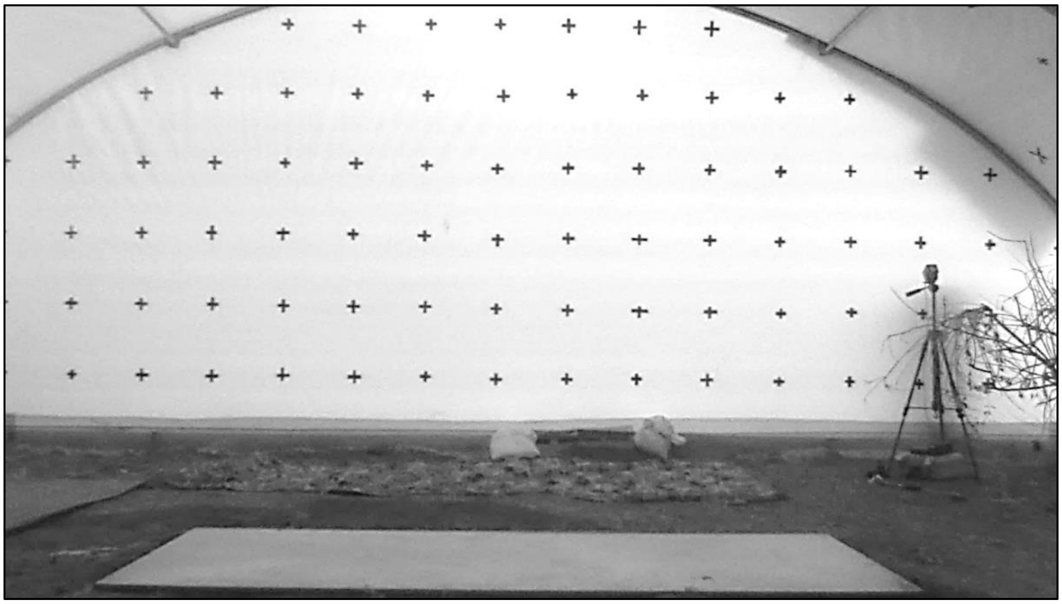

Fig. 13: Canon XA20 camcorder front view of flight room. The front view captures height above water tray.

We will focus the camera by using a rubber duck that will be centered on the treatment surface or in the area that is observed to have the most activity. With the camera in long record mode, we will capture images at 290 fps with a shutter speed of 3630 uSec which will be saved onto the internal SSD. As we can only record a total of approximately 10 minutes with these settings, we will start the recording when we first observe bats within close proximity to the treatment surface and will stop recording when the bats are no longer making passes. The recording will begin again if and when the bats return within close proximity of the focal surface.

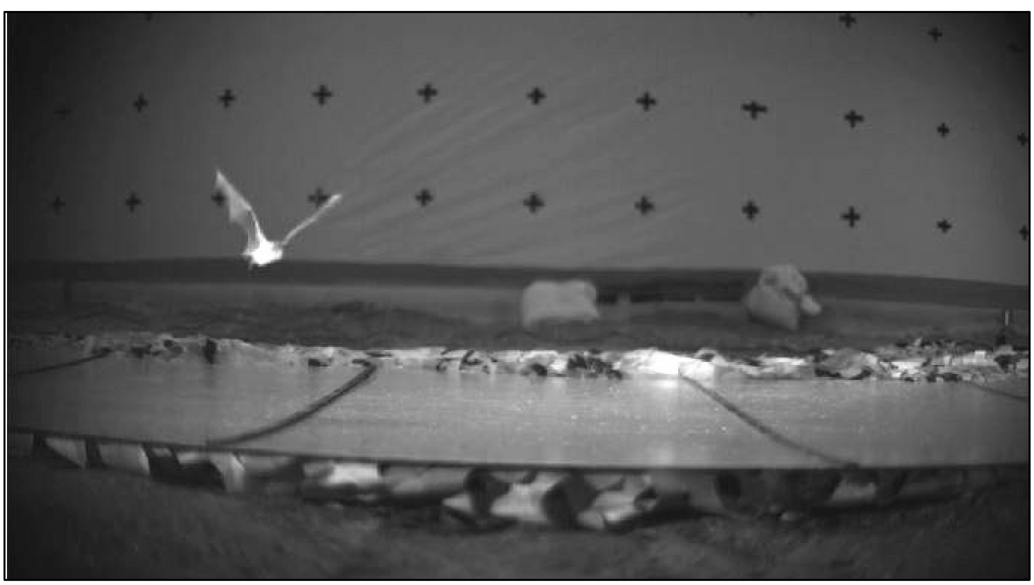

Fig. 14: Fastec IL4 high speed mono imaging camera view of applique treatment surface on camouflage netting over water tray.

As a back-up, we will also record the behavior of each bat with Olympus Digital Voice Recorders (WS-SIOM). As none of the cameras have color capability, we will identify each colored individual within close proximity to the treatment surfaces or water tray and dictate their individual behavior. The data voice recordings will also provide an additional source of data time stamps for the video analyses.

Data Analysis*:* We will process all videos from the Canon XA20 camcorders in Studiocode (version 5, Studiocode Business Group, Sydney, AU). This program links each video with a timeline that matches the length of the video and saves the video and timeline as a movie package. Within the program, we will stack the side view and front view videos to one timeline allowing us to view both camera angles simultaneously (Fig. 15).

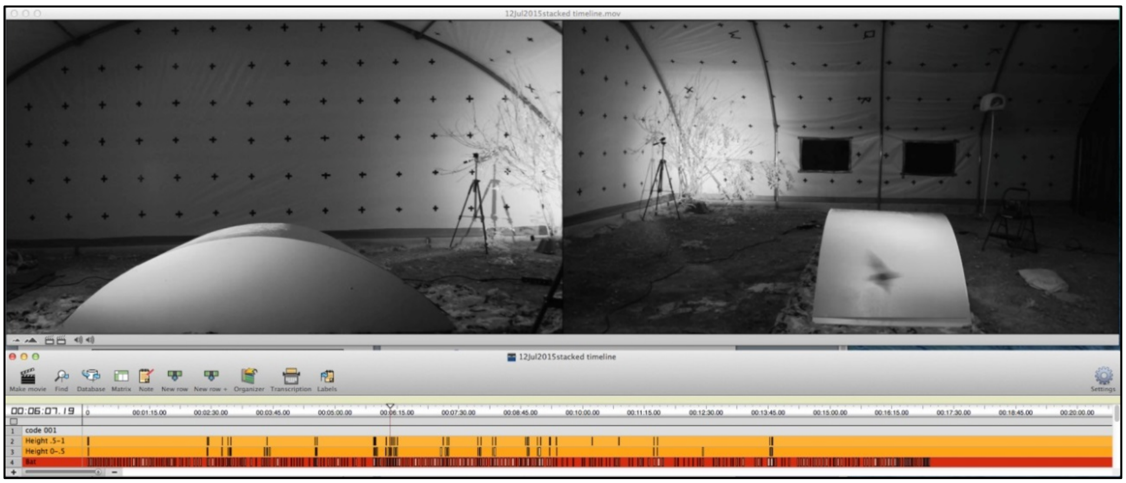

Fig. 15: Front view and side view of Cannon XA20 videos stacked together on one timeline within Studiocode.

With the assistance of the gridded flight facility walls, we will divide the camera views into zones in a code window (Fig. 16). The front view has 0.5 m high linear divisions that span the width of the camera view. The side view will be divided into vertical zones that will identify flight left, right, or over the treatment surface/water tray. We will also be able to identify specific behaviors of individual bats in each treatment trial within the stacked videos using this code window (Fig. 16).

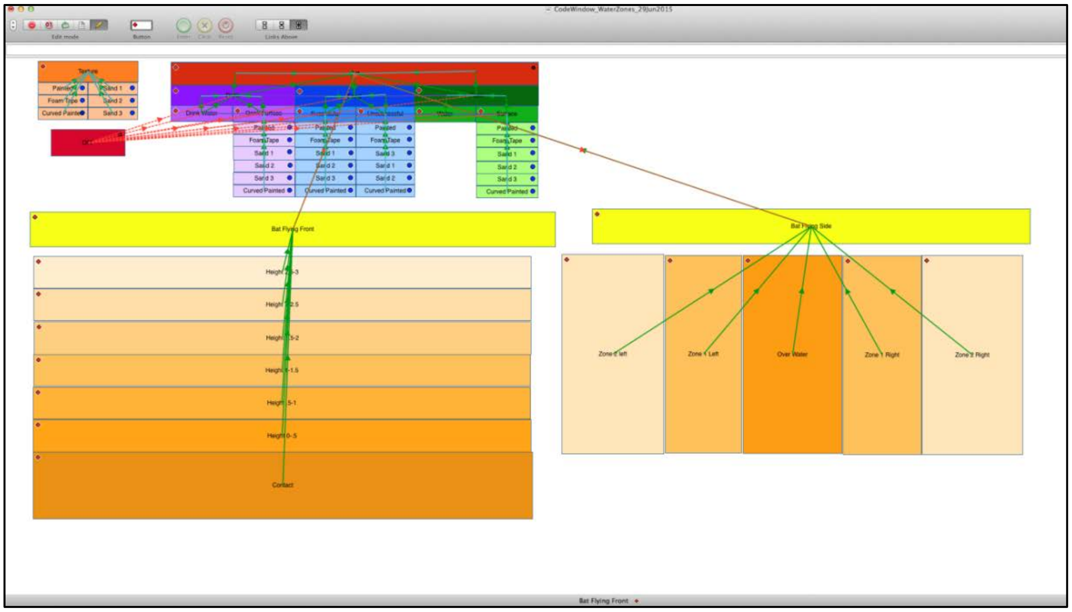

Fig. 16: The code window for identifying treatment surface and behaviors within Studiocode. The buttons at the top of the window will create instances relating to surface and behavior. The orange buttons on the lower left side are the linear zones used to indicate height above the treatment surface, and the vertical orange buttons on the right side of the window indicate position over the surface.

We will use the code window overlaying the stacked video (Fig. 17) to determine the number of passes across the treatment surface, closest approach to treatment surface (closest pass), time until approach to surface, number of drinking attempts (contact of tongue with surface and other contact will be noted), and drinks from the water tray (when water is available).

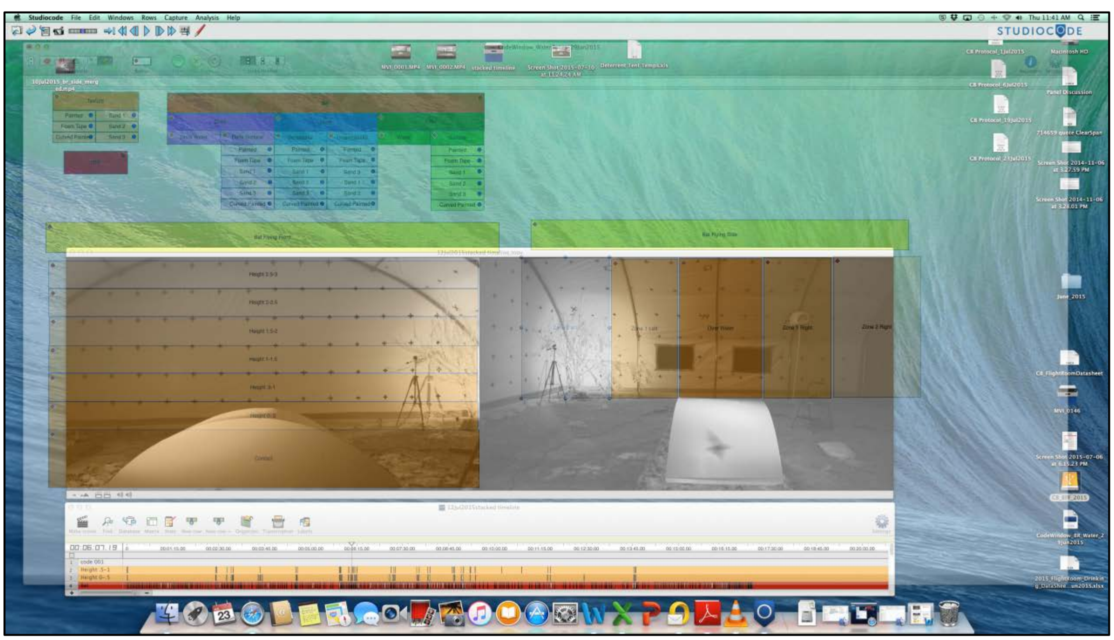

Fig. 17: A transparent code window overlaid on the stacked timeline while watching videos.

We will review the high speed IL4 images that are stored on the internal SSD in FasMotion Controller (Fastec Imaging Corp., San Diego, CA) to further identify any instances of contact with the treatment surfaces. When a bat appears in the recording, we will adjust the play back rate from 290 fps to5-20 fps to verify contact. The images showing the pass will then be saved to an external hard drive as an AVI file. Additionally, single images showing contact will be saved as a TIF files.

Bat foraging behavior trials – Foraging behavior trials will begin when the bats have voluntarily taken prey items hung on threads. This exercise is to confirm that the bats are employing the aerial hawking foraging strategy (i.e., taking prey items out of the air while flying) they would naturally do in the wild and it will also get them accustomed to foraging for mealworms. In the initial 3 day acclimation period, three live mealworms will be hung from the ceiling with sewing thread and clothesline, positioned to be in the center of the room directly above the water tray and at the same height as the wind turbine tower section, approximately 1.5 m to 2 meters above the ground (hereafter known as position 1; see table 2). If bats successfully remove the mealworms from the strings at the end of the acclimation period, we will move the mealworms to a second position located between the water tray and the wind turbine (hereafter referred to as position 2). Once bats have successfully taken mealworms from position 2, we will then conduct a series of trials to explore whether bats can glean prey items from vertical surfaces (including wind turbine tower surfaces; see table 2). Note that if bats are unsuccessful in taking mealworms suspended from position 1 or 2 over a three day period these individual bats will be released.

In gleaning trials, we will hang three mealworms against the flat metal surface of the mock turbine tower (hereafter known as position 3, Fig. 19). If bats successfully glean the mealworms from this surface, we will then turn the mock turbine tower so that the curved metal surface is facing the center of the room. We will place three mealworms against the surface and observe whether bats glean the prey items from this surface. Finally, if the bats are successful, we will place mealworms against a painted smooth curved surface. Note this surface represents a wind turbine tower surface. The next surface presented will be the control surface which is a painted smooth surface, equivalent to what is currently found on wind turbine towers. If the bats are able to take mealworms from this painted surface, we will proceed to texture trials in which we will determine prey removal rates from the various textured surfaces developed in subtask 1.1. Bats they do not glean prey items from a flat metal, curved metal, or painted curved surface will be released from the flight facility (see table 2).

In texture trials, bats will first be presented with the heavily textured surfaces: 1) coarse sand and 2) applique (see table 2). The order of the coarse sand and applique surface will be randomly selected. Again during these trials, three mealworms will be suspended up against the surfaces. If bats are unable to take the mealworms off either surface, the mealworms will be moved back to position 2 the following night to ensure the bats are still able to take mealworms off the string. We will make two further attempts in which bats are presented mealworms on either surface to confirm that bats cannot glean from these surfaces. If bats can glean off both surfaces or glean from coarse sand but not applique, the trials will be complete and the bats will be released. However, if the bats are unable to take mealworms from the coarse sand surface, we will proceed to a second tier of surfaces and present the bats with mealworms on intermediate and fine sand textures, again the order in which these will be presented will be random. These trials will be conducted in the same way as the previous two texture trials. See Table 2 for a representative schedule of the acclimation, gleaning, and texture trials.

All trials will be initiated immediately after the bats emerge from their day roosts. An individual trial will last only 10 minutes. In preliminary surveys, we determined 10 minutes was ample time for foraging bats to successfully glean all three mealworms from a surface. Thus within a survey night while the bats are flying, we will be able to conduct up to 10 individual trials.

Fig. 19: A mealworm hanging in 3rd position from thread in front of the sand 3 texture and a view of the clothesline from which the thread with mealworms are suspended.

Table 2: A representative schedule for bat foraging behavior trials.

Day	**Stage**	**Treatment**	***Details***
1-3	1	Bat acclimating to flight facility, mealworms in 1st position	*If a bat does not freely feed from suspended mealworms, we will release the bat on the 3rd night.*
4-6		Mealworms in 2nd position	*If a bat does not feed from suspended mealworms, we will release the bat on the 6th night.*
7	2	Flat Metal	Smooth metal surface with no curvature
8		Curved Metal	Smooth metal surface with the curvature of a wind turbine tower at mid-height
9		Painted curved	Painted curved is the painted smooth surface (equivalent to turbine tower surface) *If bats do not glean mealworms from the surface we will move the mealworms back to 2nd position, for a maximum of 3 nights, until they feed from the suspended mealworms*

	3	*The order of sand 3 and applique will be randomly selected and rotated hereafter.*
10	Texture (A)	Sand 3 texture
11	Texture (B)	Applique
		If bats glean from both control and textures A and B, we will not proceed with the next two textures.
		The order of intermediate texture and fine texture will be randomly selected and rotated hereafter.
13	Texture (D)	Sand 2 texture
14	Texture (E)	Sand 1 texture
		Bats released on night 14. Additional days may be used to repeat trials as needed.

As with the drinking behavior trials, we will be using 2 Canon XA20 camcorders to capture the bat flight behavior. The cameras will be positioned at a 90 degree angle from one another with the front view camera centered on the turbine tower and the side view camera centered on the area directly in front of the treatment surfaces and the hanging mealworms (see Fig. 20). Both cameras will be kept at a height of 1.25 m for the duration of the survey period. Both cameras will be turned on/off simultaneously and the videos from the camcorders saved as MP4 files on SD cards. Olympus Digital Voice Recorders will again be used as a verbal backup for data analysis. At least two technicians will be present in the flight facility during the behavioral trials.

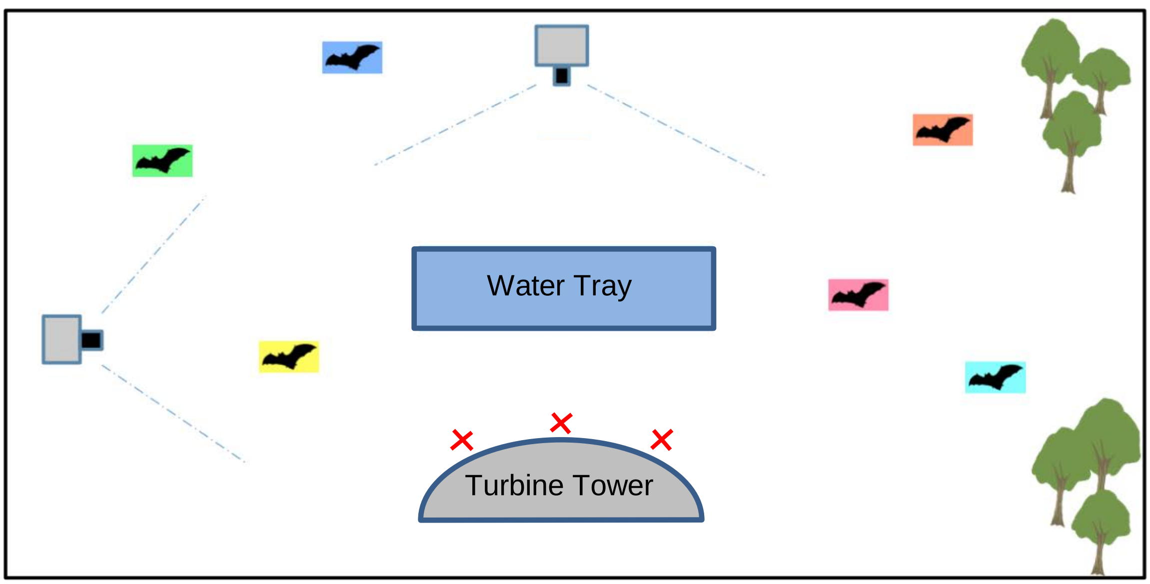

Fig. 20: An aerial representation of the bat flight facility during foraging trials. Two Canon XA20 camcorders will be placed at right angles form each other on tripods. Mealworms will be positioned in front of the turbine tower (position 3 is shown) on which surfaces with different textures will be presented.

<u>Data Analysis</u>: We will process all videos from the Canon XA20 camcorders in Studiocode. The two camera angles will be stacked together to form one timeline in which the behavior of the bats may be analyzed using a code window similar to the one used for the drinking trials (see

Figs. 15 and 16). We will use Studiocode to record the frequency of passes across the treatment surface, closest approach to treatment surface, time until the first mealworm is taken from a treatment surface, the number of attempts before a mealworm is successfully taken from a treatment surface, and the number of mealworms successfully removed from a treatment surface during each 10 minute trial. We aim to be able to identify a treatment surface that the bats will show little or no interest in approaching.

References

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Texas Christian University
Texturizing Wind Turbine Towers to Reduce Bat Mortality

EXECUTIVE SUMMARY

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

Milestone 1.2.2 – Demonstrate difference in bat activity in close proximity to textured surfaces compared to smooth surfaces in the bat flight facility.

Bat drinking behavior trials – A total of 64 behavioral trials were conducted from June 10 to September 25, 2015, and 61 trials, including eastern red bats (*Lasiurus borealis*) and evening bats (*Nycticeius humeralis*) were successfully analyzed. We found that bats made contact with smooth treatment surfaces, but not with the textured surfaces. We also found that as texture particle size increased so did the number of bat passes (straight-lined flight across the treatment surface). On further investigation, we determined that this relationship was strongly associated with gap distance between particles. Finally, we ascertained that all bat passes occurred at 0 to 1 m distances from the treatment surfaces, suggesting that the bats (used in this study) may need to be this close to a surface to accurately discern its texture. See Attachment A for full details.

Bat foraging behavior trials – A total number of 537 foraging behavioral trials were completed from July 1 – September 29, 2015, and 54 trials including eastern red and evening bats presented with control, Texture C, and applique treatment surfaces were successfully analyzed for this report. Nearly 90% of the foraging trials involved bats foraging for mealworms suspended from strings in the air, and are therefore not included in the analysis. Despite having a relatively low sample size, we found that the bats could switch their foraging strategy and glean prey from surfaces equivalent to a wind turbine tower. We noted that eastern red bats gleaned more readily and successfully than evening bats, indicating that there were species-specific differences. Bats were also able to glean off Texture C (with the largest particle sizes), but this may have been an artifact of gap distance between particles (see bat drinking trials). Finally, we recorded more bat passes in close proximity to textured treatment surface in comparison to smooth surfaces, providing further support for our findings in the bat drinking trials.

A. PROJECT OBJECTIVES

The overall goal of this project was to develop a wind turbine tower coating that 1) bats have little or interest in approaching (i.e., wind turbine towers are not perceived or misperceived to be a resource), 2) can be applied to operational wind turbine towers or incorporated into the manufacturing stage of wind turbine towers, 3) is economically feasible to produce and apply, and 4) when tested, effectively reduces bat mortality at operational wind turbines. If the results from this study support our hypothesis, that bats are coming into contact with wind turbine towers (and are therefore at risk of entering the rotor swept zone) because they perceive or misperceive the wind turbines to be a resource, then altering the tower surfaces may provide an innovative means of reducing mortality risk that does not entail a loss in power production. Incremental gains in reductions in bat mortality may be especially important in areas where take of threatened or endangered species is possible. Furthermore, depending on how effective this technology is at minimizing bat mortality, the texture treatment may be used as a stand-alone minimization solution or in combination with other solutions.

Task 1: Testing behavioral response of bats to textures in flight room (Months 1-6)

Task Summary:
Task 1 was divided into two Subtasks. Subtask 1.1 involved the production of a range of test surfaces that varied in the type and grade of texture. In Subtask 1.2, we then explored how wild-caught bats responded to each textured surface, as well as a smooth painted surface, in a controlled behavioral experiment. In this study, we also determined how wild-caught bats responded to smooth and textured surfaces on a mock wind turbine tower section. We predicted that increasing the level of texture on the painted surfaces would reduce the time bats spent in close proximity to those surfaces in comparison to smooth surfaces (i.e., surfaces equivalent to wind turbine tower surfaces). Our primary objective was therefore to identify a type and level of texture that bats in the flight room exhibited little or no interest in approaching.

Subtask 1.1: Make textured surfaces for flight facility (Month 1)

Subtask Summary:
We proposed to create types and grades of texture that were discernibly different from smooth surfaces and from each other, and do not compromise the integrity of the paint. These textured treatments were then applied to individual steel plates and presented to wild-caught bats in the flight facility as part of Subtask 1.2 (refer to milestone 1.1 Q1).

Subtask 1.2: Behavioral study in flight facility (Months 1-6)

Subtask Summary:
We proposed to record the responses of wild-caught bats when presented with a variety of smooth and textured surfaces (treatments produced in Subtask 1.1) attached to a horizontal water tray or a vertical mock wind turbine tower section in a bat flight facility (see to milestone 1.2.1 Q1). From this study, we determined rate of approach, closest distance of approach, and activities exhibited by the bats towards each treatment. We compared the results of each treatment and assessed which treatments (i.e., grade and type of texture) bats showed little or no interest in approaching. This document represents the results from the experiment (Deliverable 1.2.2) and will be used to develop a textured coating (Task 2).

B. PROJECT METHODS

For this experiment, we used mist nets to capture bats from local parks in and around Fort Worth. Captured bat species included eastern red (*Lasiurus borealis*), evening (*Nycticeius humeralis*), and Mexican free-tailed (*Tadarida brasiliensis*) bats. The bats were taken to a two-chambered flight facility, where we conducted two different sets of behavioral trials (drinking and foraging) once the bats had acclimated. In both sets of trials, five metal plates with a variety of painted and textured surfaces (hereafter referred to as treatment surfaces), created in Subtask 1.1., were attached to a mock wind turbine tower section or placed over a water tray. These treatment surfaces included a control (a surface equivalent to a painted wind turbine tower), fine (known as Texture A), intermediate (known as Texture B), and coarse grain texture (known as Texture C); and an applique.

Bat drinking behavior trials –During the trials, the water tray was covered with the treatment surface before the bats emerged, and we recorded the bats' behavior for 20 minutes at each surface. Along with the five aforementioned treatments, we also included a curved control treatment to represent a wind turbine tower section. To effectively record all behavior near and at the water tray, we set up two Canon XA20 camcorders (Canon Inc., Melville, NY) at a 90 degree angle from one another with their field of view centered on the water tray. The camcorder videos were saved as MP4 files and used in the analysis described below. In addition, we used a Fastec IL4 100 high-speed mono imaging camera (South Central Imaging, Ltd., Westfield, IN) with a 17 mm lens (f 0.95) and two 850 nm Infrared LED Light Bars (Larson Electonics LLC, Kemp, TX) to capture high definition images (saved as TIF files) of bats interacting with the treatment surfaces.

We processed all videos from the Canon XA20 camcorders in Studiocode (version 5, Studiocode Business Group, Sydney, AU). Within the program, we stacked the side view and front view videos side-by-side on one timeline allowing us to view both camera angles simultaneously. We analyzed each video to determine four dependent variables: 1) number of contacts with the treatment surface or number of drinking events at the water tray; 2) number of passes (defined as a straight path flight parallel to a treatment surface or water tray) across the treatment surface or water tray (this value includes the number of contacts with each treatment surface and drinking events at the water tray); 3) closest approach to a treatment surface by each bat during a pass; and 4) time until a bat first approaches each treatment surface or the water tray. With these variables we conducted the following analysis and where possible used statistical tests to compare the results.

To determine the **number of contacts with the treatment surface**, when a potential contact was identified in our paired videos, we used equivalent time stamped high speed IL4 images to confirm that a bat made contact with a treatment surface. We totaled the number of contacts made by each individual bat during a 5 minute period after the first contact was made with the treatment surface. We then averaged the number of contacts per bat across each treatment surface. Finally, to determine if treatment surface influenced whether bats made contact with a surface, we compared these averaged values with the average number of drinking events made at the water tray (see below) to determine whether the contact rate varied between water and the different treatment surfaces.

To determine **number of drinking events at the water tray**, we counted the number of drinking events within a 5 minute period following the initial pass made over the water by an individual bat using voice recordings describing bat activity observed during acclimation nights. We then averaged the number of drinking events per bat. Finally, we used this average in the analysis described above.

To determine **the number of passes**, in each paired video we counted the total number of passes made by an individual bat within a 5 minute period following its first pass over a treatment surface or the water tray. We excluded bats that did not fly for a full 5 minutes during a trial from this analysis. To determine if treatment surface influenced the number of passes made by bats across a surface, we compared the average number of passes per bat between treatment surfaces and water.

Furthermore, to determine if the size of gaps between particles influenced the number of bat passes observed, we randomly selected and photographed a 0.1 x 0.1 m area from each of the three textured treatment surfaces. ScanSigma Pro (version 5.0, Systat Software Inc., Point Richmond, CA) was then used to analyze each image. First, we gridded each image with 0.01 x 0.01 m cells (100 cells total; Fig. 1A) and randomly selected 30 cells. Within each cell, we measured the distance from a particle near the center of the cell to the closest particle above it (Fig.1B). We began and ended each measurement at the center of the particles. We then compared mean distances with ANOVA and Tukey Kramer tests on natural log transformed values.

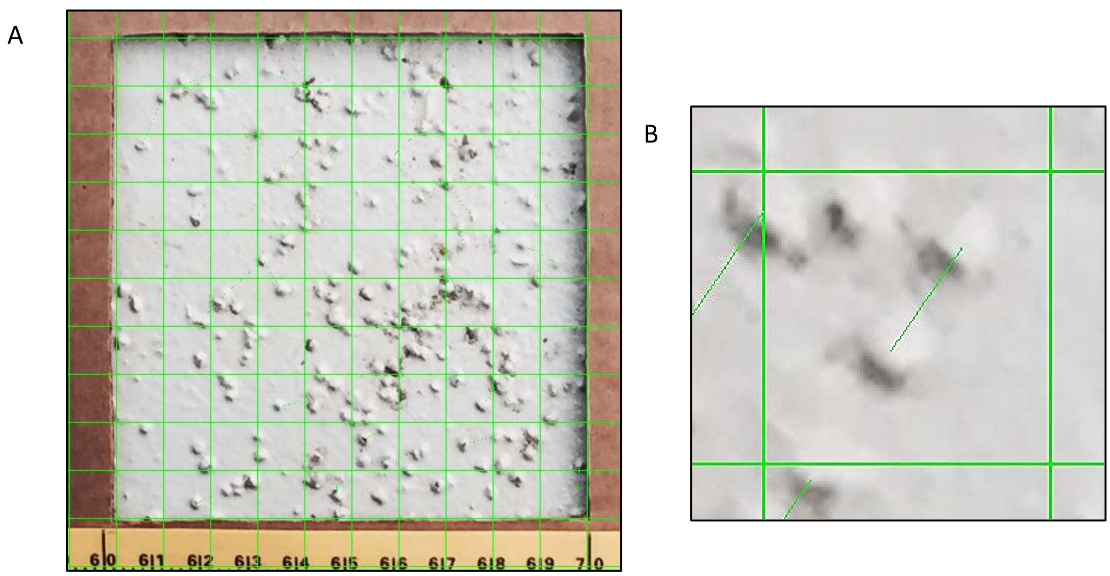


Figure 1: Images of course texture treatment in ScanSigma Pro. Image **A** shows a gridded 0.1 x 0.1 area and image **B** shows a 0.01 x 0.01 m cell with a demonstration (green diagonal line) of the distance we measured between two particles on the treatment surface.

Finally, to determine if there was a relationship between gap size in each treatment surface and the average number of passes made by individual bats, we performed a linear regression analysis on the number of passes per bat(natural log transformed) and the mean gap size of the corresponding treatment surface (Texture A, Texture B, Texture C, and Applique).

For **closest approach to treatment surface**, we used a customized code window to determine the distance at which the bats flew from each treatment surface. We divided the field of view of the front camera into four 0.5 m horizontal zones extending upwards from the treatment surface and recorded the zone in which an individual bat came closest to the treatment surface each time it passed over that surface during a trial. To determine if treatment surface influenced how close a bat came to a surface without making contact, we totaled the number of passes made by an individual bat in each zone at each treatment surface. We then averaged the total number of passes and compared them between zones and treatment surfaces.

Lastly, for **time until first pass**, we used video timestamps to calculate the time it took for a bat to make its first pass over a treatment surface or the water tray from the time that bat emerged. To determine if treatment surface influenced the time it took for bats to approach a surface, we compared the average approach time between the treatment surfaces. We used a Kruskal-Wallis test to determine if these results were statistically significant.

***Bat foraging behavior trials* –** In these behavior trials, we explored whether bats could glean prey items from vertical surfaces equivalent to wind turbine tower surfaces, and we assessed whether texturing the surface would reduce gleaning rates and/or efficiency. In addition to the five aforementioned treatments, we also included a flat metal treatment surface and a curved metal treatment surface.

In a single trial, three mealworms were hung against the surface of the turbine tower section. The first surface presented was the flat metal treatment. If the bats were observed to successfully glean the mealworms from this surface, the next surface presented was the curved metal surface, equivalent to the curvature of a turbine tower. If the bats were successful at this stage, we then presented them with mealworms against a painted smooth curved surface (hereafter referred to as the control treatment surface). Note this surface is equivalent to what is currently found on wind turbine towers. If the bats were able to glean mealworms from this control surface, we presented the bats with textured surfaces to determine if prey removal rate varied between the control and these textured surfaces. For these trials, bats were randomly presented with the heavily textured treatment surfaces: 1) texture C and 2) applique. Then, if the bats were unable to take mealworms from these surfaces, we proceeded to a second tier of treatment surfaces and presented the bats with mealworms against textures A and B, again the order of presentation was randomly selected. All trials were initiated immediately after the emergence of the bats from their day roots and ended when the bats had stopped flying. An individual trial lasted either 10 minutes or until all three mealworms had been gleaned.

As with the drinking behavior trials, we used 2 Canon XA20 camcorders to record the bats catching or attempting to catch the mealworms. The videos from the camcorders were saved as MP4 files and were processed in Studiocode. Again, the front and side view videos for each trial was stacked together and linked to form one timeline in which both camera angles could be viewed simultaneously. We analyzed each video to determine three dependent variables; 1) number of successful gleans, 2) number of gleaning attempts, and 3) closest approach to mealworms. A successful glean was defined as the removal of a mealworm from a treatment surface and a gleaning attempt was defined as a bat making contact with the mealworm or the treatment within 0.25 m from the mealworm, but did not result in the remove of the mealworm. For each individual bat included in the study, we counted the number of successful gleans and the number of gleaning attempts made at each treatment surface. From this data, first we determined if bats could successfully glean prey items from surfaces equivalent to wind turbine towers, and essentially switch their foraging strategies from aerial hawking to gleaning. We then compared gleaning activity (including successful gleaning events and gleaning attempts) across our surface treatments.

For the closest approach, we used a customized code window to determine the distance at which the bats flew from the mealworms. We divided the field of view of the side camera into five 0.5 m vertical zones extending from the treatment surface and recorded the zone in which an individual bat came closest to the treatment surface each time it passed that surface during a trial. Finally, we compared the average number of passes made by bats within each zone between treatment surfaces. We used a Kruskal-Wallis test to determine if these results were statistically significant.

C. PROJECT RESULTS AND DISCUSSION

***Bat drinking behavior trials* –** A total of 64 behavioral trials were conducted from June 10 to September 25, 2015. Three species of bat were included in the trials; 5 (1 female; 4 male) eastern red bats (*Lasiurus borealis*), 36 (19 female; 17 male) evening bats (*Nycticeius humeralis*), and 12 (11 female; 1 male) Mexican free-tailed bats (*Tadarida brasiliensis*). The latter species was not included in our analysis as they did not successfully acclimate to the flight facility. A total of 61 trials were successfully processed and analyzed in Studiocode. The three excluded trials included 1 control, 1 Texture A, and 1 Applique, as a small amount of water was present on the surface during the trials.

Number of contacts with treatment surfaces and water tray

Throughout the trials in which the water was available, we observed that once a bat successfully drank from the water tray, it would return multiple times to drink again. At the treatment surfaces, we recorded bats making contact (drinking attempts, wing, and uropatagium) with three of the six surfaces; the control, curved control, and applique treatment surfaces. Thus, bats did not contact the textured treatment surfaces A, B, or C (Fig. 2). These results demonstrate that bats did not come into contact with textured surfaces as they would smooth surfaces. Note that the majority of the applique is a smooth surface (see milestone 1.1).

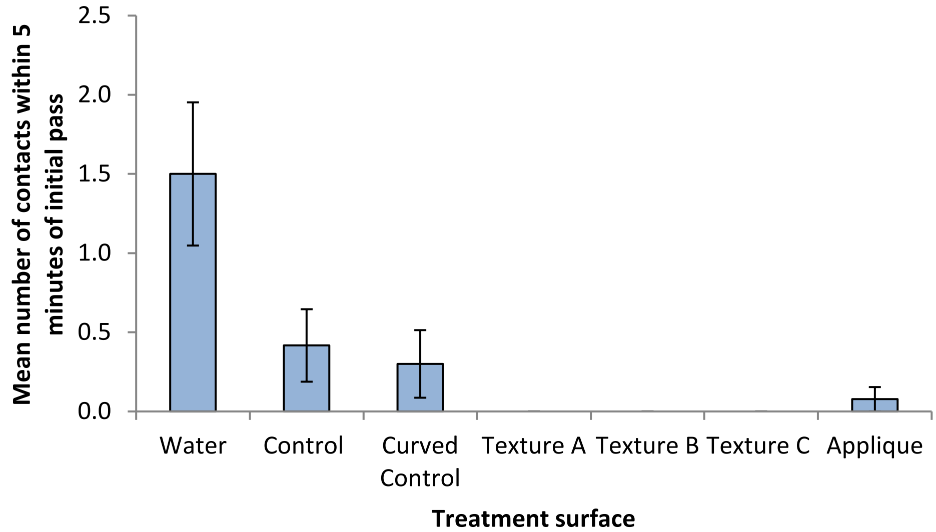


Figure 2: Mean ± SE number of contacts made at each treatment surface and number of drinking events at the water tray within 5 minutes of the bats' initial pass with standard error.

Number of passes across treatment surfaces and water tray

A total of 643 passes were made over the treatment surfaces by 28 individual bats. After the initial pass was made in each trial, a total of 351 passes occurred within 5 minutes. We used these data to calculate and mean the number of passes made by each individual at each treatment surface. Comparing these means across treatment surfaces, we found that the number of passes increased with texture gradient (Fig. 3).

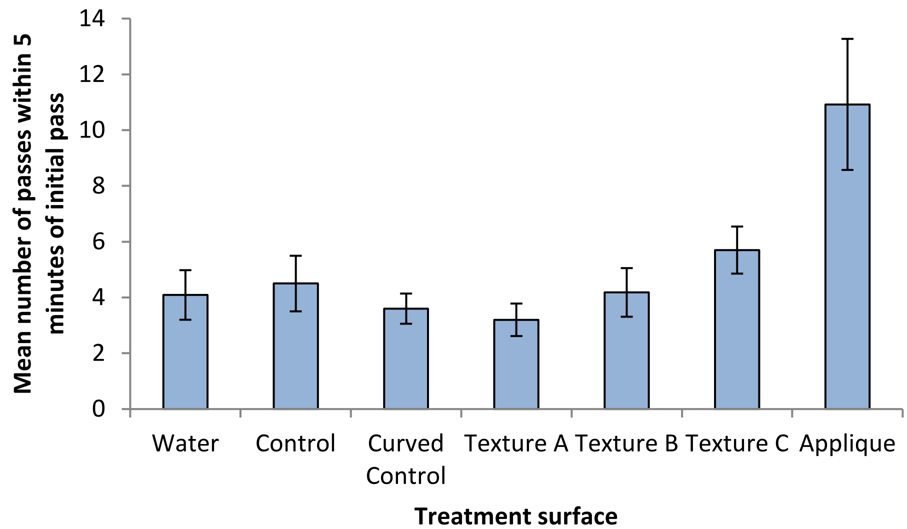


Figure 3: Mean ± SE number of passes made within 5 minutes of the bats' initial pass across the treatment surface.

When we explored whether gap size influenced the number of passes, we first found that mean gap size among our treatment surfaces varied with particle size (ANOVA, $F_{2,447} = 144.11$, $P<0.001$). Pairwise post-hoc Tukey test revealed that gap distance differed among all treatment surfaces ($P<0.001$ in all cases, Fig. 4), increasing with increasing texture grade. Note that we used the natural log transformation of gap size in this statistical analysis.

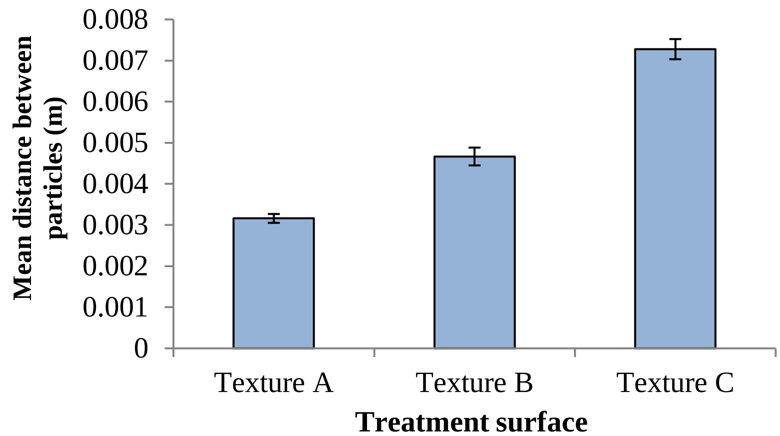


Figure 4: Mean ± SE distance between particles on treatment surfaces of varying grade (Textures A, B, and C).

We found a strong positive linear relationship between number of passes per bat and mean gap size of each treatment surface (Fig. 5).

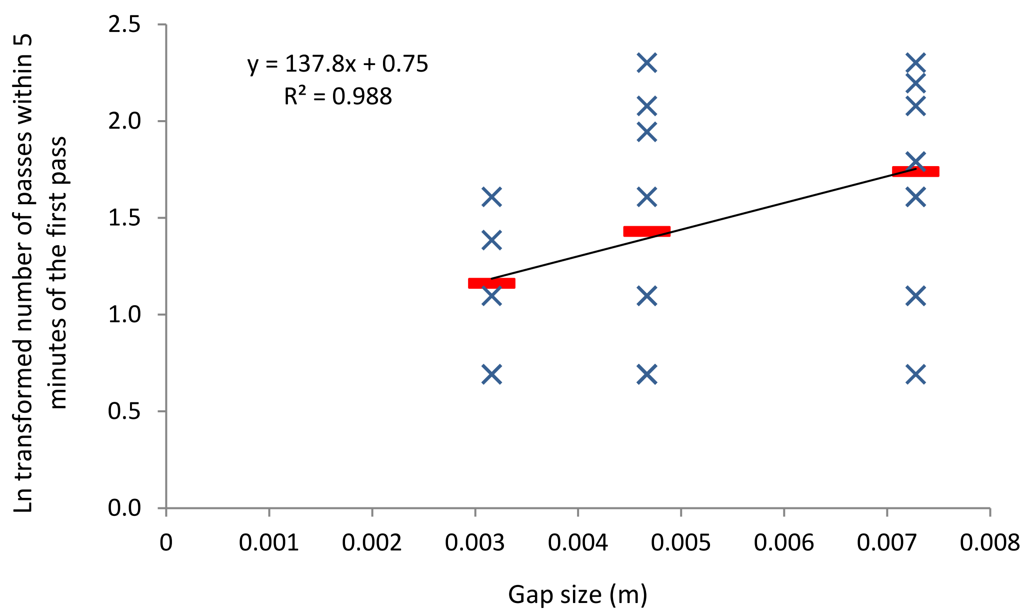


Figure 5: The number of passes within 5 minutes of the first pass made by individual bats increased with gap size across the three textured treatment surfaces (Texture A, B, and C). Horizontal red lines indicate the mean number of passes associated with each gap size and the black line is the linear regression line.

These results suggest that gap size between particles is an important property that influences bat activity patterns and interest in a surface. Thus, to develop an effective texture treatment that can be applied to wind turbine towers, gap sizes between particles should be kept to a minimum.

Closest approach to treatment surfaces

We observed that all bat passes occurred within 0 to 1 m for all treatment surfaces. Exploring these distances further, we found that the majority of passes occurred within 0.5 m of each treatment surface and that the mean number of passes within 0.5 m varied between the surface treatments (Fig. 6; Table 1). Nevertheless, the mean number of passes within 0.5 to 1 m did not vary among surface treatments.

These results suggest that bats need to be in close proximity (<0.5 m) to a surface to gather detailed sensory information about that surface. Figure 6 further demonstrates that the number of passes at close proximity increases with increasing gap sizes, suggesting that bats need to gather more information about surface treatments with larger gap sizes.

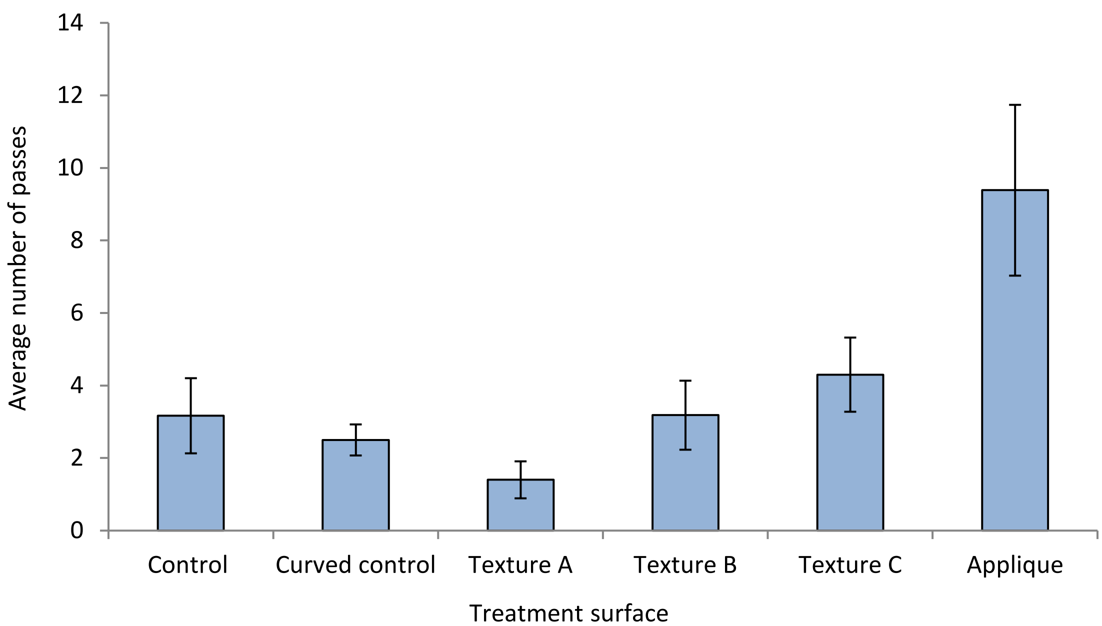


Figure 6: Mean ± SE number of passes occurring 0.0 – 0.5 m away from the treatment surfaces.

Table 1: Mean (± SE) number of passes within each distance zone away from the treatment surface.

	Distance (m)		
Treatment surface	0.5-1.0	1.0-1.5	1.5-2.0
Control	1.17 (0.37)	0 (0)	0 (0)
Curved control	0.90 (0.31)	0 (0)	0 (0)
Texture (A)	1.00 (0.32)	0 (0)	0 (0)
Texture (B)	1.09 (0.62)	0 (0)	0 (0)
Texture (C)	1.40 (0.31)	0 (0)	0 (0)
Applique	1.46 (0.86)	0 (0)	0 (0)

Time until first pass at treatment surfaces and water tray

Comparing the time that it took for bats to make their first pass over each treatment surface and the water tray, we did not observe any noticeable trends among the different surfaces (Fig. 7). A Kruskal-Wallis test confirmed that there was no significant difference for the time until first pass among all treatment surfaces and the water tray (H = 9.51; df = 6; P = 0.15).

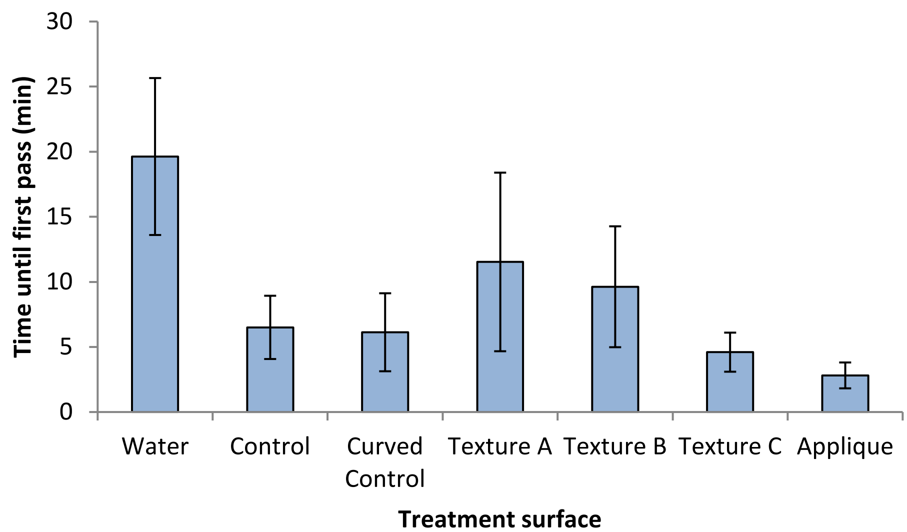


Figure 7: Mean ± SE time it took bats to make their first pass over each treatment surface and the water tray.

Bat foraging behavior trials – A total number of 537 foraging behavioral trials were completed from July 1 – September 29, 2015. The maximum number of trials we were able to complete in a night was 11 trials. Three species of bats were included: 9 (2 female; 7 male) eastern red bats, 51 (25 female; 26 male) evening bats, and 13 (11 female; 2 male) Mexican free-tailed bats. Note that Mexican free-tailed bats did not acclimate to the flight facility and therefore were not included in the trials. Furthermore, the following analysis includes the control, Texture C, and applique treatment surfaces.

Number of successful gleans and gleaning attempts

A total of 9 bats (4 eastern red and 5 evening bats) made it through the preliminary trials (including flat metal and curved metal) to the second set of treatment surfaces (including control, Texture C, and Applique). Comparing the mean number of gleans and gleaning attempts made across these treatment surfaces, we found that these behaviors occurred more frequently at applique (Fig. 8). Nevertheless, with such small sample sizes and high levels of variability it is not surprising that we found no significant difference between the treatment surfaces (H = 0.43; df = 2; P = 0.806).

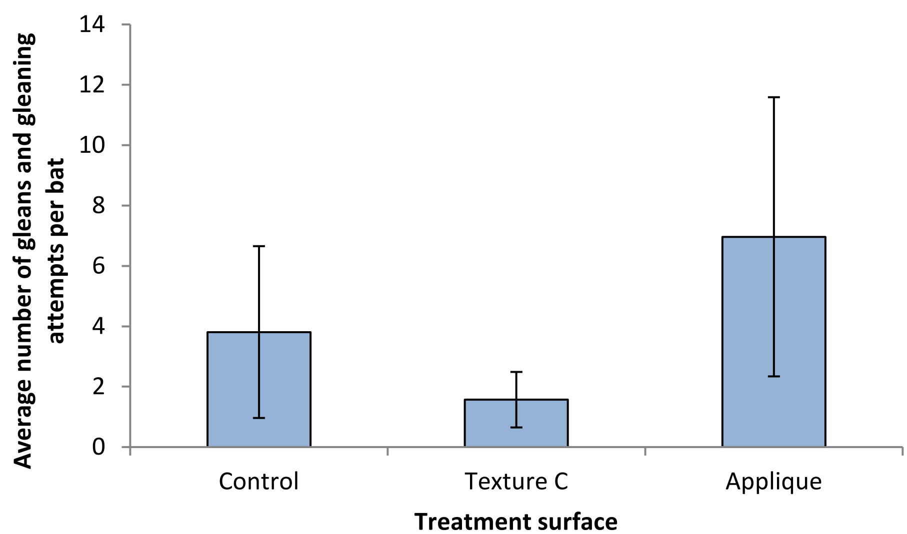


Figure 8: Mean ± SE number of passes occurring 0.5 m distances extending from each treatment surface.

During these trials, two male eastern red bats successfully gleaned prey from the treatment surfaces, thus confirming that eastern red bats are capable of switching their foraging strategy from aerial hawking to gleaning (Fig. 9). We also recorded evening bats gleaning prey from the treatment surfaces; however, these occasions were infrequent suggesting this species was not as adept at gleaning. Tables 2.1 and 2.2 below detail the number of prey items gleaned from each treatment surface (control, Texture C, and applique) by the male eastern reds. These results also show that the two bats could glean from a textured surface.

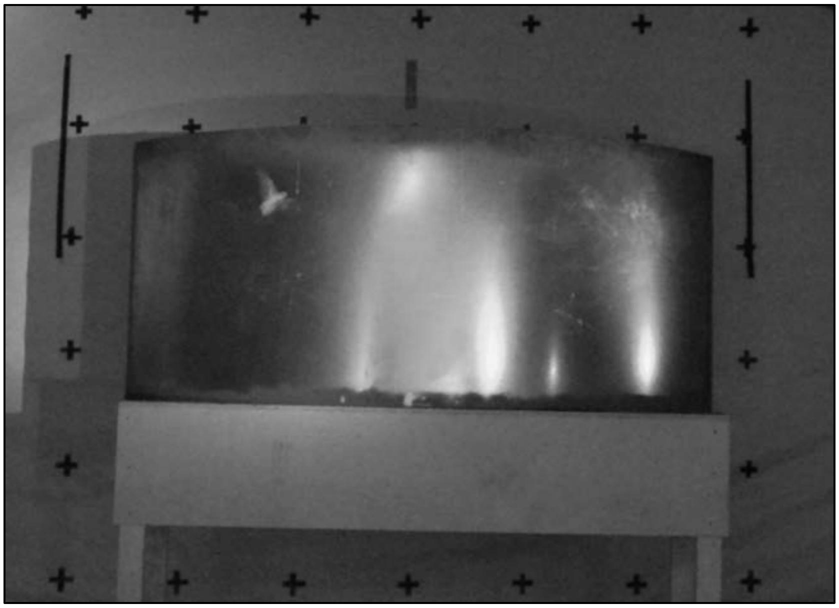


Figure 9: Camera image of eastern red bat gleaning from metal curved treatment surface.

Table 2.1: Total number and percentage of mealworms gleaned by individual 3Labo06Jul2015.

	Surface Textures		
Mealworms	Control	Texture 3	Applique
Gleaned	6	5	5
Not gleaned	27	19	21
Total Available	33	24	26
Percentage gleaned	**18.1**	**20.8**	**19.2**

Table 2.2: Total number and percentage of mealworms gleaned by individual 1Labo22Jul2015.

	Surface Textures		
Mealworms	Control	Texture 3	Applique
Gleaned	10	4	0
Not gleaned	17	5	27
Total Available	27	9	27
Percentage gleaned	**37**	**44.4**	**0**

Closest approach to mealworms

Comparing the mean number of passes (including gleans and gleaning attempts) per bat within each 0.5 m zone extending from each surface treatment, we found that the bats made more passes in close proximity to the Texture C treatment surface (Fig. 10). As the experimental set-up involved bats knowing that prey items were available on the treatment surfaces, the results suggest that they were not as effective at locating the prey items on the textured surface and therefore had to make multiple passes to find the prey. Nevertheless, as our sample size was small and demonstrated a high level variability it is unlikely that any strong inferences regarding closest approach could be made at this time.

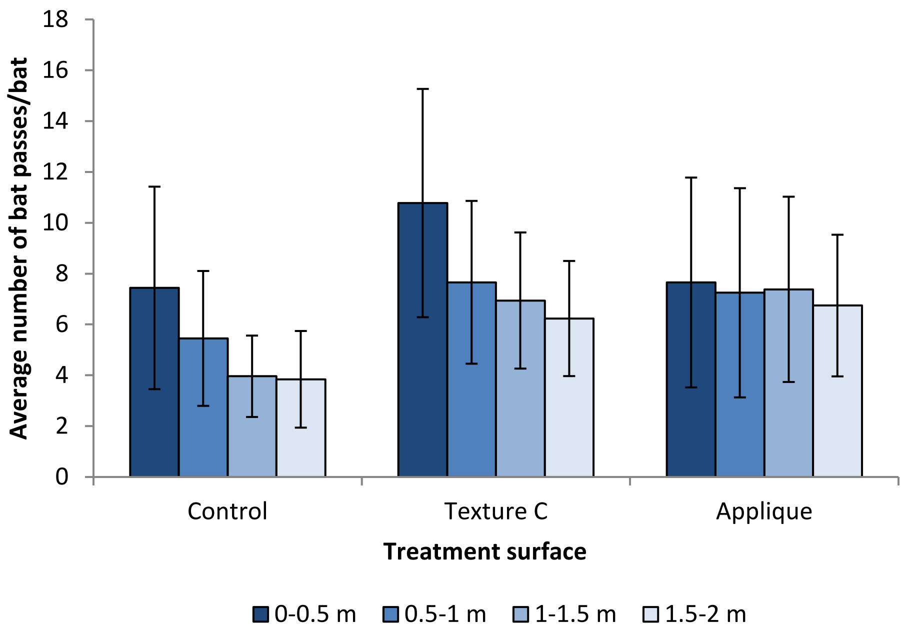


Figure 10: Mean ± SE number of passes occurring 0.5 m distances extending from each treatment surface.

DE-EE0007033
Texas Christian University
Texturizing Wind Turbine Towers to Reduce Bat Mortality

Task 2: Texture coating development, field study design, and application plan (Months 1-9)

Task Summary: The purpose of Task 2 is to develop a wind turbine tower surface treatment based on the results from Task 1. This task is divided into three Subtasks: Subtask 2.1 is the development and selection of a single turbine tower coating; Subtask 2.2 is to complete a field study design protocol to assess bat activity at control and treatment turbines; and Subtask 2.3 entails writing a detailed plan of action for applying the coating selected in Subtask 2.1 to 3-5 turbine towers at Wolf Ridge in Task 3. This document represents Milestone 2.2, the completion of a field study design protocol based on our existing behavioral survey protocol that we have refined over the past several years at Wolf Ridge. This protocol, which will be used in Task 4, describes the survey methods and provides a justification for the number of turbines included in the study (based on an analysis of the anticipated effect size, observed bat activity at the site, and feasibility of the study design).

Rationale for Change from Original Scope: Based on our results from Task 1 and work accomplished toward completion of Subtasks 2.1 and 2.3, we have revised the scope of Task 4 and therefore, revised the scope of Subtask 2.2 accordingly. Instead of conducting a bat fatality study at control and treatment turbines at Wolf Ridge in Budget Period 2 (original Task 4), we propose to evaluate bat activity and behavior at control and treatment turbines at Wolf Ridge in Budget Period 2 (revised Task 4).

We came to the decision to revise the scope of Task 4 based on 1) the financial costs of applying the texture coating to currently deployed wind turbine towers (as determined in Subtasks 2.1 and 2.3), and 2) the important link between bat activity at wind turbine towers, specifically near and within the rotor swept zone, and bat fatality at wind turbines. In the flight facility, we observed bats repeatedly making contact with smooth painted surfaces, but not with the textured surfaces (that led to the selection of the texture coating for subsequent development in Subtask 2.1). Furthermore, our findings in the flight facility supported previous studies that bats misperceive smooth surfaces to be water (see Greif & Siemers 2010, Russo et al. 2012). Based on our results (from this study and McAlexander 2013), we hypothesize that bats may be similarly misperceiving the smooth surfaces of operational wind turbine towers such as those deployed at Wolf Ridge and elsewhere across North America, to be water. Subsequently, we further hypothesize that if bats are repeatedly making contact with turbine tower surfaces, then this behavior will increase collision risk with rotating blades by increasing the amount of time bats spend in or near the rotor swept zone. Based on our observations and the water misperception hypothesis, we therefore predict that bats will spend more time in close proximity and make more contacts with smooth turbine towers compared to texture-treated towers. Hence, the best next step (i.e., Revised Task 4) is to characterize differences in bat activity and behavior at control (i.e., smooth) and texture-treated wind turbine towers at an operational wind farm. Additionally, a detailed behavioral study showing how bats approach and maneuver around turbine towers will provide important insights into the extent of surface treatment that is necessary to reduce bat activity near and within the rotor swept zone.

If we find that bat behavior depends on the texture of the turbine tower surfaces, we would then compare bat fatality rates at textured turbine towers and smooth towers in a future study, with the prediction that fatality would be higher at the smooth towers.

Deliverable 2.2 – Protocol for surveying bat activity and behavior at control and treatment wind turbines at Wolf Ridge (Task 4 – REVISED).

Protocol - Bat Activity Surveys at Control and Treatment Turbines at Wolf Ridge (Months 13-18) Task 4 REVISED

Task Summary: In this task, we will conduct a field test in which bat activity is evaluated at treated turbines (i.e., wind turbine towers texturized in Task 3) and control turbines (i.e., smooth standard towers) in Budget Period 2. The field survey effort will focus on July through September 2016 (the months with the highest expected bat activity and mortality), although some baseline monitoring will also take place in June, if necessary. We will use our existing bat activity survey protocol, which has been refined since McAlexander (2013), to maximize detection of bat activity at wind turbine tower surfaces.

Objectives

This study is designed to determine if the texture coating created in Task 1 and subsequently developed in Subtask 2.1 successfully reduces the amount of time bats are active in close proximity to wind turbine towers at a wind facility in the southern Great Plains. We will compare levels of bat activity and bat behavior at a selection of treated (towers with the texture coating) and control (towers without the texture coating) wind turbines. We hypothesize (H_A) that bat activity levels will vary between control and treatment turbines, with more contacts with the tower and a greater extent of time spent near the tower surface by bats at control turbines. The null hypothesis (H_0) is that bat activity is independent of texture coating.

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*.

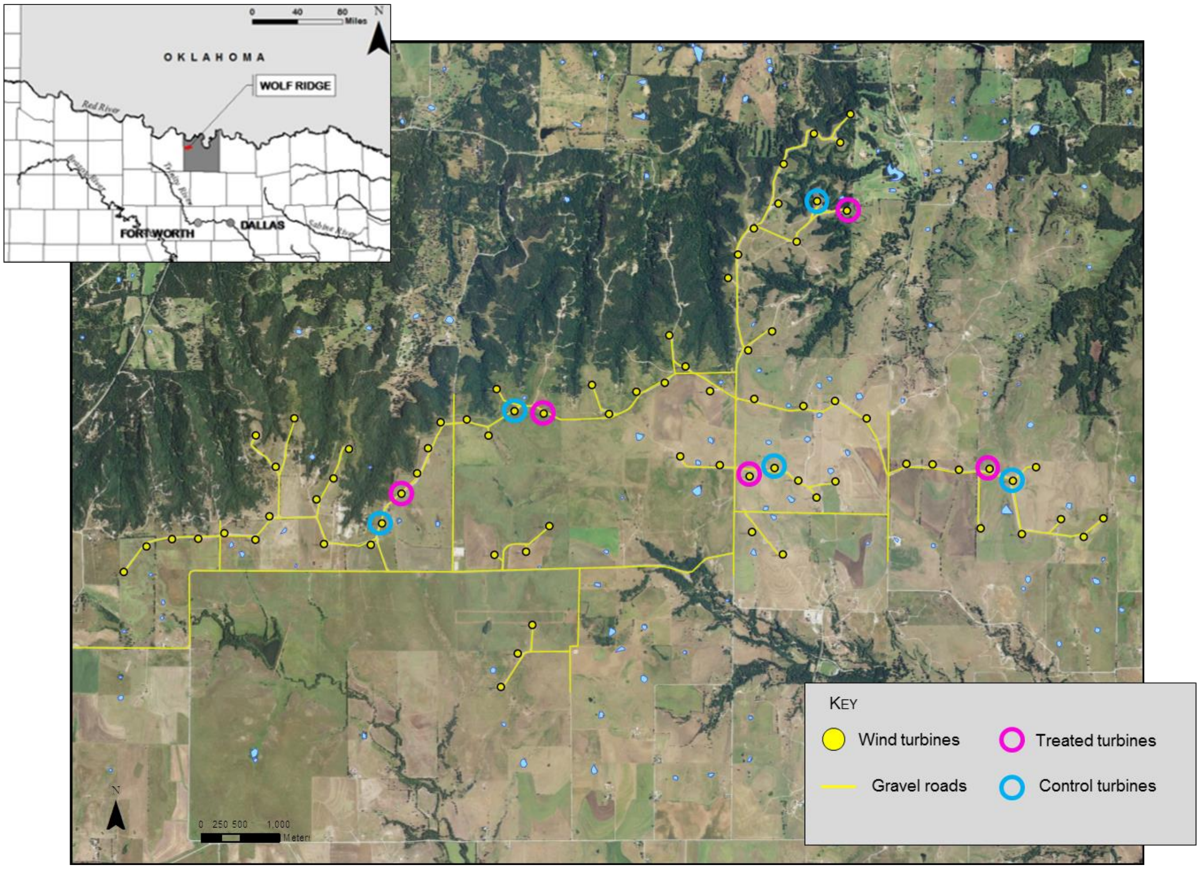


Fig. 1: Map illustrating the locations of 5 potential pairs (treated and control) of wind turbines at Wolf Ridge Wind, LLC.

Survey Methods

Surveys will be conducted at three pairs of wind turbines at Wolf Ridge (see Fig. 1) from July 1 through September 30, 2016. Weather permitting, we will survey bat activity 2-5 nights per week for approximately 50-65 survey nights during this period, although the total number of nights may be adjusted due to overall levels of bat activity or limitations in site access due to storms. As we are proposing a paired study design (i.e., recording bat activity at control and treatment turbines simultaneously), our response variables will be the difference in activity levels, number of bats, number of contacts made with tower, etc. between the control and treatment turbine on a nightly basis. The paired design will help minimize the influence of night-to-night variation in bat activity, thereby increasing the power of our tests. Using night vision technology at turbine towers at this site in 2012, McAlexander (2013) detected mean (± SD) 4.1 ± 6.1 bats per hour in the immediate vicinity of untreated turbine towers (n = 46 survey nights). If we use data from McAlexander (2013) as a starting point, we can approximate the power ($1 - \beta$) for a range of survey nights that would be required to detect a 25-75% reduction in bat activity (paired t-test and $\alpha = 0.05$; Zar 2010). We will need a sample size of at least 50 survey nights to have approximate power > 0.60 to detect a 50% reduction in bat activity at texture-treated compared to control turbines (Table 1).

Table 1: The approximate power (1 – β) to detect a 25-75% reduction in bat activity for a range of sample sizes.

Survey nights (n)	25% reduction in bat activity	50% reduction in bat activity	75% reduction in bat activity
30	0.143	0.423	0.754
40	0.177	0.538	0.869
50	0.211	0.637	0.934
60	0.246	0.719	0.968
70	0.279	0.785	0.985

Using high-definition video cameras and night vision technology, as well as thermal cameras if available, bat activity will be recorded at a paired control and treatment turbine tower surfaces concurrently. Within a single survey night, surveys will be conducted as a series of 30 min sessions that will begin approximately 30 minutes before sunset and will continue up to 3 hours after sunset (the primary activity period for bats). Note that the timing of the sessions will be the same at both control and treatment turbines within a single survey night.

Two video cameras mounted on tripods will be placed at each turbine. Sony DCR-SX45 cameras in daylight mode will be used for the first 30 minute session of each survey period, followed by SONY HDR-PJ710 cameras with ATN-NVM4 night vision scopes for the remainder of the night (Fig. 2). One camera set-up will be placed on the gravel pad beneath the windward side of the tower and the other set-up on the leeward side. Cameras will be angled (10 m above the gravel pad) up the tower surface to the face of the nacelle hub (~80 m height; Fig. 3). This positioning will allow for all bat activity to be recorded in proximity to the tower surface, and include areas with and without the texture coating on treatment turbines. 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 camera and angled upwards towards the turbine tower surfaces. If possible, one to two thermal cameras will also be placed 30 to 50 m from the turbine towers to more effectively identify individual bats approaching the turbine towers; however, these cameras would not be used to determine patterns of activity and specific behavior seen at the tower surfaces.

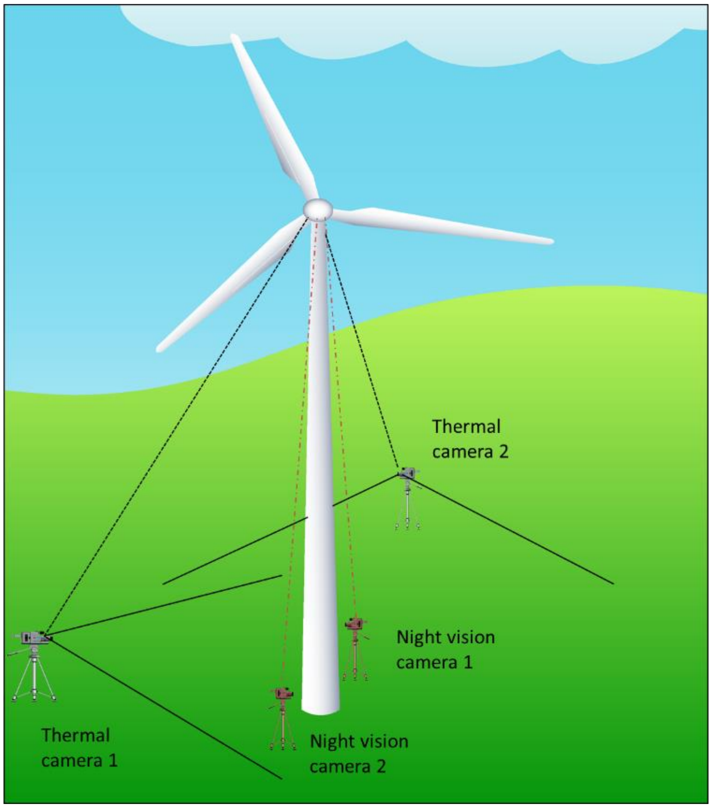


Fig. 2: Diagram of camera set-up for bat activity surveys at control and treatment wind turbine towers at Wolf Ridge Wind, LLC.

In addition, ultrasonic bat detectors will be placed in proximity to the turbines during the night vision video/thermal surveys to record acoustic bat activity. An AR-125 bat detector and recorder will be deployed near to the video camera set-up to record echolocation calls from bats near the turbine towers. The acoustic detector will record for the entire monitoring period.

At least 2 technicians will be present at each paired turbine surveyed each night. Video recordings will be started simultaneously on both cameras at each turbine, 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.

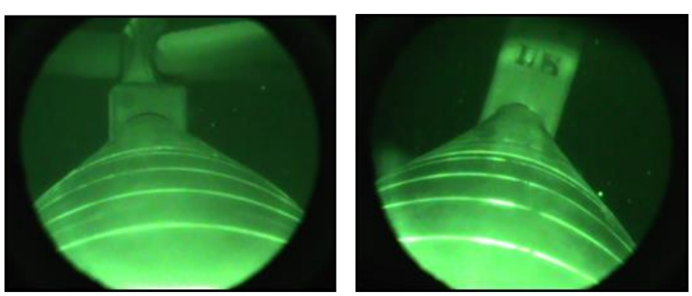


Fig. 3: Night vision camera set up on windward and leeward side of the turbine focused up the turbine tower.

Data Management and Analysis

We will process all videos from the Canon camcorders in Studiocode (version 5, Studiocode Business Group, Sydney, AU). This program links each video with a timeline that matches the length of the video and saves the video and timeline as a movie package. Within the program, we will stack the windward and leeward videos, and potentially the thermal recordings, to one timeline allowing us to view all footage at a single turbine for each session simultaneously. Using flanges (i.e., external ridges) on the tower surfaces as distance indicators, we will divide the camera views into zones in a code window. Using video analysis software, we will determine if bats are present during the paired activity surveys, document levels of activity by counting the number of bats, and document types of behavior exhibited and time spent in the field of view (i.e., in close proximity to the wind turbine tower). We will identify specific types of behavior exhibited by the bats including foraging, passing, and drinking.

If possible, we will initially use thermal camera images to confirm the presence of a bat as it approaches the tower surface. As the thermal signature from the wind turbine towers will likely mask bat activity at the tower surface itself, we will use the matching timelines to effectively identify bats in the Canon videos, from which we will further investigate and characterize behavior. 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. Finally, we will use Minitab v. 17 statistical software to analyze the data collected during this study ($\alpha = 0.05$).

References

Greif S, Siemers BM (2010) Innate recognition of water bodies in echolocating bats. Nature 1: doi:10.1038/ncomms1110.

McAlexander, A (2013) Evidence that bats perceive wind turbine surfaces to be water. Thesis, Texas Christian University.

Russo D, Cistrone L, Jones G (2012) Sensory ecology of water detection by bats: a field experiment. PloS ONE 7: doi:10.1371/journal.pone.0048144.

Zar JH (2010) Biostatistical Analysis, 5th edition. Pearson Prentice Hall, New Jersey.

Texturizing Wind Turbine Towers to Reduce Bat Mortality

Task 2: Texture coating development, field study design, and application plan (M 1-9)

Task Summary:

Task 2 is divided into three Subtasks. Subtask 2.1 is the development and ultimate selection of a single turbine tower coating. Subtask 2.2 is the completion of a field study design protocol to assess bat activity at control and treatment turbines. Subtask 2.3 entails writing a detailed plan of action for applying the coating selected in Subtask 2.1 to 3-5 turbine towers at Wolf Ridge in Task 3.

Subtask 2.3: Texture coating application plan (Months 8-9)

Subtask Summary:

We prepared a written plan of action for the application of the tower coating at Wolf Ridge. The written plan of action was developed collectively by the TCU principal investigators, the research team at NEER, the coating supplier (selected by NEER), and the site lead at Wolf Ridge. This plan of action identified the selected treatment and control turbine towers, the paint and/or applique supplier, and the contractor who will apply the treatment at Wolf Ridge. This plan provides an organizational framework for the application process and a detailed time schedule. The earliest start date for the application process will be April 1, 2016 with a target completion date of June 15 in Budget Period 2.

We selected approximately 6 to 10 wind turbines for inclusion in the bat activity surveys based on the following criteria: observed bat activity in previous years (where possible, we chose turbines with higher historical bat activity levels to increase the power of our study); uncluttered survey areas (we selected turbines with little vegetation within the survey area to enable equipment setup); and location within the wind farm (we ensured that the selected turbines were distributed across the wind resource area). Furthermore, the selected turbines were paired based on the aforementioned characteristics, and then the treatment has been randomly assigned to one turbine within each pair (with the untreated turbine within each pair serving as a control). As the treatment cannot be rotated among turbines during the study, this paired approach also allows us to control for some of the inherent variation in bat activity that we have observed among turbines over the past 4 years.

Milestone 2.3 – Completion of a written plan of action for the application of the tower coating to selected wind turbine towers at Wolf Ridge. This plan of action identifies the treatment and control turbine towers, the paint and/or applique supplier, and the contractor who will apply the treatment at Wolf Ridge. (Month 9, Budget Period 1)

Deliverable 2.3 – Written plan of action for application of turbine tower treatment.

DRAFT

To:
From:
Date:

Subject: Plan for texturizing turbines at Wolf Ridge Wind Farm (deliverable 2.3 under DE-EE0007033.00)

The application of a texture coating to operational wind turbine towers will require close coordination of multiple parties to ensure safe, efficient, and effective progress toward our study goals.

To that end, the purpose of this memorandum is to outline the plan for applying a texture to study turbines at Wolf Ridge Wind Farm (WRWF).

Broadly speaking, the plan to apply a texture coating will occur in four phases. Phase 1 is material production and transport and contractor mobilization, phase 2 is turbine prep and material application, phase 3 is contractor demobilization, and phase 4 is the site returning to normal operations. Following phase 4 the study investigators will execute their bat activity study plan.

The notional timeline below provides detail to each of these phases, and the work items required in each phase, keeping in mind that it is entirely possible—likely even—that there will be some measure of overlap between phases of this operation.

Phase 1: Material Production & Transport and Contractor Mobilization		
Plan Day	Event	Responsible Party
D – x	Coating material produced to specifications. See Attachment A for summary of coating material.	Duromar
D – (x - y)	Coating material shipped to WRWF.	Duromar; shipping provider
D – (x - y)	Contractor mobilized crew and equipment for transport to WRWF.	Selected contractor
D – (x - y)	Coating material arrives at WRWF, received by NEER site staff.	Shipping provider; NEER site staff
D – 1	Contract crew arrives at WRWF.	Selected contractor
Phase 2: Turbine Prep & Material Application		
D + 0	Site personnel pause the test turbine #1, contract personnel begin surface prep and application at test turbine #1. See Attachment B for diagram of turbine area to receive coating.	NEER site staff; selected contractor
D + x through D + y	Work continues, with test turbines being paused, surface prepared, and material applied in sequence.	NEER site staff; selected contractor
Phase 3: Contractor Demobilization		
D + z	Contract crews complete any cleanup required on site	Selected contractor
D + z	Contract crews depart WRWF	Selected contractor
Phase 4: Return to Normal Operations		
D + a	Ensure test turbines are operating within normal parameters	NEER site staff
D + a through end of study	Continue monitor test turbines for any operational changes potentially attributable to texture coating	NEER site staff

Attachment A

NEXTera ENERGY RESOURCES

DUROMAR®

PRODUCT DATA SHEET

WE-6222

Tower Coating – Wind Energy

GENERAL DESCRIPTION

WE-6222 is a zero VOC, two component coating system designed specifically to protect wind towers and nacelles. This self-priming system does not require a zinc primer and offers protection against atmospheric corrosion even under the harshest C5-M conditions.

FEATURES

- Environmentally friendly, Zero VOC coating system
- Outstanding UV resistance and color stability
- Approved for all atmospheric corrosion conditions, C1 through C5-M
- Tack-free in 4 hours at 70 °F, allowing for quick turnarounds
- Designed for superior longevity with excellent flexibility, adhesion and impact resistance
- May be applied by hand or with plural component airless spray equipment

PACKAGING

½ gal, 1 gal, 2 gal and 4 gal kits

COVERAGE

WE-6222 has the consistency of thick paint and can be applied up to 15 mils per coat. Theoretical coverage at 10 mils is 160 square feet per gallon.

MIXING RATIO

3.75 parts base (B) to 1 part (A) hardener by weight

2.5 parts base (B) to 1 part (A) hardener by volume

POT LIFE

For a ½ gallon unit, mixed at 70ºF, pot life is approximately 45 minutes. Higher temperatures or larger mass will shorten this time, lower temperatures or smaller mass will extend it. Pot life can also be extended by spreading the mass out to dissipate heat.

COLORS

WE-6222 is available in a variety of colors.

TECHNICAL DATA AND INFORMATION

Physical Properties of Cured System:	
Density	1.32 g/mL
% Solids	100
Flexural Strength @ 70ºF	14,300 psi
Tensile Strength @ 70ºF	5,500 psi
Tensile Shear @ 70ºF	3,700 psi
Adhesion (Fiberglass)	>2000 psi
Adhesion (Aluminum)	>2000 psi
Abrasion Resistance[1]	29.6 mg lost
Impact Resistance	112 in lbs
Hardness	81 – 78 Shore D

[1] ASTM D 4060 Taber Abrasion Test, CS 17 wheel with 1 kg weight. Weight lost per 500 cycles.

SURFACE PREPARATION

- For maximum adhesion, material should be applied to a firm, clean, dry and abraded surface.
- Best results will be obtained by abrasive blasting the surface.
- If blasting is impractical, a grinding wheel, needle gun, or very stiff wire brush may be used.
- Clean greasy, oily or waxed surfaces with suitable solvent before applying material.

MIXING

For standard kits mix ALL of Part A with ALL of Part B. Pour Part A into Part B bucket and mix for 5 minutes while scraping down the sides. Duromar recommends boxing material to ensure adequate mixing.

CLEANUP

Most solvents and commonly used thinners such as MEK, acetone and xylene can be used for cleaning tools and equipment. Duromar also supplies a non-flammable, non-hazardous safety solvent **Duromar T-1** which can be used. DO NOT USE TO THIN MATERIAL FOR APPLICATION.

NSF-ISR QUALITY SYSTEM REGISTERED TO ISO 9001:2000

706 Washington Street, Pembroke, MA 02359 USA • Tel. (781) 826-2525 • Fax (781) 826-2150
www.duromar.com

APPLICATION

WE-6222 is best applied by plural component airless spray or by hand with a roller or brush.

- Min. Thickness/Coat (mils) 7
- Max. Thickness/Coat (mils) 15
- Number of Coats 1-2
- Min. Application Temperature (ºF) 55

For best results, do not apply:

- When humidity is over 90%
- When there is moisture on the surface
- When surface temperature is not 5 ºF above dew point

OVERCOATING

For thicker coating and repairs, two or more coats may be employed. **WE-6222** can be overcoated with most Duromar high performance materials. In high humidity or cold temperatures a blush may develop which should first be wiped down with clean water. The following table is an approximate guide to the earliest and latest times an overcoat may be applied:

WE-6222 Overcoating Window:

55ºF	70ºF	85ºF
8 - 72 h	4 - 48 h	2 - 24 h

At 70 ºF, if 48 hours have elapsed the surface must be roughened before overcoating. The preferred method is a light abrasive brush blasting, light sanding, grinding or wire brushing.

CURING SCHEDULE

Temperature	55 ºF	70 ºF	90 ºF
Dry to Touch	8 hours	4 hours	2 hours
Functional Cure	72 hours	24 hours	12 hour
Full Cure	10 days	96 hours	48 hours

Q/C

The material should be visually inspected just after application and touched up where necessary.

STORAGE/SHELF LIFE

Store in dry area in closed containers between 50 ºF and 100ºF. Shelf life at these conditions is greater than one year.

HEALTH AND SAFETY

READ AND UNDERSTAND ALL MATERIAL GIVEN IN THE MSDS SHEETS BEFORE USING THE PRODUCT.

WE-6222 DOES NOT CONTAIN ANY FLAMMABLE MATERIAL OF ANY KIND. HOWEVER, THE MATERIAL IS COMBUSTIBLE. IN THE EVENT OF A FIRE, DRY POWDER, FOAM, OR CARBON DIOXIDE FIRE EXTINGUISHERS SHOULD BE USED. FIRE FIGHTERS SHOULD WEAR RESPIRATORS.

USE PROTECTIVE GLOVES AND EYEGLASSES WHEN USING.

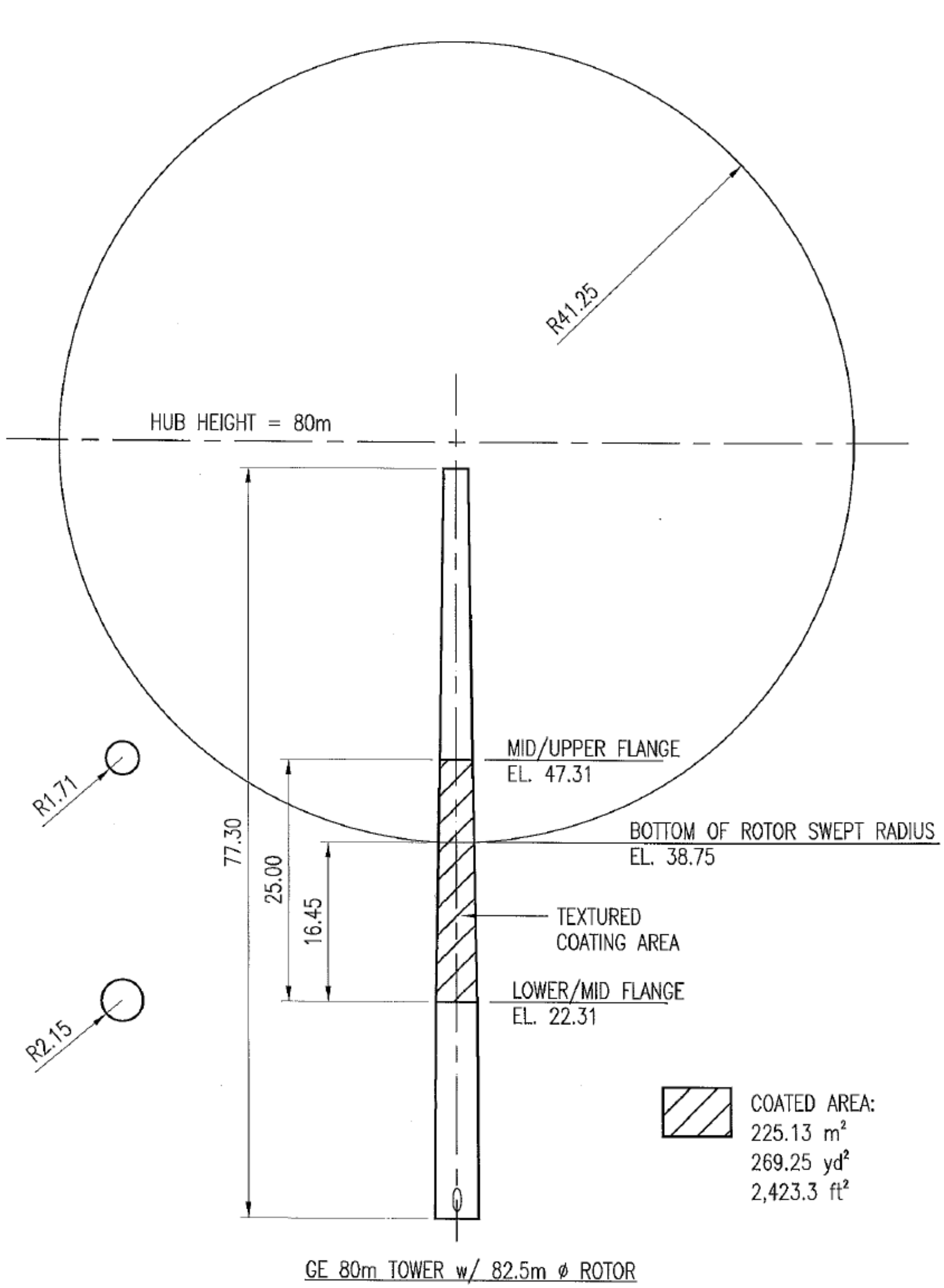
USE IN AREAS OF GOOD VENTILATION.

LIMITED WARRANTY

All recommendations covering the use of this product are based on past experience and laboratory findings. Methods or conditions of application and use of the product are beyond our control. We assume responsibility only for the uniformity of our product within normal manufacturing balances.

Rev. 06/11

Attachment B



Selected Turbines

We identified 5 pairs of turbines for possible inclusion in the behavioral study in Budget Period 2 (Fig. 1). We based our selection on results from previous fatality, acoustic, and observational surveys conducted at Wolf Ridge from 2009 to 2014. We found that these paired turbines had the highest and most consistent levels of bat activity (or fatality, depending on survey type) among the areas and turbines we surveyed across the wind farm (see Fig. 2 as an example).

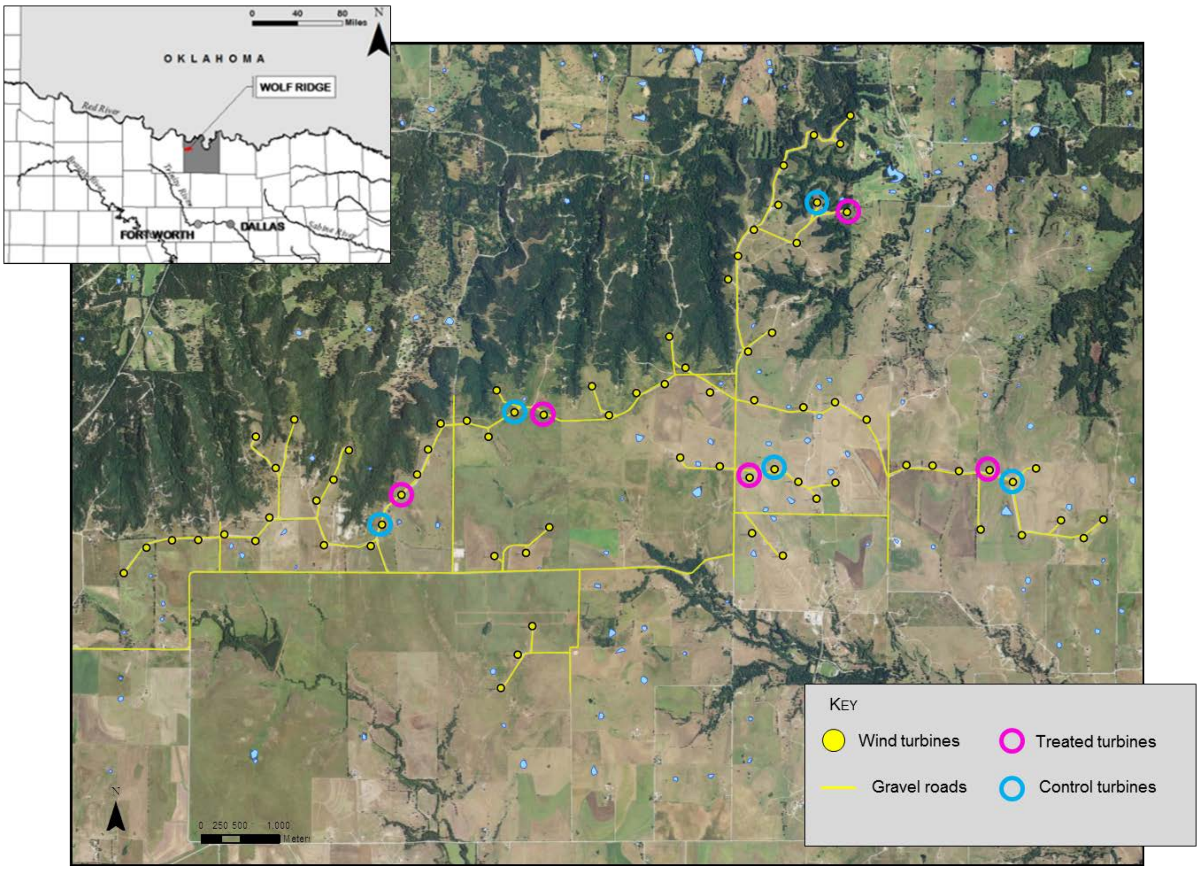


Fig. 1. Map illustrating the locations of 5 pairs of treatment and control wind turbines for possible inclusion in the 2016 study at Wolf Ridge Wind, LLC.

NEXTera ENERGY RESOURCES

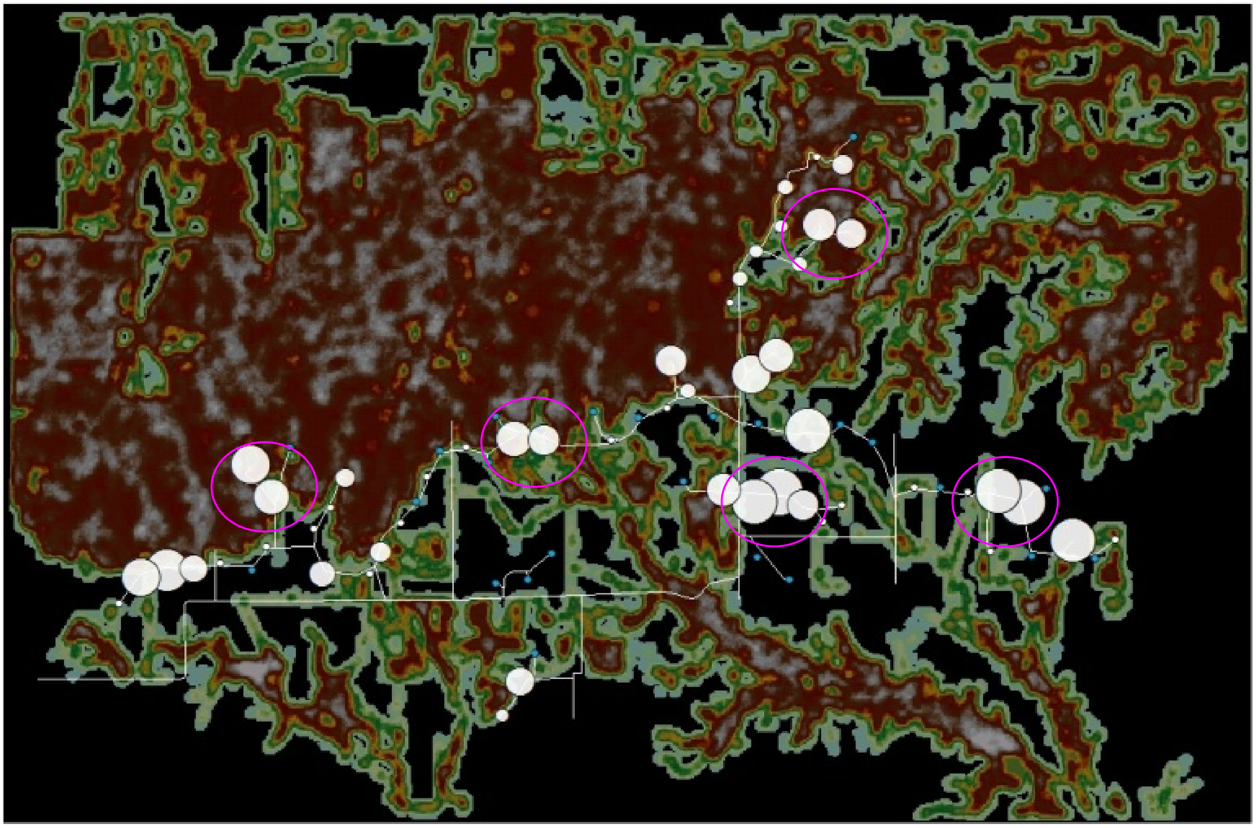


Fig. 2. Map illustrating the distribution of eastern red bat fatalities at wind turbines at Wolf Ridge Wind, LLC from 2009 to 2014. The size of the white spheres is related to the number of bat fatalities (i.e., the larger the diameter of the sphere, the higher the observed fatality). The pink ovals indicate the locations of the 5 pairs of treatment and control wind turbines that are under consideration for inclusion in the 2016 behavioral study.

Texturizing Wind Turbine Towers to Reduce Bat Mortality

Task 3 (REVISED): Testing Behavioral Response of Bats to the Texture Surface in the Flight Facility – Part II (Months 11-16)

Task Summary:

We propose an experiment in which we record the responses of wild-caught bats when presented with the texture coating (developed in Task 2) in a controlled flight facility setting. The rationale for choosing the single texture coating for further testing is based on the behavioral response of bats to preliminary testing in 2014, the behavioral response of bats to testing in 2015 (Task 1), and the results of an acoustic experiment using synthetic bat calls (Yuen 2015). From the behavioral testing in both years, the bats did not make head-first contact with any of the surface treatments consisting of paint additives, whereas they did make head-first contact with the applique. Of the various paint additive treatments we tested, the results from the behavioral trials and the acoustic experiment combined indicate that echoes returning from textures with dense particles of multiple sizes will be most different from echoes returning from smooth surfaces across a range of bat species that are commonly killed at wind turbines across North America. We therefore propose additional flight room testing with the texture coating developed in Task 2 to confirm that bats will show less interest, as evidenced by fewer touches and fewer passes within 1 m, in the texture-treated surfaces compared to smooth controls.

Vertical trials will be used to assess bat behavior at surfaces that are oriented in a way that is most similar to the wind turbine towers that free-flying bats encounter in the wild. During these trials, bats caught in mist netting surveys will be released into the flight facility and observed during their acclimation period (nights 1-4). Additional trials may be necessary if weather conditions during the first 4 nights are not conducive to bat activity (i.e., bats do not tend to actively fly and forage within the facility on cool nights or nights with rain or high humidity). Within the flight facility there will be 2 sets of flat metal plates (approx. 2 m by 2 m) mounted close to the facility walls: smooth painted plates and texture-treated plates (using the coating developed in Task 2). In successive trials, the 2 flat surface types will be rotated in a random order among 3 positions within the flight facility (see below for more detail). In addition to these flat surfaces, we will also place a curved vertical structure (approximately 3 m tall, nearly reaching from the floor to ceiling, with the curvature of an 80-m turbine tower 40 m above ground) near the center of the flight facility. One side of this curved structure will be smooth painted, whereas the other side will be texture-treated (using the coating developed in Task 2). The location of the tower will be fixed within the room, although the overall structure will rotate on its vertical axis. Thus, the position of the smooth and texture-treated sides will be determined at random (1-360°) and will vary from one trial to the next (see below for more detail).

All bat behavior within the flight facility will be recorded using high-definition video recorders. The flight facility will be illuminated with infrared lighting. We will use video analysis software to quantify bat activity at each surface type (e.g., number of passes <1 m from the plate or tower surface and number of contacts with each surface). The behavioral trials will take place from June to August 2016 and the video processing, data analysis, and synthesis will take place from September to October 2016.

Objectives:

Our objectives are therefore to verify that bats in the flight room exhibit reduced activity (as evidenced by number of passes and contacts) at texture-treated surfaces compared to smooth surfaces (i.e., all hypothesis tests will be one-tailed). The textured surface is the coating developed in Task 2. We hypothesize (H_A) that bats will make fewer passes <1 m at the textured surfaces compared to the smooth painted surfaces (i.e., surfaces equivalent to wind turbine tower surfaces). The null hypothesis (H_0) is that the number of passes <1 m at textured surfaces will be greater than or equal to the number of passes <1 m at the smooth painted surfaces. We further hypothesize (H_A) that bats will make fewer contacts with the textured surfaces compared to the smooth painted surfaces (e.g., attempt to drink from the surface). The null hypothesis (H_0) is that the number of contacts at textured surfaces will be greater than or equal to the number of contacts at the smooth painted surfaces.

Deliverable 3.1 Experimental protocol for behavioral trials in the flight facility – Part II

Field Methods and Bat Flight Facility:

The individual bats used in this experiment will be wild-caught from select locations in north-central Texas including the Wolf Ridge wind farm and local parks in and around Fort Worth (i.e., in close proximity to the existing bat flight facility; Fig 1, see mist netting permit in appendix 1). Captured bats will therefore be representative of local species and include eastern red (*Lasiurus borealis*) and hoary (*Lasiurus cinereus*) bats, that comprise the highest number of fatalities at Wolf Ridge, as well as evening bats (*Nycticeius humeralis*).

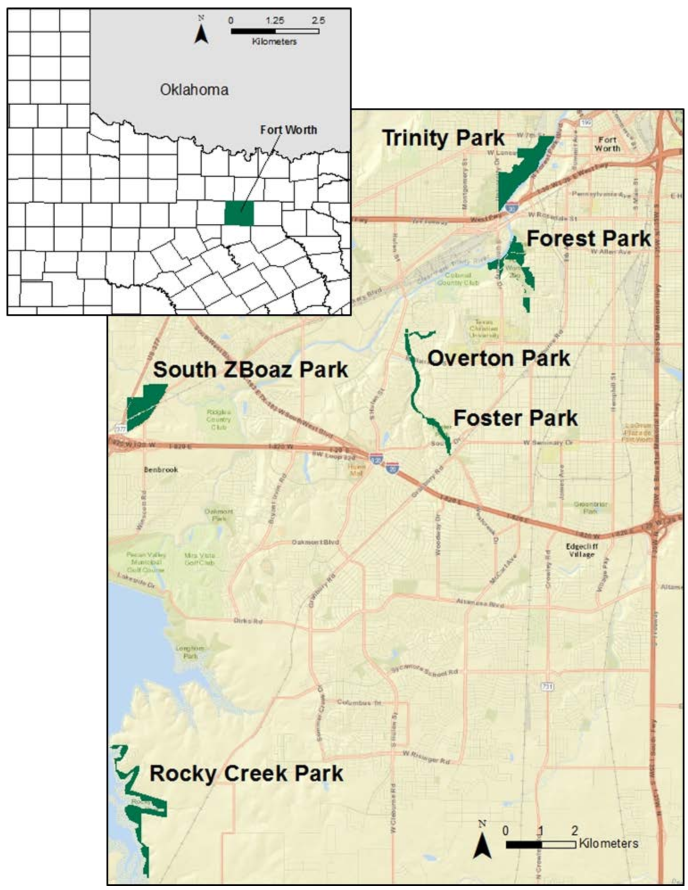


Fig 1: Locations of Fort Worth local parks that are included in our mist netting permit (Left to right: South Z Boaz Park, Overton Park, Foster Park, Trinity Park, and Forest Park).

At select locations, where we have recorded frequent bat activity, we will put up mist nets, a commonly used approach to catch bats (Fig. 2). These mist nets (triple-high and single 6-18 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 3 hours after dusk, as this represents the primary activity periods of local bats. Each net will be monitored continuously from an appropriate distance and physically checked at no more than 10 minute intervals. From the net, the bats will be placed in a cloth sack and taken from the net to a secure temporary carrier, with the exception of bats that have been identified during removal from the net 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 individuals will be taken away from the mist nets and 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. 2: Images of triple high mist netting locations before nets are opened.

At the end of the trapping session or when 2 to 6 bats have been caught, we will transport the bats to the flight facility (see below). The bats that are housed in the flight facility will only be used in the experiment for a limited amount of time and will then be released back at their site of capture. Note that each individual bat or group of bats, depending on species, successfully tested in the flight facility will represent an independent sampling unit (see data analysis section for more details). We anticipate testing only 1 or perhaps 2-3 bats at a time for the solitary species (eastern red and hoary bats) and a small number of bats (approx. 2-3 bats) for the social species (evening bats). Our goal is to successfully test approximately 15 to 45 individual bats (in approximately <20 groups) from June to August 2016. During this time, we will strive to sample a representative cross-section of males and females from each species; however, this is ultimately dependent on our trapping 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 building approximately 17 m by 10 m (Fig. 3). Hoary bats (the largest species in the area) require a minimum flight area of 23.04 m^2 (Lollar 2010); therefore, we selected a larger flight facility to provide sufficient room for maneuverability. As we want the bats in the flight facility to behave as naturally as possible, conditions within the facility will be kept similar to the bats' natural environment. Subsequently, no visible artificial lights will be used during the behavioral surveys and researchers will only use headlamps pre- and post-trials. Similarly, the temperature and humidity within the facility will be similar to the conditions outside the facility, using a series of screen-covered windows and large doors to ensure adequate ventilation (Fig. 3). The conditions within the facility will also be monitored daily and we will check on the bats throughout each day to ensure their health and safety. Daily bat checks will be conducted at approximately 8 am, 12 pm, and 4 pm, and additional checks will be conducted in inclement weather.

Fig. 3: Outside view of 2015 flight facility with custom made screen windows. The 2016 facility has large, screen-covered doors to increase air flow though the facility.

Fig. 4: Inside view of 2015 flight facility.

Species-specific roosting opportunities will be provided within the flight facility. Soft puppy carriers and carpeted cat houses will be provided for cavity-dwelling species such as the evening bat, and grouped branches in tree stands will be provided for tree-dwelling species such as the eastern red and hoary bat (Fig. 5; Lollar 2010).

Water will be available to the bats at all times throughout the experimental trials in a custom-made shallow galvanized steel water tray (2 m x 1 m x 1.5 cm) positioned on the floor of the flight facility. Three of these trays will be present in the facility, but on any given day only 1 of the 3 will be uncovered and available for bats to drink from during the day and at night. The other 2 trays will be covered with camouflage netting. As only 1 tray will be uncovered at a time, the available water source (i.e., the position of that water source) will be varied on a daily basis. The available water source on the first trial night will be determined at random and then will rotate counter-clockwise for the remaining nights.

Fig. 5: Roosting opportunities provided for the bats within the 2015 flight facility.

Bats generally emerge from their day roosting sites and fly for no more than a few hours at dusk, in which time they drink and forage for invertebrate prey. As the flight facility contains only a limited number of flying invertebrate prey items, we run a light trap outside the flight facility to capture additional prey items for the bats. Moths, flies, and beetles will be retrieved from the light traps and released into the flight facility on a nightly basis. In addition, when the bats stop flying in the evening, we will supplement their diets with mealworms (larval *Tenebrio molitor*) covered in vitamin powder (1/16 tsp. Bulk Supplements Pure Coenzyme Q10 (COQ10) to 2 tsp. Miracle Care Vionate Vitamin Mineral Powder; Lollar 2010). As previously mentioned, environmental conditions will be monitored throughout the day. During the 4 pm check on high temperature days, we will offer the bats water by holding a pipette up to their mouths.

Finally, in order to identify individual bats in the flight facility during trials and while checking on the bats during the day, we will coat their backs with combinations of non-toxic pink, green, orange, blue, purple, and yellow ECO Pigments (Day-Glo Color Corp, Cleveland, OH; Fig. 6) during the 4 pm check.

Fig. 6: Evening bat (*Nycticeius humeralis*) marked with blue ECO Pigment.

Once bats are caught and released into the flight facility, we will immediately monitor their behavior (i.e., capture night) and during the following 3 acclimation nights, depending on weather, to assess how these naïve bats respond to 2 vertical flat surfaces suspended near the walls of the flight facility and at 2 curved vertical surfaces similar to a turbine tower placed near the center of the facility (Fig. 7). The flat surfaces will each be ~2 m by 2 m, whereas the curved surfaces will be ~3 m tall with the curvature of an 80 m GE wind turbine tower at mid-tower height (approximately 40 m from the ground), which falls within the rotor swept zone and is where the blade tips are moving the fastest. On any given trial night, the bat(s) will be exposed to only 1 of the 2 surface types (flat or curved). Starting with the first set of bats, the surface type on night 1 will be determined at random, after which the surface type will alternate on a nightly basis between flat and curved. The surfaces that are not tested in a given night will be covered with camouflage netting. For all subsequent trials (with independent sets of bats), the order in which the surface types (flat or curved) are presented to the bats will alternate to avoid an order effect (i.e., approximately half of the bats will receive the flat surface types first and half of the bats will receive the curved surface types first).

For the flat surface trials, the 2 surface types (smooth and texture-treated) will be rotated in a random order among 3 positions within the flight facility (see Fig. 7). In the curved surface trials, the tower structure will rotate on its vertical axis. Thus, the position of the smooth and texture-treated sides will be determined at random (1-360°) and will vary from one trial to the next with the following constraints: the random angle must be in a different 1/8 of the pie for successive trials, sampling without replacement until each of the 1/8 sections have been selected. This process will be repeated for the remainder of the curved surface trials.

As previously mentioned, water will be provided 24/7 from a custom-made shallow galvanized steel water tray, but prior to each evening's trials the position of the "available" water source will be changed (3 rotating positions; see Fig. 7). After the first night, trials will be initiated at dusk as soon as the bats emerge from their day roosts for 1 hour as previous surveys have shown that bats primarily drink in this period. We will use high-definition Canon XA20 camcorders to visually record activity specifically at each surface. Camcorders will be placed at a 90° to the length of each surface. As the camcorders do not record in color, the unique color of each individual bat that comes within 1 m each surface and water will be verbally dictated by technicians during each trial. For this, 3 technicians will be present in the flight room during each behavioral trial and they will use UV flash lights to identify individuals. One technician will be positioned near the smooth painted surface, one technician will be positioned near the texture-treated surface, and one technician will be near the water tray. A technician will also record temperature, humidity, dew point, wind speed, etc. as these variables may influence bat activity within the flight facility.

If bats do not drink from the water source within the 60 min trials, water will be provided to the bats by hand via pipettes and we will supplement the bats with water using a pipette at 8 am and 12 pm checks to ensure they are receiving enough water. The camcorder videos will be saved as MP4 files on to SD cards within the camcorder, and at the end of each night the data will be transferred to external hard drives for analysis.

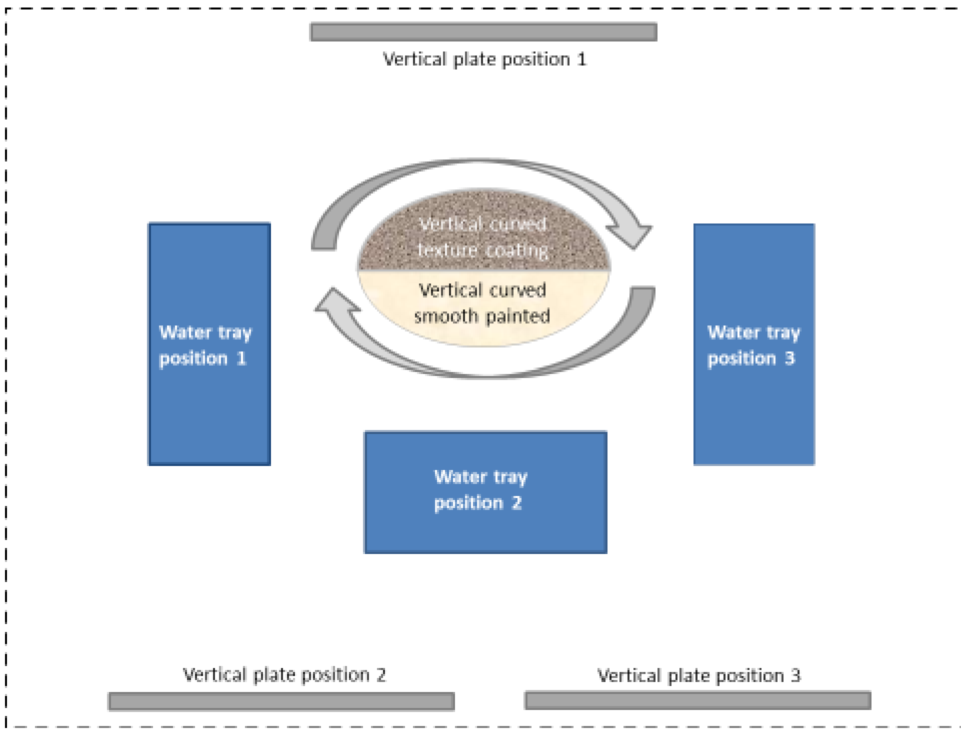


Fig. 7: Aerial representation of the vertical surface and water trays within the 2016 bat flight facility. Please note that the drawing is not to scale.

In addition, we will use a Fastec IL4 100 high speed mono imaging camera (South Central Imaging, Ltd., Westfield, IN) with a 17 mm lens (f 0.95) and 850 nm Infrared LED Light Bars (Larson Electronics LLC, Kemp, TX) to observe and record bat activity in low light conditions at surfaces (see Fig. 8).

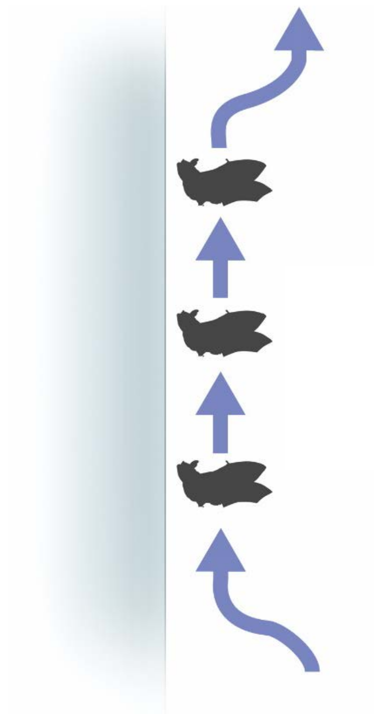


Fig. 8: Illustration of potential flight pattern of a bat making contact with a vertical test surface.

Data analysis: We will process all videos from the Canon XA20 camcorders in Studiocode (version 5, Studiocode Business Group, Sydney, AU). This program links each video with a timeline that matches the length of the video and saves the video and timeline as a movie package. Each package will be watched to identify and confirm number of passes within 1 m of each surface and the number of contacts with each surface within 60 minutes by each bat (Fig. 8). Response variables will be calculated for each bat separately. We will then compare the number of passes within 1 m and the number of contacts between the smooth painted and texture-treated surfaces for the 2 surface types (flat and curved).

As each bat or group of bats will have been tested on multiple nights, our analysis approach will need to take this into consideration to avoid pseudoreplication. If the response variables meet the assumptions of ANOVA (e.g., equal variance and normal distribution within each group) or can be transformed to meet the assumptions, we will use a repeated measures ANOVA to test for differences in mean responses between smooth and texture-treated surfaces for each surface type (flat and curved). The use of repeated measures will allow us to estimate variability within a bat and/or groups of bats between surface types. See the Appendix (Stat Doc) prepared by Valerie Cullinan at the end of this document for more details on the analysis approach. Alternatively, we may try other approaches including paired t-tests (if the differences are normally distributed) or randomization tests. For either of these alternative approaches, we will need to first summarize our response variables so that the number of data points equals the number of independent sampling units. For example, we may first calculate the difference in the number of touches at the texture-treated compared to the smooth flat surface for a single bat on each trial night. We could then use the mean of these differences over all trials (e.g., 2 trial nights) for that bat's individual response. And then, we could repeat this process to calculate the mean response for all bats within a single group.

References

Lollar, A. 2010. Standards and medical management for captive insectivorous bats. Bat World Sanctuary. 1:1-204.

Yuen, B. 2015. Surface texture differentiation using synthetic bat echolocation calls: implications for reducing bat fatalities at wind turbines. M.S. Thesis, Texas Christian University, Fort Worth, TX.

Appendix: Stats document (prepared by Valerie Cullinan)

It may very likely be that once a bat observes (echo) the textured surface it will recognize it again even though the surface is presented curved or flat. Thus, if a group of bats (or one bat, define either case as a test subject) is used twice, once with the curved and once with the flat surfaces, this will be a repeated measures experiment. For the repeated measures design, you must have each test subject go through both test scenarios. Missing repeated measures is more troublesome to analyze.

Repeated measures experiment for 15 subjects for a total of 30 trials (ok to have unequal numbers at this level) variable measured is the number of passes. Data looks like this.

Group	Subject (trial with bat or group of bats)	Smooth Surface	Textured Surface
F→ C	1	# of passes	# of passes
	2	# of passes	# of passes
	Etc.		
	7	# of passes	# of passes
C → F	1	# of passes	# of passes
	2	# of passes	# of passes
	Etc.		
	8	# of passes	# of passes

Group 1 = exposed to flat base first and curved base second = F→ C

- 7 subjects

Group 2 = exposed to curved base first and fat base second = C → F

- 8 subjects

ANOVA table (if interaction is significant need to compare surfaces within a group)

Source	Degrees of freedom	Test
Between Subjects		
Group = Order	g-1 = 1	Ho: Means are equal for either Order
Subjects w/in Group	(s1-1)+(s2-1)=6+7=13	Error for Testing Group
Within Groups		
Surface	1	Ho: Means are equal for either Surface
Order*Surface	1	Ho: Interaction of order and surface is not significant
Surface*Subject(Group)	13	Error for Test Surface and Order*Surface Interaction

DE-EE0007033
Texas Christian University
Texturizing Wind Turbine Towers to Reduce Bat Mortality

Task 4 (REVISED): Feasibility Study at Control Turbines at Wolf Ridge (Months 11-16)

Task Summary:

The purpose of this task is to conduct a field test in which bat activity is surveyed at operational wind turbine towers at Wolf Ridge Wind, LLC in Budget Period 2. This field survey effort will focus on June through mid-August 2016, a period that coincides with high levels of bat activity and mortality at this site. We will use our existing bat activity survey protocol, which will be modified to maximize detection of bat activity at wind turbine tower surfaces. Bat activity will be surveyed 2-5 nights per week during this time period at 3-5 pairs of turbines that are under consideration for turbine tower treatment in Budget Period 3. Using high-definition video cameras and night vision technology, as well as thermal cameras if available, bat activity will be recorded at paired operational turbine tower surfaces concurrently (each pair represents a potential control and texture-treated turbine pair in Task 6). In addition, ultrasonic bat detectors will be placed in proximity to the turbines during the night vision/thermal surveys to record acoustic bat activity. Using video analysis software, we will quantify the number of bats present during the paired activity surveys and document the types of behavior exhibited by bats in close proximity to turbine towers and time spent in the field of view (i.e., in close proximity to the wind turbine tower). The bat acoustic calls recorded will be used to confirm species presence at the survey sites using bat call analysis software. The results from this feasibility study will be used to refine the survey protocol for Task 6 in Budget Period 3.

Objectives:

The purpose of Task 4 is to develop, test, and refine a field survey protocol (i.e., a feasibility study) that will ultimately be used to inform Task 6 in Budget Period 3.

This document represents Milestone 4.1, a protocol for a feasibility study based on our existing behavioral survey protocol that we have refined over the past several years at Wolf Ridge. This protocol, which will be used in Task 4, describes the survey methods and provides a summary of the types of bat behavior that we anticipate seeing at control (i.e., smooth) wind turbine towers during a 11-week period in 2016. The results of this study, in conjunction with our prior field surveys and experimental trials conducted in the flight facility this year (Task 3) will be used to design a field study protocol at control and texture-treated wind turbine towers in Task 6 (if a “Go” decision is justified for Budget Period 3).

Deliverable 4.1 – Protocol for feasibility study: surveying bat activity and behavior at control wind turbines at Wolf Ridge

In a series of flight facility experiments conducted over the past 2 years, we have observed bats repeatedly making contact with smooth painted surfaces, but not with the textured surfaces, including those that led to the selection of a single texture coating for subsequent development in

Subtask 2.1. Furthermore, our findings in the flight facility support previous studies that bats misperceive smooth surfaces to be water (see Greif & Siemers 2010, Russo et al. 2012). Based on our results (from this study and McAlexander 2013), we hypothesize that bats may be similarly misperceiving the smooth surfaces of operational wind turbine towers such as those deployed at Wolf Ridge and elsewhere across North America, to be water. Subsequently, we further hypothesize that if bats are repeatedly making contact with turbine tower surfaces, then this behavior will increase collision risk with rotating blades by increasing the amount of time bats spend in or near the rotor swept zone. Based on our observations and the water misperception hypothesis, we therefore predict that bats will spend more time in close proximity and make more contacts with smooth turbine towers compared to texture-treated towers.

Hence, the purpose of this protocol is to further characterize bat activity and behavior at control (i.e., smooth) wind turbine towers at an operational wind farm. By providing detailed information about how bats approach and maneuver around smooth turbine towers, the data collected in this study will provide important insights into: 1) the extent of surface treatment that will be necessary to reduce bat activity near and within the rotor swept zone; and 2) the design of our field study in 2017. This study will also provide additional baseline data regarding bat activity in the immediate vicinity of wind turbine towers, that when added to existing data from this site, will improve our ability to estimate anticipated effect size (i.e., the reduction in bat activity) and plan for sample size in our anticipated texture treatment study (Task 6) in 2017.

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*.

Survey Methods

Surveys will be conducted at 3-5 pairs of wind turbines at Wolf Ridge (see Fig. 1) from June to mid-August 2016. Although the wind facility consists of 75 turbine towers, issues with landowners and habitat constraints greatly reduce the number of towers that are available to us to survey. Nonetheless, the selected turbines pairs are distributed across the wind resource area and we have baseline data on bat mortality and bat activity at these turbines for the past several years. Additionally, as it seems unlikely that the texture coating would be applied to more than 5 turbine towers in Budget Period 3 (assuming the second Go/No-Go decision point is passed), the sample size of turbine pairs in this feasibility study is comparable to the number of turbine pairs that would be included in the texture-treatment experiment.

Weather permitting, we will survey bat activity 2-5 nights per week for approximately 22-55 survey nights during this period, although the total number of nights may be adjusted due to overall levels of bat activity or limitations in site access due to storms. As we are ultimately proposing a paired study design (i.e., recording bat activity at control and treatment turbines simultaneously), we will survey bat activity at 2 turbine towers each night. Each turbine pair will be surveyed on at least 7 nights during this feasibility study.

Using high-definition video cameras and night vision technology, as well as thermal cameras if available, bat activity will be recorded at a set of paired turbine tower surfaces concurrently. Within a single survey night, surveys will be conducted as a series of 30 min sessions that will begin approximately 30 minutes before sunset and will continue up to 3 hours after sunset (the primary activity period for bats). Note that the timing of the sessions will be the same at both turbines within a pair each survey night.

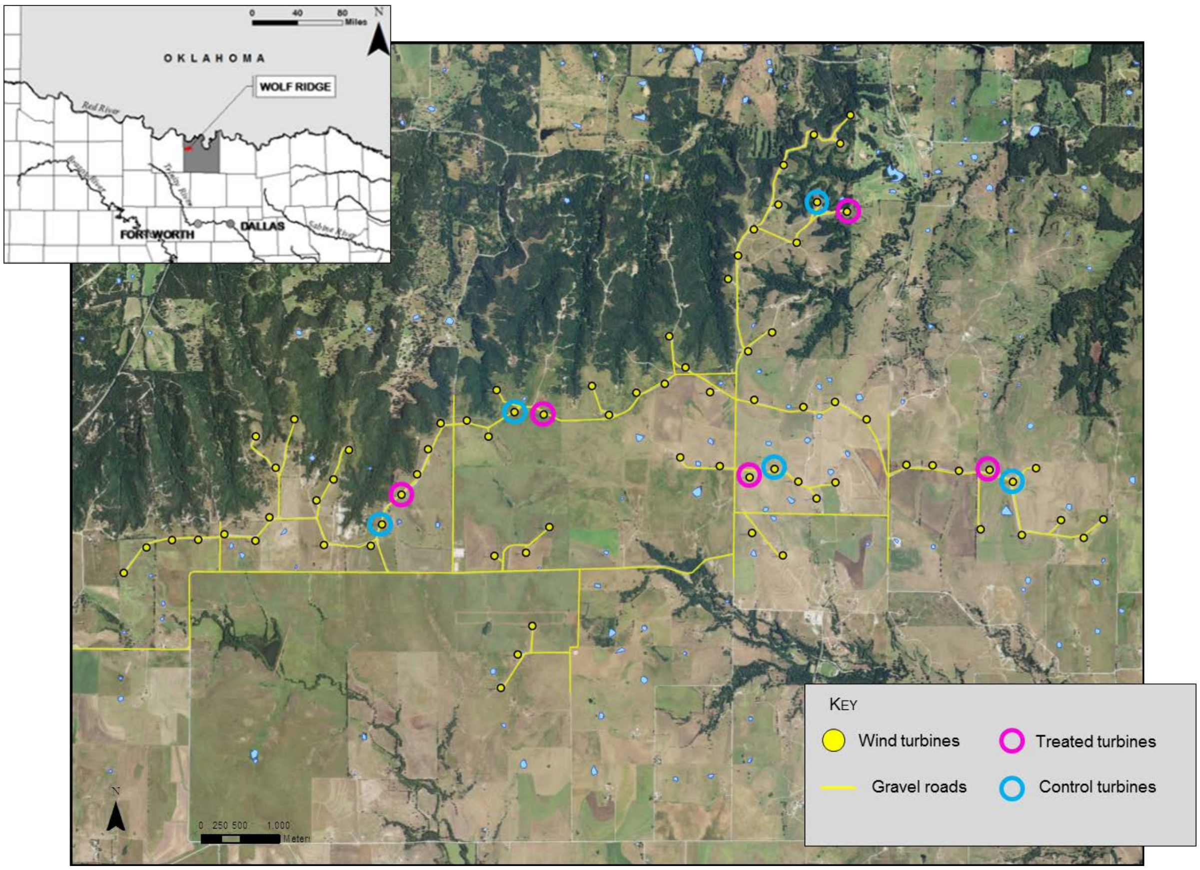


Fig. 1: Map illustrating the locations of 5 potential pairs (treated and control) of wind turbines at Wolf Ridge Wind, LLC.

Two SONY HDR-PJ790 video cameras mounted on tripods will be placed at each turbine. The video cameras in daylight mode will be used for the first 30 minute session of each survey period, then ATN-NVM14 night vision scopes will be attached to the cameras for the remainder of the night (Fig. 2). One camera set-up will be placed on the gravel pad beneath the windward side of the tower and the other set-up on the leeward side. Cameras will be angled (10 m above the gravel pad) up the tower surface to the face of the nacelle hub (~80 m height; Fig. 3). This positioning will allow for all bat activity (including, but not limited to, foraging, passing, chasing, gleaning, drinking attempt, collision, reversal of direction, etc.) to be recorded in close proximity to the tower surface, and include areas where we anticipate applying the texture coating on treatment turbines next year. 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 camera and angled upwards towards the turbine tower surfaces. If possible, one to two thermal cameras will also be placed 30 to 50 m from the turbine towers to more effectively identify individual bats approaching the turbine towers.

In addition, ultrasonic bat detectors will be placed in proximity to the turbines during the night vision video/thermal surveys to record acoustic bat activity. An AR-125 bat detector and recorder will be deployed near to the video camera set-up to record echolocation calls from bats near the turbine towers. The acoustic detector will record for the entire monitoring period.

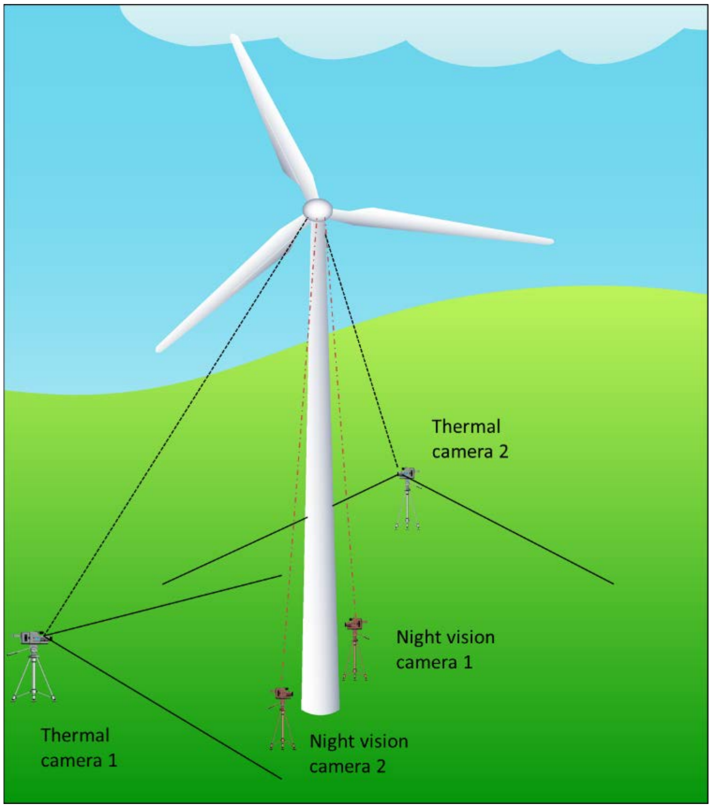


Fig. 2: Diagram of camera set-up for bat activity surveys at wind turbine towers at Wolf Ridge Wind, LLC.

At least 2 technicians will be present at each paired turbine surveyed each night. Video recordings will be started simultaneously on both cameras at each turbine, 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, humidity, dew point, barometric pressure), recording times and details, and any additional notes. We will also record the presence of condensation, if any, on the turbine towers. 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.

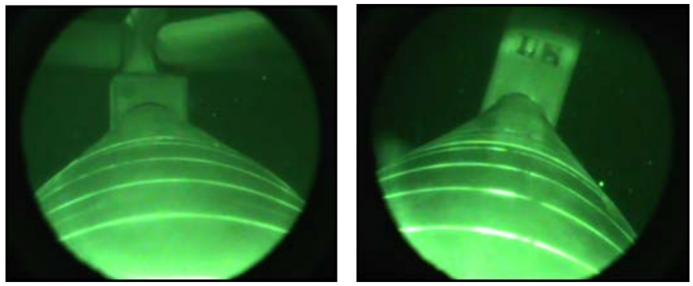


Fig. 3: Night vision camera set up on windward and leeward side of the turbine focused up the turbine tower.

Data Management and Analysis

We will process all videos from the Canon camcorders in Studiocode (version 5, Studiocode Business Group, Sydney, AU). This program links each video with a timeline that matches the length of the video and saves the video and timeline as a movie package. Within the program, we will stack the windward and leeward videos, and potentially the thermal recordings, to one timeline allowing us to view all footage at a single turbine for each session simultaneously. Using flanges (i.e., external ridges) on the tower surfaces as distance indicators, we will divide the camera views into zones in a code window. Using video analysis software, we will determine if bats are present during the paired activity surveys, document levels of activity by counting the number of bats, and document types of behavior exhibited and time spent in the field of view (i.e., in close proximity to the wind turbine tower). We will identify specific types of behavior exhibited by the bats including foraging, passing, and contacts made with the tower surface. We will also use markings on the turbine towers (see Fig. 3) to estimate the height of individual bats when they are passing, foraging, or making contact with the turbine towers. A summary of bat activity along the tower length will be used to inform the extent of the texture treatment coating that will be applied to the turbine towers in 2017.

If possible, we will initially use thermal camera images to confirm the presence of a bat as it approaches the tower surface. As the thermal signature from the wind turbine towers will likely mask bat activity at the tower surface itself, we will use the matching timelines to effectively identify bats in the Canon videos, from which we will further investigate and characterize behavior. 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. Finally, we will use Minitab v. 17 statistical software to analyze the data collected during this study ($\alpha = 0.05$).

Our anticipated response variables will be the difference in activity level as evidenced by the number of bats, number of contacts made with towers, and types of activity observed (e.g., foraging behavior, commuting behavior, etc.) between the turbines within each pair on a nightly basis. The paired design that we propose to implement in Task 6 will help control for variation in bat activity across the wind facility within survey nights. By surveying each pair of turbines on multiple evenings, we will obtain a better estimate of each mean response variable for each tower pair. We will also use a time series analysis to understand how bat activity changes over the survey period. We will calculate the mean activity at each turbine pair every 2 weeks, and will use these temporal replicates to compare bat activity over time (using either an ANOVA or a Kruskal-Wallis test if the assumptions of ANOVA cannot be met).

References

Greif S, Siemers BM (2010) Innate recognition of water bodies in echolocating bats. Nature 1: doi:10.1038/ncomms1110.

McAlexander, A (2013) Evidence that bats perceive wind turbine surfaces to be water. Thesis, Texas Christian University.

Russo D, Cistrone L, Jones G (2012) Sensory ecology of water detection by bats: a field experiment. PloS ONE 7: doi:10.1371/journal.pone.0048144.

Texas Christian University
Texturizing Wind Turbine Towers to Reduce Bat Mortality

EXECUTIVE SUMMARY

This document presents the results of Task 4 and the completion of Milestone 4.2.

> ***Milestone 4.2 – Complete activity surveys at operational wind turbines from July to-mid-August in 2016 at Wolf Ridge.***

For this task, we conducted a feasibility study consisting of monitoring bat activity at wind turbine tower surfaces at 3 pairs of turbines at Wolf Ridge Wind, LLC. The expected outcome of Task 4 was to inform Task 6 by determining how free-flying bats behave around and in close proximity to the current smooth surfaces of operational wind turbine towers from July through mid-August 2016. The majority of this time period coincides with the fall migratory season of tree bats and peak bat fatality rates at wind turbines across North America.

For this feasibility study, we conducted bat behavior surveys at wind turbine towers using a combination of night vision technology, thermal cameras, and acoustic bat detectors. Across the survey season, the night vision and acoustic set-up remained the same; however, we modified the position and field of view of the thermal camera set-up in order to maximize bat detections at turbine sites. By refining the thermal camera set-up, we were able to establish that the most effective equipment arrangement for detecting bat activity around turbine tower surfaces was to have a night vision set-up and thermal camera set-up together at both the leeward and windward sides of the turbine tower. We also refined the analysis process in order to more effectively and consistently identify bats and their behavior. For this, we created a systematic guide to bat identification for use during video processing.

From July 1 to August 10, we detected 171 video observations of bats near the turbine tower surfaces and 181 acoustic recordings representing 5 of the 6 bat species known to be at Wolf Ridge. We found that bat activity across the survey period (i.e., the fall migration period) yielded sufficient bat observations to effectively undertake a paired treatment study at the wind resource facility in Task 6. Furthermore, by examining both video observations and recorded acoustic bat activity across survey nights, we determined that the timing of the nightly survey efforts was appropriate. Among the 171 bat observations, we detected 7 of 8 defined behaviors: passing, reversing, looping, foraging, skimming, sweeping, and colliding; the exception being gleaning. We further classified these behaviors into three categories based on proximity to the turbine tower surface: contact/close contact, close-range, and far-range. Of the behaviors observed, 9% were classified as contact and close contact, 42% as close-range, and 49% as far-range. We then explored bat activity at specific turbine sites and found that bat activity did not vary within paired turbines. This similarity in activity provides strong support for our proposed paired study design at Wolf Ridge (Task 6), as it indicates that we will be able to estimate the effectiveness of the texture treatment at altering bat behavior within the selected paired turbine sites. Finally, we compared the type and frequency of behaviors exhibited by bats and how these varied in proximity to the turbine tower surface. We determined the both type and frequency of behavior varied with distance from the turbine surface and that these differences appear to be associated with turbine tower interaction. Specifically, contact, close contact, and close-range behaviors tended to be more dependent on turbine tower surface interactions, whereas far-range activity by bats appeared independent of the turbine tower surface. Our findings emphasize the importance of separating bat activity and behavior into distance categories, as we would expect that the application of the texture treatment to wind turbine tower surfaces would most likely only reduce contact, close contact, and close-range bat activity.

A. PROJECT OBJECTIVES

The purpose of Task 4 was to develop, test, and refine a field survey protocol that will be used to inform Task 6 in Budget Period 2.

This document represents Milestone 4.2, a completed survey and documented report detailing bat behavior in close proximity to operational wind turbines. The report, which details the results of surveys conducted in Task 4, describes how survey methods were tested and refined, how data collected was analyzed effectively, and provides a key to the types of bat behavior that we saw at control (i.e., smooth) wind turbine towers during a 6-week period in 2016. The results of this study, in conjunction with our prior field surveys and experimental trials conducted in the flight facility this year (Task 3), will be used to design a field study protocol at control and texture-treated wind turbine towers in Task 6 (see Milestone 6.1).

Task 4 (REVISED): Feasibility Study at Control Turbines at Wolf Ridge (Months 11-16)

Task Summary:

The purpose of this task was to conduct a field test in which bat activity was surveyed at operational wind turbine towers at Wolf Ridge Wind, LLC in Budget Period 2. This field survey effort focused on July through mid-August 2016, a period that coincides with high levels of bat activity and mortality at this site. We used our existing bat activity survey protocol, which in this feasibility study was modified to maximize detection of bat activity at wind turbine tower surfaces. Bat activity was surveyed an average of 3-4 nights per week during this time period at 3 pairs of turbines that are under consideration for turbine tower treatment in 2017. We used high-definition video cameras and night vision technology, as well as thermal cameras, to record bat activity at paired operational turbine tower surfaces (each pair represents a potential control and texture-treated turbine pair in Task 6). In addition, ultrasonic bat detectors were placed in proximity to the turbines during the night vision/thermal surveys to record acoustic bat activity. Using video analysis software, we quantified the number of bats present during the activity surveys and documented the types of behavior exhibited by bats in close proximity to turbine towers. Furthermore, the bat acoustic calls recorded were used to confirm species presence at the survey sites using bat call analysis software. The results from this feasibility study will then be used to refine the survey protocol for Task 6 in Budget Period 2.

B. PROJECT METHODS

Field 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: eastern red (*Lasiurus borealis*), hoary (*Lasiurus cinereus*), silver-haired (*Lasionycteris noctivagans*), tri-colored (*Perimyotis subflavus*), evening (*Nycticeius humeralis*), and Mexican free-tailed (*Tadarida brasiliensis*) bats. In the last three years, we have also recorded the presence of an additional bat species, the canyon bat (*Parastrellus hesperus*).

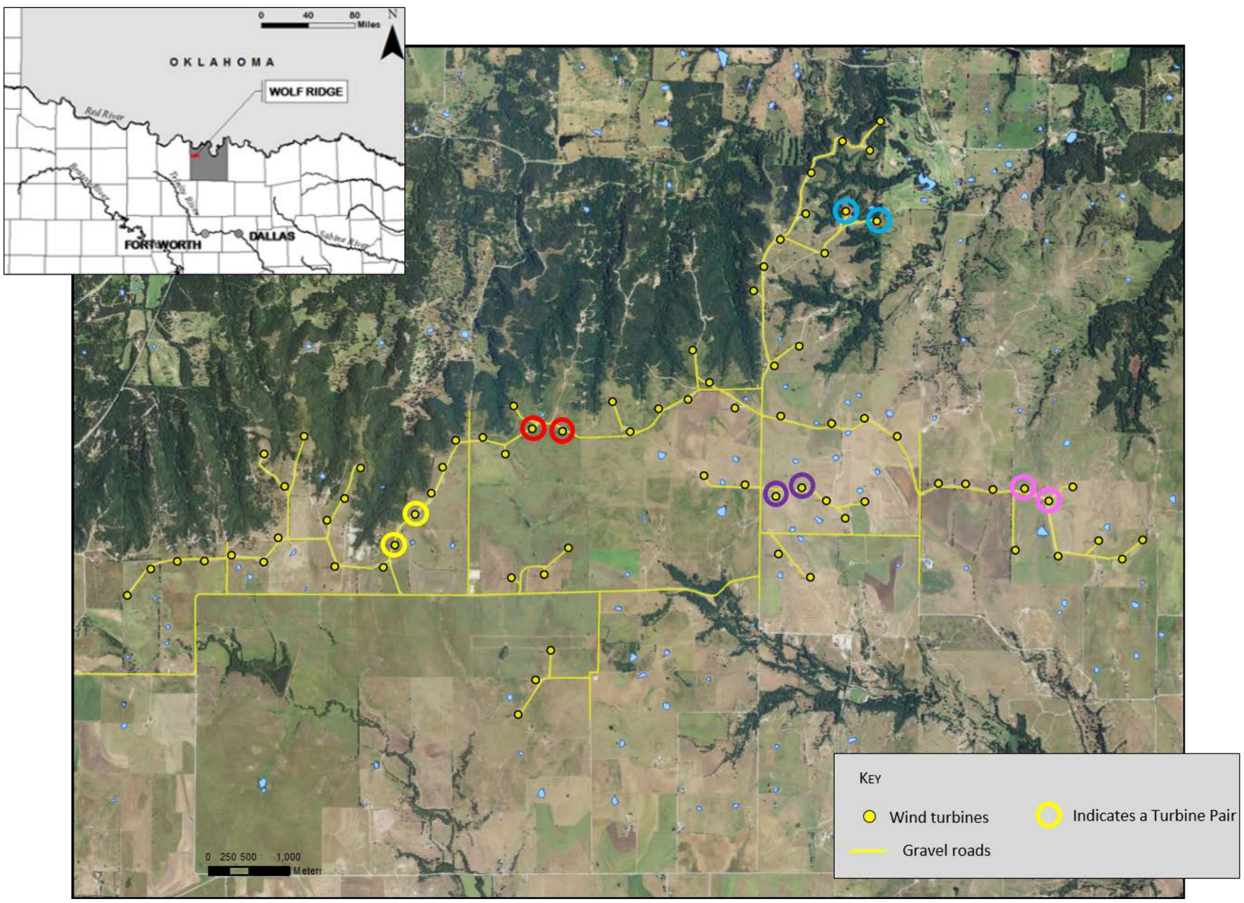


Figure 1: Map illustrating the locations of the 5 possible study pairs of wind turbines at Wolf Ridge Wind, LLC. From left to right: turbines 1a & 1b (yellow), turbines 2a & 2b (red), turbines 3a & 3b (purple), turbines 4a & 4b (blue), and turbines 5a & 5b (pink).

Five paired turbines were identified as sites where this feasibility study and the study to explore control and texture-treated wind turbine towers (Task 6) could potentially be conducted (Fig. 1). These sites were determined to have high levels of bat fatality, as shown in bat carcass searches conducted at the Wolf Ridge from 2009 to 2014. The area around each of these turbines was also clear of vegetation and other obstructions for a radius of 50 m from the base of each turbine. For the feasibility study, 3 of these paired turbine sites were selected; turbines 2a & 2b, 3a & 3b, and 4a & 4b (Fig. 1). These paired turbines were chosen at the time of the feasibility study because 2 of the 5 paired turbine sites (turbines 2a & 2b and 4a & 4b) represented sites known to have the highest levels of bat activity from night vision surveys conducted in 2012 and 2013. We also were unable to survey at turbines 5a & 5b due to safety issues caused by a damaged wind turbine blade that have since been resolved, and opted instead, to survey at turbines 4a & 4b as these turbines tended to have regular pulses of bat activity during the bat migratory period (July to September).

Survey Methods

Surveys were conducted at the 3 selected pairs of wind turbines at Wolf Ridge from July to mid-August 2016 and we surveyed bat activity 3-4 nights per week during this period. At least 2 technicians were present at each turbine surveyed each night. For these surveys, we used high-definition video cameras and night vision technology, as well as thermal cameras to record bat activity at turbine tower surfaces. As part of this feasibility study, we did vary certain aspects of the camera setup, particularly the position of the two Axis Q1932-E 19MM thermal cameras used (see below).

Night Vision Camera Set-up

Note that the night vision set-up remained the same throughout the survey period, as their placement had been determined to be optimal in previous behavioral studies conducted at the wind facility in 2012 and 2013. Each turbine was monitored with two night vision set-ups. Each set-up comprised an ATN-NVM14 night vision scope attached to a Sony HDR-PJ790 video camera on a Manfrotto MT055XPRO3 tripod, along with two ATN Super Long Range Infrared Illuminator IR450 infrared lights on VELBON EF tripods.

One night vision set-up was placed on the leeward side of the turbine (directly beneath the nacelle on the opposite side of the turbine blades) approximately 2 m from the base of the turbine; the other set-up was placed on the windward side of the turbine beneath the blades (Fig. 2). We angled the night vision set-ups via the tripod so that the field of view was up the tower surface to the face of the nacelle hub (from 10 m above the gravel pad to ~80 m above ground; Fig. 3). This positioning allowed for all bat activity to be recorded in close proximity to the tower surface from approximately 10-80 m from the ground (i.e., encompassing the majority of the turbine tower). Supplemental light was provided for each night vision camera using external tripod-mounted infrared lights. Four infrared lights were mounted on tripods and placed approximately 1 m to either side of each night vision camera and angled upwards towards the turbine tower surfaces. The Sony cameras were powered by Sony NP-FV100 batteries, while the night vision scopes and infrared lights were powered by rechargeable C cell batteries. All batteries were removed and charged at the end of the night. Finally, the night vision cameras saved video recordings internally as .MP4 files; the recordings were downloaded from the camera at the end of each survey night for storage and analysis.

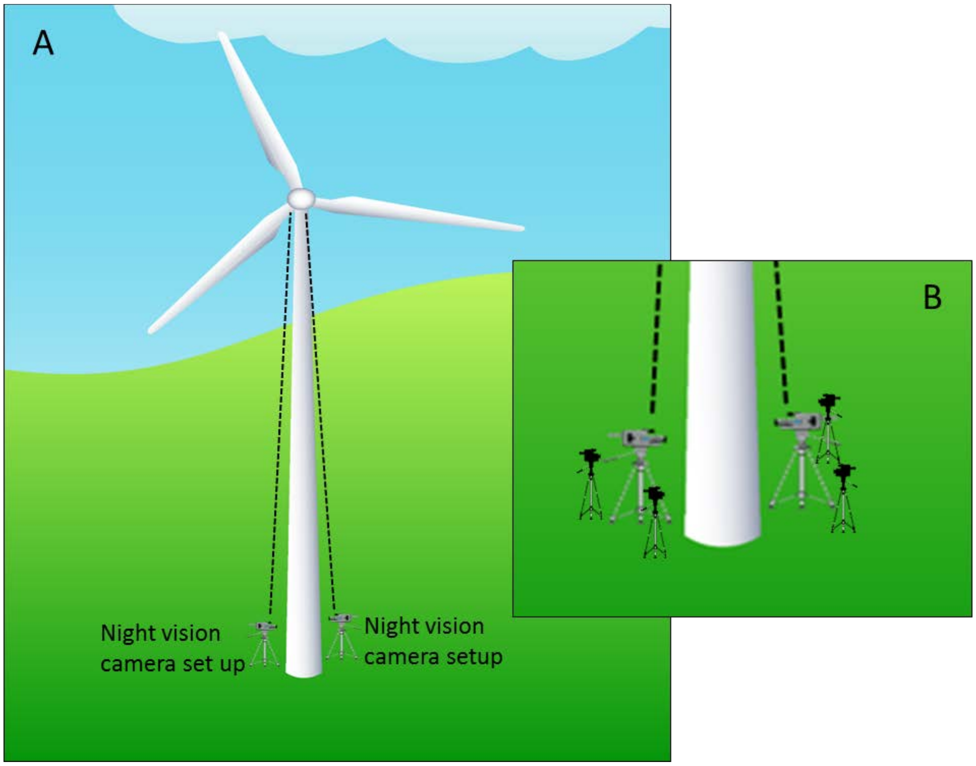


Figure 2: **A** depicts night vision camera set-up for bat activity surveys at wind turbine towers at Wolf Ridge Wind, LLC. **B** shows night vision camera set-up with two IR lights on tripods on both sides of the cameras.

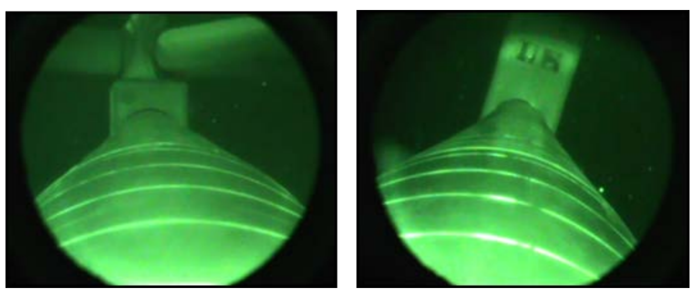


Figure 3: Night vision set-up view on windward and leeward sides of the turbine focused up the turbine tower to detect bat activity at wind turbines at Wolf Ridge Wind, LLC.

Thermal Camera Set-up

Each turbine was monitored with one or two thermal camera set-ups in a survey night. Each set-up comprised an Axis Q1932-E 19MM thermal camera on Manfrotto MT055XPRO3 tripod. These cameras were connected to an HP Compaq 8510w laptop computer via Ethernet cables and a Netgear ProSAFE 8-port fast Ethernet PoE switch. Both the laptop and the Netgear Ethernet switch were powered with a 12V car battery via a Cen-Tech Power Inverter, which in turn powered the thermal cameras. We used Axis camera software on the laptop to synchronize the thermal cameras' internal clocks and trigger recording. During the entire survey period, we placed the laptop within 5 m of the leeward camera and covered the screen during recording sessions. This measure was taken to prevent any light from the laptop screen from potentially affecting bat activity during the surveys. The thermal cameras saved recordings through a Sony 32 MB micro-SD card onto the HP laptops as .MTS files; these recordings were then converted using “Any Video Converter Free” software to .MP4 files at the each of each survey night for analysis and storage.

Note that the position of the thermal camera set-up and angle of the tripod head was modified across the beginning of the survey period season to identify the field of view that maximized detection of bat activity in proximity to wind turbine tower surfaces (see below). Initially, two thermal cameras were placed 95 m away from the turbine perpendicular to each other (Fig. 4A). The tripod head was angled so that the cameras captured a field of view that included the top 60 m of the turbine tower from the bottom of the nacelle (Fig. 4B). We surveyed using this set-up from July 1 to 11, 2016.

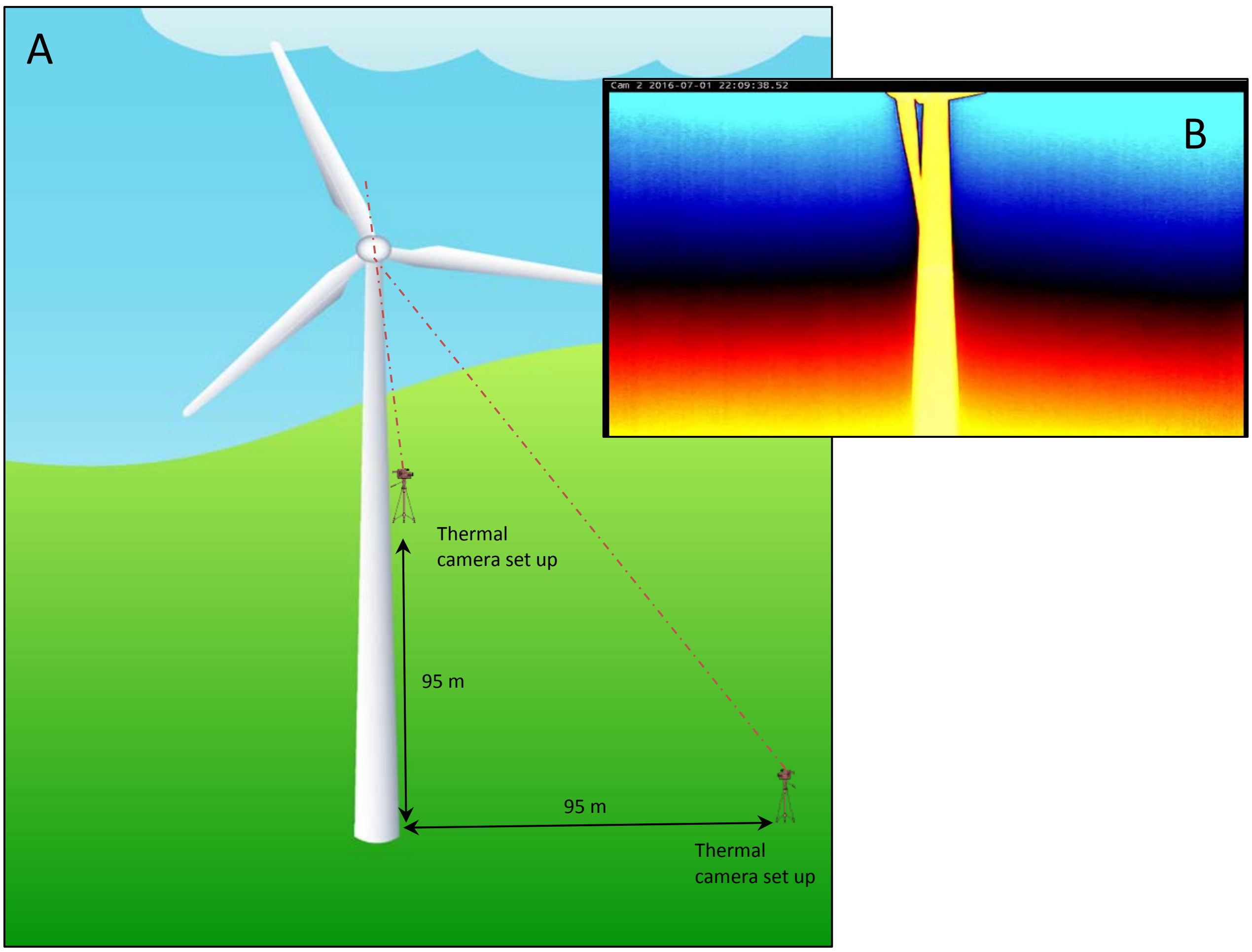


Figure 4: **A** depicts thermal camera set-up using two thermal cameras placed perpendicular to each other 95 m from the wind turbine base at Wolf Ridge Wind, LLC. **B** shows the field of view from each thermal camera that includes a 60 m length of the turbine tower: 20 m from the ground up to the bottom of the nacelle.

Variations to the thermal camera set-up

From the initial thermal camera set-up, preliminary analysis of the video data revealed that bats in this field of view were too far away to effectively distinguish from other flying objects (i.e., the resolution was too low). Thus, we moved the thermal camera set-up to a distance of 2 m from the base of the turbine (Fig. 5A). The tripod head was angled to provide a field of view in which the turbine tower was visible from 10 m from the ground up to the nacelle (Fig. 5B). With this alternative set-up, we conducted surveys at two turbine sites concurrently using one thermal camera at each site and surveyed the leeward side of the turbine tower where we have in the past recorded the majority of bat activity.

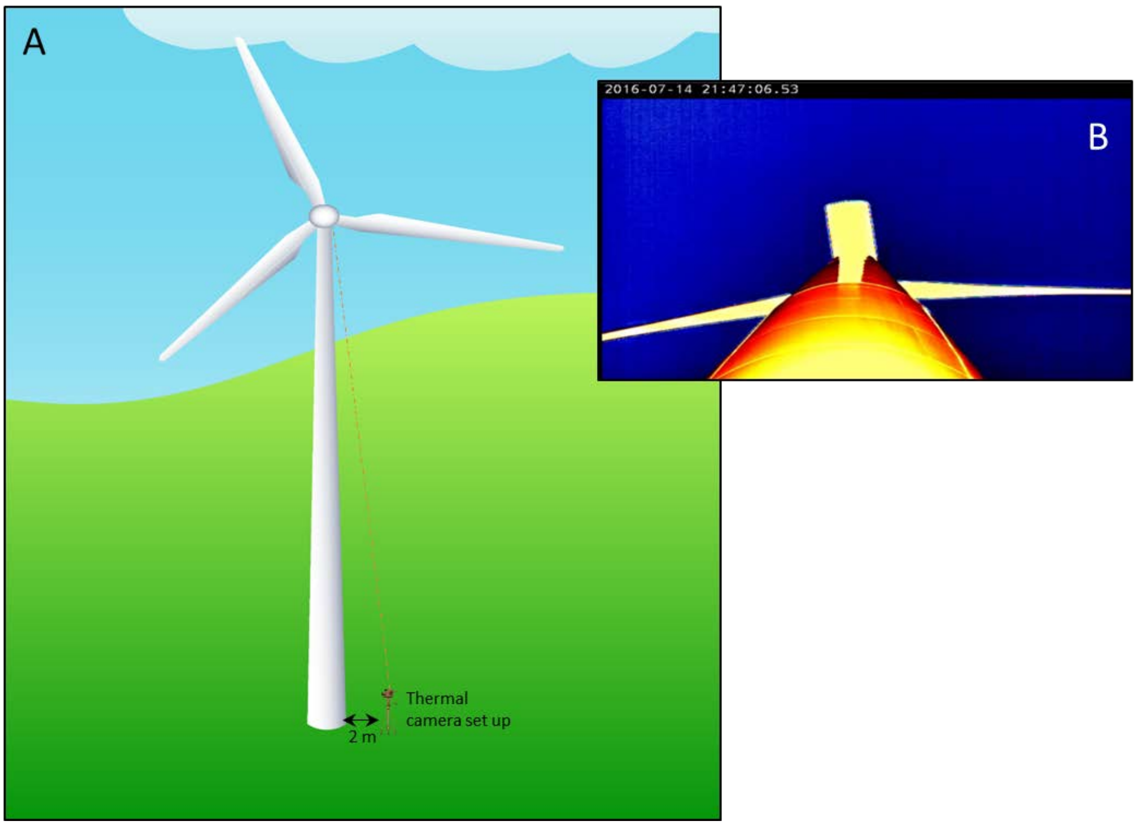


Figure 5: **A** depicts thermal camera set-up from 2 m from the wind turbine base at Wolf Ridge Wind, LLC. **B** shows the field of view from the thermal camera. Note the screen was centered where the tower meets the nacelle in order to establish a field of view that includes 10 m from the ground up to the nacelle.

At this second set up, the videos from the thermal camera at the base of the tower greatly increased our ability to distinguish bats from other flying objects; however, the field of view appeared limited to the tower surface (i.e., we could not see bats approaching the tower). As we were unable to observe bats approaching the turbine tower, we had concerns that this could make it difficult to effectively identify specific behaviors and activities conducted by the bats. Thus in subsequent surveys, to increase the field of view we angled the tripod heads so that the turbine tower was visible from 7.5 m from the ground up to the nacelle and the field of view was extended to include more airspace on either side of the turbine tower (Fig. 6). In our preliminary analysis of the video data, we found that changing the angle of the thermal cameras did provide a better field of view, which allowed us to identify bats approaching the turbine tower more effectively.

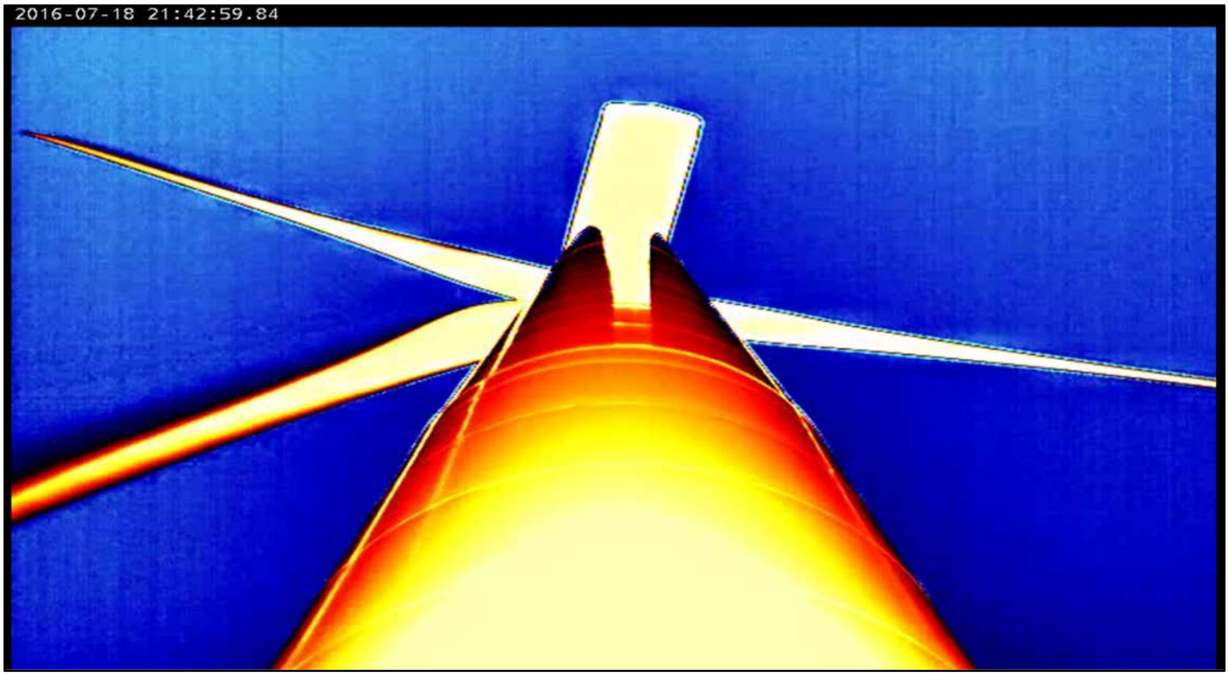


Figure 6: Thermal camera set-up from 2 m from the wind turbine base at Wolf Ridge Wind, LLC. Image shows the field of view of the turbine tower including 7.5 m from the ground up to the nacelle.

Using both thermal cameras at a single turbine site, we then set out to determine if a thermal camera placed at a 2 m distance from the turbine base would maximize bat detection. Keeping one thermal camera at this 2 m distance, we placed a second thermal camera at a distance of 50 m and angled this tripod head so that the bottom of the rotor swept zone was in the middle of the field of view (Fig. 7).

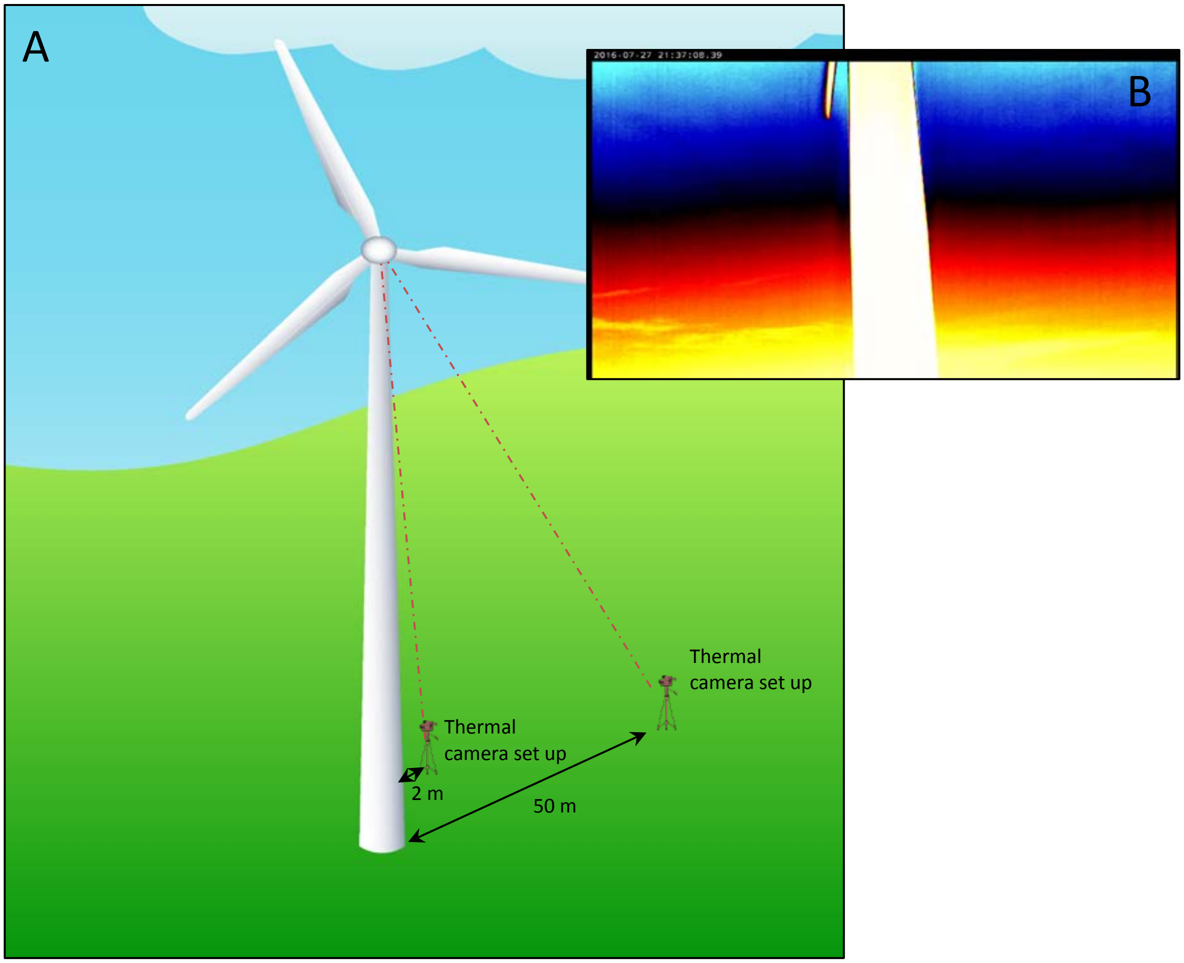


Figure 7: **A** depicts thermal camera set-up, with one camera 2 m from the wind turbine base and a second camera 50 m from the base at Wolf Ridge Wind, LLC. **B** shows the field of view from the second thermal camera.

Comparing the two distances, we found that we were able to determine bat activity to the same extent at both distances, but the bats could be more effectively distinguished at 2 m. We then proceeded to move the second thermal from 50 m to 25 m to establish if this closer distance yielded qualitatively better results (Fig. 8).

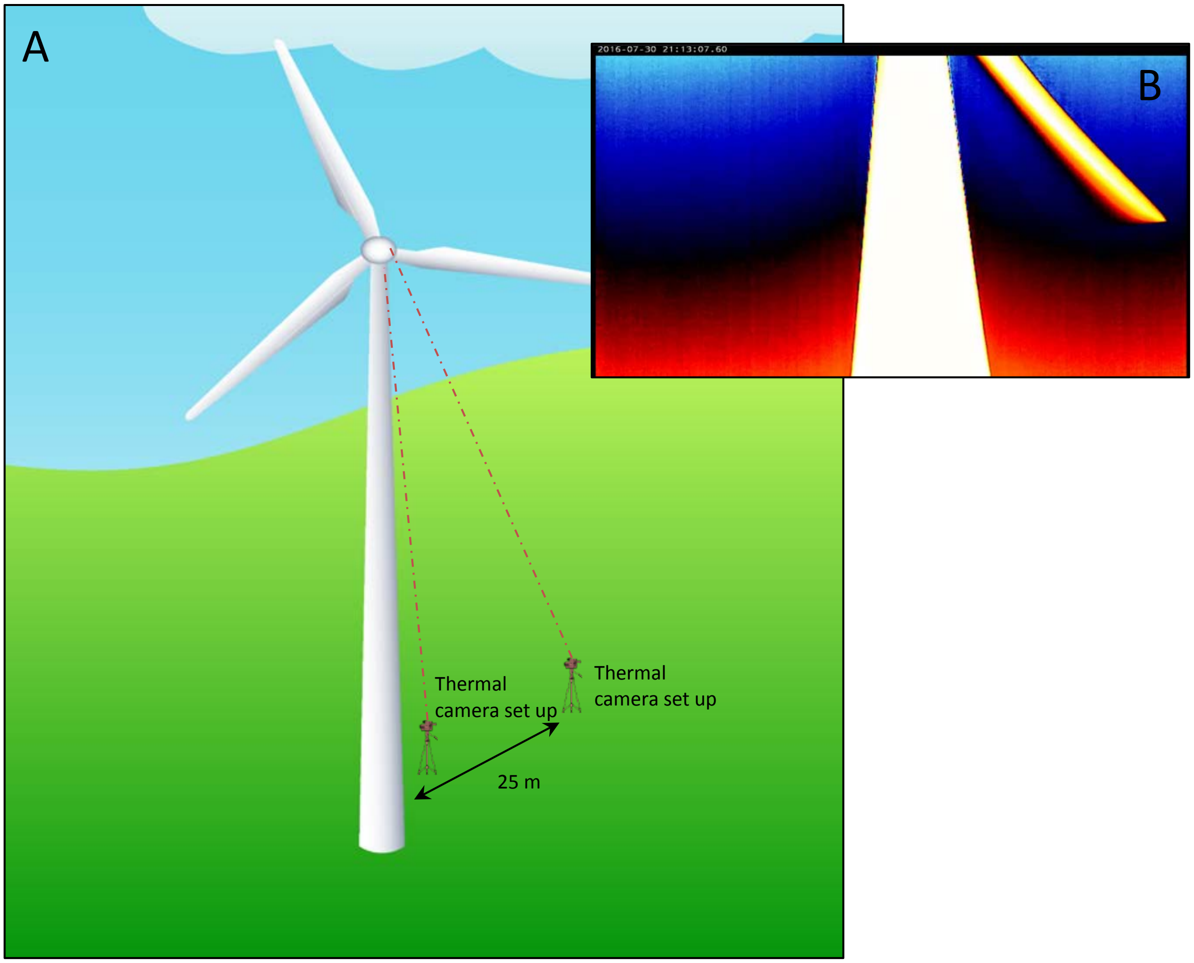


Figure 8: **A** depicts thermal camera set-up, with one camera 2 m from the wind turbine base and a second camera 25 m from the base at Wolf Ridge Wind, LLC. **B** shows the field of view from the second thermal camera.

Again upon comparison, we found that we were able to determine bat activity to the same extent at both distances, but the bats could be more effectively distinguished from other flying objects at 2 m. Based on these results, we determined that placing the thermal camera set-ups 2 m away from the base of the turbine tower with the tripod head angled so that the field of view encompassed the turbine tower surface 7.5 m from the ground up to the base of the nacelle, would maximize detection of bat activity at wind turbine tower surfaces. We then proceeded to conduct surveys at turbine sites, with one thermal camera set-up placed on the leeward side of the turbine and another thermal camera set-up on the windward side (Fig. 9). This overall set-up (i.e., the final set-up used in this feasibility study) represents the thermal camera set-up we are recommending be used in the field study protocol at control and texture-treated wind turbine towers in Task 6.

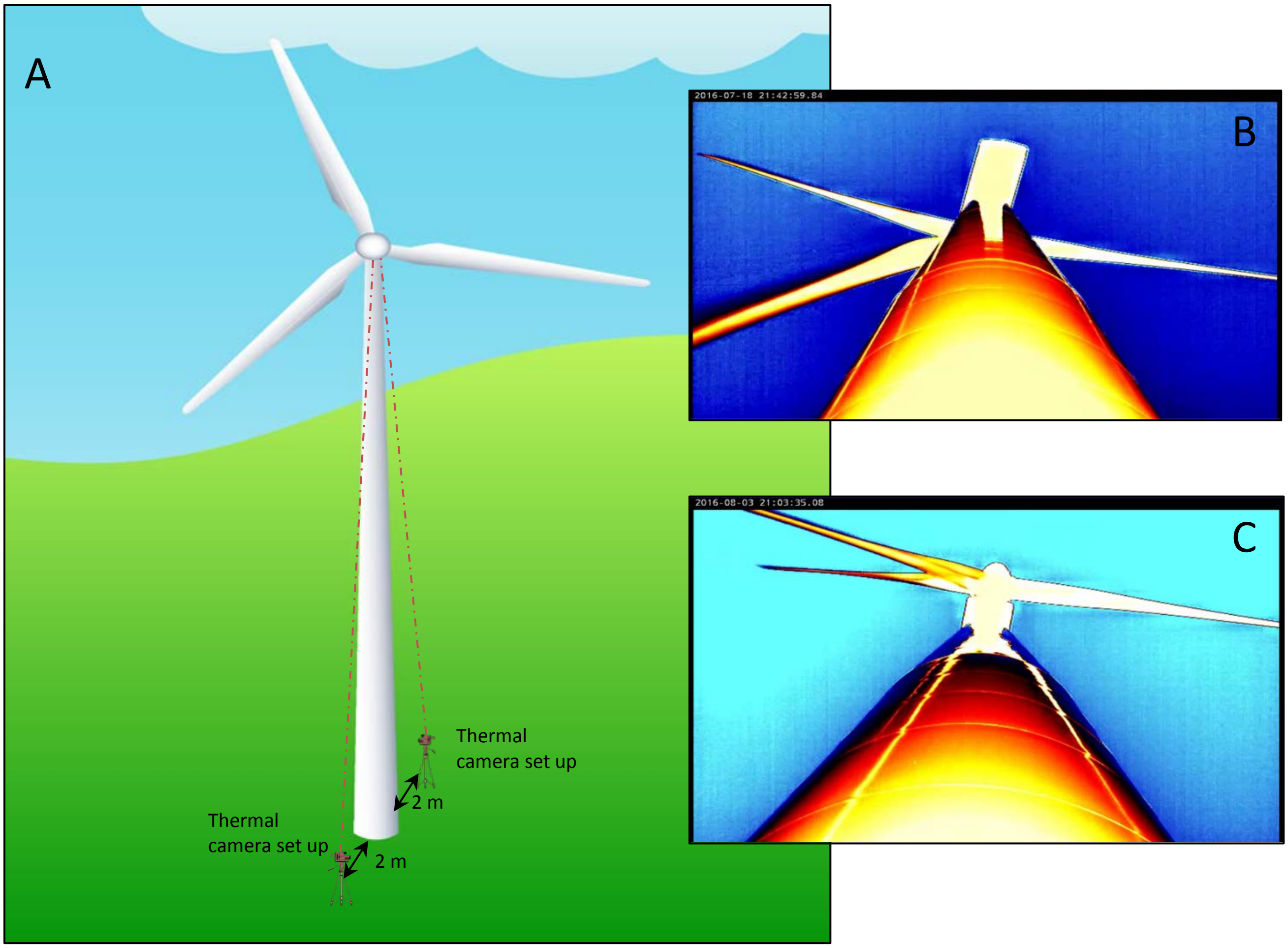


Figure 9: **A** depicts thermal camera set-up, with one camera 2 m from the wind turbine base on the leeward side of the turbine tower and a second camera 2 m from the base on the windward side at Wolf Ridge Wind, LLC. **B** shows the field of view from the thermal camera on the leeward side of the turbine tower and **C** shows the view from the camera on the windward side.

Acoustic surveys

Ultrasonic bat detectors were also placed in proximity to the turbines each night during the survey period to record acoustic bat activity. An AR-125 bat detector and recorder were deployed alongside the night vision camera set up (i.e., 2 m from the base of the turbine) on the leeward side of the turbine tower to record echolocation calls from bats near the turbine towers (Fig. 10). The acoustic detector was powered by a 12V car battery. Note that the position of this acoustic detector remained the same throughout the survey period. The AR-125 detectors saved recordings as .wav files onto a Sony 32 MB micro-SD card. These recordings were downloaded at the end of each survey night for analysis and storage.

In addition, a handheld Batbox detector was placed on a tripod next to each night vision camera. This detector was set at a frequency of 40 KHz (a frequency at which all local bat species can be detected) and volume set on maximum. The detector provides an audible indictor that a bat is present in real time, which is recorded on the camera video files and can be used to confirm bat presence in our video analysis (see Data Management and Analysis section).

Survey procedure

Within a single survey night, surveys were conducted as a series of 10 min sessions that began approximately 20 minutes after sunset and continued up to 3 hours (i.e., during the primary activity period for bats). In order to record bat activity in low light levels present at the start of each survey night, the Sony cameras were used without the ATN-NVM14 night vision scopes and infrared lights for the first 10-minute session of each survey period.

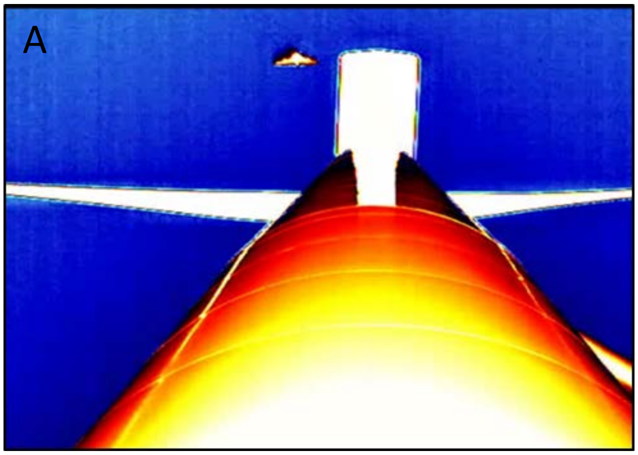
At the beginning of each session, all cameras were started simultaneously at a turbine, so that the videos could later be synchronized for video analysis (see Data Analysis section below). We also kept the timing of the sessions as synchronized as possible when two turbine sites were surveyed within the same survey night. Note that all equipment was removed from the area after the last recording session each night.

In addition, we completed a data form at the beginning of each session to record start and end times of each session, survey personnel present, and weather conditions including temperature (C°), wind speed (km/h), wind direction, humidity (%), dew point (C°), barometric pressure (Hg in), cloud cover (full, partial, and clear), moon phase, moon illumination (%), and whether the moon was visible. Furthermore, surveys were only conducted on nights with wind speeds averaging less than 24 km/h and no precipitation.

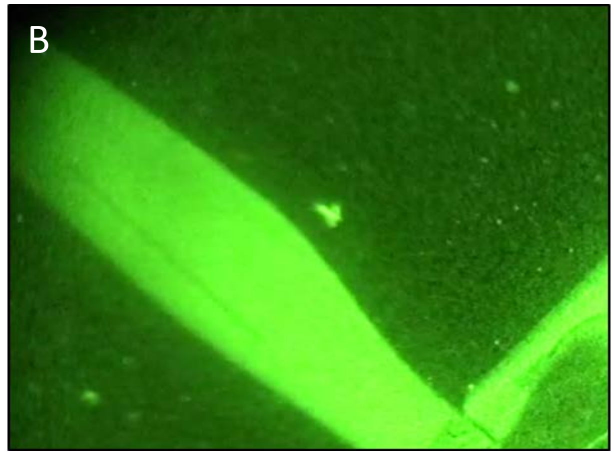
Data management and Analysis

We processed all videos from the cameras in Studiocode (version 5, Studiocode Business Group, Sydney, AU). Using this program, we were able to link videos from both night vision and thermal cameras onto a single timeline, so that the videos could be viewed together. Once the videos were linked, we were then able to view all footage for a single session at a turbine site simultaneously. We viewed each session in its entirely and marked on the timeline when an object was observed flying in the video(s).

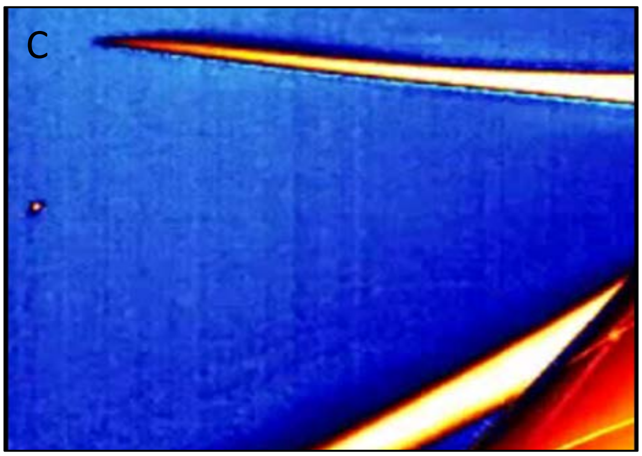
In order to systematically identify objects, we created a Bat Identification Key. This key was constructed as a step-step guide that allows the user to effectively and consistently identify flying objects as bats, non-bats, and possible bats. An object was determined to be a bat when the silhouette of the object resembled that of a bat (i.e., a visible head, body, and wings) and only had characteristics associated with a bat. We determined an object to be a non-bat when it had characteristics of an insect, bird, plane, or other flying object. In contrast, an object was considered a possible bat when 1) there were no definitive characteristics observed to indicate the object was a bat (e.g., head and distinct wings), 2) there were no characteristics that suggested the object was a non-bat (e.g., tail), and 3) characteristics were not sufficiently resolved (e.g., indistinct wings). Figure 10 provides examples of bat, non-bat, and possible bats. For this procedure, each flying object was viewed in Studiocode to determine if: 1) the object was actively flying in the area near the turbine tower (i.e., not above the nacelle); 2) the object had features and behaviors characteristic of bats or non-bats that could be seen in thermal camera images; 3) the object had features and behaviors characteristic of bats or non-bats that could be seen in night vision camera images; and 4) bat acoustic calls were heard on the videos when the object was in the field of view.



This object was identified as a bat because it had a distinct head, body, and wings. Note that you can see the finger bones in the patagium.



This object was determined to be an insect such as a dragonfly because it had a long body with wings at the front end.



This object was determined to be a possible bat because we could not ascertain whether the dark patches at the sides of the body were wings or shadows created by the body.

Figure 10: Examples of flying objects entering the field of view in video footage recorded at wind turbine tower surfaces at Wolf Ridge Wind, LLC, that were categorized as bat (**A**), non-bat (**B**), and possible bats (**C**).

Once all of the flying objects had been categorized, we reviewed all the ‘bats’ to further classify their behavior. For this process, we defined 8 specific types of behavior exhibited by the bats in proximity to turbine towers. These behaviors included: *passing* when a bat flies through the field of view with ≤1 change in direction or turning angle; *reversing* when a bat enters the field of view and before reaching the wind turbine tower turns back the way it came; *looping* when a bat enters the field of view, turns at or after it has crossed in front or behind of the wind turbine tower and then flies back the way it came; *foraging* when a bat exhibits a sig-zagging flight pattern with two or more turns; *skimming* when a bat flies low over the surface of the tower and may or may not make contact with the surface; *sweeping* when a bat flies close to the tower as if it were skimming but makes contact with the tower with just the outstretched tip of a wing; *colliding* when a bat flies into the tower at a steep angle; and *gleaning* when a bat hovers over a surface before landing on it long enough to grab a food item, such as a resting bug, before flying away.

The behaviors were further characterized by the bats' proximity to the turbine tower. Three distance categories were defined: 1) *contact/close contact*, in which bats made contact or close contact (>0.2 m) with the tower (typically behaviors that involved bats interacting with the turbine tower such as skimming, sweeping, colliding, and gleaning, were classified as contact/close contact); 2) *close-range* in which either the reflection of the bat appeared on the turbine tower surface indicating the bat was within close proximity to the surface or the distance of the bat from the surface could be estimated as <2 m using distance markers (flange) on the turbine tower (behaviors that involved bats interacting with the turbine tower within this distance category include passing, reversing, looping, or foraging); and 3) *far-range*, which included all other bats observed passing, reversing, looping, or foraging at distances >2 m from the turbine tower.

The bat acoustic calls recorded were used to confirm species presence and compare bat activity acoustically recorded with bats observed in the various camera set-ups at the survey sites. For this procedure, we used SonoBat v. 3.03 bat call analysis software.

Once we had processed both observational videos and acoustic data, we compared the patterns of activity and the types of behavior exhibited by the bats. First, to determine if bat activity during the typical July to September migration season would yield sufficient bat observations to effectively undertake a paired treatment study at Wolf Ridge, we first compared both observed and acoustic bat activity across the across the extent of our survey period. Second, to confirm that the timing of the nightly survey effort was appropriate, we examined observed and acoustic bat activity within survey nights. Third, to determine whether bat activity in proximity to the turbine tower surfaces varied, we compared bat activity across our three distance categories (contact/close contact, close-range, and far-range). Fourth, we then compared whether bat activity in proximity to the turbine tower surfaces varied between turbine sites or within paired turbines. Finally, to establish whether the frequency of behaviors was associated with proximity to turbine tower surfaces, we examined the occurrence of specific behaviors exhibited by bats within and between each distance category.

C. PROJECT RESULTS AND DISCUSSION

Bat detectability and overall patterns of activity

Bats were surveyed on 21 nights from July 1 to August 10, 2016 at Wolf Ridge Wind, LLC. A total of 432 sessions were recorded in this survey period. Due to technical difficulties, such as an occasional power failure, and adverse weather events a small number of sessions were incomplete and were excluded from our analysis. Thus, 418 sessions were successfully processed and analyzed in Studiocode and 422 flying objects were identified in these sessions. Using the bat identification key, we detected 171 bats and 99 possible bats in our field of view at turbine towers. Bats were observed on 5 of 6 survey nights at turbines 2a & 2b, 7 of 7 nights at turbines 3a & 3b, and 4 of 7 nights at turbines 4a & 4b. Our bat detectors recorded a total of 181 acoustic files with bat calls during the survey periods. A total of 194 individual bat calls were identified from 5 of the 6 species known to be in the area, including eastern red (*Lasiurus borealis*, n = 103), hoary (*Lasiurus cinereus*, n = 1), silver-haired (*Lasionycteris noctivagans*, n = 7), tri-colored (*Perimyotis subflavus*, n = 39), and evening (*Nycticeius humeralis*, n = 44) bats. Note that the eastern red bat is the bat species with the highest levels of fatality recorded in carcass searches conducted at Wolf Ridge, and this species was also the most commonly recorded bat in acoustic surveys conducted at turbine sites. In contrast, hoary bats have been the second most abundant bat species in carcass searches conducted at Wolf Ridge, yet this species was only recorded once during our acoustic surveys. This disparity may be due to the hoary bat's ecology and behavior; this bat is known to fly above tree canopies (Ammerman et al. 2012) and has been frequently observed flying around wind turbine nacelles (>80 m; Cryan et al. 2014). As our bat detectors have a range of 35 to 40 m from the ground, it is likely that we could not detect hoary bats echolocating at distances beyond the range of our detectors.

Acoustic recordings and video observations of bat activity fluctuated across the survey period (Fig. 11). For the majority of the surveys, the number of bats observed in sessions per turbine night fluctuated in a similar pattern as the number of acoustic calls recorded, with the exception of surveys conducted in the first week. During this first week, the thermal camera set-up was 95 m from the turbine tower base and this finding supports our preliminary observations that bats in this field of view were too far away to effectively distinguish from other flying objects. During this first survey week, the observed peak in acoustic activity with no corresponding peak in video observations provides evidence that bats in proximity to the turbine tower were likely to have been missed, as well as showing the importance of including thermal cameras in such behavioral surveys. As multiple acoustic files can be created for an individual bat and the range of the detector is wider than our field of view, we would expect the number of acoustic files recorded to be greater than the number of bats observed in a given survey night, and this was the case in the majority of the surveys. Nevertheless, differences in observed bat activity and acoustic activity might also be due to limitations associated with the distance at which bats can be detected by the acoustic bat detector (i.e., any bats flying above 40 m from the ground were unlikely to be recorded). As hoary bats routinely fly above this height and are known to migrate together in groups (Valdez and Cryan 2009), it is possible that more individuals would be visually observed than acoustically recorded.

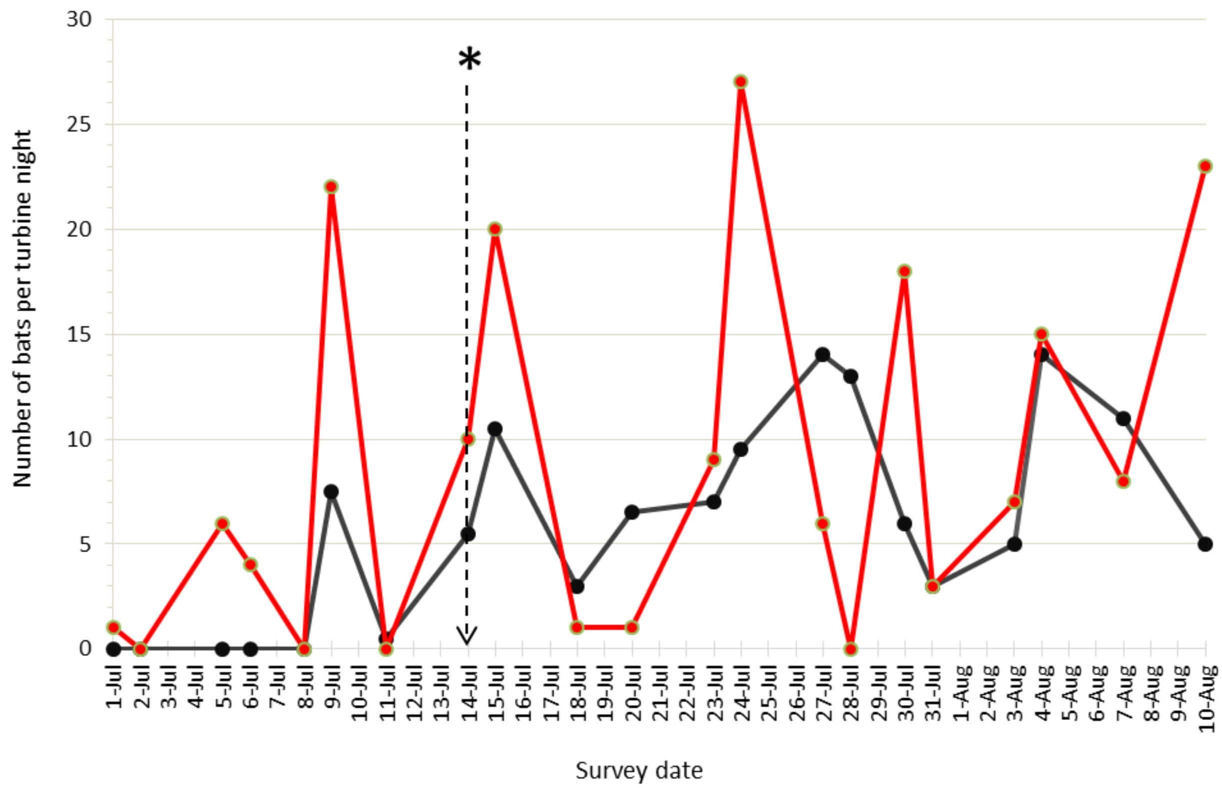


Figure 11: Number of bats detected over the entire survey period from July 1 to August 10, 2016 at Wolf Ridge Wind, LLC. The black line shows the number of bats observed in the videos and the red shows the number recorded bat calls. Asterisk indicates when the thermal camera set-up was moved from 95 m to 2 m from the base of the turbine tower.

For weekly activity, the mean number of bats observed and acoustically recorded showed a similar pattern of increasing activity across the survey period (Fig. 12). Although we did not conduct surveys across the entire migration season for bats (July through September), we can confirm from these activity patterns that surveys undertaken during this period at Wolf Ridge would enable us to effectively compare differences in bat activity levels at control and texture-treated wind turbines for Task 6.

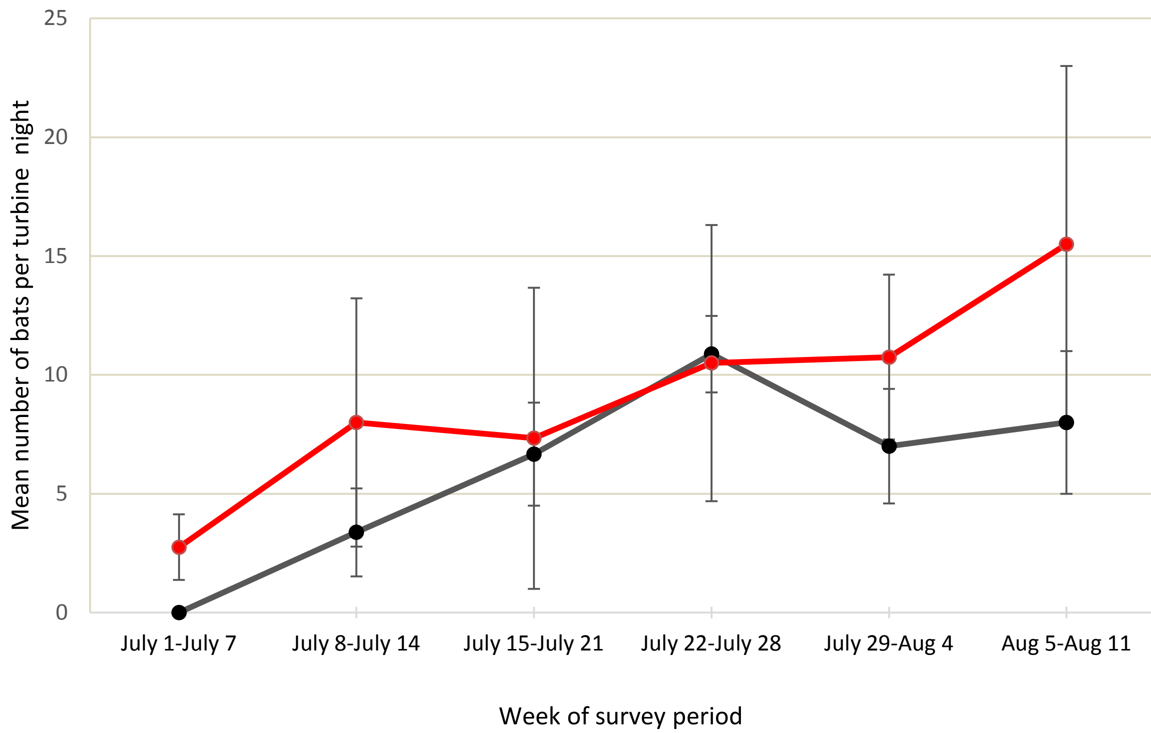


Figure 12: The number of bats detected during each week of the survey period from July 1 to August 10, 2016 at Wolf Ridge Wind, LLC. The black line shows the number of bats observed in videos and the red line shows the number of recorded bats calls.

We also investigated activity patterns of bats within survey nights to determine whether the timing of our survey efforts coincided with maximum bat activity (i.e., survey effort was appropriate). Our results for observed bat activity showed that peak activity did fall within our nightly survey period (Fig.13). Similarly, acoustic bat activity peaked within our nightly survey period (Fig. 14). These data confirmed that our nightly survey period effectively maximized bat detections.

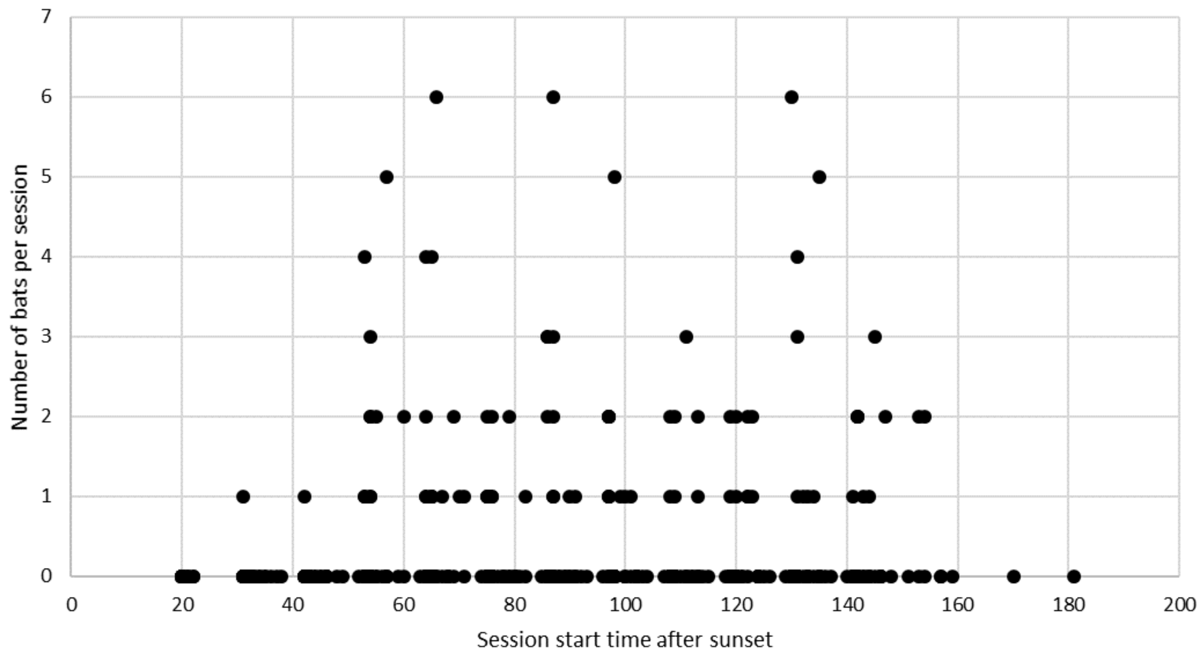


Figure 13: Number of bats per session detected over the entire survey period from July 1 to August 10 at Wolf Ridge Wind, LLC. Each dot represents the number of bats detected during each session and the sessions are organized by the start time after sunset in minutes.

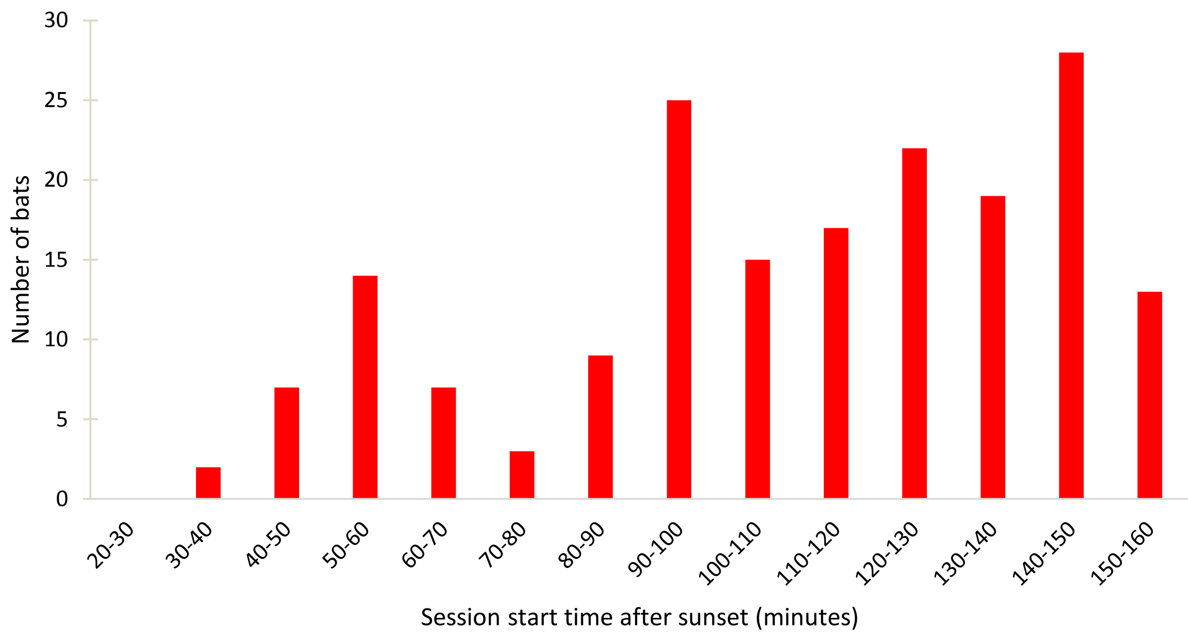


Figure 14: Number of bats recorded acoustically by the session start time (minutes after sunset) across all survey nights from July 1 to August 10, 2016 at Wolf Ridge Wind, LLC.

Bat behavior at wind turbine surfaces

We recorded 7 of the 8 distinct bat behaviors near turbine tower surfaces: passing (n = 91 bats), reversing (n = 17 bats), looping (n = 8 bats), foraging (n = 39 bats), skimming (n = 7 bats), sweeping (n = 1 bat), and colliding (n = 8 bats). In our surveys we did not observe gleaning. Of these behaviors, 9.4% were classified as contact/close contact, 42.1% as close-range, and 48.5% as far-range (Fig. 15).

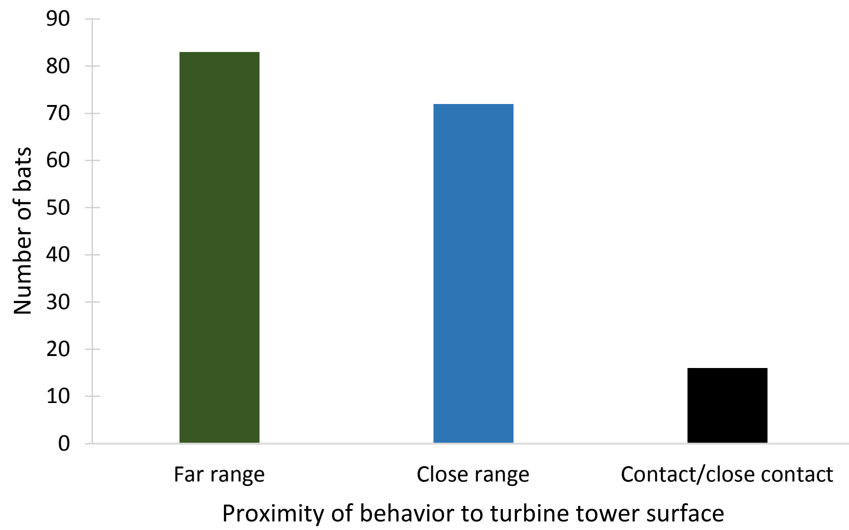


Figure 15: Number of bats detected within three distance categories from turbine tower surfaces on the thermal and night vision videos from July 1 to August 10, 2016 at Wolf Ridge Wind, LLC.

We did observe a difference in overall bat activity at the different turbine sites (Fig. 16); however, the proportions of behaviors conducted in proximity to all the turbines were similar, as were the activity levels within paired turbines. The latter provides strong support for our proposed paired study design (Task 6) and therefore we should successfully be able to demonstrate the effectiveness of the texture-treatment at altering bat behavior (compared to the control) at the paired turbine sites in Task 6. Note that in previous night vision surveys, turbines 4a and 4b yielded the majority of bat observations, yet in this feasibility study we recorded the least number of bats at these turbines. This result may be because more surveys were conducted at these paired turbines during the first week of July when we used our initial thermal camera set-up (which we found limited our ability to distinguish bats from other flying objects). In addition, this survey period also had the lowest recorded levels of acoustic bat activity (Fig. 12).

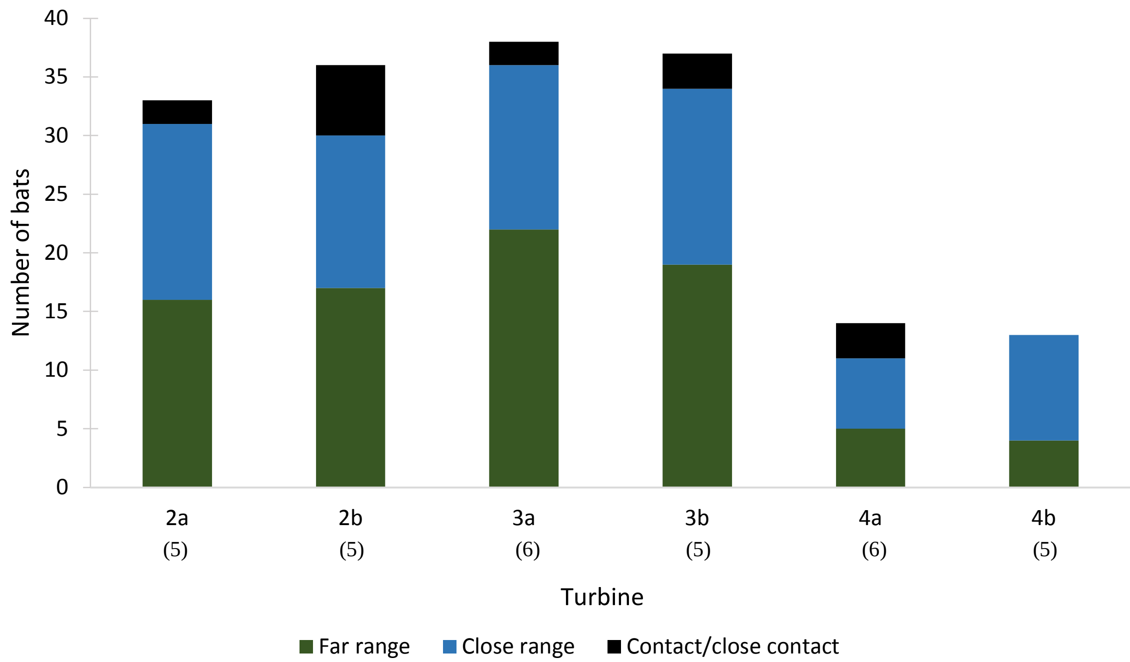


Figure 16: Number of bats observed exhibiting far-range, close-range, and contact/close contact behavior detected on the thermal and night vision videos at individual turbines from July 1 to August 10, 2016 at Wolf Ridge Wind, LLC. The numbers in parentheses beneath each turbine represents the number of survey nights conducted at that turbine over the survey season.

We further examined the specific behaviors exhibited within each distance category (contact/close contact, close-range, and far-range). For contact and close contact, we found that colliding and skimming behaviors occurred with similar frequency, while sweeping was rarely observed. Note that both gleaning and sweeping (i.e., brushing prey items from a surface and then catching the prey on the wing) are two types of foraging strategies and most bat species are optimally adapted to one particular foraging strategy (Altringham 2011). The bat species found at Wolf Ridge are aerial hawkers (i.e., catch prey on the wing) and may only switch foraging strategies if they can catch more prey items by doing so (Ratcliffe and Dawson 2003). As many flying insects appear to be abundant in proximity to the turbine towers (Foo 2016), we would expect the frequency of foraging strategy switching, from aerial hawking to gleaning or sweeping, to be low.

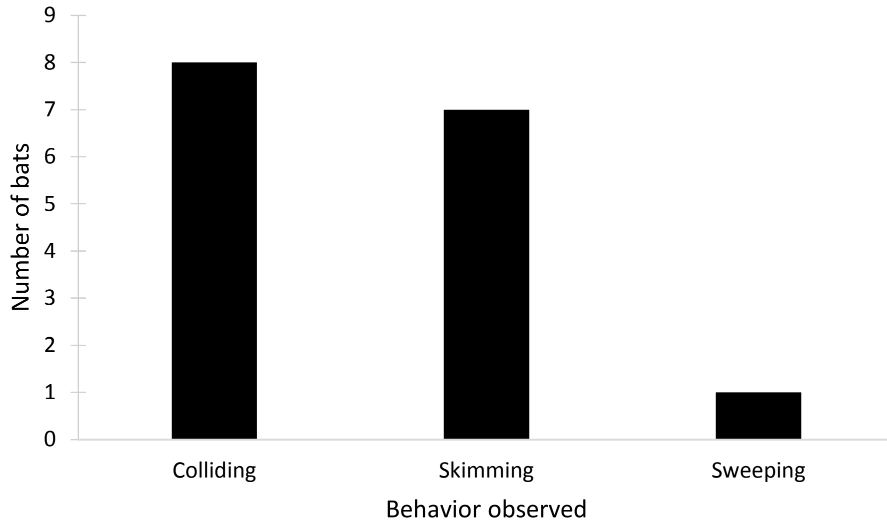


Figure 17: The number of bats exhibiting contact/close contact behaviors at wind turbine tower surfaces from July 1 to August 10, 2016 at Wolf Ridge Wind, LLC.

For the close-range behaviors, passing represented over 55% of the behaviors observed, while foraging, reversing, and looping appeared to occur at similar frequencies (Fig. 18).

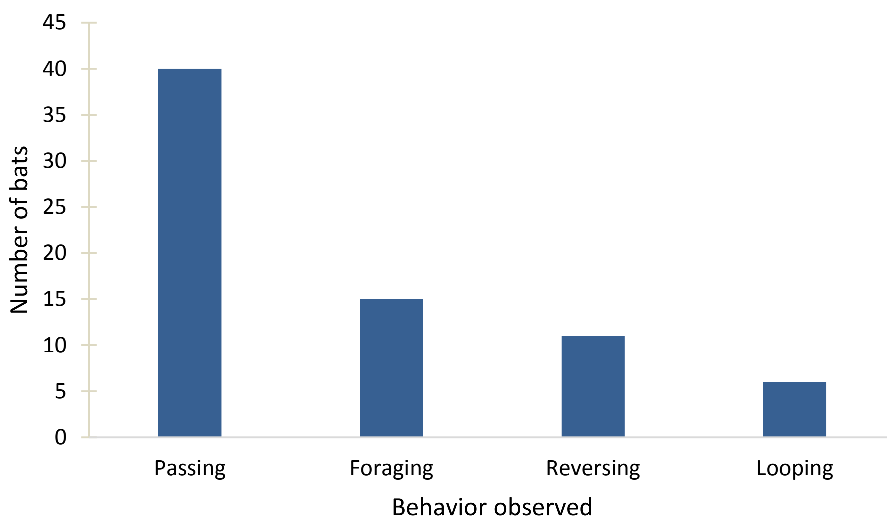


Figure 18: The number of bats exhibiting close-range behaviors near wind turbines tower surfaces from July 1 to August 10, 2016 at Wolf Ridge Wind, LLC.

For far-range behaviors, passing represented over 60% of the behaviors observed, while foraging represented ~29%, and reversing and looping occurred less frequently (Fig. 19). Comparing close- and far-ranges, we observed at least twice as many instances of reversing and looping at close-range than far-range, whereas we observed a substantial increase in passing and foraging behaviors at far-range compared to close-range. The increase in reversing and looping within close-range of the turbine tower surfaces could be due to either the bats taking measures to avoid the turbine as they approach it or potentially to investigate the tower further, respectively. Thus, both behaviors may require bats to be in close proximity to the tower surface itself. In contrast, an increase in passing and foraging behavior at far-ranges may have resulted from the far-range category comprising the majority of our field of view. Therefore, if these behaviors take place independent of turbine tower, we would expect a higher proportion of passing and foraging behaviors to occur within this category.

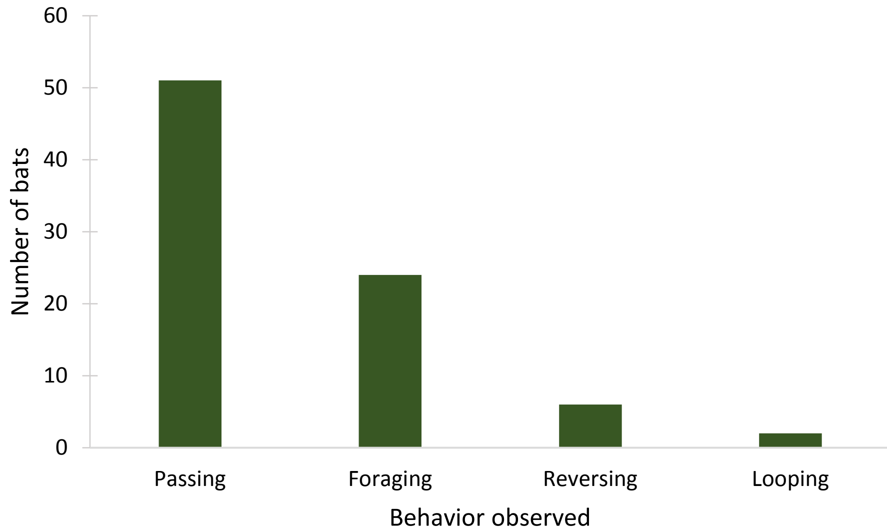


Figure 19: The number of bats exhibiting far-range behaviors near wind turbine tower surfaces from July 1 to August 10, 2016 at Wolf Ridge Wind, LLC.

Our findings emphasize the importance of separating bat activity and behavior into distance categories (contact/close contact, close-range, and far-range). Our justification for this division is that when a texture treatment is applied to wind turbine towers it would most likely only be targeting those bats that exhibit behaviors that are directly involved with the turbine tower surface itself. Thus, we would expect to observe 1) little or no reduction in the far-range behaviors that happen independent of the tower surface, 2) a reduction in close-range behaviors involving the tower surface, and 3) a significant reduction in contact and close contact behaviors.

Recommendations for survey design

Our feasibility survey revealed that the distance of the thermal camera set-up from the turbine substantially influenced our ability to detect bats in our surveys. We found that having the thermal cameras 2 m from the base of the turbines alongside the night vision cameras and angled to create a field of view which encompassed the tower from 7.5 from the base to the bottom of the nacelle maximized bat detection (Figs. 20 and 21). Thus, placing thermal and night vision camera set-ups on the leeward and windward sides of the turbine tower in surveys conducted at paired control and treatment turbines would effectively enable us to determine the effectiveness (provide statistical strength) of a texture treatment at altering bat behavior in Task 6.

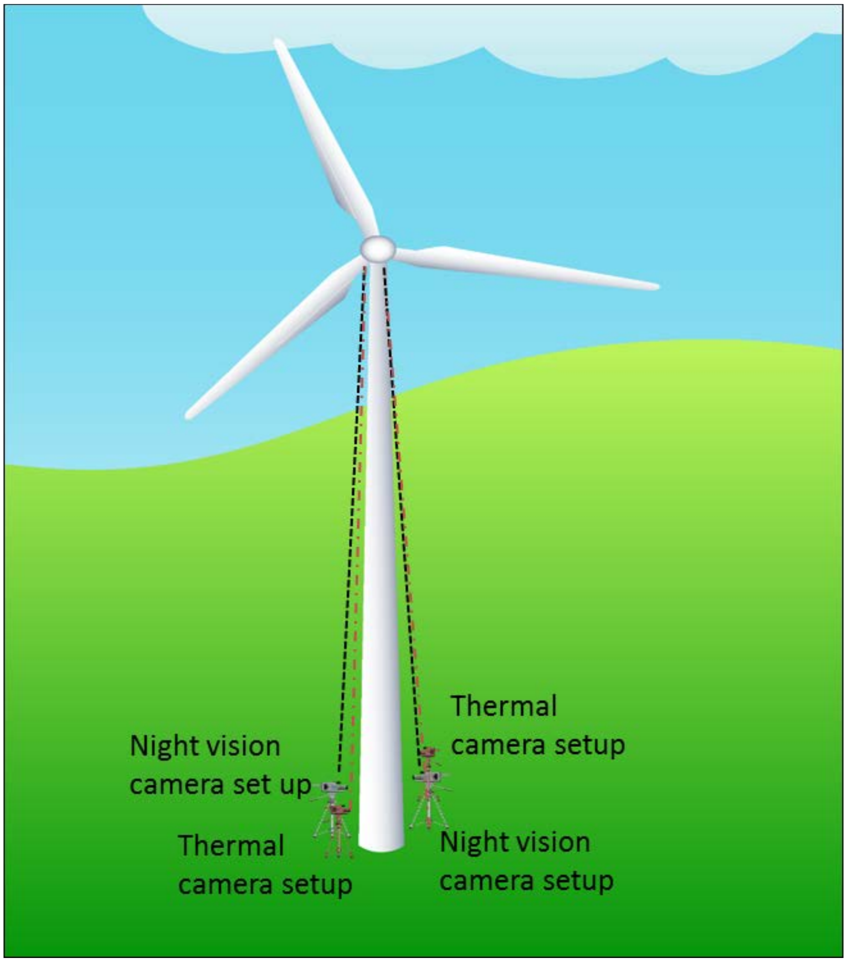


Figure 20: Image depicting recommended night vision and thermal camera set-ups for bat behavioral surveys at wind turbine tower surfaces at Wolf Ridge Wind, LLC

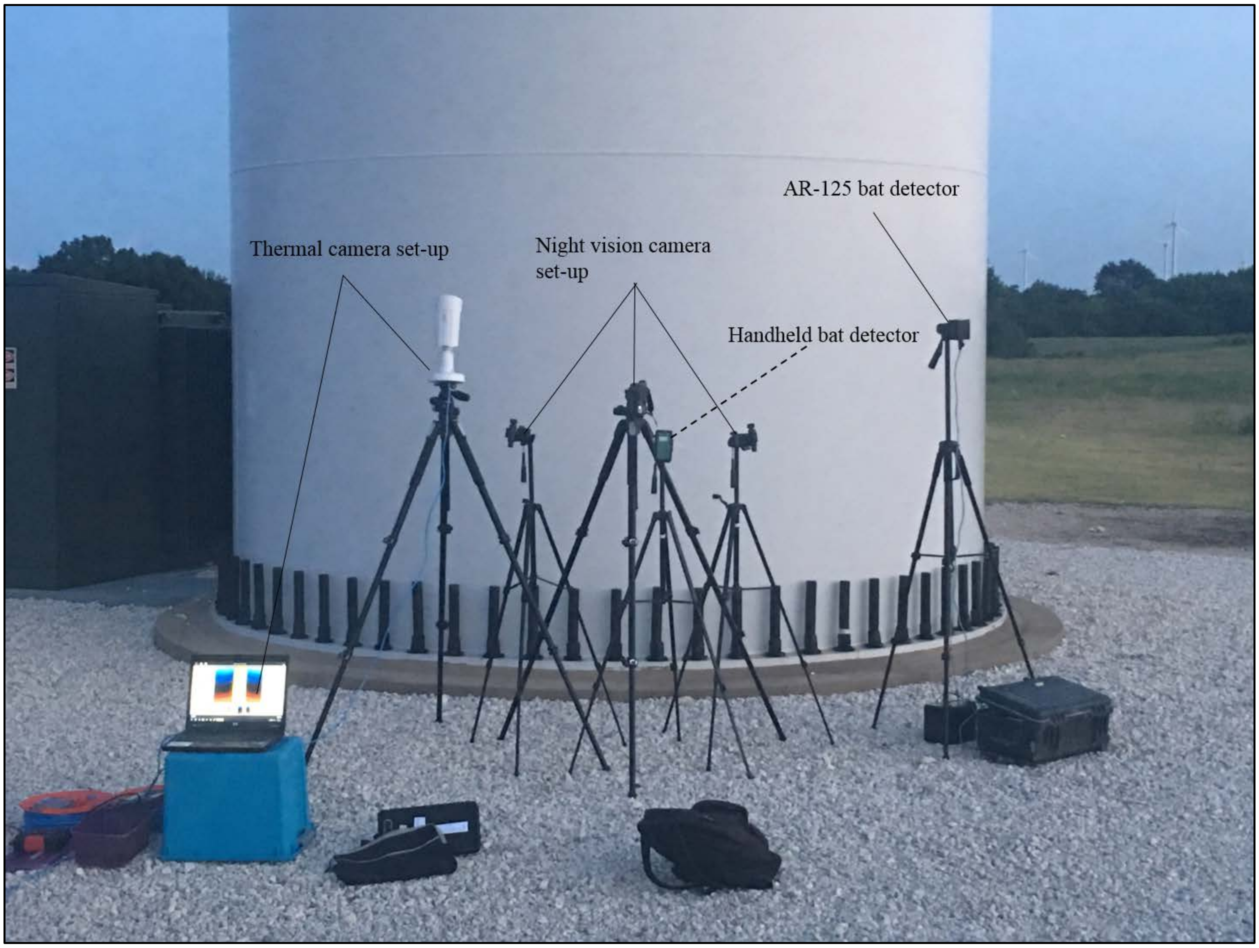


Figure 21: Picture of the recommended equipment set-up for both leeward and windward sides at a wind turbine site. This set-up would effectively allow us to maximize bat detection at wind turbine tower surfaces at Wolf Ridge Wind, LLC. Note one laptop should be used to run both thermal cameras and one AR125 be placed at the each turbine site surveyed.

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DE-EE0007033

Texas Christian University

Texturizing Wind Turbine Towers to Reduce Bat Mortality

Task 5: Application of coating treatment to turbines at Wolf Ridge (Months 20-22)

Task Summary:
Turbine treatment will take place between February and April 2017 (Months 20-22). The anticipated treatment schedule may be altered based on technical specifications of the treatment application as detailed in Deliverable 2.3. A single coating developed in Task 2.1 and tested in Task 3 will be applied to the exterior tower surface of approximately 3-5 selected wind turbine towers. The treatment will be applied to the towers as per the technical specifications developed in Task 2.2. Treatment will likely cover a 20-30 m vertical section of the turbine tower including the lower portion of the rotor swept zone.

Milestone 5 – Complete report detailing application of a single texture treatment to 3-5 wind turbine towers at Wolf Ridge. (Month 22, Budget Period 2)

Deliverable 5 – Written report verifying application (with photographs) is complete to the DOE.

Changes from Proposed Scope of Work:

Timeline **-** In the Project SOPO, we had projected that the coating application would be completed by April (Month 22). At the end of Q1 in 2017, we moved the target deadline to May (Month 23) to allow sufficient time to get the purchase orders completed for the materials and labor and reduce the risk of project delays. April tends to have some of the highest monthly wind speeds for the study site, and pushing the coating application into May had the advantage of decreasing the likelihood of significant delays due to high winds that would incur additional costs to the coating application process. Due to further constraints with equipment availability, personnel availability, and weather conditions forecasted for May that were not conducive to working up-tower (e.g., rain and high wind speeds), we again moved the target completion date of this task to the end of June (Month 24). The revised target date was not expected to adversely impact Task 6 (Bat activity surveys) as bat activity at the study site is usually very low in low in June and picks up in July when the fall migratory season of tree bats begins.

Number of turbines **-** In the Project SOPO, we had projected that the coating application would be applied to approximately 3-5 turbine towers (see Fig. 1), with the ultimate number to be based on the final budget (i.e., final cost estimates for materials, equipment, labor, etc.) and any site constraints (e.g., safety or technical issues with turbines, landowner constraints, etc.). Working within our approved budget for Task 5 ($145,922: $63,000 from DOE, $82,922 from NextEra Energy Resources), our final field application plan was designed to apply the tower coating to a subsection of 3 turbine towers (see Fig. 2) within a period of 5 full working days. Due to rental agreements for the large pieces of equipment and the skilled personnel required to operate the equipment (e.g., Bronto lift truck, spay equipment, etc.), the plan was constrained to be completed in a single mobilization effort to the field site.

TCU, NextEra Energy Resources, and third party contractors executed and completed the application of the coating treatment to 2 operational wind turbine towers at Wolf Ridge Wind, LLC in June (Month 24). The research team mobilized at the field site on Sunday June 18th, and executed the application plan from Monday June 19 through Friday June 23, with daily time in the field ranging from 12 to 14 hours.

Texture Coating Application Schedule and Accomplishments (see Suppl. Photos 1):

Day 1: Monday June 19, 2017

- Site orientation and safety training
- Tower preparation of 3 turbines (including a lightning delay that resulted in a loss of ½ day of working time)

Day 2: Tuesday June 20, 2017

- Training on equipment and application materials at the O&M
- Mobilization to the first tower, at which the adhesive coating and beads were applied to 40% of the tower from 10 m to 43 m above ground

Day 3: Wednesday June 21, 2017

- Completed the application of the adhesive coating and beads to the first tower
- De-mobilized the equipment from the first tower
- Re-mobilized the equipment at the second tower
- Completed ~60% of the adhesive coating and bead application at the second tower from 10 m to 43 m above ground

Day 4: Thursday June 22, 2017

- Completed application of the adhesive coating and beads to the second tower section
- Flushed the hose and pump system to change the product from the adhesive to the topcoat
- Applied the topcoat to ~50% of the second tower section

Day 5: Friday June 23, 2017

- Completed the application of the topcoat to the second tower section
- De-mobilized the equipment from the second tower
- Re-mobilized the equipment at the first tower
- Completed the application of the topcoat to the first tower section
- Cleaned the hose and pump system once the top coat application was complete
- The threat of a lightning stand-down from a thunderstorm that stayed just 30 miles from the wind farm required constant attention and communication between Wolf Ridge personnel and the application team throughout the day.

- **Key Findings and Accomplishments:**
  - We successfully applied the texture coating to 2 wind turbine tower sections at Wolf Ridge Wind, LLC, while staying within our approved budget.
  - On these 2 towers, the texture application was completed according to the application plan and including tower surface preparation prior to application of the adhesive base layer, beads, and protective topcoat from approximately 10 m to 43 m above ground.
  - Within this 5 day period, the resources of the application team were stretched to the limit to complete the texture coating application to 2 wind turbine tower sections.
  - While in the field, the research team was constantly evaluating the overall project progress including comparing subtask completion times and material usage rates to what had been previously estimated.
  - The research team was also in constant communication regarding how the process was moving along and identifying areas for improvement and ways to save time or materials while still maintaining the best work conditions possible.
  - Due to the lightning stand-down, the addition of several breaks each day to prevent dehydration and fatigue of the field personnel, and somewhat longer than anticipated mobilization, de-mobilization, and application times, we were only able to successfully apply the texture coating to 2 turbine tower sections.
  - The costs to deploy the equipment and personnel to the study site for a second time to apply the coating to a third tower are well beyond the reach of our approved research budget. At this time we do not plan to apply the texture coating to a third tower.

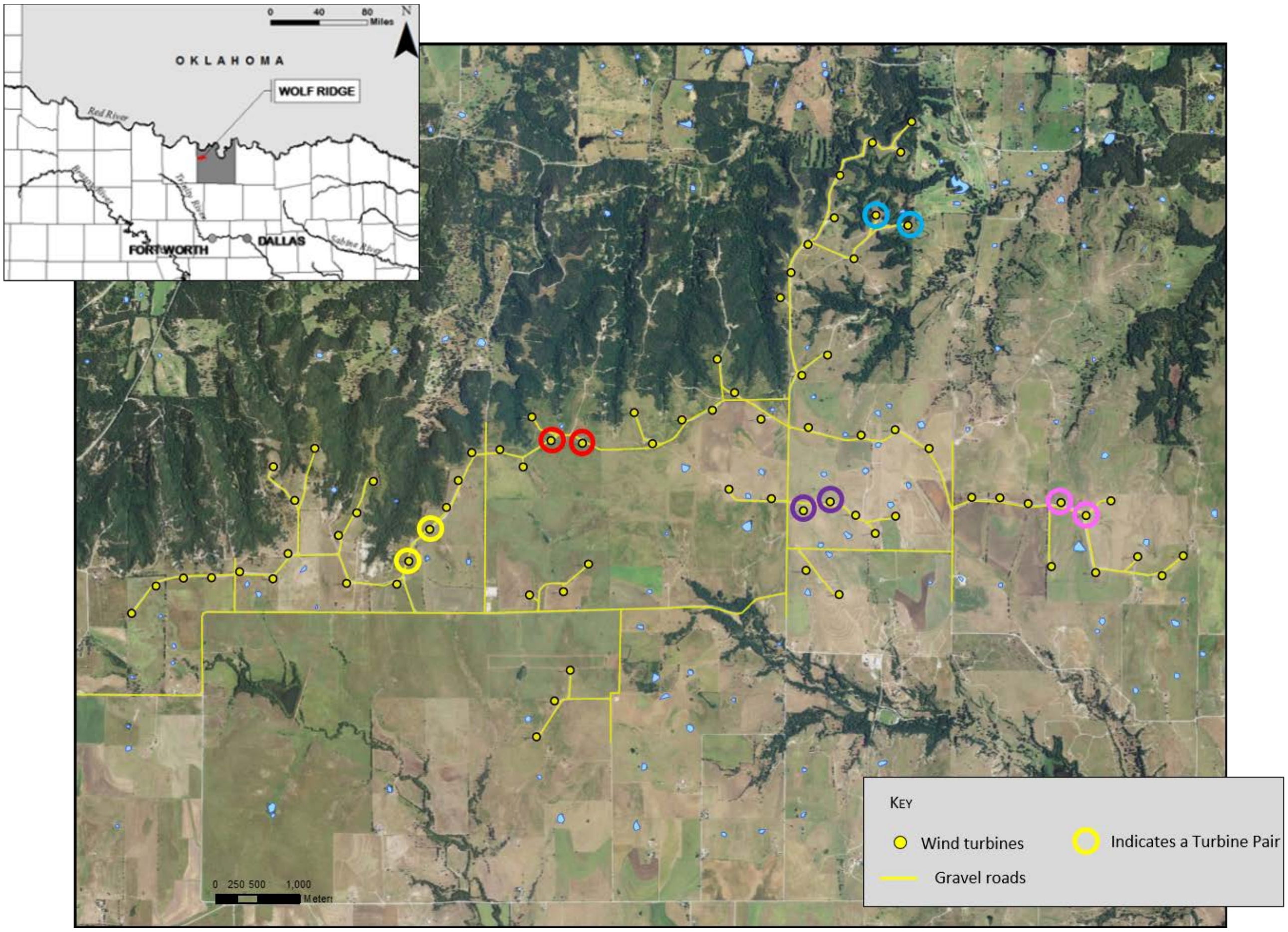


Fig. 1. Map illustrating the locations of the 5 possible study pairs of wind turbines at Wolf Ridge Wind, LLC. From left to right: turbines 1a & 1b (yellow), turbines 2a & 2b (red), turbines 3a & 3b (purple), turbines 4a & 4b (blue), and turbines 5a & 5b (pink). The wind facility is located in north-central Texas (N 33° 43' 53.538", W 97° 24' 18.186"), consists of 75 1.5-MW GE wind turbines, and has been the focus of ongoing research on the direct and indirect impacts of wind turbines on birds and bats since 2009.

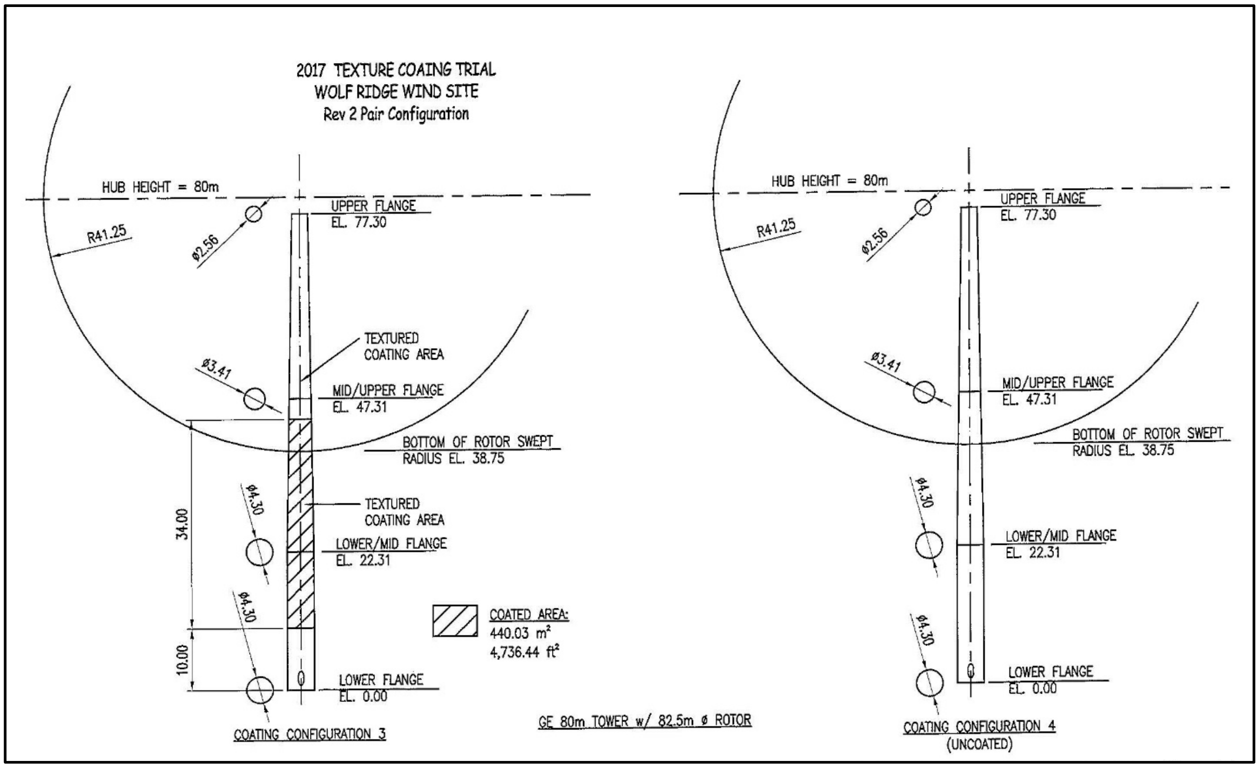


Fig. 2. Schematic illustrating where the texture coating would be applied to select turbine towers at Wolf Ridge Wind, LLC. This diagram also illustrates the paired study design: one turbine in each pair was selected at random (flip of coin) to receive the texture coating).

Supplemental Photos 1. Photos providing evidence that the texture coating was successfully applied to two turbine towers (as described in Fig. 2 above) at Wolf Ridge Wind, LLC June 19-23, 2017.

DE-EE0007033
Texas Christian University
Texturizing Wind Turbine Towers to Reduce Bat Mortality

Task 6: Bat activity surveys at control and texture-treated turbine towers at Wolf Ridge (Months 17-28) REVISED

Task Summary: In this task, we will conduct a field test in which bat activity is evaluated at control turbines (i.e., smooth standard towers) and treated turbines (i.e., wind turbine towers texturized in Task 5) in Budget Period 2. The field survey effort will focus on July through September 2017 (the months with the highest expected bat activity and mortality), although some baseline monitoring will also take place as early as May. The following survey protocol is based on a feasibility study conducted in 2016 (Task 4) to maximize detection of bat activity at wind turbine tower surfaces. The paired turbines included in these surveys were selected for inclusion in the study in Task 2 and were surveyed in Task 4. Bat activity surveys will take place at pairs of turbine towers, consisting of both control and texture-treated surfaces, 2-5 nights per week using high-definition video cameras and night vision technology and thermal cameras. In addition, ultrasonic bat detectors will be placed in proximity to the turbines during the night vision/thermal surveys to record acoustic bat activity. Using video analysis software, we will determine if bats are present during the paired activity surveys, document levels of activity by counting the number of bats, and document types of behavior exhibited in the field of view (i.e., in close proximity to the wind turbine tower). 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 texture coating developed and tested in Tasks 2 and 3 successfully reduces bat activity in close proximity to wind turbine towers at a wind facility in the southern Great Plains. We will compare levels of bat activity and bat behavior at a selection of control (towers without the texture coating) and treated (towers with the texture coating) wind turbines. We hypothesize (H_A) that bat activity levels will vary between control and treatment turbines, with more observations of bats making contact with the smooth tower surfaces compared to the texture-treated surfaces, and more bat activity within approximately 2 m of the smooth tower surfaces compared to the texture-treated surfaces. The null hypothesis (H_0) is that bat activity is independent of texture coating.

Milestone 6.1 – Complete final experimental protocol for the bat activity surveys that will take place at control and texture-treated turbine towers from May to September 2017 at Wolf Ridge. (Month 17, Budget Period 2)

Deliverable 6.1 – Written experimental protocol for the bat activity surveys at Wolf Ridge to the DOE. This protocol will be evaluated by TCU and the DOE.

Milestone 6.2 – Complete spreadsheet summarizing bat activity surveys at control and texture-treated wind turbine towers from May to September 2017 at Wolf Ridge. (Month 28, Budget Period 2)

Deliverable 6.2 – Complete spreadsheet detailing bat behavior in close proximity to control and texture-treated wind turbine towers at Wolf Ridge to the DOE and NEER.

PROJECT METHODS

Field 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: eastern red (*Lasiurus borealis*), hoary (*Lasiurus cinereus*), silver-haired (*Lasionycteris noctivagans*), tri-colored (*Perimyotis subflavus)*, evening (*Nycticeius humeralis*), and Mexican free-tailed (*Tadarida brasiliensis*) bats. In the last three years, we have also recorded the presence of an additional bat species, the canyon bat (*Parastrellus hesperus*).

Five paired turbines have been identified as sites where bat activity surveys could be conducted to explore control and texture-treated wind turbine towers (Task 6; Fig. 1). These sites were determined to have high levels of bat fatality, as shown in bat carcass searches conducted at Wolf Ridge from 2009 to 2014, as well as in behavioral surveys conducted in 2012 and 2013. Furthermore, the area around each of the 10 turbines selected remains clear of vegetation and other obstructions for a radius of 50 m from the base of each turbine. Three of these pairs were used in the feasibility study undertaken in 2016 as part of Task 4 (turbines 2a & 2b (red), 3a & 3b (purple), and 4a & 4b (blue; Fig. 1)) and during this study we found that bat activity levels were similar within each pair. Whether we incorporate three or more of the five paired turbines into the bat activity study (Task 6) will depend on the outcome of the texture application in Task 5 (i.e., based on logistical and economic requirements). Nevertheless, within each pair, one turbine will be randomly selected and treated with the texture-coating developed in Task 2.

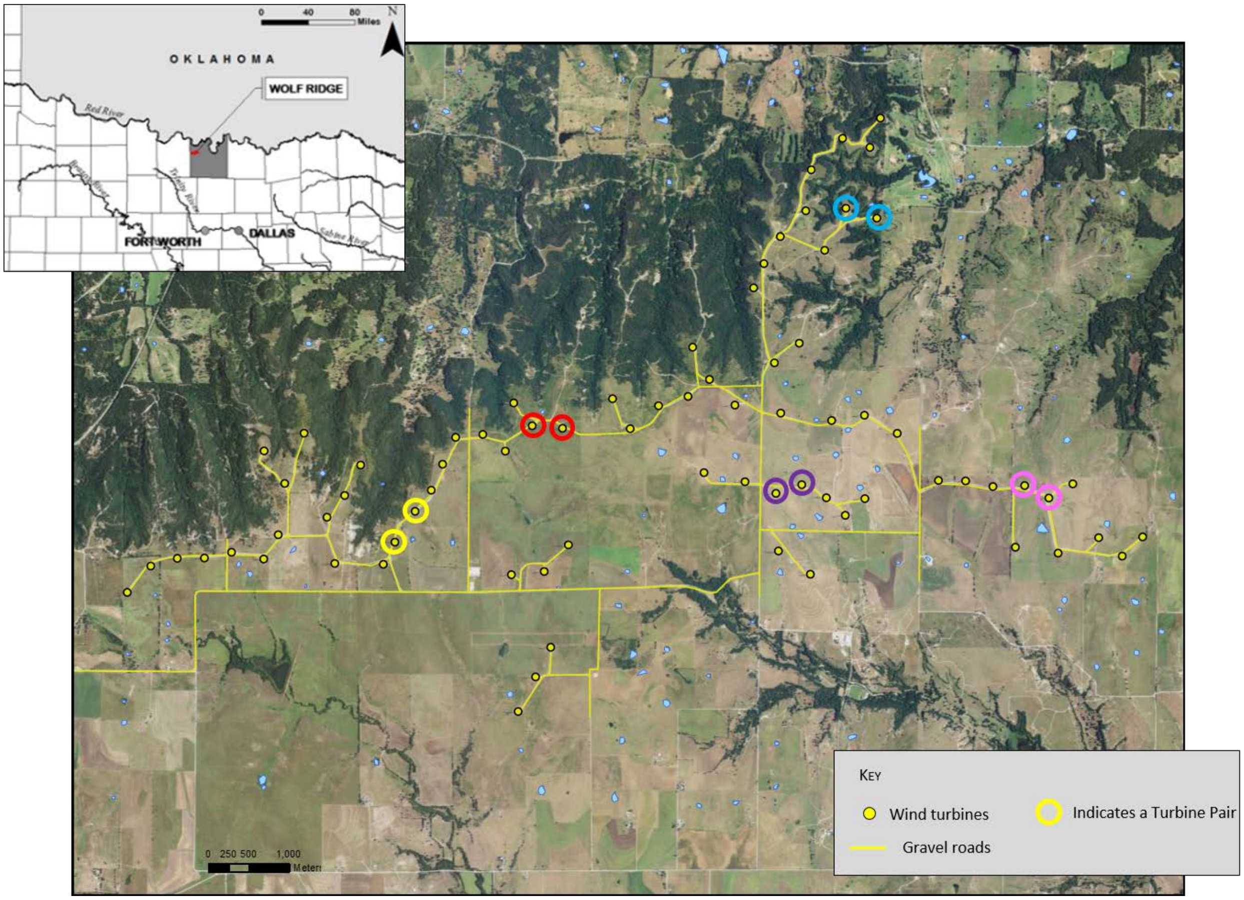


Figure 1: Map illustrating the locations of the 5 possible study pairs of wind turbines at Wolf Ridge Wind, LLC. From left to right: turbines 1a & 1b (yellow), turbines 2a & 2b (red), turbines 3a & 3b (purple), turbines 4a & 4b (blue), and turbines 5a & 5b (pink).

Survey Methods

Surveys will be conducted at the aforementioned pairs of wind turbines at Wolf Ridge from May to September 2017. Note that in our feasibility study (Task 4), we found that bat activity increased from early July through mid-August at the 3 pairs of turbines we surveyed. This result was consistent with our previous bat activity and fatality surveys at this wind facility and thus confirms that the proposed survey period for Task 6 is appropriate. Weather permitting, we will survey bat activity at pairs of turbine towers 2-5 nights per week for approximately 50-65 survey nights during the survey period, although the total number of nights may be adjusted due to overall levels of bat activity or limitations in site access due to storms. Within a single survey night, a turbine pair (consisting of both smooth and texture-treated surfaces) will be surveyed simultaneously. This paired study design will allow us to control for some of the spatial and temporal variation in bat activity, thereby increasing our ability to detect a difference between treatments if one really exists. The order in which the turbine pairs will be surveyed will be determined at random (sampling without replacement) until all turbine pairs have been surveyed. We will then repeat this process throughout the survey period to ensure that the turbine pairs are surveyed an equal number of times across the season. Note that two technicians will be present at each turbine surveyed each night.

During each survey, we will use 1) high-definition video cameras and night vision technology, 2) thermal cameras, and 3) acoustic detectors to record bat activity at turbine tower surfaces. Each of these equipment set-ups are described below.

1) Night Vision Set-up

We will monitor each turbine with 2 night vision set-ups. Each set-up comprises an ATN-NVM14 night vision scope attached to a Sony HDR-PJ790 video camera on a Manfrotto MT055XPRO3 tripod, along with 2 ATN Super Long Range Infrared Illuminator IR450 infrared lights on VELBON EF tripods. We will place one night vision set-up on the leeward side of the turbine (directly beneath the nacelle on the opposite side of the turbine blades) approximately 2 m from the base of the turbine; while the other set-up will be placed on the windward side of the turbine beneath the blades (Fig. 2). We will angle the cameras (with the lower field of view starting ~10 m above the gravel pad) up the tower surface to the ventral surface of the nacelle hub (80 m height; Fig. 3). This positioning allows for all bat activity to be recorded in close proximity to the tower surface from approximately 10 m to 80 m above ground (i.e., encompassing the majority of the turbine tower). Supplemental light will be provided for each night vision camera by using external tripod-mounted infrared lights. We will place one infrared light approximately 1 m to either side of each night vision camera, angled upwards towards the turbine tower surfaces. The Sony cameras will be powered by Sony NP-FV100 batteries, whereas the night vision scopes and infrared lights will be powered by rechargeable C cell batteries. All batteries will be removed and charged at the end of the survey night. Finally, we will save all night vision camera video recordings internally as .MP4 files; the recordings will be downloaded from the camera at the end of the survey night and transferred to solid-state external hard drives for storage and subsequent analysis.

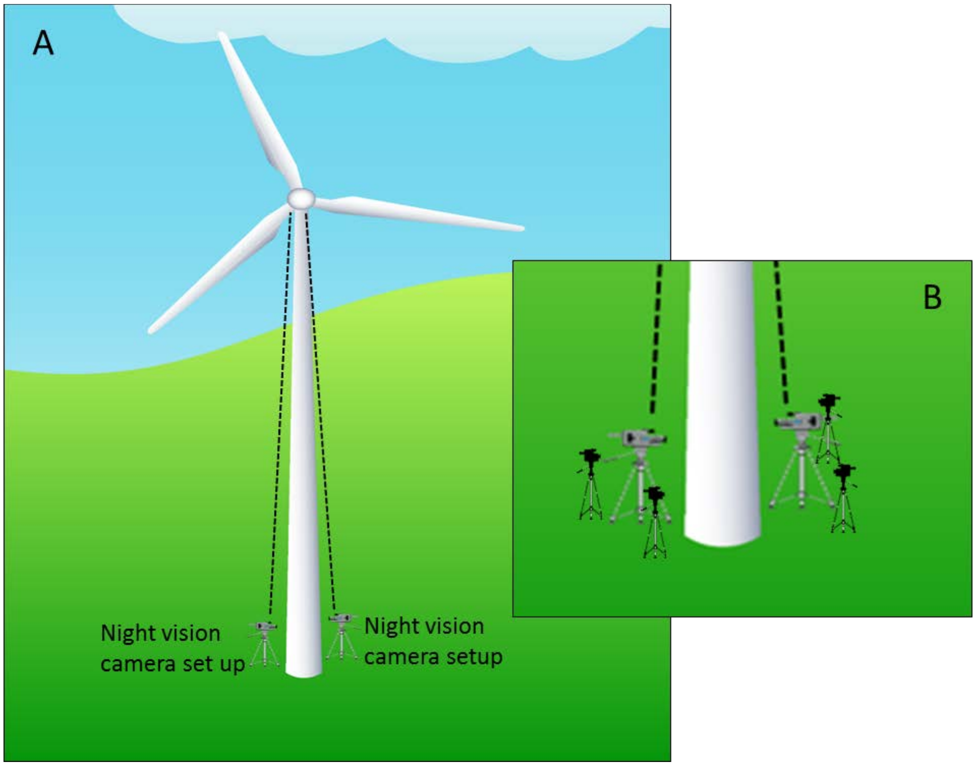


Figure 2: **A** depicts night vision camera set-up, and **B** depicts night vision camera set-up with IR lights for bat activity surveys at wind turbine towers at Wolf Ridge Wind, LLC.

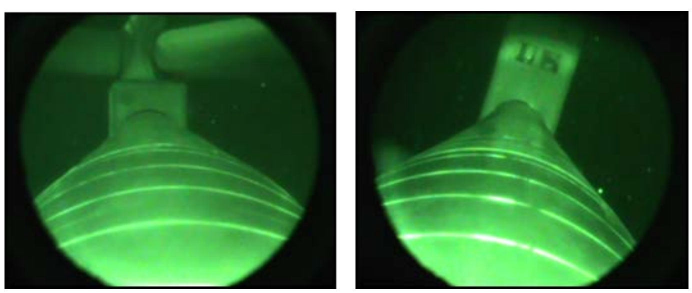


Figure 3: Night vision camera set-up on windward and leeward side of the turbine focused up the turbine tower to detect bat activity at wind turbines at Wolf Ridge Wind, LLC.

2) Thermal Camera Set-up

We will monitor each turbine with 2 thermal camera set-ups in a survey night. Each set-up comprises an Axis Q1932-E 19MM thermal camera mounted on a Manfrotto MT055XPRO3 tripod. We will place one thermal camera set-up on the leeward side of the turbine (directly next to the night vision set-up) approximately 2 m from the base of the turbine; the other set-up will be placed on the windward side of the turbine (Fig. 4). We will angle the thermal camera set-ups via the tripod so that the field of view extends up the tower surface to the ventral surface of the nacelle hub (from 10 m above the gravel pad to ~80 m above ground; Fig. 4).

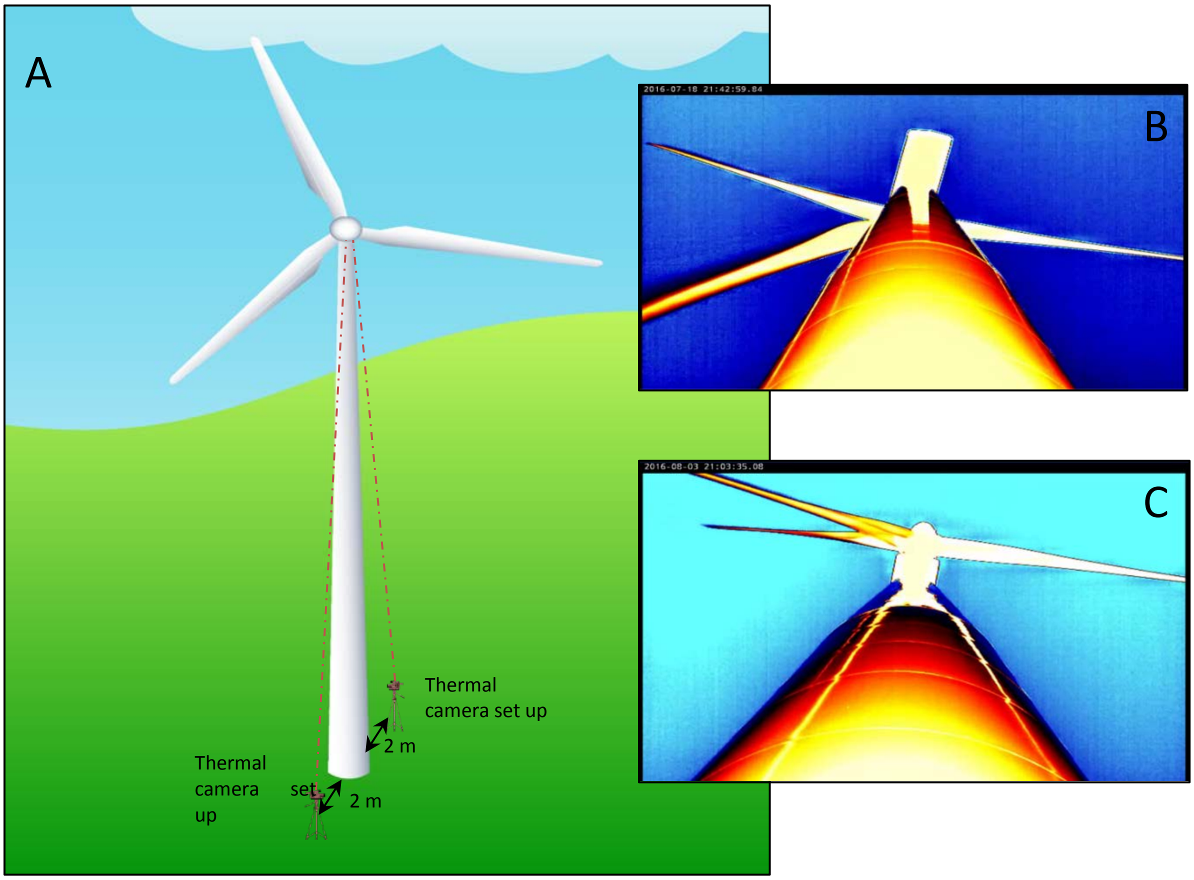


Figure 4: **A** depicts thermal camera set-up, with one camera 2 m from the wind turbine base on the leeward side of turbine tower and a second camera 2 m from the base on the windward side; **B** shows the field of view from the thermal camera on the leeward side of the turbine tower; and **C** shows the field of view from the camera on the windward side of a turbine tower at Wolf Ridge Wind, LLC.

We will connect the thermal cameras to an HP Compaq 8510w laptop computer via Ethernet cables and a Netgear ProSAFE 8-Port Fast Ethernet PoE Switch. Both the laptop and the Netgear Ethernet switch will be powered with a 12V car battery via a Cen-Tech Power Inverter, which in turn powers the thermal cameras. The 2 thermal camera set-ups will be connected to the same Netgear Ethernet switch and laptop at each turbine. We will use Axis camera software on the laptop to synchronize the thermal cameras' internal clocks and trigger recording. We will place the laptop within 5 m of the leeward camera and cover the screen during recording sessions (see Survey procedure section below). This measure prevents light from the laptop screen from potentially affecting bat activity during the surveys. We will save the thermal camera recordings through a Sony 32 MB micro-SD card onto the HP laptops as .MTS files; these recordings will be converted using "Any Video Converter Free" software to .MP4 files at the end of each survey night for storage on solid-state external hard drives and subsequent analysis.

3) Acoustic surveys

Ultrasonic bat detectors will be placed near the base of the turbine towers during each survey period to record acoustic bat activity. An AR-125 bat detector and recorder will be deployed alongside the night vision camera set-up (i.e., 2 m from the base of the turbine) on the leeward side of the turbine towers to record echolocation calls from bats near the turbine towers (Fig. 5). The acoustic detector will be powered by a 12V car battery. Note that the position of this acoustic detector will remain the same throughout the survey period. The AR-125 detectors will save recordings as .wav files onto a Sony 32 MB micro-SD card. These recordings will be downloaded to a solid-state external hard drive at the end of each survey night for storage and subsequent analysis.

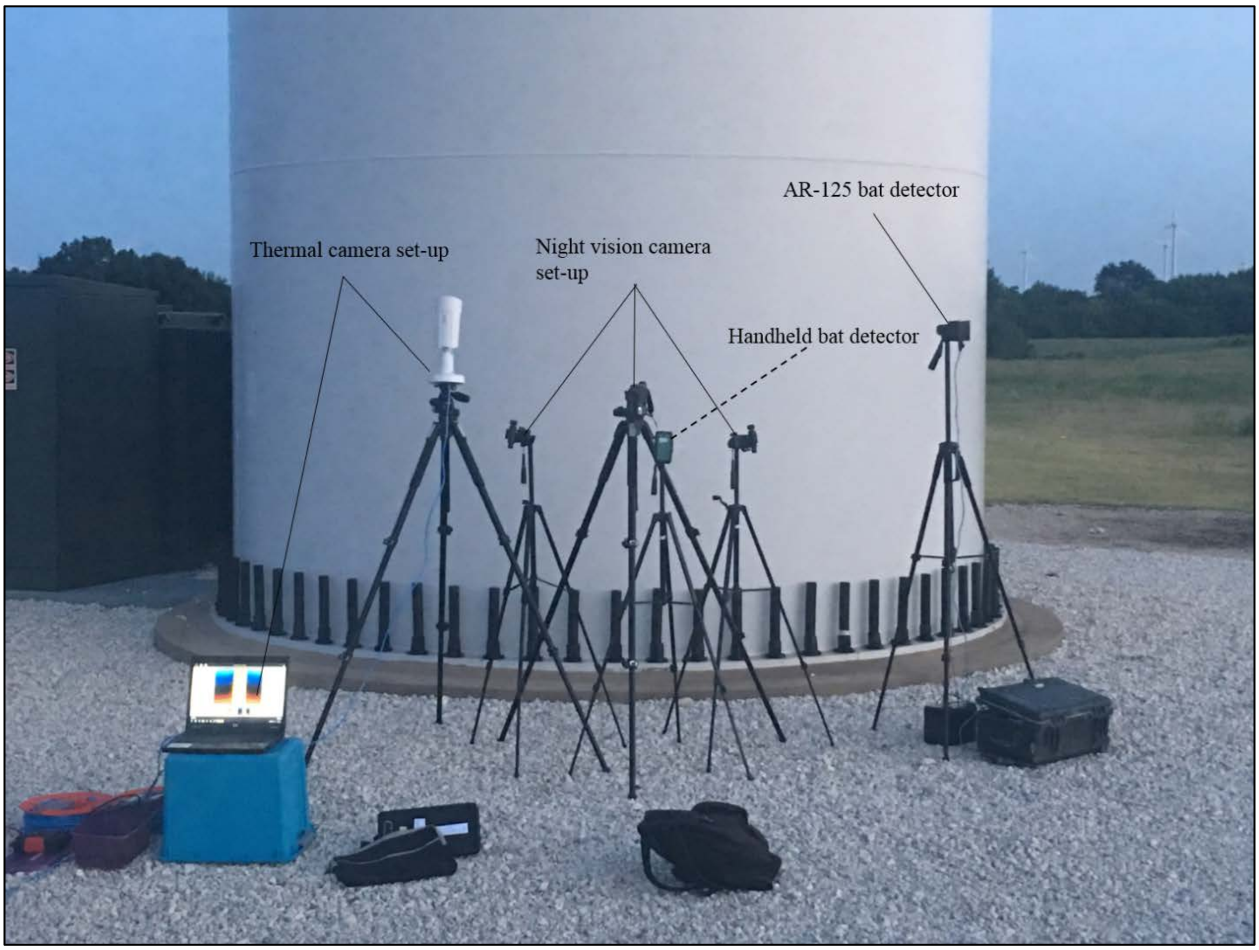


Figure 5: Picture of the equipment set-up for both leeward and windward sides at a wind turbine site to examine bat behavior at wind turbine tower surfaces at Wolf Ridge Wind, LLC. Note that the one laptop powers both thermal cameras and that only one AR-125 is placed at each turbine site surveyed.

In addition, a handheld Pettersson D240x acoustic detector will be placed on a tripod next to each night vision camera. This detector, with a range of 35-45 m, will be set at a frequency of 40 kHz (a frequency at which all local bat species can be detected) with the volume set on maximum. The detector will provide an audible indicator that a bat is present in real time, which will be recorded on the camera video files and can be used to confirm bat presence in our video analysis (See Data Management and Analysis section).

Survey procedure

Within a single survey night, surveys will be conducted as a series of 10 min sessions that begin approximately 20 minutes after sunset and continue up to 3 hours (i.e., during the primary activity period for bats). In order to record bat activity in the low light levels at the start of each survey night, the Sony cameras will be used without the ATN-NVM14 night vision scopes and infrared lights for the first 10-minute session. The scopes will then be attached to the cameras for the remainder of the night.

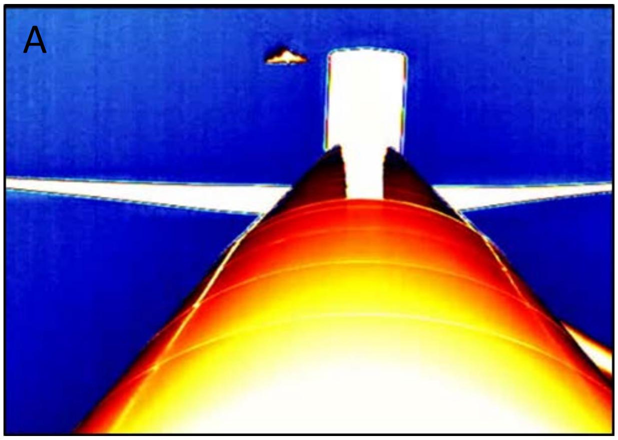
At the beginning of each session, all cameras at a turbine will be started simultaneously, so that the videos can later be synchronized for video analysis (see Data Management and Analysis section below). We also will keep the timing of the sessions as synchronized as possible between turbine sites. Note that all equipment will be removed from the area after the last recording session each night.

In addition, we will complete a data form at the beginning of each session to record start and end times, survey personnel, and weather conditions including temperature (C°), wind speed (km/h), wind direction, humidity (%), dew point (C°), barometric pressure (Hg in), cloud cover (full, partial, and clear), moon phase, moon illumination (%), and whether the moon is visible. Furthermore, surveys will only be conducted on nights with wind speeds averaging less than 24 km/h and no precipitation.

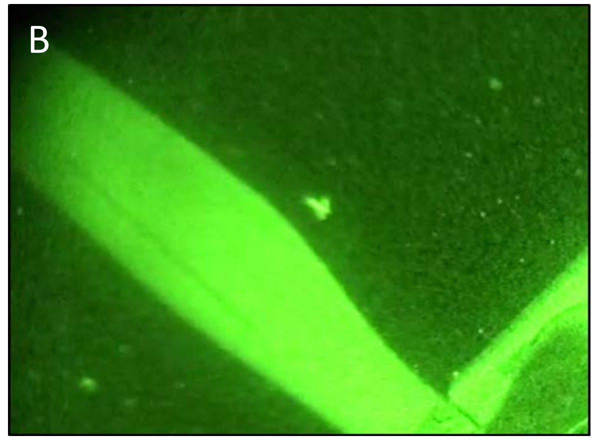
Data Management and Analysis

We will process all videos from the cameras in Studiocode (version 5, Studiocode Business Group, Sydney, AU). Using this program, we will link videos from both night vision and thermal cameras onto a single timeline, so that the videos can be viewed together. Once the videos are linked, we will then be able to view all footage for a single session at a turbine site simultaneously. We will view each session in its entirety and mark on the timeline when an object is observed flying in the video(s).

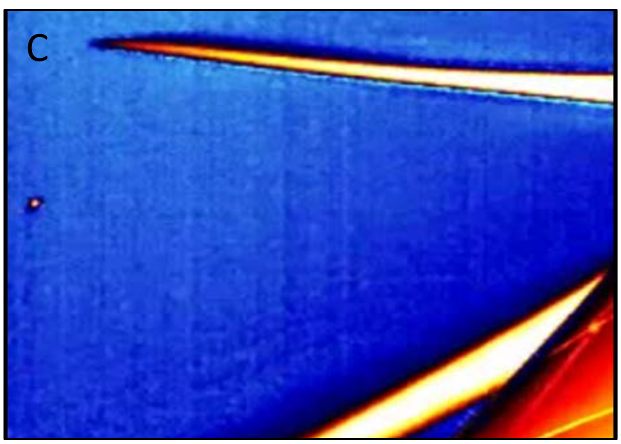
We will use our Bat Identification Key developed in Task 4 to systematically identify flying objects. This key was constructed as a step-by-step guide that allows the user to effectively and consistently identify flying objects as bats, non-bats, and possible bats. An object is determined to be a bat when the silhouette of the object resembles that of a bat (i.e., it has a visible head, body, and wings) and it only has characteristics consistent with being a bat. An object is determined to be a non-bat when it has characteristics of an insect, bird, plane, or other flying object. In contrast, an object is considered to be a possible bat when: 1) the object lacks definitive characteristics indicating that the object is a bat (e.g., we do not see the head or distinct wings), 2) the object lacks other definitive characteristics indicating that it is a non-bat (e.g., we do not see a distinct long tail), and 3) the attributes of the object are not sufficiently resolved (e.g., we see indistinct wings). Figure 6 provides representative examples of a bat, non-bat, and possible bat identified in Task 4.



This object was identified as a bat because it had a distinct head, body, and wings. Note that you can see the finger bones in the patagium.



This object was determined to be an insect such as a dragonfly because it had a long body with wings at the front end.



This object was determined to be a possible bat because we could not ascertain whether the dark patches at the sides of the body were wings or shadows created by the body.

Figure 6: Examples of flying objects that were categorized as a bat (**A**), a non-bat (**B**), and a possible bat (C) in video footage recorded at wind turbine tower surfaces at Wolf Ridge Wind, LLC.

When classifying and identifying flying objects, we will use Studiocode software to track and record answers to the following questions: 1) is the object flying near the turbine tower below or above the nacelle?; 2) does the object have features and exhibit behavior characteristic of bats or non-bats that can be seen in thermal camera images? and if so, what are they?; 3) does the object have features and exhibit behavior characteristic of bats or non-bats that can be seen in night vision camera images? and if so, what are they?; and 4) are acoustic bat calls heard on the video when the object is in the field of view?

Once all of the flying objects have been categorized, we will review all of the 'bats' to further classify their behavior. In our feasibility study (Task 4), we defined 8 specific types of behavior exhibited by the bats in proximity to turbine towers. These behaviors included: *passing* - when a bat flies through the field of view with ≦1 change in direction of turning angle; *reversing* - when a bat enters the field of view and before reaching the wind turbine tower turns back the way it came; *looping* - when a bat enters the field of view, turns at or after it has crossed in front or behind of the wind turbine tower and then flies back the way it came; *foraging* - when a bat exhibits a zig-zagging flight pattern with ≥2 turns; *skimming* - when a bat flies low over the surface of the tower and may or may not make contact with the surface. We associated this behavior with potential drinking attempts; *sweeping* - when a bat flies close to the tower as if it were skimming but makes contact with the tower with just the outstretched tip of a wing; *colliding* - when a bat flies into the tower at a steep angle; and *gleaning* - when a bat hovers over the tower surface before landing on it long enough to grab a food item, such as a resting insect, before flying away. Note that not one of the observations of a bat *colliding* with the tower in Task 4 appeared to be fatal; in all cases the bat flew out of the field of view after hitting the tower surface.

To further examine bat activity in proximity to the turbine tower surfaces, we will also characterize the aforementioned behaviors into 3 distance categories. As in our feasibility study (Task 4), these categories will be *contact/close contact*, *close-range*, and *far-range*. For a behavior to be *contact/close contact* the bat must be within 0.2 m of the tower surface and we must see the bat interacting with the turbine tower in some way, i.e. through skimming, sweeping, colliding, or gleaning from the tower surface. For a behavior to be *close-range,* we must see either the reflection of the bat on the turbine tower surface indicating the bat is within close proximity to the surface or the distance of the bat from the surface can be estimated as <2 m using distance markers (such as the flange) on the turbine tower. Behaviors within this distance category include passing, reversing, looping, and foraging. The *far-range* behaviors will include all other bats observed passing, reversing, looping, or foraging at distances >2 m from the turbine tower surface.

The bat acoustic calls recorded will be used to confirm species presence and compare patterns of acoustic bat activity with bats observed in the high-definition videos at the survey sites. For this procedure, we will use SonoBat v. 3.03 bat call analysis software to identify calls to species.

Once we have processed the videos files and the acoustic data, we will compare patterns of activity and types of behavior exhibited by bats at both the smooth and texture-treated surfaces. As we are proposing a paired study design (i.e., recording bat activity at control and treatment surfaces simultaneously), our response variables will likely include the difference in number of bats seen and heard, difference in the number or proportion of particular behaviors seen, and the difference in the number or proportion of particular behaviors seen with respect to distance from the tower at smooth and texture-treated surfaces. The paired design will help minimize the influence of spatial and temporal variation in bat activity, thereby increasing the power of our tests. We will first assess variation in overall levels of bat activity across the survey period and among the turbine pairs. Depending on the spatial patterns of activity in the data set, we may include turbine pair as a blocking factor in subsequent analyses using GLMs. Likely covariates in such an analysis would include meteorological and moonlight variables that are often associated with variation in bat activity. Likewise, we may also want to calculate mean bat activity at each turbine pair every 1-2 weeks, and then use these temporal replicates to compare bat activity over time.

It is also likely that we will use a variety of statistical approaches to answer a range of questions associated with bat activity at wind turbines. For example, we may compare the proportion of *contact/close contact* observations at smooth and texture-treated turbines using a 2-proportion test (Fisher’s exact test). We may also use a χ^2 contingency test to determine if the types of behaviors exhibited by bats are independent of surface type. For this analysis, we would predict that the number of *contacts/close contacts* and *close-range* observations would be lower at texture-treated surfaces than at smooth surfaces if turbine tower surfaces are perceived to provide a resource as hypothesized.