Curtailment Research Study for the Crescent Wind Project Hillsdale County, Michigan

May 20 – October 15, 2021

Prepared for:

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WEST

EXECUTIVE SUMMARY

Consumers Energy Company (Consumers) operates the Crescent Wind Project (Crescent) in Hillsdale County, Michigan. Crescent began operating in February 2021, and consists of 60 wind turbines with a total generating capacity of 166 megawatts. Consumers subsequently obtained a US Fish and Wildlife Service recovery (research) permit to test the effectiveness of an acoustic-activated (smart) curtailment system for Indiana bats (*Myotis sodalis*) and northern long-eared bats (*M. septentrionalis*), as well as other bat species, from May 15 to October 15, 2021. The research permit provided take coverage for the federally endangered Indiana bat and threatened northern long-eared bat that might occur as part of this study.

The main goal of this study was to investigate ways to minimize impacts to Indiana and northern long-eared bats from wind operations. To this end, 20 turbines each were assigned to one of three treatments: a control operating at a manufacturer's cut-in speed of 3.0 meters per second (m/s), blanket curtailment with a nightly raised cut-in speed of 5.0 m/s, or smart curtailment with a nightly raised cut-in speed of 5.0 m/s only when bat calls were detected. The research project aimed to answering the following questions: What are the percent reductions in fatality achieved with blanket curtailment below 5.0 m/s and smart curtailment below 5.0 m/s compared to turbines operating at manufacturer's cut-in speed (3.0 m/s)? Can a similar level of minimization be obtained through smart curtailment and blanket curtailment?

All turbines were searched twice a week from May 20 to October 15, 2021, for a total of 2,473 carcass searches. Thirty cleared plots (10 in each of three treatment groups) were searched out to 80 meters by detection dog teams, and roads and pads of the remaining 30 turbines were searched out to 100 meters by human searchers. In total, 1,699 bat carcasses were discovered during the searches. The most frequently detected species were the big brown bat (38%), eastern red bat (23%), hoary bat (20%), and silver-haired bat (19%). Searchers also found four Seminole bats, two evening bats, and one little brown bat.

Using GenEst, a generalized estimator of fatality, the estimated fatality rates by treatment were 85.00 bats/turbine/study period (90% confidence interval [CI]: 72.66–101.19) for the control group, 49.41 (90% CI: 41.91–59.41) for the blanket curtailment group, and 46.69 (90% CI: 38.84–56.32) for the smart curtailment group. Overall, curtailment reduced bat fatalities at Crescent by approximately 42 to 45%, and there was no statistical difference in fatality rates between the blanket and smart curtailment treatments. Fatality rates were higher in fall than in summer, and curtailment appeared to be somewhat more effective in the summer than the fall. No Indiana bats or northern long-eared bats were found, and the mean fatality estimate for both species was zero based on the Evidence of Absence estimator.

STUDY PARTICIPANTS

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REPORT REFERENCE

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INTRODUCTION

Wind energy development may impact migratory and local bat populations, especially for tree-roosting species (Cryan et al. 2009, Hayes 2013, Frick et al. 2017). However, the most severe threat to North American bats that overwinter in caves is white-nose syndrome, a fungal disease (Blehert et al. 2009, Cheng et al. 2021). This is the biggest challenge to the recovery of Indiana bats (*Myotis sodalis*) and northern long-eared bats (*M. septentrionalis*), species protected under the Endangered Species Act (USFWS 2016a, 2009). While these two species appear to be infrequently killed at wind facilities (Pruitt and Reed 2021, WEST 2021), wind energy development and white-nose syndrome may interact to reduce the abundance of their already depressed populations (Erickson et al. 2016).

To address the risk to bat species associated with wind turbines, studies have shown that raising the wind speed at which turbine rotors begin to rotate and produce energy (cut-in speed) is an effective measure for reducing bat fatalities (Adams et al. 2021). Bat mortality resulting from turbine collision is inversely related to wind speed (e.g., Arnett et al. 2008, Horn et al. 2008). Therefore, feathering[1] turbine blades and raising cut-in speeds (i.e., curtailing) turbines at night during periods of low wind reduces bat mortality.

"Blanket curtailment" (curtailing every turbine, every night for an entire season) has proven effective at reducing bat fatalities, though it can cause substantial losses in energy production. These losses can jeopardize the financial viability of a renewable energy project. In an effort to better balance conservation needs with turbine shutdown time, "smart curtailment" makes near real-time operational decisions based on factors associated with collision risk. There are two main types of smart curtailment. The first relies on the real-time detection of bats in order to trigger curtailment (i.e., acoustic-activated curtailment). The other relies on biologically driven predictive models that curtail at times of comparatively high risk based on factors such as wind speed and temperature, without the need for real-time monitoring of bat activity. Both approaches are still being tested, and are the subject of ongoing research—acoustic-activated smart curtailment is the focus of this study.

Curtailing turbines during nights, or portions of nights, when bats are absent, and thus not at risk of collision, results in significant losses to energy production without providing any benefit to bats. Acoustic-activated smart curtailment systems are designed to implement curtailment only when bats are present, where "presence" is indicated by calls being processed in real time by an acoustic detector. These systems can also be programmed to include thresholds for wind speed and other weather variables.

In the sole published study of acoustic-activated curtailment to date, the Turbine Integrated Mortality Reduction system (Normandeau) was tested at a wind facility in Wisconsin in mid-summer through fall (Hayes et al. 2019). Individual turbines were curtailed if wind speed was 3.5–8.0 m/s (11.4–26.2 ft/s) and a bat call was detected in the preceding 10 minutes (min). This achieved an 85% overall reduction in fatalities across five bat species as compared to control turbines. Fatalities were reduced by 91% for little brown bats (*M. lucifugus*), a species that is biologically similar to Indiana and northern long-eared bats.

[1] "Feathering" means that below the cut-in speed wind speed, turbine blades will be pitched into the wind such that they freewheel and rotate slowly (less than one rotation per minute).

The US Fish and Wildlife Service (USFWS) commonly accepts blanket curtailment at 5.0 m/s as a minimization measure in habitat conservation plans (HCPs) for Indiana and northern long-eared bats. While there are a few ongoing studies, as noted above, the only public study to examine the effectiveness of acoustic-activated curtailment was triggered anytime a bat was detected and wind speeds were below 8.0 m/s (Hayes et al. 2019). However, the cost of curtailment at wind speeds above 5.0 m/s is substantial, and unlikely to be broadly adopted by wind operators across the ranges of Indiana and northern long-eared bats. There are no published studies comparing the effectiveness of acoustic-activated curtailment at the wind speeds typically used to minimize impacts to Indiana and northern long-eared bats.

In this study, Consumers Energy Company (Consumers), with help from Western EcoSystems Technology (WEST), tested the effectiveness of curtailing at wind speeds up to 5.0 m/s only when bats are present (acoustic-activated, or smart, curtailment), and compared mortality rates to turbines operating under blanket 5.0 m/s curtailment and turbines operating at a manufacturer's cut-in speed of 3.0 m/s in the summer and fall. Consumers installed Natural Power's smart curtailment system (Detection and Active Response Curtailment) for bats at five turbines at the Crescent Wind Project (Crescent or Project) and curtailed all turbines operating under the smart curtailment treatment when the call of any bat species was detected at any of the units. The basic assumption behind the application of this system at Crescent is that conditions or time periods in which any bat is detected is also representative of conditions when Indiana and northern long-eared bats are at risk.

This study was conducted under USFWS recovery (research) permit #ESPER0011469 and was preceded by monitoring in the spring, when avoidance measures for Indiana bats and northern long-eared bats were in place (Zero et al. 2021). This research was conducted to inform a long-term operational strategy proposed as part of a 30-year HCP for Crescent. The ultimate goal was to test a novel approach to minimizing impacts to Indiana and northern long-eared bats, while also minimizing impacts to other bat species at Crescent.

METHODS

Study Area

This Project began operating in February 2021, and consists of 60 wind turbines with a total generating capacity of 166 megawatts (MW). Two General Electric (GE) turbine models are installed, both with a hub height of approximately 89 m (292 ft). The 54 GE turbines with a 2.82-MW generating capacity have a rotor diameter of 127 m (417 ft) and a maximum height of approximately 152 m (499 ft). The six GE turbines with a 2.3-MW generating capacity have a rotor diameter of 116 m (381 ft) and a maximum height of approximately 138 m (453 ft). The Project area encompasses approximately 38,320 acres (15,507 hectares) of private land in Hillsdale County in south-central Michigan. The dominant land cover is cultivated cropland (primarily corn [*Zea mays*] and soybeans [*Glycine max*]), covering 61% of the total area (Figure 1). Deciduous forest and woody wetlands are the next most abundant cover types, accounting for approximately 16% and 12% of the Project area, respectively. Water resources include tributaries of Bean Creek in the south and the South Branch of Kalamazoo River in the north.

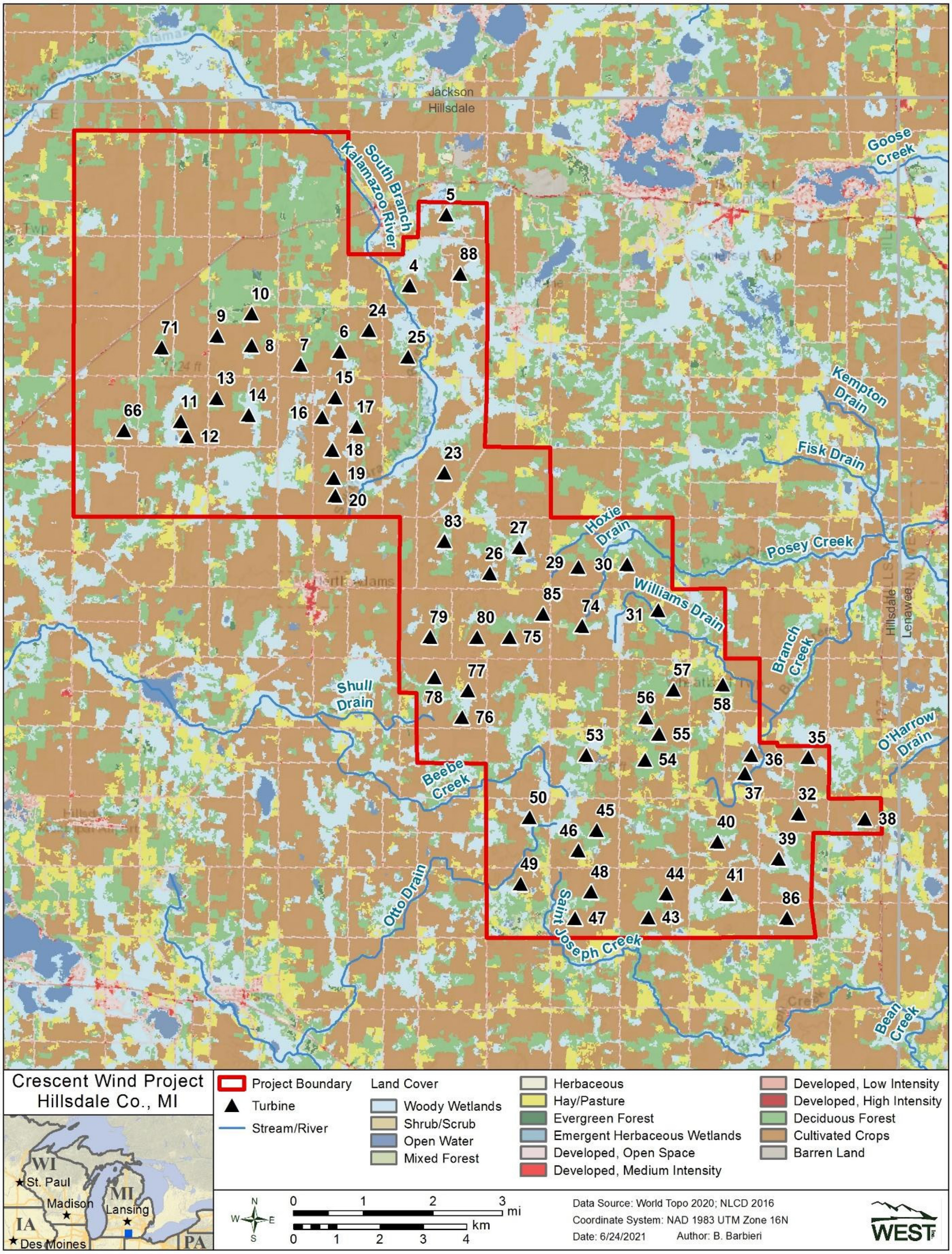


Figure 1. Land cover and turbine layout for the Crescent Wind Project.

Based on presence/probable absence surveys conducted in 2016, both Indiana and northern long-eared bats may occur at Crescent during the summer maternity season (Bishop-Boros et al. 2018). All turbines at Crescent meet the USFWS criteria for summer risk of individual turbines (i.e., the turbines all have suitable forested habitat within 1,000 ft [305 m]). Therefore, both species were assumed to be potentially present at Crescent around all turbines for the duration of the study.

Curtailment Treatments

Twenty turbines each were assigned to three treaments as described further below: control, blanket curtailment, or smart (acoustic-activated) curtailment. Treatments were assigned using a spatially balanced sample design to ensure that selected turbines provided a representative sample of the facility. Halton iterative partitioning was used to select turbine treatments and plot types (Robertson et al. 2018), as implemented in the SDraw R package (McDonald and McDonald 2020). Within the 20 turbines assigned to each treatment, the plot type (10 cleared and 10 road-and-pad plots) was randomly assigned (Figure 2). Curtailment assignments were subsequently verified using operational and weather data.

The control group was feathered below the manufacturer's cut-in speed of 3.0 m/s whenever temperatures were above 10 degrees (°) Celsius (C; 50 °Fahrenheit). The blanket curtailment treatment was implemented 45 min before civil dusk (twilight) through 45 min after civil dawn[2] when temperatures were above 10 °C. The smart curtailment system included integrated acoustic monitoring units (BATLOGGER WE-X2 [Elekon AG, Luzern, Switzerland]) at five turbines distributed across the Project area (Figure 2). The system detected bats continuously and shut down turbine operations for a minimum of 30 min when any bat call was detected and wind speeds were below 5.0 m/s. The smart curtailment treatment was implemented 45 min before sunset through 45 min after sunrise when temperatures were above 10 °C.

The smart curtailment system consists of two components: the bat detection subsystem and the decision subsystem. The bat detection subsystem is installed on turbine nacelles and consists of integrated acoustic monitoring units, ultrasonic microphones, and a communications system. Two microphones were mounted on the outside of the nacelle, while the rest of the hardware was placed inside the nacelle. A custom bracket attaches the microphones to the nacelle and ensures the largest possible sampling area. The decision subsystem integrates the data collected by the two subsystems and makes a recommendation on turbine curtailment. It consists of a server that runs the smart curtailment software, a data logger to provide the curtailment recommendation, and various security and support elements. The system includes logic for triggering curtailment, monitoring system health, and alerting Natural Power staff to any operational issues.

[2] It was noted on August 4, 2021 that the two curtailment groups were operating on different time tables: civil dusk (twilight) and dawn for blanket curtailment, and sunset and sunrise for smart curtailment. Sunset and sunrise occur before and after civil dusk and dawn, respectively. This resulted in the potential for up to an extra hour of nightly curtailment time under the smart curtailment treatment, assuming bats were active during this period. It was determined at that time that it would take several weeks to change the programming of either treatment. To keep the difference consistent between the summer and fall portions of the study, as well as within the fall, Consumers did not reprogram the operational windows.

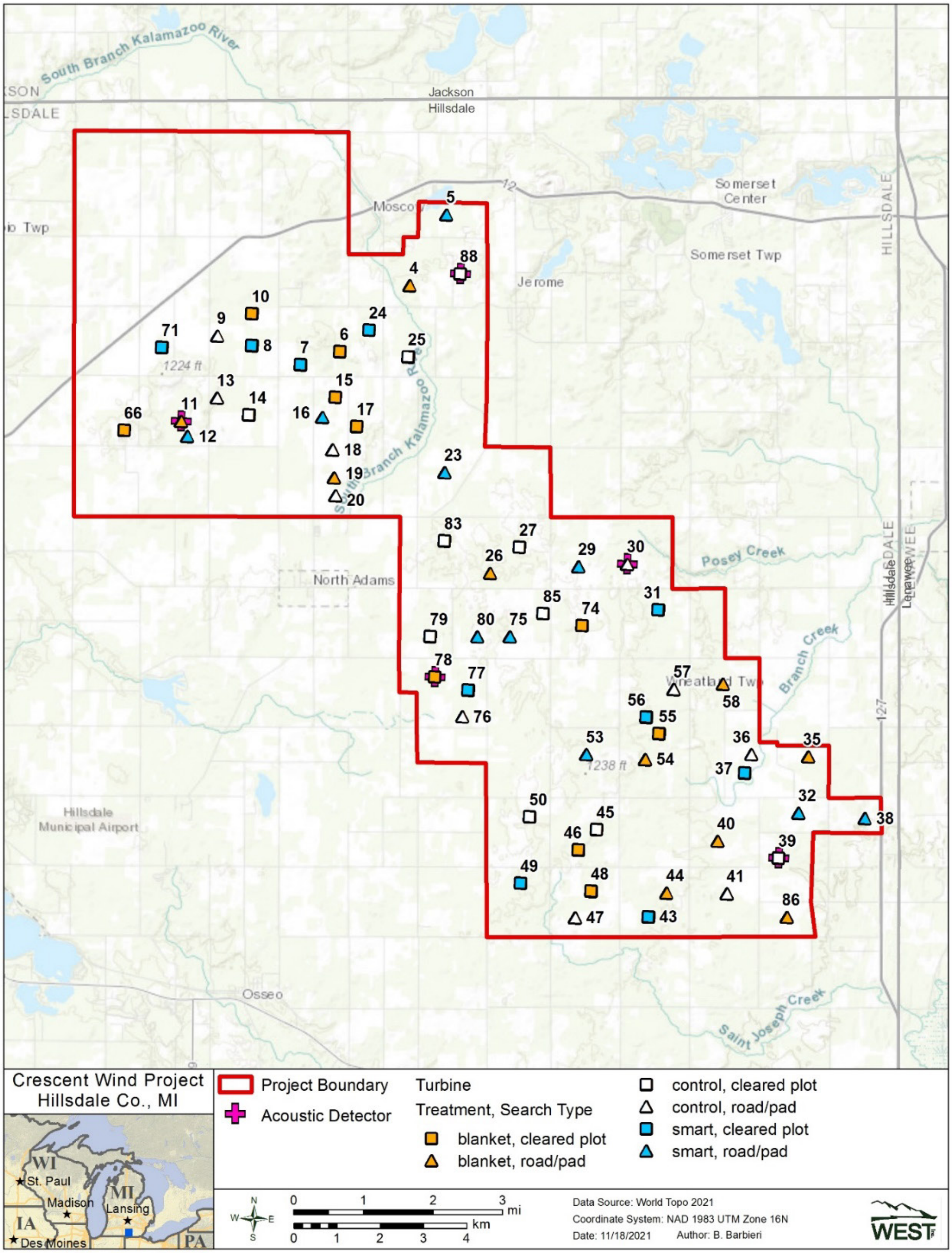


Figure 2. Turbine treatment, plot type, and acoustic detector locations.

Weather Conditions

Each turbine is equipped with a supervisory control and data acquisition (SCADA) operations and communications system that provides automated, independent, and remote operation of the turbine. SCADA data provide detailed information for each turbine's operation and performance, allowing real-time control and continuous monitoring to ensure optimal operation and identification of potential problems. Wind speed, temperature, and operational status were recorded every 10 min for each turbine.

Standardized Carcass Searches

Search Methods

The facility was operating under avoidance measures May 15 – May 18, 2021 (Zero et al. 2021); turbine operations were switched on May 19, and the first research searches were conducted May 20. Standardized carcass searches were conducted at all turbines twice weekly (approximately every 3.5 days) May 20 – October 15, 2021. Thirty road-and-pad plots were searched by technicians out to 100 m (328 ft) along gravel roads (Figure 3). Thirty 160 x 160-m (525 x 525-ft) cleared plots were searched by dog-handler teams (Figure 4). While some plot types were switched early in the study to accommodate landowner permissions, this was taken into account in statistical analyses; treatment assignments were constant throughout the study. All personnel were trained to follow the Project's study plan (WEST 2020), including proper handling and reporting of carcasses. Searches began after first light and ended by 17:00 hours.

Figure 3. Representative photograph of a 100-meter road and pad plot, all of which were searched by humans only. (The dog and biologist were not conducting a search when this photo was taken.)

Figure 4. Representative photograph of a 160 x 160-meter cleared plot, all of which were searched by dog-handler teams. For scale, note researcher vehicle parked on the road at 80 meters from the turbine.

Human Searchers

Technicians walked transects spaced five m (16 ft) apart at a rate of approximately 45–60 m (148–197 ft) per min on all gravel roads and pads within 100 m of the turbine. The technicians scanned the area for fatalities on both sides of the transects out to approximately 2.5 m (8.2 ft) to ensure full visual coverage of each search area.

Dog-Handler Teams

Detection dog teams, consisting of one handler and one dog, searched cleared plots for bat carcasses. Detection dogs were considered candidates for conducting carcass searches at the Project if they met certain temperament, obedience, and carcass-detection requirements. Characteristics that are sought after in a detection dog are high-energy, high toy or food drive, and successful completion of WEST's detection dog scent training protocol. Prior to conducting searches at the Project, handlers trained their detection dogs on the scent of bat carcasses using techniques derived from search and rescue, and/or drug detection programs (Kay 2012, Helfers 2017). Dogs were initially trained on dehydrated bat carcasses as the target odor. Once the dog had achieved a passing grade of 80% or higher in a scent recognition test consisting of 10 blind trial lineups using bat carcasses, the dog and handler were evaluated in the field to measure performance under conditions representative of the actual survey area. The detection dog coordinator conducted a 1- or 2-day field evaluation for any dog-handler team new to WEST, and again on an annual basis for returning teams. If a dog-handler team achieved a searcher efficiency (SEEF) of 75% or greater out of a minimum 15 trial bats placed during evaluation trials, the team was approved to conduct carcass searches. Breeds of detection dogs used at the Project included Border collie, blue heeler (Australian cattle dog) and Brittany spaniel.

Prior to each search, handlers determined the survey start points and the number of transects needed to cover the plot after taking into account wind speed and direction, as well as vegetation density (when applicable). Handlers oriented dogs to start searches perpendicular to the wind to maximize scent detection. Both wind speed and vegetation density can affect dispersal of the target odor (bat carcass) across the search area. To maximize detection rates during an olfactory search, transect width varied with vegetation density, ranging from 5 to 10 m (16 to 33 ft) apart in densely vegetated areas, to 10 to 15 m (33 to 49 ft) apart in shorter vegetation. Cleared plots were mowed regularly (up to eight times during the study) to ensure vegetation did not exceed approximately 13 centimeters (five inches) in height. All plots were searched and mowed as far out as possible, with some practical constraints, including fence lines and forested habitat along plot edges. Any unsearchable areas were measured and accounted for statistically.

Data Collection

For each scheduled search, technicians recorded the date, start and end times, technician name, turbine number, type of search (cleared plot or road and pad plot), and if any fatalities were found. When a fatality was found, technicians placed a flag near it and continued the search. After searching the entire plot, the technician returned to record information for each fatality on a fatality data sheet. Data recored included the date and time, species, sex and age (when possible), technician name, turbine number, measured distance from turbine, azimuth from turbine, location of carcass as Universal Transverse Mercator coordinates, habitat surrounding carcass, condition of carcass (i.e., intact, scavenged, dismembered, injured), and estimated time of death (e.g., less than one day, two days). Technicians took digital photographs of each fatality, including any visible injuries, and surrounding habitat. The technician also plotted the location of each fatality on a map of the search area. Carcasses found in non-search areas (e.g., outside of a plot boundary) or outside of the scheduled study period were recorded as incidental discoveries and documented following the same protocol for those carcasses found during standard searches, but these carcasses were not included in analysis.

The condition of each carcass found was recorded using the following categories:

- Intact—a carcass that is complete, is not badly decomposed, and shows no sign of being fed upon by a predator or scavenger.
- Scavenged—an entire carcass that shows signs of being fed upon by a predator or scavenger, or a portion(s) of a carcass in one location (e.g., wings, skeletal remains, portion of a carcass, etc.), or a carcass that has been heavily infested by insects.
- Dismembered—an entire carcass found in multiple pieces distributed more than 1.0 m (3.3 ft) apart from one another due to scavenging or other reasons.
- Injured—a bat found alive.

Bat carcasses were collected under the Project's research permit (#ESPER0011469), WEST's Federal Native Endangered and Threatened Species Recovery Permit (TE234121-9), and WEST's State Scientific Collection Permit (21-086). Technicians placed all bat carcasses in a re-sealable plastic bag labeled with the unique carcass identification number, turbine number, and date for storage in a freezer on site. Leather and latex/nitrile gloves were used to handle all bat carcasses to eliminate possible transmission of rabies or other diseases.

Carcass Identification

A permitted bat biologist (TE234121-9) verified the identifications of all bat carcasses in hand at the end of the surveys. In the event a bat could not be identified to species by a permitted bat biologist, a tissue sample was taken and sent to the Northern Arizona Bat Ecology and Genetics Lab for DNA identification. No federally listed species were discovered during the study, but the USFWS and the Michigan Department of Natural Resources were notified within 24 hours of positive identification of the state-threatened evening bat (*Nycticeius humeralis*).

Bias Trials

Searcher Efficiency Trials

The objective of SEEF trials was to estimate the probability that a carcass was found by searchers. SEEF trials were conducted in the same areas where carcass searches occurred. Searchers did not know when SEEF trials were being conducted or the location of the trial carcasses. Trial carcasses consisted of eastern red bats (*Lasiurus borealis*), hoary bats (*L. cinereus*), big brown bats (*Eptesicus fuscus*), and silver haired bats (*Lasionycteris noctivagans*) that had previously been found on site. A minimum of 10 bat carcasses were placed and confirmed available per plot type and per season by the trial administartor. Multiple trials were conducted in each season to measure potential changes in plot conditions on SEEF over time.

Each trial carcass was discreetly marked with a black zip-tie around the upper forelimb for identification as a study carcass. Carcasses were dropped from waist-height or higher and allowed to land in a random posture. The number and location of trial carcasses found during the subsequent search were recorded, and the number of trial carcasses available for detection during each search was determined immediately after each trial by the trail administrator. Searchers had one chance to locate trial carcasses during the first search after carcass placement. The trial administrator walked in a meandering path and dropped trials for detection dogs the night prior to the next search to allow time for the scent to pool and disperse prior to scheduled searches. Following searches, the trial administration checked any carcasses that were not detected to confirm availability.

Carcass Persistence Trials

The objective of carcass persistence trials (CPT) was to estimate the length of time (in days) a carcass would persist, or be available for detection, in the field. Carcasses could be removed by scavenging or rendered undetectable by typical farming activities. A minimum of 10 trial carcasses were placed in each season and plot type to incorporate the effects of varying weather and climatic conditions on carcass persistence (CP). CPT were conducted across all plot types to incorporate the effects of varying weather and scavenger densities. No more than two trial carcasses were placed on a plot to avoid potential over-seeding and attracting scavengers.

Technicians monitored the CPT carcasses as closely as possible over a 30-day period according to the following schedule: carcasses were checked daily for the first four days, then on day 7, 10, 14, 20, and 30. Trial carcasses were monitored until the carcasses were completely removed or the trial period ended.

Search Area Mapping

Technicians recorded the boundaries of all plots using a Trimble (Sunnyvale, California) submeter global positioning system unit. Unsearchable areas within plot boundaries were also mapped. The plot boundaries were used to verify if carcasses were found inside the search areas, and to inform the distribution of carcasses around turbines to estimate the number of carcasses that fell inside or outside of search areas.

Quality Assurance and Quality Control

Quality assurance and quality control measures were implemented at all stages of the study, including in the field, during data entry and analysis, and report writing. Following field surveys, technicians were responsible for inspecting data forms for completeness, accuracy, and legibility. Potentially erroneous data were identified using a series of database queries. Irregular codes or data suspected as questionable were discussed with the technician and/or Project manager. Errors, omissions, or problems identified in later stages of analysis were traced back to the raw data forms, and appropriate changes and measures were implemented. A Microsoft® SQL database was developed to store, organize, and retrieve survey data. All data forms and electronic data files were retained for reference.

Statistical Analysis

Fatality estimates were calculated for all bats by season, plot/searcher type[3], and treatment, using GenEst (a generalized estimator of fatality; Dalthorp et al. 2018, Simonis et al. 2018). Each carcass included in the analysis was adjusted for SEEF, CP, a detection reduction factor (*k*; see below), and a search area adjustment. Seasonal estimates were summed by search area type. Within each season, estimates from different plot types (cleared, road and pad) were combined using a weighted average, weighted by the number of each plot type; an overall estimate for each treatment and across all treatments was the sum across seasons. Estimates and 90% confidence intervals (CI) were calculated using a parametric bootstrap (Dalthorp et al. 2018) for each category listed above.

The Evidence of Absence (EoA; Dalthorp et al. 2017) modeling framework was used to estimate take of Indiana and northern long-eared bats. To estimate take, EoA used data collected in the field to estimate the overall probability of detecting a bat fatality, the arrival distribution (seasonal

[3] Note that plot type (clear plots or road and pad plots) and searcher type (technician or dog-handler team) were always associated with one another in this study, such that plot type and searcher type are interchangeable.

arrival proportion) of bats (described below), and the number of detections for the species of interest.

Searcher Efficiency Estimation

EoA uses raw SEEF data (number of found and available trial carcasses) to inform the overall probability of detection. However, to determine if SEEF data should be pooled, or separated by strata such as season or plot type, we modeled SEEF using logistic regression, while accounting for the detection reduction factor, *k* (Dalthorp et al. 2018). Models included plot type and season as potential covariates, and SEEF was modeled separately for humans and dog teams to account for different modes of detection (sight for humans, scent for dogs). Model selection was completed using the corrected Akaike Information Criterion (AICc; Burnham and Anderson 2002). The best model was selected as the most parsimonious model (with the fewest parameters) within two AICc units of the model with the lowest AICc value. SEEF values were input into the EoA software according to the model selection results. GenEst uses the best fit model directly (Dalthorp et al. 2018, Simonis et al. 2018).

The change in SEEF between successive searches was defined by a parameter called the detection reduction factor (*k*) that can range from zero to one. When *k* is zero, it implies a carcass that was missed on the first search would never be found on subsequent searches. A *k* of one implies SEEF remained constant no matter how many times a carcass was missed. Huso et al. (2017) estimated a value of *k* = 0.67 for bats, and this value was used to calculate bat fatality estimates using EoA and GenEst.

Carcass Persistence Rate Estimation

Data collected during CPT were used to estimate the amount of time, in days, carcasses remained available to be located by the searcher. The average probability a carcass persisted through the search interval (i.e., the time between scheduled searches) was estimated using an interval-censored survival regression with four potential distributions: exponential, loglogistic, lognormal, and Weibull distributions (Kalbfleisch and Prentice 2002, Dalthorp et al. 2018). Potential covariates were fit to all parameters of the candidate distributions; we considered season (summer, fall) and plot type (road and pad, cleared). The best model was selected as the most parsimonious model within two AICc units of the model with the lowest AICc value. The parameter estimates of the selected model (α [shape] and β [scale], including the 95% CI of β) were used as inputs in the EoA Single Class Module. As with the SEEF model, GenEst uses the best fit model directly (Dalthorp et al. 2018, Simonis et al. 2018).

Area Adjustment

The search area adjustment accounted for unsearched areas beneath turbines, and was calculated as a probability that ranged from zero to one. The area adjustment was estimated as the product of the searched area around each turbine and a carcass-density distribution. A truncated weighted maximum likelihood (TWL) modeling approach was used to estimate the carcass-density distribution using site-specific fatality locations (Khokan et al. 2013). TWL uses a weight-based probability of detection and the proportion of area searched in each 1.0-m annulus around the turbine. Distributions considered were normal, gamma, Gompertz, Rayleigh, and

Weibull (parameterized according to R Development Core Team [2016] and Yee [2015]). The best model was selected using AICc. The proportion of area searched was calculated in a Geographic Information System as the amount of area searched divided by the total area searched at each 1.0-m annulus around the turbine.

Fatalities were excluded from the area adjustment calculation when the carcass was discovered outside of the spatial and temporal scope of the survey design. Carcasses found outside a designated plot were not included because the area adjustment accounts for the carcass by adjusting for unsearched areas. Carcasses found prior to the start of surveys (e.g., a carcass found on a plot in the spring that is not searched until the summer) were also excluded because the carcass occurred outside of the study period. Carcasses found on a plot incidentally were included in the analysis if that plot had a scheduled search in the future.

Indiana Bat and Northern Long-Eared Bat Take Estimates

EoA was used to estimate the median cumulative take to-date (*M**) and the mean annual take rate (λ) for Indiana bat and northern long-eared bat. Estimates were calculated using EoA with the Single Class, Multiple Class, and Multiple Years modules (Dalthorp et al. 2017).

The probability of detection (*g*) was estimated using the bias corrections for SEEF, CP, and area searched, as well as the assumed seasonality of risk for Indiana bats and northern long-eared bats, which was 7% in spring, 36% in summer, and 57% in fall, based on a *Myotis* dataset from the Midwest (USFWS 2016b). However, the monitoring associated with this research did not begin until summer, so the re-apportioned arrival percentages are 38.7% in summer (May 20 – July 31) and 61.3% in fall (August 1 – October 15). In this analysis, the summer season was further divided into sub-seasons because some plots switched search types (cleared plot versus road and pad) within the season. The summer arrival proportion of 0.387 was divided among the sub-seasons within summer according to the duration of each.

The EoA Single Class Module was used to estimate the distribution of the detection probability for each search stratum. This resulted in alpha and beta parameters that defined the Beta distribution of detection probability in each stratum. The area adjustment for each plot type was included as the “Spatial coverage (a)” parameter in the Single Class Module.

The EoA Multiple Class Module was then used to combine detection probability distributions across strata (cleared plots, road and pad plots, and unsearched plots) within season, with weights for each class defined by the sampling fraction. Beta distribution parameters were set to Ba = 0.01 and Bb = 1,000 for unsearched turbines. The Multiple Class Module was used again to combine Beta distribution parameters across seasons, with weights for each season defined by the arrival proportions (described above).

The Multiple Years Module was used to estimate the study-wide detection probability (Ba and Bb parameters for the detection probability) and was then used to estimate *M**, mean take rate λ, and 90% and 95% CIs of take rate. The Multiple Years Module requires the input ρ, which weights the years appropriately. ρ was set to one for 2021 because 2021 was the only monitoring conducted to date under the recovery (research) permit conditions.

Effectiveness of Acoustic-Activated Curtailment

GenEst can produce an adjusted fatality estimate distribution for each treatment group: m_C = mortality estimate for the control group, m_B = mortality estimate for the blanket curtailment group, and m_A = mortality estimate for the acoustic-activated curtailment group. The estimate vectors were subtracted from one another to test whether the pairwise differences included zero (no difference between treatments) or not (difference between treatments). For example and per the draft HCP, to test whether blanket curtailment had a lower fatality rate than the control treatment, we calculated the difference ($d_{BC} = m_B - m_C$). We then calculated the probability that d_{BC} was less than zero, $\Pr(d_{BC} < 0)$. If $\Pr(d_{BC} < 0)$ is greater than 0.95 (a 1-tailed significance test), we can conclude that the blanket curtailment treatment had a lower fatality rate than the control treatment. The same procedure applies to any treatment comparison.

RESULTS

Standardized Carcass Searches

Two-thousand-four-hundred-seventy-three (2,473) carcass searches were conducted (Table 1). One-hundred-seven (107) searches (less than 5%) were missed due to turbine maintenance, weather constraints, or safety hazards.

Table 1. Number of searches by season and plot type at the Crescent Wind Project from May 20 – October 15, 2021.

Season	Plot Type	Search Interval	Number of Searches	Search Team
Summer (May 20–July 31)	road and pad plot	3.5 days	619	Human
	160 x 160-m cleared plot	3.5 days	614	Dog Team
Fall (August 1–October 15)	road and pad plot	3.5 days	607	Human
	160 x 160-m cleared plot	3.5 days	633	Dog Team

Species Composition

One-thousand-six-hundred-ninety-nine (1,699) bat carcasses were found during surveys and incidentally (Appendix A). Over the course of the monitoring period, 66 heavily scavenged bats (wing membrane only, bones, or partial carcasses) were sent for DNA identification. All but one were identified as common species, such as the big brown bat, silver-haired bat, hoary bat, or eastern red bat, and one sample was identified as a little brown bat. Due to the advanced state of decomposition, three carcasses could not be positively identified, although one of the three was determined to a non-*Myotis* species based on the forearm length.

The most common species found were the big brown bat (37.9%), eastern red bat (22.5%), hoary bat (19.8%), and silver-haired bat (19.2%). Searchers also found four Seminole bats (*Lasiurus seminolus*; 0.2% of all bats), two evening bats (0.1%), and one little brown bat (less than 0.1%; Table 2). Five-hundred-three (503) bat carcasses were found in the summer and 1,175 bats were found in the fall (Appendix A). The timing of mortality appeared to peak in the early fall for the big brown bat, eastern red bat, and hoary bat, while most silver-haired bat fatalities occurred in mid to late fall (Figure 5).

No bat species listed under the federal Endangered Species Act were found. The little brown bat is undergoing a species status review to determine if it should be federally listed (USFWS 2016c). Two evening bats, listed as endangered by the State of Michigan (MDNR 2009), were found on June 2, 2021, and June 30, 2021, respectively. A complete list of carcassess is presented as an attachment to this report (Appendix A).

Table 2. Summary of bat carcasses found at the Crescent Wind Project from May 20 – October 15, 2021.

	Included in Area Adjustment		Outside Search Area[1]		Outside Study Period[1]		Total	
Species	**Total**	**%**	**Total**	**%**	**Total**	**%**	**Total**	**%**
big brown bat	637	38.0	5	62.5	2	15.4	644	37.9
eastern red bat	378	22.5	1	12.5	3	23.1	382	22.5
hoary bat	334	19.9	1	12.5	2	15.4	337	19.8
silver-haired bat	319	19.0	1	12.5	6	46.2	326	19.2
Seminole bat	4	0.2	0	0	0	0.0	4	0.2
evening bat	2	0.1	0	0	0	0.0	2	0.1
unidentified bat	2	0.1	0	0	0	0.0	2	0.1
little brown bat	1	0.1	0	0	0	0.0	1	0.1
unidentified non-*Myotis*	1	0.1	0	0	0	0.0	1	0.1
Total	**1,678**	**100**	**8**	**100**	**13**	**100**	**1,699**	**100**

[1] Carcasses not included in analysis

Sums can differ from values shown due to rounding

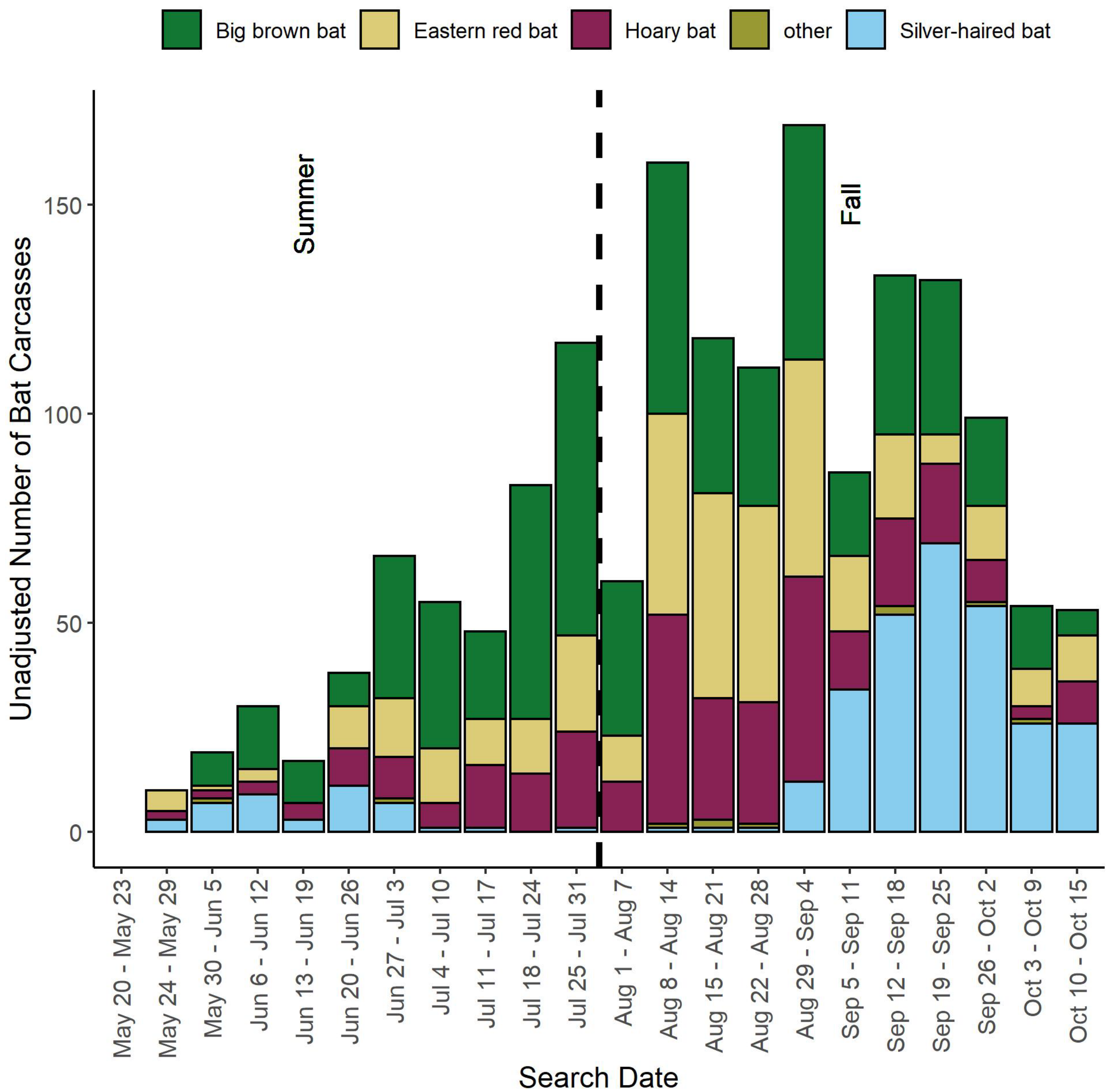
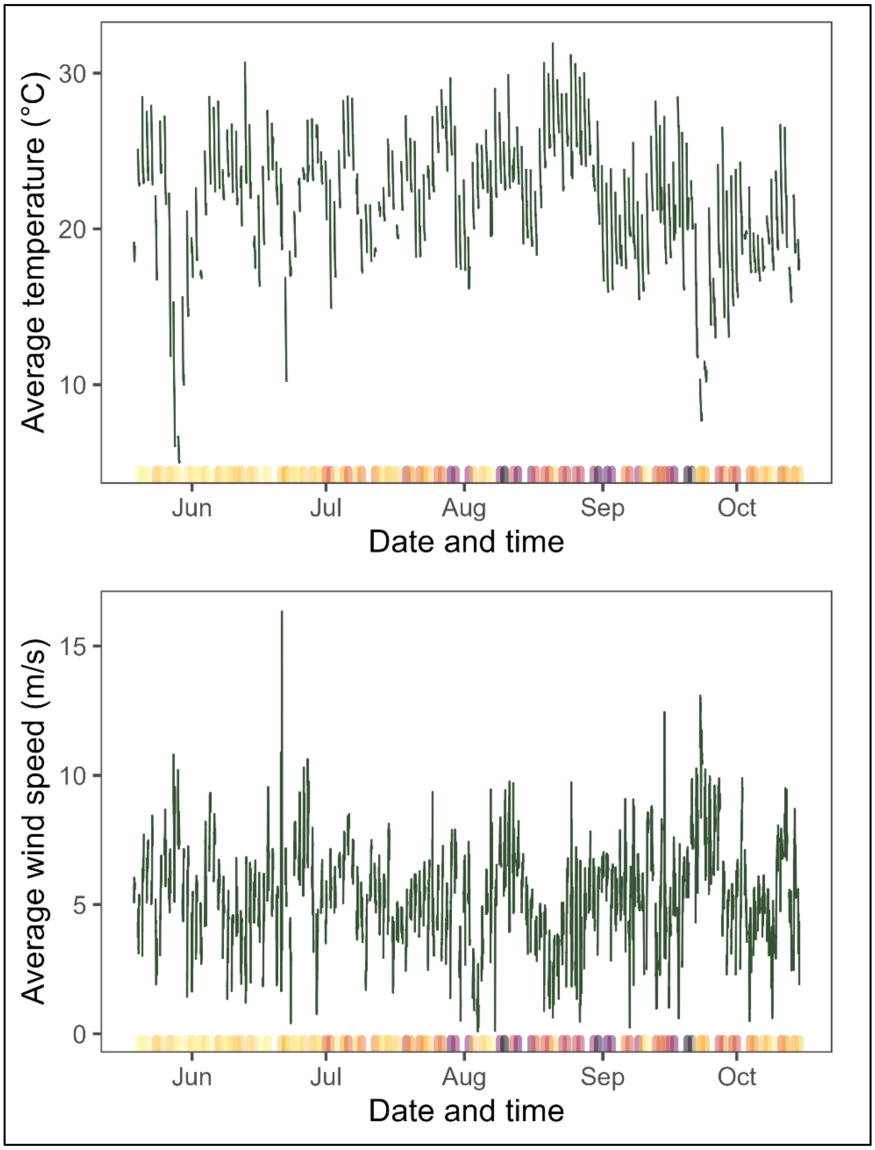
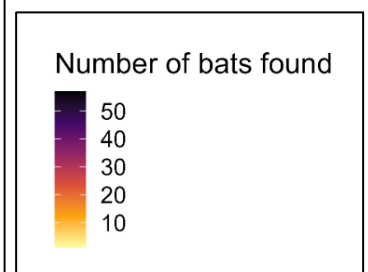


Figure 5. Timing of bat carcasses, by species, found at the Crescent Wind Project from May 20 – October 15, 2021.

Weather Conditions

The time series below show the average temperature and the average wind speed compared to the associated number of fatalities for each day of searches (Figure 6). Wind speed and temperature are only plotted during nighttime hours and are the average at each 10-min time step from four representative turbines: T-10, T-53, T-83, and T-86.





(b)

(a)

Figure 6. (a) Average temperatures, wind speeds, and associated number of fatalities for the Crescent Wind Project. The "rug" shows dates on which fatalities were found (b) color coded by the number of fatalities.

Statistical Analysis

Searcher Efficiency Estimates

Fifty-five (55) bats were placed for SEEF trials on 14 separate dates[4], and 50 were available for search teams to find across all plot types. The best-fit model for SEEF for bats did not support the inclusion of plot type as a covariate, meaning there was not a substantial difference between SEEF rates based on plot type or between seasons (Appendix B1). SEEF rates ranged from 83.3% to 100% on human-searched road and pad plots, and from 66.7% to 83.3% on dog-searched cleared plots (Table 3). Because season and plot type were not included in the best-fit SEEF model, the total number of available and found SEEF carcasses were summed across season and plot type for EoA. The EoA inputs for all plot types and seasons were 50 available carcasses and 41 found carcasses.

Carcass Persistence Estimates

Forty-one (41) carcasses were placed to estimate CP. The best-fit model for CP rates was based on plot/search type with a Weibull distribution, which suggests bat carcass persistence rates varied by plot type (Table B2). The estimated median CP times were 17.7 days on cleared plots and 3.7 days on road and pad plots (Table B3). The average probability that a carcass persisted through a 3.5-day search interval was 0.74 (90% CI: 0.62–0.85) on road and pad plots, and 0.82 (90% CI: 0.69–0.91) on cleared plots (Figure 7).

Area Adjustment

Twenty-one (21) of the 1,699 bats found during the research period were excluded from modeling the area adjustment for GenEst and EoA. Eight carcasses were excluded because the carcasses were found off plot, and another 13 bats were excluded because the estimated time of death was prior to the start of surveys (Appendix A).

The best-fit model for the distribution of bats with respect to distance from turbine base was a Weibull distribution (Table B4). The TWL area adjustment for bats was estimated to be 0.98 for cleared plots and 0.16 for road and pad plots (Figure 8, Appendix B5).

Table 3. Searcher efficiency results by plot type at the Crescent Wind Project from May 20 – October 15, 2021.

Season	Plot Type	Number Placed	Number Available	Number Found	% Found
Summer	road and pad plot	18	18	15	83.3
	160 x 16-m cleared plot	15	15	10	66.7
Fall	road and pad plot	11	11	11	100
	160 x 160-m cleared plot	11	6	5	83.3
Total		**55**	**50**	**41**	**82.0**

[4] 5/27/2021, 5/31/2021, 6/2/2021, 6/21/21, 6/24/21, 7/7/21, 8/9/21, 8/13/21, 9/12/21, 9/13/21, 9/19/21, 9/20/21, 10/7/21, and 10/11/21

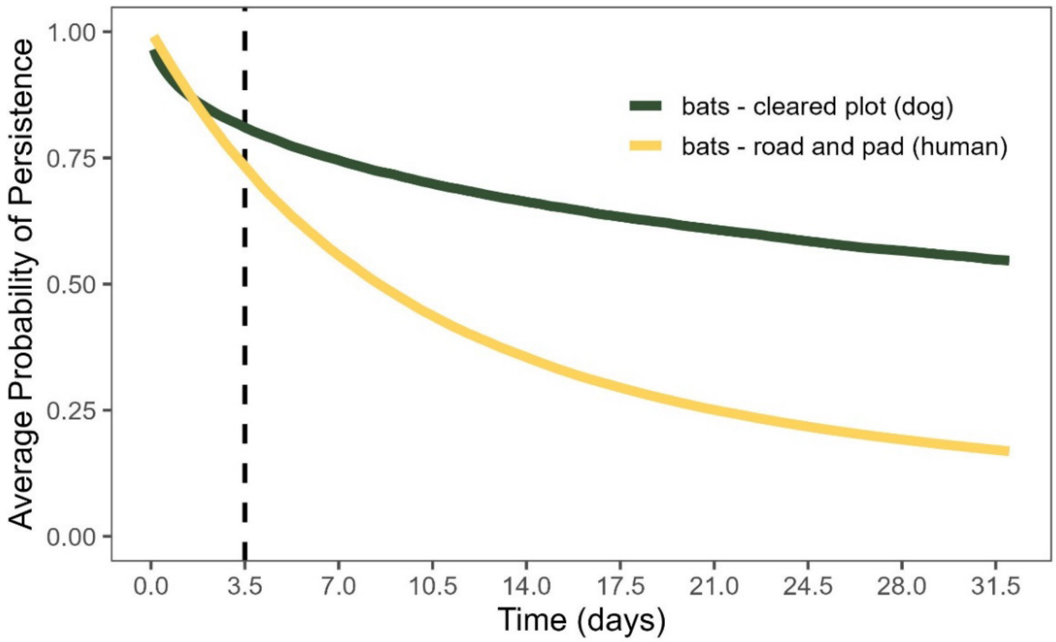


Figure 7. The average probability of persistence, in days, at different search intervals at the Crescent Wind Project from May 20 – October 15, 2021.

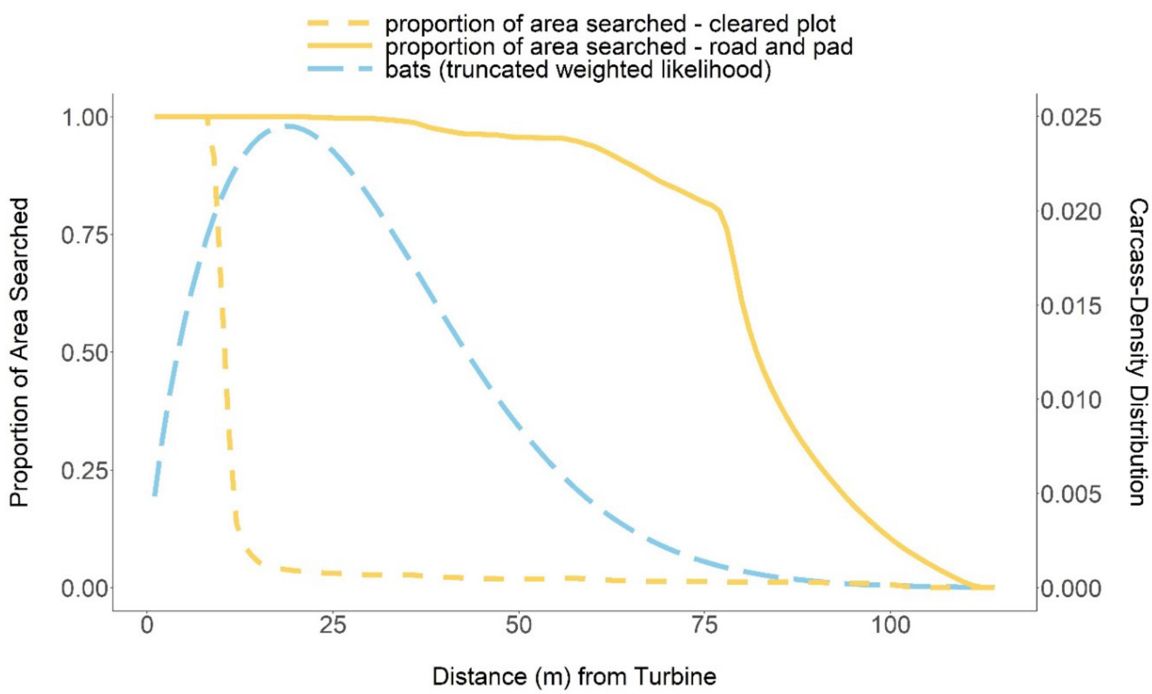


Figure 8. Density of bat carcasses per area searched at all cleared plots and road and pad plots at the Crescent Wind Project from May 20 – October 15, 2021.

Indiana Bat and Northern Long-Eared Bat Take Estimates

Zero Indiana bat and zero northern long-eared bat carcasses were found during the study. Using EoA, the overall probability of detection distribution for the study period had a mean of 0.41 (90% and 95%[5] CIs: 0.38–0.45; Table C1). Inputs required to run the EoA Single Class Module and stratum-specific *g* distribution values and inputs required for the Multiple Class Module are described in Appendix C.

The mean fatality estimate (*M**) was zero (0) for both Indiana and northern long-eared bats. The mean annual take rate, which is always greater than zero when using EoA, was estimated to be 1.21 (90% CI = less than 0.01–3.28, 95% CI = less than 0.01–6.11) for both Indiana bats and northern long-eared bats from May 20 – October 15, 2021.

Effectiveness of Acoustic-Activated Curtailment

The point estimates for the control, blanket curtailment, and smart curtailment groups were approximately 85, 49, and 47 bats per turbine per study period, respectively (Table 4). Overall, control turbines had a higher fatality rate than both the blanket curtailment (difference = 35.7 bats per turbine, 90% CI: 26.0 – 46.4, p = <0.001) and smart curtailment (difference = 38.2 bats per turbine, 90% CI = 28.7 – 49.5, p = <0.001) treatments (Figure 9). Curtailment reduced overall bat fatalities by 41.9% to 45.1% throughout the study period. Based on the test for effectiveness of the treatments, there was no statistical difference between fatality rates for the blanket curtailment treatment and the smart curtailment treatment (difference = 2.9, 90% CI = -5.1 – 10.1, p = 0.28; Figure 9).

Fatality rates were higher in the fall than in summer (Table 4). Curtailment appeared to be somewhat more effective in the summer than the fall, resulting in roughly 52 – 59% and 37 – 43% reductions in fatalities, respectively (Table 4).

A complete list of bat fatality estimates and CIs calculated using the GenEst estimator is included in Appendix B6.

Table 4. Overall bat fatality rates per turbine for each treatment and by season for research conducted at the Crescent Wind Project in Hillsdale County, Michigan, from May 20 – October 15, 2021.

Period	Treatment	Bat Fatality Estimate per Turbine	90% Confidence Interval
Summer	Control	30.31	24.54 – 37.38
	Blanket curtailment	14.64	11.44 – 18.73
	Smart curtailment	15.45	12.05 – 20.45
Fall	Control	54.63	46.62 – 65.43
	Blanket curtailment	34.61	29.28 – 41.63
	Smart curtailment	31.04	25.71 – 38.48
Overall	Control	85.00	72.66 – 101.19
	Blanket curtailment	49.41	41.91 – 59.41
	Smart curtailment	46.69	38.84 – 56.32

[5] These values are the same when rounded to two decimal places.

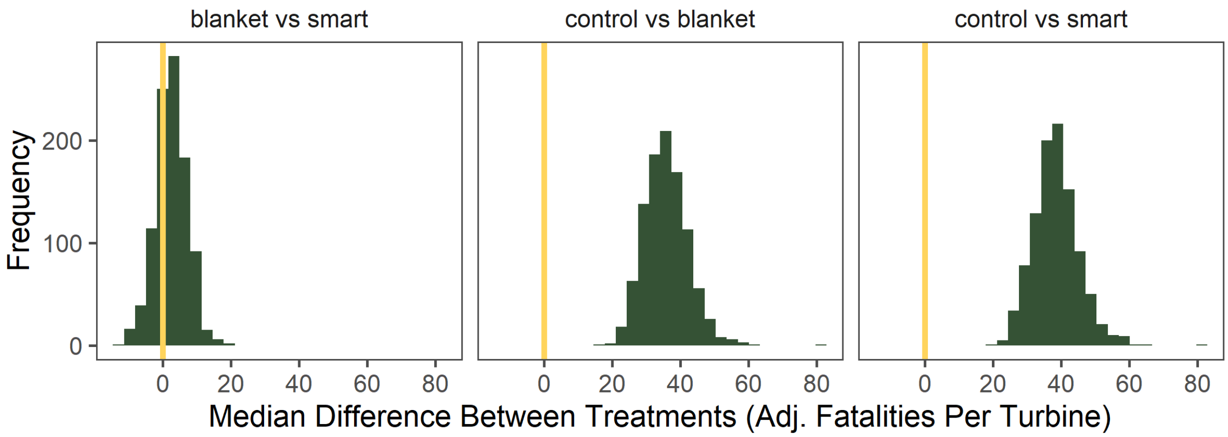


Figure 9. Histograms of the pairwise differences between adjusted fatality rates in each treatment. The yellow line indicates no difference (difference = 0). If the histogram broadly overlaps 0, the difference is not significant. P-values are reported for each comparison in the main text.

DISCUSSION

Species Composition

As is typical of other wind projects, tree bats accounted for most fatalities (~62%) found at the Project during this study. Based on public data from 81 facilities throughout the Midwest, big brown bats comprise roughly 8% of bat fatalities, on average (WEST 2021). However, their prevalence at Crescent resulted in a relatively high percentage of big brown fatalities (38% of carcasses found). Big brown bats are the most common bat in the southern half of the lower peninsula of Michigan making up 65 to 80% of mist-net captures in that region (Kurta 2008). Additionally, big brown bats comprised approximately 93% of pre-construction mist-net captures at the Project (Bishop-Boros et al. 2018). Although this facility is assumed to pose a risk to Indiana bats and northern long-eared bats, neither species was found during this study or during spring monitoring. One little brown bat, a species that is undergoing review for listing, was found at a control (3.0 m/s) turbine. Seminole bats (four carcasses) and evening bats (two carcasses) were not expected to occur in southern Michigan, although these observations provide further evidence for the northward and westward expansion of these two species (Kaarakka 2018, Perry 2018).

Take of Listed Species

Consumers Energy was permitted to take up to six Indiana bats and three northern long-eared bats during the course of this research study. No Indiana bats or northern long-eared bats carcasses were found during the research study or during prior monitoring in the spring. Based on EoA, the estimated take (M^*) for this study period was zero bats for both species. Therefore, permitted take was not exceeded under the research permit.

Seasonality of Fatalities

The timing of bat fatalities is consistent with that reported for other species, particularly with respect to tree bats (EPRI 2020). That is, there was broad overlap between hoary and eastern red bat fatalities, which peaked in August, while silver-haired bat fatalities peaked in mid- to late-fall.

Fatality rates were higher in the fall than in the summer, with around 66% of fatalities occurring in the fall during the study period. While there are few Michigan facilities with summer data to reference, the general pattern of higher fatalities in fall is typical. For *Myotis* in particular, it is often assumed that 7% of fatalties will occur in spring, 36% will occur in summer, and 57% will occur in fall (USFWS 2016).

Curtailment Results and Implications for Operations

Compared to baseline turbine operations, where turbines were feathered below 3.0 m/s, curtailment reduced bat fatalities by 41.9% to 45.1% in this study. To provide context for these values, the results of other curtailment studies (n = 27; Table 5) were used to predict reductions in all-bat fatality rates for a given cut-in speed using simple linear regression (Figure 10). Based on this analysis, feathering turbine blades and raising the cut-in speed to 5.0 m/s from a baseline of 3.0, 3.5, or 4.0 m/s generally results in a 53% (95% CI: 47%–59%) reduction in bat mortality (Figure 10). Subsetting this dataset to just those facilities with a baseline cut-in speed of 3.0 m/s (n = 8) results in a predicted reduction of 40% (95% CI = 30 – 50%). All results from turbines with baseline 3.5 or 4.0 m/s cut-in speeds were from studies conducted between 2007 and 2011. All of the studies from turbines with a baseline cut-in speed of 3.0 m/s were conducted more recently, from 2012 to 2018, and presumably with more current turbine models. Therefore, curtailment at this facility resulted in greater reductions than expected based on the average (but still within the expected range based on the 95% CI) for more recent studies with the same manufacturer's baseline cut-in speed.

Blanket curtailment is designed to operate all night and all season, and smart curtailment is designed to operate during only those portions of the night or season when bats are active (using recorded calls as the proxy for activity). Therefore, we would have predicted fatality rates for blanket curtailment to be lower than for smart curtailment, if there was any difference. While there was no statistical difference between the two treatments, the point estimate for smart curtailment was slightly lower than for blanket curtailment. This difference could have been due simply to random variation. However, the potential for additional curtailment time (described in *Methods*) under the smart curtailment treatment may have contributed to the smaller point estimate under that treatment. The small absolute and relative difference in fatality rates and lack of a statistical difference, however, points to comparatively low collision exposure during the early evening (between sunset and civil dusk) and early morning (between civil dawn and sunrise).

Table 5. Dataset used to generate expected reductions in bat fatalities from curtailment.

Year	Normal Cut-in Speed (m/s)	Treatment Cut-in Speed (m/s)	Reduction in Fatalities (%)	Seasons (Dates)	Source
2007	4	4	57	Fall (Aug 1 - Sep 7)	Baerwald et al. 2009
		5.5	60	Fall (Aug 1 - Sep 7)	Baerwald et al. 2009
2009		6	60	Summer - Fall (Jun 3 - Sep 30)	Arnett et al. 2013
2010		4	35	Late Summer - Fall (Jul 15 - Oct 13)	Young et al. 2011
2011		4.5	48	Late Summer - Fall (Jul 15 - Sep 30)	Stantec Consulting 2012
		5.5	73	Spring (Apr 1 - May 15) and Fall (Jul 15 - Oct 29)	Good et al. 2012
		5.5	60	Late Summer - Fall (Jul 15 - Sep 30)	Stantec Consulting 2012
2008	3.5	5	82	Fall (Jul 27 - Oct 9)	Arnett et al. 2011
		6.5	82	Fall (Jul 27 - Oct 9)	Arnett et al. 2011
2009		5	72	Fall (Jul 26 - Oct 8)	Arnett et al. 2011
		6.5	72	Fall (Jul 26 - Oct 8)	Arnett et al. 2011
2010		4.5	47	Fall (Aug 1 - Oct 1)	Arnett et al. 2013
		5	50	Spring (Apr 13 - May 15) and Fall (Aug 1 - Oct 15)	Good et al. 2011
		5.5	72	Fall (Aug 1 - Oct 1)	Arnett et al. 2013
		6.5	78	Spring (Apr 13 - May 15) and Fall (Aug 1 - Oct 15)	Good et al. 2011
2011		3.5	36	Spring (Apr 1 - May 15) and Fall (Jul 15 - Oct 29)	Good et al. 2012
		4.5	57	Spring (Apr 1 - May 15) and Fall (Jul 15 - Oct 29)	Good et al. 2012
2012	3	4	20.1	Fall (Aug 2 - Sep 30)	Arnett et al. 2013
		5	34.5	Fall (Aug 2 - Sep 30)	Arnett et al. 2013
		5	32.6	Fall (Aug 2 - Sep 30)	Arnett et al. 2013
		5	47	Late Summer - Fall (Jul 15 - Sep 30)	Hein et al. 2013
		6	38.1	Fall (Aug 2 - Sep 30)	Arnett et al. 2013
2013		5	54	Late Summer - Fall (Jul 15 - Sep 30)	Hein et al. 2014
		5.5	66	Fall (Aug 1 - Sep 30)	BLM 2018
		6.5	72	Fall (Aug 1 - Sep 30)	BLM 2018
		6.5	76	Late Summer - Fall (Jul 15 - Sep 30)	Hein et al. 2014
2018		5	42.5	Late Summer - Fall (Jul 23 - Oct 23)	Iskali et al. 2019

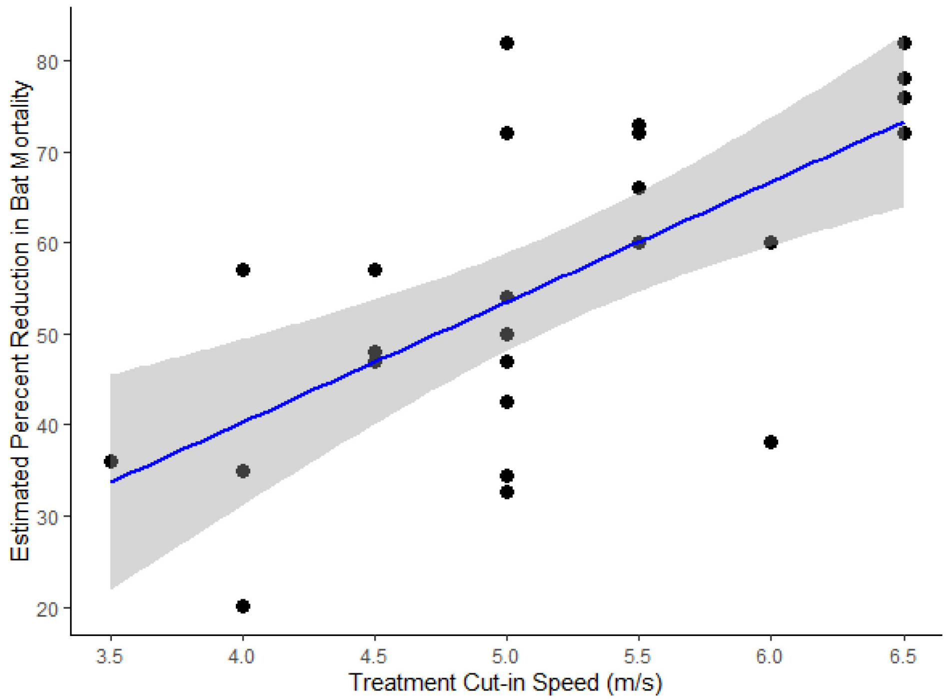


Figure 10. The observed and predicted reductions in bat mortality from curtailment measures at wind facilities.[6] The predicted reductions (blue line) are shown with a 95% confidence interval (gray band).

Curtailment appeared to be somewhat more effective in the summer (52 – 59% reductions) than in the fall (37 – 43% reductions). Most curtailment studies occurred in the fall and do not provide estimated reductions for summer curtailment (Table 5), making it difficult to assess whether this pattern is typical of other wind facilities. Some tree bats may not call as frequently during migration (Corcoran et al. 2021), and therefore may not trigger smart curtailment as frequently. However, this is unlikely be the cause of this discrepancy, since the estimates for both the blanket and smart curtailment treatments were statistically indistinguishable in both seasons. One potential explanation is that bats are flying at rotor height (are more active) at higher wind speeds in migration, on average, than they are during the summer. If this were the case, we would expect greater fatalities in the fall for a given population density, above 5.0 m/s. Perhaps more plausibly, there is evidence that behavioral changes in the late summer and fall are one cause for bat fatalities peaking during migration (Goldenberg et al. 2021). These researchers found that bats were more likely to approach (investigate) turbines in the fall than during the rest of the year. If for a given cut-in speed and population density tree bats are engaging in riskier behaviors in the fall, this may also result in curtailment being less effective in the fall compared to the summer. Alternatively, the effectiveness of curtailment may vary by species (e.g., Iskali et al. 2019, Hayes

[6] The observed reductions (black dots) represent 11 facilities, 14 studies (facility-years), and 27 total observations. All studies included control turbines for comparison. Arnett et al. 2011 (n = 4), Arnett et al. 2013 (n = 7), Baerwald et al. 2009 (n = 2), Bureau of Land Management 2018 (n = 2), Good et al. 2011 (n = 2), Good et al. 2012 (n = 3), Hein et al. 2013 (n = 1), Hein et al. 2014 (n = 2), Iskali et al. 2019 (n = 1), Stantec Ltd. 2012 (n = 2), Young et al. 2011 (n = 1).

et al. 2021, Whitby et al. 2021). It is possible that curtailment is more effective for some species than others, and there did appear to be a seasonal shift in species composition at Crescent. Because fatality rates under the blanket and smart curtailment treatment were similar and resulted in significant reductions to bat fatality rates compared to operating at the manufacturer's cut-in speed, we conclude that either curtailment approach is a viable option for minimizing risk to bats at Crescent.

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Appendix A. Carcasses Found during the 2021 Curtailment Study at the Crescent Wind Project in Hillsdale County, Michigan, from May 20 – October 15, 2021

[See Attachment]

Appendix B. Carcass Count Adjustments and GenEst Results

Searcher Efficiency

Appendix B1. Searcher efficiency models for bats at the Crescent Wind Project in Hillsdale County, Michigan, from May 20 – October 15, 2021.

Covariates	k Value	AICc	Delta AICc
Plot Search Type	0.67	48.67	0
No Covariates*	0.67	49.22	0.55 [1]
Season + Plot Search Type	0.67	50.68	2.01
Season	0.67	51.14	2.47

[1] Selected model.

AICc = corrected Akaike Information Criterion.

Carcass Persistence

Appendix B2. Carcass persistence models with covariates and distributions for bats at the Crescent Wind Project in Hillsdale County, Michigan, from May 20 – October 15, 2021 (n = 41).

Location Covariates	Scale Covariates	Distribution	AICc	Delta AICc
PlotSearchType*	PlotSearchType	Weibull	165.32	0 [1]
PlotSearchType	PlotSearchType	lognormal	166.01	0.69
PlotSearchType	PlotSearchType	loglogistic	167.19	1.87
Season + PlotSearchType	PlotSearchType	Weibull	167.24	1.92
PlotSearchType	No Covariates	Weibull	167.47	2.15
PlotSearchType	Season + PlotSearchType	Weibull	167.54	2.22
Season + PlotSearchType	PlotSearchType	lognormal	168.4	3.08
PlotSearchType	Season + PlotSearchType	lognormal	168.44	3.12
PlotSearchType	-	exponential	168.7	3.38
No Covariates	PlotSearchType	lognormal	169.23	3.91
Season + PlotSearchType	PlotSearchType	loglogistic	169.57	4.25
PlotSearchType	Season	Weibull	169.62	4.3
PlotSearchType	Season + PlotSearchType	loglogistic	169.63	4.31
Season + PlotSearchType	Season + PlotSearchType	Weibull	169.74	4.42
No Covariates	PlotSearchType	loglogistic	169.76	4.44
Season + PlotSearchType	No Covariates	Weibull	169.89	4.57
Season + PlotSearchType	-	exponential	170.87	5.55
Season + PlotSearchType	Season + PlotSearchType	lognormal	170.99	5.67
PlotSearchType	No Covariates	lognormal	171.12	5.8
Season	PlotSearchType	lognormal	171.4	6.08
PlotSearchType	No Covariates	loglogistic	171.58	6.26
No Covariates	Season + PlotSearchType	lognormal	171.68	6.36
Season	PlotSearchType	loglogistic	171.83	6.51
Season + PlotSearchType	Season + PlotSearchType	loglogistic	172.17	6.85
Season + PlotSearchType	Season	Weibull	172.19	6.87
No Covariates	Season + PlotSearchType	loglogistic	172.22	6.9
No Covariates	PlotSearchType	Weibull	173.16	7.84
PlotSearchType	Season	lognormal	173.54	8.22
Season + PlotSearchType	No Covariates	lognormal	173.57	8.25
PlotSearchType	Season	loglogistic	173.99	8.67
Season	Season + PlotSearchType	lognormal	174	8.68
Season + PlotSearchType	No Covariates	loglogistic	174.04	8.72
Season	Season + PlotSearchType	loglogistic	174.43	9.11
Season	PlotSearchType	Weibull	174.99	9.67
No Covariates	No Covariates	lognormal	175.13	9.81

Appendix B2. Carcass persistence models with covariates and distributions for bats at the Crescent Wind Project in Hillsdale County, Michigan, from May 20 – October 15, 2021 (n = 41).

Location Covariates	Scale Covariates	Distribution	AICc	Delta AICc
No Covariates	No Covariates	loglogistic	175.32	10
No Covariates	Season + PlotSearchType	Weibull	175.61	10.29
Season + PlotSearchType	Season	lognormal	176.14	10.82
Season + PlotSearchType	Season	loglogistic	176.58	11.26
No Covariates	Season	lognormal	177.39	12.07
Season	No Covariates	lognormal	177.46	12.14
Season	Season + PlotSearchType	Weibull	177.55	12.23
No Covariates	Season	loglogistic	177.57	12.25
Season	No Covariates	loglogistic	177.64	12.32
No Covariates	No Covariates	Weibull	178.17	12.85
Season	Season	lognormal	179.85	14.53
Season	Season	loglogistic	180.03	14.71
No Covariates	Season	Weibull	180.4	15.08
Season	No Covariates	Weibull	180.48	15.16
Season	Season	Weibull	182.84	17.52
No Covariates	-	exponential	187.22	21.9
Season	-	exponential	189.4	24.08

[1] Selected model

AICc = corrected Akaike Information Criterion.

Appendix B3. Carcass persistence top model with covariates, distributions, and model parameters for the Crescent Wind Project in Hillsdale County, Michigan, from May 20 – October 15, 2021.

Size Class	Plot Search Type	Distribution	Estimated Median Removal Times (days)	Parameter 1	Parameter 2
Bat	road and pad plot	Weibull[1]	3.7	shape = 1.0152	scale = 5.3335
	160 x 160-meter cleared plot	Weibull[1]	17.7	shape = 0.498	scale = 36.9291

[1] Parameterization follows the base R parameterization for this distribution.

Area Adjustment

Appendix B4. Search area adjustment models for bats from the Crescent Wind Project in Hillsdale County, Michigan, from May 20 – October 15, 2021.

Distribution	AICc	Delta AICc
Weibull	28,769.49	0 [1]
normal	28,771.53	2.03
gamma	28,928.80	159.30
Rayleigh	28,938.08	168.59
Gompertz	28,942.66	173.17

[1] Selected model

Appendix B5. Truncated weighted maximum likelihood search area estimates for the Crescent Wind Project in Hillsdale County, Michigan, from May 20 – October 15, 2021.

Size Class	Search Area Type	Distribution	Parameter 1	Parameter 2	Area Adjustment
Bat	road and pad plot	Weibull	1.6904	31.8951	0.16
	160 m x 160-meter cleared plot	Weibull	1.6904	31.8951	0.98

n = 1,678 bats

GenEst Results

Appendix B6. Estimated fatality rates and adjustment factors, with 90% confidence intervals at control turbines for studies conducted at the Crescent Wind Energy Project, Hillsdale County, Michigan, from May 20, 2021 to October 15, 2021.

	cleared plots 30 turbines searched		road and pad plot 30 turbines searched	
	Estimate	90% CI	Estimate	90% CI
Search Area Adjustment				
Summer	0.98	0.97 - 0.98	0.16	0.14 - 0.18
Fall	0.98	0.97 - 0.98	0.16	0.14 - 0.18
Searcher Efficiency				
Summer	0.82	0.71 - 0.89	0.82	0.71 - 0.89
Fall	0.82	0.71 - 0.89	0.82	0.71 - 0.89
Average Probability of a Carcass Persisting Through the Search Interval**				
Summer	0.82	0.69 - 0.92	0.74	0.62 - 0.85
Fall	0.82	0.69 - 0.91	0.74	0.62 - 0.84
Probability of Available and Detected				
Summer	0.74	0.64 - 0.86	0.62	0.49 - 0.75
Fall	0.74	0.64 - 0.86	0.62	0.49 - 0.75
Estimated Fatality Rates (Fatalities/Turbine/Seasons(s))				
Summer	30.95	27.04 - 37.02	30.27	20.05 - 43.54
Fall	69.71	61.30 - 83.52	37.40	25.64 - 53.95
Overall	101	88.27 - 119.97	68.10	48.86 - 92.99
Estimated Fatality Rates (Fatalities/MW/Seasons(s))				
Summer	11.05	9.66 - 13.22	11.17	7.42 - 15.96
Fall	24.90	21.89 - 29.83	13.69	9.36 - 19.69
Overall	35.97	31.52 - 42.85	24.94	17.89 - 34.06

** The search interval was twice per week.

Appendix B6 (cont.). Overall fatality rates per megawatt (MW) and per turbine for control turbines for studies conducted at the Crescent Wind Energy Project, Hillsdale County, Michigan, from May 20, 2021 to October 15, 2021.

	Per MW Estimates		Per Turbine Estimates	
	Estimate	90% CI	Estimate	90% CI
Summer	11.17	9.05 - 13.83	30.78	25.05 - 38.09
Fall	19.47	16.52 - 23.27	54.08	45.94 - 64.68
Overall	30.66	26.15 - 36.43	84.91	72.60 - 101.14

Appendix B6 (cont.). Estimated fatality rates and adjustment factors, with 90% confidence intervals at blanket curtailment turbines for studies conducted at the Crescent Wind Energy Project, Hillsdale County, Michigan, from May 20, 2021 to October 15, 2021.

	cleared plots 30 turbines searched		road and pad plot 30 turbines searched	
	Estimate	90% CI	Estimate	90% CI
Search Area Adjustment				
Summer	0.98	0.97 - 0.98	0.16	0.14 - 0.18
Fall	0.98	0.97 - 0.98	0.16	0.14 - 0.18
Searcher Efficiency				
Summer	0.82	0.71 - 0.89	0.82	0.71 - 0.89
Fall	0.82	0.71 - 0.89	0.82	0.71 - 0.89
Average Probability of a Carcass Persisting Through the Search Interval**				
Summer	0.82	0.69 - 0.91	0.74	0.62 - 0.86
Fall	0.82	0.70 - 0.92	0.74	0.61 - 0.86
Probability of Available and Detected				
Summer	0.74	0.64 - 0.86	0.62	0.49 - 0.75
Fall	0.74	0.64 - 0.86	0.62	0.49 - 0.75
Estimated Fatality Rates (Fatalities/Turbine/Seasons(s))				
Summer	16.30	14.03 - 19.86	13.16	7.40 - 20.74
Fall	41.41	36.32 - 49.27	26.63	18.46 - 38.74
Overall	57.84	50.67 - 68.71	40.04	28.66 - 56.95
Estimated Fatality Rates (Fatalities/MW/Seasons(s))				
Summer	6.06	5.23 - 7.40	5.08	2.82 - 7.98
Fall	15.36	13.46 - 18.25	9.72	6.75 - 14.22
Overall	21.45	18.79 - 25.48	14.86	10.68 - 21.15

** The search interval was twice per week.

Appendix B6 (cont.). Overall fatality rates per megawatt (MW) and per turbine for blanket curtailment turbines for studies conducted at the Crescent Wind Energy Project, Hillsdale County, Michigan, from May 20, 2021 to October 15, 2021.

	Per MW Estimates		Per Turbine Estimates	
	Estimate	90% CI	Estimate	90% CI
Summer	5.63	4.37 - 7.22	15.00	11.68 - 19.24
Fall	12.64	10.74 - 15.25	34.26	28.98 - 41.25
Overall	18.32	15.50 - 22.05	49.38	41.87 - 59.36

Appendix B6 (cont.). Estimated fatality rates and adjustment factors, with 90% confidence intervals at smart curtailment turbines for studies conducted at the Crescent Wind Energy Project, Hillsdale County, Michigan, from May 20, 2021 to October 15, 2021.

	cleared plots 30 turbines searched		road and pad plot 30 turbines searched	
	Estimate	90% CI	Estimate	90% CI
Search Area Adjustment				
Summer	0.98	0.97 - 0.98	0.16	0.14 - 0.18
Fall	0.98	0.97 - 0.98	0.16	0.14 - 0.18
Searcher Efficiency				
Summer	0.82	0.71 - 0.89	0.82	0.71 - 0.89
Fall	0.82	0.71 - 0.89	0.82	0.71 - 0.89
Average Probability of a Carcass Persisting Through the Search Interval**				
Summer	0.82	0.69 - 0.91	0.74	0.60 - 0.86

Appendix B6 (cont.). Estimated fatality rates and adjustment factors, with 90% confidence intervals at smart curtailment turbines for studies conducted at the Crescent Wind Energy Project, Hillsdale County, Michigan, from May 20, 2021 to October 15, 2021.

	cleared plots 30 turbines searched		road and pad plot 30 turbines searched	
	Estimate	**90% CI**	**Estimate**	**90% CI**
Fall	0.82	0.68 - 0.92	0.74	0.61 - 0.85
Probability of Available and Detected				
Summer	0.74	0.64 - 0.86	0.62	0.49 - 0.75
Fall	0.74	0.64 - 0.86	0.62	0.49 - 0.75
Estimated Fatality Rates (Fatalities/Turbine/Seasons(s))				
Summer	14.86	12.80 - 18.18	16.83	10.42 - 25.60
Fall	33.93	29.68 - 41.04	27.53	17.67 - 39.20
Overall	48.83	42.90 - 58.77	44.43	31.39 - 60.58
Estimated Fatality Rates (Fatalities/MW/Seasons(s))				
Summer	5.70	4.91 - 6.95	6.25	3.87 - 9.51
Fall	12.60	11.01 - 15.21	10.34	6.59 - 14.67
Overall	18.32	16.08 - 22.08	16.62	11.66 - 22.59

** The search interval was twice per week.

Appendix B6 (cont.). Overall fatality rates per megawatt (MW) and per turbine for smart curtailment turbines for studies conducted at the Crescent Wind Energy Project, Hillsdale County, Michigan, from May 20, 2021 to October 15, 2021.

	Per MW Estimates		Per Turbine Estimates	
	Estimate	**90% CI**	**Estimate**	**90% CI**
Summer	5.98	4.66 - 7.78	15.89	12.39 - 20.84
Fall	11.49	9.43 - 14.26	30.72	25.33 - 38.07
Overall	17.49	14.54 - 21.08	46.77	38.90 - 56.40

Appendix C. Inputs and Results of the Evidence of Absence Analysis for Indiana and Northern Long-Eared Bats

Table C1. Annual and overall probabilities of detection (*g*), Ba, Bb, and ρ for the Crescent Wind Project in Hillsdale County, Michigan, from May 20 – October 15, 2021.

Year	Ba [1]	Bb [1]	ρ [2]	*g*	95% Confidence Intervals
2021	268.09	379.01	1	0.41	0.38–0 .45

[1] Ba and Bb are the parameters for the Beta distribution used to characterize the probability of detection. The *g* value is the mean of that distribution.

[2] ρ is the weight in the weighted average that is used to combine the probability of detection distributions across years.

Table C2. Inputs needed to run Evidence of Absence: Single Class Module for the Crescent Wind Project in Hillsdale County, Michigan, from May 20 – October 15, 2021.

		Search	Number	Spatial	Searcher Efficiency		Carcass Persistence[2]	
		Interval	of	Coverage	Carcasses	Carcasses		
Season[1]	Plot Type	(I)	Searches	(a)	Available	Found	Shape (α)	Scale (β)
Summer 1	Road/pad	3.5	4	0.16	50	41	1.01	5.33
Summer 1	Cleared plot	3.5	3	0.98	50	41	0.50	36.93
Summer 2	Road/pad	3.5	2	0.16	50	41	1.01	5.33
Summer 2	Cleared plot	3.5	2	0.98	50	41	0.50	36.93
Summer 3	Road/pad	3.5	15	0.16	50	41	1.01	5.33
Summer 3	Cleared plot	3.5	15	0.98	50	41	0.50	36.93
Fall	Road/pad	3.5	20	0.16	50	41	1.01	5.33
Fall	Cleared plot	3.5	21	0.98	50	41	0.50	36.93

[1] There are three (3) summer seasons because some plots switched from road and pad to cleared plot during the summer season

[2] A loglogistic distribution was used for the carcass persistence distribution.

Cleared plot = 160 x 160-meter cleared plot, Road/pad = road and pad plot. The summer season is divided into sub-seasons because some plots switched search types (cleared versus road and pad) within the season.

Table C3. Inputs needed to run Evidence of Absence to combine plot types within each season: Multiple Class Module for the Crescent Wind Project in Hillsdale County, Michigan, from May 20 – October 15, 2021.

Season	Plot Type	Ba	Bb	Sampling Fraction (DWP)
Summer 1	Unsearched	0.01	1,000	0.02
Summer 1	Road/pad	100.56	908.96	0.50
Summer 1	Cleared plot	46.10	20.80	0.48
Summer 2	Unsearched	0.01	1,000	0.02
Summer 2	Road/pad	181.77	1,653.56	0.50
Summer 2	Cleared plot	95.66	54.38	0.48
Summer 3	Road/pad	105.83	938.66	0.50
Summer 3	Cleared plot	43.29	15.78	0.50
Fall	Road/pad	93.36	829.50	0.50
Fall	Cleared plot	44.97	829.50	0.50

Cleared plot = 160 x 160-meter (m) cleared plot, Road/pad = road and pad plot, Unsearched = missed search due to logistical constraints. The summer season is divided into sub-seasons because some plots switched search types (cleared versus road and pad) within the season. DWP = density-weighted proportion.

Table C4. Inputs needed to run Evidence of Absence to combine across seasons: Multiple Class Module for the Crescent Wind Project in Hillsdale County, Michigan, from May 20 – October 15, 2021.

Season	Ba	Bb	Arrival Proportion (DWP)
Summer 1	118.76	191.43	0.06
Summer 2	222.29	398.36	0.04
Summer 3	120.82	168.84	0.29
Fall	125.23	174.63	0.61

The summer season is divided into sub-seasons because some plots switched search types (cleared versus road and pad) within the season. DWP = density-weight proportion.

Table C5. Inputs needed to run Evidence of Absence: Multiple Class Module for the Crescent Wind Project in Hillsdale County, Michigan, from May 20 – October 15, 2021.

Year	Ba	Bb	Weights (ρ)
2021	266.15	378.28	1.0