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Activity-based Informed Curtailment: Using Acoustics to Design and Validate Smart Curtailment to Reduce Risk to Bats at Wind Farms

Final Technical Report

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Executive Summary

The potential effects of climate change on wildlife are vast, multifaceted, and well represented in scientific literature. Rapid expansion of renewable energy infrastructure is a key part of any global strategy to reduce the pace and severity of anthropogenic climate change, although the potential impacts of renewable energy infrastructure on wildlife are also becoming increasingly apparent. Bats appear vulnerable to population-level impacts from the cumulative effect of turbine-related fatalities at commercial wind energy facilities in North America, particularly as the industry continues to expand to meet renewable energy generation targets. Long-distance migratory species account for the largest proportion of bat fatalities documented in North America, and current mortality rates could threaten the viability of hoary bats (*Lasiurus cinereus*) in particular. Fatalities of federally listed and candidate species including Indiana bats (*Myotis sodalis*), northern long-eared bats (*Myotis septentrionalis*), gray bats (*Myotis grisescens*), and tricolored bats (*Perimyotis subflavus*) also occur at wind energy facilities, necessitating measures to minimize risk and metrics to validate the success of such measures.

Turbine curtailment is the most widely used and consistently effective method to reduce bat fatality rates and involves pitching turbine blades parallel to prevailing winds to restrict turbine rotation when turbines would otherwise be operating and capable of producing power. Curtailment is effective because it eliminates the exposure of bats to fast-moving turbine blades but is unpopular with the wind energy industry due to the resulting energy loss and associated cost. The higher the cut-in speed wind speed threshold below which turbines are curtailed, the greater the reduction in risk to bats and the greater the associated amount of energy loss, although the actual cost of curtailment is determined by weather conditions and wind regime and is therefore difficult to predict.

If conducted with sufficient intensity, carcass monitoring can show that curtailment reduces bat fatality estimates, but the precision and accuracy of fatality estimates are limited by small sample sizes of bat carcasses, imperfect detection, carcass removal, and incomplete coverage relative to the area in which carcasses may fall. More importantly, carcass data do not indicate precisely when fatalities occurred and therefore provide coarse feedback on wind speed and temperature when bats were at risk. Lacking site-specific information to guide when and under what conditions curtailment should be applied, most curtailment strategies apply a single cut-in speed, typically selected by regulatory precedent rather than site-specific data. There is seldom an opportunity or desire to adjust parameters of these so-called "blanket" curtailment strategies due to the lack of information to guide such adjustments and the high cost of subsequent carcass monitoring that would be required to determine if the changes achieved the intended effect. The combination of these factors has severely limited the ability to use curtailment strategically as a tool to manage risk to bats.

The rapid expansion of the wind energy industry coupled with increasing awareness of the potential impacts of cumulative turbine-related fatalities on bat populations highlights the need to understand and manage environmental turbine-related impacts to bats more aggressively and strategically than the current use of blanket curtailment allows. "Smart" curtailment strategies offer a potential solution by concentrating curtailment on periods and conditions where bats are most active, thereby protecting bats while simultaneously reducing the overall amount of curtailment and associated energy loss. Smart curtailment can be implemented using a variety of methods, but strategies share a common principle that curtailment is only beneficial when bats are present in the rotor-swept zone; curtailing at other times does nothing to reduce risk but results in energy loss all the same. The challenge for implementing smart curtailment is knowing when bats are likely present or absent in the rotor-swept zone.

Regardless of what type of curtailment is implemented and how strategies are designed, the wind energy industry and regulators alike need a better method than carcass searches to measure curtailment effectiveness and tailor curtailment strategies around patterns in risk. Through a combination of existing data summary and analysis and an unprecedented deployment of turbine-mounted acoustic bat detectors at wind energy facilities across Iowa, this study demonstrates that acoustic exposure (the rate or proportion of bat passes detected when turbine rotors are moving) is an ideal metric to evaluate the effectiveness of curtailment strategies and provides feedback on how to optimize curtailment strategies to balance the simultaneous needs to boost renewable energy generation and reduce cumulative impacts to bats.

This study spanned a period of nearly five years, beginning with an initial demonstration, based on data collected previously at a pair of wind energy facilities in West Virginia, that acoustic exposure and bat fatality rates were positively correlated across multiple timescales (Peterson et al. 2021). Building on this successful proof-of-concept, we conducted an intensive acoustic monitoring effort to supplement ongoing bat carcass monitoring at the Orient and Arbor Hill wind energy facilities in Iowa in 2021–2023; this effort was expanded in 2022–2023 to additional facilities throughout Iowa, with acoustic monitoring occurring at a total of 210 turbines at 13 wind energy facilities across the state. The overall purpose of this research project was to demonstrate how acoustic data from turbine-mounted bat detectors could be used to design curtailment strategies that achieve equivalent reduction in bat fatality while resulting in less energy loss and subsequently measure the effectiveness of these strategies. This report is arranged around four research objectives identified in our study plan, each of which is addressed in a separate section.

The first objective was to characterize the seasonal and temporal distribution of bat activity and explore relationships with temperature and wind speed, then evaluate the consistency of such patterns among facilities, turbines, species, and years. Seasonal distribution of bat activity across the 13 wind energy facilities monitored was consistent, aligning with well-established patterns that have also been observed in pre-construction acoustic surveys and fatality monitoring results throughout much of North America. Seasonal distribution varied somewhat among species, but most bat activity occurred between mid-July and early September across species. Of the variables we considered, day of year (a proxy for season) and time of night were the most important factors in predicting bat presence in the rotor-swept zone, followed by wind speed and temperature, with turbine and year ranked least important at most facilities. In the context of designing curtailment strategies to reduce fatality risk to bats, these results suggest that the broad seasonal and temporal patterns in acoustic bat activity in the rotor-swept zone provide a reliable basis for designing activity-based curtailment strategies that apply higher cut-in speeds (and as a result, more curtailment) when bats are most active and lower cut-in speeds when bats are less active.

The second objective was to quantify the relationship between exposed bat activity and fatality, both in terms of alignment between fatality estimates derived from carcass searches against acoustic exposure measured acoustically and in terms of the ability to discern the effect of curtailment using acoustic data versus carcass data. Reanalysis of acoustic data and fatality estimates from a pair of wind energy facilities in West Virginia demonstrated a close relationship between acoustic exposure and fatality and culminated in a peer-reviewed paper cited herein (Peterson et al. 2021) and an interim technical report, included as Appendix A. Fatality estimates at the 13 facilities in Iowa, whether based on weekly road and pad carcass searches or twice-weekly searches of cleared plots, showed no discernable relationship with acoustic exposure. The level of effort for carcass searches used in this study was designed to satisfy permit compliance requirements when aggregated among sites but was insufficient to measure fatality rates with the accuracy needed to differentiate operational treatments due to small sample sizes of carcasses and uncertainty introduced by bias correction factors. The lack of correlation between acoustic exposure and fatality estimates in our study does not mean these processes are not related but illustrates the challenge in evaluating curtailment strategies using carcass searches when sample sizes are limited. In the second part of this objective, fatality estimates did not indicate consistent effects of curtailment, whereas curtailment resulted in clear and consistent reductions in acoustic exposure relative to operational control treatments across facilities, years, and even among individual turbines. The resulting rate of acoustic exposure (exposed passes per detector night) varied among sites, but proportional reductions in exposure due to curtailment were similar among facilities and years, suggesting that the magnitude of risk to bats varied among sites in our study but that curtailment reduced risk by a relatively consistent margin. Acoustic exposure also provided accurate, quantitative feedback on how successfully curtailment was implemented per facility, treatment, and turbine, highlighting a practical advantage of using acoustic exposure to evaluate curtailment.

Our third objective was to demonstrate use of nacelle-height acoustic bat and weather data to optimize site-specific smart curtailment strategies. We used acoustic data recorded at two facilities in 2021 to design a smart alternative to blanket curtailment below 5.0 meters per second (m/s); this alternative was then implemented at subsets of turbines at two facilities in 2022 and at five additional facilities in 2023. The smart curtailment alternative successfully reduced acoustic exposure by the same margin as blanket curtailment while resulting in less energy loss at almost all sites where implemented. We also demonstrated the ability to simulate turbine operation using wind speed and temperature data, enabling acoustic exposure to be evaluated for each of the three operational treatments (operational control, blanket, and smart curtailment) as if they had been implemented across all facilities in our study. Simulated exposure improved the ability to measure inter-facility and inter-year comparison across a larger sample size and represents a key advantage of acoustic exposure measurement in assessing curtailment effectiveness. Our results demonstrated that slight changes in cut-in speed and start/stop times in designing the smart curtailment alternative, though based on data from only 2 sites, effectively yielded equivalent levels of exposure reduction and less energy loss than blanket curtailment when applied to 13 facilities across Iowa over multiple years.

The final objective of this study was to compare effectiveness and energy loss between blanket and smart curtailment programs. Building on the results of the third objective, we simulated four blanket curtailment strategies with cut-in speeds ranging from 5.0–8.0 meters per second (m/s) and designed a smart curtailment alternative for each, then compared acoustic exposure and energy loss across each pair of strategies across facilities and years. The smart curtailment alternatives successfully outperformed blanket alternatives across facilities and among years in almost every case, highlighting the consistency in bat activity patterns around which smart curtailment alternatives were tailored. We demonstrated an exponential increase in the difference in energy loss between blanket and smart curtailments alternatives at higher cut-in speeds. As was the case for the blanket strategy implemented in the study, curtailment strategies resulted in similar reductions in the percent of acoustic exposure, while the cumulative rate of exposed passes was more variable among sites. This highlights an opportunity to use curtailment strategically to manage risk across a fleet of wind energy facilities by adjusting cut-in speeds or otherwise scaling the intensity of curtailment according to the site-specific level of risk.

Key Results

- Objective 1: Quantify consistence of relationship between bat activity and aerospheric conditions
    - Seasonal and temporal distribution of acoustic bat activity was similar among species and across turbines, facilities, and years.
    - Seasonal distribution of acoustic bat activity aligned with well-established patterns in timing of turbine-related fatalities in North America.
    - Temperature and wind speed had a consistent relationship with bat activity among species and across turbines, facilities, and years.
    - Acoustic exposure provided a reliable basis for designing activity-based smart curtailment strategies that apply higher cut-in speeds when bats are most active and lower cut-in speeds when bats are less active.
    - Where data were available from nacelle-mounted and ground-level detectors, seasonal and temporal distribution of bat activity was similar between positions, but the rate of bat activity was substantially higher at ground level than nacelle height.
    - *Myotis* species and tricolored bats represented very small proportions of recorded bat activity, but the seasonal and temporal distribution of these species/groups was similar to those of all species combined.

- Objective 2: Quantify relationship between exposed bat activity and fatality at multiple spatial and temporal scales
    - Acoustic exposure provided accurate, quantitative feedback on how successfully curtailment was implemented per facility, treatment, and turbine.

  - Curtailment resulted in clear and consistent reductions in acoustic exposure relative to operational control treatments across facilities, years, and even among individual turbines.
  - Reductions in acoustic exposure from curtailment were similar to reductions in bat mortality based on meta-analyses of curtailment studies.
  - Fatality estimates, whether based on weekly road and pad carcass searches or twice-weekly searches of cleared plots, showed no discernable difference between curtailment treatments or relationship with acoustic exposure.
  - The level of effort for carcass searches used in this study was designed to satisfy permit compliance requirements when aggregated among sites but was insufficient to measure fatality rates with the accuracy needed to differentiate operational treatments due to small sample sizes of carcasses and uncertainty introduced by bias correction factors.
  - Seasonal patterns in acoustic exposure and bat fatalities were similar.
  - Hoary bats accounted for the majority of acoustic exposure at nacelle height whereas eastern red bats accounted for the majority of bat carcasses found
- Objective 3: Demonstrate use of nacelle-height acoustic and weather data to optimize site-specific smart curtailment strategies
  - The smart curtailment alternative reduced acoustic exposure by a similar margin as blanket curtailment with less energy loss at most sites where it was implemented.
  - Simulated and measured acoustic exposure were closely aligned, allowing us to compare blanket and smart curtailment alternatives as if they had been implemented at all sites.
  - Slight changes to blanket curtailment resulted in equivalent protectiveness of bats with less associated energy loss.
- Objective 4: Compare effectiveness and energy loss of blanket and smart curtailment programs.
  - Energy loss associated with blanket curtailment increased with cut-in speeds ranging from 5–8 m/s, as did the potential for smart alternatives to reduce energy loss. We were able to design smart curtailment alternatives that were equivalently protective as blanket curtailment strategies with cut-in wind speeds ranging from 5–8 m/s while resulting in significantly less energy loss.
  - Acoustic avoidance associated with blanket curtailment strategies with low cut-in speeds (e.g., 5 m/s) varied substantially among facilities, whereas there was limited variation in acoustic avoidance among sites for curtailment strategies with high cut-in speeds (8 m/s).

- Energy savings between blanket curtailment strategies with 5.0 m/s cut-in speed and equivalently protective smart alternatives was relatively low and consistent among facilities, whereas substantial variation in energy loss existed between blanket strategies with high cut-in speeds (8 m/s) and equivalently protective smart alternatives.

Glossary of Terms

acoustic exposure–the subset of bat passes detected when turbine rotor speed exceeded 1 revolution per minute

activity-based informed curtailment–general term for smart curtailment based on site-specific acoustic data. Note that this term is often used interchangeably with algorithm-based informed curtailment.

acoustic avoidance–the proportion of bat activity not exposed to turbine operation (the inverse of acoustic exposure)

aerospheric conditions–physical attributes of the lower portion of the atmosphere in which living organisms are present, such as temperature, wind speed, relative humidity, precipitation, barometric pressure, that may affect species presence, distribution, and/or behavior.

bat pass–a sequence of two or more ultrasonic pulses with characteristics of bats within a 15-second period

bat presence–at each 10-minute interval presence was defined as the detection of bat passes recorded at nacelle height, with presence indicating at least one bat pass recorded during the interval and absence indicating no passes.

blanket curtailment–operational treatment that assigned a single cut-in speed over the same time period for the duration of the curtailment period; the blanket curtailment strategy in this study used a 5.0 m/s cut-in speed, applied from sunset to sunrise between 15 July and 30 September above a temperature threshold of 10°C.

curtailment–feathering turbine blades to prevent rotor movement when power generation would otherwise be possible

curtailment evaluation–analysis to determine whether turbines were operated according to the parameters of their assigned curtailment strategy

curtailment effectiveness–analysis of the degree to which curtailment strategies reduced acoustic exposure and/or bat fatality rates

cut-in speed–wind speed threshold above which turbines are able to generate energy; this is typically increased as part of a curtailment strategy

feathering–pitching turbine blades parallel to the wind direction to restrict rotor movement

free-wheeling–the operational state when turbine blades are not feathered at wind speeds below the manufacturer cut-in speed where turbine rotors may spin greater than 1 rpm but are not able to generate energy

manufacturer cut-in–cut-in speed assigned by turbine manufacturers; turbine rotors typically free-wheel but cannot typically generate power below this wind speed *measured exposure*–the rate (bat passes per detector night) and/or percent of bat passes detected when turbine rotors were spinning faster than one revolution per minute

nacelle–the enclosed housing at the top of wind turbines where the rotor interfaces with the tower that contains the generator, gearbox, and other turbine components

operational control–operational treatment in which turbine blades were feathered below manufacturer's cut-in speed

simulated exposure–the rate and/or percent of bat passes detected when turbines should have been operating based on time of year, time of night, wind speed, and temperature measurements and the associated cut-in speed and temperature thresholds of the curtailment strategy

treatment (as assigned)–the curtailment treatment to which turbines and/or facilities were assigned during each field season

treatment (as implemented)–the curtailment treatment under which turbines and/or facilities operated based on evaluation of rotor speed as a function of wind speed

smart curtailment–curtailment strategy whose parameters such as cut-in speed, start/stop times, seasonal coverage, temperature thresholds, etc. are based on site-specific information on bat activity and/or that incorporates additional triggers such as real-time detection of bats. In this study, smart curtailment refers to activity-based informed curtailment treatment designed to achieve equivalent levels of exposure reduction as corresponding blanket curtailment.

uncurtailed–the operational state where turbine blades are pitched to be able to catch the wind and the turbine rotor can either free-wheel or generate energy depending on the wind speed

Abbreviations

AEP–annual energy production

dB–decibel

C–Celsius

DOE–U.S. Department of Energy

DWP–density-weighted proportion

EPRI–Electrical Power Research Institute

kHz–kilohertz

Kpro–Kaleidoscope Pro software

kW–kilowatt

ms–milliseconds

m/s–meters per second

MW–megawatt

MW-hr–megawatt hours

NREL–National Renewable Energy Laboratory

rpm–revolutions per minute

SCADA–supervisory control and data acquisition

s–seconds

1.0 STUDY DESIGN AND RESEARCH OBJECTIVES

This study used data from turbine-mounted acoustic bat detectors to characterize relationships between bat activity and conditions in the rotor-swept zone of wind turbines, evaluate effectiveness of a blanket curtailment strategy across multiple wind energy facilities, design an activity-based smart curtailment alternative intended to achieve equivalent risk reduction as blanket curtailment with less energy loss, and compare energy loss and risk reduction across a wide range of blanket and smart curtailment strategies. Initially, we compiled two large datasets collected at a pair of wind energy facilities in West Virginia from 2011–2018 to explore several methodological questions and demonstrate the proof of concept of relating acoustic exposure to bat fatality (see Appendix A; Peterson et al. 2021). Building on these methods and initial data summary, our study explored relationships between bat activity and fatality on a broader scale in comparing acoustic bat exposure, fatality rates, and energy loss at 13 wind energy facilities across Iowa over a 3-year period. Our field methods consisted primarily of acoustic bat data collection and analysis; we relied on concurrent carcass monitoring being conducted at the facilities as part of a compliance monitoring program to provide the corresponding fatality estimates, as outlined in our Study Plan (Appendix B). Our overall goal was to demonstrate how acoustic bat data coupled with operational data that are readily available to the wind energy industry can be used to change the design and implementation of curtailment from a prescriptive “blanket” strategy to a risk-based strategy based on site-specific data, thereby reducing bat fatality rates and simultaneously reducing the amount of energy loss and encouraging broader adoption by the industry.

1.1 STUDY TIMELINE

This study was initiated in September 2019 and data collection was intended to begin in 2020, but logistical challenges associated with the COVID-19 pandemic delayed data collection until 2021, when fieldwork began at two facilities. The scope of the study was expanded following the 2021 field season to include sampling at an additional 11 facilities (collectively referred to as the expansion sites); all 13 facilities were monitored in 2022 and 2023. Acoustic data collected in 2022 and 2023 were reanalyzed between May and July 2024 to take advantage of updated filtering capabilities of the analysis software which improved the accuracy of automated species identification considerably and helped remove unwanted ultrasonic noise recorded by the acoustic bat detectors, which were generated by active anemometers on the turbine nacelles. Final operations and fatality data were obtained in September 2024.

Within the timeframe of this study, proposed listing of tricolored bats (*Perimyotis subflavus*) as federally endangered, and the consideration of listing the hoary bat (*Lasiurus cinereus*) have highlighted a need to address managing risk to bats on a range wide scale. Among other things, these proposed listings have highlighted the need for broader implementation of curtailment and better metrics to measure its effectiveness. Numerous post-construction fatality studies have demonstrated that curtailment reduces bat fatality rates at North American wind energy facilities, but collectively, these studies have done little to sharpen our understanding of how curtailment can be used strategically. As originally proposed, this research focused on design and validation of smart curtailment strategies designed to reduce energy loss and associated cost of curtailment; that objective has remained relevant, but the need for better methods to evaluate curtailment in general has grown more apparent during the course of this study.

1.2 RESEARCH OBJECTIVES

Our research addressed four primary objectives, each related to an overall theme of using acoustic bat data from turbine-mounted bat detectors to evaluate the effectiveness of curtailment strategies to reduce bat fatality rates at commercial wind energy facilities;

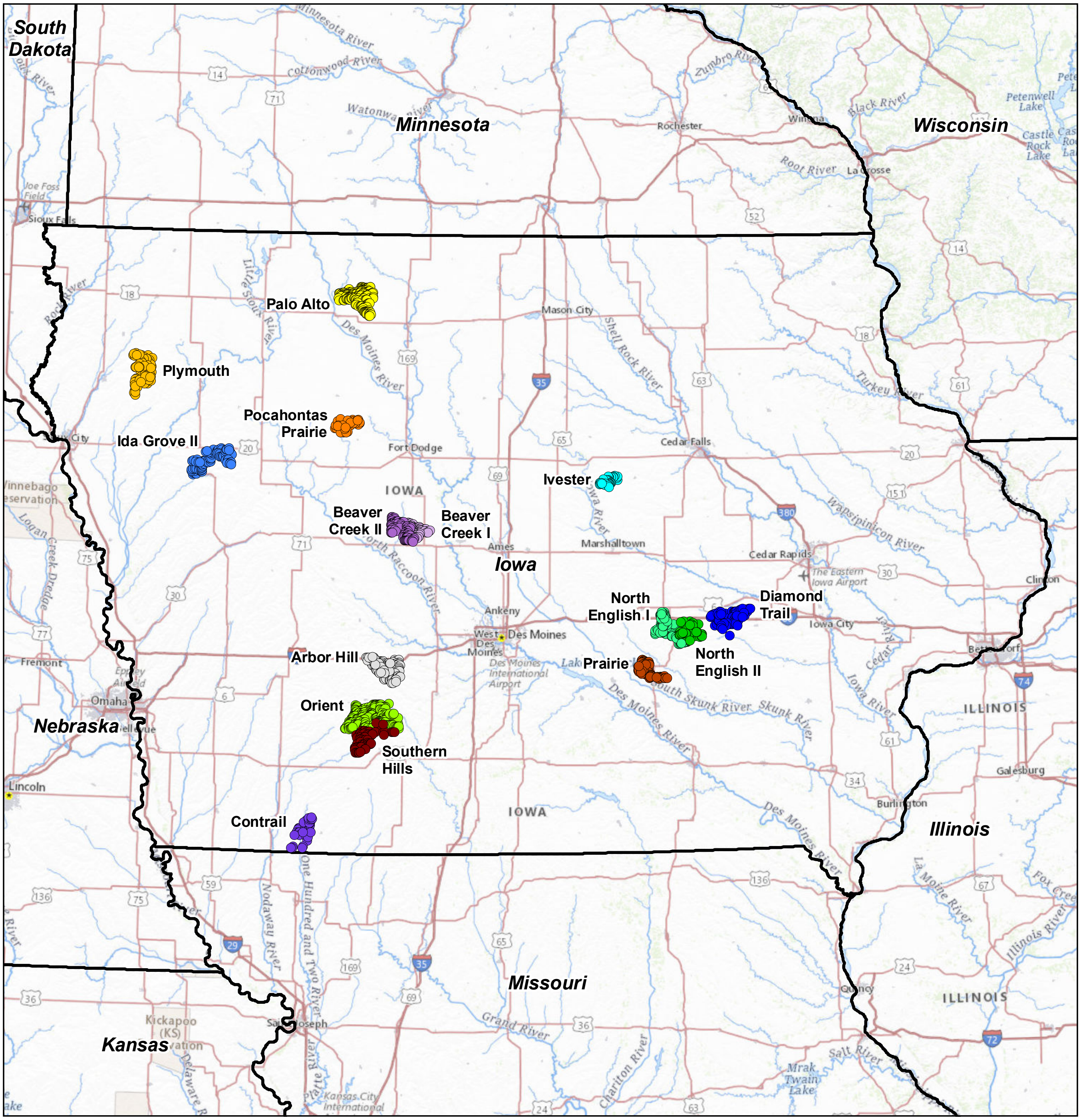
- Objective 1: Quantify consistency of relationship between bat activity and aerospheric conditions
- Objective 2: Quantify relationship between exposed bat activity and fatality at multiple spatial and temporal scales
- Objective 3: Demonstrate use of nacelle-height acoustic and weather data to optimize site-specific smart curtailment strategies
- Objective 4: Compare effectiveness and energy loss of blanket and smart curtailment programs

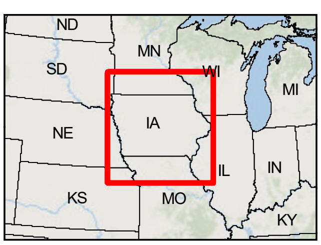
When possible, we evaluated each goal for individual bat species of interest (e.g., federally listed and/or candidate species) in addition to all bat species overall. We purposefully identified research objectives that would have practical applications for wind energy facility operators and regulatory agencies alike, recognizing an increasing need for quantitative feedback on curtailment effectiveness and efficiency to balance the needs to boost renewable energy production while protecting sensitive bat species.

1.3 STUDY SITES

This study occurred at 13 commercial wind energy facilities owned and operated by MidAmerican and located across the state of Iowa (Figure 1-1). Originally, the study focused on Orient and Arbor Hill, which were the only sites monitored in 2021. The scope of the study was expanded in 2022 to include 11 additional sites, and all 13 sites were monitored in 2022 and 2023. Acoustic bat data collection at Orient and Arbor Hill included a combination of ground-level and nacelle-height detectors; all remaining sites included only nacelle-height detectors.

The facilities range in size from 35 to 244 turbines and include a variety of turbine manufacturers and models (Table 1-1). Turbines included in our study ranged in overall height (hub height + ½ rotor diameter) from 134–180 m tall and the ground clearance to the bottom of the rotor-swept zone ranged from 22–45 m. Facilities within range of the federally endangered Indiana bat (*Myotis sodalis*) were required to implement a blanket curtailment strategy with a 5.0 m/s cut-in speed at night from July 15 through September 30. The wind energy facilities in this study occur in the Rolling Loess Prairies of the Western Corn Belt Plains Ecoregion, which includes much of Iowa and is characterized by glaciated till





Wind Power Sites

- Arbor Hill
- Beaver Creek I
- Beaver Creek II
- Contrail
- Diamond Trail
- Ida Grove II
- Ivester
- North English I
- North English II
- Orient
- Palo Alto
- Plymouth
- Pocahontas Prairie
- Prairie
- Southern Hills

0 50 Miles

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Stantec

Project Location
State of Iowa

Prepared by GC on 2022-04-26
Reviewed by TP on 2022-04-26

Client/Project
US Department of Energy
Curtailment Research Project

195601685

Figure No.
1-1

Title
Project Location Map

Notes
1. Coordinate System: NAD 1983 UTM Zone 15N
2. Background: The USGS National Map

V:\1956\active\195601686\03_data\gis_cad\gis\MXDs\Curtailment\01686_4-1_Location2022.mxd Revised: 2022-04-26 By: gcarpentier plains and undulating loess plains. Mean elevations of study turbines (15 turbines per facility) ranged from 266 – 412 m above sea level, with range in elevation among study turbines ranging from 9 m at Pocahontas Prairie to 54 m at Ida Grove (Table 1-2). Land cover within 1 km of study turbines, based on National Land Cover Database (U.S. Geological Survey 2023) consists primarily (>90%) of cultivated cropland and developed area (~5%; Figure 1-2). Forest, herbaceous, shrubland, water, and wetlands comprising less than 1% of land cover at most facilities (Table 1-2). Commercial agricultural crops in the region consist primarily of corn (*Zea mays*), soybeans (*Glycine max*), and livestock (Baumgartner et al. 2020a, 2020b). Appendix C includes maps of each site showing all turbine locations and the spatial distribution of turbines equipped with acoustic detectors.

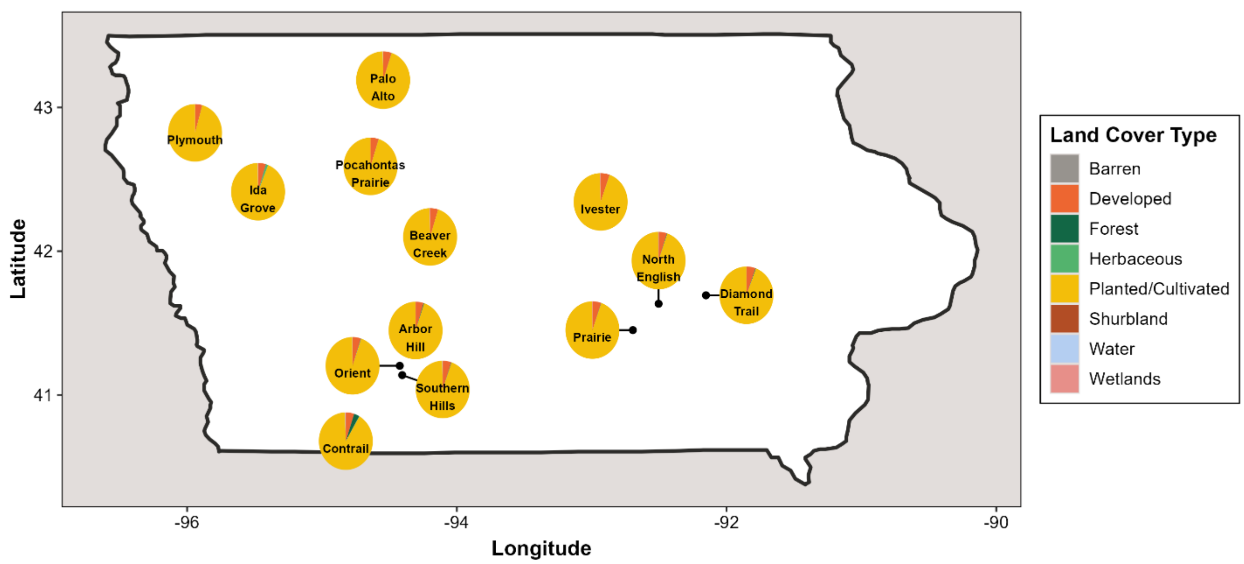

Figure 1-2. Land cover within 1 km of study turbines at 13 MidAmerican wind energy facilities in Iowa included in 2021–2023 acoustic activity-based smart curtailment study.

Table 1-1. Turbine characteristics for 13 MidAmerican wind energy facilities in the state of Iowa included in 2021–2023 acoustic activity-based smart curtailment study.

Facility	County	Manufacturer (per-turbine output)	Number of Turbines	Manufacturer Cut-in Speed (m/s)	Hub Height (m)	Rotor Diameter (m)	Indiana Bat Range
Arbor Hill I/II	Adair	Vestas (2 MW)	130	3	95	110	Yes
		Vestas (4.2 MW)	12	3	105	150	Yes
Beaver Creek I/II	Boone	Vestas (2 MW)	56	3	95	110	Yes
		Vestas (2.05 MW)	1	3	95	110	Yes
		Vestas (2.2 MW)	28	3	95	110	Yes
	Greene	Vestas (2 MW)	56	3	95	110	No
		Vestas (2.05 MW)	1	3	95	110	No
		Vestas (2.2 MW)	28	3	95	110	No
Contrail	Taylor	GE (2.3 MW)	5	3.5	80	116	Yes
		GE (2.72 MW)	6	3	90	116	Yes
		GE (2.82 MW)	30	3	89	127	Yes
Diamond Trail	Iowa	Vestas (2 MW)	8	3	95	110	Yes
		Vestas (2.2 MW)	11	3	95	110	Yes
		GE (2.82 MW)	25	3	89	127	Yes
		Vestas (4.2 MW)	4	3	105	136	Yes
		Vestas (4.3 MW)	32	3	105	136	Yes
Ida Grove II	Ida	GE (2.3 MW)	8	3.5	80	116	No
		GE (2.52 MW)	73	3	89	127	No
Ivester	Grundy	Siemens (2.415 MW)	5	3	80	108	No
		Siemens (2.625 MW)	30	3	85.1	120	No
North English I/II	Poweshiek	Vestas (2 MW)	75	3	95	110	Yes
		Vestas (2.15 MW)	21	3	95	110	Yes
		Vestas (2.2 MW)	4	3	95	110	Yes
		Vestas (2 MW)	46	3	95	110	Yes
		Vestas (2.15 MW)	19	3	95	110	Yes
		Vestas (2.2 MW)	5	3	95	110	Yes
Orient I/II	Adair	Vestas (2 MW)	77	3	95	110	Yes
		Vestas (2.15 MW)	11	3	95	110	Yes
		Vestas (2.2 MW)	92	3	95	110	Yes
		Vestas (2.2 MW)	64	3	95	120	Yes
Palo Alto I/II	Palo Alto	Vestas (2 MW)	125	3	95	110	No
		Vestas (2 MW)	45	3	95	110	No
Plymouth County	Plymouth	GE (2.3 MW)	6	3.5	80	116	No
		GE (2.82 MW)	67	3	89	127	No
Pocahontas Prairie	Pocahontas	Vestas (2 MW)	24	3	100	110	No
		Vestas (2.2 MW)	16	3	100	110	No
Prairie	Mahaska	Vestas (2 MW)	49	3	95	110	Yes
		Vestas (2.15 MW)	7	3	95	110	Yes
		Vestas (2.2 MW)	28	3	95	110	Yes
Southern Hills	Adair, Union, Adams	Vestas (2 MW)	2	3	95	110	Yes
		Vestas (2.2 MW)	19	3	95	110	Yes
		Vestas (4.3 MW)	25	3	105	136	Yes
		Siemens (4.8 MW)	21	3	107	145	Yes

Table 1-1. Landcover within 1 km of turbines equipped with acoustic bat detectors across 13 MidAmerican wind energy facilities in the state of Iowa included in 2021–2023 acoustic activity-based smart curtailment study.

Facility	Elevation (range) in meters	Latitude	Longitude	Percent landcover by category within 1 km of turbines							
				Barren	Developed	Forest	Herbaceous	Planted/ Cultivated	Shrubland	Water	Wetlands
Arbor Hill	369 (346-395)	41.44829	-94.30588		4.8	0.4		94.7			0.1
Beaver Creek	332 (314-348)	42.09961	-94.19818		4.8			94.8			0.3
Contrail	367 (358-378)	40.67864	-94.82327		5	3.3	0.2	90.9	0.1	0.2	0.3
Diamond Trail	272 (255-278)	41.69311	-92.15256		5.4	0.3	0.1	94.1			
Ida Grove	412 (385-439)	42.41359	-95.47363	0.1	4.5	0.2	1.3	93.7		0.1	0.1
Ivester	332 (319-340)	42.34296	-92.93381		5.3	0.1		94.2		0.1	0.3
North English	289 (281-299)	41.63424	-92.50403		5	0.3		94.5	0.1	0.1	
Orient	401 (390-416)	41.2026	-94.42335		5	0.2	0.1	94.5		0.2	
Palo Alto	391 (379-406)	43.18964	-94.5466	0.1	5			94.6		0.1	0.1
Plymouth	431 (420-441)	42.82318	-95.94128		4.3	0.1		95.7			
Pocahontas Prairie	375 (371-380)	42.58981	-94.64006		4.8	0.1		95.1			
Prairie	266 (254-274)	41.45097	-92.69454		5.2	0.2		94.5			0.1
Southern Hills	398 (388-407)	41.13793	-94.40499	0.1	5	0.2		94.4		0.2	0
			Overall	*<0.1*	*4.9*	*0.4*	*0.1*	*94.2*	*<0.1*	*0.1*	*0.1*

2.0 QUANTIFY CONSISTENCY OF RELATIONSHIP BETWEEN BAT ACTIVITY AND AEROSPHERIC CONDITIONS (OBJECTIVE 1)

2.1 METHODS

2.1.1 Acoustic Monitoring

2.1.1.1 Data Collection

We configured acoustic bat detectors (Wildlife Acoustics SM4BAT-FS) with omnidirectional microphones (Wildlife Acoustics SMM-U1) for long-term deployment on turbine nacelles and/or the access stair railings at the base of turbines. All nacelle-mounted detector microphones were deployed at the downwind end of turbine nacelles, oriented horizontally and pointing away from the rotor (downwind) and ground-level detector microphones, where present, were angled slightly above horizontal and located ~4 m above the ground. The number of detectors and method to power and mount detector components varied by year, although systems used a single microphone type and acoustic detector model throughout the study (Table 2-1).

We programmed detectors using the Wildlife Acoustics SM4 Configurator software tool to operate each night from 30 minutes before sunset until 30 minutes past sunrise, with sunset and sunrise times determined automatically by the detectors based on the latitude and longitude of each site. Audio recording settings included a gain of 0 decibel (dB), no high 16k filter, 256 kilohertz (kHz) sampling rate, 1.5 milliseconds (ms) minimum duration, minimum trigger frequency of 16 kHz, trigger level of 12 dB, trigger window of 3 seconds (s), maximum length of 15 s, and W4V-6 file compression. Each detector was equipped with 2 SD cards (minimum 128 GB capacity per card). Project operations staff or contractors installed detectors on turbines and demobilized equipment at the end of the monitoring period. Data were offloaded from some units partway through the monitoring period, but most detectors were not inspected until they were demobilized at the end of the survey period. Detector installation and demobilization dates varied among years according to logistical constraints and staff availability, but sampling effort targeted July–November each year to fully encompass 15 July–30 September, the date range over which curtailment strategies were implemented at the facilities.

Table 2-1. Yearly deployment details for turbine-mounted acoustic detectors installed at Orient and Arbor Hill, and 11 other MidAmerican wind energy facilities (Expansion Sites) in the state of Iowa, 2021–2023.

Site	Year	Number of Detectors	Power Supply	Microphone Deployment
Orient and Arbor Hill	2021	45 Total 30 on turbine nacelles 15 at each site and 15 at ground level (8 at Orient and 7 at Arbor Hill)	12-volt 7.2 amp-hour sealed lead-acid batteries charged by 10-watt solar panels regulated by charge controllers (Morningstar SunGuard) and mounted on purpose-built aluminum plates secured to a thermal radiator at the back of the nacelle with rubber-coated rare earth magnets (Vestas)	Attached to a ~0.5 m section of angled aluminum oriented horizontally away from the turbine rotor off the downwind end of the nacelle (Figure 2-1).
	2022	Same as 2021		
	2023	30 Total on turbine nacelles, 15 at each site	110/120-volt AC power receptacles inside the nacelle with 5v AC/DC inverters (Triad Model 812WSU050-2000)	Attached to the anemometer masts using 90-degree aluminum brackets secured with stainless steel worm drive clamps (Figure 2-1).
Expansion Sites	2022	165 Total on turbine nacelles 15 at each site	110/120-volt AC power receptacles inside the nacelle using external power cables (Wildlife Acoustics SM3CABPWR) and 9-volt DC adapters (XP Power model VEL12US090-US-JA).	Attached to the anemometer masts using 90-degree aluminum brackets secured with stainless steel worm drive clamps (Figure 2-1).
	2023	165 Total on turbine nacelles 15 at each site	110/120-volt AC power receptacles inside the nacelle with 5v AC/DC inverters (Triad Model 812WSU050-2000)	Attached to the anemometer masts using 90-degree aluminum brackets secured with stainless steel worm drive clamps (Figure 2-1).

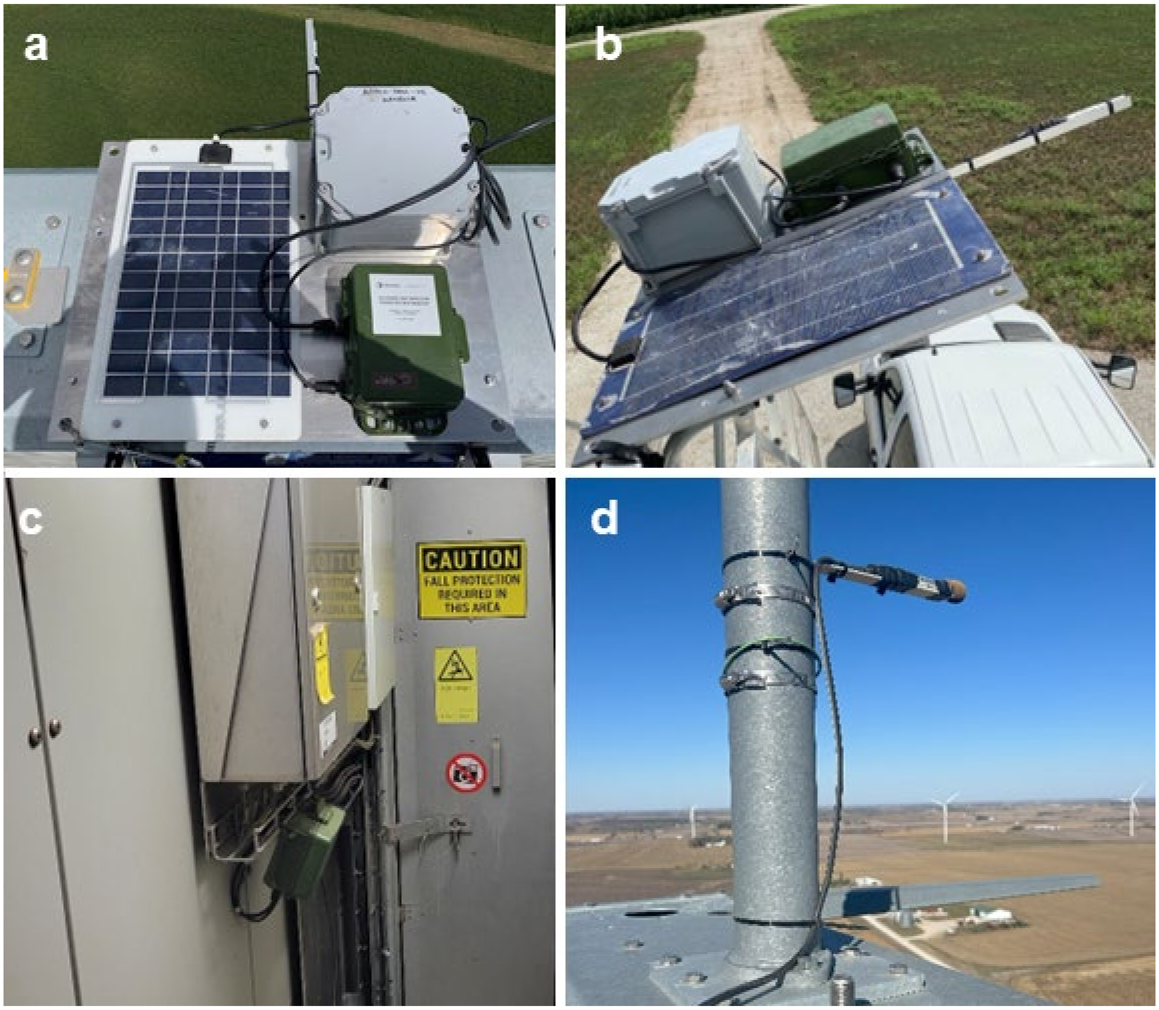

Figure 2-1. Acoustic bat detectors as deployed with solar-charged batteries on turbine nacelles (a), and at ground (~4m off the ground, at the base of the turbine) level (b) at MidAmerican the wind energy facilities, Orient and Arbor Hill, in 2021 and 2022, and as deployed inside turbine nacelles with AC/DC inverters (c) with microphones mounted externally on nacelle-mounted anemometer masts (d) at the 11 MidAmerican expansion sites in 2022 and all 13 sites in 2023.

2.1.1.2 Data Retention Parameters:

We reviewed acoustic data and turbine operations data for completeness as part of our analysis to validate proper detector operation, to determine if weather and turbine operation data were within acceptable ranges, and to remove spurious data points and non-bat acoustic files, as outlined below.

Operations data:

MidAmerican provided timestamped measurements of wind speed (m/s), rotor revolutions per minute (rpm), energy output (kW), and temperature averaged across 10-minute intervals for each turbine equipped with an acoustic detector from 1 March–15 November each year from a centralized database of SCADA measurements. We subjected each dataset to a data cleaning process to remove erroneous entries and identify periods with missing data. For a 10-minute time bin to be included the temperature had to be between -20° and 40° C, wind speed between 0 and 40 m/s, and the rotor speed had to be between 0 and 20 rpm.

If all three measurements remained the same for 60 minutes that time period was removed and considered as sensor malfunction, missing data, or the turbine being shut down for maintenance. In some cases where turbine operations data were missing for extended periods, we requested supplementary data from individual sites. In such cases, we performed additional visual review of data to verify the proper time zone for the datasets and confirm that units for each parameter aligned with those from MidAmerican's centralized database. We used ambient temperature relative to sunset and sunrise to confirm proper temporal alignment of operations data, comparing against publicly available temperature observations sourced from weatherunderground.com.

Acoustic data:

We evaluated acoustic data and detector system log files to categorize every attempted detector night as operating or not according to the following conditions, all of which needed to be met for a detector night to be considered successful:

1. Correct microphone type: microphone must correctly indicate proper microphone type (U1) throughout the deployment; status files with microphone type switching from U1 or U2 or other values identify a potentially faulty or damaged microphone element.
2. Sufficient power: the voltage must be above 4V during 90% of minutes within a night; voltage below this level could indicate a loss of proper battery voltage, lack of charging from the solar panel, or abnormal operation.
3. Active microphone: evidence of active microphone function (documented through the number of files recorded or the number of files scrubbed) must be present during the first 50% of the night. This check is to diagnose loss of microphone functionality, with a properly functioning detector we would expect some amount of bat acoustic activity or ambient noise.
4. Correct amount of sampling time: timestamps must be present for at least 90% of minutes within the theoretical operation period (30 minutes before sunset and 30 minutes after sunrise). This check is to flag minutes that were not recorded by the summary file created by the detector.

2.1.1.3 Acoustic Data Analysis

Acoustic bat data were processed using Kaleidoscope Pro software (KPro software, version 5.4.7) with autoclassifier 5.4.0, balanced sensitivity (setting = 0), minimum pulse setting of 2, and using the species set for Iowa. The automated process was used to convert full spectrum files (.W4V-6 format) to zero crossing format and automatically identify files to species level depending on the amount of information present in the file. We applied a constant frequency filter with a bandwidth of 1 kHz below a maximum frequency of 39 kHz to reduce incorrect classification of noise from ultrasonic anemometers as bats. Following autoclassification, Stantec dispersed files to species-specific folders and visually vetted classifications using AnalookW software (Titley Scientific, version 4.2g). This process began by properly delineating bat passes from non-bat noise files, defining bat passes as files with 2 or more ultrasonic pulses with characteristics of bats (Kunz et al. 2007b). Subsequent vetting focused on confirming that bat call files labeled as a *Myotis* species or tricolored bat (*Perimyotis subflavus*) during autoclassification could have been produced by those species. Files labeled as NoID by the software were also vetted to reclassify any files that could have been produced by *Myotis* species or tricolored bats. We exported file-level species identifications incorporating the results of visual vetting using the “countlabels” tool in AnalookW software. We used R software[1] to extract timestamps from the filename of acoustic datafiles, and to merge acoustic data with metadata including turbine, detector position (i.e., nacelle or ground level), latitude, longitude, night, and sunset/sunrise times. In some cases, we grouped species (e.g., eastern red bat and evening bat) where differentiation based on acoustic call parameters was potentially compromised by ultrasonic anemometer noise, or in the case of *Myotis* and tricolored bats, where sample sizes were small but where management actions would be similar.

2.1.2 Data Visualization and Statistical Analysis

We aligned the 10-minute time bin operations and weather data with acoustic bat data, rounding timestamps of acoustic bat passes to the nearest 10 minutes. Each 10-minute time bin includes average rotor speed, wind speed, temperature, power output, and a count of bat passes per species or species group for that 10-minute interval. This 10-minute dataset formed the basis of all subsequent analyses.

2.1.2.1 Data Visualization

We plotted the weekly rate of bat passes recorded per detector night, pooling data among turbines, for each site on an annual basis as a visual representation of seasonal activity patterns. Similarly, we plotted the hourly distribution of bat passes relative to sunset and relationships with temperature and wind speed by turbine, detector position, site, and species to visually assess temporal distribution of bat activity and relationships with weather variables. Where shown, 95% confidence intervals were calculated using the pooled bat activity per detector for each site and year.

2.1.2.2 Importance of Aerospheric Conditions on the Prediction of Bat Activity

To determine the ranking of aerospheric conditions influencing bat presence at turbines, we used a Random Forest modeling approach. Bat presence at each 10-minute interval was defined based on the detection of bat passes recorded at nacelle height, with presence indicating at least one bat pass recorded during the interval and absence indicating no passes. Only 10-minute intervals occurring when acoustic detectors were operational, from 30-minutes before sunset to 30-minutes after sunrise, were

[1] R Core Team (2024). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, URL https://www.R-project.org/

included in analysis and the timing of each interval was converted to the proportion of time between sunset and sunrise. For each wind facility, we generated a Random Forest model using *randomForest* (Liaw and Wiener, 2002) in R which predicted bat presence based on the time of night, day of year, wind speed, temperature, and year of the corresponding 10-minute intervals. Each model was created using 500 trees and 2 predictor variables per tree. To address class imbalance due to the higher frequency of absence intervals (Appendix I Table 1), we down-sampled absence data by randomly selecting 10-minute intervals to match the number of presence samples prior to training each mode. We generated variable importance plots for each site-specific model and used the mean Gini impurity to rank the importance of each predictor variable. We compared the rankings across all models to identify the most important conditions in predicting bat presence and observe if the ranking of conditions varied by site.

2.1.2.3 Sample Size Analysis

We used bootstrapping to assess variance in bat activity estimates by wind speed, temperature, day of year, and time of night based on the number of deployed detectors. Bat activity data for each variable was divided into bins: 0.5 m/s intervals for wind speed, 2.5°C for temperature, 1-hour for time of night, and 14-days for time of year. For each bin, we calculated the bat activity per detector as the percentage of passes for wind speed and temperature, and activity per detector night or hour for time of year and night. For each site, we sampled the activity measurement per variable bin from 2 to 100 detectors. We resampled each bin 1,000 times and calculated the mean variance of bat activity measurements within each bin. The total variance for each variable was obtained by summing the bin variances for each number of sampled detectors. Using plots of sum variance per sample size, we visually determined the point at which the variance stabilized which indicated the optimal number of deployed detectors and observed if this number was the same across variables and sites.

2.2 INTRODUCTION

The potential effects of climate change on wildlife are vast and well recognized and represented in scientific literature (Root and Schneider 2002; Sattar et al. 2021). Rapid expansion of renewable energy infrastructure is a key part of any global strategy to reduce the pace and severity of anthropogenic climate change (e.g., Arent et al. 2011), although the potential impacts of renewable energy infrastructure on wildlife are also becoming increasingly apparent (Adams et al. 2024). Bats appear vulnerable to population-level impacts from the cumulative effect of turbine-related fatalities at commercial wind energy facilities in North America, particularly as the industry continues to expand to meet renewable energy generation targets (Arnett and Baerwald 2013; Arnett et al. 2016). Long-distance migratory species including the hoary bat (*Lasiurus cinereus*), eastern red bat *(Lasiurus borealis),* and silver-haired bat *(Lasionycteris noctivagans)* account for the largest proportion of bat fatalities documented in North America (American Wind Wildlife Institute 2020; Kunz et al. 2007a). In particular, current fatality rates could threaten the viability of hoary bats (Frick et al. 2017; Friedenberg and Frick 2021). Fatalities of several federally endangered bat species also occur at wind energy facilities, necessitating measures to minimize risk and metrics to validate the success of such measures.

The lowest portion of Earth's atmosphere in which living organisms are active, known as the aerosphere, is a highly dynamic habitat where birds, flying insects, and bats forage, travel, and migrate (Kunz et al.

2008). The rotor-swept zone of wind turbines, extending anywhere from ~20–180 meters (m) above ground, is within the bottom portion of the aerosphere, and turbine-related impacts to bats occur as the result of exposure to fast-moving turbine blades within this complex and poorly understood habitat. The first studies to report unexpectedly high rates of bat fatality at commercial wind farms in North America noted an apparent relationship between bat fatalities and conditions in the aerosphere, with more bat carcasses typically found following relatively calm, warm nights (Arnett et al. 2008; Kunz et al. 2007). The same studies noted pronounced seasonal concentration of bat fatalities in late summer and early fall. These patterns have remained remarkably consistent across numerous post-construction fatality studies conducted throughout North America (Arnett and Baerwald 2013, American Wind Wildlife Institute 2020). Pre-construction bat surveys have been useful for documenting species presence and identifying seasonal patterns in bat activity but have not identified factors that could enable the wind energy industry to avoid impacts through siting facilities in areas with lower risk to bats (Solick et al. 2020); two decades of standardized carcass monitoring in North America have instead shown that bat mortality is a widespread issue that must be evaluated and managed once facilities become operational.

Bats are at risk of turbine-related impacts only when turbine rotors are in motion. Risk of turbine-related impacts therefore depends on presence of bats in the rotor-swept zone while turbine blades are moving fast enough to strike and cause injury or death (Horn et al. 2008; Lawson et al. 2020) and is therefore a highly dynamic process dependent on bat behavior, conditions, and how turbines are programmed to operate. Bats and wind turbines both respond to changing conditions in the aerosphere; turbines turn on and off and rotate to face the wind based on programmed settings such as cut-in wind speed and temperature thresholds. Commercial wind turbines are designed to rotate under as wide a range of conditions as possible but do not generate electricity until the wind speed reaches a manufacturer and model-specific threshold “cut-in” speed, typically between 3 and 4 meters per second (m/s). Unless turbine blades are pitched parallel to prevailing winds, a process known as feathering, most turbines rotate slowly below the default cut-in speed. Bats could be at risk of impact from free-wheeling turbines, although no energy can typically be produced at these low wind speeds (Anderson et al. 2022).

Factors affecting bat presence and behavior in the rotor-swept zone is complex and difficult to characterize. Numerous hypotheses as to why bats are present near wind turbines have been put forward, but the cause remains unclear (Cryan and Barclay 2009, Guest et al. 2022). There are well documented relationships between bat fatality and wind speed (Arnett et al. 2008). This relationship with wind speed has also been observed with bat acoustic activity (Baerwald and Barclay 2011; Ellerbrok et al. 2024; Squires et al. 2021; Wellig et al. 2018). Previous studies have also documented seasonal trends in bat fatalities (Arnett et al. 2008; Lloyd et al. 2023; Squires et al. 2021) and acoustic activity (Baerwald and Barclay 2011; Squires et al. 2021). These broad scale relationships allow for the drafting of curtailment programming that is tailored to site-specific conditions, species, and trends.

Turbine curtailment is the most widely used and consistently effective method to reduce turbine-related bat mortality and involves pitching or feathering turbine blades parallel to prevailing winds to restrict turbine rotation when turbines would otherwise be operating and capable of producing power (Arnett et al. 2011). Curtailment reduces bat fatality rates because it removes the source of risk, exposure of bats to fast-moving turbine blades. Though effective, turbine curtailment also reduces the energy output of wind energy facilities (Hayes et al. 2019, Thurber et al. 2023). Potential energy output increases exponentially as wind speed increases from the manufacturer's cut-in speed to approximately 12–15 m/s, when turbines typically reach their rated output (Carrillo et al. 2013). Energy generation potential increases as a cubic function of wind speed (Spiru et al. 2024), so energy loss from curtailment can vary substantially depending on the wind regime and parameters of curtailment strategies. Accordingly, both energy production and bat fatalities both decrease with cut-in wind speed, such that determining the appropriate cut-in speed for a curtailment strategy represents a tradeoff between energy loss and the degree of protection of bats (Hayes et al. 2023; Martin et al. 2017; Voigt et al. 2024).

At its core, curtailment simply involves pitching turbine blades to prevent rotor movement, but the potential combinations of parameters chosen to determine when and under what conditions turbines are curtailed are nearly limitless. So-called blanket curtailment strategies prevent turbine rotor movement when wind speed is below a selected cut-in speed, applied at night across the broad season in which bats are potentially at risk (Hayes et al. 2019). Blanket curtailment strategies are usually defined according to their cut-in wind speed; a recent meta-analysis of curtailment studies conducted in North America cited 32 examples of blanket curtailment strategies with 8 distinct cut-in speeds ranging from 3.5–7.9 m/s[2], with 5.0 m/s, 5.5 m/s, and 6.5 m/s accounting for 69% of strategies (Whitby et al. 2024). No rationale for selection of cut-in speeds or dates or time periods over which curtailment was implemented was indicated, but such decisions are typically based on regulatory and/or company precedent rather than site-specific data on wind regimes or bat activity patterns. Most strategies referenced in the study involved increasing the cut-in speed 2–3 m/s above the default manufacturer's cut-in speed. The effectiveness of blanket curtailment strategies may be predicted based on regional results and/or meta-analyses such as Whitby et al. (2024; e.g., 5.0 m/s blanket curtailment is often assumed to reduce fatality rates by 50%) but is rarely identified in the definition or name of the blanket strategy.

Several recent studies have demonstrated that increasing the complexity of curtailment strategies to account for additional factors that affect bat activity could narrow the range of conditions under which turbines are curtailed and reduce energy loss associated with curtailment (Barré et al. 2023; Behr et al. 2017; Hayes et al. 2019; Hayes et al. 2023). Other studies have explored the use of additional parameters, such as real-time detection of bats in the rotor-swept zone to trigger turbine curtailment (Hayes et al. 2019). These recent studies share a recognition that curtailment can be optimized to better target conditions when bats are most likely to be present, reducing the amount of energy loss. Recent guidance from the US Fish and Wildlife Service (USFWS) acknowledges the potential benefits of smart curtailment and differentiates between activity-based smart curtailment strategies, which use site-specific data on the temporal, seasonal, and spatial distribution of bat activity to design curtailment strategies, and "acoustic-activated" smart curtailment strategies, which incorporate real-time detection of bats into algorithms that control when turbines are curtailed.

Activity-based curtailment strategies use site-specific data on bat activity, derived from turbine-mounted acoustic detectors, to determine appropriate cut-in wind speed and temperature thresholds for different

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[2]Cut-in speeds of blanket curtailment strategies cited in the study (and numbers of cases studied) were 3.5 m/s (n = 3), 4.0 m/s (n = 1), 4.5 m/s (n = 3), 5.0 m/s (n = 12), 5.5 m/s (n = 4), 6.0 m/s (n = 2), 6.5 m/s (n = 6), and 7.9 m/s (n = 1) whereas turbine manufacturer's default cut-in speeds were 3.0 m/s (n = 7), 3.5 m/s (n = 21), and 4.0 m/s (n = 4).

times of the year and/or night based on seasonal and temporal patterns in bat activity and relationships with weather variables. These strategies apply higher cut-in speeds, which are more protective of bats, during seasonal periods and conditions associated with higher bat activity levels, and lower cut-in speeds during periods and conditions where bats are less active. Adjusting parameters to match bat activity patterns opens a wide array of possibilities for optimizing curtailment strategies to site-specific patterns in risk, even when only using wind speed and temperature thresholds. A similar approach could apply higher cut-in speeds at subsets of turbines with greater levels of risk. Unlike blanket curtailment, activity-based curtailment strategies are typically identified by their targeted reduction in exposure (e.g., a 50% reduction strategy) and not the parameters needed to achieve that targeted reduction.

Activity-based curtailment is an example of a “smart” curtailment strategy whose parameters are based on site-specific bat activity information, typically derived from acoustic data. By applying higher cut-in speeds during periods with higher levels of bat activity (and associated risk) and reducing cut-in speeds at other times, smart curtailment strategies reduce the overall amount of curtailment and associated energy loss compared to similarly protective blanket curtailment strategies. Selecting appropriate parameters for activity-based curtailment relies on an accurate characterization of bat activity patterns and the consistency of such patterns. Better understanding of such relationships should enable wind energy facilities to tailor curtailment strategies around site-specific patterns in bat activity, which would in turn help balance the simultaneous goals of reducing impacts to bats and the associated energy loss from curtailment.

Acoustic detectors have long been used to document spatial and temporal patterns in bat presence, species composition, and activity across a wide range of habitats (Parsons et al. 2009). Though pre-construction acoustic surveys proved ineffective at predicting turbine-related fatality rates for wind energy facilities (Solick et al. 2020), seasonal patterns in bat fatalities have been closely aligned with those documented in pre-construction bat surveys (Hein et al. 2013). Weller et al. 2012 found that bat presence in the rotor-swept zone of turbines could be predicted using occupancy models, highlighting the potential to optimize curtailment strategies. Peterson et al. (2021) distinguished between total bat activity measured at nacelle height detectors and the subset of bat passes exposed to turbine operation and demonstrated positive correlation between exposed bat activity and bat fatality rates at multiple scales. Similar studies have continued to document positive associations between exposed bat activity and fatalities, and acoustic data from turbine-mounted bat detectors are being used extensively in Europe to characterize bat fatality patterns at wind energy facilities (Behr et al. 2023).

This study used turbine-mounted acoustic bat detectors deployed at an unprecedented scale across 13 wind energy facilities in the state of Iowa to characterize seasonal and temporal distribution of bat activity and relationships with temperature and wind speed in the rotor-swept zone and to explore consistency of such patterns among facilities, turbines, years, and species. For activity-based curtailment strategies to be effective, the bat activity patterns around which they were designed must be well characterized and relatively consistent. The curtailment strategy also must not overfit existing data; selecting cut-in wind speed based on nightly distribution of bat passes would likely perform poorly the following year based on the inability to predict nightly trends in bat activity, while biweekly or monthly trends in bat activity are less variable, based on decades of pre-construction surveys and fatality surveys.

We used a combination of qualitative data visualization and quantitative analyses to explore variation in the seasonal and temporal distribution of bat activity and relationships between bat activity and temperature and wind speed among facilities, turbines, detector positions, years, and species. By combining qualitative and quantitative methods we demonstrated that relatively few variables, all of which are readily available to most wind energy facilities, explain pronounced and consistent variation in bat activity. Such patterns could therefore provide the basis for designing reliable and effective activity-based curtailment strategies that reduce energy loss while achieving equivalent reductions in risk as blanket curtailment.

2.3 RESULTS

Acoustic detectors recorded 43,268,401 audio files during 52,219 successful detector-nights of acoustic monitoring at 13 MidAmerican wind energy facilities between 2021–2023. Acoustic bat detectors were programmed to record files only when triggered by ultrasound in the frequency range of bats, but detectors at some sites were triggered to record nearly constantly by a weak ultrasonic signal at approximately 34 kHz, which appears to have been generated by active anemometers located near the acoustic detectors. This signal appears to have not prevented detectors from recording bats (ultrasonic bat passes were considerably louder than the anemometer noise), but many of the noise files were incorrectly identified as bats when data were originally processed using KPro software in 2022 and 2023. We reprocessed all acoustic data in 2024, following release of an updated version of KPro software with a constant frequency filter, which substantially reduced the number of noise files incorrectly identified as bats. KPro software categorized 3,256,077 files as bats, labeled 13,542,579 files as noise, and scrubbed the remaining 26,433,979 files. Visual vetting confirmed that 90% of files KPro categorized as bats did not contain bat passes, leaving a total of 331,040 bat passes. Appendix D includes tables summarizing survey effort and acoustic data availability on a per-turbine basis for each site and field season.

Acoustic detectors functioned properly during 53.9–100.0% of attempted detector nights by facility and year, recording data during 24,390 of 31,810 attempted detector-nights within the 15 July–30 September curtailment period, which was the focus of our monitoring effort (Table 2-2); sources of data loss were related primarily to failure of power supply components and/or inadvertent disconnection of detectors from the power supply in nacelles. Microphone damage occurred primarily during winter months in cases where detectors could not be demobilized at the end of the fall monitoring period.

Hoary bats accounted for 57.8% of identified bat passes at nacelle height and were distributed slightly earlier in the summer than silver-haired bats and eastern red/evening bats, which were the next most frequently detected species, representing 17.3% and 14.6%, respectively, of bat passes at nacelle height that were assigned a species identification by KPro software (Table 2-3). Passes identified as tricolored bats and *Myotis* species, all of which were manually vetted, each accounted for less than 0.5% of identified bat passes at nacelle height or ground level. Big brown bats accounted for a considerably higher proportion of identified bat passes at ground level (50.5%) than nacelle height (9.9%), as did eastern red/evening bats (23.1% at ground level and 14.6% at nacelle height), while the opposite was true for hoary bats (57.8% of identified passes at nacelle height and 17.1% at ground level; Table 2-3).

Hoary bats accounted for the majority of identified passes across all facilities and all species (grouping *Myotis* together) were present at all facilities. Activity of *Myotis* species was disproportionally higher at North English than other sites, and tricolored bat activity was disproportionally higher at Diamond Trail (Table 2-4).

Table 2-2. Acoustic data survey effort during 15 July–30 September by facility, position, and year at 13 MidAmerican wind energy facilities in the state of Iowa, 2021–2023.

Site	Year	Detector Position	Detector-nights	
			Attempted	Successful (% of Attempted)
Arbor Hill	2021	Ground	546	546 (100%)
		Nacelle	1,170	1,037 (88.6%)
	2022	Ground	546	461 (84.4%)
		Nacelle	1,170	732 (62.6%)
	2023	Nacelle	1,170	661 (56.5%)
Beaver Creek	2022	Nacelle	737	462 (62.7%)
	2023	Nacelle	1,170	643 (55.0%)
Contrail	2022	Nacelle	1,075	1,017 (94.6%)
	2023	Nacelle	1,170	659 (56.3%)
Diamond Trail	2022	Nacelle	784	781 (99.6%)
	2023	Nacelle	1,170	697 (59.6%)
Ida Grove	2022	Nacelle	1,170	906 (77.4%)
	2023	Nacelle	1,170	938 (80.2%)
Ivester	2022	Nacelle	1,170	1,029 (87.9%)
	2023	Nacelle	1,170	1,170 (100%)
North English	2022	Nacelle	749	696 (92.9%)
	2023	Nacelle	1,170	991 (84.7%)
Orient	2021	Ground	624	620 (99.4%)
		Nacelle	1,140	1,040 (91.2%)
	2022	Ground	610	329 (53.9%)
		Nacelle	1,170	779 (66.6%)
	2023	Nacelle	1,170	1,003 (85.7%)
Palo Alto	2022	Nacelle	973	973 (100%)
	2023	Nacelle	1,170	788 (67.4%)
Plymouth	2022	Nacelle	1,008	850 (84.3%)
	2023	Nacelle	1,170	645 (55.1%)
Pocahontas Prairie	2022	Nacelle	611	544 (89.0%)
	2023	Nacelle	1,170	677 (57.9%)
Prairie	2022	Nacelle	616	395 (64.1%)
	2023	Nacelle	1,170	948 (81.0%)
Southern Hills	2022	Nacelle	731	629 (86.0%)
	2023	Nacelle	1,170	744 (63.6%)
Totals				
2021		Nacelle	2,310	2,077 (89.9%)
		Ground	1,170	1,166 (99.7%)
2022		Nacelle	11,964	9,793 (81.9%)
		Ground	1,156	790 (68.3%)
2023		Nacelle	15,210	10,564 (69.5%)

Table 2-3. Species composition of identified bat passes during acoustic monitoring at 13 MidAmerican wind energy facilities, 2021–2023.

Position	Species*	# Passes (%)
Nacelle (13 facilities)	Big Brown	17,944 (9.9%)
	Eastern Red/Evening	26,353 (14.6%)
	Hoary	104,262 (57.8%)
	Myotis spp.	390 (0.2%)
	Silver-haired	31,256 (17.3%)
	Tricolored	194 (0.1%)
	Total	180,399 (100%)
Ground (2 facilities)	Big Brown	32,063 (50.5%)
	Eastern Red/Evening	14,665 (23.1%)
	Hoary	10,880 (17.1%)
	Myotis spp.	241 (0.4%)
	Silver-haired	5,405 (8.5%)
	Tricolored	227 (0.4%)
	Total	**63,481 (100%)**

*Manual vetting was performed for *Myotis* species passes (at the genus level due to overlapping call characteristics) and tricolored bats; otherwise, identifications are based on autoclassification by Kaleidoscope Pro software.

Table 2-4. Number of bat passes (and rate per detector-night) by species per facility, based on Kalidoscope Pro autoidentification (manual vetting for *Myotis* and tricolored bats) of acoustic data recorded by nacelle-height detectors during acoustic monitoring at 13 MidAmerican wind energy facilities in Iowa, 2021–2023. Data limited to 15 July–30 September.

Facility	# Detector-nights	Big Brown Bat	Eastern Red Bat	Evening Bat	Hoary Bat	Silver-haired Bat	Myotis species	Unidentified	Tricolored Bat	Total
Arbor Hill	2,352	2,090 (0.89)	1,899 (0.81)	1,334 (0.57)	10,292 (4.38)	2,420 (1.03)	2 (0.00)	6,799 (2.89)	9 (0.00)	24,845 (10.56)
Beaver Creek	1,105	1,014 (0.92)	662 (0.60)	425 (0.38)	3,689 (3.34)	1,521 (1.38)	3 (0.00)	3,290 (2.98)	5 (0.00)	10,609 (9.60)
Contrail	1,676	2,543 (1.52)	2,170 (1.29)	2,631 (1.57)	18,700 (11.16)	4,648 (2.77)	57 (0.03)	12,544 (7.48)	37 (0.02)	43,330 (25.85)
Diamond Trail	1,478	869 (0.59)	1,063 (0.72)	206 (0.14)	6,277 (4.25)	3,245 (2.20)	51 (0.03)	4,365 (2.95)	56 (0.04)	16,132 (10.91)
Ida Grove	1,844	1,105 (0.60)	894 (0.48)	189 (0.10)	9,656 (5.24)	2,901 (1.57)	48 (0.03)	4,778 (2.59)	13 (0.01)	19,584 (10.62)
Ivester	2,199	1,317 (0.60)	1,084 (0.49)	521 (0.24)	5,357 (2.44)	2,150 (0.98)	12 (0.01)	2,646 (1.20)	5 (0.00)	13,092 (5.95)
North English	1,687	1,056 (0.63)	1,299 (0.77)	369 (0.22)	6,013 (3.56)	2,317 (1.37)	76 (0.05)	3,800 (2.25)	8 (0.00)	14,938 (8.85)
Orient	2,822	2,326 (0.82)	2,116 (0.75)	1,142 (0.4)	11,659 (4.13)	2,671 (0.95)	23 (0.01)	7,316 (2.59)	17 (0.01)	27,270 (9.66)
Palo Alto	1,761	585 (0.33)	437 (0.25)	137 (0.08)	2,538 (1.44)	826 (0.47)	16 (0.01)	1,991 (1.13)	4 (0.00)	6,534 (3.71)
Plymouth	1,495	400 (0.27)	275 (0.18)	25 (0.02)	4,560 (3.05)	1,295 (0.87)	33 (0.02)	2,228 (1.49)	4 (0.00)	8,820 (5.90)
Pocahontas Prairie	1,221	469 (0.38)	383 (0.31)	1,058 (0.87)	1,510 (1.24)	444 (0.36)	10 (0.01)	1,706 (1.40)	5 (0.00)	5,585 (4.57)
Prairie	1,343	1,396 (1.04)	1,922 (1.43)	493 (0.37)	6,933 (5.16)	2,417 (1.80)	2 (0.00)	4,571 (3.40)	11 (0.01)	17,745 (13.21)
Southern Hills	1,373	1,372 (1.00)	1,022 (0.74)	523 (0.38)	5,377 (3.92)	1,302 (0.95)	35 (0.03)	3,835 (2.79)	3 (0.00)	13,469 (9.81)

Weekly distribution of bat activity was similar among facilities and years with highest rates of activity occurring between late July and late August (Figure 2-2). Where detectors were placed at nacelle height and ground level (2 facilities), substantially more bat passes were recorded at ground-level, although the seasonal distributions were similar between detector positions. Species-specific seasonal patterns in bat activity were also generally similar, although silver-haired bat activity peaked in early September whereas activity of other species was highest in mid-August (Figure 2-3). The seasonal peak in bat activity varied somewhat among years but was remarkably consistent across facilities (Figure 2-4). Patterns in overall species composition and the seasonal distribution of activity were also similar across facilities (Figure 2-5). Spikes in species-specific activity that differed from this pattern occurred at some sites, although this was attributable to outliers observed at individual turbines (e.g., Pocahontas Prairie Turbine 035; see Appendix E). Although weekly bat activity patterns observed at individual turbines exhibited greater variation, with occasional gaps in datasets due to detector malfunction, turbine-specific datasets generally followed consistent seasonal patterns. Appendix E includes weekly plots of bat activity per turbine and year for each facility. Note the overall similarity in seasonal distribution of bat activity among detectors and years despite weekly variation.

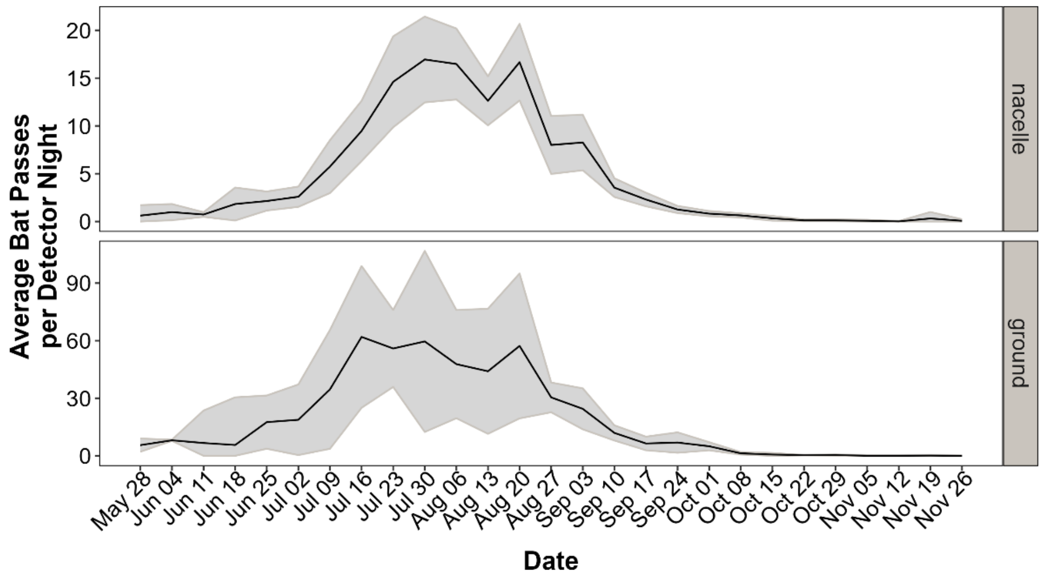

Figure 2-2. Mean weekly bat passes per detector-night (black line) and 95% confidence intervals (gray shading) based on data summarized per facility and year, recorded at nacelle-mounted and ground-level detectors at 13 MidAmerican wind energy facilities in Iowa from 2021–2023.

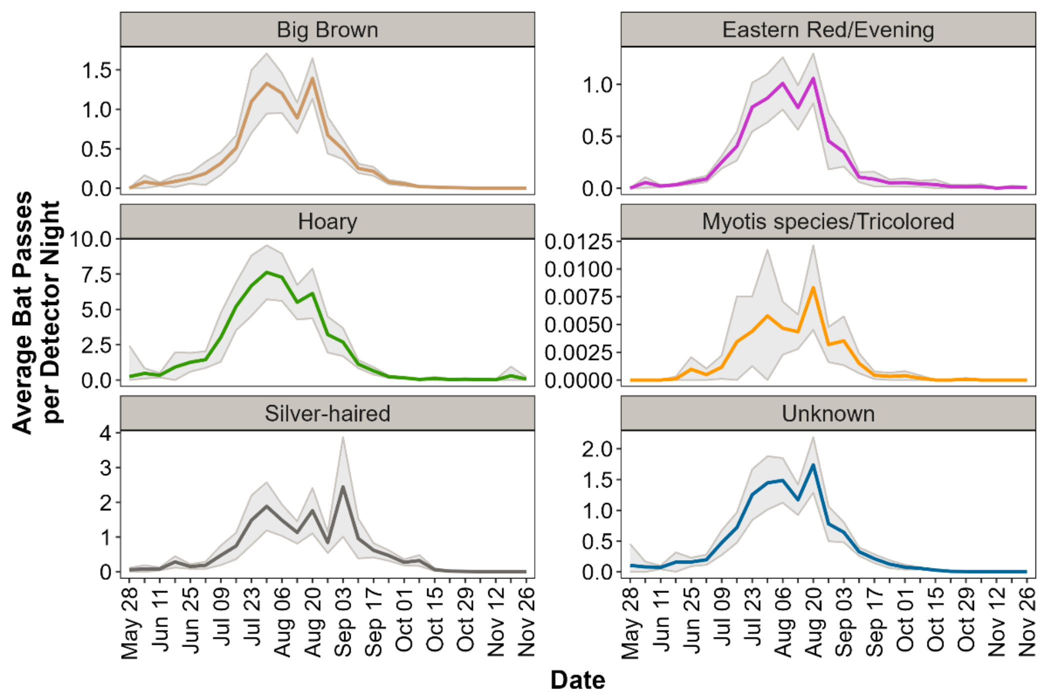

Figure 2-3. Mean weekly bat passes per detector-night by species (colored lines) and 95% confidence intervals (gray shading) based on data summarized per facility and year, recorded at nacelle-mounted detectors at 13 MidAmerican wind energy facilities in Iowa from 2021–2023.

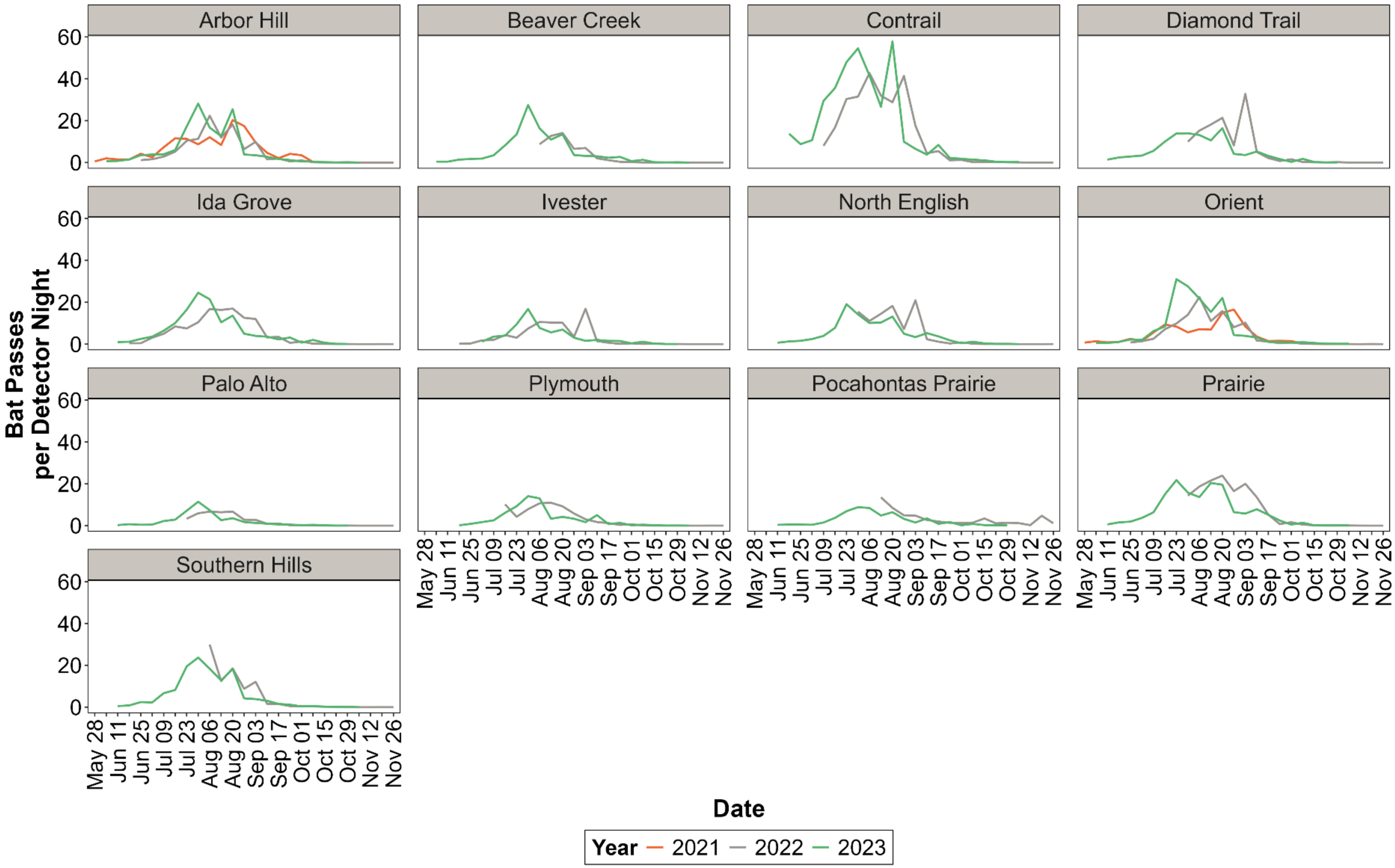

Figure 2-4. Weekly bat passes per detector-night by facility and year, recorded at nacelle-mounted detectors at 13 MidAmerican wind energy facilities in Iowa from 2021–2023.

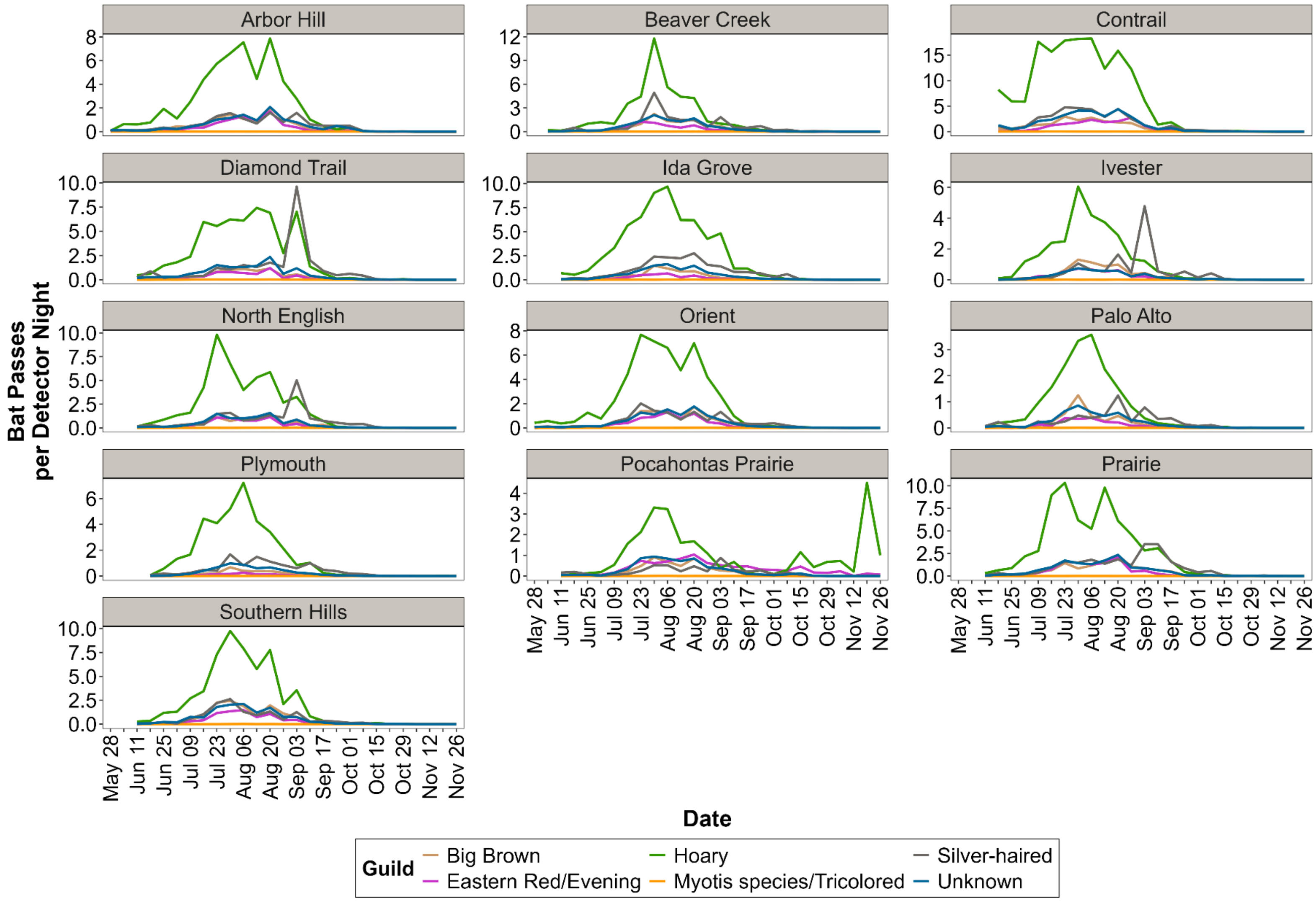

Figure 2-5. Weekly bat passes per detector-night by species, facility and year, recorded at nacelle-mounted detectors at 13 MidAmerican wind energy facilities in Iowa from 2021–2023.

Bat activity at nacelle-height and ground level detectors increased steadily from sunset to 1 hour past sunset, then declined steadily through the end of the night (Figure 2-6). Hourly distribution of bat passes was remarkably similar among facilities and years, although a slight bimodal pattern occurred at some facilities, with a smaller peak in activity 7–8 hours after sunset (Figure 2-7). As was the case with weekly distribution of bat activity, hourly patterns documented at individual detectors exhibited greater variation but tended to follow the same general patterns described above. Appendix F includes plots of the hourly distribution of bat passes detected at individual turbines for each facility in our study which demonstrate consistency among detectors, facilities, and years.

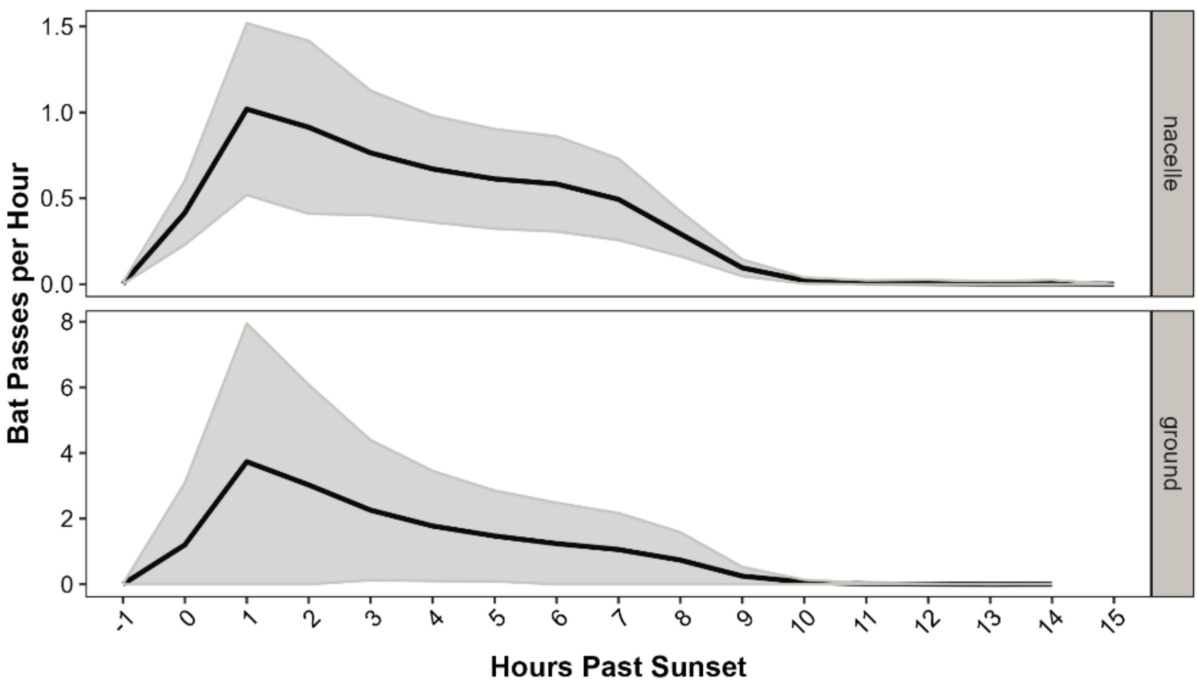

Figure 2-6. Mean bat passes per hour (solid line) and 95% confidence intervals (gray shading) based on data summarized per facility and year at nacelle-mounted and ground-level detectors at 13 MidAmerican wind energy facilities in Iowa from 2021–2023.

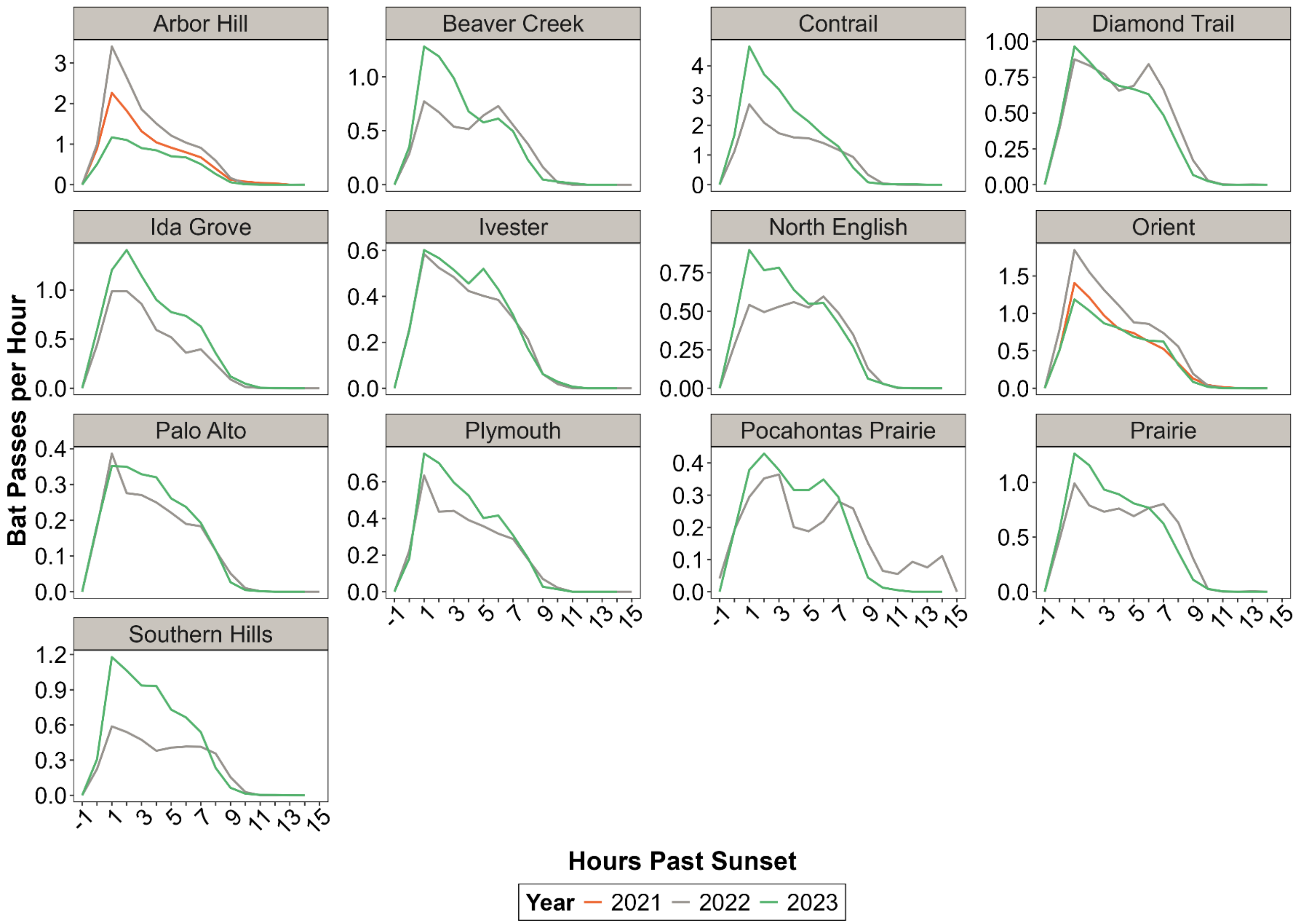

Figure 2-7. Hourly bat activity patterns per facility and year, recorded at nacelle-mounted detectors at 13 MidAmerican wind energy facilities in Iowa from 2021–2023.

Approximately half of bat passes recorded at nacelle height (52.5%) and near ground (45.2%) occurred when wind speed at nacelle height was below 5 m/s, although only ~25% of intervals at both detector positions had wind speeds less than 5 m/s (Figure 2-8). The disproportionate distribution of bat activity at lower wind speeds was consistent among facilities, although bat activity was distributed at slightly higher winds at Pocahontas Prairie than at other facilities, possibly due to the later deployment of detectors at that site (Figure 2-9). Hoary bat activity tended to occur at slightly lower wind speeds than other species, and the distribution of tricolored and *Myotis* species activity as a function of wind speed was more variable among sites than for other species, likely due to small sample sizes (Figure 2-10). Appendix G includes figures of the distribution of bat activity as a function of wind speed by species at each facility and detector.

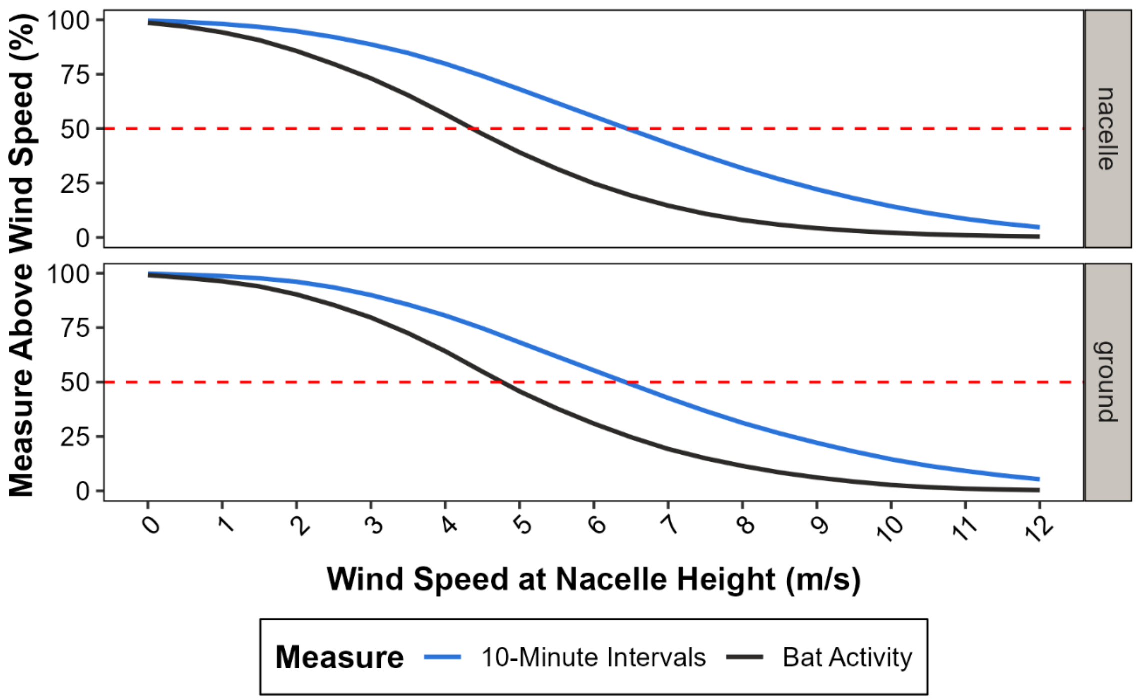

Figure 2-8. Percent distribution of bat passes as a function of wind speed at nacelle height by detector position (pooled across facilities, detectors, and years) recorded at nacelle-mounted and ground-level detectors at 13 MidAmerican wind energy facilities in Iowa from 2021–2023.

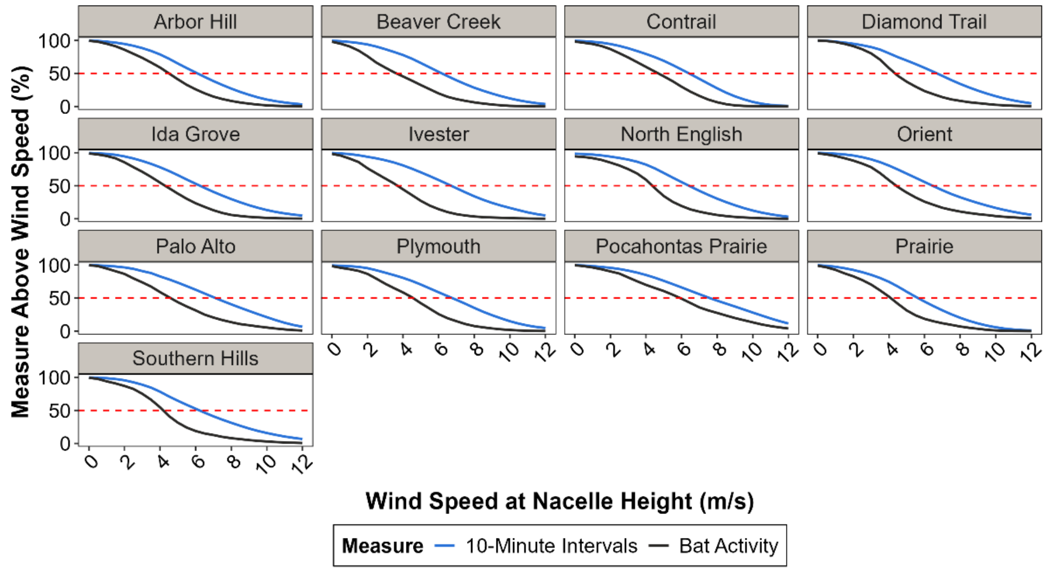

Figure 2-9. Percent distribution of bat passes as a function of wind speed at nacelle height by facility (pooled across detectors and years) recorded at nacelle-mounted detectors at 13 MidAmerican wind energy facilities in Iowa from 2021–2023.

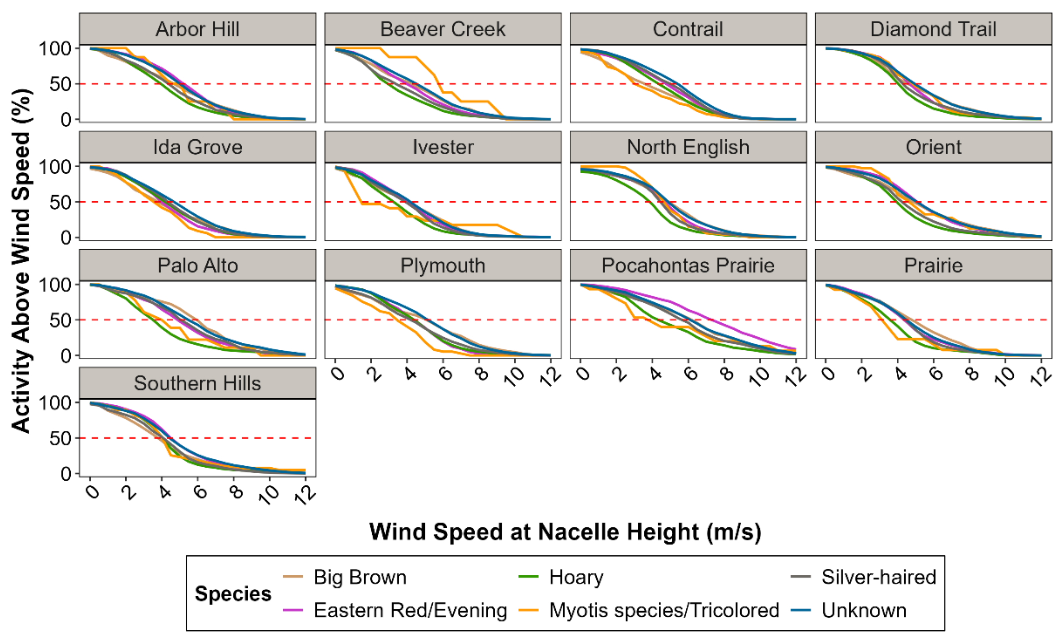

Figure 2-10. Percent distribution of bat passes as a function of wind speed at nacelle height by facility and species (pooled across detectors and years) recorded at nacelle-mounted detectors at 13 MidAmerican wind energy facilities in Iowa from 2021–2023.

Bat activity at nacelle height and near ground was disproportionally distributed during warmer temperatures, with over 50% of bat passes occurring during ~25% of intervals in which ambient temperature was above ~24°C (Figure 2-11). This general pattern was consistent among sites, although the midpoint of the distribution occurred at higher temperatures ranging from ~21°C at Ivester to ~25°C at Contrail (Figure 2-12). Hoary bat activity tended to occur at slightly higher temperatures than other species, likely due to the timing of their seasonal peak in July, and the distribution of tricolored and *Myotis* species activity as a function of temperature was more variable among sites than for other species, likely due to small sample sizes (Figure 2-13). Plots of the distribution of bat passes as a function of temperature, recorded at individual detectors by species group are included in Appendix H.

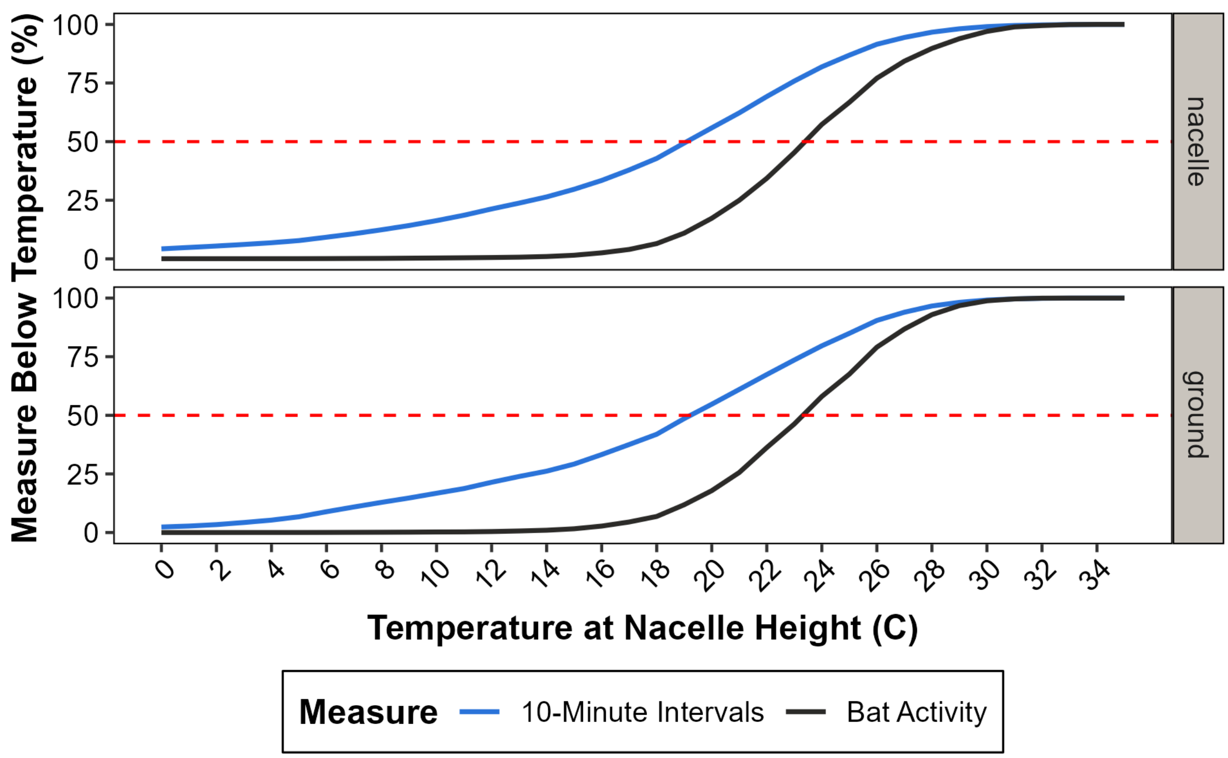

Figure 2-11. Percent distribution of bat passes as a function of temperature at detector position recorded at nacelle-mounted and ground-level detectors at 13 MidAmerican wind energy facilities in Iowa from 2021–2023.

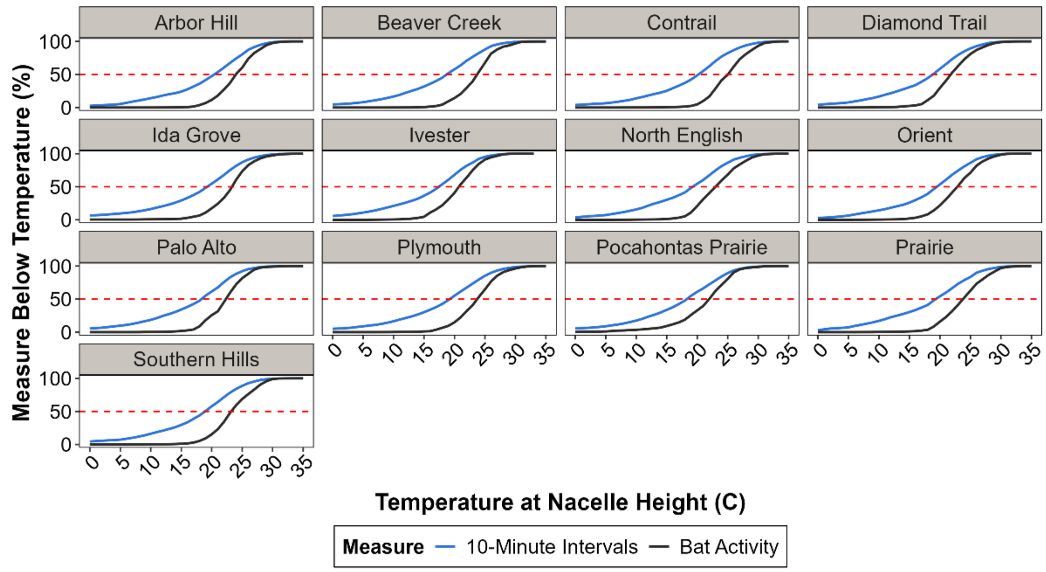

Figure 2-12. Percent distribution of bat passes as a function of wind speed at nacelle height by facility (pooled across detectors and years) recorded at nacelle-mounted detectors at 13 MidAmerican wind energy facilities in Iowa from 2021–2023.

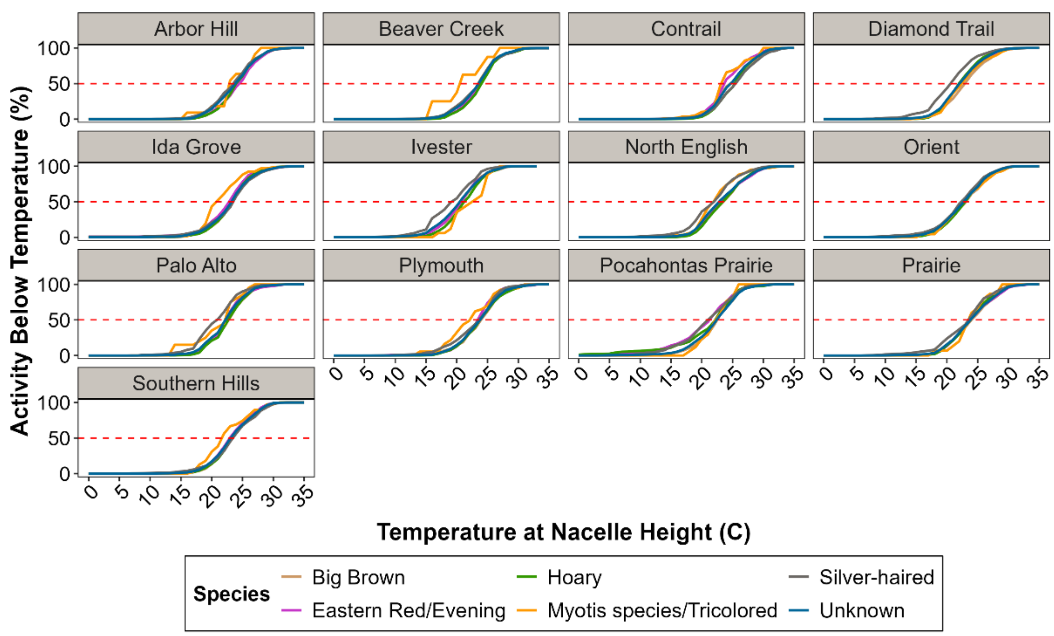

Figure 2-13. Percent distribution of bat passes as a function of wind speed at nacelle height by facility and species (pooled across detectors and years) recorded at nacelle-mounted detectors at 13 MidAmerican wind energy facilities in Iowa from 2021–2023.

The proportion of 10-minute intervals with bat presence detected by nacelle-mounted acoustic detectors ranged from 1.88–8.82%, with a mean of 4.28%. Presence varied on a biweekly basis (14-day intervals) following a similar pattern to the biweekly rate of activity, reaching a maximum of 6.6–21.7% among sites in July/August (Figure 2-14). Random forest models correctly classified bat presence and absence for 77.9–83% of 10-minute intervals across all sites (Appendix I Table 2). Models indicated that day of year, followed by time of night, were the two variables of greatest importance in predicting bat presence on a 10-minute basis at 12 of 13 facilities. Wind speed and temperature were ranked next highest at all but one facility, and year was ranked as having the lowest importance at all facilities (Figure 2-15). Turbine also ranked as the second lowest variable of importance at 12 of 13 facilities.

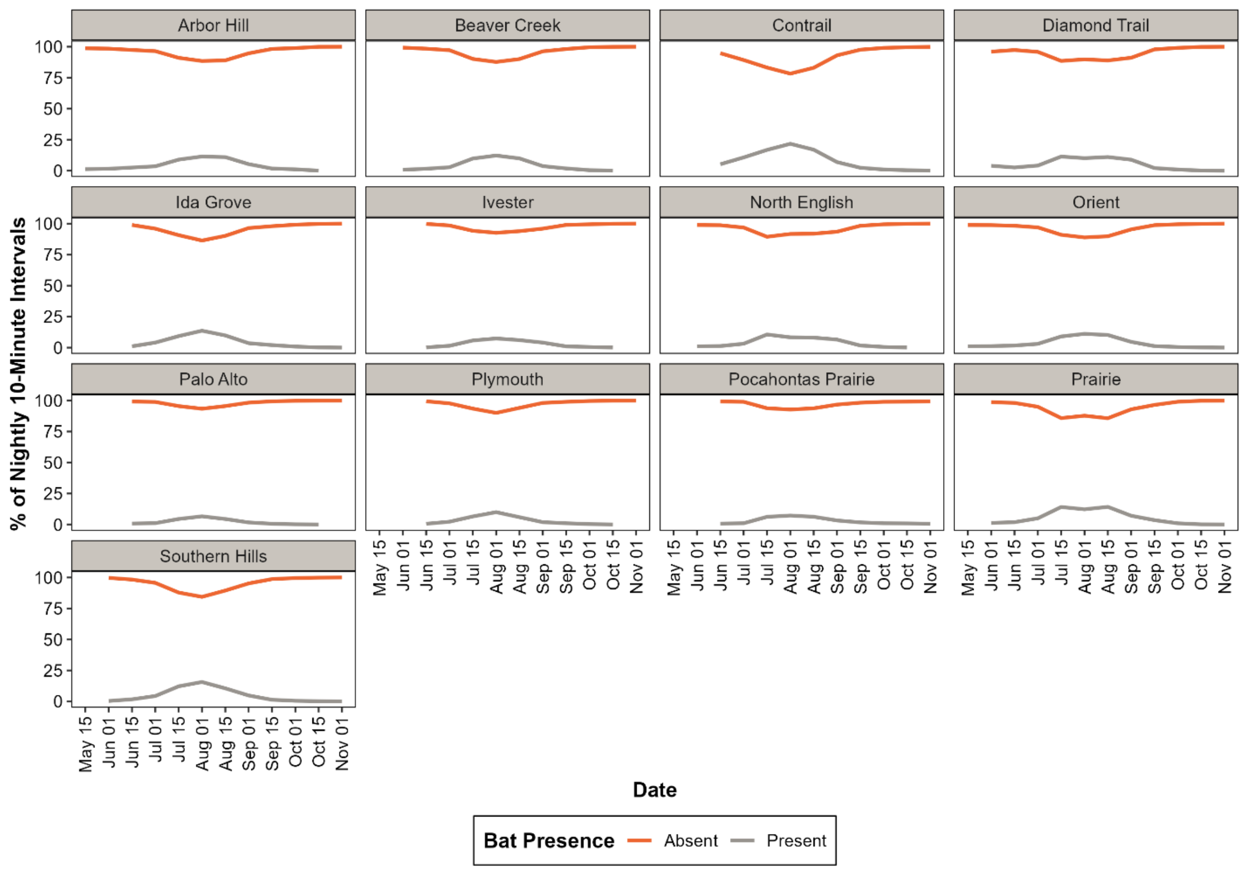

Figure 2-14. Percent of 10-minute intervals with bat presence at nacelle-height on a biweekly basis at 13 MidAmerican wind energy facilities in Iowa from 2021–2023.

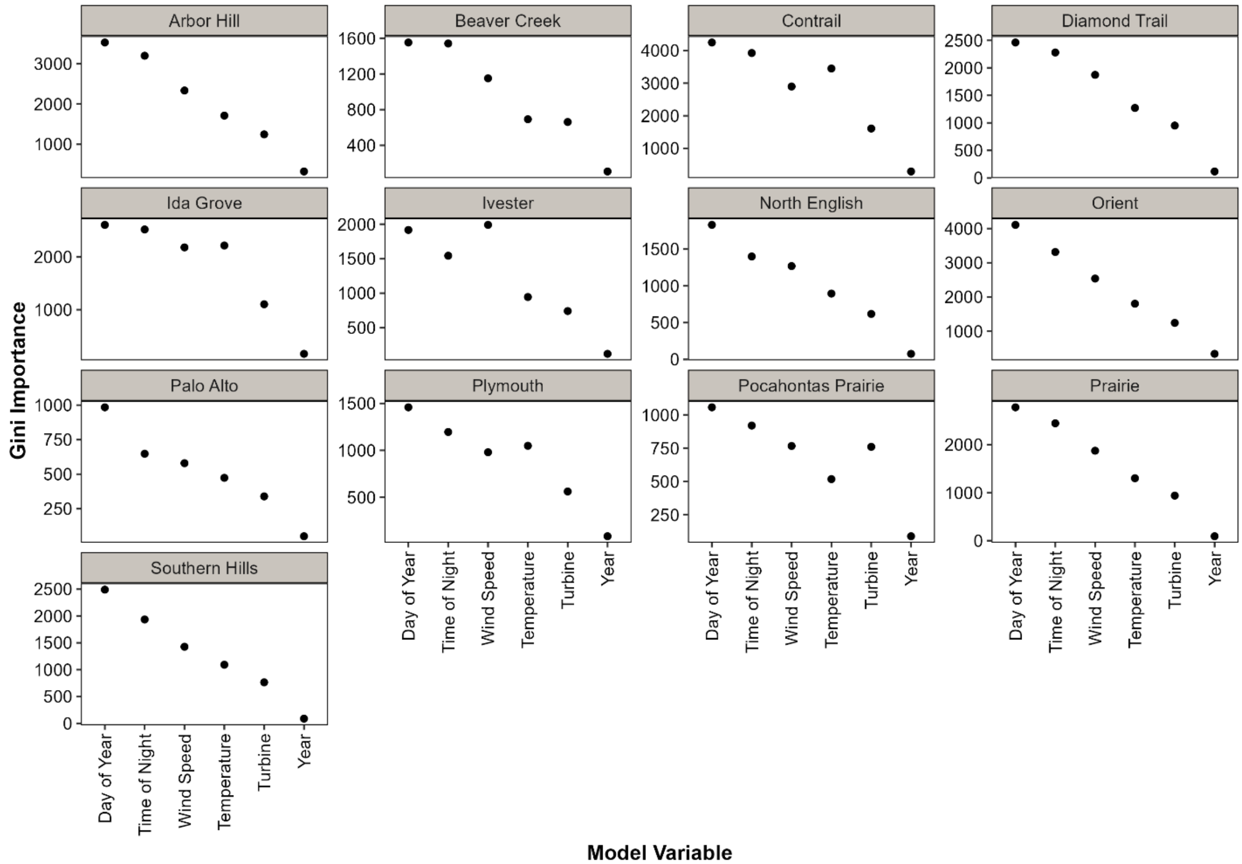

Figure 2-15. Facility specific variable importance scores for predictors included in random forest models of bat presence in 10-minute intervals based on acoustic datasets recorded by nacelle-height detectors at 13 MidAmerican wind energy facilities in Iowa from 2021–2023.

Based on bootstrapping analysis, the variability in biweekly bat activity measurements decreased as the number of detectors sampled increased, stabilizing around 10-15 detectors, beyond which sampling additional detectors had minimal impact (Figure 2-16). This pattern was consistent across most sites and was also true for the distribution of activity by hour (Appendix I Figure 1), and as a function of wind speed (Appendix I Figure 2) and temperature (Appendix I Figure 3). However, there were some instances, such as biweekly distributions measurements at Contrail and Prairie, where variation in bat activity was still relatively high despite sampling more than 15 detectors (Figure 2-16). It is important to note that this analysis focused on the variance of each bat activity measure as a function of the number of detectors rather than distinguishing the impact these factors may have had on bat activity rates.

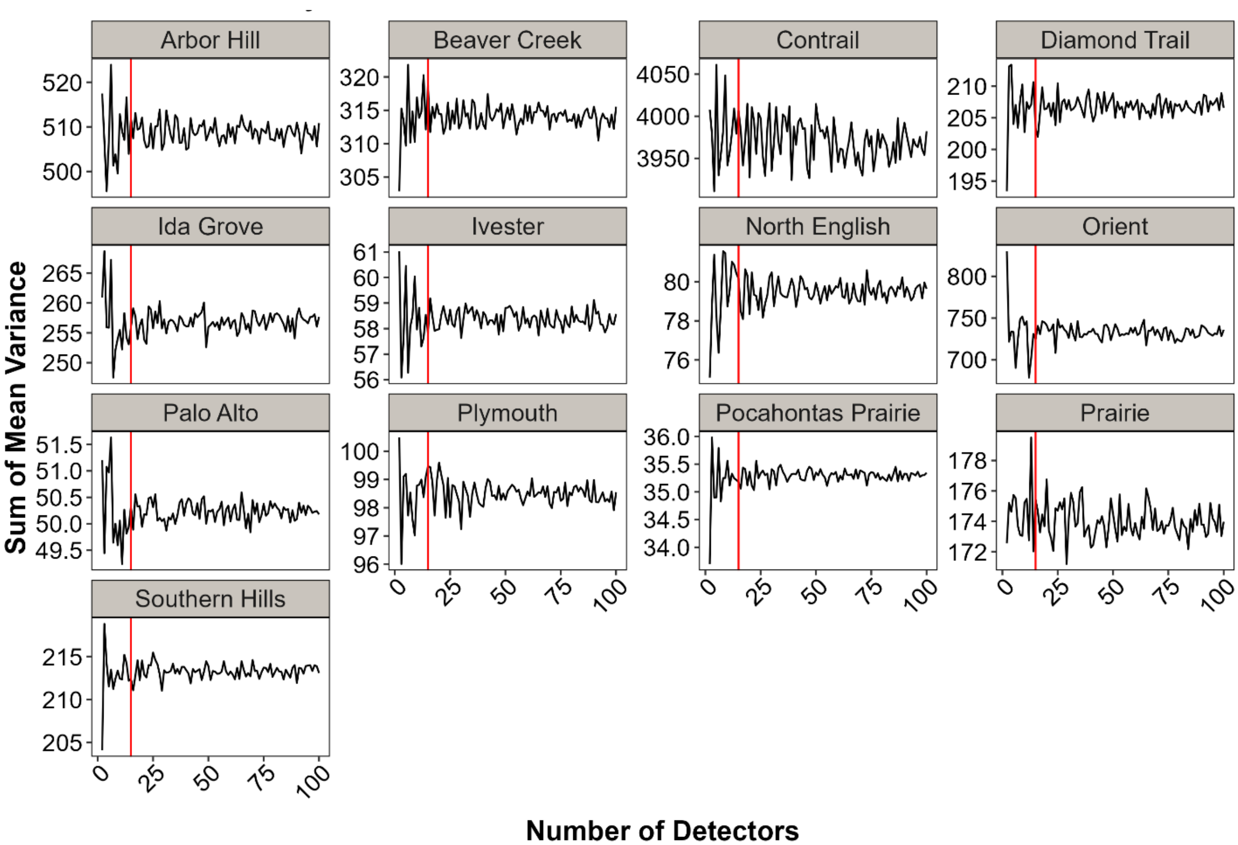

Figure 2-16. Sum of mean variance in biweekly distribution of bat activity as a function of bootstrapped number of samples (red line indicates 15 samples) drawn from nacelle-height detectors at MidAmerican wind energy facilities in Iowa from 2021–2023.

2.4 DISCUSSION

This study provided further empirical evidence that bat activity in the rotor-swept zone of wind turbines follows consistent seasonal patterns and relationships with wind speed and temperature that have been observed in fatality data since the earliest reports of turbine-related fatalities at commercial wind energy facilities (Kunz et al. 2007a). Nightly timing of bats in the rotor-swept zone also confirms what has long been observed from behavioral studies of bats in more typical habitat (Kunz, 2002), suggesting that timing of bat presence in the rotor-swept zone of turbines is similar to those that have been documented elsewhere in the aerosphere. Variation in these distributions was relatively small among detectors, facilities, and years, suggesting that the same patterns likely occur throughout Iowa.

Day of year and time of night were the most important factors in predicting bat presence in the rotor-swept zone, followed by wind speed and temperature, with turbine and year ranked least important at most facilities. This underscores the likelihood that the seasonal distribution of bats on the landscape, linked to migratory patterns and the phenology of bat life history, drives large-scale patterns in turbine-related fatality risk. Consistent hourly distribution of bat presence in the rotor-swept zone, peaking ~1 hour past sunset, is also likely linked to bats nocturnal activity and typical behavior patterns. Wind speed and temperature vary substantially within and between nights but follow consistent seasonal trends, reflecting seasonal and nightly patterns and effects of variable weather. The distribution of bat activity in the rotor-swept zone as a function of wind speed and temperature therefore reflects nightly and broad seasonal patterns. Turbine and year were the least important variables in predicting bat presence in the rotor-swept zone, suggesting that the combined effects of season (day of year), time of night, temperature, and wind speed explain most variation in our dataset but that similar processes occur across sites and years.

Seasonal bat activity patterns observed across the 13 MidAmerican facilities we monitored in 2021–2023 closely align with the seasonal distribution of bat fatalities documented at other MidAmerican facilities in Iowa in 2015 (9 facilities) and 2016 (13 facilities; MidAmerican 2019). A recent compilation of data from a national database of carcass studies found a similar pattern in seasonal timing of bat fatalities throughout the central plains region of the United States (Lloyd et al. 2023). The similarity of these seasonal distributions of fatalities, documented over a time period spanning many years, suggests that the patterns we documented are stable from year to year.

Bat detectors cannot sample the entire rotor-swept zone of wind turbines due to the relatively rapid atmospheric attenuation of ultrasound. Higher frequency bat species can be detected over a shorter distance than low frequency species and atmospheric attenuation increases with humidity (Griffin 1971). The combined effects of air turbulence, wind speed, temperature, air density, and bats' ability to vary the intensity of their echolocation pulses, possibly in response to changing conditions, cannot realistically be measured in situ within the rotor-swept zone of turbines. Similarly, the potential effect that turbine rotor movement may have on bats' tendency to be present in the rotor-swept zone and/or echolocation behavior is not presently known, although initial data exploration suggests that turbine operational state does not appear to affect bat acoustic activity (Stantec, unpublished data). Nevertheless, the similarity in the seasonal and temporal distribution of bat activity and relationships with wind speed and temperature we observed across multiple sites, years, and turbine manufacturers/models suggests that these potential sources of variation in detection probability do not undermine the ability to accurately characterize patterns in bat presence in the rotor-swept zone. Furthermore, the similarity in patterns between nacelle-height and ground-based detectors suggests that spatial variation in seasonal or temporal distribution of bats is minimal; activity levels were much higher closer to the ground, suggesting that risk of turbine-related impacts are greater in the lower portion of the rotor-swept zone, but the seasonal and temporal distribution of risk was indistinguishable between nacelle-height and ground-based detectors.

In the context of designing curtailment strategies to reduce fatality risk to bats, our results suggest that the broad seasonal and temporal patterns in acoustic bat activity in the rotor-swept zone provide a reliable basis for adjusting the cut-in wind speed threshold, the primary parameter dictating the amount of time turbines are curtailed. Bat activity varied substantially on a nightly and weekly basis, but variation became smoother on a biweekly and monthly basis, suggesting that cut-in speed should be adjusted on biweekly or longer intervals to reduce risk of overfitting curtailment strategies to existing data. The pronounced and consistent seasonal patterns in bat activity suggest that blanket curtailment strategies, which apply the same cut-in speed threshold over multiple months, fail to take into account clear seasonal patterns in risk that have been noted since the earliest published reports of turbine-related bat fatalities. Similarly, applying curtailment before sunset and after sunrise provides limited if any benefit to bats and does not take into account bats' nocturnal behavior. In essence, blanket curtailment strategies underestimate the predictability of broad patterns in bat activity and are therefore too restrictive during times of year and time periods where bats tend to be less active and not restrictive enough during the time periods when bats are at greatest risk of impact.

Despite the well-known variability in bat activity levels among nights and detectors, which was occasionally evident in plots of hourly and weekly patterns in bat activity recorded at individual detectors (see Appendices E and F), consistent seasonal and temporal patterns were evident in the data obtained by individual acoustic detectors. Pooling data among detectors and summarizing results across biweekly or even weekly intervals revealed consistent patterns that occurred repeatedly throughout our study, regardless of operational treatment, detector placement, or location across Iowa. Random forest models indicated that day of year, a proxy for season in our analysis, ranked as the most important variable in predicting bat presence, with time of night, wind speed, and temperature typically ranking higher than turbine and year. The cases in which turbine ranked higher were likely attributable uneven date coverage resulting in stronger inter-turbine variation at the tails of the monitoring period (e.g., Prairie Turbine 039). Combining the results of bootstrapping analysis, random forest models, and qualitative review of plots in Appendices E and F, a relatively small number of acoustic detectors are needed to characterize the most prominent patterns in bat activity, which were consistent across turbines, sites, and years. These results are limited to Iowa, though similar patterns have been documented elsewhere across the eastern U.S. (Stantec, unpublished data).

Our results indicated that a relatively small amount of acoustic data was sufficient to accurately characterize the distribution of bat activity on a seasonal and temporal basis and as a function of temperature and wind speed. Bootstrapping analysis suggested that 15 detectors provided adequate replication to reveal consistent patterns despite inter-turbine variation, although sampling effort (number of detectors, detector positions, years) would be dependent on the goals of a particular monitoring program and size and characteristics of a facility. Our results suggest that complete seasonal and temporal coverage (monitoring across the full range of dates and times of night in which bats may be active) is likely more important than spatial replication in characterizing patterns in risk of turbine-related impacts to bats. In cases where inter-turbine variation in risk was expected, due to differences in topography, habitat, turbine characteristics, or some other factor, increased spatial replication in acoustic monitoring across turbines would be necessary to characterize such patterns.

As acoustic detector technology and options for long-term deployment on turbine nacelles improve, features such as remote data download and the ability to monitor system status and performance remotely will reduce the amount of replication needed to guard against data loss. For a given level of overall survey effort, a smaller number of detectors (e.g., 5–10) installed permanently and monitored over 3 years would likely require fewer turbine climbs than an increased number of detectors (e.g., 15–30) deployed during a single season and may provide more useful information for managing risk. Ultimately, determining an appropriate level of acoustic sampling effort depends on how resulting data are to be applied and what assumptions are being tested.

3.0 QUANTIFY RELATIONSHIP BETWEEN EXPOSED BAT ACTIVITY AND FATALITY (OBJECTIVE 2)

3.1 INTRODUCTION

Turbine-related bat fatalities at commercial wind energy facilities constitute a potentially significant ecological impact associated with an industry that is simultaneously an important part of the strategy to decarbonize utility-scale energy production. Preventing turbine operation during times of night when turbines would otherwise be rotating, a practice known broadly as curtailment, is the most reliable method to reduce bat fatality rates. Implementing turbine curtailment reduces energy production, however, and the amount of energy loss depends largely on the amount of time and wind speeds when turbines are curtailed. Though an effective method to reduce bat fatalities, curtailment therefore represents a tradeoff whose efficiency could be measured in terms of impact reduction as a function of energy loss.

Cumulative bat fatality estimates are high enough to threaten the future viability of some bat species (Frick et al. 2017; Friedenberg and Frick 2021), and yet fatalities themselves are difficult to document; carcasses are very small (20 grams or less in most cases), inconspicuously colored, and distributed across a large search area. Even at times of year when fatality rates are highest, standardized turbine searches often do not result in discovery of bat carcasses. Many bat carcasses are removed by scavengers during the period between turbine searches and human searchers do not find all carcasses. Lastly, searches often cannot occur throughout the area in which carcasses might fall, nor can all turbines or the full area in which carcass may fall typically be searched. Nevertheless, standardized carcass monitoring has been the primary method used to estimate turbine-related bat fatality rates and to evaluate the effectiveness of curtailment (Adams et al. 2021; Whitby et al. 2021, 2024).

Generating empirical estimates of turbine-related bat fatalities, even when surveys are intensive and follow standardize methods, requires correction factors to account for the combined effects of imperfect carcass detection, carcass removal by scavengers, size of searchable area relative to the turbine, among other factors (Bernardino et al. 2013; Dalthorp et al 2018). When implemented, curtailment reduces the number of bat carcasses available to be detected, further contributing to challenges of small sample size. The combined effect of such corrections typically results in wide confidence intervals around point estimates of bat fatality (Canadian Wind Energy Association 2018). Curtailment studies based on carcass counts at individual wind energy facilities often lack the sample size and statistical power to detect differences among operational treatments in the context of curtailment studies (Arnett et al. 2011). Demonstrating the effectiveness of curtailment often requires data aggregation, and meta-analyses have shown consistently that curtailment reduces bat fatalities and that higher cut-in speeds yield greater reductions in bat fatality rates (Adams et al. 2021; Whitby et al. 2024).

The underlying principle of curtailment is that reducing exposure of bats to turbine operation also reduces fatality rates. While turbine curtailment at low wind speeds (e.g., 4.5–6.5 m/s) has been shown to be effective at reducing bat fatality rates (Adams et al. 2021; Whitby et al. 2024), minimal quantitative information exists to identify a suitable minimum cut-in speed threshold for curtailment. In the context of managing risk of turbine-related impacts to rare bat species, finding zero carcasses when searches were conducted with suitable intensity can satisfy permit requirements that estimated take levels have not been exceeded (Dalthorp et al. 2017). Though useful for indicating that fatality rates were within acceptable bounds, this approach provides no quantitative feedback to evaluate effectiveness of curtailment as a minimization measure or to compare strategies. Should take limits be exceeded or should a rare species fatality be documented, carcass data provide little or no useful information to guide subsequent management actions such as modifying curtailment parameters or lengthening the time and cost required to adaptively manage risk. More importantly, fatality monitoring cannot precisely determine the timing of fatalities, rendering such datasets unhelpful in understanding which variables affect risk of fatality with any temporal precision.

Turbine-related bat fatalities result from exposure of bats to rotating turbine rotors, and acoustic bat detectors mounted on turbine nacelles can measure such exposure directly as the number of bat passes detected when turbine rotors were spinning. Wind speed, temperature, and turbine rotor speed (revolutions per minute; rpm) data recorded at corresponding turbines can be aligned with bat passes at 10-minute intervals to determine the proportion and rate of bat passes exposed to turbine operation with temporal precision. Acoustic bat exposure, the subset of bat passes occurring when turbine rotor speed exceeds 1 rpm (Peterson et al. 2021), can then be compared across turbines and curtailment strategies as a sensitive metric of how effectively curtailment strategies prevent turbine operation during periods and conditions when bats are active. Unlike carcass data, acoustic exposure can directly measure the amount of bat activity avoided by curtailment, providing an ideal metric to compare how effectively curtailment strategies reduce exposure of bats to turbine operation or simulate how adjusting parameters such as cut-in speed would affect curtailment effectiveness. Not all bats present in the rotor swept zone collide with turbines, nor does every bat pass recorded when turbine blades are spinning indicate a fatality, but the accumulation of exposure of bats to fast-moving turbine blades over time increases the potential for turbine-related impacts.

Previous studies have confirmed a positive relationship between the rate and proportion of exposed bat activity and bat fatality rates at wind energy facilities. The rate of exposed bat passes explained significant variation in treatment-level bat fatality estimates at two wind energy facilities in West Virginia, whereas relationships between overall bat activity (including passes detected when turbines were curtailed) were less clear, highlighting the importance of distinguishing between bat activity occurring when turbines are on or off (Peterson et al. 2021; Appendix A). Subsequently, a study at a pair of facilities in Missouri demonstrated a strong positive relationship between the biweekly rate of exposed bat passes and carcass found per search (Peterson et al. in prep). Each of these previous studies included two facilities, and analyses focused on within-site relationships. This study expanded the scope of comparison to include 13 sites, enabling inter-site comparison in acoustic exposure and fatality estimates.

Carcass searches used to generate fatality estimates in this study were designed to estimate the cumulative take of rare bat species in aggregate across a fleet of facilities. This level of effort was designed to verify that rare bat take limits were not exceeded during the survey period across all projects, but the resulting fatality estimates at individual sites and treatments were bounded by wide confidence intervals and lacked the resolution to detect differences among sites or curtailment treatments at the site-specific level. Fatality estimates varied widely and inconsistently among curtailment sites, treatments, and years, with considerable overlap in confidence intervals. By contrast, acoustic data provided clear and consistent evidence that curtailment reduced acoustic bat exposure by ~50% relative to normally operating turbines across sites and years. We also found that comparing simulated exposure against measured exposure indicated whether individual turbines were operated according to their assigned treatments; such cases were corroborated by plotting median rotor speed as a function of wind speed, enabling turbines to be recategorized according to treatments as implemented.

Biweekly variation in acoustic bat exposure explained a significant amount of variation in biweekly carcass counts (corrected for survey effort), aligning with results of previous studies, however facility-level fatality estimates showed no discernible relationship with facility-level acoustic exposure. The absence of such a relationship at the facility level or treatment level likely stems from increased variation and uncertainty in fatality estimates due to the need to extrapolate facility-wide estimates from the small number of carcasses found on roads and pads. In this case, intensity of carcass searches was insufficient to document reductions in fatality due to curtailment, whereas acoustic data provided clear feedback on how effectively curtailment was applied and how well the strategies reduced exposure. Our results contribute to a growing body of research that demonstrates the utility of acoustic exposure to measure how effectively curtailment reduces risk to bats.

Lacking specific information on the algorithms used to control turbine operation, the resolution of data feeding such algorithms, or the sources of these data among facilities or turbine manufacturers/models, it is possible that SCADA data at 10-minute intervals do not enable accurate simulation of turbine operations. Once turbines have been assigned to their proper curtailments, however, comparing simulated versus measured exposure reflects the degree to which available data on turbine operation reflect actual turbine performance. We found strong alignment between measured exposure and simulated exposure (as implemented), enabling us to also simulate the effectiveness of the activity-based curtailment strategy across all turbines and sites included in the study, enabling an additional level of comparison among facilities and turbines.

3.2 METHODS

3.2.1 Turbine Operation and Curtailment

3.2.1.1 Curtailment Settings and Implementation

Turbines at the 13 facilities generate energy when wind speeds exceed the manufacturer cut-in speed ranging from of 3.0–3.5 m/s. Curtailment decisions were implemented into MidAmerican's centralized database based on rolling 10-minute wind speed measurements recorded at individual turbines. The range in manufacturer cut-in wind speed was due to different makes and models of turbines, as outlined in Table 1-1. Unless turbine blades are pitched parallel to the wind (a practice referred to as "feathering"), turbine rotors typically spin when the wind speed exceeds 1.5–2.0 m/s but do not generate energy until the wind speed reaches the manufacturer's standard cut-in speed. We understand that MidAmerican intended to use feathering on all turbine blades below the manufacturer cut-in speed at night from 15 April–15 November. Individual turbines in the study were assigned to one of three treatment groups, including operational control, blanket, or smart. Treatments were assigned for the duration of a sampling year and were not rotated among turbines. See Table 3-1 for curtailment parameters including treatment-based cut-in speeds as well as time of year, time of night, and temperature. The number of turbines per facility assigned to each treatment is indicated in Table 3-2 and Table 3-3. See Appendix D for a breakdown of treatment assignments by facility, year, and turbine. Operational control treatment turbines were feathered below manufacturer cut-in speed (3.0–3.5 m/s). At Orient and Arbor Hill, subsets of 5–8 turbines that would otherwise have been curtailed were assigned as operational controls; turbines outside the range of the Indiana bat (*Myotis sodalis*) were considered operational controls. Beaver Creek spanned one county inside and one county outside the Indiana bat range, providing an additional opportunity to compare acoustic exposure and fatality between control and curtailment treatments. Turbines at which curtailment was not implemented as assigned (see Section 3.2.2) also served as operational controls.

Blanket curtailment treatment turbines were feathered below 5.0 m/s between the dates of July 15–September 30. The activity-based smart curtailment strategy, applied during the same period as blanket curtailment (15 July–30 September), involved reducing the temporal window of curtailment to 30 minutes after sunset until 60 minutes before sunrise, raising the cut-in speed to 5.5 m/s in August, and reducing the cut-in speed to 4.5 m/s in September. The smart treatment curtailment parameters were designed to be equivalently protective of bats as the blanket treatment while reducing the amount of energy production lost (see Section 4.2.1). Seasonal timing and cut-in speeds for the smart curtailment treatment group were based on analysis of data collected in 2021 at Orient and Arbor Hill. Facilities located in a county with documented Indiana bat presence were assigned a blend of smart and blanket curtailment treatments. With the exception of Orient and Arbor Hill (Table 1-1) where all three treatment groups were assigned including operational control.

Table 3-1. Seasonal timing and cut-in speeds for acoustic activity-based smart curtailment study treatment groups used at 13 MidAmerican wind energy facilities in Iowa from 2021–2023.

Treatments	Date Range				
	Jul 1–14	Jul 15–31	Aug 1–30	Sep 1–30	Oct 1–15
Operational Control	< 3.0–3.5 m/s*				
Blanket	< 3.0–3.5 m/s*	5.0 m/s cut-in speed applied from sunset to sunrise at temperatures above 10°C			< 3.0–3.5 m/s*
Smart	< 3.0–3.5 m/s*	5.0 m/s cut-in above 10°C 30 mins after sunset–60 mins before sunrise	5.5 m/s cut-in above 10°C 30 mins after sunset–60 mins before sunrise	4.5 m/s cut-in above 10°C 30 mins after sunset–60 mins before sunrise	< 3.0–3.5 m/s*

* cut-in speed corresponds with the manufacturer cut-in, range is due to different makes and models of turbines, refer to Table 1-1 for specific information about turbine model by site

3.2.2 Curtailment Evaluation

Before measuring the effectiveness of curtailment strategies in reducing risk to bats, it is important to first verify that turbines operated according to the parameters of their assigned operational treatment group. We used acoustic exposure to initially identify instances where turbines did not appear to be operating according to their assigned treatment. Next, we evaluated these instances by plotting turbine rotor speed as a function of wind speed.

3.2.2.1 Acoustic Exposure

Acoustic exposure is the subset of bat passes detected when turbine rotor speed exceeded or would have been higher than 1 rpm. We used 1 rpm as the threshold rotor speed above which potential impacts to bats may occur based on Peterson et al. (2021) although we note that future studies could explore whether it would be more appropriate to determine a threshold blade tip speed to account for variation in turbine rotor size. Acoustic exposure can be calculated in two ways, measured or simulated exposure. Measured exposure represents the real-world operation of turbines compared to simulated exposure that simulates turbine operation based on parameters such as treatment group, temperature, and wind speed. We defined measured exposure as bat passes detected when actual turbine rotor speed exceeded 1 rpm. Simulated exposure refers to bat passes detected when the turbine would have been operational based on the parameters of its assigned treatment. Measured and simulated exposure are both expressed as a percentage of bat calls exposed to moving turbine blades. The percent of bat activity exposed to turbine operation (and associated risk of turbine-related impacts) in the rotor-swept zone can be measured or simulated as an indication of whether turbines operated as expected based on the operational treatment to which they were assigned. Comparing these metrics indicates whether curtailment strategies were implemented as assigned because the assigned curtailment parameters are the same for turbine operation whether simulated or with real world implementation. Turbine operation should be roughly equivalent due to the same curtailment parameters. Cases when measured exposure is higher than simulated exposure indicate that turbines operated more than expected according to the parameters of the assigned operational strategy. Whereas measured exposure being lower than simulated exposure indicates that turbines were non-operational for more time than expected, either due to unplanned outages, maintenance, or other factors (Figure 3-1).

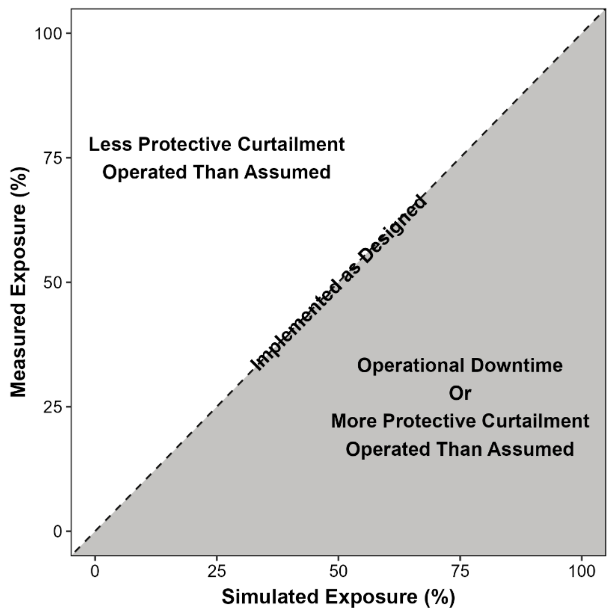

Figure 3-1. The relationship between measured exposure and simulated exposure indicates whether turbines operated as expected (points on or near the dashed 1:1 line), more than expected (points in unshaded area) or less than expected (points in shaded area).

We used the cleaned dataset of turbine rotor speed (rpm), wind speed (m/s), temperature (°C), and energy output (kW) provided by MidAmerican described above in Section 2.2.1.2 to categorize every 10-minute period meeting or not meeting parameters of the assigned curtailment strategy. We calculated measured acoustic exposure as the percent of bat passes detected during 10-minute intervals in which turbine rotor speed exceeded 1 rpm and calculated simulated exposure as the percent of bat passes detected during intervals not meeting the parameters of the assigned curtailment treatment (i.e., when the turbine should have been spinning). Data for this analysis was limited to bat passes for which weather and turbine rotor speed data were available and occurred within the curtailment season of 15 July–30 September.

3.2.2.2 Rotor Speed

We then reviewed plots of median turbine rotor speed as a function of wind speed (binned at 0.5 m/s increments) by day and night on a monthly basis for each turbine, categorizing each turbine according to the curtailment treatment as implemented (Figure 3-2). We reviewed cases where the turbine operation differed from the assigned treatment, then confirmed with MidAmerican that we had categorized turbines properly according to curtailment treatments as assigned and implemented.

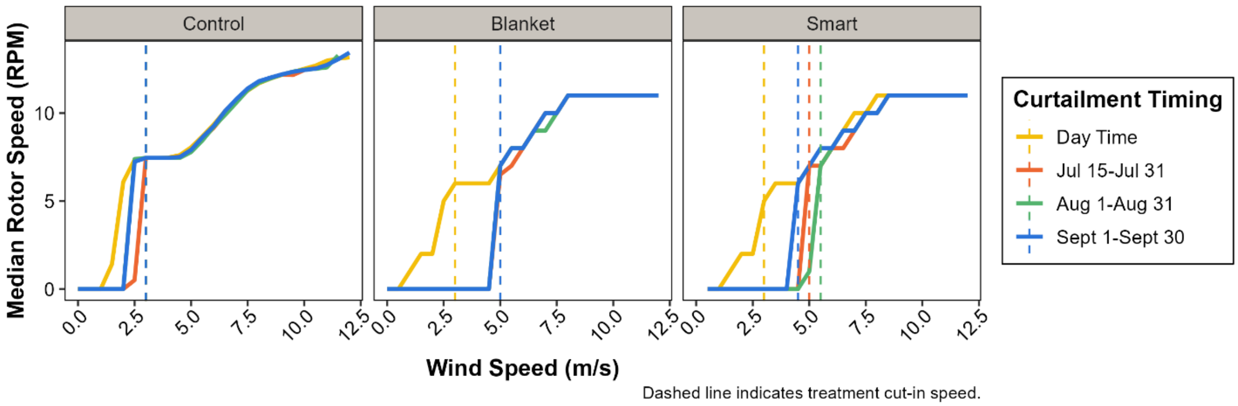

Figure 3-2. Comparison of median turbine rotor speed during the daytime (30 minutes after sunrise to 30 minutes before sunset) versus at night within date ranges over which curtailment was applied, indicating whether turbines at the 13 MidAmerican wind energy facilities were operated according to their assigned operational treatment from 2021 to 2023.

Once turbines were properly categorized to the curtailment treatments as implemented, we evaluated the success of operational treatments based on acoustic exposure, carcass counts, and bat fatality estimates as outlined below.

3.2.3 Curtailment Effectiveness

Curtailment effectiveness refers to how well curtailment strategies reduced risk to bats; this study provided an opportunity to assess curtailment effectiveness using acoustic exposure and carcass data.

3.2.3.1 Acoustic Bat Exposure

We determined the measured and simulated acoustic bat exposure for each distinct operational treatment across the 13 MidAmerican facilities during each field season as a percent to measure how effectively curtailment reduced risk of turbine-related impacts to bats relative to the operational control treatment. In cases where subsets of turbines were operated without curtailment as a control (Orient and Arbor Hill in 2021 and 2022), we were able to calculate reductions in measured exposure for curtailment treatments; in all other cases, we simulated exposure for the operational control to evaluate how effectively curtailment treatments reduced exposure.

To determine the magnitude of risk to bats among curtailment treatments and facilities, we also calculated acoustic bat exposure as the cumulative biweekly (14-day intervals) rate of exposed bat passes by dividing the total number of bat passes per detector night at biweekly intervals, pooling detectors by operational strategy, and summing this rate across the monitoring period. Pooling data in this manner accounted for variation in the number of properly operating detectors. Percent and rate of exposure mean slightly different things in the context of evaluating curtailment; equal reductions in percent of exposure indicate equivalent effectiveness of curtailment but may or may not indicate equivalent risk to bats unless the underlying rate of exposure is also known.

We assessed the site-specific magnitude of risk to bats and, where appropriate, the success of curtailment treatments in reducing risk, by plotting cumulative biweekly acoustic bat exposure and total percent bat exposure per curtailment strategy, pooling data among turbines according to treatment as implemented and calculating 95% confidence intervals on a per-site basis. We also calculated each measure strategy using data pooled by site and year and applied t-tests with 95% confidence intervals to determine differences in exposure per treatment. The cumulative rate of acoustic bat exposure was used to represent risk of turbine-related impacts and was calculated across the range of dates over which carcass searches occurred (1 July–15 October). We then compared the cumulative rate of acoustic bat exposure to treatment-level fatality estimates based on carcass monitoring. We also calculated the biweekly measured rate of acoustic exposure per treatment (as implemented) and site for comparison to the number of bat carcasses found per turbine search within the same biweekly intervals.

3.2.3.2 Bat Carcass Counts and Fatality Estimates

Standardized carcass counts occurred at each of the 13 study sites from 1 July to 15 October as part of an ongoing monitoring program conducted by MidAmerican. Western EcoSystems Technology, Inc. (WEST) conducted all carcass monitoring fieldwork and associated validation trials to correct for imperfect carcass detection, scavenger removal, and variable search area. Field methods followed a study plan developed in coordination with MidAmerican and the US Fish and Wildlife Service (Baumgartner et al. 2020a, 2020b). Level of survey effort varied among sites, as outlined in the Study Plan (see Appendix B). At Orient and Arbor Hill, in 2021–2023, searches occurred along linear transects spaced at 5 m intervals in square plots, 100m x 100m centered on the turbine in which vegetation was maintained at a short height to promote carcass detection. Full plots also were searched at a subset of turbines at Plymouth and Pocahontas Prairie in 2023. Road and pad searches occurred weekly at all turbines across the remaining facilities and at all turbines without full plot searches at Orient, Arbor Hill, Plymouth, and Pocahontas Prairie. Field methods for carcass searches followed standard protocols, as outlined in Appendix B.

WEST generated bat fatality estimates (per turbine and per megawatt) with 90% confidence intervals for each distinct operational treatment (as implemented; see Appendix B) per facility and monitoring period using GenEst (Dalthorp et al. 2018). Separate estimates were generated for road and pad versus full plot searches, taking into account survey effort, results of site-specific bias trials, extent of searchable area, and spatial distribution of carcasses. Treatment assignments were based on treatments as implemented, based on analysis of acoustic exposure and turbine rotor speed described in Section 3.2.2.

For each facility, Stantec also calculated the biweekly rate of bat carcasses found per search, pooling data among turbines after first dividing by turbine-specific density-weighted proportion, carcass persistence, and searcher efficiency metrics provided by WEST. The resulting biweekly fatality index therefore accounted for variation in search effort, search area, searcher efficiency, carcass persistence, and spatial carcass distribution and represented a combination of operational treatments at facilities where multiple curtailment strategies were implemented. Correction factors were available per facility and year, so variation in these factors among biweekly intervals could not be incorporated into the fatality index. Additionally, we summarized species composition of bat carcasses found at each facility and plotted the weekly distribution of bat carcasses, by species, detected during fatality searches. Biweekly fatality analyses and species composition summaries were limited to turbines equipped with acoustic detectors.

3.3 RESULTS

3.3.1 Curtailment Evaluation

Turbine curtailment was implemented properly for all turbines equipped with acoustic detectors at 8 of 13 sites, as evidenced by close alignment between measured and simulated exposure. At Diamond Trail, North English, Prairie, and Southern Hills, measured and simulated exposure were closely aligned; turbines with low simulated exposure had correspondingly low measured exposure while the same was true for turbines where simulated exposure was higher (Figure 3-3). Similarly, turbines at four operational control sites (Ida Grove, Ivester, Palo Alto, and Plymouth) had correspondingly high measured and simulated exposure, indicating that turbines operated as expected. Measured exposure was higher than expected for some turbines at Arbor Hill, Beaver Creek, and Orient, and for all turbines at Contrail, and lower than expected for certain turbines at Pocahontas Prairie (Figure 3-3). Subsequent review of median turbine rotor speed versus wind speed during the curtailment period confirmed that these turbines were not curtailed as expected during the 15 July–30 September curtailment period (see Appendix J for plots of turbine rotor speed by wind speed for each turbine by site and year). We reassigned turbines to the proper operational treatment based on actual turbine performance and then replotted measured exposure versus simulated exposure as implemented (Table 3-2, Table 3-3). Once turbines were recategorized based on their actual operational strategy, the alignment between measured versus simulated exposure improved considerably (Figure 3-4). Cases in which measured exposure was substantially lower than simulated exposure, as could be seen for some turbines at Ida Grove, Arbor Hill, Orient, and Ivester, appear to have been related to unplanned outages or down-time for reasons other than bat curtailment.

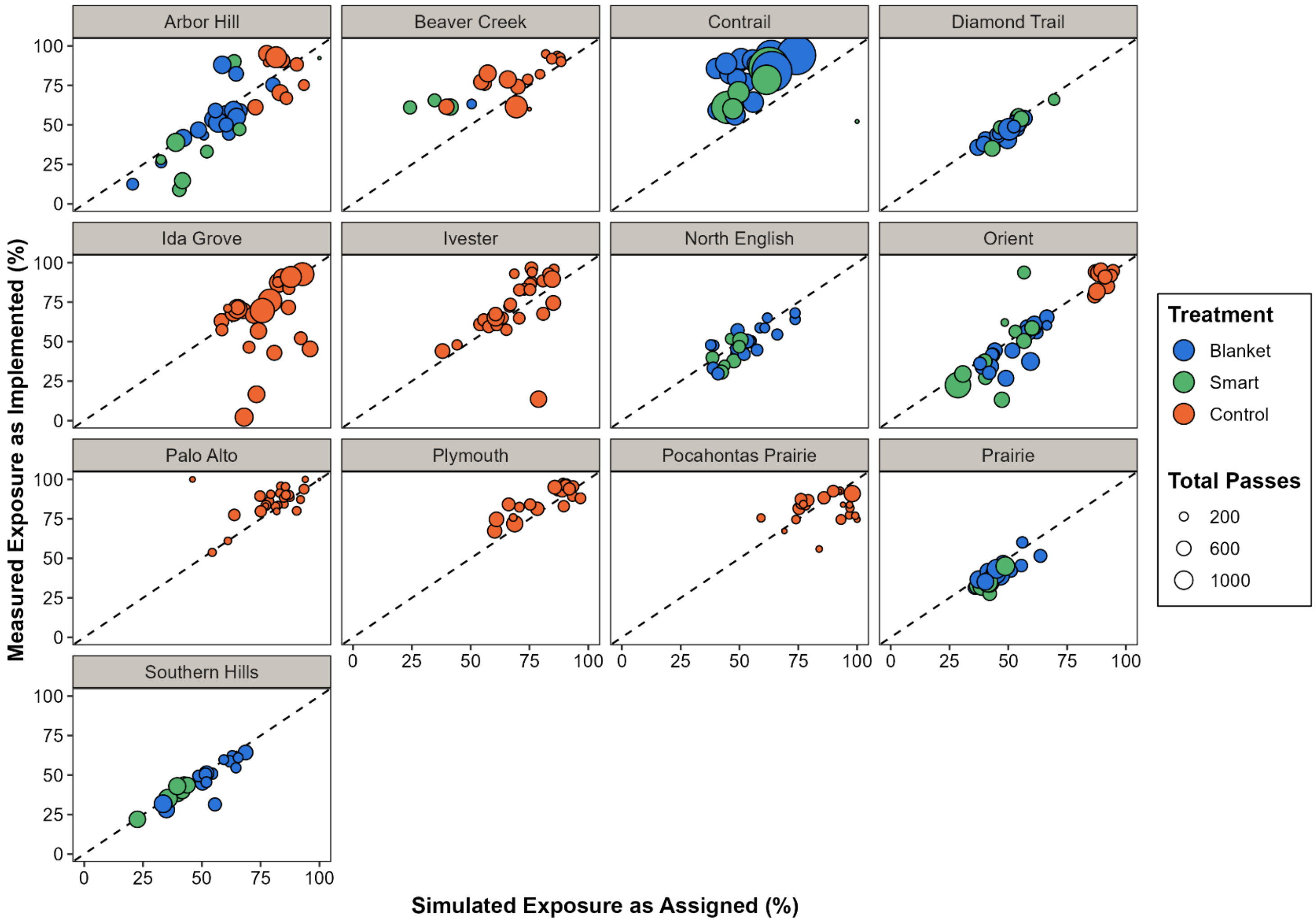

Figure 3-3. Measured acoustic exposure as a function of simulated acoustic exposure (based on treatments as assigned) at 13 MidAmerican wind energy facilities in Iowa from 2021–2023. Dashed reference lines indicate one-to-one relationships between simulated and measured exposure.

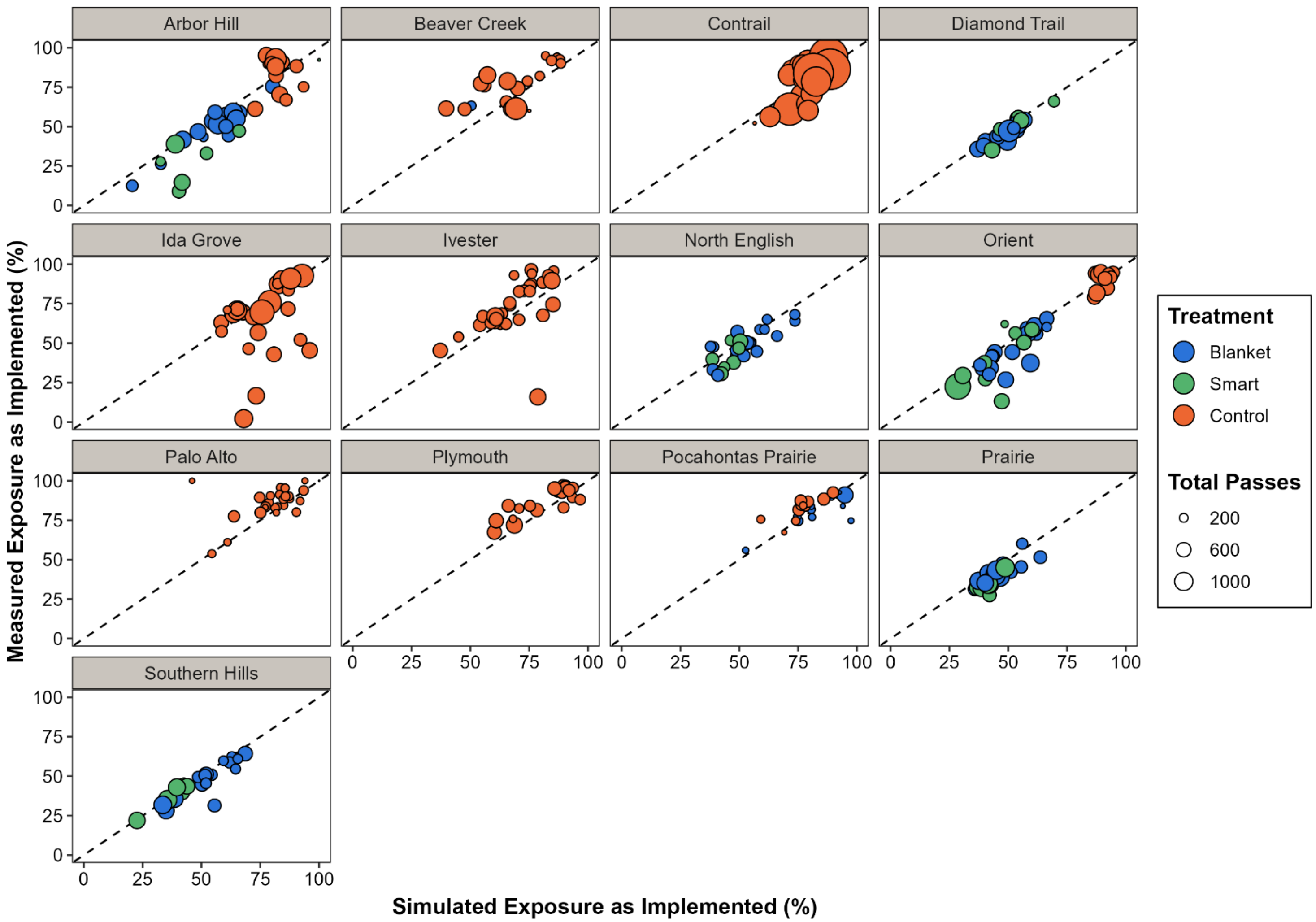

Figure 3-4. Measured acoustic exposure as a function of simulated acoustic exposure (based on treatments as implemented) at 13 MidAmerican wind energy facilities in Iowa from 2021–2023. Dashed reference lines indicate one-to-one relationships between simulated and measured exposure.

Table 3-2. Operational treatments as assigned and implemented at the Orient and Arbor Hill energy facilities in Iowa, 2021–2023.

Facility	Year	Treatment (n turbines)	
		Assigned	Implemented
Arbor Hill	2021	Control (7) Blanket (8)	Control (7) Blanket (8)
	2022	Control (5) Blanket (5) Smart (5)	Control (11) Blanket (2) Smart (2)
	2023	Blanket (7) Smart (8)	Blanket (7) Smart (8)
Orient	2021	Control (7) Blanket (8)	Control (7) Blanket (8)
	2022	Control (5) Blanket (5) Smart (5)	Control (6) Blanket (5) Smart (4)
	2023	Blanket (8) Smart (7)	Blanket (8) Smart (7)

Table 3-3. Operational treatments as assigned and implemented at the 11 expansion energy facilities at MidAmerican in Iowa, 2022–2023.

Facility	Year	Treatment (n turbines)	
		Assigned	Implemented
Beaver Creek	2022	Control (10) Blanket (5)	Control (10) Blanket (5)
	2023	Control (10) Blanket (2) Smart (3)	Control (13) Blanket (2)
Contrail	2022	Blanket (15)	Control (15)
	2023	Blanket (7) Smart (8)	Control (15)
Diamond Trail	2022	Blanket (15)	Blanket (15)
	2023	Blanket (7) Smart (8)	Blanket (7) Smart (8)
Ida Grove	2022	Control (15)	Control (15)
	2023	Control (15)	Control (15)
Ivester	2022	Control (15)	Control (15)
	2023	Control (15)	Control (15)
North English	2022	Blanket (15) Blanket (7) Smart (8)	Blanket (15) Blanket (7) Smart (8)
Palo Alto	2022	Control (15)	Control (15)
	2023	Control (15)	Control (15)
Plymouth	2022	Control (15)	Control (15)
	2023	Control (15)	Control (15)
Pocahontas Prairie	2022	Control (15)	Blanket (15)
	2023	Control (15)	Control (15)
Prairie	2022	Blanket (15) Blanket (8) Smart (7)	Blanket (15) Blanket (8) Smart (7)
Southern Hills	2023	Blanket (15) Blanket (8) Smart (7)	Blanket (15) Blanket (8) Smart (7)

3.3.2 Curtailment Effectiveness

3.3.2.1 Acoustic Exposure

Once categorized according to how curtailment treatments were implemented, measured and simulated, acoustic bat exposure were closely aligned. Acoustic bat exposure was clearly higher for the control treatment than for blanket curtailment or the smart curtailment alternative, with overlapping levels of acoustic exposure between the two curtailment treatments (Figure 3-5). Cumulative biweekly exposure rate (the rate of exposed bat passes per night in biweekly intervals, pooled across turbines in each operational treatment and summed cumulatively across the curtailment period) varied among sites and years but was consistently higher at operational control treatments than either of the curtailment strategies, demonstrating the effective reduction in acoustic exposure resulting from the curtailment treatments (Figure 3-6). Measured cumulative biweekly exposure was equivalent or lower at the smart curtailment strategy versus blanket treatment at all sites except Orient in 2023. Cumulative biweekly exposure followed similar seasonal patterns among turbines; despite inter-year and inter-turbine variation in the rate of exposure, reductions due to curtailment treatment could often be discerned in the acoustic data from individual turbines (see Appendix E).

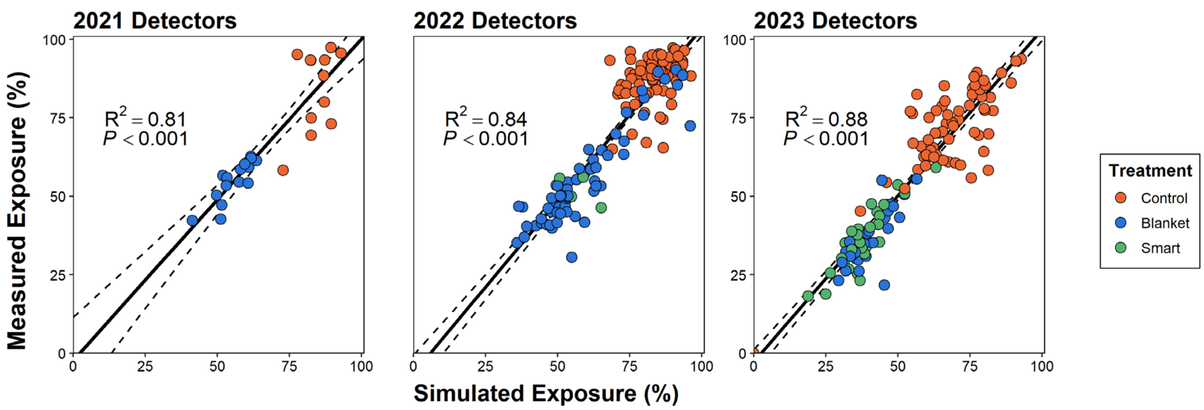

Figure 3-5. Measured acoustic exposure as a function of simulated acoustic exposure (as implemented) by operational treatment at 13 MidAmerican wind energy facilities in Iowa from 2021–2023. Solid lines indicate the fitted linear regression and dashed lines are the 95% confidence intervals of the regression.

At Orient and Arbor Hill, where operational treatments were implemented simultaneously, measured acoustic exposure was lower for both curtailment treatments compared to control operation, whether expressed as the cumulative biweekly rate of exposed passes per detector-night (Figure 3-7) or percent of passes exposed to turbine operation (Figure 3-8). Acoustic data loss at turbines assigned to blanket and smart curtailment treatments at Beaver Creek prevented determination of measured acoustic exposure for curtailment treatments at that facility. Variations in acoustic exposure between operational treatments were also evident across facilities, particularly when expressed as a percent. Averaging data by treatment across facilities, years, and turbines, the proportion of bat passes exposed to turbine operation was 80.4% at control turbines, 49.9% for turbines under blanket curtailment and 37.0% for turbines operated under the smart curtailment strategy (Figure 3-9). The cumulative biweekly rate of exposed bat passes was 52.8% lower at the blanket treatment and 56.7% lower at smart treatment than control operation when data were averaged across facilities and years (Figure 3-9). The amount of curtailment and energy losses associated with curtailment treatments is discussed in Section 4.0 of this report.

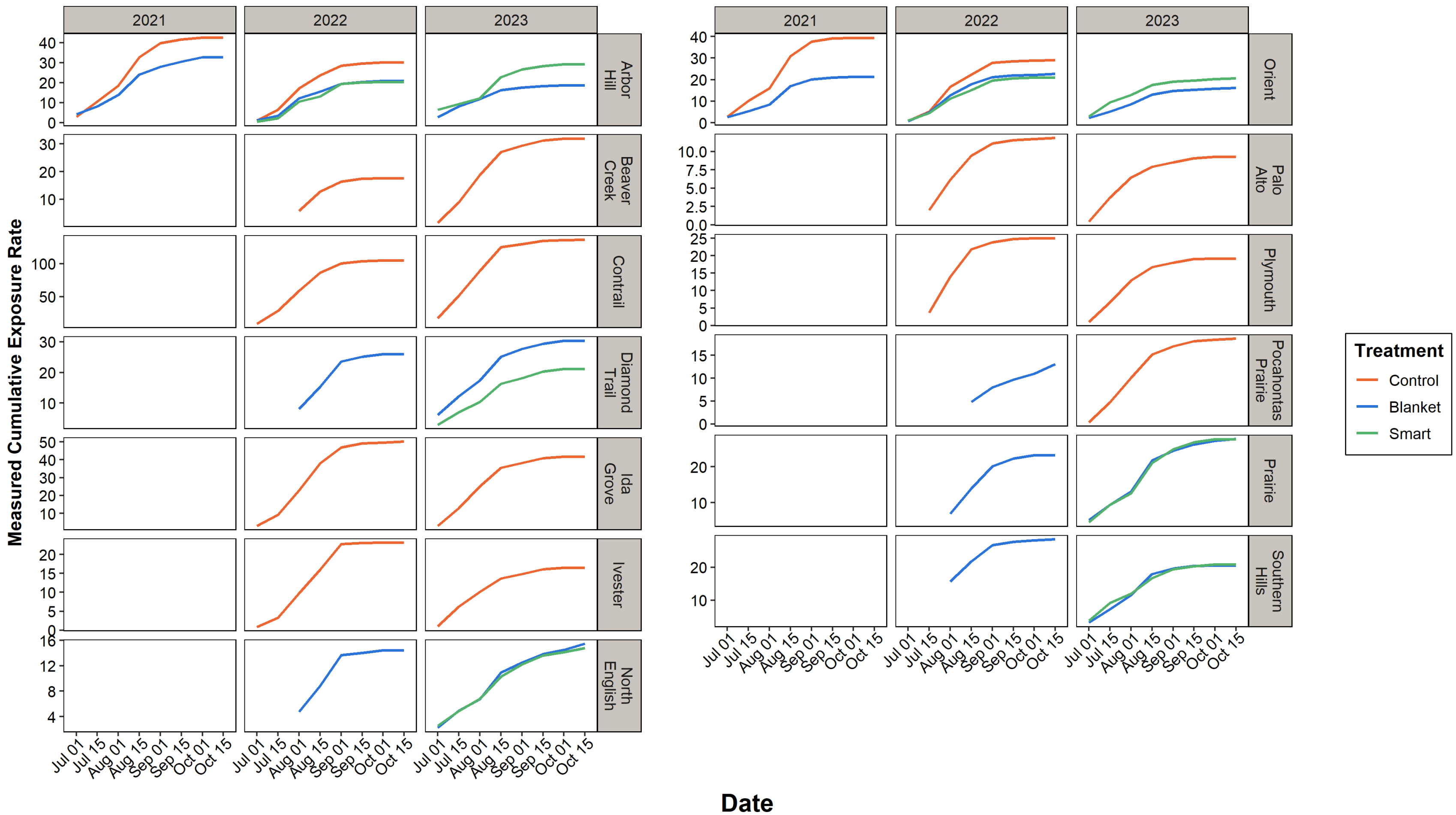

Figure 3-6. Cumulative biweekly acoustic exposure measured per operational treatment. Note varying y-axis limits among sites. Data were collected at 13 MidAmerican wind energy facilities in Iowa from 2021–2023.

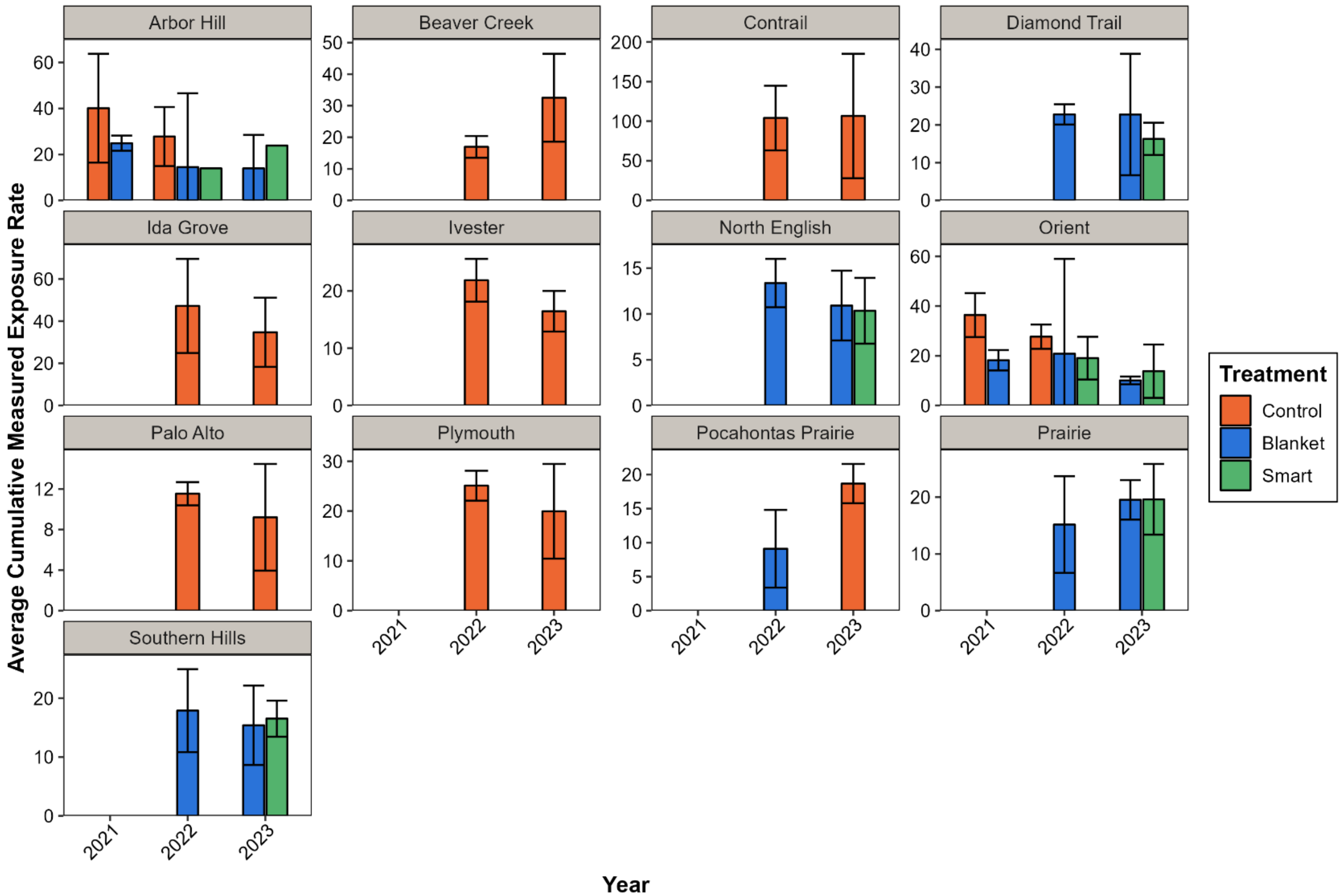

Figure 3-7. Cumulative yearly acoustic exposure rate (measured) by facility, and curtailment treatment in the 15 July–30 September curtailment period at 13 MidAmerican wind energy facilities in Iowa, 2021–2023. Error bars represent 95% confidence intervals.

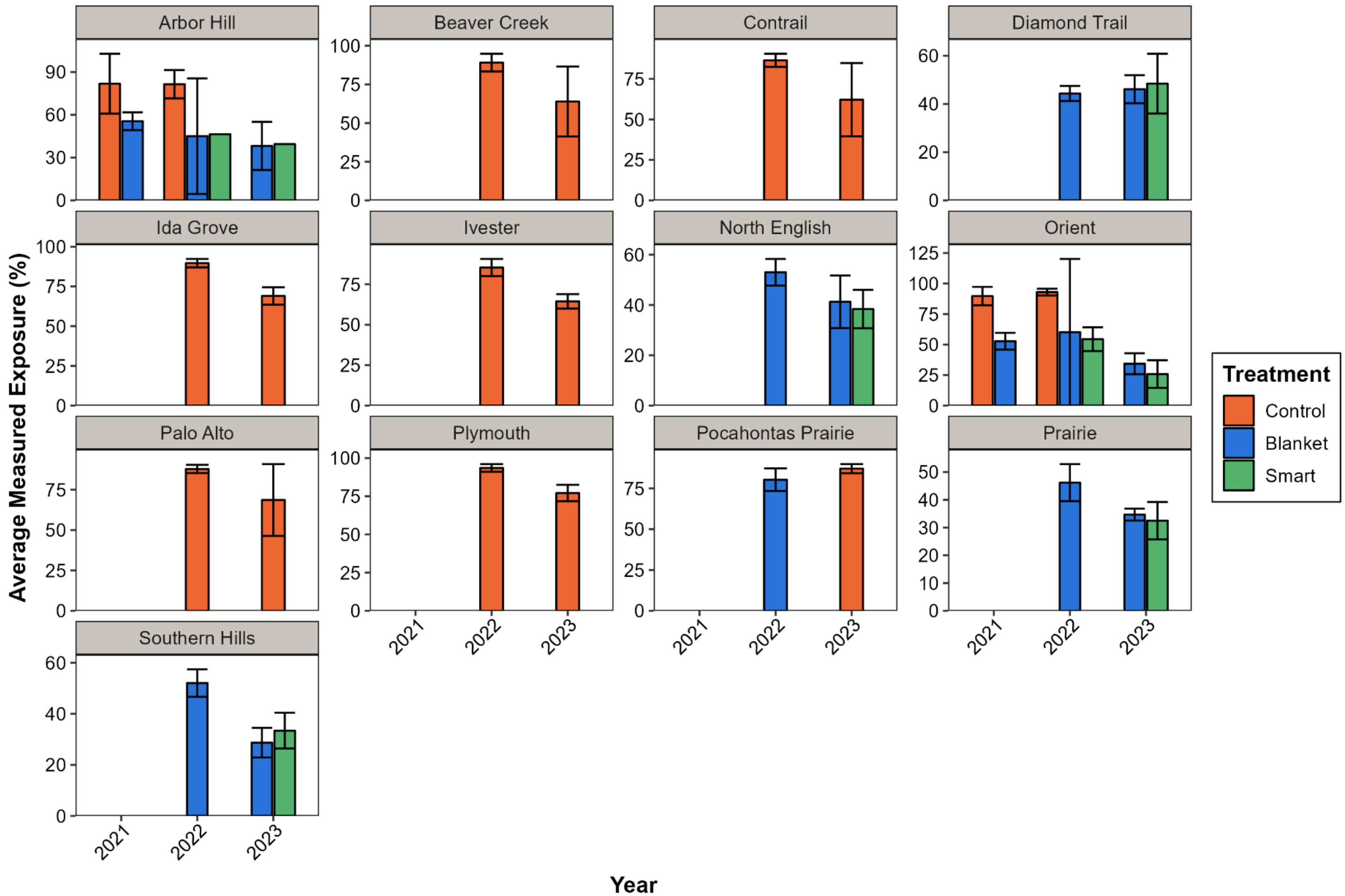

Figure 3-8. Percent yearly acoustic exposure (measured) by facility, and curtailment treatment in the 15 July–30 September curtailment period at 13 MidAmerican wind energy facilities in Iowa, 2021–2023. Error bars represent 95% confidence intervals.

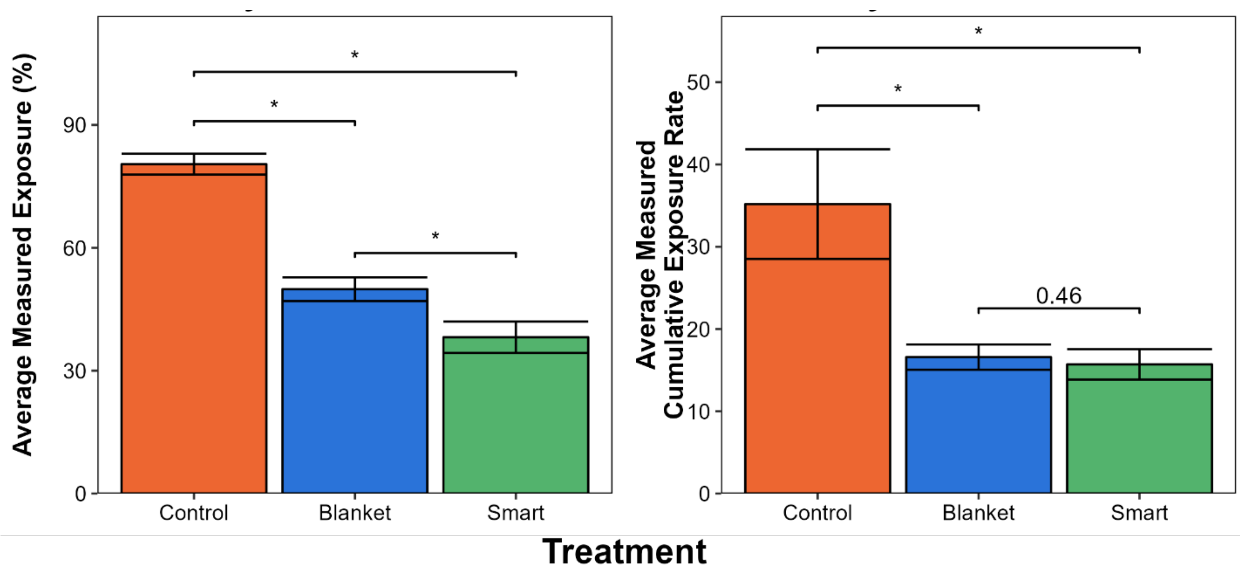

Figure 3-9. Measured acoustic exposure by treatment, expressed as a percent (left) and measured cumulative biweekly exposure rate (right) in the 15 July–30 September curtailment period, based on data summarized per turbine at 13 MidAmerican wind energy facilities in Iowa from 2021–2023. Error bars represent 95% confidence intervals around the mean, with asterisks indicating significant differences between means based on a t-test, and numbers above the horizontal lines are p-values from t-tests.

3.3.2.2 Bat Fatality Estimates

The number of carcass searches varied among treatments according to the number of turbines per treatment and allocation of search types among facilities and treatments (Table 3-4). Searcher efficiency was higher for road and pad searches (80.5%) than full plot searches (37.4%), although the estimated percent of carcasses persisting from arrival until the subsequent search was 47.3% for weekly road and pad searches and 52.3% for twice-weekly full plots (Table 3-4). The mean density-weighted proportion (DWP), a metric that accounts for searchable area and carcass distribution and ranges from 0–1, was 0.06 for road and pad plots and 0.77 for full plots (Table 3-4).

At Orient and Arbor Hill, fatality estimates varied among years and treatment, but treatment did not have a consistent effect on fatality estimates. Fatality estimates from Arbor Hill in 2022 suggested that the blanket and smart curtailment strategies reduced bat fatalities by 51–61%, respectively, relative to control operation (Figure 3-10). At Orient, the bat fatality estimate for blanket curtailment was 84% less than control operation in 2022, but the estimate for the smart curtailment treatment was ~8% higher than control operation (Figure 3-10). In each of these cases, the range in 90% confidence intervals produced by GenEst was greater than variation among year and treatment (Figure 3-10).

In most cases across all facilities, fatality estimates based on road and pad searches were higher and bounded by wider confidence intervals than those based on full plot searches (Figure 3-11). Where a combination of full plot and road and pad searches occurred, fatality estimates based on road and pad searches were higher in all but one case (Orient in 2023), regardless of operational treatment. At Beaver Creek, fatality estimates for the blanket curtailment strategy were lower than those for control turbines. Confidence intervals were again wider than the difference in fatality estimates between treatments, but the effect of curtailment on fatality rates was not consistent across sites and years where such comparisons were possible (Figure 3-11).

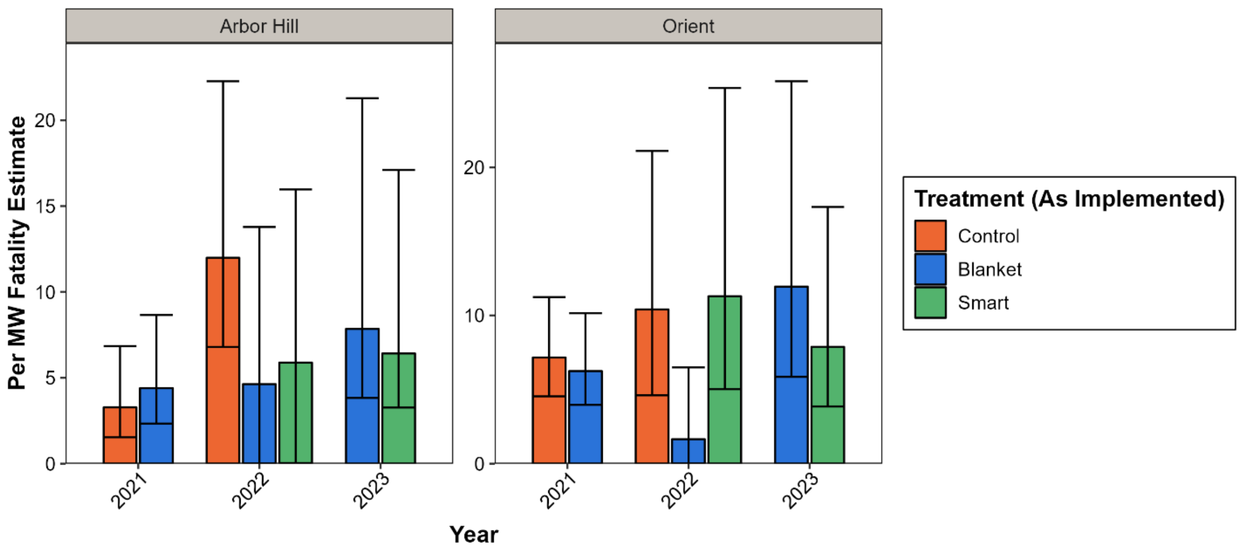

Figure 3-10. Bat fatality estimates (error bars indicate 90% confidence intervals from GenEst) at full plots per operational treatment by year based on carcass monitoring at the Orient and Arbor Hill MidAmerican wind energy facilities in Iowa, 2021–2023.

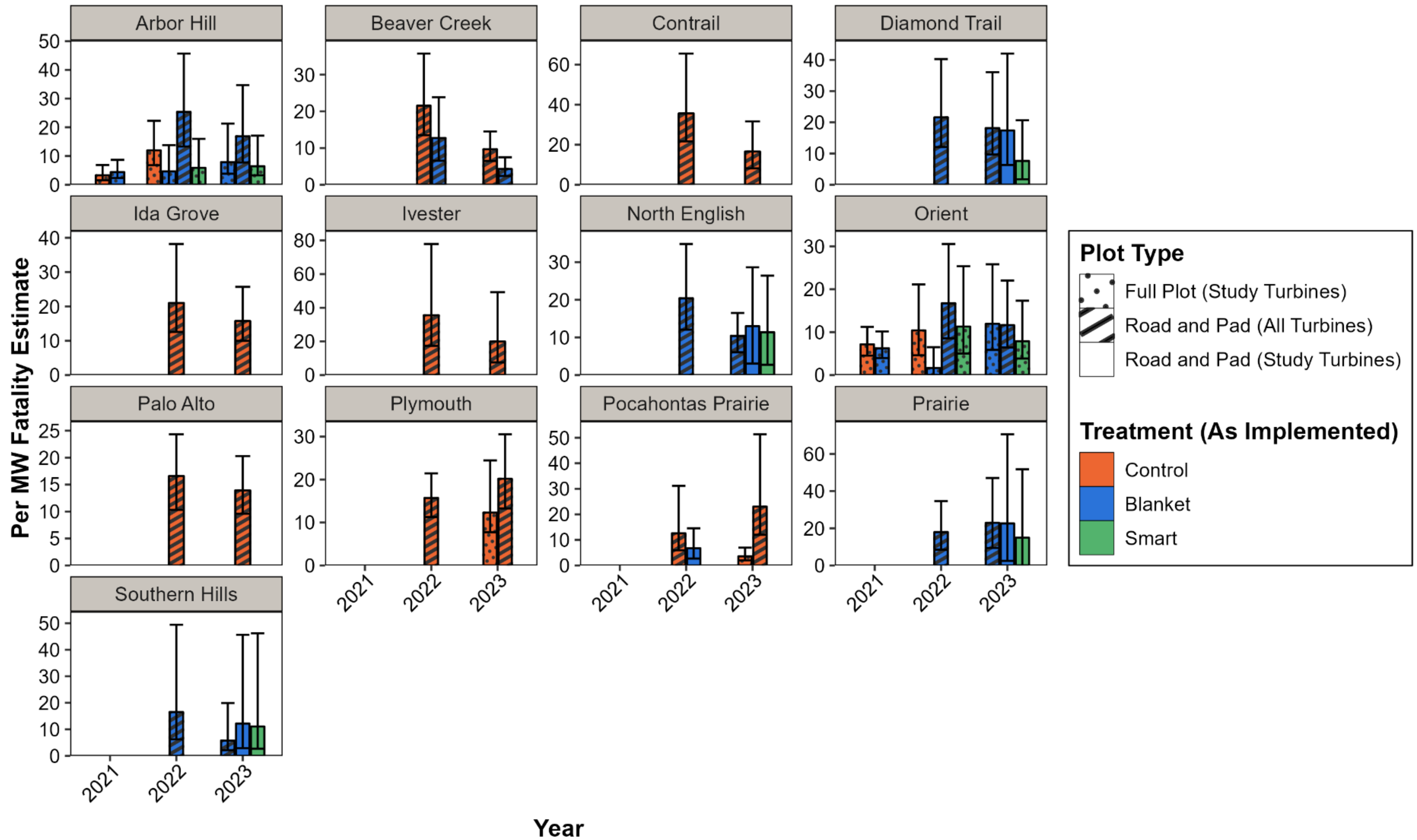

Figure 3-11. Bat fatality estimates (error bars indicate 90% confidence intervals from GenEst) per facility and operational treatment by year and plot type based on carcass monitoring at 13 MidAmerican wind energy facilities in Iowa, 2021–2023.

Table 3-4. Carcass search details and correction factors used in GenEst fatality estimates per treatment, facility, and year at 13 MidAmerican wind energy facilities in Iowa, 2021–2023.

Facility	Year	Treatment	Carcass Survey Type	Searcher Efficiency (SEEF)	Carcass Persistence Rate	Distribution	Density-weighted Proportion (DWP*)	per MW Estimate (90% CI)	per Turbine Estimate (90% CI)	# Searches	# Bat Carcasses*
Arbor Hill	2021	Blanket	Full Plot (Study Turbines)	0.32	0.709	exponential	0.69 (0.68-0.72)	4.4 (2.33-8.66)	8.8 (4.66-17.33)	166	14
		Control	Full Plot (Study Turbines)	0.32	0.709	exponential	0.74 (0.71-0.78)	3.28 (1.54-6.84)	6.56 (3.08-13.68)	143	10
	2022	Blanket	Full Plot (Study Turbines)	0.407	0.359	exponential	0.72 (0.72-0.72)	4.63 (0-13.78)	9.25 (0-27.55)	57	2
		Control	Full Plot (Study Turbines)	0.407	0.359	exponential	0.71 (0.68-0.74)	11.99 (6.79-22.27)	23.98 (13.59-44.54)	320	29
		Smart	Full Plot (Study Turbines)	0.407	0.359	exponential	0.7 (0.69-0.7)	5.88 (0.03-15.97)	11.75 (0.05-31.93)	55	3
		Blanket	Road and Pad (All Turbines)	0.92	0.237	exponential	-	25.36 (13.31-45.67)	54.51 (28.37-97)	1,830	61
	2023	Blanket	Full Plot (Study Turbines)	0.346	0.565	exponential	0.76 (0.74-0.81)	7.85 (3.83-21.28)	15.71 (7.66-42.57)	208	17
		Smart	Full Plot (Study Turbines)	0.346	0.565	exponential	0.76 (0.71-0.81)	6.42 (3.27-17.1)	12.84 (6.55-34.2)	233	16
		Blanket	Road and Pad (All Turbines)	0.885	0.288	exponential	-	16.86 (7.74-34.71)	34.76 (16-70.69)	1,855	33
Beaver Creek	2022	Blanket	Road and Pad (All Turbines)	0.74	0.522	exponential	0.1 (0.09-0.11)	12.74 (6.54-23.85)	26.23 (13.4-48.34)	656	1
		Control	Road and Pad (All Turbines)	0.74	0.522	exponential	0.06 (0.04-0.08)	21.55 (13.5-35.75)	44.65 (28.23-74.27)	1,837	107
	2023	Blanket	Road and Pad (All Turbines)	0.863	0.664	exponential	0.06 (0.06-0.07)	4.29 (2.39-7.48)	8.78 (4.88-15.31)	644	0
		Control	Road and Pad (All Turbines)	0.863	0.664	exponential	0.06 (0.05-0.09)	9.67 (6.48-14.52)	19.98 (13.51-30)	1,815	106
Contrail	2022	Control	Road and Pad (All Turbines)	0.692	0.272	loglogistic	0.08 (0.07-0.09)	35.62 (21.65-65.53)	97.57 (59.22-178.41)	597	72
	2023	Control	Road and Pad (All Turbines)	0.96	0.348	lognormal	0.12 (0.11-0.13)	16.59 (8.19-31.66)	44.56 (22.06-84.85)	388	53
Diamond Trail	2022	Blanket	Road and Pad (All Turbines)	0.76	0.287	loglogistic	0.1 (0.08-0.12)	21.59 (12.08-40.26)	63.61 (35.78-119.53)	1,134	103
	2023	Blanket	Road and Pad (All Turbines)	0.68	0.564	exponential	-	18.14 (9.71-36.06)	52.91 (28.51-107.36)	907	50
		Blanket	Road and Pad (Study Turbines)	0.68	0.564	exponential	0.04 (0.03-0.04)	17.39 (6.3-42.02)	74.79 (27.08-180.67)	105	7
		Smart	Road and Pad (Study Turbines)	0.68	0.564	exponential	0.04 (0.03-0.04)	7.62 (1.75-20.66)	32.78 (7.54-88.83)	119	4
Ida Grove	2022	Control	Road and Pad (All Turbines)	0.84	0.51	exponential	0.04 (0.04-0.05)	21 (12.57-38.19)	51.63 (30.95-93.67)	1,117	79
	2023	Control	Road and Pad (All Turbines)	0.84	0.526	loglogistic	0.08 (0.07-0.09)	15.75 (9.98-25.7)	39.37 (24.94-64.14)	1,123	110
Ivester	2022	Control	Road and Pad (All Turbines)	0.8	0.431	exponential	0.04 (0.04-0.06)	35.57 (17.39-77.89)	92.16 (45.1-202.35)	518	46
	2023	Control	Road and Pad (All Turbines)	0.98	0.371	loglogistic	0.05 (0.05-0.07)	19.96 (7.55-49.23)	51.95 (19.51-127.51)	522	37
North English	2022	Blanket	Road and Pad (All Turbines)	0.7	0.368	exponential	-	20.4 (12.07-34.83)	42.15 (24.89-71.58)	2,529	66
	2023	Blanket	Road and Pad (All Turbines)	0.816	0.62	lognormal	-	10.4 (6.07-16.51)	21.21 (12.4-33.79)	2,285	63
		Blanket	Road and Pad (Study Turbines)	0.816	0.62	lognormal	0.04 (0.03-0.06)	12.99 (3.07-28.64)	26.42 (6.29-58.02)	101	4
		Smart	Road and Pad (Study Turbines)	0.816	0.62	lognormal	0.03 (0.03-0.04)	11.37 (2.74-26.42)	22.75 (5.49-52.84)	119	4
Orient	2021	Blanket	Full Plot (Study Turbines)	0.64	0.478	lognormal	0.82 (0.72-0.85)	6.25 (3.97-10.16)	13.76 (8.74-22.35)	243	35
		Control	Full Plot (Study Turbines)	0.64	0.478	lognormal	0.82 (0.71-0.87)	7.17 (4.54-11.24)	15.65 (9.9-24.48)	209	34
	2022	Blanket	Full Plot (Study Turbines)	0.346	0.357	exponential	0.68 (0.68-0.68)	1.65 (0-6.5)	3.62 (0-14.3)	135	1
		Control	Full Plot (Study Turbines)	0.346	0.357	exponential	0.71 (0.71-0.71)	10.41 (4.61-21.11)	22.2 (9.88-44.46)	164	11
		Smart	Full Plot (Study Turbines)	0.346	0.357	exponential	0.68 (0.68-0.68)	11.3 (5.03-25.36)	24.85 (11.07-55.8)	112	9
		Blanket	Road and Pad (All Turbines)	0.923	0.178	exponential	-	16.71 (8.58-30.54)	35.56 (18.36-64.98)	2,569	55
	2023	Blanket	Full Plot (Study Turbines)	0.24	0.54	exponential	0.93 (0.93-0.93)	11.95 (5.86-25.81)	25.91 (12.85-56.32)	237	25
		Smart	Full Plot (Study Turbines)	0.24	0.54	exponential	0.93 (0.93-0.93)	7.88 (3.86-17.33)	17.34 (8.49-38.13)	207	17
		Blanket	Road and Pad (All Turbines)	0.625	0.322	exponential	-	11.64 (6.42-22.02)	24.9 (13.67-47.01)	3,368	78
Palo Alto	2022	Control	Road and Pad (All Turbines)	0.74	0.61	exponential	0.03 (0.02-0.05)	16.59 (10.31-24.32)	33.17 (20.62-48.64)	2,514	92
	2023	Control	Road and Pad (All Turbines)	0.8	0.757	exponential	0.04 (0.03-0.06)	13.93 (9.59-20.29)	27.86 (19.18-40.58)	2,544	146
Plymouth	2022	Control	Road and Pad (All Turbines)	0.939	0.533	weibull	0.06 (0.06-0.07)	15.72 (11.29-21.44)	43.13 (31.06-58.94)	1,801	99
	2023	Control	Full Plot (Study Turbines)	0.36	0.815	exponential	0.74 (0.67-0.77)	12.31 (7.74-24.46)	34.21 (21.52-68.02)	443	143
		Control	Road and Pad (All Turbines)	0.96	0.81	exponential	0.06 (0.06-0.07)	20.2 (13.27-30.53)	55.93 (36.77-84.23)	864	131

* The DWP and bat carcass count columns are calculated based only on the 15 study turbines

Facility	Year	Treatment	Carcass Survey Type	Searcher Efficiency (SEEF)	Carcass Persistence Rate	Distribution	Density-weighted Proportion (DWP*)	per MW Estimate (90% CI)	per Turbine Estimate (90% CI)	# Searches	# Bat Carcasses*
Pocahontas Prairie	2022	Blanket	Road and Pad (All Turbines)	0.84	0.498	exponential	0.04 (0.03-0.06)	17.95 (8.51-34.59)	37.5 (17.75-71.84)	1,240	42
		Blanket	Road and Pad (All Turbines)	0.833	0.269	exponential	-	22.95 (9.42-47.04)	47.21 (19.45-96.57)	1,022	26
	2023	Blanket	Road and Pad (Study Turbines)	0.833	0.269	exponential	0.04 (0.03-0.06)	22.6 (2.48-70.52)	47.28 (4.96-147.05)	119	3
		Smart	Road and Pad (Study Turbines)	0.833	0.269	exponential	0.04 (0.03-0.06)	14.93 (0-51.73)	29.87 (0-103.46)	104	2
Prairie	2022	Blanket	Road and Pad (All Turbines)	0.667	0.208	exponential	0.05 (0.04-0.08)	16.51 (6.23-49.44)	60.7 (22.74-172.9)	883	23
	2023	Blanket	Road and Pad (All Turbines)	0.808	0.471	exponential	-	5.76 (2.12-19.92)	21.12 (7.78-71.62)	773	19
		Blanket	Road and Pad (Study Turbines)	0.808	0.471	exponential	0.05 (0.04-0.07)	12.16 (2.9-45.65)	30.58 (7.17-112.22)	120	4
		Smart	Road and Pad (Study Turbines)	0.808	0.471	exponential	0.05 (0.04-0.06)	11.06 (2.69-46.2)	37.84 (9.46-162.01)	105	5
Southern Hills	2022	Blanket	Road and Pad (All Turbines)	0.84	0.498	exponential	0.04 (0.03-0.06)	17.95 (8.51-34.59)	37.5 (17.75-71.84)	1,240	42
	2023	Blanket	Road and Pad (All Turbines)	0.833	0.269	exponential	-	22.95 (9.42-47.04)	47.21 (19.45-96.57)	1,022	26
		Blanket	Road and Pad (Study Turbines)	0.833	0.269	exponential	0.04 (0.03-0.06)	22.6 (2.48-70.52)	47.28 (4.96-147.05)	119	3
		Smart	Road and Pad (Study Turbines)	0.833	0.269	exponential	0.04 (0.03-0.06)	14.93 (0-51.73)	29.87 (0-103.46)	104	2

* The DWP and bat carcass count columns are calculated based only on the 15 study turbines

3.3.3 Relationship between Acoustic Bat Exposure and Fatalities

3.3.3.1 Treatment and Facility-level

While exposure of acoustic bat activity at nacelle-height was consistently higher for control treatments at Orient and Arbor Hill, fatality estimates were highly variable among treatments. Bat fatalities and bat acoustic exposure, when compared on a site-wide basis at these two sites, showed no discernible relationship, whether fatalities were estimated per turbine or per megawatt (Figure 3-12). Control, blanket, and smart curtailment treatments were implemented simultaneously only at Orient and Arbor Hill in 2022; during that year, acoustic exposure and estimated fatality rates showed a slight positive relationship, but the same was not evident in 2021 or 2023 (Figure 3-13). Control turbines were not operated at either site in 2023. Despite the higher intensity of carcass monitoring at these sites (searches twice a week at cleared plots), the number of turbines per treatment was relatively small and confidence intervals around fatality estimates remained large. Similarly, no relationship existed between bat fatality estimates based on road and pad monitoring and nacelle-height acoustic bat exposure when calculated at the facility, treatment, and year level across all 13 sites (Figure 3-14).

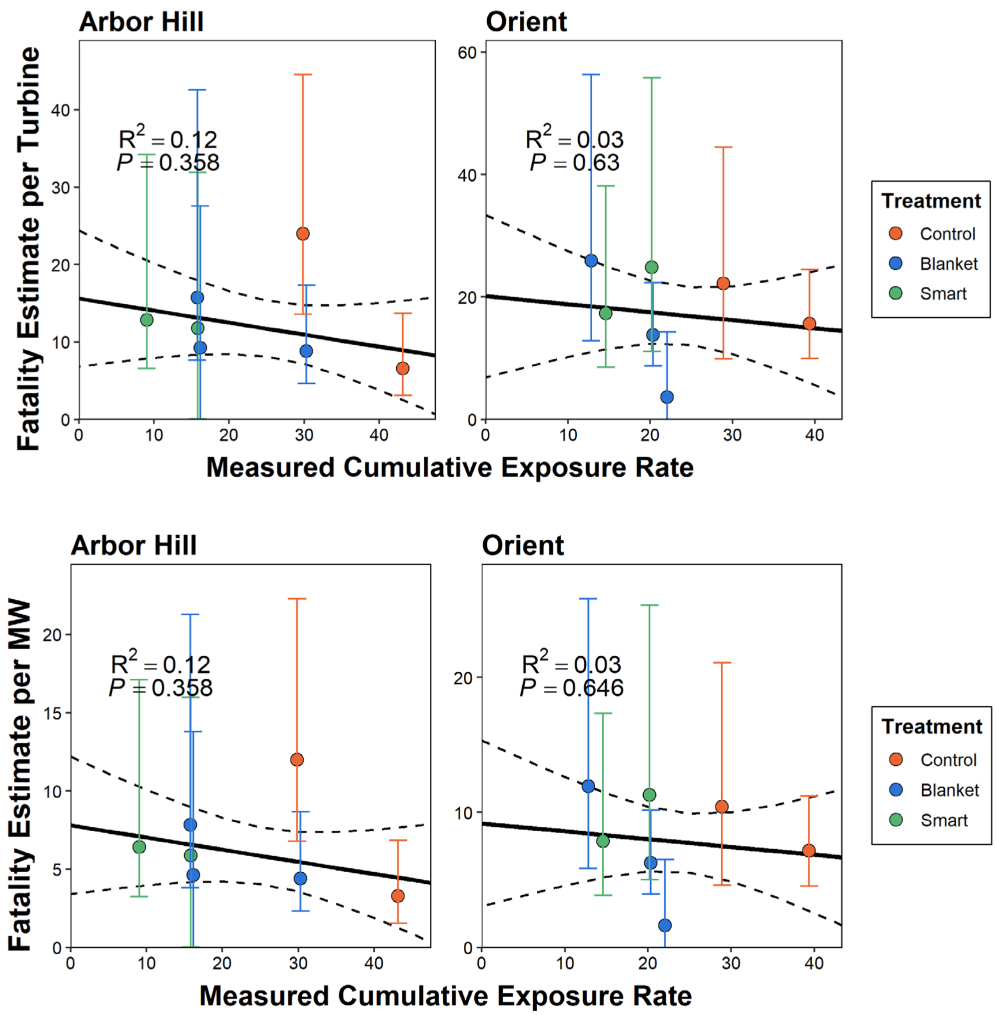

Figure 3-12. Estimated bat fatality per turbine (upper plot) and MW (lower plot) based on full plot searches as a function of cumulative acoustic exposure (nacelle height) as measured at the Orient and Arbor Hill MidAmerican wind energy facilities in Iowa, 2021–2023. Solid lines indicate the fitted linear regression, dashed lines are the 95% confidence intervals of the regression, and error bars indicating 90% GenEst confidence intervals.

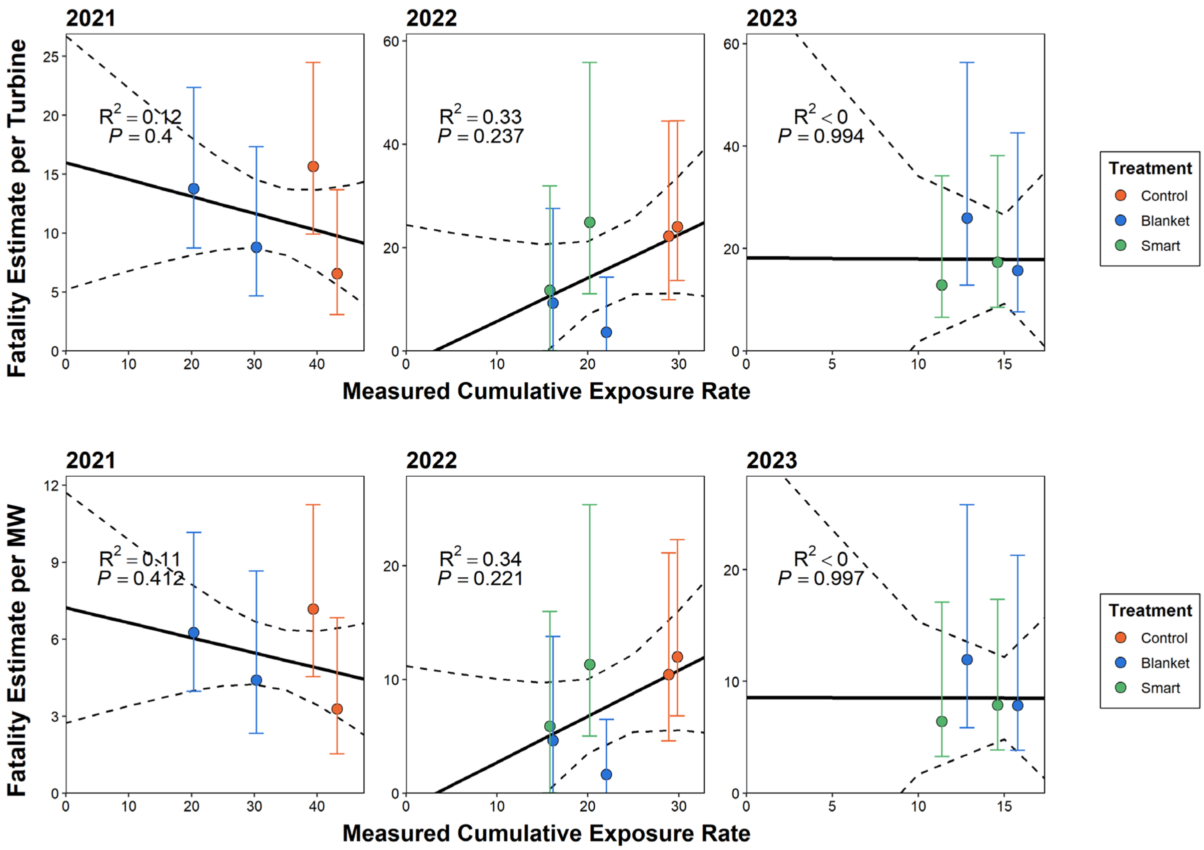

Figure 3-13. Estimated bat fatality per turbine (upper plot) and MW (lower plot) based on full plot searches as a function of cumulative acoustic exposure (nacelle height) as measured per year at the Orient and Arbor Hill MidAmerican wind energy facilities in Iowa, 2021–2023. Solid lines indicate the fitted linear regression, dashed lines are the 95% confidence intervals of the regression, and error bars indicating 90% GenEst confidence intervals.

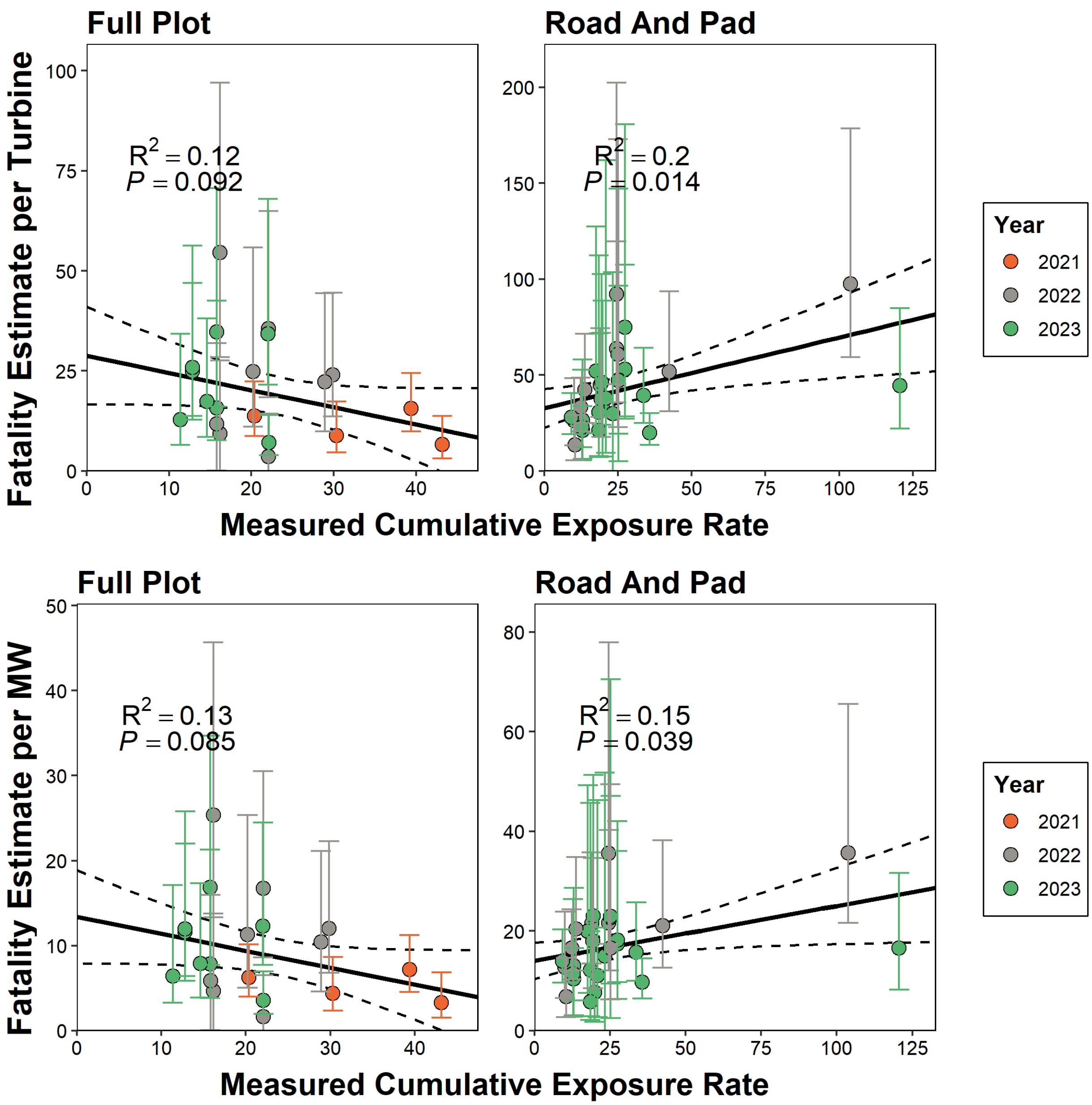

Figure 3-14. Estimated bat fatality per turbine (upper plot) and MW (lower plot) based on full plot and road/pad searches as a function of cumulative acoustic exposure (both metrics calculated per facility, treatment, and year) as measured at 13 MidAmerican wind energy facilities in Iowa, 2021–2023. Solid lines indicate the fitted linear regression, dashed lines are the 95% confidence intervals of the regression, and error bars indicating 90% GenEst confidence intervals.

3.3.3.2 Species Composition and Seasonal Patterns

The number of bat carcasses found per turbine search within biweekly intervals (corrected for search area, searcher efficiency, and carcass persistence), showed a positive relationship with the biweekly rate of acoustic exposure, pooling data among turbines and treatments, whether based on data from full plot or road and pad searches (Figure 3-16). Eastern red bats accounted for 392 (57.0%) of 688 bat carcasses found during standardized searches, with hoary bats the next most commonly found species (n = 164; 23.8%), followed by big brown bats (n = 93; 13.5%) and silver-haired bat (n = 35; 5.1%). Four tricolored bats were found (0.6%), and one carcass could not be identified to species; no *Myotis* species carcasses were found at turbines with acoustic detectors. Hoary bats accounted for a substantially larger proportion of exposed bat passes than eastern red bats at nacelle height (22.8% and 4.0% respectively), although the proportion of hoary bats and eastern red bats were more similar at ground level detectors (7.1% and 5.9%, respectively). Despite differences in species composition, the weekly distributions of carcasses (Figure 3-16) and exposed bat passes (Figure 3-17) were similar.

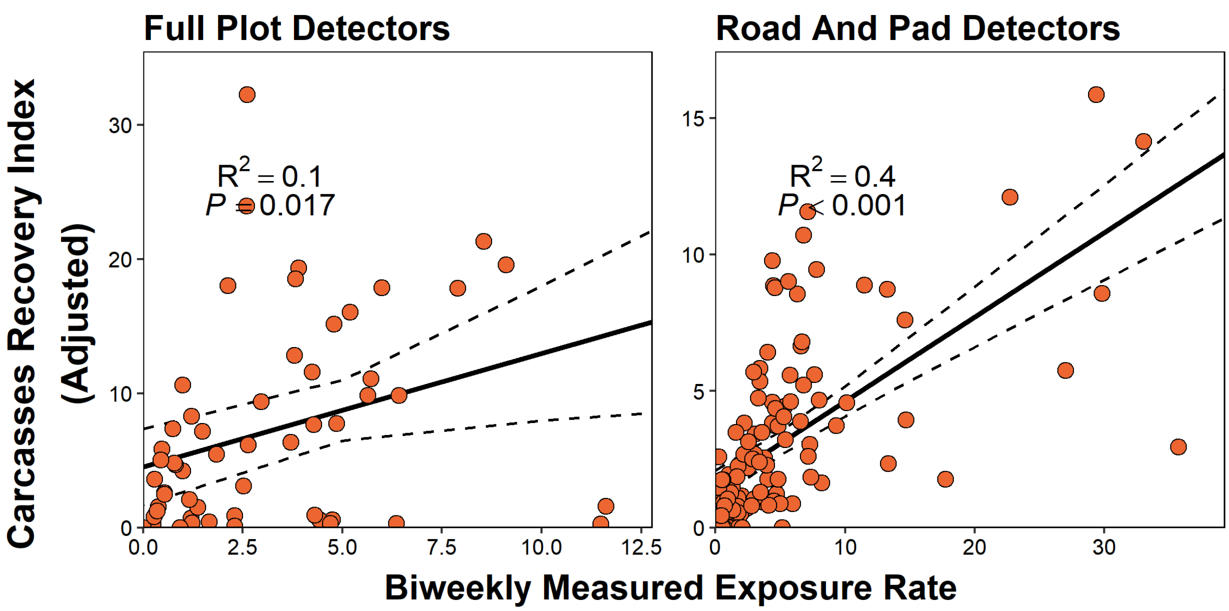

Figure 3-15. Bat carcasses found per search as a function of the rate of exposed bat passes per detector-night, calculated on a biweekly basis, pooling data among turbines and treatments across the 13 MidAmerican wind energy facilities in Iowa, 2021–2023. Solid lines indicate the fitted linear regression and dashed lines are the 95% confidence intervals of the regression.

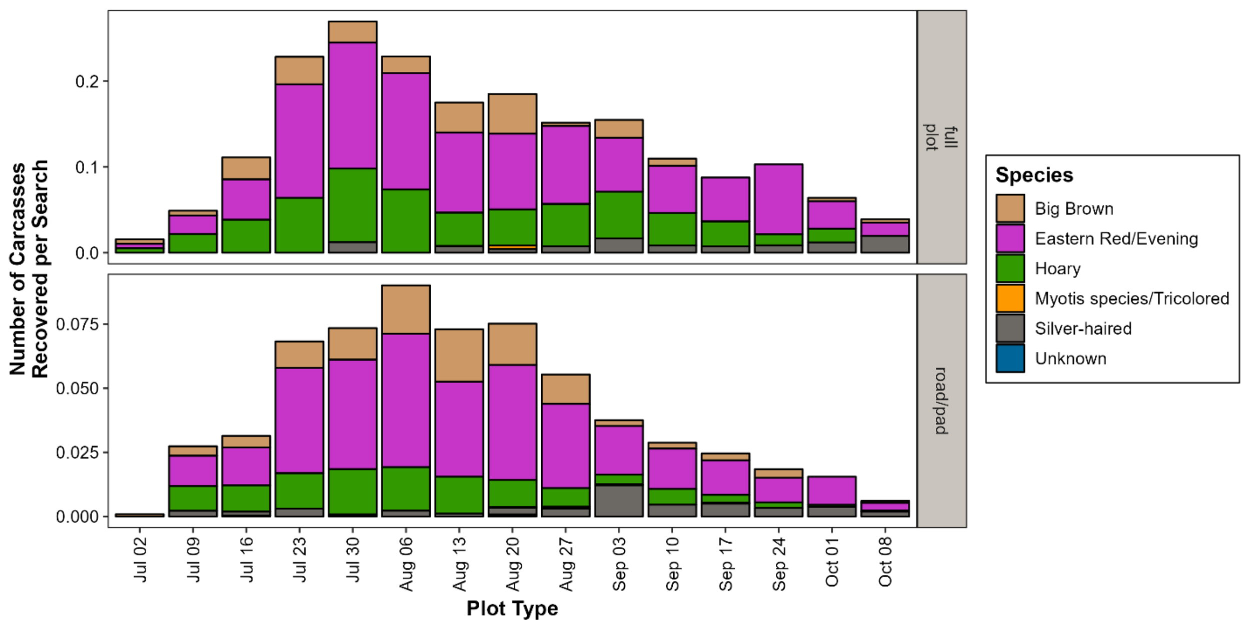

Figure 3-16. Weekly distribution of bat carcasses by species, pooling data across facilities, treatments, and years at 13 MidAmerican wind energy facilities in Iowa, 2021–2023.

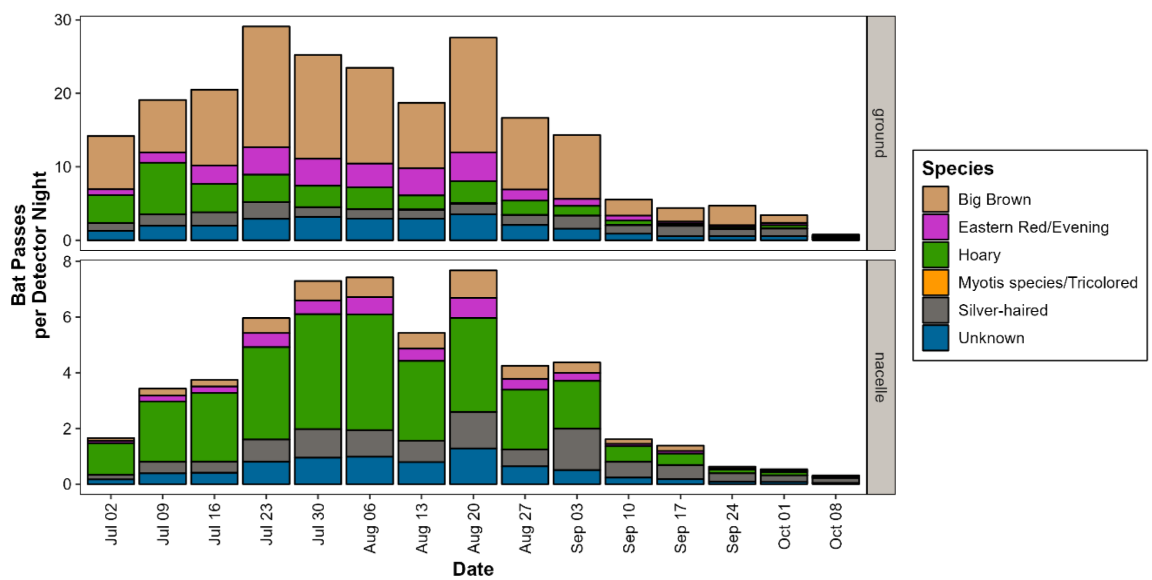

Figure 3-17. Weekly rate of exposed bat passes per detector-night by species, pooling data across facilities, treatments, and years at 13 MidAmerican wind energy facilities in Iowa, 2021–2023.

3.4 DISCUSSION

Acoustic exposure provided a clear and consistent indication of whether turbines were operating according to the parameters of their assigned curtailment treatments. Proper implementation of curtailment was then confirmed by reviewing plots of turbine rotation as a function of wind speed for individual turbines. We documented more deviations from assigned treatments than expected; subsequent review of curtailment parameters and methods to implement treatments with MidAmerican revealed multiple potential factors that could have affected proper implementation of curtailment, such as manual entry of parameters, gaps in data transmission between the turbines/facilities and the server triggering curtailment, and/or clearing of curtailment triggers due to turbine/facility shutdowns or resets. We suspect that such issues are not limited to the facilities in this study and have likely occurred in previous curtailment studies where proper implementation of curtailment was not evaluated. Most curtailment studies at North American wind energy facilities have not provided detailed information on how successfully curtailment was implemented. The differences between assigned and implemented curtailment could undermine the ability to document the effectiveness of curtailment. Our results highlight the importance of evaluating the success of curtailment and categorizing turbines appropriately before assessing the effectiveness of curtailment. Acoustic exposure provided a sensitive, quantitative metric to identify such deviations and data from turbine SCADA systems summarized at 10-minute intervals were sufficient to detect slight differences in curtailment strategies and confirm proper implementation of curtailment.

Acoustic exposure clearly demonstrated that curtailment strategies reduced exposure of bats to turbine operation relative to the operational control treatment across facilities, years, and even among individual turbines. When expressed as percent exposure, acoustic exposure was consistent across facilities for the three operational strategies; both curtailment strategies typically exposed ~38% (smart) and ~50% (blanket) of passes to turbine operation, on average, whereas ~80% of bat passes were exposed to turbine operation under control operation. The cumulative rate of exposed bat passes, summed across biweekly intervals, was more variable among sites, with higher rates of acoustic exposure recorded at some facilities operating under curtailment than others operating as operational controls. Considered together, these results suggest that the magnitude of risk to bats varied among sites in our study, but that curtailment reduced risk by a relatively consistent proportion across sites. The smart curtailment strategy was slightly more protective of bats than the blanket strategy based on greater reductions in exposed bat activity, as described in greater detail in Section 4 of this report.

Direct reductions in acoustic exposure could be measured only at Orient and Arbor Hill in 2021 and 2022, as these were the only facilities at which subsets of turbines were operated according to curtailment treatment with an experimental control group (acoustic data loss and issues with implementation of curtailment at Beaver Creek prevented such comparisons). At both facilities, blanket curtailment and the smart alternative reduced exposure by a consistent and significant margin, whether expressed as a percent or a cumulative biweekly rate (~40% for both metrics when averaging estimates between treatments for both facilities and years). The consistency of reductions in acoustic exposure due to curtailment are ultimately the result of the consistent distributions in acoustic bat activity with respect to temperature and wind speed outlined in Section 2.0 of this study.

Bat fatality estimates based on carcass searches did not show consistent patterns with respect to curtailment treatments at Orient and Arbor Hill, where treatments were adjusted experimentally and where carcass searches occurred at a relatively higher level of effort than other facilities. The fatality estimate was lower for curtailed treatments than operational control at Arbor Hill in 2022, but the same was true only for the blanket treatment at Orient in 2022 (the fatality estimate for the smart treatment was slightly higher than that for control operation at Orient in 2022). Despite the relatively high level of survey effort at Orient and Arbor Hill, there were few turbines per treatment and a small sample size of carcasses (in some cases less than 10 carcasses), particularly for the curtailment treatments. Small sample sizes contributed to high confidence intervals surrounding fatality estimates, as did variation in searcher efficiency, carcass persistence, and the density-weighted distribution of carcasses. At Beaver Creek, where fatality estimates were based on a larger number of turbine searches across more turbines (due to turbines across facility operating as controls or blanket curtailment based on the county they were in), fatality estimates were lower for the blanket treatment, but uncertainty around these estimates was considerable.

Experimental control treatments and curtailment strategies were not implemented simultaneously at subsets of turbines at other sites, and meaningful inter-site comparison in bat fatality estimates based on road and pad monitoring were not possible due to the wide confidence intervals surrounding estimates. More often than not, fewer than 10 bat carcasses were found total per treatment at facilities where only road and pad searches occurred, with carcasses found during fewer than 10% of searches. Fatality estimates based on road and pad searches, which occurred at all sites including Orient and Arbor Hill, tended to be higher than those based on full plot searches, suggesting potential bias from the greater amount of extrapolation required to estimate overall fatality based on a small, surveyed area. Mean bat fatality estimates, aggregated among all facilities and years, were slightly lower for curtailment treatments than for control operation, suggesting a potential effect of curtailment, but this could not be discerned consistently at the facility level.

A parallel study, also funded by the U.S. Department of Energy, occurred at Orient in 2021 and 2022 and compared bat fatality estimates between the same control operation and blanket curtailment treatments (implemented at different subsets of turbines) used in our study. Issues with proper implementation of curtailment in 2021 reduced the amount of time over which strategies could be compared and the effect of curtailment could not be determined; the number of turbines per treatment was increased from 6 to 12 in 2022, and the study was able to document a 30.8% decrease in estimated fatality between blanket curtailment and control operation (EPRI 2024). Both the number of turbines (12) and full plot turbine searches per treatment (751 for blanket curtailment and 787 for control treatment) were more than double those in our study (4–6 turbines and 169–241 full plot searches per treatment at Orient in 2022).

We were not able to demonstrate a relationship between fatality estimates and acoustic exposure at the facility or treatment level, although we do not consider this evidence that such a relationship does not exist. Instead, our study demonstrated that weekly road and pad searches at 15 turbines, and even biweekly searches of full plots at a small number of turbines, were insufficient to detect the effect of curtailment consistently. The factors needed to extrapolate fatality estimates due to the small numbers of turbines per treatment (Orient and Arbor Hill) or small search area of road and pad searches resulted in levels of uncertainty that rendered the estimates unhelpful in validating the effectiveness of curtailment. The EPRI study was able to discern the effect of curtailment only by doubling their own level of effort from 2021 to 2022; such an increase in level of effort would not have been feasible in our study given the number of sites involved. Applying a similar level of effort used in the EPRI study in 2022 (daily searches of 140 x 140 m plots with transects spaced at 5 m intervals) to the 13 sites included in this study would have required 15,015 turbine searches, and 60,961 km (37,879 mi) of walked transects (30,480 hours of walking, assuming a moderate pace of 2,000 m/hr) each year.

Regardless of how intensively they are conducted, carcass searches cannot precisely indicate conditions when fatalities occur. When aggregated across dozens of studies over more than a decade, carcass monitoring provides clear evidence that curtailment is effective, but fatality estimates typically cannot detect differences among operational treatments whose cut-in speed differ by less than 1 m/s due to the many factors that contribute to imprecision of fatality estimates (Adams et al. 2021; Whitby et al. 2024). The coarse feedback from carcass monitoring at even a moderate intensity is therefore insufficient to obtain useful feedback to implement curtailment strategically. Even when conducted at a level of effort far exceeding the standard amount of monitoring associated with compliance-level monitoring, the EPRI study was only able to measure the reduction in fatality from curtailment at a single site during a single monitoring period.

By contrast, we could document the effectiveness of curtailment at individual facilities, and even on a turbine-by-turbine basis, using acoustic exposure. We documented similar reductions in acoustic exposure (35.3%) to reductions in estimated fatality (30.8%) that the EPRI team documented in 2022. Although the EPRI study was unable to detect the effect of curtailment at Orient in 2021 due to a lower level of survey effort, we documented a 41.2% reduction in acoustic exposure at Orient that year, suggesting that curtailment was effective in both years (though potentially more so in 2021).

The reductions we documented in acoustic exposure due to blanket curtailment and that EPRI documented at Orient in 2022 (~30-35%) were less than the 62% average reduction associated with 5.0 m/s blanket curtailment reported in recent meta-analyses of dozens of curtailment studies across North America (Adams et al. 2021; Whitby et al. 2024). Regardless of the cut-in wind speed of a curtailment strategy, the amount of curtailment is a function of facility-specific wind patterns, such a blanket curtailment strategy could yield substantially different reductions in fatality risk among states or regions with different wind regimes. Wind resource maps modeling the wind resource at 80 meters compiled by the National Renewable Energy Laboratory (NREL 2017) indicate that Iowa is a windy state relative to states in which many of the studies referenced by Whitby et al. (2024) occurred.

Patterns in acoustic exposure we documented across sites and years were remarkably consistent with seasonal distribution of fatalities documented in carcass searches, at the facility level and in aggregate. This same seasonal distribution, with most fatalities occurring between mid-July and early September, is similar to previous carcass data collected at other MidAmerican facilities in Iowa (MidAmerican 2019) and across North America (Lloyd et al. 2023). The same seasonal pattern in acoustic activity is typical of the results of pre-construction surveys at proposed wind energy facilities across North America. Though unsurprising, the similarity in seasonal distribution of acoustic exposure and bat fatalities suggests that variation in acoustic exposure is indicative of variation in fatality risk.

The consistent and pronounced difference between species composition based on carcass searches and acoustic monitoring is noteworthy and deserves additional scrutiny. Although low echolocation pulses travel further than higher frequency pulses of the same amplitude (Griffin 1971), the range over which acoustic bat passes can reliably be detected at nacelle-height has not been experimentally measured. Bats may vary the amplitude and characteristic frequency of their echolocation pulses, in response to changing atmospheric conditions (humidity, temperature, wind speed, turbulence), which could affect their detection range (de Framond et al. 2023). Although hoary bats have been reported to fly without echolocating or while producing quiet echolocation pulses (Corcoran et al. 2021), hoary bats were clearly detectable at nacelle height and accounted for a disproportionally high amount of acoustic activity relative to carcasses in this study and other similar studies (Peterson et al. 2021). Hoary bats echolocate at a lower frequency than any other bat species in Iowa; such that hoary bat echolocation pulses likely travel further than those of higher frequency bats and therefore be disproportionally well represented in passive acoustic datasets recorded at nacelle height.

Behavioral differences between hoary bats and eastern red bats, such as tendency to echolocate, flight height, social interactions, or vertical partitioning of the air space between species could also explain differences in species composition of fatalities versus acoustic activity. Though the height above ground level where most fatalities occur is unknown, ground-level detectors recorded substantially more exposed bat activity, and higher proportions of eastern red bats, than nacelle-height detectors. Hoary bats, by contrast, accounted for a higher proportion of exposed bat activity at nacelle-height than at ground level, suggesting that hoary bats tended to be higher-flying than eastern red bats. The relationship between the number of individuals present and number of recorded echolocation pulses could also differ between species.

Acoustic detectors at nacelle height measure exposure to turbine operation whereas carcass searches document the result of exposure; while these processes are not expected to be exactly analogous, measuring exposure has distinct advantages to carcass searches when evaluating curtailment. Curtailment is effective because it reduces exposure, and acoustic detectors can directly measure this process, recording not only bat passes that are exposed, but also those detected when turbines are successfully curtailed. This information helps differentiate variation in baseline fatality risk versus curtailment effectiveness when considering fatality risk among facilities with different operational strategies.

Beyond the challenges in detecting the effect of curtailment on bat fatality rates, carcass counts cannot indicate the timing of fatalities at any scale finer than the night during which the fatality was expected to occur, regardless of the intensity of monitoring. As such, carcass searches provide limited feedback to guide selection or modification of critical curtailment parameters such as cut-in wind speed. By design, curtailment strategies reduce exposure of bats to risk, resulting in fewer fatalities, but the amount by which risk has been reduced cannot be measured directly without comparing fatality rates between curtailed turbines and operational control turbines. Considering the enormous level of effort required to detect the effect of curtailment, let alone differentiate among curtailment treatments with slightly different parameters when using carcass searches, and the increased fatality risk associated with running control treatments, fatality monitoring is not a suitable method to evaluate curtailment at scale. More importantly, carcass searches do not provide the type of feedback that the wind industry or regulators alike require to use curtailment more strategically. Carcass monitoring remains an important tool for establishing turbine-related bat mortality rates and determining species composition of fatalities but is not well suited for the specific task of comparing curtailment strategies or providing feedback to optimize curtailment.

By contrast, acoustic exposure not only revealed instances when curtailment treatments were not implemented as designed on a per-facility and per-turbine basis but provided two distinct but related metrics of curtailment efficacy (percent exposure and cumulative rate of exposure) which could be compared among turbines, treatments, and facilities. As shown in Section 4.0, acoustic exposure also offers the additional advantage of enabling curtailment strategies to be simulated, dramatically reducing the length of time needed to compare alternatives or adjust curtailment parameters to achieve targeted levels of fatality risk reduction. By monitoring risk, as opposed to the result of such risk, acoustic exposure can detect small differences between curtailment strategies with greater precision and provides actionable feedback on how wind project operators can manage risk.

4.0 OBJECTIVE 3: DEMONSTRATE USE OF NACELLE-HEIGHT ACOUSTIC AND WEATHER DATA TO OPTIMIZE SITE-SPECIFIC SMART CURTAILMENT STRATEGIES

4.1 INTRODUCTION

Turbine-related bat mortality at commercial wind energy facilities is driven by interactions between bats and fast-moving rotor blades. Curtailing turbine operation to prevent rotor movement when bats are active removes the source of risk and effectively reduces bat fatality rates (Arnett et al. 2011; Baerwald and Barclay 2009; Hayes et al. 2019; Whitby et al. 2024). Curtailing turbine operation during periods when bats are not present does nothing to further reduce risk. The amount of energy loss associated with turbine curtailment depends primarily on wind speed, with more complex factors such as price structuring of a power purchase agreement and fluctuating energy costs ultimately influencing the economic impact of curtailment for a wind energy facility (Hayes et al. 2023; Maclaurin et al. 2022). The potential benefit and cost of curtailment during an interval therefore depends on the relative amounts of bat activity and energy generation potential during that interval, both of which are influenced by wind speed and other factors.

By applying the same parameters throughout the date range over which curtailment occurs, blanket curtailment strategies essentially assume that risk to bats is either equal or varies unpredictably through the period of curtailment. The premise of activity-based informed curtailment strategies is that site-specific information on bat activity patterns derived from turbine-mounted acoustic detectors can inform when curtailment would be most productive (Peterson et al. 2021). Activity-based curtailment strategies are designed to achieve an equivalent level of exposure reduction as a comparable blanket curtailment strategy, which they accomplish by applying higher cut-in speeds during times of year and conditions associated with more bat activity and lower cut-in speeds when bats tend to be less active. This approach typically results in less energy loss for a given level of exposure reduction because bat activity (and corresponding risk of turbine-related impacts) is usually concentrated during a relatively brief seasonal peak in late summer and early fall and follows consistent temporal patterns. By applying more restrictive curtailment during the relatively smaller number of intervals when bats are most active, smart curtailment strategies are able to curtail less during the bulk of time periods, thereby reducing the amount of energy loss while achieving equivalent reductions in exposure as blanket strategies (Hayes et al. 2019).

Acoustic exposure derived from nacelle-mounted bat detectors can be measured by turbine rotor speed or simulated based on whether curtailment conditions were met during a given interval in which bat activity occurred (Peterson et al. 2021). Simulated and measured exposure were highly correlated across facilities and years (see Section 3 and Figure 3-5), indicating that simulated turbine operation was representative of how turbines actually operated across sites. Measured acoustic exposure and fatality estimates based on carcass counts can be generated only for curtailment strategies as implemented, limiting the number of strategies that can be compared, requiring implementation of operational controls (which increases risk to bats), and increasing the complexity and scale of studies needed to evaluate curtailment. In this study, measured acoustic exposure could be directly compared between control and curtailment treatments only at 3 facilities (Orient, Arbor Hill, and Beaver Creek), but issues with implementation of curtailment and acoustic detector function limited comparisons to Orient and Arbor Hill in 2021 and 2022 only.

By contrast, simulated acoustic exposure can be determined as if all facilities had implemented each of the different curtailment treatments, increasing the ability to discern differences in curtailment effectiveness across all sites/years and boosting the sample size of turbines and facilities at which curtailment could be evaluated. This offers an important advantage of acoustic exposure over carcass searches as a method to evaluate curtailment effectiveness, as one or more curtailment strategies can be simulated using a given set of data. Even when all turbines are operated according to the same treatment, the underlying assumption that measured and simulated exposure are closely correlated can be tested in most cases, providing empirical support for the validity of curtailment simulations.

We tested the ability of an activity-based informed curtailment strategy to achieve equivalent reductions in acoustic exposure as blanket curtailment with less energy loss across 13 wind energy facilities across Iowa. Based on the similarity of temporal and seasonal patterns in bat activity observed across facilities, as outlined in Section 2, we predicted that activity-based informed curtailment strategy designed around patterns observed at Orient and Arbor Hill in 2021 would be effective across facilities. The large number of facilities included in our study allowed us to also explore variation in the effectiveness and cost of blanket curtailment and the activity-based alternative among facilities and years.

4.2 METHODS

4.2.1 Smart Curtailment Design and Parameters–Orient and Arbor Hill

The blanket curtailment strategy used at facilities and turbines within range of the Indiana bat applied a 5.0 m/s cut-in speed from 15 July–30 September from sunset to sunrise when temperature was above a threshold of 10°C. At two sites where blanket curtailment was implemented (Orient and Arbor Hill), a subset (5–8 per facility) of turbines was also assigned as an operational control treatment, feathered below manufacturer's cut-in speed. One additional site (Beaver Creek) had turbines inside and outside the range of the Indiana bat; all other sites were either in or out of the Indiana bat range at the site level, as indicated in Table 3-3.

We aligned bat passes recorded in 2021 at Orient and Arbor Hill turbine nacelle-mounted detectors with temperature, wind speed, rotor speed, and power generation measurements recorded at the same turbines in corresponding 10-minute increments. We used this information to determine the measured exposure, defined as the subset of bat passes detected during intervals in which mean rotor speed exceeded 1 rpm, for each operational strategy. We calculated the reduction in measured exposure between the operational control and blanket curtailment strategy in 2021 as the target level of exposure reduction for the activity-based curtailment alternative (smart curtailment), considering data from Orient and Arbor Hill separately. We pooled data from individual detectors/turbines per facility and treatment, limiting analyses to nacelle-height detectors, when calculating reductions in acoustic exposure to design curtailment strategies.

We then reviewed the seasonal and temporal distribution of acoustic exposure, along with relationships between bat activity and temperature/wind speed using an interactive data visualization tool developed in R Shiny (Chang et al. 2024). The tool used the 10-minute dataset to generate plots of simulated acoustic exposure and simulated exposure and energy loss for the blanket curtailment strategy, operational control, and user-defined smart curtailment strategy whose cut-in wind speed and temperature thresholds could be set at any numerical value over custom intervals and time periods. This tool allowed the user to visualize how adjusting parameters of the smart curtailment strategy affected energy loss and acoustic exposure. Based on this process, we determined that the same adjustments to cut-in wind speed and temperature thresholds would achieve equivalent reductions in acoustic exposure for slightly less energy loss at Orient and Arbor Hill. Parameters for the activity-based smart curtailment strategy, applied during the same period as blanket curtailment (15 July–30 September), involved reducing the temporal window of curtailment to 30 minutes after sunset until 60 minutes before sunrise, raising the cut-in speed to 5.5 m/s in August, and reducing the cut-in speed to 4.5 m/s in September.

4.2.2 Measured Curtailment Effectiveness and Energy Loss–Orient and Arbor Hill

In the 2022 field season, smart curtailment, blanket curtailment, and operational control treatments were implemented at subsets of turbines at Orient and Arbor Hill[3]. In 2023, a third year of monitoring was conducted to compare blanket and smart curtailment alternatives using the same smart alternative implemented in 2022 but discontinued the operational control at these sites to reduce overall risk to bats and to increase sample size of turbines in each curtailment treatment. We used the same process to

[3]Operational control, blanket, and smart curtailment treatments turbines were also applied at Beaver Creek in 2023, although issues with curtailment implementation and acoustic detector function prevented comparison of measured exposure between control and treatments at the facility.

evaluate curtailment on a per-turbine basis described in Section 3.2.2 to verify that curtailment was implemented as designed, recategorizing turbines when necessary. We calculated reductions in measured acoustic exposure between the operational control and both the blanket and smart curtailment alternatives as implemented at Orient and Arbor Hill as described in Section 3.2.3.1, pooling data among turbines per facility and treatment. For this analysis, we limited the dataset used to measure acoustic exposure to detectors that functioned for 39 or more nights (50% of the period) within the 15 July–30 September curtailment period.

4.2.2.1 Energy Loss Analysis, "EPRI" Method

We collaborated with the Electrical Power Research Institute (EPRI) based on input from DOE and the National Renewable Energy Laboratory (NREL) to develop a method to estimate energy loss resulting from curtailment at Orient and Arbor Hill. This method used power generation data recorded at 10-minute intervals at operational control turbines to establish total energy production (AEP) to serve as a baseline for estimating energy loss from curtailment. Due to the need for comparison between curtailment strategies and operational controls, this method could only be applied at Orient and Arbor Hill based on data collected in 2021 and 2022. We did not rotate operational treatments at either facility, so we were able to pool data across the full monitoring period to calculate generation potential and determine energy losses associated with blanket and smart curtailment. We reported energy loss as the percent of energy generation lost during the curtailment period (July 15–Sept 30) relative to AEP based on annual energy output data provided by MidAmerican for Orient (EPRI 2024). Based on input from MidAmerican that Orient and Arbor Hill experience similar wind regimes (the facilities are ~20 km apart and have similar topographies and conditions), we used the annual production data for Orient as the basis for calculating AEP at Arbor Hill. Following the method outlined by EPRI, we observed percent energy lost with 90% confidence intervals to compare production lost between treatments.

4.2.3 Simulated Curtailment Effectiveness and Energy Loss–All Facilities

We simulated turbine operation according to the operational control, blanket curtailment, and smart curtailment alternative treatments for all turbines and facilities and calculated the percent of exposed passes within each simulated treatment, pooling data among turbines by site and detector position. Simulated exposure was closely aligned with measured exposure, indicating that simulations provided a realistic indication of how turbines would actually operate when assigned to a curtailment strategy, enabling us to assess curtailment effectiveness at sites run as operational controls. We also compared the cumulative rate of exposed bat passes per detector-night at biweekly intervals based on these simulations. For this comparison, we limited the dataset used to simulate cumulative biweekly exposure to detectors that functioned for 39 or more nights (50% of the period) within the 15 July–30 September curtailment period. As was the case for Orient and Arbor Hill after the 2021 monitoring period, we used the blanket 5.0 m/s curtailment strategy to define the target level of acoustic exposure reduction (as compared to the control strategy of feathering below manufacturer's cut-in speed). We calculated the average cumulative exposure and reduction in exposure per facility and turbine with 95% confidence intervals and conducted t-tests to determine differences in exposure per treatment.

4.2.3.1 Energy Loss Analysis, Power Curve Method

We obtained 10-minute mean rotor speed, power output, wind speed, and temperature data recorded from 1 March–15 November 2021–2023 at every turbine equipped with an acoustic detector. We calculated a site-specific empirical power curve for 0.5 m/s wind speed bins based on mean power generation data between the 25th and 75th percentile recorded during daytime at turbines equipped with acoustic detectors (15 per facility), grouping data by turbine model, and multiplied this power curve by 10-minute wind speed to simulate energy generation potential in each 10-minute time bin. For each simulated curtailment strategy, we summed potential energy generation across 10-minute time bins meeting curtailment conditions by turbine and calculated mean energy loss per turbine for each treatment, then converted the resulting sum to megawatt hours (MW-hr). We calculated the average energy loss per turbine by treatment group with associated 95% confidence intervals and used t-tests to determine significance differences in energy loss between curtailment strategies.

4.3 RESULTS

4.3.1 Measured Curtailment Evaluation and Effectiveness, Orient and Arbor Hill

Blanket curtailment reduced measured acoustic exposure by ~25–50% at Orient and ~35–50% at Arbor Hill relative to the control treatment during the 2021 and 2022 field seasons, pooling data among nacelle-height detectors. Exposure reductions from blanket curtailment varied between the two sites and between years, with greater reductions in exposure at Arbor Hill in 2022 versus 2021 and the opposite pattern at Orient (Table 4-1). Issues with implementation of curtailment strategies at Orient and Arbor Hill reduced the number of turbines per treatment from which measured exposure could be calculated. Despite small sample sizes, the effect of curtailment on acoustic exposure could still be discerned, and patterns in cumulative exposure were similar across individual detectors regardless of treatment, as can be seen in plots for individual turbines by facility and year in Appendix K. Percent exposure and cumulative biweekly exposure responded similarly at both sites and years. At both sites, the smart curtailment alternative implemented at Orient and Arbor Hill in 2022 achieved slightly greater reductions in exposure when compared to the blanket strategy, whether evaluated in terms of percent exposed passes or a cumulative rate, confirming the prediction that the smart alternative would be equivalently protective of bats as blanket curtailment.

Table 4-1. Reduction of bat passes and cumulative biweekly exposure rate of blanket curtailment and activity-based smart curtailment alternative, relative to operational control treatment, as measured at the Orient and Arbor Hill MidAmerican wind energy facilities in Iowa, 2021 and 2022.

Site	Year	Treatment (# Turbines)	Detector Nights	# Passes	Exposed Passes (% Reduction)	Cumulative Exposure Rate (% Reduction)
Arbor Hill	2021	Control (5)	390	3,786	3,180 (-)	40.14 (-)
		Blanket (8)	624	5,810	3,148 (35.5%)	24.88 (38.03%)
	2022	Control (6)	464	3,069	2,550 (-)	27.76 (-)
		Blanket (2)	156	968	439 (45.4%)	14.46 (47.89%)
		Smart (1)	78	444	206 (44.2%)	13.92 (49.84%)
Orient	2021	Control (6)	465	3,830	3,440 (-)	36.27 (-)
		Blanket (7)	542	3,853	2,030 (41.3%)	18.19 (49.84%)
	2022	Control (4)	312	1,799	1,671 (-)	27.68 (-)
		Blanket (2)	156	1,065	643 (35.0%)	20.86 (24.63%)
		Smart (3)	233	1,602	868 (41.7%)	19.05 (31.19%)

The smart curtailment alternative resulted in less energy loss than the blanket strategy at Orient and Arbor Hill during the 2022 field season, reducing the percent of production lost from 0.64–0.52% at Arbor Hill and from 0.61–0.49% at Orient, relative to annual energy production (AEP; Figure 4-1). Experimental control turbines were not operated at Orient or Arbor Hill in 2023, limiting the ability to directly calculate measured energy loss and reductions in measured exposure from experimental controls to curtailment treatments to the 2021 and 2022 field seasons.

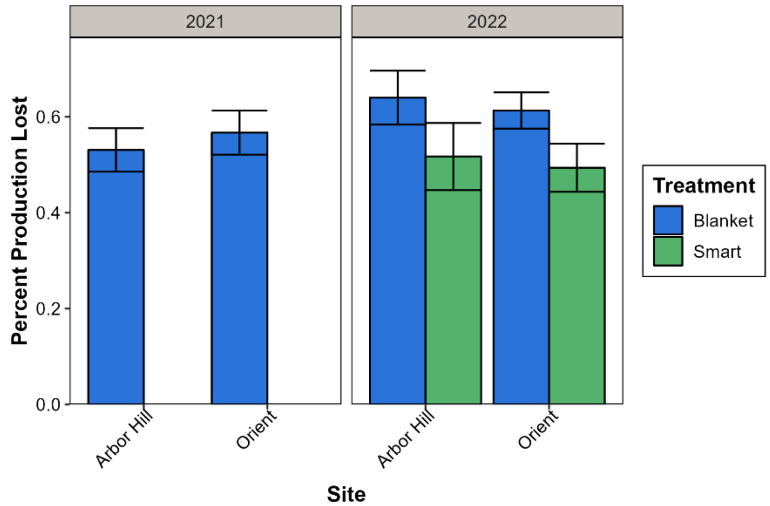

Figure 4-1. Percent energy production loss as a percentage of potential generation in the 15 July–30 September curtailment period for the blanket strategy and smart alternative at the Orient and Arbor Hill MidAmerican wind energy facilities in Iowa, 2021 and 2022. Error bars represent 90% confidence intervals.

4.3.2 Simulated Curtailment Evaluation and Effectiveness, All Facilities

The blanket curtailment strategy reduced simulated acoustic exposure by 12–55% (mean 39%) and cumulative biweekly exposure by 13–55% (mean 39%) relative to the control treatment, based on simulations across facilities and years. The smart alternative reduced the proportion of exposed passes by 15–60% (mean 42%) and reduced cumulative biweekly exposure by 16–60% (mean 42%) relative to the control treatment based on simulations at each facility. Overall, the smart curtailment alternative resulted in slightly greater reductions in exposure than blanket (though not significantly different), and both strategies resulted in significantly greater reductions in exposure in 2023 versus 2022 (Figure 4-2). Had the blanket and smart alternatives been implemented across all sites from which acoustic data were available, the smart curtailment alternative would have reduced acoustic exposure by an equivalent or slightly higher degree in 25 of 28 cases based on percent exposure and 26 of 28 cases based on cumulative biweekly exposure, with greater reductions in exposure in 2023 versus 2022 at all sites except Diamond Trail (Table 4-2). Even when assessed at the level of individual turbines/detectors, the effectiveness of the blanket strategy and smart alternative could be compared against control operation, as can be seen in plots of cumulative biweekly exposure per treatment for all turbines and facilities (see Appendix L).

Table 4-2. Simulated acoustic exposure as a percent and cumulative rate for simulated blanket and smart curtailment treatments and percent reductions relative to operational control in the 15 July-30 September curtailment period at 13 MidAmerican wind energy facilities in Iowa, 2021–2023.

					Control		Blanket		Smart	
Site	Year	# Turbines	Detector Nights	# Passes	Exposed Passes	Cumulative Exposure Rate	Exposed Passes (% Reduction)	Cumulative Exposure Rate (% Reduction)	Exposed Passes (% Reduction)	Cumulative Exposure Rate (% Reduction)
Arbor Hill	2021	13	1,014	9,596	8,242	40.22	5,249 (36.3%)	25.51 (36.6%)	5,228 (36.6%)	25.58 (36.4%)
	2022	9	698	4,481	3,859	28.16	2,702 (30.0%)	19.9 (29.3%)	2,534 (34.3%)	18.7 (33.6%)
	2023	6	392	2,970	1,998	24.73	1,213 (39.3%)	14.79 (40.2%)	1,077 (46.1%)	13.36 (46.0%)
Beaver Creek	2022	7	336	1,724	1,435	17.43	955 (33.5%)	11.29 (35.2%)	900 (37.3%)	10.54 (39.5%)
	2023	8	550	5,437	3,480	29.68	2,009 (42.3%)	16.93 (43.0%)	1,863 (46.5%)	15.81 (46.7%)
Contrail	2022	14	991	23,078	18,938	95.08	13,285 (29.9%)	65.71 (30.9%)	12,662 (33.1%)	63.03 (33.7%)
	2023	8	576	17,659	14,562	117.25	9,417 (35.3%)	75.42 (35.7%)	8,806 (39.5%)	70.63 (39.8%)
Diamond Trail	2022	15	781	9,701	8,743	45.44	4,566 (47.8%)	25.15 (44.7%)	4,858 (44.4%)	26.04 (42.7%)
	2023	9	650	5,677	4,743	35.9	2,749 (42.0%)	20.62 (42.6%)	2,630 (44.6%)	19.7 (45.1%)
Ida Grove	2022	8	604	6,370	5,567	45.78	3,454 (38.0%)	28.9 (36.9%)	3,194 (42.6%)	26.86 (41.3%)
	2023	10	657	7,694	5,436	36.98	3,180 (41.5%)	21.36 (42.2%)	3,040 (44.1%)	20.67 (44.1%)
Ivester	2022	15	1,029	5,847	4,561	22.13	2,519 (44.8%)	12.53 (43.4%)	2,344 (48.6%)	12.12 (45.2%)
	2023	14	1,092	5,632	3,328	14.96	1,535 (53.9%)	6.79 (54.6%)	1,460 (56.1%)	6.45 (56.9%)
North English	2022	13	680	3,960	3,679	22.94	2,186 (40.6%)	14.02 (38.9%)	2,275 (38.2%)	14.02 (38.9%)
	2023	13	974	5,445	4,048	19.96	2,332 (42.4%)	11.57 (42.0%)	2,231 (44.9%)	11.15 (44.1%)
Orient	2021	13	1,007	7,683	6,920	33.56	4,252 (38.6%)	20.63 (38.5%)	4,097 (40.8%)	19.99 (40.5%)
	2022	9	701	4,466	4,157	30.41	2,867 (31.0%)	21.06 (30.7%)	2,598 (37.5%)	19.06 (37.3%)
	2023	12	888	7,579	5,517	30.87	2,645 (52.1%)	14.69 (52.4%)	2,466 (55.3%)	13.66 (55.8%)
Palo Alto	2022	15	973	2,720	2,282	11.55	1,646 (27.9%)	8.26 (28.5%)	1,495 (34.5%)	7.62 (34.1%)
	2023	9	640	1,594	1,168	8.66	606 (48.1%)	4.4 (49.2%)	599 (48.7%)	4.35 (49.8%)
Plymouth	2022	13	848	4,758	4,309	24.76	2,988 (30.7%)	17.31 (30.1%)	2,635 (38.9%)	15.47 (37.5%)
	2023	8	565	3,137	2,085	17.51	1,179 (43.5%)	9.69 (44.7%)	1,155 (44.6%)	9.52 (45.6%)
Pocahontas Prairie	2022	12	502	1,831	1,758	11.18	1,539 (12.5%)	9.66 (13.5%)	1,502 (14.6%)	9.4 (15.9%)
	2023	8	550	2,607	2,111	17.72	1,354 (35.9%)	11.26 (36.5%)	1,295 (38.7%)	10.84 (38.8%)
Prairie	2022	4	198	1,957	1,612	34.85	1,028 (36.2%)	22.31 (36.0%)	1,056 (34.5%)	21.75 (37.6%)
	2023	12	912	10,976	8,282	43.64	4,146 (49.9%)	21.9 (49.8%)	3,928 (52.6%)	20.82 (52.3%)
Southern Hills	2022	13	627	4,977	4,540	40.64	2,797 (38.4%)	27.66 (31.9%)	2,592 (42.9%)	24.93 (38.7%)
	2023	10	706	6,770	5,327	35.74	2,393 (55.1%)	16.02 (55.2%)	2,124 (60.1%)	14.41 (59.7 %)

Relative reductions in exposure from blanket and smart curtailment compared to control operation were generally consistent among facilities and years, although the magnitude of acoustic exposure varied substantially among sites. Cumulative acoustic exposure was higher at some sites when operated with curtailment treatments than for others operated without curtailment (Figure 4-3). This pattern was also similar for the subset of bat passes identified as *Myotis* species and tricolored bats, although the magnitude of exposure was much lower for these species groups (Figure 4-4). The consistency of curtailment strategies' proportional reduction in exposure despite varying rates of activity was also clear at the individual turbine level (see Appendix L). Cumulative acoustic exposure increased most rapidly during August across treatments, although the rate of increase was slightly lower for the smart curtailment alternative in this period due to the higher cut-in speed applied in August (Figure 4-5).

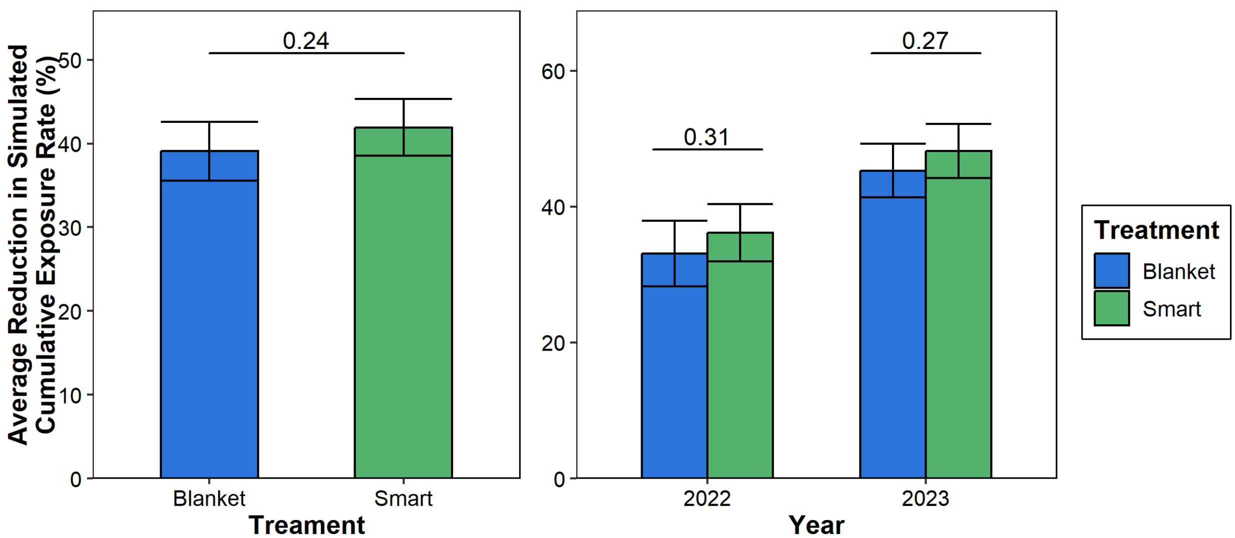

Figure 4-2. Reduction in cumulative acoustic exposure for the simulated curtailment treatments relative to control operation by treatment (left) and by treatment and year (right) in the 15 July–30 September curtailment period at 13 MidAmerican wind energy facilities in Iowa, 2021–2023. Error bars indicate 95% confidence intervals and numbers above the horizontal lines are p-values from t-tests.

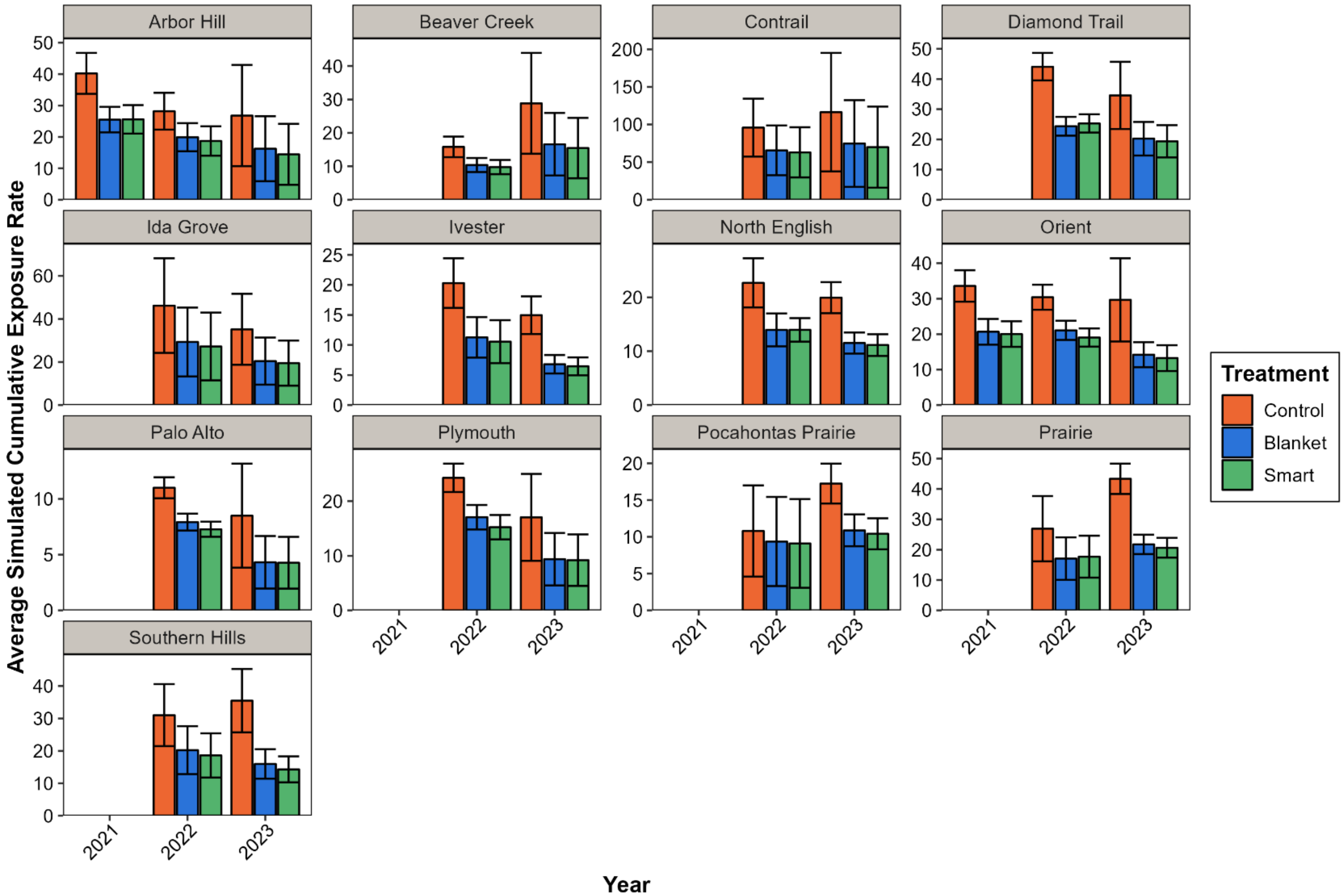

Figure 4-3. Average simulated cumulative acoustic exposure rate for the simulated blanket, and smart alternative curtailment treatments relative to control operation for each year within the 15 July–30 September curtailment period at 13 MidAmerican wind energy facilities in Iowa, 2021–2023.

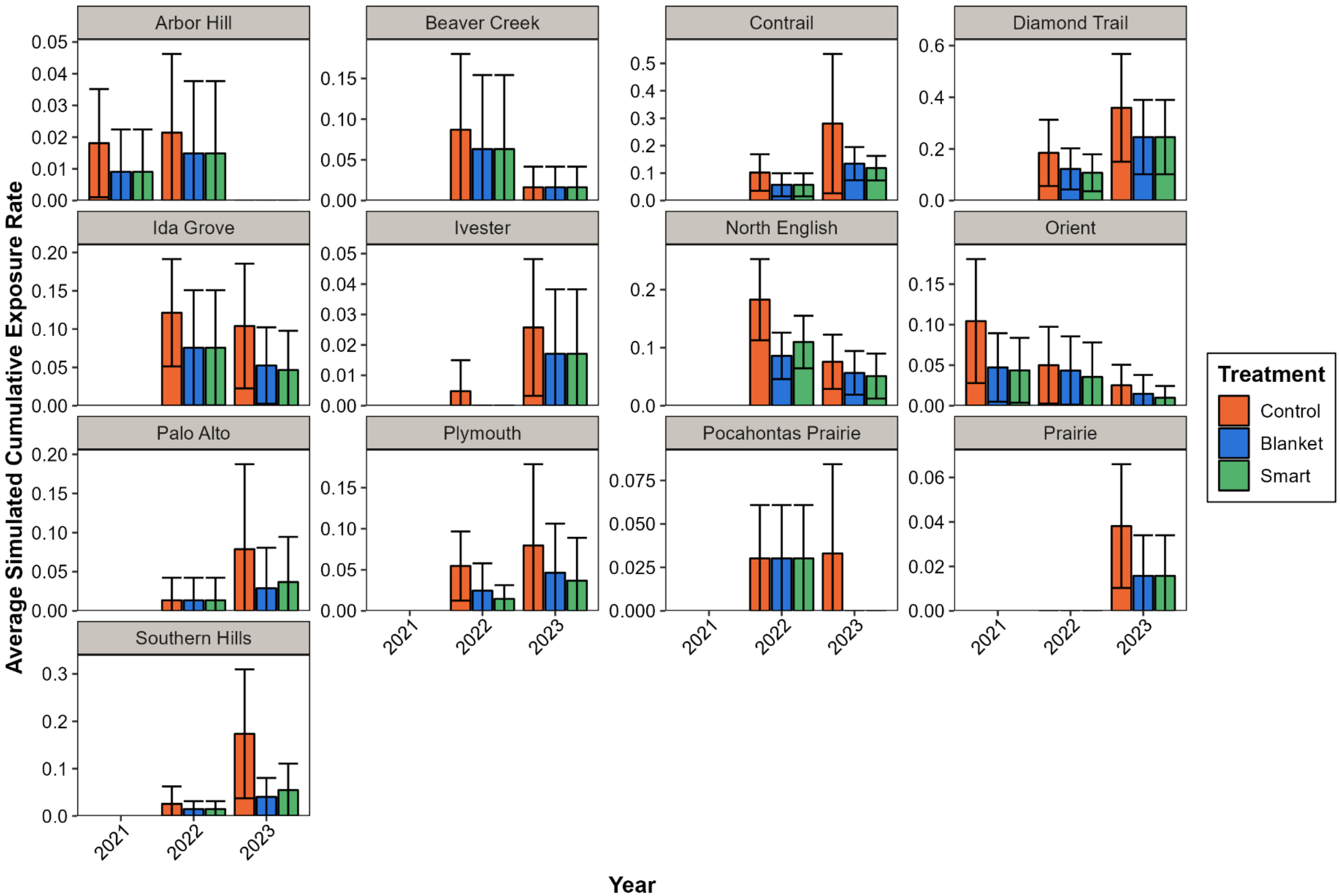

Figure 4-4. Average simulated cumulative acoustic exposure rate of bat passes visually vetted as *Myotis* species and tricolored bats for the simulated blanket, and smart alternative curtailment treatments relative to control operation for each year within the 15 July–30 September curtailment period at 13 MidAmerican wind energy facilities in Iowa, 2021–2023.

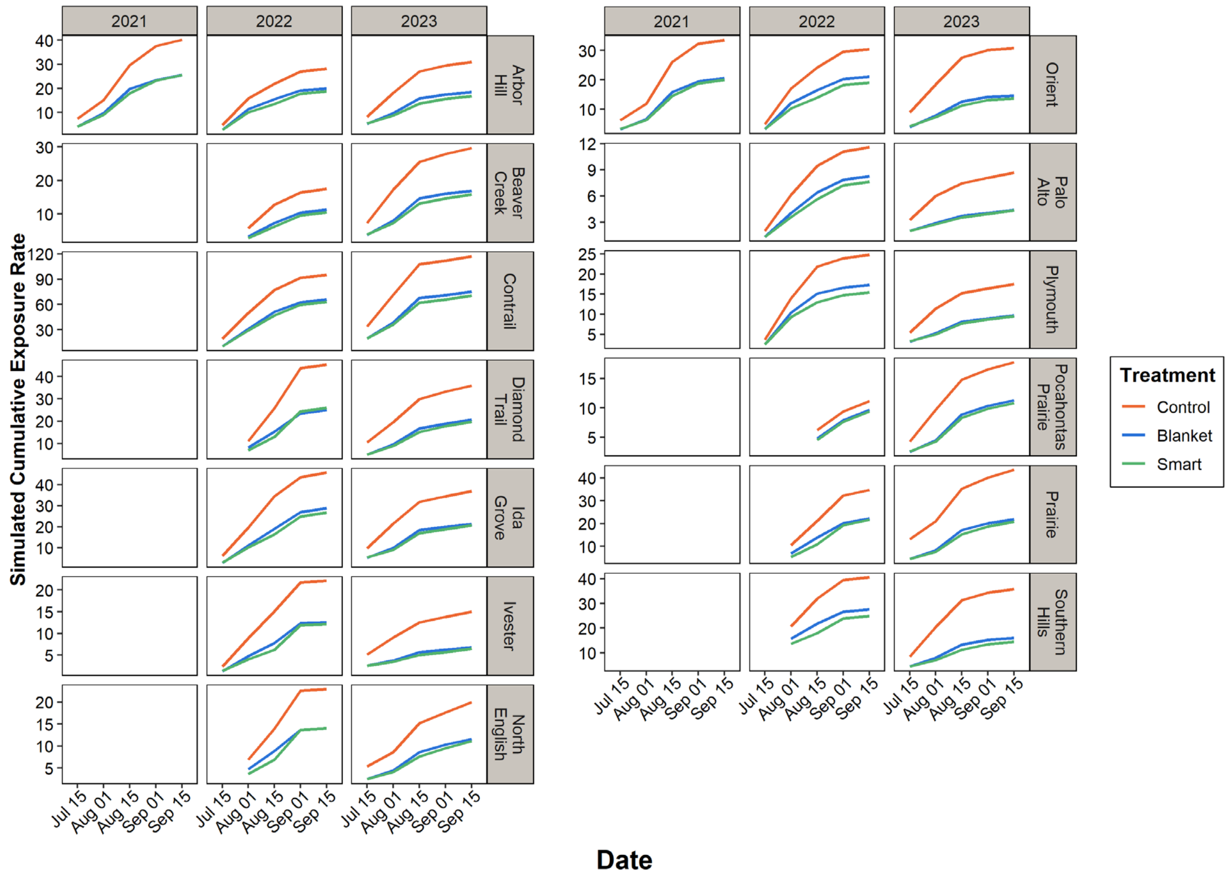

Figure 4-5. Simulated cumulative acoustic exposure rate for blanket and smart curtailment treatments and control operation in the 15 July–30 September curtailment period at 13 MidAmerican wind energy facilities in Iowa, 2021–2023.

Energy losses associated with simulated curtailment strategies ranged from ~20–40 MW-hr per turbine per year, with the smart alternative resulting in less energy loss than the blanket strategy in 21 out of 28 datasets that could be compared (Figure 4-6). Though the smart alternative resulted in slightly lower energy loss than blanket curtailment, when averaged across sites, the difference in energy loss between treatments was not statistically significant (Figure 4-7). Curtailment efficiency, or the relative amount of exposure reduction as a function of energy loss, varied among sites and years between the two curtailment treatments based on simulations, with higher amounts of energy loss typically associated with greater reductions in acoustic exposure, whether comparing among sites, years, or treatments (Figure 4-8).

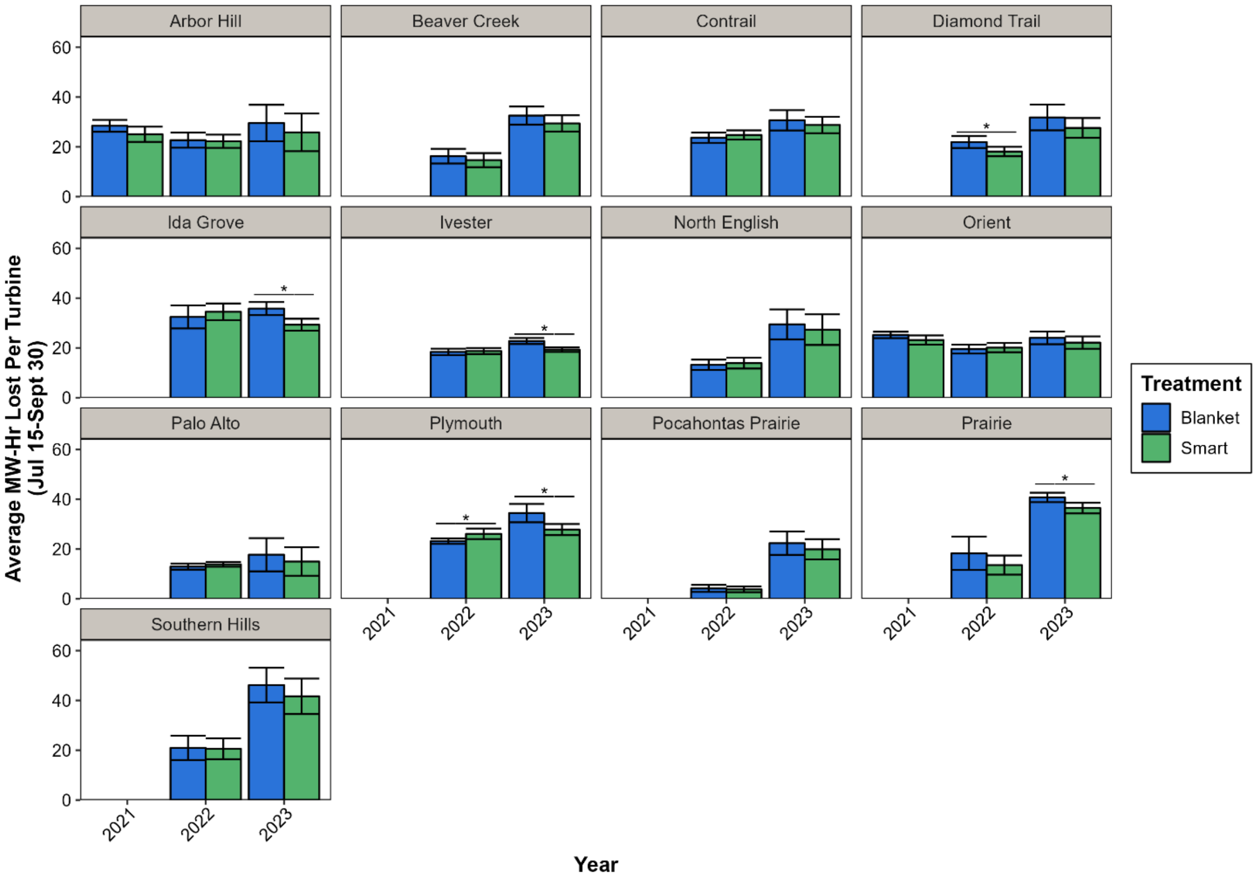

Figure 4-6. Average yearly energy loss (MW per hour) per site associated with simulated curtailment strategies implemented from 15 July–30 September at 13 MidAmerican wind energy facilities in Iowa, 2021–2023. Error bars represent 95% confidence intervals around the mean, with asterisks indicating significant differences between means based on a t-test.

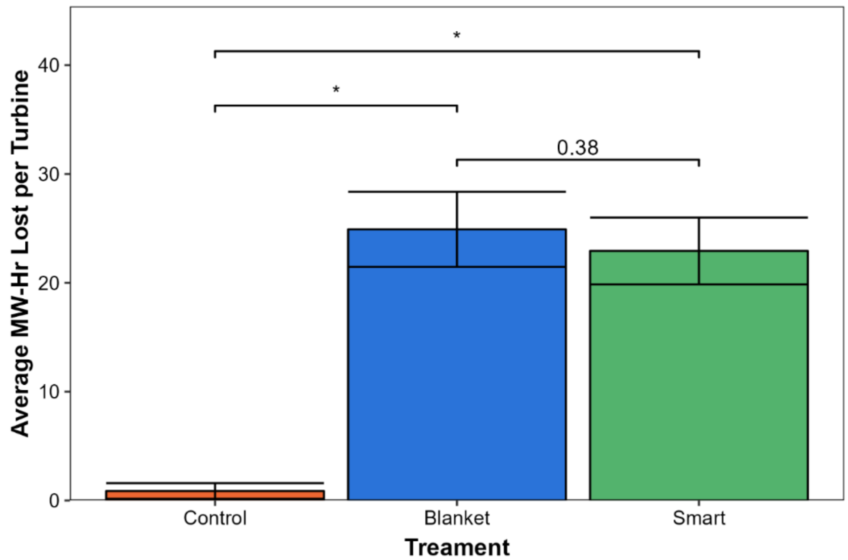

Figure 4-7. Energy loss (MW per hour) for the average turbine as associated with simulated curtailment strategies implemented from 15 July–30 September across the 13 MidAmerican wind energy facilities in Iowa, 2021–2023. Error bars represent 95% confidence intervals around the mean, numbers above the horizontal lines are p-values from t-tests, with asterisks indicating significant differences between means.

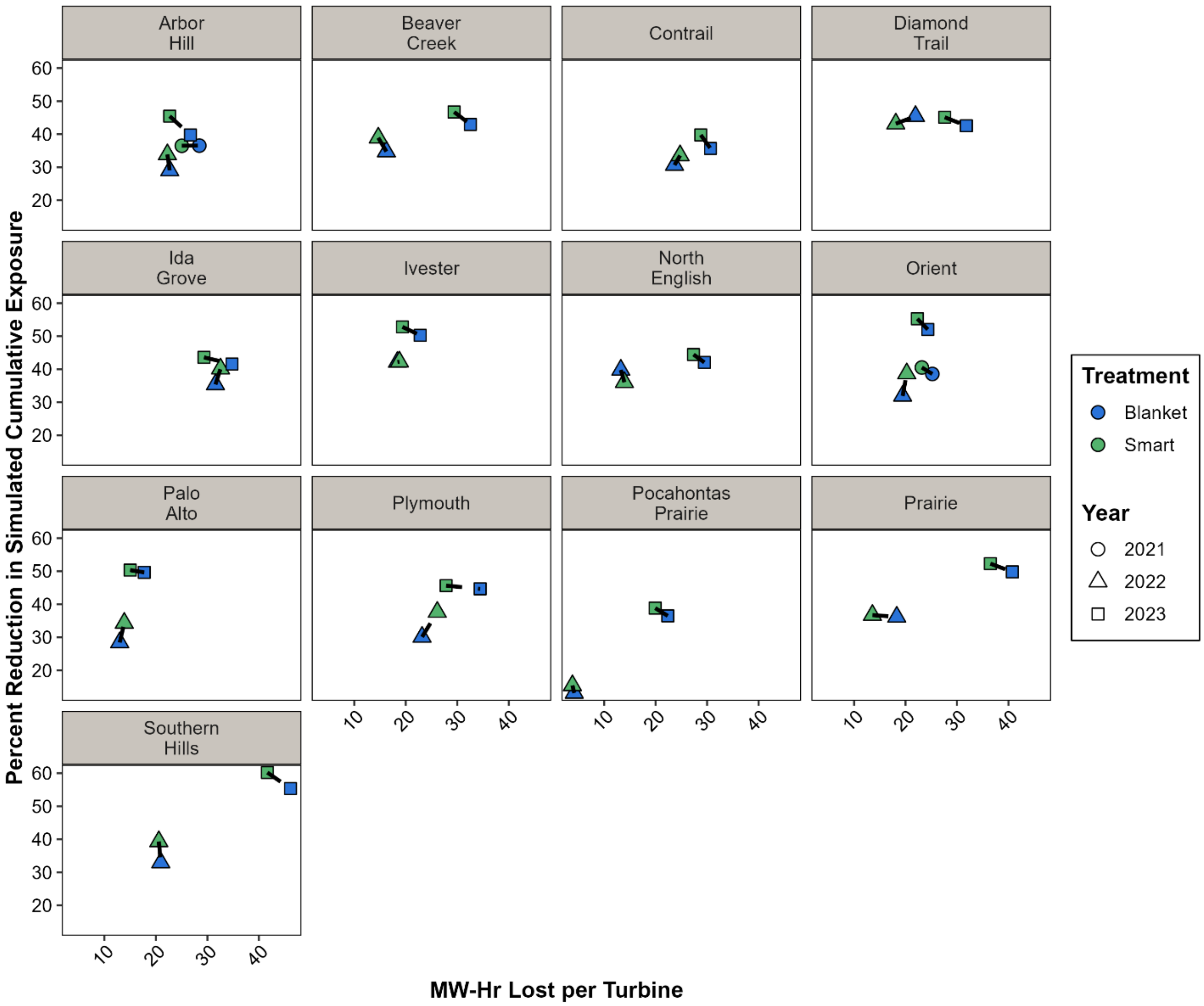

Figure 4-8. Percent reduction in cumulative acoustic exposure (vertical axis) as a function of energy loss for the blanket and smart curtailment strategies (horizontal axis) by facility and year as simulated for the 15 July–30 September curtailment period at 13 MidAmerican wind energy facilities in Iowa, 2021–2023. Black lines connect the smart and blanket simulations for each year.

4.4 DISCUSSION

This study provided an opportunity to evaluate the effectiveness and energy loss of a blanket curtailment strategy and smart curtailment alternative across 13 wind energy facilities in Iowa. We found smart curtailment reduced acoustic exposure, whether calculated as a cumulative biweekly rate or as the proportion of passes exposed to turbine operation, by a slightly greater amount than blanket curtailment, whereas smart curtailment resulted in less energy loss than blanket curtailment based on comparison to the operational control treatment. We were able to demonstrate the effectiveness of curtailment across a range of sites representing multiple turbine manufacturers and models and compare the relative effectiveness and importance of curtailment. We also demonstrated the ability to discern how slight differences in curtailment parameters affected acoustic exposure and associated risk of turbine-related impacts.

Measured exposure (bat passes detected when turbine rotor speed exceeded 1 rpm) and simulated exposure (bat passes detected when curtailment conditions were not met, and when turbines should have been spinning) based on 10-minute wind speed and rotor speed data were closely aligned, indicating that simulations provided an accurate representation of turbine performance. This allowed us to simulate acoustic exposure at the other 11 sites as if they had been operated under the blanket curtailment, smart curtailment, and operational control treatments. Our analysis showed that the blanket curtailment strategy and smart curtailment alternative were similarly protective of bats in most cases, yet smart curtailment resulted in less energy loss relative to the blanket strategy. The activity-based smart curtailment alternative therefore achieved the simultaneous goals of being equivalently or more protective of bats while reducing associated energy loss in most cases when compared to blanket curtailment.

The smart curtailment alternative designed for Orient and Arbor Hill, based on acoustic data collected at these sites in 2021, effectively reduced acoustic exposure by a similar or greater margin than blanket curtailment while resulting in slightly less energy loss than blanket curtailment based on subsequent monitoring at these facilities in 2022. Direct measurement of acoustic exposure among curtailment treatments applied to subsets of turbines at multiple sites demonstrated curtailment effectiveness among completely independent samples with replication at the site level. The same strategy was also effective across a wider range of sites in 2023, suggesting that the patterns around which the smart strategy was designed (namely, the seasonal and hourly distribution of activity described in Section 2), were stable across sites and years and that the same strategy would likely remain effective in future years. The greater reductions in acoustic exposure associated with simulated blanket and smart curtailment in 2023, and increased energy loss in 2023, are likely attributable to later deployment of detectors overall in 2022 compared to 2023, when acoustic data were more representative of the full curtailment period.

When simulated across all facilities in the study, the smart curtailment alternative resulted in slightly less energy loss than blanket curtailment while achieving slightly greater reductions in exposure, although differences between the two curtailment strategies were generally not significant. We obtained similar estimates of energy loss whether using the method based on energy output at control turbines or simulations based on the empirical power curve derived from site-specific data. Energy loss estimates according to both methods varied more between years than between treatments or sites. Accordingly, based on a combination of measured and simulated exposure and energy loss, the smart curtailment alternative, even though it was based on data from a single year at two facilities, accomplished the simultaneous goals of reducing exposure by an equivalent amount as blanket curtailment while resulting in less energy loss across a wide range of sites over multiple years.

The ability to simulate curtailment strategies and calculate their associated reductions in acoustic exposure compared to simulated control operation demonstrates a key advantage of acoustic exposure in assessing curtailment effectiveness. Fatality estimates and measured exposure can only be calculated for curtailment treatments as implemented; this requires a large number of turbines to be monitored, some of which must also be operated without curtailment, increasing risk to bats. Because bat activity can be recorded regardless of turbine operation, exposure can be simulated for multiple curtailment strategies and control operation regardless of how turbines were actually operated. Simulated exposure was closely aligned with measured exposure, whether evaluated on a per-turbine basis or at the treatment level. By simulating the curtailment strategies across all sites and years, we were able to dramatically increase the number of sites and years over which comparisons could be made, improving the ability to evaluate inter-site and inter-year differences in the effectiveness and cost of blanket curtailment and an equivalent smart curtailment strategy. Spatial replication at this scale requires a substantial monitoring effort and is often not possible outside the context of large-scale studies of this type; considering the level of effort required to detect the effect of curtailment at even a single site based on fatality monitoring (see Section 3.0). Comparing two curtailment treatments across 13 sites over two years would not have been possible using fatality monitoring.

Our results indicate that both curtailment alternatives consistently reduced acoustic exposure across a wide range of sites representing different turbine manufacturers and models. The only site/year at which curtailment was notably less effective than other sites was Pocahontas Prairie in 2022, where blanket and smart curtailment reduced acoustic exposure by ~13–15%, well below the average across all other facilities and years. Detectors were deployed at Pocahontas Prairie 1-2 weeks later in 2022 than other sites, so acoustic data represented a windier month (September) where curtailment occurred less frequently. Simulated energy loss associated with curtailment at Pocahontas Prairie in 2022 was also correspondingly low.

No single previous study in North America has provided quantitative feedback on the effectiveness and associated energy loss of blanket versus smart curtailment across more than a dozen facilities over multiple years, enabling inter- and intra-site comparisons. The proportional reduction in acoustic exposure resulting from curtailment was generally similar among sites and years, whether based on percent or cumulative rate of exposure, though the rate of exposure varied substantially among sites across treatments. For example, the blanket and smart curtailment treatments reduced exposure at Diamond Trail and North English by a similar relative amount (with similar amounts of energy loss), though the cumulative rate of exposed passes at Diamond Trail was approximately double that recorded at North English. This highlights an important distinction between curtailment effectiveness (proportional reduction in risk) and relative importance of curtailment in terms of reducing cumulative fatalities when considering options to manage risk to bats across a fleet of facilities. Curtailing turbines at sites with more risk will avoid a greater number of bat fatalities than if the same curtailment strategy were applied at sites with less risk.

We also demonstrated the ability to detect slight differences in acoustic exposure among curtailment strategies with similar parameters. The ability to accurately simulate curtailment strategies and their associated exposure reductions and energy losses greatly expands options for comparing curtailment strategies and adjusting their parameters to improve their efficiency. Using a combination of measured and simulated exposure across a wide range of sites over multiple years, we provided robust evidence that the smart curtailment alternative would likely be effective at other sites and years where the same underlying seasonal and temporal patterns in bat activity occur.

5.0 OBJECTIVE 4: COMPARE EFFECTIVENESS AND ENERGY LOSS OF BLANKET AND SMART CURTAILMENT PROGRAMS

5.1 INTRODUCTION

Turbine curtailment studies based on carcass counts are labor intensive and require aggregation of data over multiple turbines operating under distinct curtailment strategies throughout entire monitoring periods to be able to estimate bat fatalities. The level of effort required to document effectiveness of one curtailment treatment, let alone compare alternatives, is often not feasible based on the number of turbines or availability of funding. To measure reduction in bat mortality rates due to curtailment, carcass studies also require operational controls to provide a baseline, increasing impacts to bats. Recent meta-analyses of curtailment studies using fatality monitoring demonstrated that the cut-in wind speed threshold of a curtailment strategy would need to be changed by at least 1 m/s for the associated change in turbine-related bat fatalities to be detectable (Adams et al. 2021; Whitby et al. 2024).

Even when conducted as intensively as theoretically possible (all turbines searched daily with evenly spaced transects across fully cleared plots)[4], the temporal resolution of carcass data (nightly) would be insufficient to determine how windy it was when fatalities occurred. Instead, curtailment parameters would need to be adjusted and another year of monitoring would be required before determining whether the changes had the desired outcome. Uncertainty surrounding the estimated mortality rate would still likely preclude definitive determination if subtle changes to curtailment strategies resulted in slight increases or decreases in fatality. For these reasons, reliance on carcass-based fatality monitoring severely limits the extent to which curtailment can be used as a management tool to manage risk to bats.

The overarching goal of this study was to explore the efficacy of acoustic bat exposure as an alternative measure of curtailment effectiveness with several advantages over carcass monitoring. Temporal and seasonal distribution of bat activity documented by turbine-mounted acoustic detectors were consistent among sites (see Section 2), supporting the concept that such patterns could form the basis of designing activity-based informed curtailment strategies, as was also apparent in summary of existing data conducted during the first phase of this project (Peterson et al. 2021). As outlined in Section 3, acoustic exposure was able to document whether curtailment was implemented properly at individual turbines, and

[4] The cost of daily searches at full plots would have far exceeded funding available for this project. As outlined in Section 3, daily searches of 140 x 140 m plots with transects spaced at 5 m intervals would have required 60,961 linear km of transects walked, or 30,480 hours of walking (assuming a moderate pace of 2 km per hour) each year.

clearly demonstrated effectiveness of blanket curtailment at preventing turbine operation when bats were active across a range of facilities. By contrast, the combination of full plot and road and pad carcass searches employed in this study was unable to measure consistent reductions in bat mortality estimates from curtailment (see Section 3). A parallel study, using substantially more intensive search protocols (daily searches with trained dog teams) documented reductions in bat mortality rates that were similar to reductions in acoustic exposure we documented at Orient (EPRI 2024). This result corroborated the relevance of acoustic exposure as a quantitative indicator of bat mortality, as was also established in the first phase of this research (see Peterson et al. 2021).

Perhaps most useful in the context of managing risk to bats at commercial wind energy facilities is the ability to simulate curtailment strategies enabling calculation of acoustic exposure for turbines as if they had been operated according to different curtailment strategies, as demonstrated in Section 3.0 and 4.0. This helps address challenges of sample size and simplifies study design by lessening or even eliminating the need for operational controls. Simulations used in Section 4.0 enhanced the ability to compare blanket curtailment and an activity-based smart curtailment strategies across a wider range of facilities and with a more robust dataset than was possible with measured exposure or with results of carcass searches.

Section 4.0 simulated three operational strategies (control operation, blanket curtailment, and an activity-based informed curtailment alternative), all of which were implemented at selected facilities, enabling a comparison of measured and simulated exposure. As was the case in Peterson et al. (2021), measured and simulated exposure were closely aligned, indicating that wind turbines turn on and off predictably according to a set of predetermined parameters; so long as these parameters are understood, curtailment can be simulated and evaluated using wind speed and temperature data recorded at turbine nacelles at 10-minute intervals. In a similar study of acoustic exposure at a pair of wind energy facilities in Missouri, measured and simulated exposure were also similar across a range of blanket curtailment strategies with cut-in wind speeds ranging from 3.0–8.0 m/s (Peterson et al. in review).

In this section, we simulated a wider range of curtailment strategies with cut-in speeds ranging from 5.0–8.0 m/s to better understand inter-site variation in energy loss and effectiveness of curtailment. Based on the exponential relationship between wind speed and energy generation (Spiru and Simona 2024), we predicted that the potential differences in energy loss between blanket curtailment and smart curtailment alternatives would be greater as the cut-in speed (and associated protectiveness of bats) increased. As in previous sections, this analysis was exploratory, focusing on quantifying variation in energy loss and exposure reduction among facilities, years, and strategies.

5.2 METHODS

5.2.1 Curtailment Simulation

We used the set of acoustic bat data and turbine operation data described in Section 2 to simulate reduction in acoustic exposure and energy loss associated with four blanket curtailment strategies with cut-in speeds 5.0 m/s, 6.0 m/s, 7.0 m/s, and 8.0 m/s applied from sunset to sunrise above a temperature threshold of 10°C between 15 July–30 September. We selected these cut-in speeds to illustrate a range of acoustic exposure and energy loss scenarios with moderate to high levels of risk reduction that could establish targets for comparable activity-based informed alternatives. We simulated blanket curtailment by categorizing 10-minute intervals as meeting or not meeting the parameters of each strategy and then calculated acoustic exposure and energy loss following the same methods described in Section 4.2.3 for each treatment on a per-turbine, per-site basis.

We plotted the cumulative biweekly exposure and simulated acoustic exposure versus simulated energy loss based on the power curve method for each blanket curtailment strategy at each site (pooling data across years) following methods outlined in Section 4.2.3 using a custom data visualization tool developed using R Shiny (Chang et al. 2024). As described above, we limited the dataset used to simulate cumulative biweekly exposure and energy loss to detectors that functioned for 39 or more nights (50% of the period) within the 15 July–30 September curtailment period. We configured the data visualization tool to set cut-in wind speed and temperature thresholds for activity-based informed curtailment strategies over customized data ranges and time of night and selected parameters that achieved comparable levels of exposure as each blanket strategy with less energy loss, following a similar qualitative approach as described in Section 4.2.3. For each blanket curtailment strategy, we attempted to design a single activity-based curtailment alternative that would accomplish these goals across all sites.

We used the percent of acoustic exposure associated with simulated blanket strategies to establish targets for smart curtailment alternatives. Either the percent exposure or the cumulative biweekly rate of exposed bat passes could be used as a target for designing equivalently protective smart curtailment alternatives; we considered both when exploring alternatives but focused on the percent of bats avoided by each strategy. We assessed inter-site variation in blanket curtailment effectiveness but designed a single smart curtailment alternative for each blanket strategy to be applied at all sites.

We designed four smart curtailment alternatives (one for each blanket strategy) that adjusted cut-in wind speeds higher or lower than the corresponding blanket cut-in speed on a monthly or biweekly basis to match the seasonal distribution of bat activity observed across sites. We also delayed the start of curtailment 30 minutes after sunrise in some cases and ended curtailment 90 minutes before sunrise in all cases, as outlined in Table 5-1. The smart alternative we designed for the blanket 5.0 m/s strategy in this simulation exercise differed slightly from what was implemented and simulated in Sections 3.0 and 4.0 of this report.

Table 5-1. Seasonal timing and cut-in speeds for blanket curtailment treatments and smart alternatives applied to the 15 July–30 September curtailment window using simulated exposure measurements for 13 MidAmerican wind energy facilities in Iowa for 2022 and 2023.

Treatments	Date Range			
	Jul 15–31	Aug 1–31	Sep 1–15	Sep 16–30
Operational Control	3.0–3.5 m/s (turbines feathering below manufacturer's standard cut-in speed)			
Blanket 5.0	5.0 m/s cut-in speed applied from sunset to sunrise at temperatures above 10°C			
Smart 5.0	5.0 m/s cut-in above 10°C, 30 mins after sunset–90 mins before sunrise	5.5 m/s cut-in above 10°C, sunset–90 mins before sunrise	4.5 m/s cut-in above 10°C, 30 mins after sunset–90 mins before sunrise	3 m/s cut-in above 10°C 30 mins after sunset–90 mins before sunrise
Blanket 6.0	6.0 m/s cut-in speed applied from sunset to sunrise at temperatures above 10°C			
Smart 6.0	6.0 m/s cut-in above 10°C, 30 mins after sunset–90 mins before sunrise	6.75 m/s cut-in above 10°C, sunset–90 mins before sunrise	5 m/s cut-in above 10°C, 30 mins after sunset–90 mins before sunrise	4 m/s cut-in above 5°C, 30 mins after sunset–90 mins before sunrise
Blanket 7.0	7.0 m/s cut-in speed applied from sunset to sunrise at temperatures above 10°C			
Smart 7.0	6.5 m/s cut-in above 10°C, 30 mins after sunset–90 mins before sunrise	7.5 m/s cut-in above 10°C, sunset–90 mins before sunrise	7 m/s cut-in above 10°C, 30 mins after sunset–90 mins before sunrise	5 m/s cut-in above 5°C, 30 mins after sunset–90 mins before sunrise
Blanket 8.0	8.0 m/s cut-in speed applied from sunset to sunrise at temperatures above 10°C			
Smart 8.0	7.5 m/s cut-in above 10°C, 30 mins after sunset–90 mins before sunrise	8.75 m/s cut-in above 10°C, sunset–90 mins before sunrise	7.5 m/s cut-in above 10°C, 30 mins after sunset–90 mins before sunrise	7.0 m/s cut-in above 5°C, 30 mins after sunset–90 mins before sunrise

5.2.2 Curtailment Comparison Evaluation

We calculated average cumulative acoustic exposure and energy loss with 95% confidence intervals for each simulated blanket curtailment strategy and activity-based curtailment alternative for each site and year, pooling data among turbines, to evaluate how consistently the activity-based alternative was able to yield comparable reductions in exposure for less associated energy loss among sites and years. We used this feedback to explore the extent to which site-specific modifications of the activity-based curtailment parameters could further reduce energy loss while achieving equivalent levels of exposure reduction. We calculated the average energy loss per turbine and used t-tests to determine if energy loss was significantly different between each blanket strategy and its comparable activity-based strategy. We fit a log-linear regression for the difference in energy loss between blanket curtailment strategies and their activity-based counterparts as a function of their associated amount of acoustic avoidance (the inverse of acoustic exposure that refers to the percent of bat passes that would be protected from turbine operation by the curtailment strategy) by site to determine whether potential energy savings vary according to the targeted level of reduction.

5.3 RESULTS

Blanket curtailment strategies with cut-in speeds ranging from 5.0–8.0 m/s reduced the rate of cumulative biweekly acoustic exposure by 39.0–85.1% relative to the simulated operational control strategy, averaging data among facilities. As was the case for the blanket curtailment strategy actually implemented at a subset of the 13 facilities we studied, the percent of bat passes exposed under each blanket strategy (Figure 5-1) was similar among sites whereas the cumulative biweekly rate of exposure (Figure 5-2) exhibited greater variation among sites.

The smart curtailment alternatives avoided a similar percent of bat activity as their corresponding blanket curtailment strategies across most facilities and years (Figure 5-3). Inter-annual variation in acoustic exposure between blanket and smart alternatives was similar to inter-site variation, suggesting that the smart curtailment strategies performed reasonably well under a range of conditions. Energy losses were lower for smart curtailment alternatives than equivalently protective blanket strategies in almost all cases (Figure 5-3), and the differences in energy loss between each pair of blanket and smart strategies were statistically significant (Figure 5-4). The amount of additional energy production associated with smart curtailment alternatives increased exponentially as a function of the margin by which strategies reduced acoustic exposure relative to control operation (Figure 5-5).

Variation in acoustic exposure among facilities and years decreased as a function of increasing protectiveness of the curtailment strategies, while the opposite was true for energy loss (Figure 5-5). In other words, slight adjustments to blanket strategies with 5.0 m/s cut-in speeds can make substantial differences in protectiveness of the resulting smart strategy with little impact on energy losses, whereas adjusting cut-in speeds for blanket strategies with 8.0 m/s cut-in speeds have a dramatic impact on energy losses but result in minimal differences in acoustic exposure.

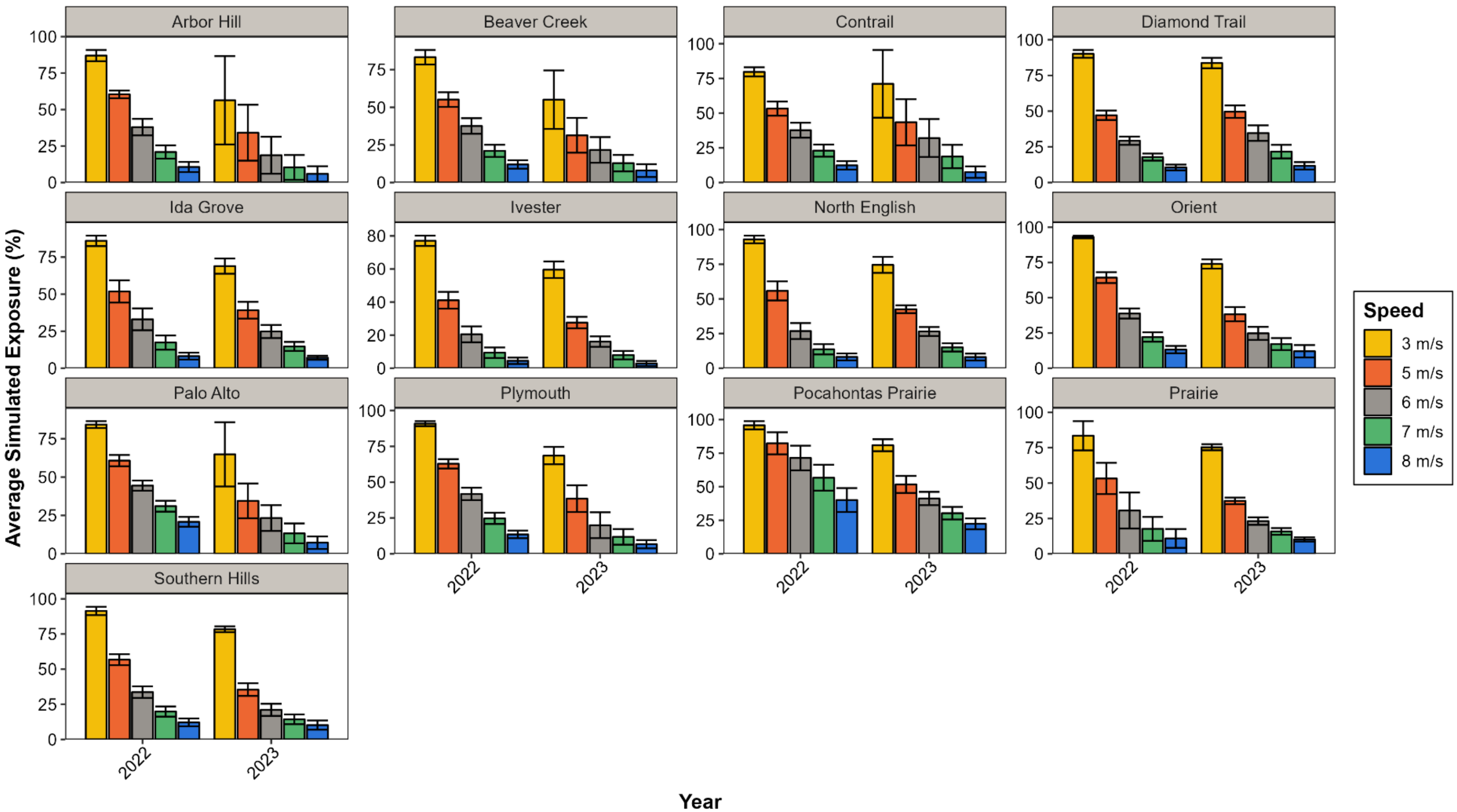

Figure 5-1. Average simulated acoustic exposure expressed as a percent of recorded passes for different simulated blanket curtailment strategies based on nacelle-height acoustic data recorded at 13 MidAmerican facilities in Iowa, 2022–2023. The 3.0 m/s strategy represents the operational control treatment implemented at MidAmerican sites during the monitoring period. Error bars represent 95% confidence intervals around the mean.

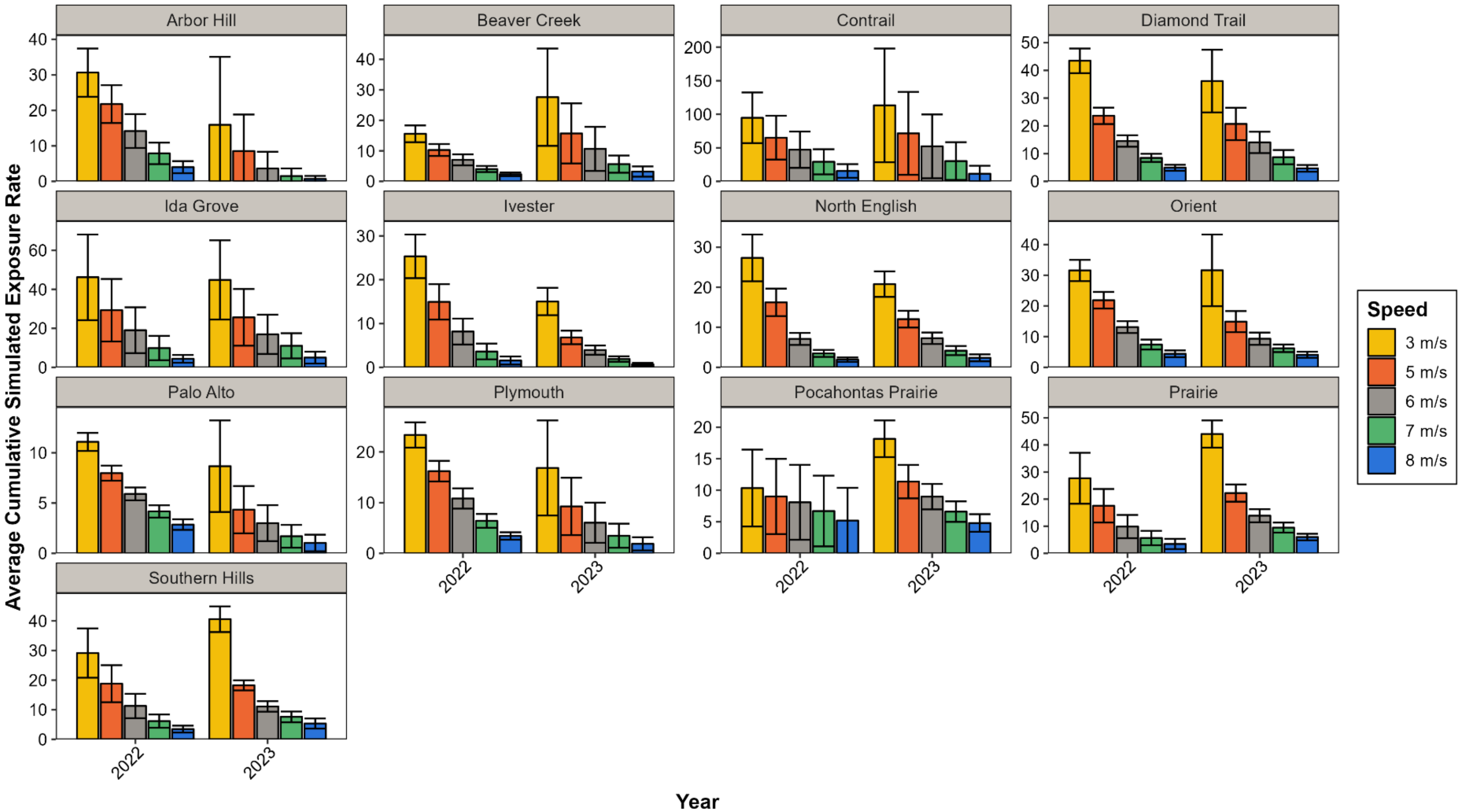

Figure 5-2. Simulated acoustic exposure expressed as a cumulative biweekly rate of exposed passes per detector night for simulated blanket curtailment strategies based on nacelle-height acoustic data recorded at 13 MidAmerican facilities in Iowa, 2022–2023. The 3.0 m/s strategy represents the operational control treatment implemented at MidAmerican sites during the monitoring period. Error bars represent 95% confidence intervals around the mean.

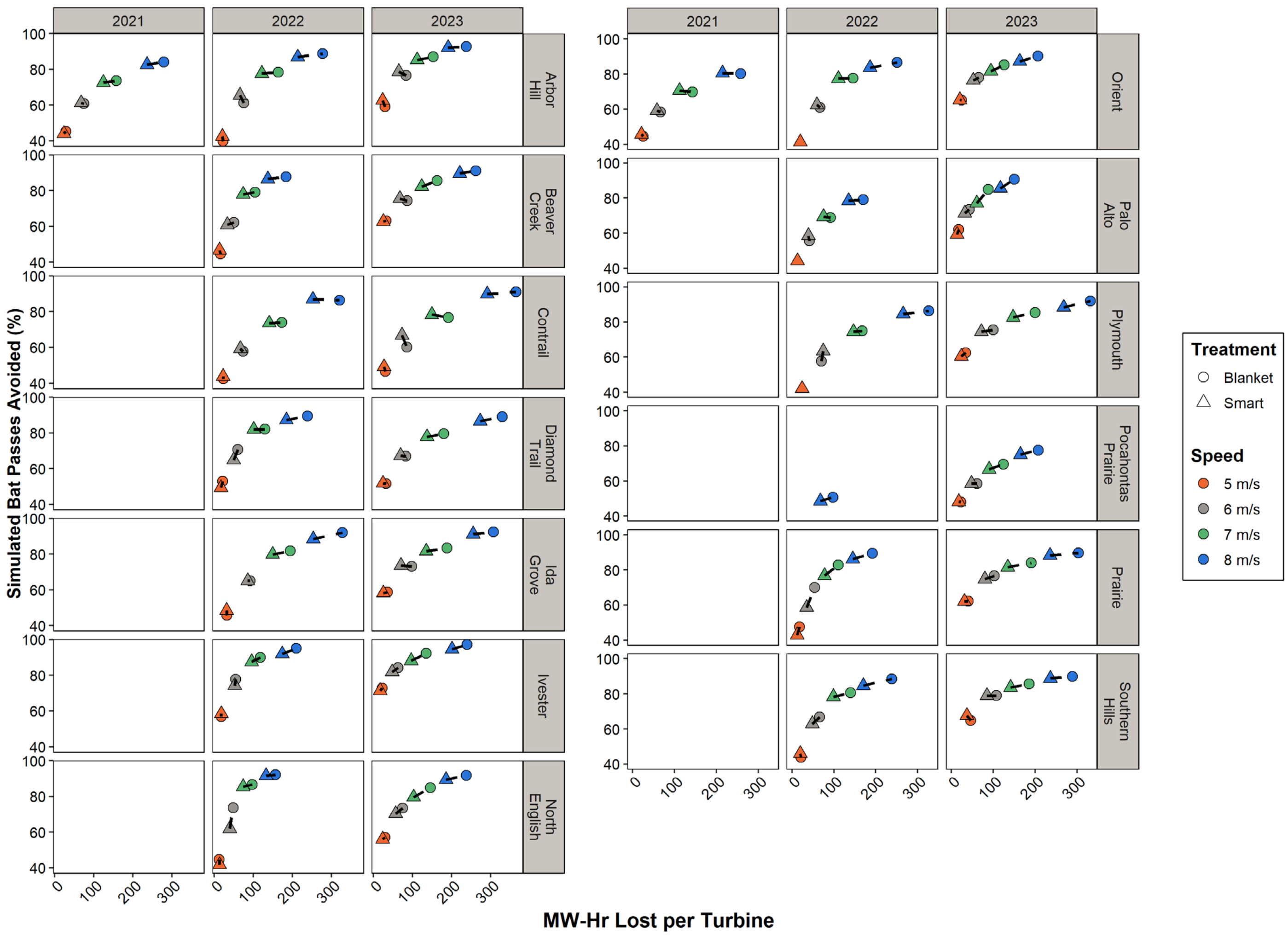

Figure 5-3. Percent of simulated bat passes avoided during simulated blanket curtailment strategies, and smart curtailment strategies that curtail at the same speed as the blanket strategy, and the associated energy loss (MW per hour) due to either strategy for curtailment at 13 MidAmerican wind energy facilities in Iowa, 2021–2023.

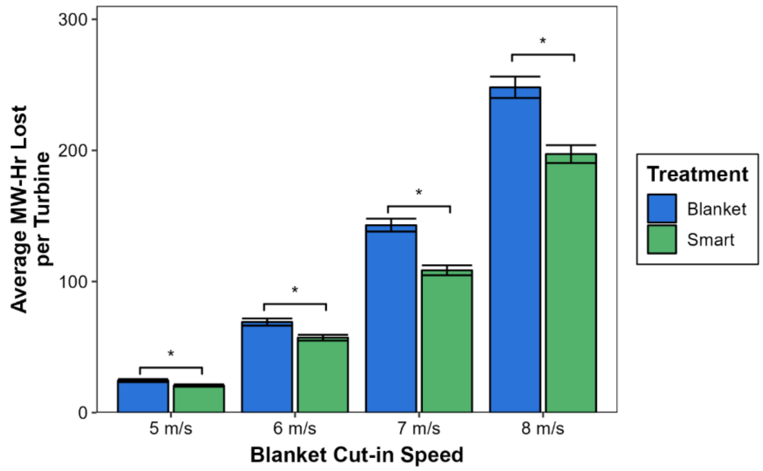

Figure 5-4. Average energy loss (MW per hour) per turbine (across the 13 sites and years) during simulated blanket curtailment strategies, and smart curtailment strategies that curtail at the same speed as the blanket strategy at 13 MidAmerican wind energy facilities in Iowa, 2021–2023. Error bars represent 95% confidence intervals around the mean, with asterisks indicating significant differences between means based on a t-test.

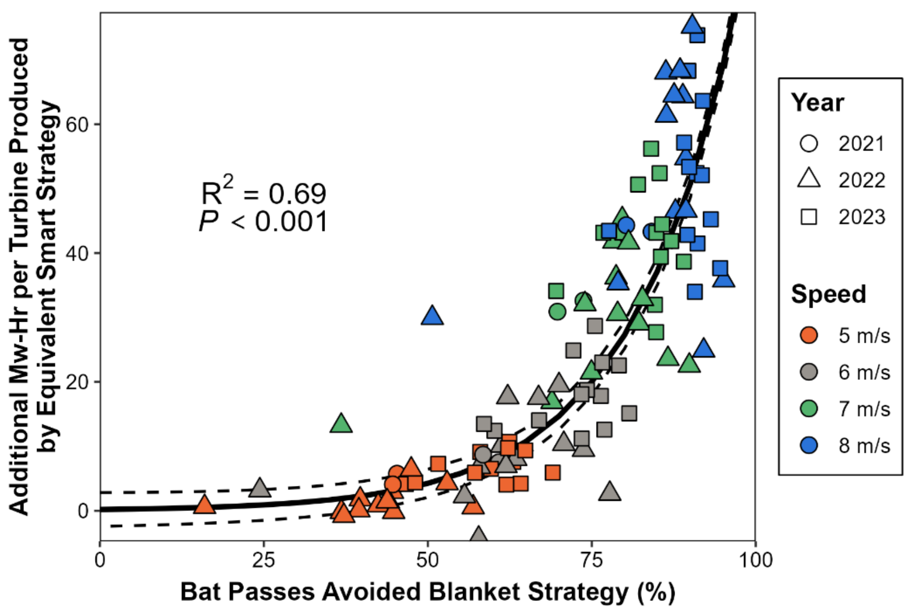

Figure 5-5. Difference in energy production between equivalently protective smart and blanket curtailment strategies by facility and year at 13 MidAmerican wind energy facilities in Iowa, 2021–2023. Solid lines indicate the fitted linear regression and dashed lines are the 95% confidence intervals of the regression.

5.4 DISCUSSION

Energy losses associated with curtailment inevitably increase with cut-in wind speed, as does the margin by which curtailment reduces risk of turbine-related impacts to bats. Any curtailment strategy other than complete turbine shutdown therefore represents a compromise between risk reduction and energy loss. The blanket strategy implemented at a subset of the 13 facilities we monitored in Iowa used a 5.0 m/s cut-in speed applied from 15 July–30 September; this strategy effectively reduced acoustic exposure by an average of 52.8% relative to control operation across sites and resulted in annual mean energy loss of ~ 38 MW-hr per turbine per facility (~0.5% of annual energy production; see Section 3.3.2). The strategy was originally designed to encompass the range of dates in which most bat carcasses were found across other wind energy facilities in Iowa where previous carcass monitoring occurred (MidAmerican 2019) but used a single cut-in speed throughout this period. This study demonstrated that activity-based informed curtailment alternatives whose cut-in wind speeds and start/stop times more closely aligned with patterns in bat activity measured acoustically at the sites could be equivalently protective while resulting in less energy loss. The relative difference in energy loss between blanket and smart curtailment alternatives was greater for more protective curtailment strategies, highlighting that the relative benefits and costs of implementing smart curtailment will depend on site-specific objectives for managing risk to bats.

By simulating acoustic exposure and energy loss associated with a range of blanket strategies and smart alternatives, we demonstrated an exponential increase in the difference in energy loss between blanket and smart alternatives at higher cut-in speeds. Our simulations revealed an interesting pattern that variation in acoustic exposure among facilities and years was greater for curtailment strategies with ~5 m/s cut-in speeds than for curtailment strategies with ~8 m/s cut-in speeds while the opposite was true of energy loss. This pattern is perhaps not surprising, as bat activity tends to be concentrated at relatively low cut-in speeds, and slight adjustments to cut-in speeds from 3.5–5.5 m/s have a far greater impact on acoustic exposure. By contrast, fewer bats are active when wind speeds are 7.5–8.5 m/s, but the implications for energy loss are much greater when adjusting cut-in speeds in this range. Simply put, it is substantially more costly to protect bats flying at higher wind speeds than it is to protect bats flying at low wind speeds. Fortunately, many more bats are active when wind speeds are lower, when it is less costly to protect them.

The approach to smart curtailment explored in this study, known generically as activity-based informed curtailment, uses temporal and seasonal patterns in acoustic bat activity and relationships between bat activity and weather variables as the basis for designing curtailment strategies that reduce bat exposure by a targeted level while attempting to minimize associated energy loss (Peterson et al. 2021). This strategy depends on accurate characterization of bat activity patterns and an understanding of their variability. The seasonal and temporal distribution of bat activity was consistent among facilities and years in our study, as were relationships with temperature and wind speed. As a result, the same adjustments to curtailment strategies were generally effective across all sites and years. Facility-specific adjustments to parameters of the smart curtailment alternatives may have yielded marginal reductions in energy loss and/or acoustic exposure in some instances, but variation in energy loss and exposure reduction was relatively small and evenly split between facilities and years.

The seasonal and temporal distribution of rare bat activity (represented as passes visually confirmed as *Myotis* species and tricolored bats) and associated relationships with wind speed and temperature were indistinguishable from those based on all species combined. As a result, the curtailment strategies we simulated were as effective for rare bats as other species. Given the small number of bat passes that could be identified as rare bat species recorded in our study, we suggest that metrics of acoustic exposure based on all recorded bat passes will be more reliable than those based on individual species; provided that available data do not suggest systematic differences in the seasonal or temporal distribution of acoustic activity among species. This pattern may not necessarily apply to other regions where tricolored bats and/or *Myotis* species may be more numerous and/or better represented in acoustic datasets from turbine-mounted detectors, highlighting the importance of comparing seasonal, temporal, and weather-related distributions of rare species to those of all bats before deciding whether to design and evaluate curtailment around target species or all species combined.

Simulations emphasized that minor adjustments to cut-in speeds and the start/stop times for curtailment can yield significant reductions in energy loss. We limited our smart curtailment alternatives to the same season as blanket curtailment (15 July–30 September) but recognize that bats are at risk of turbine-related impacts outside this period as well. Extending the start and end dates of smart curtailment alternatives and applying low cut-in speeds could likely have reduced energy losses further while providing equivalent levels of risk reduction as more seasonally restricted blanket strategies.

Simulating the cost and effectiveness of blanket curtailment strategies with cut-in wind speeds ranging from 5.0–8.0 m/s emphasized the same pattern discussed in Section 4.0 of this report that curtailment reduced exposure by a similar margin across facilities but that variation in the magnitude of exposure was greater among sites. More bat passes would have been exposed to turbine operation at Contrail under an 8.0 m/s blanket curtailment strategy than at Palo Alto without curtailment during 2022 or 2023. While acoustic exposure may or may not provide a consistent indication of fatality risk among facilities, the pronounced differences in acoustic exposure we documented among sites suggests that applying a single strategy across facilities misses an opportunity to manage risk strategically across a fleet. Similar to how adjusting cut-in speeds up or down on a monthly basis to align with bat activity can yield equivalent reductions in exposure for less energy loss, applying higher cut-in speeds at sites with higher rates of acoustic exposure and reducing cut-in speeds at sites with lower rates of acoustic exposure could yield greater reductions in cumulative bat fatalities for less overall energy loss, although such a strategy would result in disproportionately higher levels of energy loss as some facilities than others.

The parameters we adjusted to design activity-based curtailment alternatives were limited to monthly, or in some cases biweekly increases or decreases in cut-in speed 0.25–1 m/s higher or lower than blanket cut-in speed and delaying start of curtailment until 30 minutes past sunset and ending curtailment 60–90 minutes before sunrise. Ultimately, these adjustments acknowledge what has long been known about bat behavior and turbine-related fatalities; most fatalities are concentrated in a brief seasonal window in late summer and early fall, and bats tend to not be very active immediately after sunset or close to sunrise. Adjusting curtailment parameters to match these patterns, both of which are strongly rooted in theory and empirical data, represent obvious first steps in improving curtailment efficiency. More complex combinations of variables could certainly yield slight additional increases in efficiency, but a tradeoff undoubtedly exists between the minimizing complexity of a curtailment alternative and avoiding overfitting parameters to data used to design the strategy.

More important than the specific adjustments to curtailment parameters needed to improve curtailment efficiency is the ability to use acoustic exposure as the basis for curtailment design and evaluation. This study was able to provide a detailed breakdown of how multiple curtailment strategies would have worked for individual turbines, subsets of operational treatments, and sites across multiple years. We were able to demonstrate that slight adjustments to curtailment strategies can allow for additional energy production while maintaining the same level of fatality reduction as a blanket curtailment alternative across a wide range of facilities representing different turbine manufacturers and models. This highlights the ability to transform how curtailment strategies are designed and evaluated while highlighting the potential for wind energy facility operators to achieve targeted reductions in risk using curtailment strategies tailored to their site-specific patterns in risk as opposed to blanket strategies.

6.0 CONCLUSIONS

- Seasonal and temporal distribution of bat activity and relationships with temperature and wind speed were similar among facilities and years.
- Bat detectors at ground level record substantially more bat passes than detectors at nacelle-height; species composition differed between positions, but seasonal and temporal patterns and relationships with wind speed and temperature were similar at nacelle height and ground level.
- *Myotis* species and tricolored bats represented very small proportions of recorded bat activity, but the seasonal and temporal distribution of these species/groups was similar to those of all species combined.
- Comparing simulated versus measured acoustic exposure identified cases where curtailment strategies were not implemented as assigned on a turbine-by-turbine basis; our results demonstrate the need to validate proper implementation of curtailment and show how acoustic data are useful in this process.
- Curtailment (blanket and smart treatments) reduced acoustic exposure by a consistent margin across sites and years, while the magnitude of acoustic exposure varied among sites.
- Fatality estimates based on weekly road and pad searches and twice weekly full plots at ~5–15 turbines per treatment were insufficiently accurate to detect the effect of curtailment.
- Acoustic exposure and fatality estimates were not correlated at the treatment or facility level but were positively correlated on a biweekly basis.

- Hoary bats accounted for most acoustic exposure while eastern red bats accounted for most fatalities; differences in species composition between datasets may be due to vertical stratification of species composition (detectors record at nacelle height while fatalities likely occur more frequently in the lower part of the rotor-swept zone), greater detection range of lower-frequency detectors, or other behavioral differences affecting collision risk and echolocation behavior.
- A smart curtailment alternative to blanket curtailment below 5.0 m/s, based on data from Orient and Arbor Hill in 2021, resulted in equivalent reductions in acoustic exposure with slightly less energy loss when applied across facilities.
- Simulating curtailment allowed us to evaluate acoustic exposure and energy loss of blanket curtailment and the smart alternative as if they had been applied across all sites; the smart alternative would have yielded equivalent reductions in exposure for less energy loss in almost every annual dataset.
- Simulating blanket curtailment strategies with cut-in speeds from 5.0–8.0 m/s and corresponding smart alternatives revealed an exponential increase in the difference in energy loss between blanket and smart alternatives at higher cut-in speeds.
- Acoustic detectors performed accurately at nacelle-height when connected to a reliable source of power; equipment failure and data loss occurred for a variety of reasons, with more damage to equipment during winter months, but 15 detectors provided adequate spatial coverage and replication in most cases.

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Appendix A

Acoustic Bat Activity, Turbine Operation, and Bat Fatality at Commercial Wind Projects

A reanalysis of results of nacelle-height acoustic monitoring at two West Virginia wind farms

April 29, 2020

Prepared for:

US Department of Energy
EERE

Prepared by:

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Executive Summary

Widespread fatalities of bats at commercial wind energy facilities across North America have prompted substantial efforts by the wind industry, researchers, and managers alike to better understand factors affecting fatality risk and develop measures to minimize such risk. Wind turbines pose a risk to bats only when their rotors are spinning, and turbine-related fatality risk is therefore a dynamic factor that can be manipulated by curtailing turbine operation when bats are active. We used acoustic detectors mounted on top of wind turbines to monitor bat activity in the rotor zone of turbines at two commercial wind farms in West Virginia. Both wind farms implemented multiple curtailment strategies and conducted concurrent bat fatality monitoring, providing an opportunity to explore relationships between acoustic bat activity and fatality under different operational scenarios. Stantec conducted additional analyses of data from each site, providing an empirical foundation to the approach we have proposed in our smart curtailment research program. This report summarizes the methods and results of this analysis, which has been conducted as part of the first phase of smart curtailment research program funded by the US Department of Energy (Award DE-EE0008728).

We found that the amount of bat activity exposed to turbine operation aligned closely with bat fatality rates on multiple scales, indicating that exposed activity provides a meaningful, quantitative indicator of turbine-related risk to bats. Bats responded consistently to changing wind speed and temperature, and seasonal activity patterns were stable among years at both sites, underlying the ability to predict exposure accurately among turbines and years. Building on these results, we simulated exposure of bats to turbine operation under various curtailment strategies recommended by state and federal agencies in the United States and Canada. We were able to reduce the simulated energy losses of curtailment plans by an average of more than 40% while maintaining equal or better protection of bat activity simply by making relatively minor adjustments to cut-in wind speeds and temperature thresholds on a monthly basis. These results provide empirical support for use of acoustic data recorded at nacelle height to characterize risk of turbine-related impacts to bats and design smart curtailment strategies that focus curtailment on conditions with highest risk. Collection of similar data in other geographic regions will allow a more rigorous test of the assumptions underlying this approach to smart curtailment and will provide a broader context for our preliminary results. Stantec's proposed smart curtailment research will include acoustic and fatality monitoring in 2020 and 2021 at 2 additional commercial wind farms in the Midwest.

1.0 INTRODUCTION

Widespread fatalities of bats at commercial wind energy facilities across North America have prompted substantial efforts by the wind industry, researchers, and managers alike to better understand factors affecting fatality risk and develop measures to minimize such risk. Turbine-related bat fatalities occur only when turbine rotors are spinning (Arnett et al. 2016), and feathering turbine blades to curtail operation at low wind speeds effectively reduces fatality risk. Baerwald et al. (2009) first reported reductions in bat fatalities resulting from curtailing turbines at low wind speeds, and Arnett et al. (2010) also demonstrated effectiveness of curtailment, noting similar reductions at turbines with cut-in wind speeds of 5.5 and 6.5 meters per second (m/s). Subsequent curtailment studies have demonstrated variable reductions in bat fatality rates for cut-in speeds ranging from 3.5 to 6.9 m/s (Arnett et al. 2013, American Wind and Wildlife Institute [AWWI] 2018). Although effective at reducing bat fatality, curtailing turbine operation also eliminates the ability to generate renewable electricity, and the cost of curtailment increases as an approximately cubic function of wind speed between normal cut-in speeds and ~12–15 m/s (Carrillo et al. 2013). Accordingly, wind farm operators seek to minimize the amount of curtailment but often lack empirical evidence to justify lower cut-in speeds, shortened periods of curtailment, or incorporation of parameters other than wind speed.

Stantec proposed a study to evaluate use of acoustic bat data recorded passively in the rotor zone of wind turbines to characterize risk of turbine-related bat fatality at commercial wind farms and design strategic curtailment programs that prevent turbine operation when risk is greatest. As a first phase of this research (US Department of Energy Award # DE-EE0008728), we have prepared this report summarizing results of similar work conducted at two commercial wind farms in West Virginia between 2011 and 2018. Unlike carcass searches, which are labor intensive and provide results at a coarse temporal scale, acoustic detectors can operate passively for long periods of time (e.g., months to years) and provide temporally precise information on bat activity within a surveyed area.

Previous efforts to compare bat activity with risk of turbine-related bat fatality have found inconsistent relationships between activity and risk. Hein et al. (2013) found no significant relationship between pre-construction bat activity levels and subsequent fatality estimates in an analysis of results from 12 wind energy facilities with paired data. The magnitude of pre-construction acoustic bat activity and fatality during operation showed no relationship across 12 wind energy projects in Pennsylvania, although seasonal patterns in bat activity and fatality were consistent (Taucher et al. 2012). By contrast, Baerwald and Barclay (2009) noted a significant association between pre-construction bat activity and fatalities among 5 sites in Alberta and reported significant relationships between bat activity and fatalities on a nightly basis (Baerwald and Barclay 2011). Johnson et al. (2011) also reported a correlation between regional trends in nightly acoustic bat activity and fatalities.

Given the inconsistent results of prior efforts to link acoustic bat activity and fatality risk, we have analyzed data collected at the Laurel Mountain Wind Facility (Laurel Mountain) from 2011 to 2015 and at the New Creek Wind Project (New Creek) in 2017 and 2018 to provide empirical context and support for our proposed research. We have prepared this report to summarize the methods and results of the analysis conducted during this initial phase of our study for internal review by the Department of Energy team. We received permission from the operators of each facility to aggregate data from both sites and intend to incorporate these results into one or more manuscripts for peer review. These results have also been incorporated into a dissertation written by Trevor Peterson, the primary author of this document and the principal investigator.

The five primary objectives of the analyses are to:

- Compare bat fatality to bat activity measured acoustically at nacelle height;
- Compare simulated and measured bat activity exposure to evaluate the ability to predict curtailment effectiveness;
- Measure the consistency of distribution of bat activity at nacelle height versus temperature and wind speed across sites, years, turbines, species, and seasons;
- Demonstrate how nacelle-height acoustic and weather data can be used to simulate cost and effectiveness of curtailment strategies; and
- Compare suitability of different acoustic data analysis methods (e.g., visual versus automatic identification) for predicting and evaluating curtailment.

2.0 METHODS

2.1 STUDY SITES

Data analyzed in this report were collected at two commercial wind projects on forested ridgelines in the northeastern part of West Virginia. Laurel Mountain is a 97.6-megawatt (MW) wind farm spanning approximately 20 km along the ridgeline of Laurel Mountain, which forms the border between Randolph and Barbour counties. Laurel Mountain consists of 61 1.6-MW GE XLE turbines arranged in a single string at elevations ranging from 780 to 945 m above sea level (Figure 2.1). Each turbine has an 80-m hub height (the height at which the nacelle is mounted on the tower) with an 82.5-m rotor diameter such that the rotor zone extends from approximately 39–122 m above ground level. During normal operation, these turbines rotate at speeds ranging from 10 to 18 revolutions per minute (rpm) between the manufacturer's cut-in wind speed of 3.5 m/s and the maximum wind speed of 25.0 m/s, and often freewheel (rotate without generating electricity) at wind speeds less than 3.5 m/s. Other than synchronized flashing red beacons on 22 of the turbines, the turbines themselves do not have any lighting. Mature hardwood forests under various commercial harvest regimes occur across most of the ridgeline and relatively steep side slopes, with no extensive wetland features or exposed rocky talus slopes along the ridgeline.

New Creek is a 103-MW wind farm located on approximately 11 km of forested ridgeline on New Creek Mountain in Grant County, West Virginia (Figure 2.2). The ridgeline elevation within New Creek is approximately 900 m above sea level, with elevations in the surrounding valleys ranging from 400 to 450

m. New Creek includes 49 Gamesa turbines (45 model G97 and 4 model G90), each with a 2.0-MW capacity and 78-m hub height. The rotor diameters of the G97 and G90 turbines are 97 m and 90 m, respectively. During normal operation, these turbines rotate at speeds up to 17.8 rpm between the standard cut-in wind speed of 3.0 m/s and the maximum wind speed of 25.0 m/s. Other than synchronized flashing red beacons on 18 of the turbines, the turbines themselves do not have any lighting. New Creek Mountain is primarily forested, dominated by relatively short-canopy oak and scrub oak. Wetlands on New Creek Mountain are limited to a few ephemeral pools along existing roadways and a small pond at the south end of the site. The bedrock of New Creek Mountain consists of sandstone with several exposed rocky talus fields occupying much of the steep western slope of the mountain. The eastern slope is generally less steep and lacks exposed talus fields.

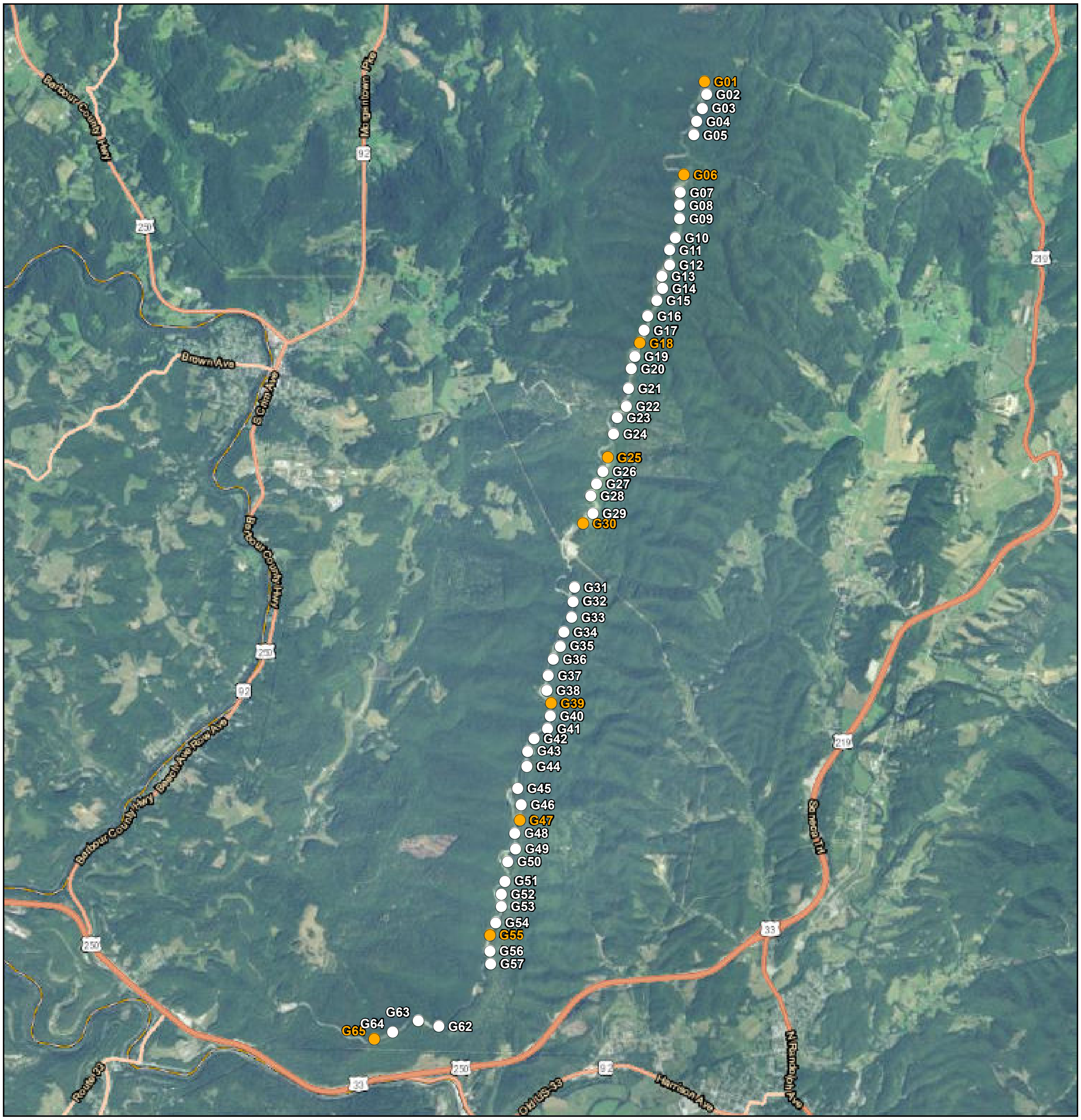
2.2 TURBINE CURTAILMENT

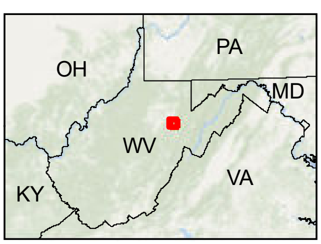
Laurel Mountain

Turbines at Laurel Mountain were operated under a variety of curtailment scenarios during various periods between 2011 and 2015. During the 2011–2012 survey period, which encompassed 15 August–30 November 2011 and 1 April–31 July 2012, 24 study turbines were divided among three operational treatments of 8 turbines each, consisting of feathering below manufacturer's cut-in speed of 3.5 m/s, increased cut-in speed of 4.5 m/s, and an operational control. These cut-in speeds were applied across all temperatures. Between 2013 and 2015, a restrictive curtailment system was applied to all turbines between April and November. Unlike blanket curtailment systems that use a single cut-in wind speed applied across all temperatures, this curtailment system applied progressively higher cut-in speeds at warmer temperatures. Multiple curtailment system parameters were modified after 2013 to focus on a narrower set of conditions, including capping the cut-in speed at 6.9 m/s in 2014 and 2015, lowering cut-in speeds during April (2015), and removing curtailment in November (2015; Table 2.1). A 30-minute buffer before sunset and after sunrise (updated weekly) also was removed in 2015. The turbine control system used real-time data from nacelle-mounted anemometers and temperature sensors at 2 on-site meteorological towers to automatically trigger curtailment of individual turbines during the prescribed combinations of temperature and wind speed.

New Creek

New Creek turbines were divided into 4 operational groups and curtailed at cut-in speeds ranging from 4.5 to 6.9 m/s depending on the time of year, with treatments applied sequentially to turbines (Table 2.2). Curtailment treatments were implemented between sunset and sunrise (updated weekly) and triggered automatically based on temperature and wind speed data recorded by instruments mounted on the nacelles of each turbine. During 2018 monitoring, 12 turbines were operated without curtailment (control) and 37 were operated according to a curtailment program based on acoustic data collected in 2017, which applied cut-in speeds ranging from 4.0 to 6.0 m/s depending on the time period (Table 2.2).





Legend
- Turbine Location
- Turbine Location with Acoustic Detector

0 7,000 Feet
(At original document size of 8.5x11)
1:84,000

N

Stantec

Project Location
Barbour and Randolph Counties
West Virginia

Prepared by REM on 2020-03-11
TR by KWH on 2020-03-13
IR Review by TP on 2020-03-00

Client/Project
Acoustic Research Study Plan
US Department of Energy

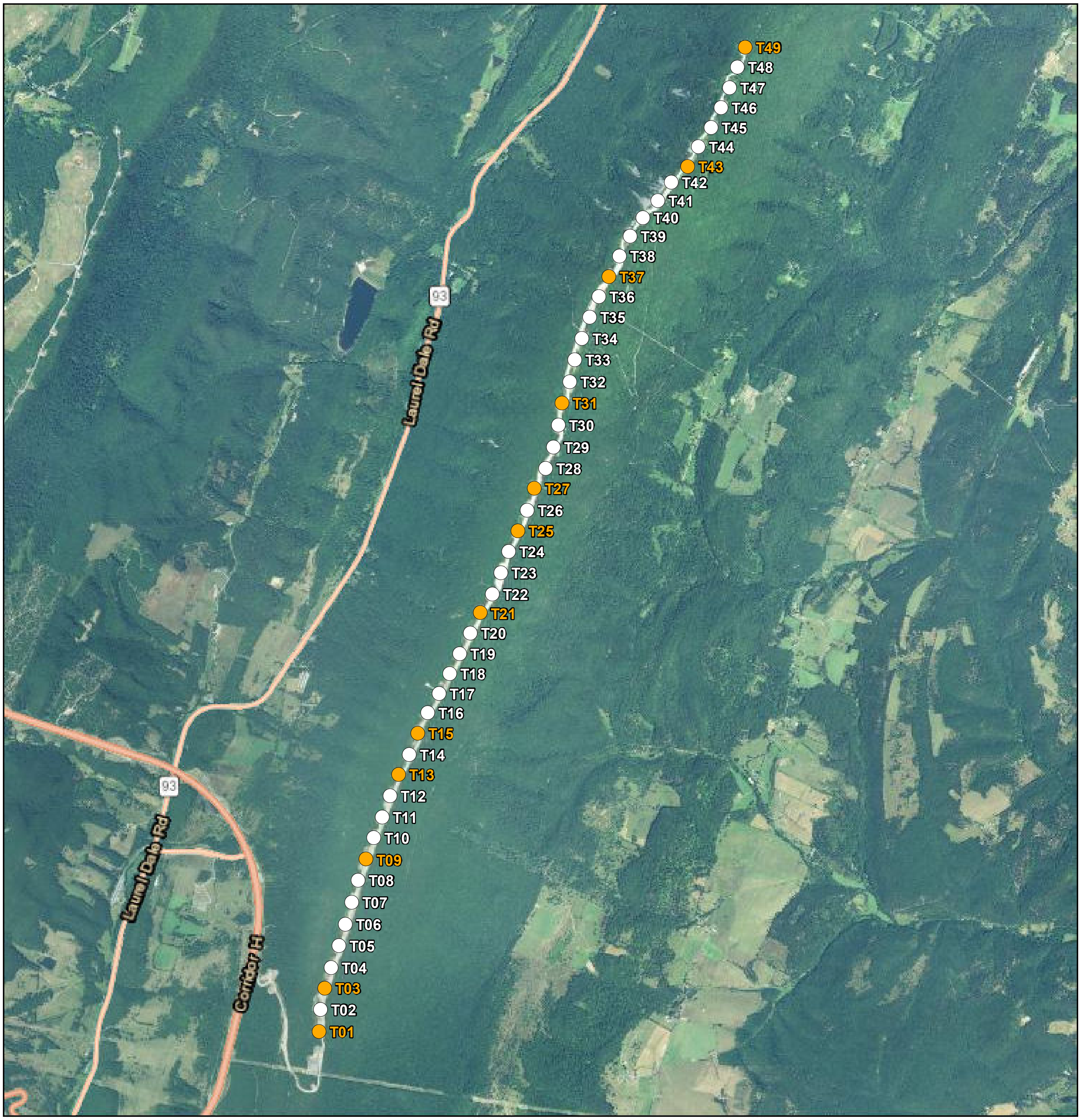
195601686

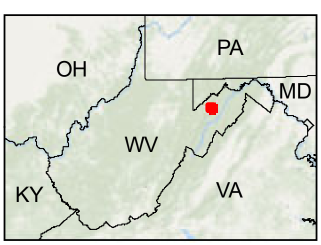
Figure No.
2.1

Title
Laurel Mountain Wind Project
Acoustic Monitoring Locations

Notes
1. Coordinate System: NAD 1983 UTM Zone 17N
2. Background: ESRI ArcGIS Online NAIP imagery web mapping service.

\\Us0241-ppfss01\workgroup\1956\active\195601686\03_data\gis_cad\gis\MXDs\Monitoring\01686_2-1_Laurel.mxd Revised: 2020-03-13 By: rmack





Legend

- Turbine Location
- Turbine Location with Acoustic Detector

0 5,000 Feet

(At original document size of 8.5x11)
1:60,000

N

Stantec

Project Location
Grant County
West Virginia

Prepared by REM on 2020-03-11
TR by KWH on 2020-03-13
IR Review by TP on 2020-03-00

Client/Project
195601686
Acoustic Research Study Plan
US Department of Energy

Figure No.
2.2

Title
New Creek Wind Energy Project
Acoustic Monitoring Locations

Notes
1. Coordinate System: NAD 1983 UTM Zone 17N
2. Background: ESRI ArcGIS Online NAIP imagery web mapping service.

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Table 2.1. Cut-in wind speeds of curtailment treatments applied at Laurel Mountain between 2011 and 2015.

Temperature	Study Period							
	2011 – 2012	Fall 2012		2013	2014	2015		
	15 Aug–31 Oct; 1 Apr–31 Jul	1 Aug–5 Sep*	6 Sep–15 Nov	1 Apr–15 Nov	1 Apr–15 Nov	1 Apr–30 Apr	1 May–31 Oct	1 Nov–15 Nov
> 15°C	control, 3.5 m/s, 4.5 m/s	shutdown	8.0 m/s	8.0 m/s	6.9 m/s	4.0 m/s	6.9 m/s	control
12.5–15°C	control, 3.5 m/s, 4.5 m/s	shutdown	7.5 m/s	7.5 m/s	6.9 m/s	4.0 m/s	6.9 m/s	control
10.0–12.5°C	control, 3.5 m/s, 4.5 m/s	shutdown	6.5 m/s	6.5 m/s	6.5 m/s	4.0 m/s	6.5 m/s	control
7.5–10.0°C	control, 3.5 m/s, 4.5 m/s	shutdown	5.5 m/s	5.5 m/s	5.5 m/s	4.0 m/s	5.5 m/s	control
< 7.5°C	control, 3.5 m/s, 4.5 m/s	shutdown	3.5 m/s	3.5 m/s	3.5 m/s	3.5 m/s	3.5 m/s	control

*All turbines at Laurel were fully curtailed at night (all wind speeds) during 1 Aug–5 Sep 2012, during which no fatality searches occurred.

Table 2.2. Cut-in wind speeds of curtailment treatments applied at New Creek in 2017 and 2018.

Temperature	Study Period						
	2017			2018			
	1 Apr–30 Jun	1 Jul–15 Oct	16 Oct–15 Nov	1 Apr–30 Jun	1 Jul–30 Sep	1 Oct–31 Oct	1 Nov–15 Nov
> 10°C	6.9 m/s	6.0 m/s, 6.9 m/s	4.5 m/s, 5.5 m/s, 6.0 m/s, 6.9 m/s	control, 5.5 m/s	control, 6.0 m/s	control, 5.0 m/s	control, 4.0 m/s
5–10°C	6.9 m/s	control, 6.0 m/s, 6.9 m/s	control, 6.9 m/s	control, 5.5 m/s	control, 6.0 m/s	control, 5.0 m/s	control, 4.0 m/s
≤ 5°C	6.9 m/s	control, 6.0 m/s, 6.9 m/s	control, 6.9 m/s	control	control	control	control

2.3 TURBINE OPERATION DATA

We obtained 10-minute mean rpm and wind speed data from each surveyed turbine and 10-minute mean temperature from turbines and on-site meteorological towers (met towers) during each study period. For Laurel Mountain, we used temperature data averaged between 2 met towers, and for New Creek, we used temperature data recorded externally at each turbine nacelle, as these were the temperature data referenced by corresponding turbine control systems. We removed spurious wind speed readings (e.g., < 0 m/s and > 30 m/s) and omitted sequences of 6 or more identical wind speed readings, which were indicative of anemometers becoming stuck at relatively low wind speeds. We calculated the energy generation potential associated with each 10-minute period during the study period by multiplying the wind speed by the standard power generation curve for a GE XLE 1.6-MW wind turbine, binned at 0.25 m/s wind speed increments (Laurel Mountain) and for Gamesa G90/G97 turbines, binned at 0.5 m/s wind speed increments (New Creek). We expressed energy loss associated with each treatment as the sum of potential energy during periods when turbines were curtailed divided by the total energy potential possible at night during the monitoring period.

2.4 STANDARDIZED CARCASS MONITORING

Standardized carcass monitoring occurred seasonally at subsets of turbines at Laurel Mountain in 2011–2015 and at New Creek in 2017–2018. Survey dates varied from year to year, although search methods remained consistent across turbines, years, and sites (Table 2.3). Trained observers visually scanned the ground on either side of marked, linear transects extending to the limits of the turbine search plots, with transects spaced at 5-m intervals at Laurel Mountain (Stantec 2013) and 4-m intervals at New Creek (Stantec 2019). Plot sizes were defined by the cleared area around each turbine or the limit of searchable terrain up to a maximum square plot, centered on the turbine and 90 m on a side. Periodic mowing occurred at Laurel Mountain to maintain visibility and carcass detection, whereas ground cover at New Creek was sufficiently sparse during the monitoring periods and mowing was not required.

The bat fatality rate per turbine was estimated separately for turbines in each operational treatment at each site using estimators that augmented the number of carcasses found during searches by incorporating results of site-specific bias trials and thereby accounting for imperfect carcass detection, carcass removal by scavengers, search interval, and the proportion of area that could be searched. Bat fatality estimates for all operational treatments at Laurel Mountain were generated using the “Shoenfeld method” (Shoenfeld 2004; Young et al. 2011) as described in Stantec 2016 whereas fatality was estimated for all treatments at New Creek using the “Huso estimator” (Huso 2010; Huso et al. 2012) at New Creek, as described in Stantec 2019. The Huso and Shoenfeld estimators have both been used frequently for estimating bat fatality rates and include the same general correction factors but make different assumptions about carcass detectability, persistence, and other factors (Bernardino et al. 2013).

Table 2.3. Standardized carcass monitoring survey effort for Laurel Mountain and New Creek, 2011–2018.

Site	Monitoring Period	Dates	Curtailment Cut-in Speeds (m/s)	# Turbines/Interval	Estimator	Reference
Laurel	2011/2012	15 Aug–31 Oct 2011; 1 Apr–31 Jul 2012	Control	12 turbines/3-day	Shoenfeld	Stantec 2013*
			4.5	12 turbines/3-day	Shoenfeld	Stantec 2013*
	2012	6 Sep–15 Nov	3.5–8.0 (based on temperature)	24 turbines/3-day	Shoenfeld	Stantec 2014
	2013	1 Apr–15 Nov	3.5–6.9 (based on temperature)	24 turbines/3-day	Shoenfeld	Stantec 2014
	2014	1 Apr–15 Nov	3.5–6.9 (based on temperature)	24 turbines/3-day	Shoenfeld	Stantec 2015
	2015	1 Apr–15 Nov	3.5–6.9 (based on temperature)	24 turbines /3-day	Shoenfeld	Stantec 2016
New Creek	2017	1 Apr–15 Nov	6.9	12 turbines/7-day	Huso	Stantec 2018
			6.0–6.9 (by season)	12 turbines/7-day	Huso	Stantec 2018
			5.5–6.9 (by season)	13 turbines/7-day	Huso	Stantec 2018
			4.5–6.9 (by season)	12 turbines/7-day	Huso	Stantec 2018
	2018	7 May–14 Nov	Control	24 turbines/7-day	Huso	Stantec 2019
			4.0–6.9 (by season)	25 turbines/7-day	Huso	Stantec 2019

*Fatality estimates for the first year of operation at Laurel were based on combined monitoring in fall 2011 (8 turbines per treatment) and spring/summer 2012 (12 turbines per treatment).

2.5 ACOUSTIC BAT SURVEYS

Acoustic Data Collection

At Laurel Mountain, we monitored bat activity at nacelle height (~90 m above ground level) using Anabat (Titley Electronics, Queensland, Australia) model SD1 and SD2 echolocation detectors deployed in weatherproof housings bolted to nacelle-mounted anemometer masts. Each detector was powered by a 12-volt battery charged by a 10-watt solar panel. Monitoring occurred at 6 turbines in 2011, and 9 turbines in years 2012–2015. We selected turbines among the subset of 24 turbines at which standardized carcass searches occurred, positioned relatively evenly within the single string of turbines. We tested all system microphones using an ultrasonic transmitter (Bat Chirp II, Tony Messina, Las Vegas, Nevada) prior to and following deployment and manually adjusted the sensitivity to ~6–7, or 1 unit below the point where constant static was recorded (Peterson et al. 2014). Detectors were rotated among turbines and/or replaced between survey years. We attached microphones directly to the acoustic detectors and used 90-degree 1.5- inch PVC elbows to protect the detector microphones from precipitation and serve as an acoustic reflector. We oriented the opening of each PVC elbow to point horizontally off the back end of the nacelle (Figure 2.3).

Figure 2.3. Photo of acoustic bat detector (in gray box) mounted on the nacelle of Turbine 47 at Laurel Mountain, fall 2011.

We set detector clocks using a network-connected computer and programmed detectors to record data on a nightly basis between 18:00 and 08:00, to sample the full period from sunset to sunrise, plus a buffer on either side. In 2011–2014, GLM1 (Titley Electronics, Queensland, Australia) modems enabled remote data transfer and in 2015, we manually downloaded data from detectors' compact flash memory cards and inspected detector systems on an approximately monthly basis. We replaced malfunctioning system components when possible throughout each monitoring period. After downloading data files using CFCread software (version 4.3s, Titley Scientific, Queensland, Australia) with default settings in place, we categorized each attempted detector-night as successful or not by reviewing system status files and diagnostic information such as battery voltage and reported sensitivity.

We monitored acoustic bat activity at New Creek using full-spectrum bat detectors (Wildlife Acoustics SM4), deploying detectors on the nacelle-mounted anemometer mast of 9 turbines evenly distributed throughout the wind farm. Omni-directional SMM-U1 microphones were oriented horizontally, aiming away from the rotor off the back of the nacelle (Figure 2.4). We programmed detectors to operate continuously from 30 minutes before sunset to 30 minutes after sunset based on the latitude and longitude of the site, using a built-in scheduling function of the detectors. We operated detectors in "triggered wav" mode with default sampling rate of 256 kHz, gain of 12 dB, 15 s maximum file length, and trigger settings of 16 kHz frequency, 1.5 ms minimum duration, 12 dB level, and 3 s window. Detectors were powered by 12-volt batteries charged by 10-watt solar panels. We performed sensitivity checks on detector microphones prior to deployment using a Wildlife Acoustics Ultrasonic Calibrator to ensure microphones were operating according to manufacturers' specifications. We converted .wav files recorded by detectors to zero-crossing format using Kaleidoscope Pro software (version 3.1.7) and manually generated a nightly status file categorizing each attempted survey night as successful or not successful based on recorded data and a system status file generated by each detector.

Figure 2.4. Photo of acoustic bat detector (in green box) mounted on the nacelle of Turbine 1 at the New Creek Wind Project, 2017.

Acoustic Data Analysis

After conversion to zero-crossing format, we visually inspected each recorded file using AnalookW software (version 3.8s or later; Titley Scientific, Queensland, Australia) and defined a bat pass as a single file containing 2 or more visually discernable echolocation pulses within a 15-second file (Kunz 2007). We assigned each recorded pass to species, species group, or a high/low frequency category based on visual comparison of frequency, slope, duration, against reference libraries of known bat calls.

We rounded the time stamp of each bat pass up to 10-minute intervals in R version 3.5.1 (R Core Team 2018) package *xts* (Ryan and Ulrich 2018) and determined the corresponding wind speed and turbine rotor speed (rpm) from the same turbine nacelle and mean temperature at the 2 on-site meteorological towers. We also tallied the number of bat passes per species/species group for every 10-minute period in which acoustic data were collected. We manipulated timestamps using R package *lubridate* (Grolemund and Wickham 2011) and determined sunrise and sunset times for each surveyed night using R package *suncalc* (Thieurmel and Elmarhraoui 2019).

2.6 COMPARISON OF BAT ACTIVITY AND FATALITY RISK

Using a threshold rotor speed of 1 rpm or higher to indicate turbine operation, we categorized every recorded bat pass for which rpm data were available as either exposed to turbine operation or not using R package dplyr (Wickham et al. 2019). This allowed us to differentiate bat activity in terms of exposure to turbine operation and associated risk of turbine-related fatality. We calculated the proportion of bat passes exposed to turbine operation and the number of exposed passes per night for turbines in each curtailment treatment and test relationships between exposed bat activity and fatality risk at multiple temporal scales.

2.6.1 Bat Activity and Fatality Estimates by Treatment

We pooled acoustic data from turbines within operational treatments for which empirical bat fatality estimates were available (see Table 2.3) and calculated, for the date ranges represented by the fatality estimates, the rate of total bat passes and the subset of passes exposed to turbine operation per night. We also calculated the percent of recorded bat passes that were exposed to turbine operation (detected when turbine rpm ≥ 1) at turbines in each operational treatment. The number of bat passes recorded by a detector can be influenced by many factors (Hayes 2000), and we tested two metrics of bat activity to determine whether they showed similar relationships with bat fatality rates. We limited acoustic data summaries to the range of dates in which treatments were in effect and/or time periods represented by the corresponding fatality estimate. Because detectors were not deployed on all turbines at which carcass searches took place, bat fatality estimates were based on a larger number of turbines than acoustic bat activity metrics.

We used general linear models to compare bat fatality estimates for each treatment to the pooled rate and percent of bat activity measured at turbines in the same treatment. We ran separate models for total bat activity and the subset of bat activity exposed to turbine operation and conducted Wald likelihood ratio tests using R package aod (Lesnoff and Lancelot 2012) to compare models with and without site as a factor.

2.6.2 Bat Activity and Raw Carcass Counts per Turbine

To compare fatality patterns and acoustic bat activity at a finer spatial and temporal scale, we calculated the rate of total bat passes and the subset of passes exposed to turbine operation per night measured at each turbine and compared each metric to the raw number of carcass found per turbine during standardized carcass searches. We calculated carcass totals and acoustic activity metrics for turbines within the period same periods, representing the intervals in which distinct operational treatments were implemented (see Table 2.3). We considered acoustic data and carcass totals to be independent among turbines and monitoring periods based on temporal and spatial isolation of the datasets from one another. We modeled the raw carcass count per turbine as a function of bat activity measured per turbine during the same monitoring period using generalized linear models with a Poisson distribution. As we did at the treatment level, we ran separate models for total bat activity and the subset of activity exposed to turbine operation. Search area, number of turbine searches, and ground visibility, each of which can influence raw carcass counts, were similar among turbines at each site but differed between sites. As above, we compared models with and without site as a factor to account for these factors and evaluated significance of site using Wald tests.

2.6.3 Bat Activity and Carcass Detection during Individual Turbine Searches

We determined the number of bat passes recorded at each turbine during nights between standardized carcass searches and calculated the rate of total and exposed bat passes per 10-minute period to account for seasonal variation in length of nights. Such intervals were typically 3 nights for Laurel Mountain and 7 nights for New Creek, corresponding to the turbine search interval at each site. We compared this interval-specific metric of total and exposed bat activity to the binary probability of detecting or not detecting fresh bat carcasses (e.g. fatalities estimated to have occurred since the last turbine search) during the subsequent turbine search using logistic regression. This comparison explored the relationship between bat activity and bat fatality on as fine a temporal scale as available carcass data allowed. As above, we ran separate models for total bat activity and the subset of exposed activity and compared models with and without site using Wald tests.

2.7 PREDICTING, SIMULATING, AND MEASURING ACOUSTIC EXPOSURE

We simulated turbine operation under each implemented curtailment strategy for which acoustic data were available by categorizing every 10-minute period as meeting or not meeting the parameters of each turbine's curtailment treatment. We then calculated the rate and percent of bat activity with measured exposure (bats detected when turbine rpm ≥ 1) and simulated exposure (bats detected when curtailment conditions were met) to turbine operation. This comparison indicated how closely actual turbine operation aligned with the design of each curtailment strategy. For uncurtailed control turbines, we used the wind speed bin at which rotor speed exceeded 1 more than 50% of the time (2.0 m/s for New Creek and 3.0 m/s for Laurel Mountain) as the threshold for simulating exposure.

Next, we evaluated the ability to predict the amount of bat activity exposed to turbine operation by calculating measured exposure associated for each turbine and comparing this to simulated exposure for the same treatment based on data recorded at the same turbine during the previous monitoring period (usually the previous year). We compared predicted and measured exposure for individual turbines, limiting the dataset to turbines surveyed acoustically in consecutive years. We also tested predictions based on a pooled dataset (separated by site) of acoustic data from all turbines except those in the treatment being predicted. We compared predicted versus measured exposure for individual turbines and the pooled dataset using general linear models, log-transforming simulated and measured exposure for analyses based on individual turbine data to account for the bias towards restrictive curtailment treatments that resulted in low exposure of bat activity to turbine operation. We compared models with and without site using likelihood ratio tests and evaluated the accuracy of predictions based on models using the individual turbine and pooled datasets by calculating the root mean square error (RMSE) and 95% confidence intervals of model residuals.

2.8 DISTRIBUTION OF BAT ACTIVITY AND WEATHER VARIABLES

We used counts of bat passes per 10-minute interval and corresponding wind speed and temperature measurements to analyze relationships between bat activity and weather and assess seasonal patterns in bat activity and species composition. To assess distribution of bat activity as a function of wind speed, we tallied the number of bat passes within 0.5 m/s wind speed bins and 2.5°C temperature bins and calculated the cumulative percent of recorded bat activity versus each variable, aggregating data among turbines. We performed a similar summary by species, aggregating data among turbines and years. We manipulated and summarized data using R version 3.5.1 (R Core Team 2018) package dplyr (Wickham et al. 2019).

We measured seasonal variation in bat activity by calculating a monthly rate of bat passes recorded per 10-minute period for each site, aggregating turbines and years, and determining the percent species composition of the subset of bat passes identified to species (or genus in the case of *Myotis* species). We manipulated and summarized data using R version 3.5.1 (R Core Team 2018) package *dplyr* (Wickham et al. 2019). We prepared heat maps using R package *ggplot2* (Wickham 2016) to display visually and compare the distribution of bat activity as a function of wind speed and temperature among different groups of acoustic data. Expressed as a continuous surface, these heat maps represent wind speed and temperature as x and y coordinates and can be compared using spatial distance metrics following methods routinely applied to species distribution maps (Lavigne et al. 2010; Levine et al. 2009). Wilson et al. (2011) found Hellinger distance, a metric used to quantify the similarity between probability distributions, to be particularly effective in comparing species distribution maps.

To determine whether relationships between activity, temperature, and wind speed were consistent among years, months, turbines, and sites, we calculated Hellinger distance between all pairwise combinations of data grouped by turbine (aggregating years), species (aggregating turbines and years), and year (aggregating turbines), following methods described in Wilson et al. (2011). We truncated the dataset to exclude periods with wind speeds less than 2 m/s or greater than 8 m/s and temperatures outside the range of 0 to 22.5°C to create a common extent over which to calculate Hellinger distances. To standardize the extent of conditions over which to analyze activity and calculate Hellinger distance, we manually entered zeroes in empty cells representing combinations of variables that did not occur with zeroes. We compared Hellinger distances among all possible pairwise combinations for different data groupings using general linear models.

2.9 ANALYSIS OF ACOUSTIC SAMPLE SIZE AND SURVEY EFFORT

We also used Hellinger distance to evaluate the amount of data needed to adequately characterize the relationship between bat activity, temperature, and wind speed as indicated by aggregate datasets. We combined the most recent 2 years of acoustic data from each site to represent a fully saturated dataset, consisting of n individual turbine datasets from Laurel Mountain and m individual turbine datasets from New Creek. We deployed acoustic detectors for extended periods encompassing late spring through fall, such that 6–9 months of data from a single detector represents a practical sampling unit. We then drew 100 random subsamples (without replacement) of data representing each of up to n samples from Laurel Mountain and up to m samples from New Creek and calculated the Hellinger distances between each subsample and the full dataset, plotting Hellinger distance as a function of the number of samples. Because subsamples with increasing numbers of turbines more closely resemble the fully saturated dataset, Hellinger distance inevitably decreases with sample size. The shape of this decrease provides information on the amount of data needed to adequately characterize the relationships between bat activity and temperature and wind speed at each site. The Hellinger distance between the samples of n and m datasets and the full dataset, therefore, represented the difference between each site and an aggregate dataset.

2.10 SIMULATING BLANKET CURTAILMENT STRATEGIES AND ACTIVITY-BASED INFORMED CURTAILMENT ALTERNATIVES

We reviewed peer-reviewed literature, guidance documents published by state, federal, and provincial agencies, industry and non-government organization reports, and proceedings from wind project siting processes to compile the parameters of curtailment strategies currently being recommended by various stakeholders in North America. We limited the scope of our analysis to curtailment strategies in the public domain that were defined by cut-in wind speed and temperature thresholds with explicit seasonal and temporal ranges. We extracted parameters from each suitable curtailment recommendation and simulated how these programs would have worked had they been applied at two commercial wind farms at which we previously conducted nacelle-height acoustic bat monitoring and recorded corresponding temperature and wind speed data.

We used acoustic and weather data from Laurel Mountain and New Creek to simulate the reduction in exposed bat activity and the energy loss associated with each agency-recommended curtailment strategy. We omitted from analysis data from a partially surveyed year at Laurel Mountain in 2011 and 3 detectors at New Creek that operated for fewer than 30 nights or for which insufficient weather data were available. We rounded the timestamps of all recorded bat passes to the nearest 10 minutes and tallied the number of bat passes (total and per species) recorded during each corresponding interval, omitting time periods in which all four variables were not available. To determine the potential amount of energy that could be generated during each 10-minute interval, we rounded wind speeds into 0.25 m/s or 0.5 m/s bins (depending on the resolution of the turbine model-specific power curve) and determined the potential energy generation in kilowatts (kW) of that wind speed bin based on the power curve of turbines at each site. We developed code using R version 3.5.1 (R Core Team 2018) package *dplyr* (Wickham et al. 2019) to categorize every 10-minute interval as meeting or not meeting conditions of each curtailment strategy. For comparison, we also simulated curtailment strategies applying blanket cut-in speed increases in 0.5 m/s increments from 3.0 to 7.0 m/s for the period between 1 June and 30 September from sunset to sunrise without a temperature threshold.

To evaluate effectiveness of each simulated curtailment strategy, we summed the number of bat passes recorded during periods meeting curtailment conditions and calculated a corresponding exposure index (number of exposed bat passes per 10-minute interval) and the proportion of all recorded passes exposed to turbine operation per strategy at each site. By aggregating data among turbines and years, our simulations incorporated realistic naturally occurring inter-turbine and inter-year variation. To estimate baseline exposure associated with uncurtailed turbines, we first used wind speed and rpm measurements from the subset of turbines operating without curtailment at each site to determine the threshold wind speed bin in which rpms exceeded 1 greater than 50% of the time, then calculated the activity index and proportion of passes associated with this threshold. We used these values as the reference points for calculating the percent reduction in exposure for each simulated curtailment strategy. We performed similar calculations using species-specific tallies of bat activity to estimate reductions in exposure among species.

We simulated mean energy loss per turbine associated with each curtailment strategy by summing the energy generation potential (kW) across 10-minute intervals meeting curtailment conditions, converting the resulting value to megawatt hours (MWh), and calculating the mean among turbines. This total represented an annual estimate, per turbine, of the amount of potential energy generation that would be lost due to curtailment under each strategy. Using R package *shiny* (Chang et al. 2018), we built a data visualization app to plot simulated energy loss and reductions in bat exposure for each curtailment strategy at each site as an aggregate or for individual species, years, and turbines. We designed the app to allow the user to manually set parameters of a smart curtailment alternative with different temperature and wind speed thresholds for each month. To help determine appropriate temperature and wind speed thresholds, we also designed the app to generate heat maps of the distribution of bat passes and time in the conditions space defined by wind speed and temperature and monthly bar plots of bat activity showing the proportion of exposed passes under the selected curtailment parameters.

We used the app to visualize changes in exposure reduction and energy loss for each site and attempt to design a smart (activity-based informed curtailment [ABIC]) curtailment alternative for each agency-recommended plan that resulted in equivalent or greater reductions in exposure while minimizing energy loss. We generated an initial set of ABIC alternatives based on all bat activity, combining species and including unidentified passes, and designed a second set of ABIC alternatives based only on the subset of bat passes categorized as *Myotis* species. In West Virginia, this group could include the federally endangered Indiana bat (*Myotis sodalis*), federally threatened northern long-eared bat (*Myotis septentrionalis*), little brown bat (*Myotis lucifugus*), and eastern small-footed bat (*Myotis leibii*). We did not identify bat passes to species within the genus *Myotis* during the data analysis process due to the similarity of acoustic characteristics among these species. We calculated the predicted reduction in bat activity exposure and energy loss for each agency-recommended strategy and ABIC alternative and calculated reductions in energy loss between comparable pairs. Lastly, to assess the efficiency of curtailment programs, we calculated the percent of total energy loss occurring during periods with bat activity for each curtailment plan.

2.11 MANUAL AND AUTOMATIC ACOUSTIC ANALYSIS

We processed acoustic data files collected at Laurel Mountain and New Creek using Kaleidoscope Pro software (Kaleidoscope; version 5.1.9g; classifier 5.1.0; set to “0 Balanced (Neutral)” setting) and BCID software (version 2.7d), both configured for bat species expected to occur in West Virginia. Full-spectrum files from New Creek were first converted to zero crossing format. We also processed original full-spectrum data (New Creek only) using SonoBat (version 4.3.0), an automated analysis program designed to analyze full spectrum data. We used SonoBat’s default settings and selected the Northeast: New York-Pennsylvania-West Virginia region pack to include all bat species expected to occur in West Virginia.

We created heat maps of the distribution of bat activity per site (aggregating data among years) as a function of temperature and wind speed for each analysis method (and for original visual analysis) and compared these visually and by calculating Hellinger distance, as described above. As above, we omitted data from 2011 at Laurel mountain and from 3 partially surveyed turbines at New Creek. We did not conduct any visual vetting of the output of analysis program but compared each to the results of manual identification, which involved visual inspection of every recorded bat pass in the dataset.

3.0 RESULTS

3.1 BAT ACTIVITY AND FATALITY RISK

3.1.1 Bat Activity and Fatality Estimates by Treatment

Paired nacelle-height acoustic bat data and fatality estimates were available for 10 distinct operational treatments implemented at Laurel Mountain (n = 6) and New Creek (n = 4; Table 3.1). Empirical bat fatality estimates ranged from 1.4–38.2 bats per turbine per monitoring period among treatments, and the associated number of bat passes per night ranged from 5.3–12.8 (Table 3.1). The nightly rate of total bat activity measured at turbines within each operational treatment had no discernable relationship with estimated bat fatality rates, although the subset of exposed bat activity explained close to 80 percent of the variation in estimated bat fatality rates among treatments (F(1,8) = 26.1, R^2 = 0.77, p < 0.001; Figure 3.1). Likewise, the percent of bat passes exposed to turbine operation was even more closely aligned with estimated fatality rates (F(1,8) = 63.6, R^2 = 0.89, p < 0.001; Figure 3.1). Site was not a significant factor for any of the models comparing bat activity and fatality estimates.

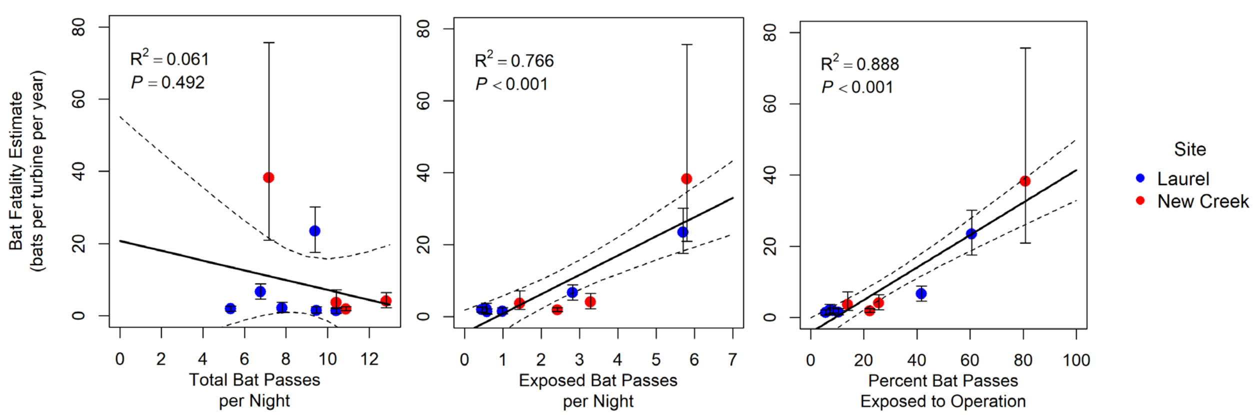

Figure 3.1. Estimated bat fatality rate for curtailment treatments as a function total bat passes per night (left), the subset of bat passes exposed to turbine operation (center), and percent of bat passes exposed to turbine operation (right) for Laurel Mountain and New Creek. Dashed lines indicate 95% confidence intervals around the regression line. Error bars represent upper and lower 95% confidence intervals surrounding fatality estimates and were not included in the model structure.

Table 3.1. Acoustic bat survey effort and results by site, year, and treatment, with corresponding bat fatality estimates (bats per turbine per monitoring period), where available, for Laurel Mountain and New Creek.

Site	Monitoring Period	Dates Surveyed Acoustically	Curtailment Cut-in Speed (m/s)	# Turbines (# Detector-nights)	# Bat Passes (Exposed)	# Bat Passes per Detector-night (Exposed Rate)	% Passes Exposed	Bat Fatality Estimate (95% CI)*
Laurel Mountain	2011/2012	24 Aug–11 Nov; 28 Mar–31 Jul	control	4 (483)	4,543 (2,755)	9.4 (5.7)	60.6	23.4 (17.6–30.2)
	2011**	24 Aug–13 Sep	3.5	1 (21)	260 (133)	12.4 (6.3)	51.2	NA
	2011/2012	24 Aug–11 Nov; 30 Mar–31 Jul	4.5	5 (609)	4,125 (1,720)	6.8 (2.8)	41.7	6.6 (4.6–8.8)
	2012***	1 Aug–5 Sep	shutdown	6 (198)	3,711 (0)	18.7 (0.0)	0.0	NA
	2012	6 Sep–14 Nov	3.5–8.0 (by temperature)	6 (384)	3,636 (381)	9.5 (1.0)	10.5	1.5 (0.8–2.5)
	2013	31 Mar–14 Nov	3.5–8.0 (by temperature)	9 (1,741)	18,135 (1,030)	10.4 (0.6)	5.7	1.4 (0.7–2.2)
	2014	9 Apr–15 Nov	3.5–6.9 (by temperature)	9 (1,874)	9,998 (843)	5.3 (0.4)	8.4	1.9 (1.3–2.7)
	2015	9 Apr–15 Nov	3.5–6.9 (by temperature)	9 (1,679)	13,123 (951)	7.8 (0.6)	7.2	2.1 (1.0–3.8)
New Creek	2017	NA	6.9 m/s	NA	NA	NA	NA	2.6 (1.5–4.6)
		NA	6.0–6.9 (by season)	NA	NA	NA	NA	2.2 (1.3–3.4)
		19 May–14 Nov	5.5–6.9 (by season)	5 (724)	9,281 (2,384)	12.8 (3.3)	25.7	4.0 (2.2–6.5)
		19 May–14 Nov	4.5–6.9 (by season)	2 (220)	2,394 (534)	10.9 (2.4)	22.3	1.9 (1.4–2.6)
	2018	9 May–16 Nov	control	4 (694)	4,981 (4,022)	7.2 (5.8)	80.7	38.2 (21.0–75.7)
		16 May–16 Nov	4.0–6.9 (by season)	5 (666)	6,936 (964)	10.4 (1.4)	13.9	3.7 (2.2–7.2)

*Bat fatality estimates as reported in references cited in Table 2.3.
**The 3.5 m/s cut-in speed was discontinued after fall 2011 and no fatality estimate was available.
***Fatality monitoring did not occur during the fall 2012 shutdown and no fatality estimate was available.
****Acoustic data were unavailable from turbines in these operational treatments in 2017.

3.1.2 Bat Activity and Raw Carcass Counts per Turbine

Bat carcass counts and acoustic data were available for 22 individual turbines (after removing 2 turbines with fewer than 1 week of acoustic data) across up to 7 distinct monitoring periods at Laurel Mountain and New Creek (see Table 2.3), representing 53 independent carcass totals with corresponding measures of bat activity. Significantly more bat carcasses were found at turbines with higher rates of exposed bat activity within the corresponding monitoring period (χ^2 = 124.28, p < 0.001). The total number of bat passes per night also explained significant variation in raw carcass counts per turbine (χ^2 = 10.2, p = 0.001), although the strength of this relationship was substantially weaker than when only exposed activity was modeled (Figure 3.2). Fewer carcasses were found at New Creek than Laurel Mountain due in large part to a longer search interval (fewer total carcass searches) and site was a significant factor in both models.

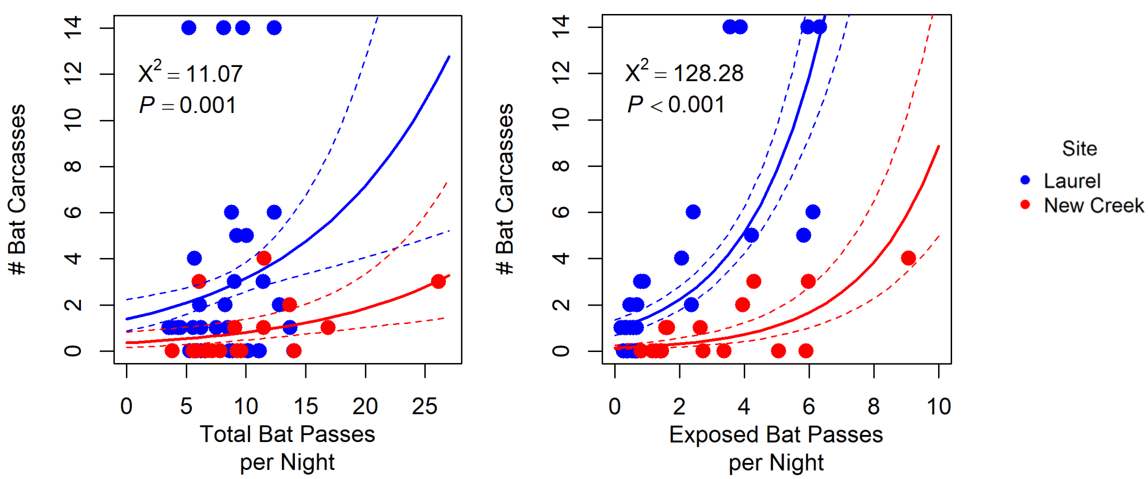

Figure 3.2. Total number of bat carcasses found per turbine as a function of the rate of exposed activity (left), total bat activity (center), and percent of passes exposed to turbine operation (right) for Laurel Mountain and New Creek. Dashed lines indicate 95% confidence intervals around model predictions.

3.1.3 Bat Activity and Carcass Detection during Individual Turbine Searches

Acoustic and fatality data were available for 2,172 turbine search intervals at Laurel Mountain (mean length = 3.05 days) and 322 intervals at New Creek (mean length = 7.07 days). Carcasses were found following 55 intervals (2.5%) at Laurel Mountain and 10 intervals (3.1% at New Creek). The probability of finding a bat carcass was significantly greater following intervals with a higher rate of exposed bat activity (logistic regression, χ^2 = 64.3, p < 0.001). The probability of carcass detection was still greater following intervals with higher rates of total bat activity (logistic regression, χ^2 = 9.8, p = 0.002), although the relationship was weaker; Figure 3.3). Site was not a significant factor for models with all bat activity or subsets of exposed and unexposed activity based on likelihood ratio tests.

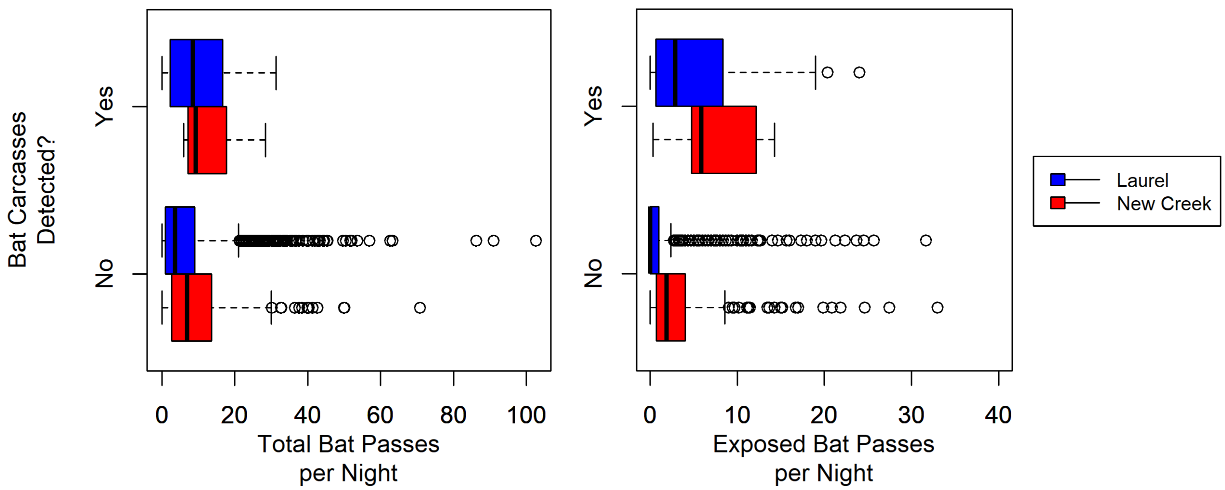

Figure 3.3. Distribution of bat activity in intervals preceding turbine searches with and without detection of bat carcasses finding a fresh bat carcass during a search as a function of the number of exposed bat passes (left), all bat passes (center), and unexposed bat passes (right) per night during the interval since the previous turbine search for Laurel Mountain and New Creek.

3.2 PREDICTING, SIMULATING, AND MEASURING EXPOSURE

Curtailment treatments implemented at Laurel Mountain and New Creek between 2011 and 2018 should have exposed 2.7–91.2% of bat passes to turbine operation at individual turbines based on simulations using 10-minute temperature and wind speed data, whereas measured exposure ranged from 3.6 to 88.5% among turbines based on turbine operation data using a threshold of 1 rpm. Log-transformed simulated and measured exposure were highly correlated based on data from 62 independent measurements from individual turbines ($F(1,60) = 742.7$, $R^2 = 0.93$, $p < 0.001$; Figure 3.4).

Predictions based on simulations using acoustic and weather data collected the previous year at the same turbine (n = 33 paired datapoints) were similarly related to measured exposure ($F(1,31) = 163.1$, $R^2 = 0.84$, $p < 0.001$; Figure 3.4). The mean of the absolute value of differences between measured and predicted exposure, based on data from the previous year at the same turbine, was 4.3%. The 95% quartiles for residuals of the model comparing predicted and measured exposure ranged from -0.30 to 0.21, with a residual RMSE of 0.149. The relationship between predicted and measured exposure did not vary significantly between sites.

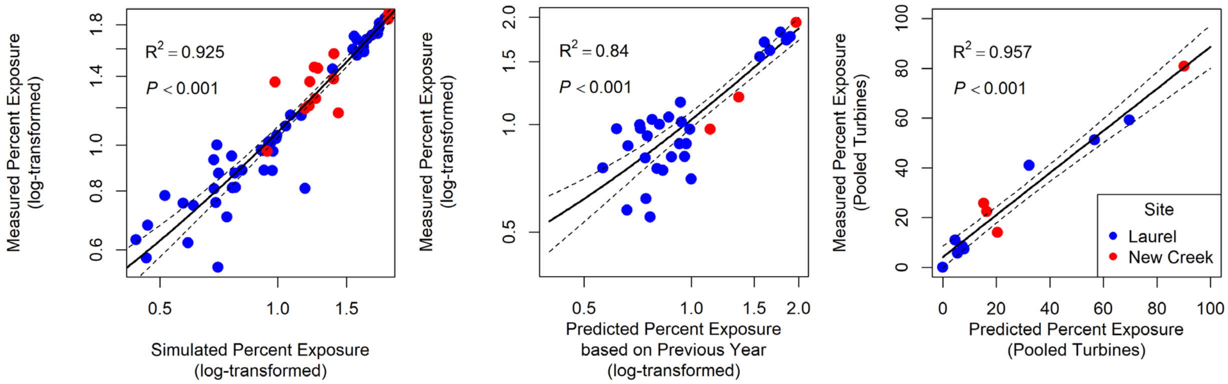

Figure 3.4. Measured versus simulated exposure of bat activity to turbine operation (left; n = 62) and predicted exposure based the previous year's data (center; n = 33) for individual turbines and pooled turbines by operational treatment (right; n = 12) at Laurel Mountain and New Creek, 2011–2018.

Predicted exposure, based on data pooled among turbines at each site excluding the treatment in question, ranged from 0.0–90.2 percent of bat passes among 12 distinct operational treatments for which nacelle-height acoustic data were available. Predictions were highly correlated with measured exposure (F(1,10) = 220.0, R2 = 0.96, p < 0.001), which ranged from 0.0–80.8 percent of bat passes (Table 3.2; Figure 3.4). The 95% quartiles for residuals of the model comparing predicted and measured exposure ranged from -6.6–9.2, with a residual RMSE of 5.1. The relationship between predicted and measured exposure of bat activity did not differ among sites based on likelihood ratio tests and predicted exposure explained over 90% of variance in measured exposure among treatments (Figure 3.4). The mean of the absolute value of differences between predicted and measured exposure based on pooled data was 5.4 percent.

Table 3.2. Predicted and measured exposure of acoustic bat activity to turbine operation by treatment at Laurel Mountain and New Creek, 2011–2018.

Site	Monitoring Period	Curtailment cut-in Speed (m/s)	Predicted Exposure (%)	Measured Exposure (%)	Difference (%)
Laurel	2011/2012	control	69.7 (n = 53,092)	59.2 (n = 4,659)	11.3
	2011	3.5 m/s (2011/2012)	56.8 (n = 57,491)	51.2 (n = 260)	5.7
	2011/2012	4.5 m/s (2011/2012)	32.4 (n = 53,547	40.9 (n = 4,204)	8.3
	2012	shutdown	0.0 (n = 55,836)	0.0 (n = 3,711)	0.0
		3.5–8.0 (by temperature)	4.7 (n = 53,895)	10.9 (n = 3,636)	6.2
	2013	3.5–8.0 (by temperature)	5.6 (n = 39,396)	5.7 (n = 18,135)	0.3
	2014	3.5–6.9 (by temperature)	7.3 (n = 49,533)	8.4 (n = 9,998)	0.7
	2015	3.5–6.9 (by temperature)	8.1 (n = 44,408)	7.3 (n = 13,123)	3.0
New Creek	2017	Mode 3 (2017)	15.3 (n = 14,339)	25.7 (n = 9,281)	7.7
		Mode 4 (2017)	16.5 (n = 21,211)	22.4 (n = 2,410)	3.2
	2018	Control (2018)	90.2 (n = 18,627)	80.8 (n = 4,993)	9.9
		Curtailed (2018)	20.5 (n = 16,684)	13.9 (n = 6,936)	8.9

3.3 DISTRIBUTION OF BAT ACTIVITY, WIND SPEED, AND TEMPERATURE

Acoustic bat detectors recorded bat activity from the nacelles of selected turbines at Laurel Mountain from 2011–2015 and at New Creek in 2017–2018. We omitted from analysis data from a partial sampling season in 2011 and from 3 individual turbines at New Creek that operated properly for less than 30 nights or for which insufficient weather data were available, resulting in a total of 8,820 detector-nights of data for which temperature, wind speed, and turbine rpm data were also available. These nights represented 612,328 10-minute periods at night (30 minutes before sunset until 30 minutes past sunrise), within which we identified 78,212 bat passes based on visual analysis (Table 3.3). Of these passes, 45,769 (58.5%) were identified to species (or species group in the case of Myotis), with eastern red, hoary, and silver-haired bats together accounting for 86.5% and 95.8% of identified bat passes at Laurel Mountain and New Creek, respectively (Table 3.4).

Table 3.3. Survey effort and data availability for acoustic bat monitoring, weather, and turbine operation from Laurel Mountain and New Creek, 2012–2018.

Site	Year	Date Range	# Turbines*	Detector-nights**	10-minute Periods**	Bat Passes**
Laurel Mountain	2012	Apr–Nov	6	1,286	88,630	13,636
	2013	Apr–Nov	9	1,733	119,545	18,133
	2014	Apr–Nov	9	1,874	130,693	9,998
	2015	Apr–Nov	9	1,679	114,120	13,112
New Creek	2017	May–Nov	7	930	66,684	11,675
	2018	May–Dec	8	1,318	92,656	11,658
Total			*21*	*8,820*	*612,328*	*78,212*

*Data from a partial season in fall 2011 at Laurel Mountain and from 3 detectors at New Creek were omitted from subsequent analysis as they represented a small subset of the full season over which bat activity could occur.
**Data limited to subset of nights and periods for which acoustic bat, temperature, wind speed, and turbine rpm data were available.

Table 3.4. Species composition of the subset of bat passes identified to species from nacelle-height monitoring at Laurel Mountain and New Creek, 2012–2018.

Species	Laurel Mountain (n = 31,707)		New Creek (n = 14,062)	
	# Passes	% Identified	# Passes	% Identified
big brown bat	2,883	9.1	366	2.6
eastern red bat	5,433	17.1	3,638	25.9
hoary bat	13,892	43.8	6,838	48.6
silver-haired bat	8,114	25.6	2,999	21.3
Myotis species	111	0.4	15	0.1
tri-colored bat	1,274	4.0	206	1.5

3.3.1 Bat Activity Varied with Wind Speed and Temperature

Although bats were detected during periods with wind speed exceeding 15 m/s at both sites, 77% and 69% of recorded passes occurred below 5.0 m/s at Laurel Mountain and New Creek, respectively (Table 3.5; Figure 3.5). Between 30–40% of bat passes were detected below manufacturer's cut-in speed, and most bat activity (69% at Laurel Mountain and 59% at New Creek) occurred during periods with wind speeds between 2–5 m/s. Among species, the proportion of bat activity below 5.0 m/s ranged from 83% for hoary bats to 97% for *Myotis* species at Laurel Mountain and from 72% for big brown bats to 87% for Myotis species at New Creek (Figure 3.5).

Bat activity also occurred primarily during warmer temperatures, with 86% and 91% of recorded bat passes occurring above 10°C at Laurel Mountain and New Creek, respectively (Table 3.6; Table 3.6). Distribution of bat activity varied slightly more among years for temperature than wind speed. Silver-haired bats were more active during colder temperatures than other species at Laurel Mountain and New Creek, where 31% and 19% of silver-haired passes were recorded when temperatures were less than 10°C (Table 3.6).

Table 3.5. Percent distribution of bat passes among wind speed bins at Laurel Mountain and New Creek, 2012–2018.

Wind Speed Bin (m/s)	Laurel Mountain (n = 54,879)		New Creek (n = 23,333)	
	% Passes	Cumulative	% Passes	Cumulative
0.0 < 0.5	0.0	0.0	0.5	0.5
0.5 < 1.0	2.0	2.0	2.2	2.7
1.0 < 1.5	0.3	2.2	3.2	5.9
1.5 < 2.0	5.3	7.5	4.8	10.7
2.0 < 2.5	10.6	18.1	7.3	17.9
2.5 < 3.0	12.9	31.0	8.8	26.7
3.0 < 3.5	12.5	43.4	8.9	35.6
3.5 < 4.0	13.0	56.4	9.7	45.3
4.0 < 4.5	11.2	67.6	12.4	57.6
4.5 < 5.0	9.3	76.9	11.7	69.3
5.0 < 5.5	6.8	83.7	8.9	78.3
5.5 < 6.0	5.0	88.7	6.1	84.4
6.0 < 6.5	3.7	92.5	4.3	88.7
6.5 < 7.0	2.3	94.8	3.5	92.2
7.0 < 7.5	1.5	96.3	2.6	94.8
7.5 < 8.0	1.2	97.5	1.7	96.5

Table 3.6. Percent distribution of bat passes among temperature bins at Laurel Mountain and New Creek, 2012–2018.

Temperature Bin (C)	Laurel Mountain (n = 54,879)		New Creek (n = 23,333)	
	% Passes	Cumulative	% Passes	Cumulative
< 0	0.1	0.1	0.0	0.0
0 < 2.5	0.2	0.3	0.5	0.5
2.5 < 5.0	1.4	1.6	1.1	1.6
5.0 < 7.5	4.4	6.0	3.0	4.7
7.5 < 10.0	7.7	13.7	4.4	9.1
10.0 < 12.5	11.5	25.2	7.3	16.4
12.5 < 15.0	19.6	44.8	11.0	27.5
15.0 < 17.5	25.6	70.4	21.2	48.6
17.5 < 20.0	23.2	93.7	26.2	74.8
20.0 < 22.5	5.8	99.5	16.7	91.5
22.5 < 25.0	0.4	99.9	8.3	99.8
25.0 < 27.5	0.1	100.0	0.2	100.0

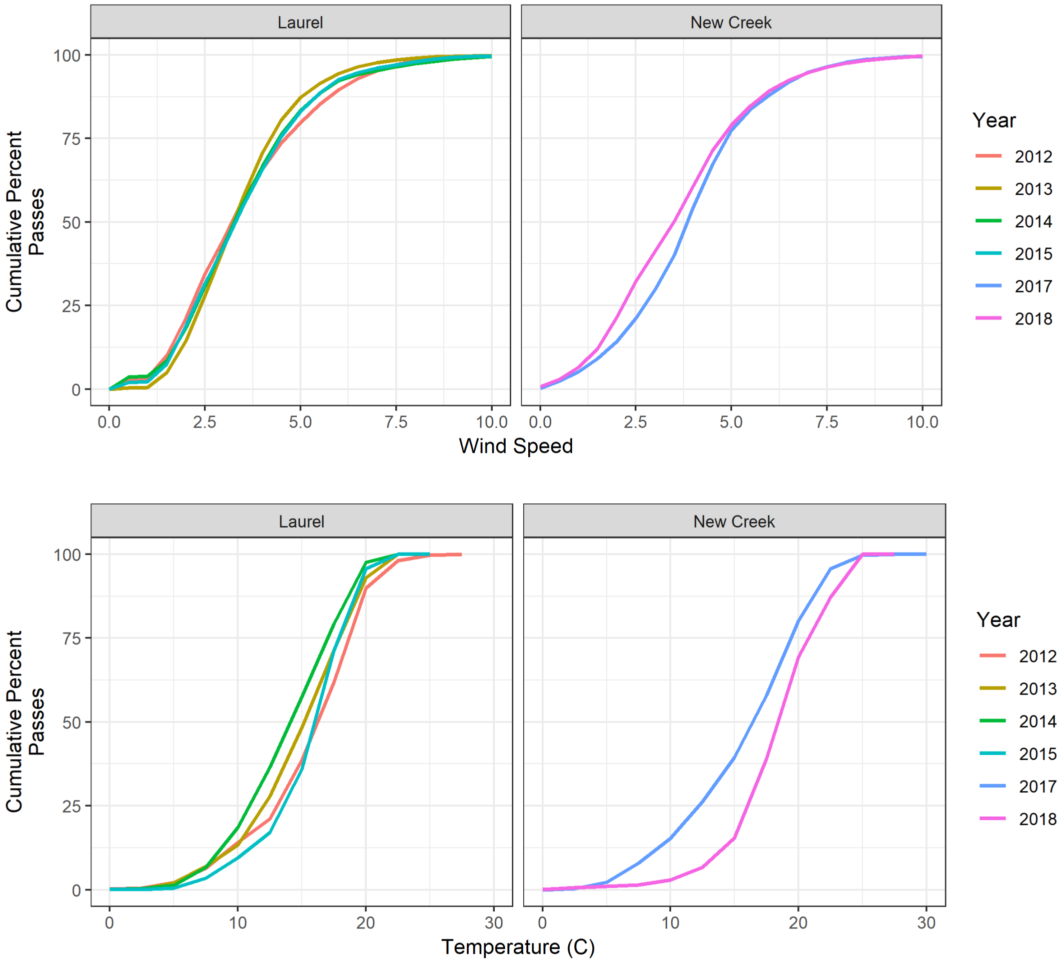

Figure 3.5. Cumulative percent of bat passes versus wind speed (upper plot) and temperature (lower plot) recorded between May and October at Laurel Mountain in 2012–2015 and New Creek in 2017–2018, aggregating data among turbines.

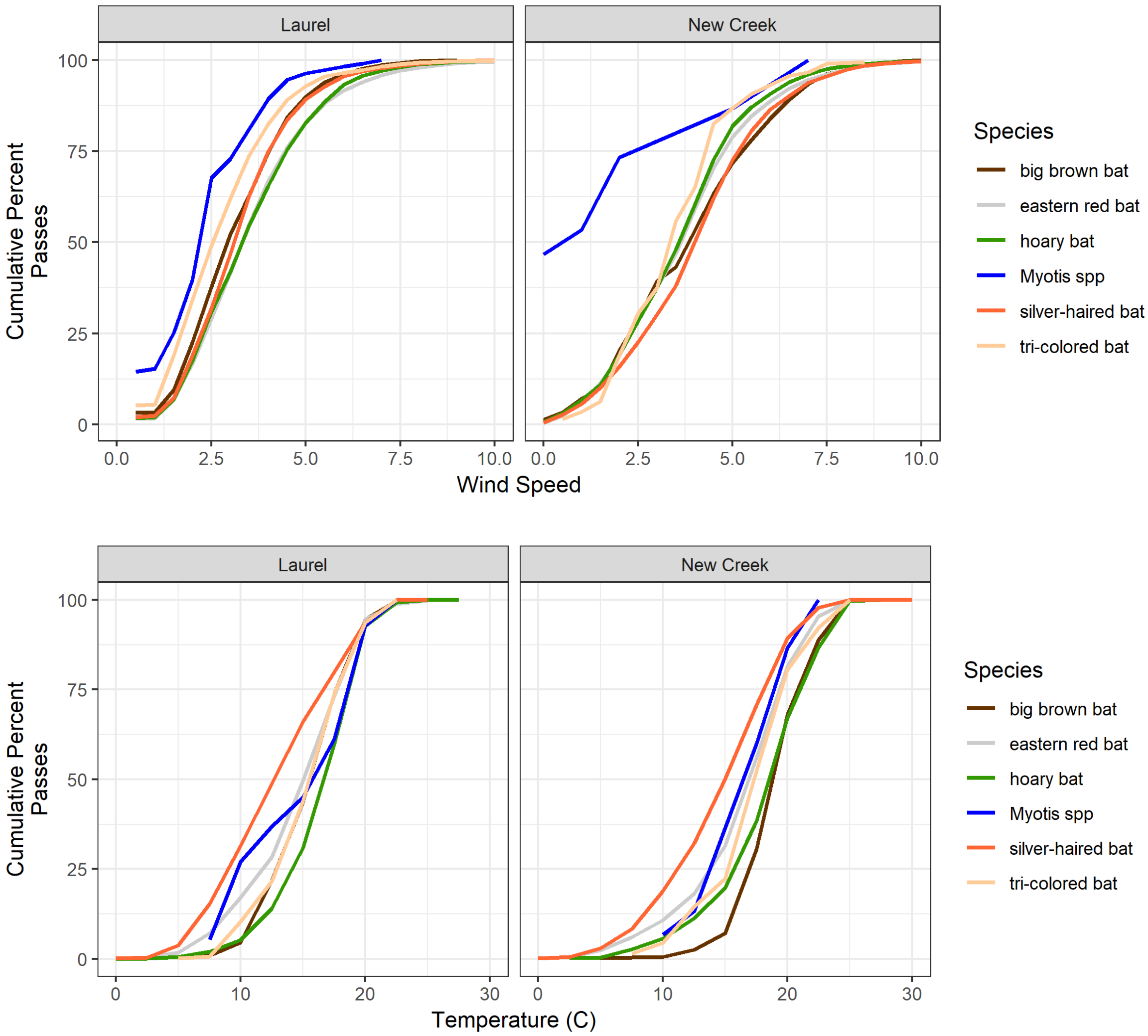

Figure 3.6. Cumulative percent of bat passes identified to species versus wind speed recorded between May and October at Laurel Mountain in 2012–2015 and New Creek in 2017–2018, aggregating data among turbines and years.

3.3.2 Seasonal Variation in Bat Activity

Bats were most active during September at Laurel Mountain and in August at New Creek, with 76% of recorded bat passes occurring in July, August, and September overall. Species composition varied among months with similar patterns at Laurel Mountain and New Creek. Hoary bats were the most frequently identified species in May–August while silver-haired bats accounted for most identifications in September and October (Figure 3.7). Distribution of bat activity with respect to wind speed and temperature also differed among months, reflecting variation in both the number of periods and amount of bat activity with given wind speeds and temperatures (Figure 3.8). Notably, less than 1% of bat passes occurred below 10°C in May whereas approximately 9% of bat activity occurred below 10°C during September at both Laurel Mountain and New Creek. Aggregating data among months, most bat activity was distributed in relatively warm temperatures (> 10°C) and low wind speeds (<5 m/s) at Laurel Mountain and New Creek (Figure 3.9). Because most bat passes were detected in July–September, these months have the greatest influence over overall distributions of bat activity versus wind speed and temperature.

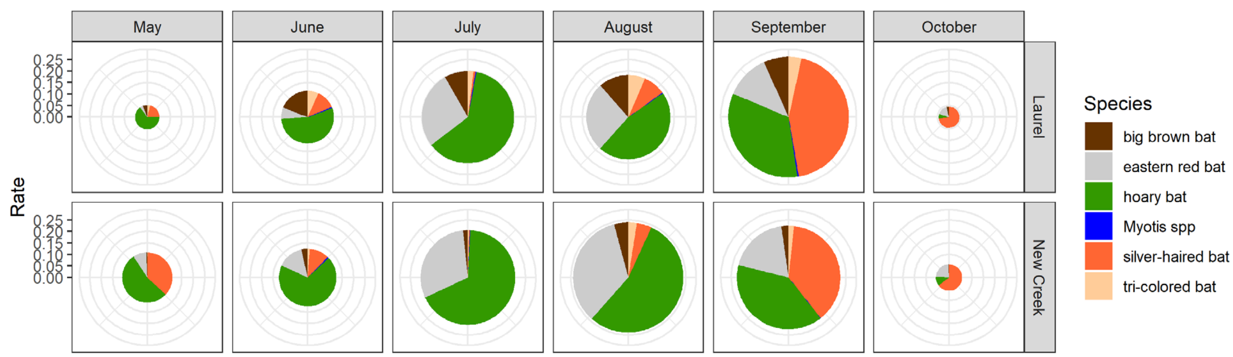

Figure 3.7. Monthly rate of total bat passes per 10-minute period and species composition of identified passes recorded between May and October at Laurel Mountain in 2012–2015 and New Creek in 2017–2018, aggregating data among turbines and years.

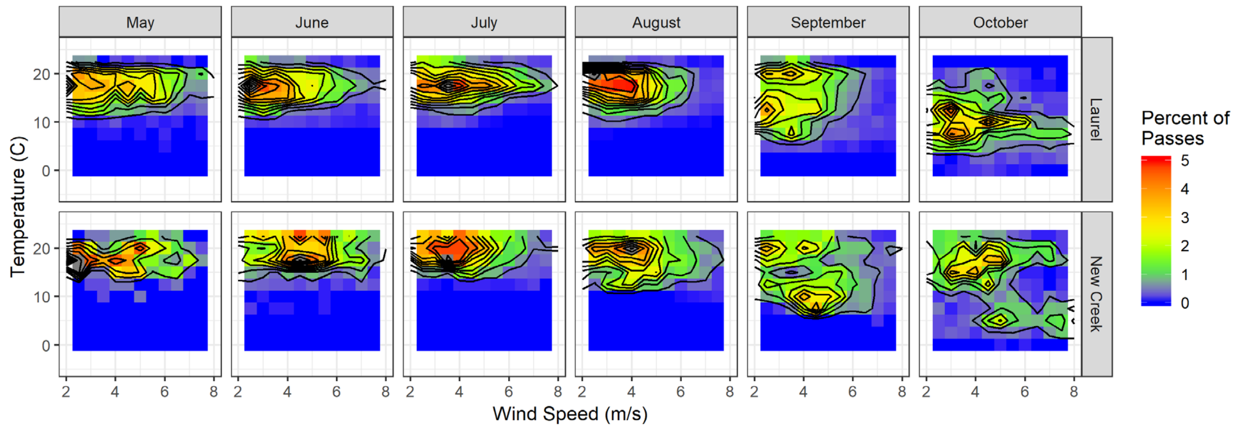

Figure 3.8. Monthly distribution of bat activity by wind speed and temperature as a percent of passes recorded between May and October at Laurel Mountain in 2012–2015 and New Creek in 2017–2018, aggregating data among turbines and years.

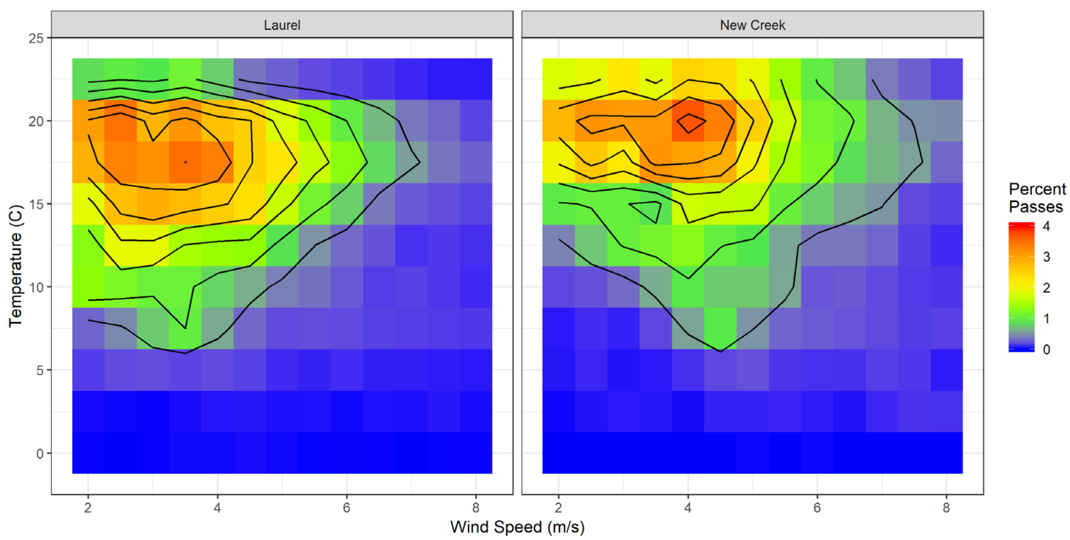

Figure 3.9. Overall distribution of bat activity by wind speed and temperature as a percent of total passes recorded at Laurel Mountain in 2012–2015 and New Creek in 2017–2018, aggregating data among turbines and years.

3.3.3 Consistency of Relationship between Bat Activity and Conditions

We used Hellinger distances to quantify consistency of distributions of bat activity in the conditions space among sites, turbines, months, and species. Hellinger distance between the percent distributions of bat activity by wind speed and temperature at Laurel Mountain and New Creek was 0.23, combining turbines and years, providing a reference point to which other Hellinger distances could be compared. When grouped by year, distributions of bat activity showed greater variation based on visual comparison and Hellinger distance, which ranged from 0.17 to 0.39 (mean = 0.26) for 15 unique pairwise comparisons among year and site (Figure 3.10). Grouping data by site and month yielded Hellinger distances ranging from 0.16 to 0.97 (mean = 0.55) based on 105 pairwise comparisons, indicating substantially greater variation among months. Hellinger distance between species-specific distributions ranged from 0.19 to 0.95 (mean = 0.48) based on 66 pairwise comparisons among species and site and showed pronounced differences between certain species (Figure 3.11). Myotis species were least similar to other species in terms of distribution of activity according to wind speed and temperature, although very few Myotis species were recorded at nacelle height at either site (n = 90 *Myotis* out of 39,904 identified passes included in the dataset used for calculating Hellinger distance). Hellinger distance between 210 pairwise comparisons between turbines, aggregating data among years, ranged from 0.13 to 0.60 (mean = 0.34), with more pronounced differences among turbines at New Creek, for which only 1 year of data were available in most cases due to sampling different turbines in 2017 and 2018 (Figure 3.12).

Differences between distributions of bat activity by wind speed and temperature were greatest among months and species, moderate among turbines, and lowest among years ($F(3,392) = 45.3$, $R^2 = 0.26$, $p < 0.001$). Hellinger distances for inter-site comparisons were significantly greater when comparing among years ($F(1,13) = 16.39$, $R^2 = 0.56$, $p = 0.001$) and turbines ($F(1,208) = 29.72$, $R^2 = 0.13$, $p < 0.001$), but Hellinger Distances varied similarly within and between sites when data were grouped by species ($F(1,64) = 1.34$, $R^2 = 0.02$, $p = 0.25$) and month ($F(1,103) = 0.15$, $R^2 = 0.001$, $p = 0.7$; Figure 3.13).

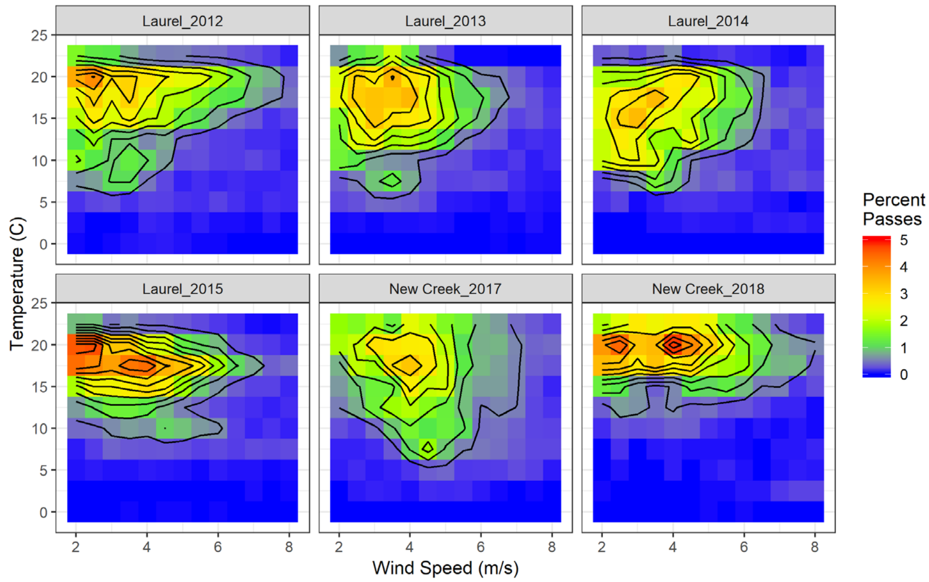

Figure 3.10. Distribution of bat activity by wind speed and temperature as a percent of passes recorded per year at Laurel Mountain in 2012–2015 and New Creek in 2017–2018, aggregating data among turbines.

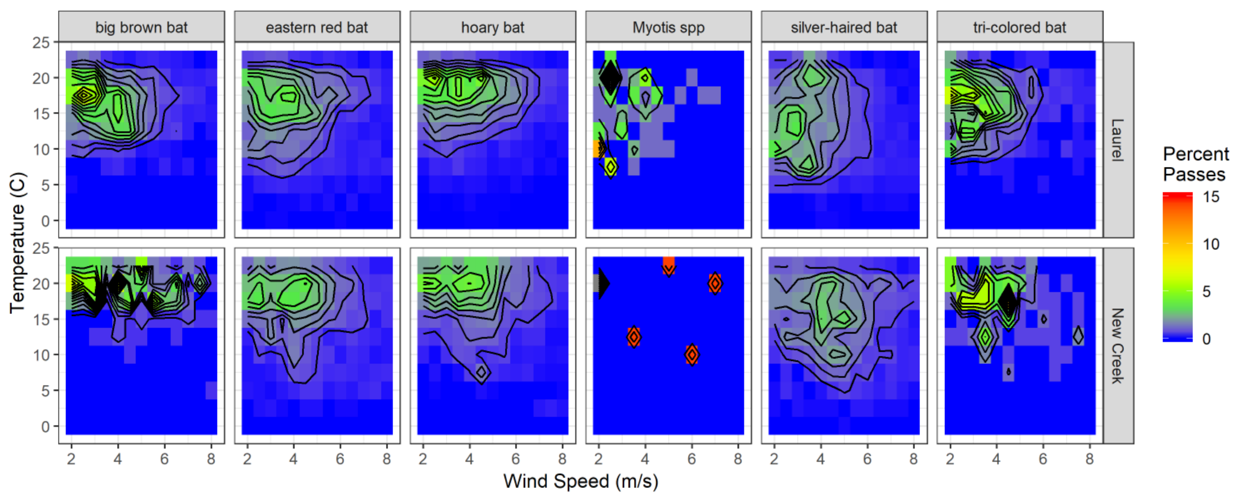

Figure 3.11. Distribution of bat activity by wind speed and temperature as a percent of passes recorded per year at Laurel Mountain in 2012–2015 and New Creek in 2017–2018, aggregating data among turbines.

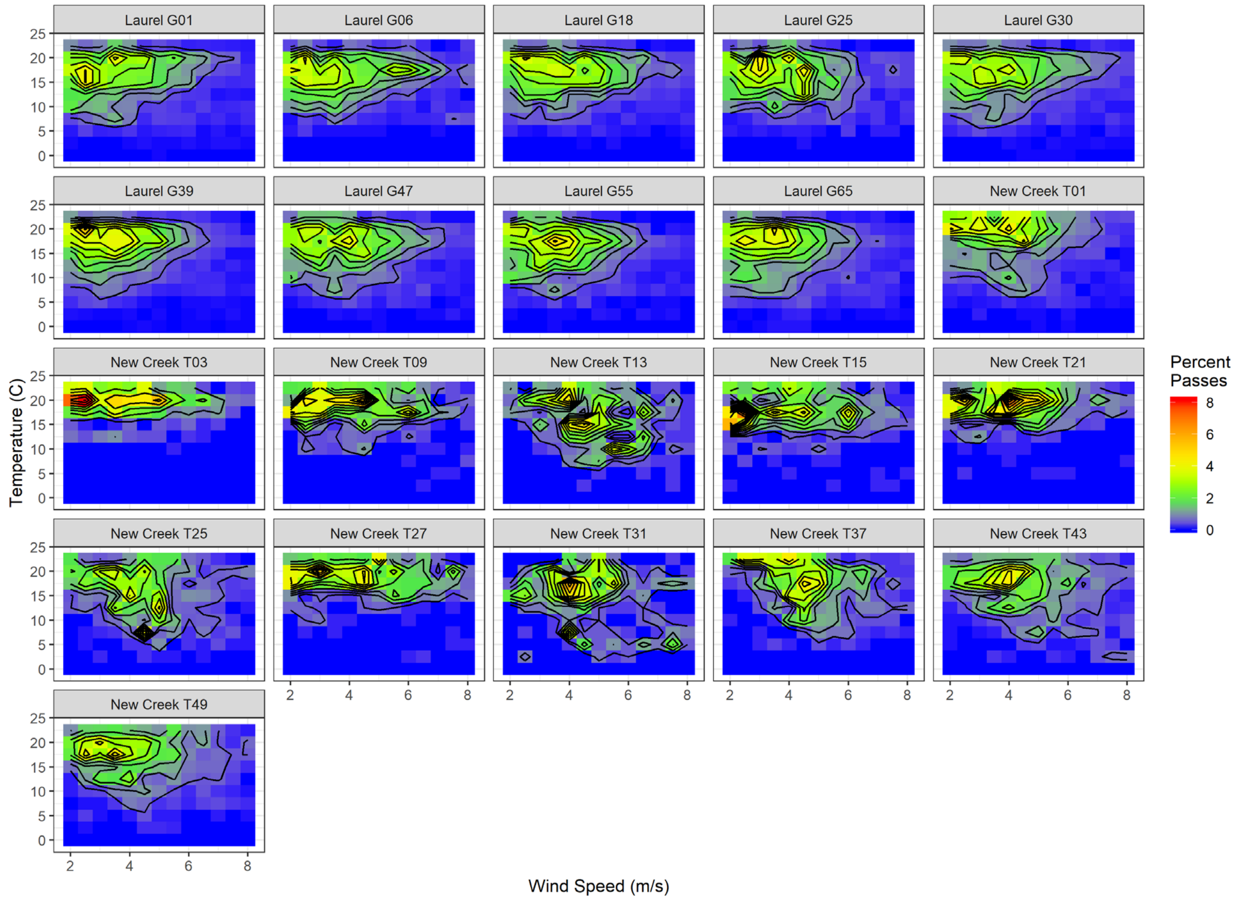

Figure 3.12. Overall distribution of bat activity by wind speed and temperature as a percent of passes recorded at Laurel Mountain in 2012–2015 and New Creek in 2017–2018, aggregating data among turbines and years.

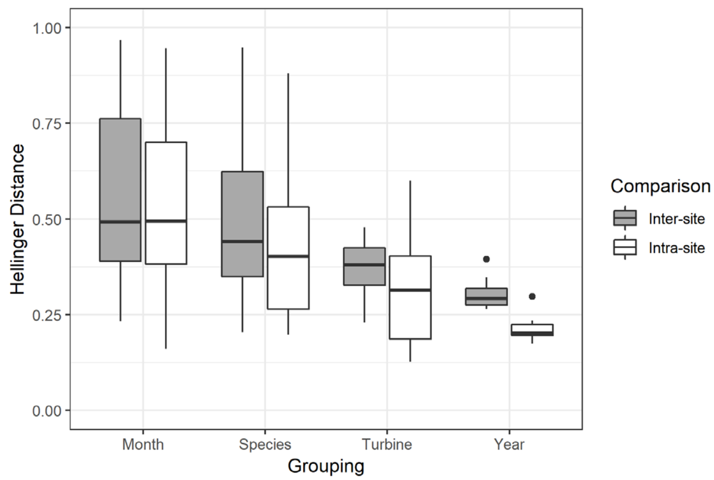

Figure 3.13. Hellinger distances for pairwise comparisons of distributions of bat data when grouped by month, species, turbine, and year at Laurel Mountain for 2012–2015 at Laurel Mountain and 2017–2018 at New Creek.

3.3.4 Evaluating Optimal Sample Sizes to Characterize Distribution of Bat Activity and Conditions

Acoustic datasets used to evaluate the effect of sample size on characterizations of bat activity and conditions during the most recent 2 years of monitoring per site represented 76–216 nights each, with a range of 398–2,974 bat passes recorded per turbine. The distribution of bat activity versus temperature and wind speed became less variable and more representative of overall patterns for Laurel Mountain and New Creek as sample size increased. Hellinger distance between the merged dataset and subsamples of increasing numbers of individual turbines during a single year demonstrated a rapid initial decrease in variation from 1 to 5 samples, then a gradual decrease from 6 to 10 samples, at which point the metric converged at the midpoint of the distance between the two sites (Figure 3.14). At 10 samples, mean Hellinger distances between subsamples and full datasets from the most recent 2 years of monitoring at each site were 0.14 for Laurel Mountain and New Creek. For comparison, the Hellinger distance between the aggregate distributions of bat activity from the most recent 2 years of data from Laurel Mountain and New Creek was 0.26.

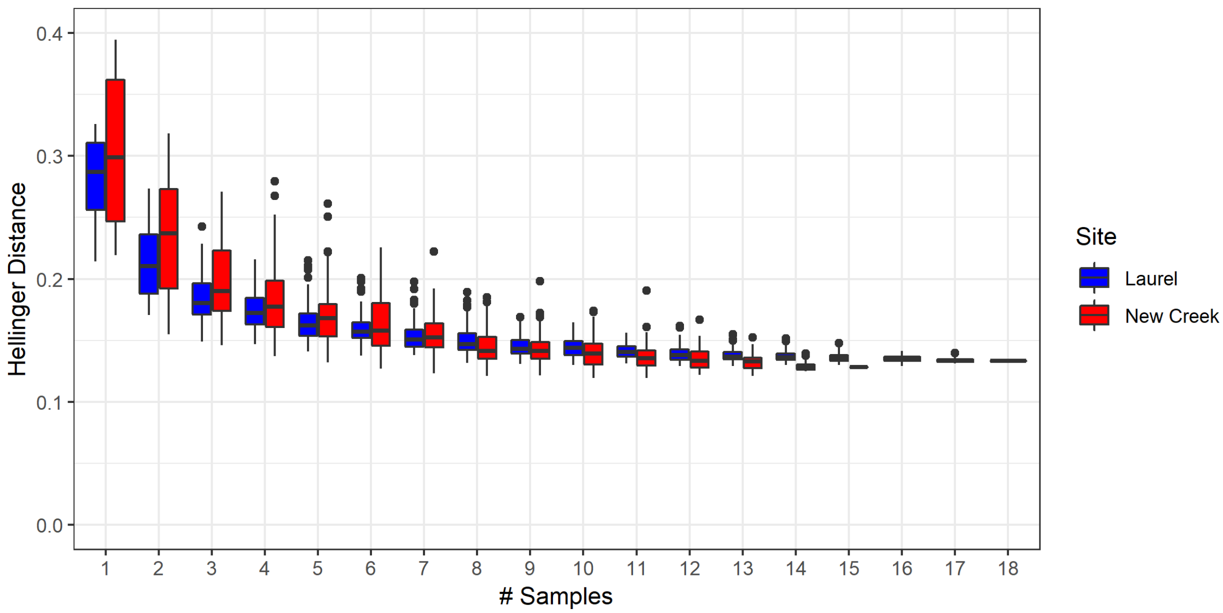

Figure 3.14. Hellinger distances between 100 randomly drawn subsamples of varying size from Laurel Mountain and New Creek versus an aggregate distribution representing data from Laurel Mountain in 2014–2015 (18 turbines) and New Creek in 2017–2018 (15 turbines).

3.4 SIMULATING AGENCY-RECOMMENDED CURTAILMENT STRATEGIES AND ACTIVITY-BASED INFORMED ALTERNATIVES

3.4.1 Existing Curtailment Strategies

Regulatory agencies in five states and three Canadian provinces and the US Fish and Wildlife Service have made public recommendations for curtailment strategies designed to reduce bat fatality rates. In some cases, state agencies recommended higher cut-in speeds or longer curtailment seasons for wind projects with greater perceived risk to bats, resulting in a total of 15 distinct strategies outlined in Table 3.7. We also found several examples of curtailment programs implemented voluntarily by wind projects and other cases in which curtailment plans were developed as part of project-specific permitting requirements, although we limited our analysis to general recommendations made by various agencies. All strategies involved feathering turbine blades below cut-in speeds ranging from manufacturer’s cut-in speed (3–4 m/s) to a maximum of 6.9 m/s, occasionally including a temperature threshold of 10°C. Seasonal duration of curtailment varied from 41 to 229 calendar nights among plans, although no plan required curtailment before March or after November. Most plans required curtailment to be implemented all night, often including a 30-minute buffer before sunset and after sunrise, and several plans recommended seasonal changes in cut-in speeds (Table 3.7).

Table 3.7. Parameters for selected curtailment scenarios recommended by state and federal regulatory agencies in the US and Canada.

Agency (Curtailment Plan)	Season	Parameters	Source
US Fish and Wildlife Service, Northeast Region (USFWS, Northeast)	1 Apr–15 May	5.0 m/s; > 10°C; ½ hr before sunset–½ hr after sunrise	US Fish and Wildlife Service 2015
	16 May–30 Sep	6.9 m/s; > 10°C; ½ hr before sunset–½ hr after sunrise	
	1 Oct–31 Oct	Manufacturer's cut-in; > 10°C; ½ hr before sunset–½ hr after sunrise	
US Fish and Wildlife Service, Midwest Region (USFWS, Midwest)	1 Aug–15 Oct	6.9 m/s; > 10°C; ½ hr before sunset–½ hr after sunrise	US Fish and Wildlife Service 2014b
Maine Department of Inland Fisheries and Wildlife (ME, low risk)	15 Apr–30 Sep	6.0 m/s; > 0°C; ½ hr before sunset–½ hr after sunrise	Maine Department of Inland Fisheries and Wildlife 2018
Maine Department of Inland Fisheries and Wildlife (ME, high risk)	15 Apr–30 Jun; 1–15 Sep	6.0 m/s; > 0°C; ½ hr before sunset–½ hr after sunrise	Maine Department of Environmental Protection 2019
	16 Jul–15 Sep	6.5 m/s; > 0°C; ½ hr before sunset–½ hr after sunrise	
Ontario Ministry of Natural Resources (Ontario)	15 Jul–30 Sep	5.5 m/s; > 10°C; ½ hr before sunset–½ hr after sunrise	Barnes et al. 2018
Alberta, Canada (Alberta)	1 Aug 1–10 Sep	5.5 m/s; sunset - sunrise	Barnes et al. 2018
British Columbia, Canada (British Columbia)	15 Mar–15 Oct*	6.0 m/s; ½ hr before sunset–½ hr after sunrise	Barnes et al. 2018
Pennsylvania Game Commission (PA, high risk)	1 Apr–30 Jun	5.0 m/s; > 10°C; ½ hr before sunset–½ hr after sunrise	Pennsylvania Game Commission 2013
	1 Jul–30 Sep	5.5 m/s; > 10°C; ½ hr before sunset–½ hr after sunrise	
	1 Oct–15 Nov	5.0 m/s; > 10°C; ½ hr before sunset–½ hr after sunrise	
Pennsylvania Game Commission (PA, low risk)	1 Jul–30 Sep	5.5 m/s; > 10°C; ½ hr before sunset–5 hrs later	Pennsylvania Game Commission 2013
Vermont Agency of Natural Resources (VT, ≥ 5 turbines)	1 Jun–30 Sep	6.0 m/s; > 10°C; ½ hr before sunset–½ hr after sunrise	Vermont Agency of Natural Resources Fish and Wildlife Department 2016
Vermont Agency of Natural Resources (VT, < 5 turbines)	1 Jun–30 Sep	5.0 m/s; > 10°C; ½ hr before sunset–½ hr after sunrise	
New York State Department of Environment and Conservation (NYSDEC, avoidance)	1 Jun–30 Sep	6.9 m/s; > 10°C; ½ hr before sunset–½ hr after sunrise	New York State Department of Public Service 2019
New York State Department of Environment and Conservation (NYSDEC, minimization)**	1 Jul–30 Sep	5.0 m/s; > 10°C; ½ hr before sunset–½ hr after sunrise	New York State Department of Environment and Conservation 2019
New York State Department of Public Service (NYSDPS, minimization)	1 Jun–30 Sep	6.0 m/s; > 10°C; ½ hr before sunset–½ hr after sunrise	New York State Department of Public Service 2019
Minnesota Department of Natural Resources (MN)	1 Apr–31 Oct	Manufacturer's normal cut-in; ½ hr before sunset–½ hr after sunrise	Minnesota Department of Natural Resources 2018

*Maximum recommended curtailment window

3.4.2 Acoustic and Weather Data from Nacelle Height

Nacelle-height acoustic bat recordings and corresponding temperature and wind speed measurements were available for a total of 8,848 detector-nights representing 1,246 calendar dates between 2011–2018. Combined, weather data were available for 1,245,648 10-minute periods, 560,201 of which occurred between sunset and sunrise. Bat activity occurred during 46,095 periods, representing a total of 78,226 recorded bat passes, 78,162 (99.9%) of which occurred between sunset and sunrise. The number of recorded bat passes per 10-minute interval ranged from 0 to 34, although the distribution of bat passes among intervals was heavily skewed with 30,820 (67%) of the subset of intervals with bat activity having only 1 bat pass. Of only 212 intervals with more than 10 recorded bat passes, all but 23 occurred at wind speeds greater than 5 m/s.

3.4.3 Simulations of Agency-Recommended Curtailment Strategies

Using parameters associated with the curtailment strategies outlined in Table 3.7, simulations based on temperature, wind speed, and acoustic bat activity recorded at Laurel and New Creek predicted energy losses of 0–126 MWh per turbine per year and reductions of 25–85% in exposure of total bat activity relative to uncurtailed turbines (Figure 3.15). In general, more protective curtailment strategies resulted in greater energy loss, although this was not always the case. The 15 plans we simulated were grouped as low (20–35%), moderate (~50–65%) and high (75–85%) in terms of exposure reduction, although predicted energy losses within these clusters varied substantially. Simulated energy loss ranged 69 to 126 MWh among the five strategies with 75% or greater predicted reductions in exposed bat activity.

For comparison, blanket curtailment strategies applying cut-in speeds from 1 June to 30 September at 0.5 m/s increments from 3 to 7 m/s resulted in mean predicted energy losses of 0 to 121 MWh per turbine per year and reductions of 14 to 80% in exposed bat activity when applied to the same datasets (Figure 3.16). Simulated blanket curtailment strategies achieved 75% reductions in exposed bat activity at or above 6.0 m/s at Laurel Mountain and 6.5 m/s at New Creek. The relationships between reduction in bat activity exposure as a function of cut-in speeds was nonlinear, with the most rapid reductions in exposure accumulating below 5.5 m/s, where avoidance was 67 and 70% at New Creek and Laurel Mountain, respectively. By contrast, power loss accumulated slowly below 5.0 m/s but grew exponentially above that speed, as did differences in simulated energy loss between sites (Figure 3.17).

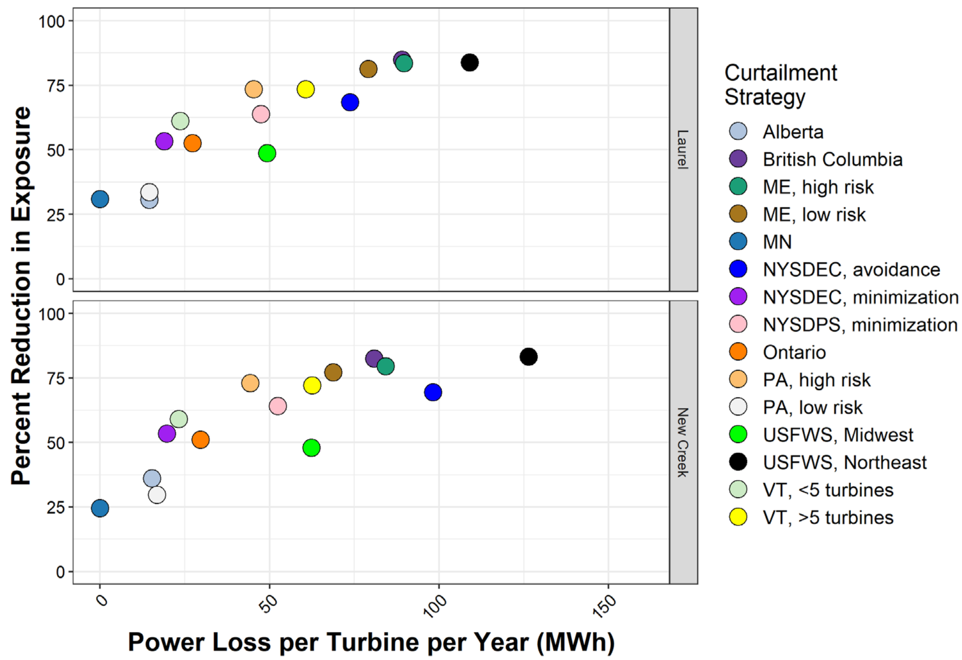

Figure 3.15. Predicted annual power loss (MWh) and reduction in bat activity exposure for agency-recommended curtailment strategies based on simulations using data from Laurel Mountain and New Creek.

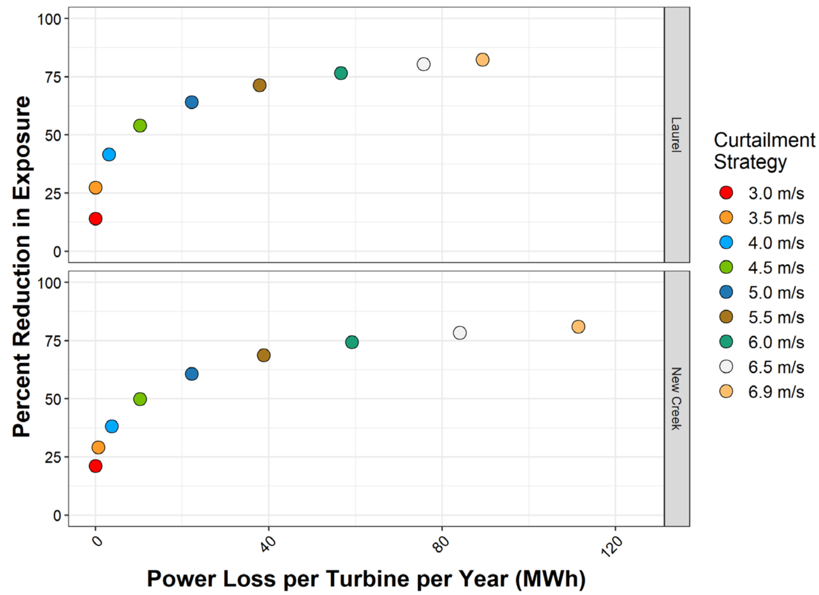

Figure 3.16. Predicted annual power loss (MWh) and reduction in bat activity exposure for blanket curtailment strategies with cut-in speeds from 3 to 7 m/s at 0.5 m/s increments based on simulations using data from Laurel Mountain and New Creek.

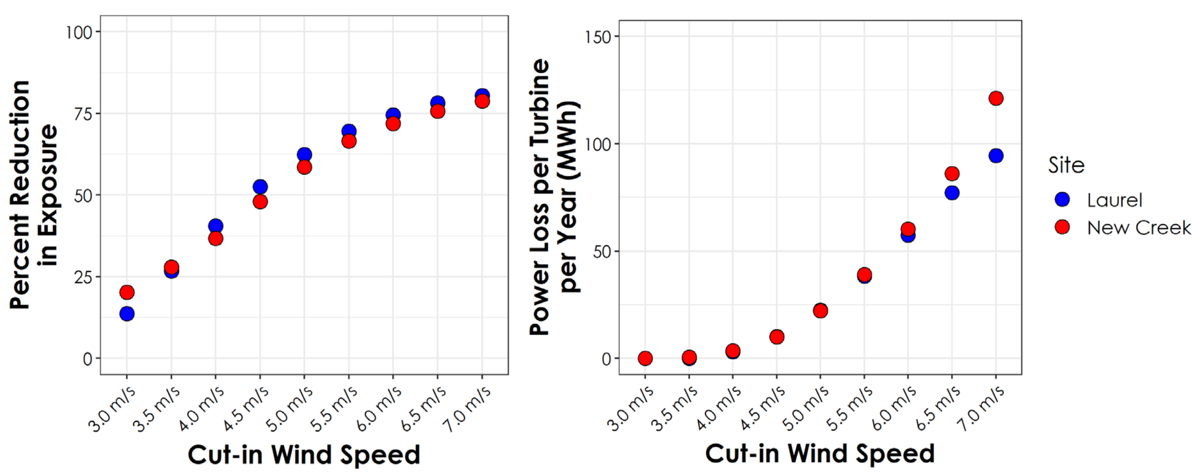

Figure 3.17. Percent reduction in exposed bat activity (left) and power loss (MWh) as a function of cut-in speed for blanket curtailment strategies simulated for 1 July–30 September using data from Laurel Mountain and New Creek.

3.4.4 Activity-Based Informed Curtailment Strategies

We used the interactive data visualization app to manipulate monthly cut-in wind speeds and temperature thresholds and toggle on or off a 30-minute buffer before sunset and after sunrise and view how these changes affected predicted exposure reduction and energy loss (Figure 3.18). We were able to design ABIC alternatives that were equally or more protective of bats while resulting in less energy loss than each of the 15 agency-recommended curtailment strategies outlined in Table 3.7. By visualizing simulations based on subsets of data, we were able to qualitatively assess how consistently curtailment strategies would work among years, species, sites, and turbines.

ABIC alternatives reduced predicted per-turbine energy losses by 7–68 MWh per turbine per year compared to equivalently protective blanket strategies, with ABIC alternatives resulting in an average of 49.2% and 47.4% less energy loss based on simulations using data from Laurel and New Creek, respectively (Table 3.8). The percent of energy loss during intervals with bat activity was also equal or higher for all ABIC strategies than their blanket curtailment counterparts, indicating an improved alignment between curtailment parameters and conditions associated with bat activity. Despite the improved efficiency of ABIC strategies, bat activity still occurred during 20% or less of curtailed periods, suggesting that ABIC strategies could be tailored further to more closely align with site-specific patterns in risk. For comparison, a hypothetical curtailment program that could avoid all bat activity by preventing turbine operation only during intervals with bat activity would result in losses of 20.2 MWh and 31.6 MWh per turbine per year based on simulations using data from Laurel and New Creek, respectively.

We developed a second set of ABIC strategies using only the subset of Myotis activity recorded at Laurel (n = 111 passes) and New Creek (n = 15 passes). ABIC alternatives targeting Myotis activity resulted in 11–85 MWh less energy loss per turbine per year, with mean energy loss reductions of 78.2% and 81.8% for Laurel and New Creek, respectively. Feathering turbine operation below manufacturer's cut-in speed from April to November reduced exposure of Myotis species bats by 50% at Laurel Mountain and 55% and New Creek, achieving greater reductions than several plans resulting in estimated energy losses up to 74 MWh per turbine per year (Table 3.9).

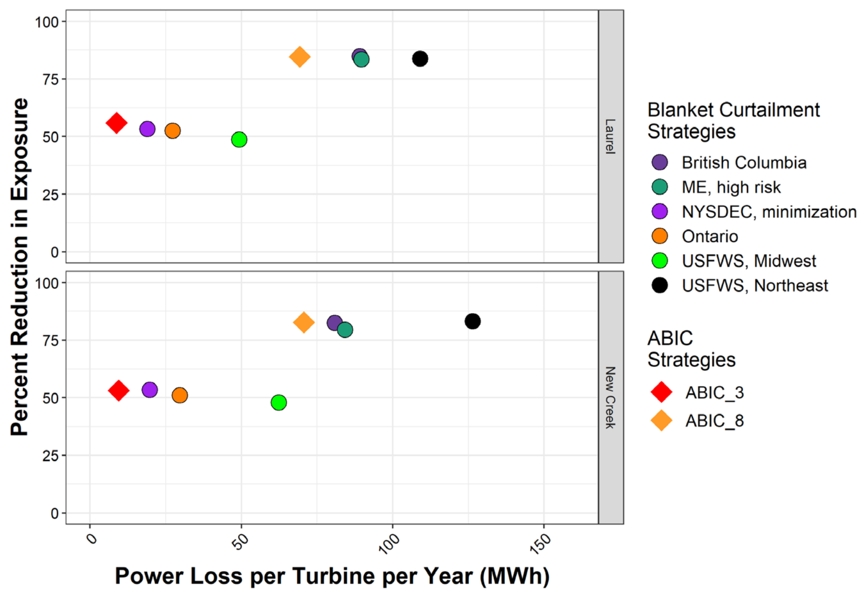

Figure 3.18. Predicted power loss and reduction in bat exposure for selected agency-recommendations and equivalently protective ABIC alternatives based on simulations using data from Laurel Mountain and New Creek.

Table 3.8. Parameters of activity-based informed curtailment (ABIC) alternatives and associated exposure reduction, power loss, and power loss efficiency (percent of energy loss occurring when bats were active) predictions compared against agency-recommended strategies based on simulations using nacelle-height acoustic bat and weather data from Laurel Mountain and New Creek.

Smart Curtailment Strategy					Baseline Strategy			
Name	**Description**	**Exposure Reduction (%)**	**Power Loss (MWh) & Efficiency (%)**	**Site**	**Name**	**Exposure Reduction (%)**	**Power Loss (MWh) / Efficiency (%)**	**Reduction in Energy Loss**
ABIC 1	Apr–Nov, manufacturer's cut-in, ½ hr before sunset–½ hr after sunrise, all temperatures	31	0 (NA)	Laurel	MN	31	0 (NA)	NA
		25	0 (NA)	New Creek	MN	25	0 (NA)	NA
ABIC 2	Apr–Jul, 3.5 m/s, 10°C; Aug– Sep, 4.0 m/s, 10°C; Oct–Nov, 3.5 m/s, 10°C; sunset - sunrise	38	2 (17%)	Laurel	Alberta	31	14 (13%)	12 MWh; 86%
					PA, low risk	34	14 (15%)	12 MWh; 86%
		39	3 (19%)	New Creek	Alberta	36	15 (20%)	12 MWh; 80%
					PA, low risk	30	17 (19%)	14 MWh; 82%
ABIC 3	Apr–May, 3.5 m/s, 10°C; Jun, 4.0 m/s, 10°C; Jul–Aug, 4.5 m/s, 10°C; Sep, 4.5 m/s, 5°C; Oct–Nov, 3.5 m/s, 5°C; sunset-sunrise	56	9 (16%)	Laurel	USFWS, Midwest	49	49 (10%)	40 MWh; 82%
					Ontario	53	27 (12%)	18 MWh; 67%
					NYSDEC, minimization	53	19 (13%)	10 MWh; 53%
		53	10 (20%)	New Creek	USFWS, Midwest	48	62 (13%)	52 MWh; 84%
					Ontario	51	30 (16%)	20 MWh; 67%
					NYSDEC, minimization	53	20 (17%)	10 MWh; 59%
ABIC 4	Apr–May, 3.5 m/s, 10°C; Jun, 4.0 m/s, 10°C; Jul, 4.5 m/s, 10°C; Aug, 5.0 m/s, 10°C; Sep, 5.0 m/s, 5°C; Oct–Nov, 3.5 m/s, 5°C; sunset-sunrise	63	15 (15%)	Laurel	VT, < 5 turbines	61	24 (12%)	9 MWh; 38%
		60	16 (19%)	New Creek	VT, < 5 turbines	59	23 (17%)	7 MWh; 30%
ABIC 5	Apr, 4.0 m/s, 10°C; May–Jun, 4.5 m/s, 10°C; Jul–Aug, 5.25 m/s, 10°C; Sep, 5.25 m/s, 5°C; Oct, 4.5 m/s, 5°C; Nov, 3.5 m/s, 5°C; sunset - sunrise	72	29 (13%)	Laurel	NYSDEC, avoidance	68	76 (10%)	47 MWh; 62%
					NYSDPS, minimization	64	47 (11%)	18 MWh; 38%
		69	30 (17%)	New Creek	NYSDEC, avoidance	69	98 (11%)	68 MWh; 69%
					NYSDPS, minimization	64	52 (14%)	22 MWh; 42%
ABIC 6	Apr, 4.0 m/s, 10°C; May, 4.5 m/s, 10°C; Jun–Jul, 5.0 m/s, 10°C; Aug, 5.5 m/s, 10°C; Sep, 5.5 m/s, 5°C; Oct, 5.0 m/s, 5°C; Nov, 3.5 m/s, 5°C; sunset–sunrise	75	36 (12%)	Laurel	PA, high risk	73	45 (10%)	9 MWh; 20%
					VT, > 5 turbines	73	61 (10%)	25 MWh; 41%
		73	37 (16%)	New Creek	PA, high risk	73	44 (15%)	7 MWh; 16%
					VT, > 5 turbines	72	63 (14%)	26 MWh; 41%
ABIC 7	Apr, 4.0 m/s, 10°C; May, 5.0 m/s, 10°C; Jun, 5.5 m/s, 10°C; Jul–Aug, 5.75 m/s, 10°C; Sep, 5.75 m/s, 5°C; Oct, 5.0 m/s, 5°C; Nov, 3.5 m/s, 5°C; sunset - sunrise	81	52 (11%)	Laurel	ME, low risk	81	79 (9%)	27 MWh; 34%
		79	54 (15%)	New Creek	ME, low risk	77	69 (14%)	15 MWh; 22%
ABIC 8	Apr, 4.0 m/s, 10°C; May, 5.5 m/s, 10°C; Jun, 6.0 m/s, 10°C; Jul, 6.0 m/s, 10°C; Aug, 6.0 m/s, 10°C; Sep, 6.0 m/s, 5°C; Oct, 5.5 m/s, 5°C; Nov, 3.5 m/s, 5°C; sunset–sunrise	85	69 (10%)	Laurel	ME, high risk	84	90 (9%)	21 MWh; 23%
					USFWS, Northeast	84	109 (9%)	40 MWh; 37%
					British Columbia	85	89 (8%)	20 MWh; 22%
		83	71 (14%)	New Creek	ME, high risk	80	84 (13%)	13 MWh; 15%
					USFWS, Northeast	83	126 (11%)	55 MWh; 44%
					British Columbia	83	81 (13%)	10 MWh; 12%

Table 3.9. Parameters of activity-based informed curtailment (ABIC) alternatives and associated exposure reduction, power loss, and power loss efficiency (percent of energy loss occurring when bats were active) predictions compared against agency-recommended strategies based on simulations using nacelle-height acoustic bat detection data (*Myotis* only) from Laurel Mountain and New Creek.

Smart Curtailment Strategy				Site	Baseline Strategy			
Name	Description	Exposure Reduction (%)	Power Loss (MWh) & Efficiency (%)		Name	Exposure Reduction (%)	Power Loss (MWh) & Efficiency (%)	Reduction in Energy Loss
ABIC M1	Apr–Nov, feathering below manufacturer's cut-in, sunset–sunrise, all temperatures	50	0 (NA)	New Creek	PA, low risk	13	17 (< 0.1%)	17 MWh; 100%
					Alberta	13	15 (< 0.1%)	15 MWh; 100%
					USFWS, Midwest	38	62 (< 0.1%)	62 MWh; 100%
					NYSDEC, minimization	50	20 (< 0.1%)	20 MWh; 100%
					VT, < 5 turbines	50	23 (< 0.1%)	24 MWh; 100%
					MN	50	0 (NA)	NA
		55	0 (NA)	Laurel	PA, low risk	21	14 (< 0.1%)	14 MWh; 100%
					Alberta	30	14 (< 0.1%)	14 MWh; 100%
					USFWS, Midwest	37	49 (< 0.1%)	49 MWh; 100%
					Ontario	43	27 (< 0.1%)	27 MWh; 100%
					NYSDEC, minimization	45	19 (< 0.1%)	19 MWh; 100%
					NYSDPS, minimization	49	47 (< 0.1%)	47 MWh; 100%
					NYSDEC, avoidance	52	74 (< 0.1%)	74 MWh; 100%
					MN	55	0 (NA)	NA
ABIC M2	Apr–May, 3.0 m/s, 10°C; Jun, 4 m/s, 10°C; Jul–Aug, 4.5 m/s, 10°C; Sep, 5.5 m/s, 10°C; Oct–Nov, 3 m/s, 10°C; sunset–sunrise	75	15 (< 0.1%)	New Creek	ME, low risk	63	69 (< 0.1%)	54 MWh; 78%
					NYSDPS, minimization	63	52 (< 0.1%)	37 MWh; 71%
					Ontario	63	30 (< 0.1%)	15 MWh; 50%
					VT, >5 turbines	63	63 (< 0.1%)	48 MWh; 76%
					British Columbia	75	81 (< 0.1%)	66 MWh; 81%
					ME, high risk	75	84 (< 0.1%)	69 MWh; 82%
					NYSDEC, avoidance	75	98 (< 0.1%)	83 MWh; 85%
					PA, high risk	75	44 (< 0.1%)	29 MWh; 66%
ABIC M3	Apr–May, 3.0 m/s, 10°C; Jun–Aug, 4.5 m/s, 10°C; Sep, 5.0 m/s, 5°C; Oct–Nov, 3 m/s, 5°C; sunset–sunrise	87	13 (< 0.1%)	Laurel	VT, < 5 turbines	82	24 (< 0.1%)	11 MWh; 46%
					PA, high risk	85	45 (< 0.1%)	35 MWh; 78%
ABIC M4	Apr–May, 3.0 m/s, 10°C; Jun, 4.5 m/s, 10°C; Jul–Aug, 5.0 m/s, 10°C; Sep, 5.5 m/s, 5°C; Oct–Nov, 3 m/s, 10°C; sunset–sunrise	91	24 (< 0.1%)	Laurel	VT, >5 turbines	87	61 (< 0.1%)	37 MWh; 61%
					USFWS, Northeast	90	109 (< 0.1%)	85 MWh; 78%
ABIC M5	Apr–May, 3.0 m/s, 10°C; Jun, 4.5 m/s, 10°C; Jul–Aug, 6.0 m/s, 10°C; Sep, 6.5 m/s, 10°C; Oct–Nov, 3 m/s, 10°C; sunset–sunrise	88	55 (< 0.1%)	New Creek	USFWS, Northeast	88	126 (< 0.1%)	71 MWh; 56%
ABIC M6	Apr–May, 3.0 m/s, 10°C; Jun, 5.0 m/s, 10°C; Jul, 6.5 m/s, 10°C; Aug, 6.0 m/s Sep, 5.5 m/s, 5°C; Oct–Nov, 3 m/s, 5°C; sunset–sunrise	96	48 (< 0.1%)	Laurel	British Columbia	96	89 (< 0.1%)	41 MWh; 46%
					ME, low risk	96	79 (< 0.1%)	31 MWh; 39%
					ME, high risk	96	90 (< 0.1%)	42 MWh; 47%

3.5 MANUAL AND AUTOMATIC ACOUSTIC ANALYSIS

When applied to the set of bat passes recorded during 10-minute periods at night (30 minutes before sunset–30 minutes after sunrise), omitting 2011 data from Laurel Mountain and results from 3 partially surveyed New Creek turbines as described above, identification methods resulted in substantially different numbers of recorded bat passes (Table 3.10). Kaleidoscope Pro (KPRO) identified 2–3 times as many bat passes as manual identification at Laurel Mountain, but close to the number of manually identified passes for New Creek. BCID software identified consistently fewer (~50% less) bat passes than manual identification at both sites, and SonoBat (SONO), which could only be used for full-spectrum results from New Creek, identified similar number of bat passes as BCID, substantially less than the number indicated by manual identification.

Table 3.10. Total number of bat passes indicated by manual identification and three automated analysis programs from Laurel Mountain and New Creek.

Site	Year	Identification method			
		Manual	KPRO	BCID	SONO
Laurel Mountain	2012	13,636	48,028	4,955	NA
	2013	18,133	35,822	5,020	NA
	2014	9,998	31,973	5,034	NA
	2015	13,112	64,115	3,836	NA
New Creek	2017	11,675	10,258	3,312	4,565
	2018	11,658	12,157	4,898	5,338
Laurel Mountain Total		54,879	179,938	18,845	NA
New Creek Total		23,333	22,415	8,210	9,903

Heat maps of the distribution of bat passes versus wind speed and temperature for each identification method demonstrate more consistent patterns among methods for New Creek than Laurel Mountain, whereas distributions based on BCID and KPRO were visibly different, with KPRO indicating a cluster of bat passes at relatively cold temperatures and high wind speeds (Figure 3.19). Comparison with manual identification results and visual inspection of these files indicates that they contained static as opposed to bat passes. Hellinger distances among identification methods for each site ranged from 0.074 to 0.333 for Laurel Mountain and 0.018 to 0.067 for New Creek (Table 3.11).

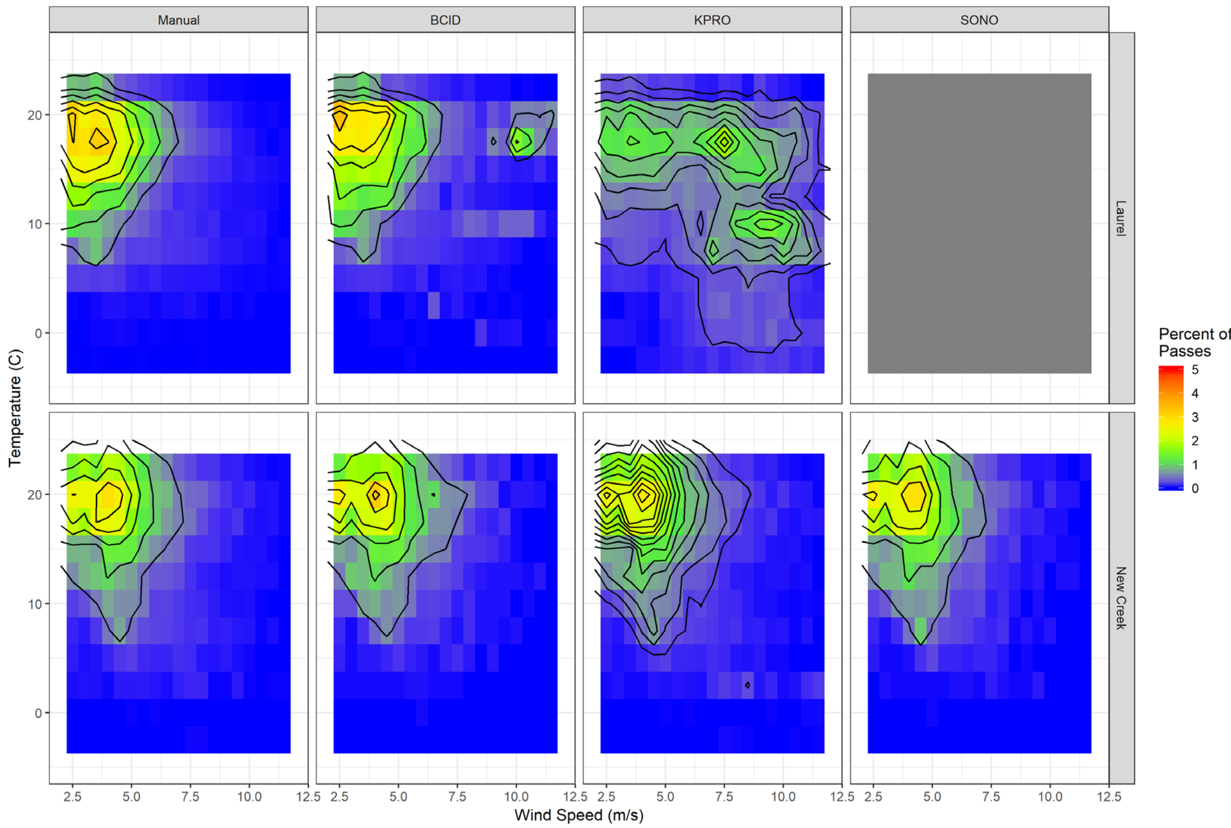

Figure 3.19. Distribution of bat passes versus wind speed and temperature by identification method, aggregating data among years.

Table 3.11. Hellinger Distances among distributions of bat activity versus wind speed and temperatures based on different identification methods.

Site	Comparison	Hellinger Distance
Laurel	Manual vs. BCID	0.074
	Manual vs. KPRO	0.333
	BCID vs. KPRO	0.329
New Creek	Manual vs. BCID	0.063
	Manual vs. KPRO	0.018
	Manual vs. SONO	0.047
	BCID vs. KPRO	0.067
	BCID vs. SONO	0.052
	KPRO vs. SONO	0.049

Predicted cost and exposure reduction for various agency-recommended curtailment strategies were similar based on manual identification and results of each automated software program for New Creek but differed substantially among identification methods for Laurel Mountain (Figure 3.20). Notably, identification of substantial numbers of static at higher wind speeds as bats by KPRO for Laurel Mountain resulted in lower predicted effectiveness for curtailment programs. As above, acoustic data from Laurel Mountain were collected in zero-crossing format and could not be analyzed using SonoBat software.

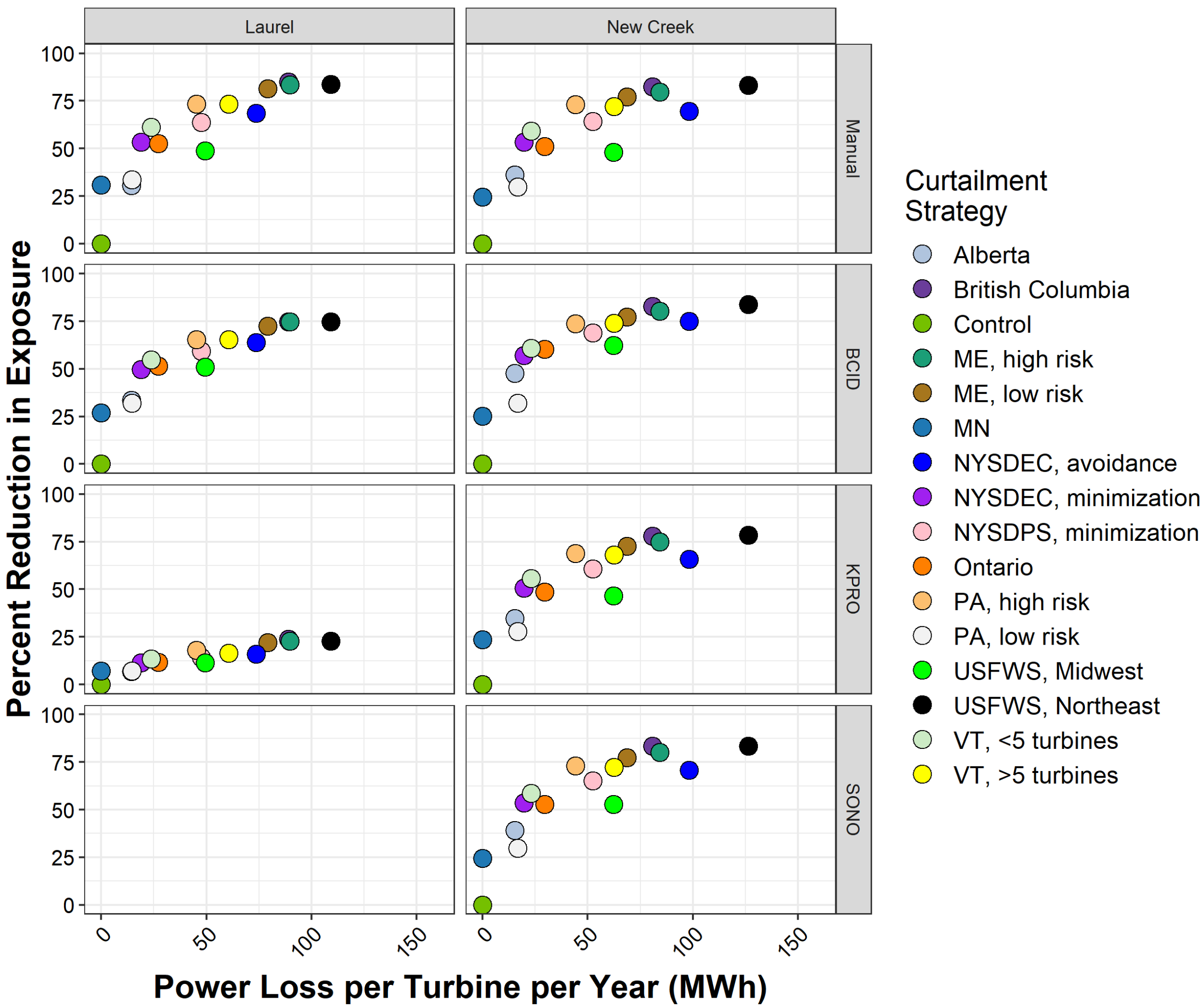

Figure 3.20. Predicted power loss and reduction in bat exposure for selected agency-recommendations based on simulations using results of different acoustic identification methods from Laurel Mountain and New Creek.

4.0 DISCUSSION

4.1 BAT ACTIVITY AND FATALITY RISK

The amount and relative proportion of bat activity exposed to turbine operation (occurring when turbine rpm ≥ 1) explained a significant amount of variation in estimated bat fatality rates among distinct operational treatments ranging from normally operating turbines to aggressive curtailment programs. Exposed bat activity also explained a significant amount of the variation in raw carcass counts among turbines and the probability of detecting bat carcasses during individual turbine searches. However, the total amount of bat activity, which includes passes not exposed to turbine operation, demonstrated weaker or no relationship with these fatality metrics, suggesting that only the subset of bat activity that is exposed to wind turbine operation is a meaningful indicator of fatality risk.

Similar patterns occurred at Laurel Mountain and New Creek indicating consistency in relationships between activity exposure and fatality risk at both sites. The only models in which site was a significant factor were those comparing raw carcass counts to acoustic activity. Raw carcass counts depend on the search area, ground conditions, and number of searches per monitoring period, among other factors (Bernardino et al. 2013). Although these factors were relatively consistent among turbines at each site, they differed between the two sites monitored, affecting the relationship between exposed activity and carcass counts. However, exposed activity explained a significant amount of the variation in bat carcasses found per turbine at both sites.

Of the scales we tested, the strongest relationship was the treatment-level comparison between acoustic data pooled among turbines and fatality estimates. Such fatality estimates represent an aggregation of exposure and associated risk over a longer time period and variable conditions among turbines. The treatment-level results demonstrated not only that curtailment can dramatically reduce fatality, but that exposed bat activity was a quantitative measure of this reduction. Although exposed bat activity was positively correlated with fatality rates, the curtailment treatments implemented at the two sites provided an insufficient sampling of curtailment programs and associated fatality estimates to fully characterize the nature of the relationship between exposed activity and risk. Additional opportunities to directly compare measured exposure to fatality rates at sites implementing multiple curtailment treatments will be necessary to determine whether the relationship is linear, or whether fatality risk decreases rapidly when exposure drops below a certain threshold.

Our detection of strong associations between exposed bat activity and fatality rates does not necessarily contradict previous studies that documented weak, if any, relationships between acoustic activity and risk. No other study has differentiated between exposed and unexposed bat activity and analyzed only the subset of bat activity exposed to turbine operation. Exposed activity measured at nacelle height is the result of a bat flying within the rotor zone of a turbine when the turbine is spinning. While most bats that fly near turbine nacelles or pass through the rotor zone of operating turbines do not collide with turbine blades (Horn et al. 2008), quantifying the amount of bat activity in this zone indicates the magnitude of potential risk at any given moment. By contrast, bat activity occurring when turbines are idle or curtailed should have no relationship with risk. Our results demonstrated that the amount of exposed bat activity varied considerably among curtailment treatments and that only the subset of exposed activity affected bat fatality. We suspect that future comparisons that analyze only the subset of activity exposed to rotating turbine blades, whether measured or simulated, will likely detect relationships with fatality. Additional comparisons of exposed bat activity and fatality rates across a broader geographic range will provide better resolution surrounding their relationship, enabling more robust tests among different sites and landscapes.

4.2 PREDICTABILITY OF EXPOSURE

Our simulations of curtailment treatments aligned closely with measured exposure, demonstrating that simulations accurately characterized turbine operation under different curtailment scenarios. Also, simulated exposure aligned closely with measured exposure during subsequent years, indicating the likelihood that risk can be predicted for future years. These results demonstrate that acoustic bat and weather data recorded at nacelle height can be used to characterize site-specific patterns in bat activity, simulate curtailment plans, and predict their associated reductions in exposure and associated risk of fatality. This in turn enables direct comparison of alternatives and lays a foundation for designing curtailment programs that either maximize risk reduction for a given amount of energy loss or that achieve a target reduction threshold with minimal energy loss.

4.3 DISTRIBUTION OF BAT ACTIVITY, WIND SPEED, AND TEMPERATURE

Bat activity at Laurel Mountain and New Creek occurred primarily during relatively low wind speeds and warm temperatures, with 75–85% of bat passes recorded when wind speed was less than 5.0 m/s and 86%–91% of passes occurring above 10°C. Distributions of bat activity according to wind speed and temperature were similar among years at both sites, indicating consistent relationships between bat activity and both weather variables. Seasonal distribution of bat activity and changes in species composition were surprisingly similar at Laurel Mountain and New Creek, considering that surveys at the two sites were separated by a minimum of two years. Most bat activity occurred in July–September at both sites, with long-distance migratory species accounting for most activity at both sites. Species composition varied among months in a similar pattern between sites, likely explaining some of the observed variation among species in distribution of activity as a function of wind speed and temperature.

When analyzed in terms of wind speed and temperature, distribution of bat activity was most consistent among years and sites and grew increasingly dissimilar among turbines, species, and months. Given the morphological and behavioral diversity of bats, inter-species variation in the distribution of bat activity as a function of temperature and wind speed is not surprising (see Ciechanowski et al. 2007). Similarly, bats likely respond differently to changing temperatures and wind speeds when foraging during the maternity period versus migrating long distances in the fall, providing numerous reasons for seasonal variation in distributions of bat activity in the conditions space (Fleming and Eby 2003; Liechti and McGuire 2017; Krauel and McCracken 2013; Pettit and O'Keefe 2017). However, these types of variation are likely systematic and would, therefore, be incorporated in acoustic datasets that encompass the full seasonal extent of bat activity and associated range in species composition. Indeed, when acoustic and weather data were aggregated across species and seasons, the distribution of bat activity versus conditions was substantially more consistent.

Broadly, this pattern suggests that bats respond consistently to conditions in the aerosphere at the macro scale, whereas predictable variation may occur among species and different seasons. In our study, consistency of distributions is also likely a reflection of similar weather patterns among the sites within surveyed years. We purposely chose to evaluate overall distribution of bat passes in the conditions space as opposed to incorporating the distribution of conditions themselves. Accordingly, the distributions we measured reflect both the availability of certain temperature and weather conditions and bats tendency to be more active during certain conditions. This aligns with our overall purpose of characterizing distribution of exposure for predicting impacts at wind farms but may mask more subtle behavioral relationships between bats and weather variables. Additional data of this type from a greater diversity of wind farms will help quantify how consistent the distribution of bat activity is on a seasonal basis and in response to parameters such as temperature and wind speed that are relevant for risk of turbine-related impacts at commercial wind farms.

Variation among distributions of bat activity in the conditions space decreased as a function of the number of samples (each representing a single detector deployed for a period of ~3–7 months), although ~10 samples was generally adequate to characterize the distribution of activity at both sites. Combined with the greater variation among months and species and minimal variation among years, our results highlight the importance of sampling throughout the period over which risk may occur and suggest that detectors should be deployed on the nacelles of ~10 turbines. However, collecting multiple years of data provided less additional information for the sites we monitored.

4.4 SIMULATING AND OPTIMIZING CURTAILMENT

Evaluations of curtailment strategies simulated using wind speed, temperature, and acoustic bat data recorded over multiple years at two different wind farms indicated that blanket curtailment strategies can effectively reduce exposure of bat activity by substantial margins, but that exposure reductions and energy losses were highly variable among plans. For example, curtailment strategies with the same level of exposure reduction (e.g., “ME, low risk” and “NYSDEC, avoidance”) differed by as much as 50% in terms of predicted energy loss. Energy losses were generally higher for more protective plans, although some plans (e.g., “PA, low risk” and “USFWS, Midwest”) resulted in substantially more energy loss than equivalently protective plans (e.g., “MN” and “Ontario”). Each curtailment strategy recommended by regulatory agencies in the US and Canada involved feathering turbine blades below cut-in speeds ranging from 3 to 6.9 m/s. Although the seasonal duration, cut-in speeds, time of night, and temperature thresholds varied among strategies, all involved some degree of restricted operation during late summer (July–August).

We were able to reduce the simulated energy losses of curtailment plans by an average of more than 40% while maintaining equal or better protection of bat activity simply by making relatively minor adjustments to cut-in wind speeds and temperature thresholds on a monthly basis. Even greater reductions in energy loss were possible when designing smart curtailment alternatives specifically targeting Myotis activity, although sample sizes were very small. More aggressive reductions in exposure inevitably required more energy loss, although we were able to match reductions of the most restrictive agency-recommended curtailment plans with less energy loss. Adjusting cut-in speeds and temperature thresholds on a monthly basis to align more closely with risk were the primary modifications needed to achieve target reductions with substantially less energy loss. Adjusting parameters on a monthly basis reduces the possibility of overfitting a curtailment strategy to finer scale variation in bat activity that are less likely to occur repeatedly.

Although fatality studies at wind farms have consistently noted gradual increases in bat fatality rates in spring and early summer, peak risk during late summer, and gradual decline into fall (Arnett et al. 2005; Arnett et al. 2008; Kunz et al. 2007; Arnett and Baerwald 2013; AWWI 2018a), none of the agency-recommended curtailment plans we simulated attempted to match this well-established pattern. By contrast, our ABIC strategies applied gradually higher cut-in speeds during months with greater bat activity, thus matching the intensity of curtailment to the magnitude of risk. Accordingly, the ABIC strategies we simulated represent a relatively simple and straightforward approach to smart curtailment that uses parameters that are easily measured and already incorporated in turbine control algorithms, provided that turbine operators anticipate the need or desire to alter operations. Acoustic bat data are used to provide the quantitative basis for setting appropriate parameter thresholds, but curtailment is triggered by the conditions themselves.

Our results indicated that curtailment programs would be similarly effective between Laurel Mountain and New Creek. These sites are similar in terms of topography and region, and results may differ more substantially among sites in different landscapes and habitats. Conducting similar studies and simulations at more wind farms will provide an opportunity to assess inter-site variation in predicted curtailment effectiveness and cost.

The purpose of this analysis was neither to criticize any particular curtailment strategy nor recommend a specific smart curtailment alternative, but to demonstrate how nacelle-height acoustic data, when aligned with readily available temperature and wind speed data, can inform a quantitative framework to improve the efficiency of conditions-based curtailment program. This information will, in turn, dictate how complex a smart curtailment strategy needs to be to meet bat fatality reduction targets. We were able to meet or exceed reductions in bat activity exposure of all 15 agency-recommended curtailment strategies we simulated through relatively minor adjustments of cut-in speeds and temperature parameters on a monthly basis, indicating that smart curtailment alternatives do not necessarily need to be complicated to be effective.

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Appendix B

Using Acoustics to Design and Evaluate Activity-based Smart Curtailment at Wind Farms

Updated Research Study Plan

Phase 1: Orient & Arbor Hill

Phase 2: Expansion Sites

May 6, 2022

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1.0 INTRODUCTION

Bat fatality at commercial wind farms has emerged over the past 15 years as a novel and potentially significant impact to bat populations in North America. Numerous post-construction studies have demonstrated that bat fatality, including potential impacts to rare species, is a widespread occurrence for wind projects operating in diverse habitats and landscapes throughout much of North America. Hoary bats (*Lasiurus cinereus*) account for a consistently large proportion of fatalities, and current fatality rates could threaten the viability of this species over time (Frick *et al.* 2017). The first studies to report unexpectedly high rates of bat fatality at commercial wind farms in North America noted an apparent relationship between bat fatality and conditions in the aerosphere (lower portion of the atmosphere in which bats and other living organisms are active), with more bat carcasses typically found following relatively calm, warm nights (Arnett *et al.* 2005; Kunz *et al.* 2007). The same studies noted pronounced seasonal concentration of bat fatalities in late summer and early fall. These patterns have remained remarkably consistent across numerous post-construction fatality studies conducted throughout North America (Arnett and Baerwald 2013; AWWI 2018).

Bats are at risk of wind turbine-related impacts only when turbine rotors are spinning. For this reason, feathering turbine blades to prevent turbine rotation when bats are active avoids risk to bats (Arnett *et al.* 2010). Commercial wind turbines do not generate electricity until the wind speed reaches a manufacturer and model-specific threshold “cut-in” speed, typically between 3 and 4 meters per second (m/s). Turbines reach their rated power output at wind speeds of 12–15 m/s (Carrillo *et al.* 2013), such that the capacity for a wind turbine to generate power varies with conditions. Similarly, bat activity varies seasonally, temporally, and in response to changing temperature and wind speed in the aerosphere. Risk of turbine-related fatality is therefore a dynamic process driven by a combination of bat behavior and turbine operation.

Previous research at wind farms suggests that curtailing turbine operation below 6.0 m/s can substantially reduce fatality rates (Arnett *et al.* 2010; Arnett *et al.* 2013), and more recent studies have documented substantial decreases in fatality using cut-in speeds as low as 4.5 m/s, although the ability to predict measured fatality reductions as a function of cut-in speed is hampered by large confidence intervals surrounding fatality estimates and substantial variation among results (Barnes *et al.* 2018). The US Fish and Wildlife Service (USFWS) has established a benchmark curtailment cut-in speed of 6.9 m/s as an approved means for wind companies to avoid risk of turbine-related impacts to federally endangered Indiana bats (*Myotis sodalis*) and federally threatened northern long-eared bats (*Myotis septentrionalis*). However, increasing cut-in speeds can result in unacceptably large amounts of energy loss for certain wind projects, particularly when cut-in speeds exceed 6 m/s. Accordingly, even though curtailment below 6.9 m/s appears to be an effective tool to avoid risk to federally listed bats and can substantially reduce overall bat fatality rates, the resulting decrease in energy production due to curtailment represents a barrier to widespread implementation of this strategy by the industry.

Energy loss associated with curtailment is primarily a function of wind speed and is less affected by time of night, season, temperature, or other variables. By contrast, many factors beyond wind speed affect the amount of bat activity occurring in the rotor zone during any given interval, which in turn determines the associated potential benefit of curtailment. We define curtailment programs with parameters such as cut-in wind speed or temperature thresholds that are not informed by site-specific data, or which do not take into account seasonal trends in bat activity as “blanket” curtailment strategies. While blanket curtailment strategies may effectively reduce bat fatality rates, they typically result in substantial energy loss from curtailment during periods or conditions when very little bat activity occurs. By contrast, “smart” curtailment strategies to use site-specific data on bat activity patterns to determine parameters and/or incorporate additional parameters to focus curtailment on conditions when most bat activity occurs. By focusing on conditions when bats are most active, smart curtailment strategies seek to reduce the amount of energy loss while still reducing turbine-related bat fatality rates.

The underlying principle of curtailment is that reducing exposure of bats to turbine operation also reduces fatality rates. While turbine curtailment at low wind speeds (e.g., 4.5–6.5 m/s) has been shown to be effective at reducing bat fatality rates, scant quantitative information exists to identify a suitable minimum cut-in speed threshold for curtailment. The range in confidence intervals surrounding bat fatality estimates is typically substantial relative to estimates themselves, due in part to a combination of imperfect carcass detection and small sample sizes, limiting the ability to detect subtle differences in fatality among alternative curtailment programs, even if conducted in a rigorous manner. This is particularly true for sites with low baseline fatality rates, where statistical power to differentiate treatments or assess relationships between conditions and risk will be correspondingly low if using carcass counts. More importantly, fatality monitoring cannot precisely determine the timing of fatalities, rendering such datasets unhelpful in understanding which variables affect risk of fatality with any temporal precision.

In contrast to fatality monitoring, acoustic bat monitoring at nacelle height generates time-stamped data ideally suited for characterizing conditions affecting bat activity in the aerosphere. Wind speed, temperature, and turbine rotor speed (revolutions per minute; rpm) data are also recorded at the nacelles of most wind turbines and can be compared to bat activity patterns with temporal precision. Such information can then be used to determine whether bats were detected when turbines were operating and therefore at risk of impact. Although cannot record bat activity in the entire rotor zone of a wind turbine (maximum detection range is ~30 m) and cannot indicate the number of individual bats in the sampled airspace, acoustics provides a suitable method to measure trends in bat activity over time, which is the primary metric of interest for our proposed approach for designing and evaluating curtailment strategies. By measuring the amount of exposed bat activity (passes occurring when turbine rotors were spinning greater than 1 rpm), we can calculate how effectively any curtailment strategy reduced exposure of bats to risk. Using the same information, we can also design smart curtailment alternatives that focus curtailment on conditions with greatest bat activity, thereby achieving equal or greater reduction in exposure and fatality risk with less associated energy loss. The goal of our research is to demonstrate how acoustic bat and weather data recorded at turbine nacelles can be combined with results of standardized carcass monitoring to design and evaluate “smart” curtailment strategies that are tailored to site-specific patterns in bat activity.

Stantec monitored acoustic bat activity on turbine nacelles at the Laurel Mountain and New Creek wind farms in West Virginia between 2011–2018 and used these data to demonstrate that bats are active during a relatively narrow subset of aerospheric conditions, that these patterns are stable among turbines and even among years, and that the amount of bat activity exposed to turbine operation is positively correlated with bat fatality on multiple scales (Stantec, manuscript in preparation). Together, these results suggest that nacelle-height acoustic data can provide the basis for designing smart curtailment plans tailored to site-specific and species-specific bat activity patterns and be used to evaluate the degree to which a given curtailment program reduces exposure of bats to turbine operation and the associated risk. Specifically, the metric of exposed bat activity will be used as a quantitative and temporally precise metric of risk. This study is designed to build on previous findings and will provide a robust test of the assumptions underlying our strategy for refining curtailment.

Using the results of our previous studies as a proof of concept, our proposed research will assess relationships between bat activity and fatality on a broader scale and compare acoustic exposure, fatality rates, and energy loss between smart and blanket curtailment strategies. Our overall goal is to demonstrate how data that are readily available to the wind industry can be used to change the design and implementation of curtailment from a prescriptive to a risk-based strategy, thereby reducing bat fatality rates and simultaneously reducing the amount of energy loss and encouraging broader adoption by the industry. Our study will establish and test a framework that uses site-specific data to design strategic curtailment programs, will be broadly applicable, and will enable wind farm developers and operators to use widely available technology and techniques to reduce cost of curtailment while maintaining its effectiveness as a tool to minimize impacts to bats.

2.0 RESEARCH OBJECTIVES

Our proposed research will address four primary technical goals, each of which is described further in the context of our study design. We will evaluate each of these goals in the context of species-specific and pooled activity patterns as allowed by the dataset, recognizing potential issues with small sample sizes for rare species.

2.1 OBJECTIVE 1: QUANTIFY CONSISTENCY OF RELATIONSHIP BETWEEN BAT ACTIVITY AND AEROSPHERIC CONDITIONS

For activity-based informed curtailment to be effective, bat activity must respond consistently to variables used as parameters in the turbine control system. While bat activity undoubtedly is influenced by numerous factors that interact with one another, our goal is to demonstrate that wind speed and temperature, as measured on a fine temporal scale (10-minute intervals) encompass sufficient variation in bat activity to be the only variables needed to strategically manage bat fatality risk. By design, we have chosen to focus on variables that are already collected by most wind turbines and that are available in the SCADA systems available to wind project operators. Our project will provide an excellent opportunity to test this assumption, as it will generate a robust set of nacelle-height acoustic bat data coupled with weather and turbine operation across two 2-year research phases spanning up to four years (2020 –

2023) and representing up to 13 wind farms, across two 2-year research phases. We will use this dataset to measure how consistently bat activity is distributed throughout the year and in response to temperature and wind speed, comparing across turbines, projects, years, and species. Using a combination of visual heat maps and spatial analysis techniques, we will analyze distribution of bat activity in the multidimensional conditions space defined by temperature and wind speed over time, providing a quantitative test of how individual bat species use the air space surrounding turbines at a finer temporal resolution than can be derived from carcass data.

2.2 OBJECTIVE 2: QUANTIFY RELATIONSHIP BETWEEN EXPOSED BAT ACTIVITY AND FATALITY

Annual bat fatality estimates, corrected to account for uncertainty introduced by carcass removal, imperfect detection, and other factors, are the metric most often used to evaluate wind farm impacts and guide minimization efforts. Although typically bounded by relatively large confidence intervals, fatality estimates provide the quantitative evidence that curtailment reduces fatality rates. However, fatality estimates alone typically provide insufficient precision to differentiate curtailment programs with similar parameters. Stantec's ongoing analyses of existing data demonstrates that exposed bat activity is positively correlated with bat fatality and is a more quantitative and temporally precise metric of risk of turbine-related impacts than carcass counts (Peterson et al. 2021). We will compare exposed bat activity (bat passes recorded when turbine blades are rotating >1 rpm) and fatality at the scale of individual turbine searches, turbine-level totals, and aggregated fatality estimates to further characterize the relationship between exposed activity and fatality. By comparing models incorporating linear and non-linear relationships and allowing for inter-turbine, inter-site, and inter-year variation, we will have a better understanding of how exposed activity should be calculated to best represent risk to bats. These results will lay the foundation for use of exposed bat activity as a metric to design and evaluate curtailment programs.

2.3 OBJECTIVE 3: DEMONSTRATE USE OF NACELLE-HEIGHT ACOUSTIC AND WEATHER DATA TO OPTIMIZE SITE-SPECIFIC SMART CURTAILMENT STRATEGIES

Comparing curtailment programs based on estimated fatality rates requires that treatments be implemented across a sufficient number of turbines throughout a monitoring period, severely limiting the number of treatments that can be compared in a study. The high cost of carcass monitoring coupled with the low temporal resolution and imprecision in ensuing fatality estimates precludes the practicality of using fatality data to determine an optimal curtailment strategy or adaptively manage risk of turbine-related impacts to bats for a commercial wind farm over long time periods. By contrast, nacelle-height acoustic data are relatively easy to collect and provide a quantitative basis to demonstrate long-term effectiveness of curtailment and adaptively modify curtailment parameters should conditions change. Simulating the amount of exposed bat activity and energy loss of curtailment programs using nacelle-height acoustic and weather data enables quantitative comparison of any potential curtailment strategy, providing a basis to optimize curtailment efficiency based on site-specific data. We will use data from the first year of monitoring at each site to design a smart curtailment alternative and predict its effectiveness at simultaneously reducing bat exposure and energy generation losses. We will then test the accuracy of predictions during the second year by comparing predicted and measured exposure and energy loss. This information will provide a robust test of the reliability curtailment forecasting within and among sites, addressing a key knowledge gap and establishing a quantitative framework for optimizing and evaluating smart curtailment programs.

2.4 OBJECTIVE 4: COMPARE EFFECTIVENESS AND ENERGY LOSS OF BLANKET AND SMART CURTAILMENT PROGRAMS

This project will generate fatality estimates and measurements of energy loss for blanket curtailment programs and smart curtailment alternatives at multiple host sites, allowing direct comparisons of curtailment effectiveness and energy loss in different environments and regions. Simultaneously, the nacelle-height acoustic data recorded at each host site will indicate the proportion and amount of bat activity exposed to turbine operation under each curtailment treatment. By comparing measured reductions in acoustic exposure and fatality rates in the context of energy loss we will be able to test the extent to which a smart curtailment program can allow for additional energy production while maintaining the same level of fatality reduction as a blanket curtailment alternative. This test is critical to refining curtailment as a targeted risk management tool. Importantly, the potential cost savings of smart curtailment programs depend on the parameters of the blanket curtailment strategies they are designed to replace, and the ability to compare smart and blanket curtailment strategies in different regions and regulatory environments will provide useful context for evaluating the potential benefits of smart curtailment.

3.0 STUDY DESIGN

We will address our research objectives using a combination of nacelle-height acoustic bat monitoring with corresponding temperature, wind speed, and turbine operation measurements, and standardized carcass monitoring. The research will occur at two groups of study sites, consisting of two phase one sites (Orient and Arbor Hill) that will be monitored in 2021 and 2022[1], and up to 11 phase two “expansion sites” that will be monitored in 2022 and 2023. The study will include two field seasons per study site, the first of which will document baseline bat fatality rates and acoustic exposure associated with two treatments including blanket curtailment below 5.0 m/s and an operational control consisting of feathering turbine blades below manufacturer’s cut-in speed (3.0 – 3.5 m/s, depending on the site). The second season will test the effectiveness of a smart curtailment alternative based on acoustic data collected during the first year and designed to be equally protective of bats as the blanket strategy implemented at each site. The second field season will also involve carcass searches and acoustic monitoring using the

[1] A third monitoring season, the objectives of which would mirror those during the second monitoring period, may be conducted at Orient and Arbor Hill in 2023 to enable additional inter-annual comparison.

same methods as in the first field season and will include the same treatments plus a site-specific smart curtailment alternative designed to be equally protective of bats as the blanket curtailment strategy. The study design will be largely the same between the two phases/groups of study sites, except that during the first year, Orient and Arbor Hill will have subsets of control turbines operated without curtailment (e.g., turbines feathered below manufacturer’s normal cut-in speed). During the first year at the 11 expansion sites, six sites will operate with a blanket curtailment strategy (5.0 m/s cut-in speed) and five will operate with feathering below the normal cut-in wind speed (3.0 – 3.5 m/s, depending on the site; Table 3-1). During the second year of the study, an additional treatment consisting of a smart curtailment alternative based on acoustic data collected during the first year will be added to each site implementing blanket curtailment. For Orient and Arbor Hill, the smart curtailment treatment will be applied to a subset of 5 turbines per site, and for the six curtailed expansion sites, smart curtailment will be applied to 50% of turbines at each site. Sites operating without curtailment (5 phase two sites) will be operated without curtailment during both field seasons, providing an operational control at the site level (Table 3-1).

Acoustic bat monitoring at nacelle height (15 turbines per site) will be used to measure the amount of exposed bat activity per treatment during each field season and project phase. Additional acoustic detectors will be deployed near ground level at 7–8 turbines at Orient and Arbor Hill (phase one sites) to provide additional spatial coverage with acoustic data. For all sites implementing blanket curtailment (Orient, Arbor Hill, and up to 6 of the expansion sites), acoustic and weather data from the first field season will be used to design a smart curtailment alternative that targets the same level of reduction in bat fatality and exposed bat activity associated with the blanket curtailment strategy. Results of the two field seasons will be combined to characterize the relationship between exposed bat activity and fatality on multiple scales and measure inter-turbine, inter-site, and inter-annual variation in the relationship between bat activity, temperature, and wind speed.

Our study design will use results of standardized carcass monitoring being conducted at each host site in two primary ways. First, empirical fatality estimates, corrected to account for carcass persistence, search area, and searcher efficiency and other factors, will indicate the magnitude of bat fatality for each site and/or operational treatment. More importantly, however, carcass monitoring results will be used to quantify the relationship between exposed acoustic bat activity and fatality rates, thereby enabling the more quantitative and temporally precise acoustic bat data to be used to evaluate the exposure of bats under each operational treatment and provide the basis to optimize curtailment. Acoustic data will therefore provide the primary means of comparing and contrasting curtailment alternatives, lessening the burden to conduct fatality searches at the intensity necessary to obtain precise fatality estimates and enabling different carcass search methods to be implemented among host sites. Our curtailment evaluations will be based on data summarized at 10-minute intervals, enabling better temporal precision than results of carcass monitoring. Moreover, we predict that even the most intensive carcass monitoring protocols will be insufficient to evaluate curtailment programs that are subtly different in terms of exposure of bat activity due to inevitable uncertainty introduced by imperfect detection, carcass removal by scavengers, and limited search area.

Table 3-1. Summary of activities to occur in 2021 through 2023

Phase/Site/Characteristics	Year	Curtailment Treatments (n turbines)	Carcass Monitoring	Acoustic Monitoring/Weather Data	Analysis
Phase One *Orient, IA* • 170 Vestas V110 turbines • 74 Vestas V120 turbines • 3 m/s cut-in *Arbor Hill, IA* • 130 Vestas V110 turbines • 12 Vestas V150 turbines • 3 m/s cut-in	2021	• Blanket (5.0 m/s, 15 Jul–30 Sep, sunset–sunrise, >10°C (8 turbines per site) • Control (3.0 m/s, 15 Apr–15 Nov, sunset–sunrise (7 turbines per site) •	Full plots at 15 turbines per site • 1 Jul–15 Nov* • Twice weekly search interval • 100 m x 100 m cleared plots (all turbines in agricultural landscape) • Transects spaced at 5 m intervals • Searcher efficiency and carcass persistence trials Road/pad plots at remaining turbines (as described below) in 2021 and 2022 Road/pad plots at all turbines in 2023	• 15 turbines • Detectors mounted on nacelle anemometer masts, facing downwind • Analysis with Kaleidoscope Pro, visual vetting of all bat passes • Bat passes aligned with 10-minute turbine rpm, wind speed, and temperature data • Exposed bat activity = bat passes recorded when turbine rpm >1 • Data summarized per species and per turbine and loaded into • Simulate potential energy generation for every 10-minute period using wind speed and temperature data • Load acoustic and weather data into interactive data viewer	• Calculate measured exposed bat activity (aggregating data among turbines within each treatment) and reduction in exposed activity for each treatment • Estimate energy loss for each treatment using interactive data viewer • Design smart curtailment alternative that targets same level of exposure reduction (based on aggregated acoustic data and/or species-specific patterns depending on site-specific objectives) with less predicted energy loss • Predict exposed bat activity for each treatment to be implemented in year 2 • Compare measured exposure (based on year 2) to predicted exposure (based on year 1 data) for each treatment • Compare predicted energy loss (based on year 1 to estimated energy loss (based on year 2 data) for each treatment • Aggregate acoustic data from years 1 and 2 for each site and similar data collected previously (2011–2018) to evaluate inter-turbine, inter-year, inter-species, and inter-site variation in distribution of bat activity versus temperature and wind speed • Aggregate acoustic data from years 1 and 2 for each site and similar data collected previously (2011–2018) to model relationship between exposed bat activity and fatality at three scales (treatment, turbine, and individual search)
	2022 – 2023	• Blanket (5.0 m/s, 15 Jul–30 Sep, sunset–sunrise, >10°C (5 turbines per site) • Control (3.0 m/s, 15 Apr–15 Nov, sunset–sunrise (5 turbines per site) • "Smart" curtailment; parameters based on 2021 acoustic data (5 turbines per site)			
Phase Two *Expansion sites* (up to 11 Wind XI/XII sites including Beaver Creek I/II, Contrail, Diamond Trail, North English I/II, Prairie, Southern Hills, Ida Grove II, Ivester, Palo Alto I/II, Plymouth County, Pocahontas Prairie) – See Table 4-1 for individual site details.	2022	• Blanket (5.0 m/s, 15 Jul–30 Sep, sunset–sunrise, >10°C; all turbines at 6 sites) • Control (3.0 m/s, 15 Apr–15 Nov, sunset–sunrise; all turbines at 5 sites)	Road/pad plots at all turbines (9 sites) • 1 Jul–15 Oct* • Weekly search interval • Searcher efficiency and carcass persistence trials Full plots (as described above) at all turbines at 2 sites (Plymouth County and Pocahontas Prairie)		
	2023	• Blanket (5.0 m/s, 15 Jul–30 Sep, sunset–sunrise, >10°C; 50% turbines at 6 sites) • "Smart" curtailment (parameters based on 2022 acoustic data; 50% turbines at 6 sites) • Control (3.0 m/s, 15 Apr–15 Nov, sunset–sunrise; all turbines at 5 sites)			

*Stantec will calculate fatality rates based on the subset of data from 1 July–15 October from each site to improve inter-site comparability.

We will calculate the proportion and rate of bat passes exposed to turbine operation for individual turbines and for each operational treatment and/or site based on acoustic bat data and turbine rpm measured at 10-minute intervals. The same data will be used to calculate potential energy generation during each 10-minute interval based on the power curve for the corresponding turbine model to quantify the amount of energy loss associated with each curtailment program and determine what proportion of energy loss occurred during periods with and without bat activity. Energy loss data measured at Orient and Arbor Hill will also be evaluated as a percentage of annual energy production. Comparison of simulated and measured energy loss will provide a basis to calibrate energy loss predictions, which are crucial for evaluating potential curtailment alternatives during the smart curtailment design process.

For each site implementing blanket curtailment, we will use 10-minute acoustic and weather data to design a smart curtailment plan that targets the same level of acoustic exposure achieved by the default blanket curtailment strategy during the first year of the study. Before the second year, curtailment parameters will be negotiated with host sites and adjusted within the constraints of their existing SCADA system and turbine control mechanism. These parameters will presumably include a combination of temperature and wind speed thresholds that will be adjusted on a monthly or biweekly basis as guided by the distribution of bat activity in the conditions space. Whether curtailment parameters differ among turbines or groups of turbines will depend on site-specific data and objectives/constraints of each host site. We will use a customized data visualization tool to predict the acoustic exposure and energy loss for the smart curtailment treatment for each host site, in comparison with alternative blanket strategies. The underlying code for this data visualization tool is being updated as part of Stantec's research grant and will be provided in an open-source format.

The second year of monitoring will provide the opportunity to directly test the accuracy of our predictions based on an independent set of acoustic and operational data from turbines at each site and/or within each operational treatment. Simulated and measured energy loss will again be assessed and compared to predictions based on the first year of data for each site/treatment. Because the smart curtailment strategy will be designed to be equivalently protective as the blanket alternative, we anticipate that exposure and associated fatality risk will be similar between treatments whereas energy loss will differ by a wider margin. Standardized carcass monitoring following the same methods used in year one will provide empirical fatality estimates for the blanket and smart curtailment alternatives as well as an operational control for an independent evaluation of the effectiveness of both strategies. Acoustic exposure and fatality will again be compared, this time using data from both years as well as similar data Stantec collected previously at the Laurel Mountain and New Creek wind farms in West Virginia.

The expansion of our study to a total of 13 wind projects operated by the MidAmerican Energy Company (MEC) will enable a larger scale comparison of acoustic exposure and fatality rates among facilities. In addition to operating at different curtailment regimes (e.g., 3.0 or 5.0 m/s cut-in speeds and a smart curtailment alternative), natural variation in bat populations, wind regimes, and habitat should result in a range of acoustic exposure and fatality rates among sites. The expanded study will provide an opportunity to evaluate relationships between acoustic exposure and fatality rate on an unprecedented scale.

Collectively, our study will demonstrate how acoustic data collected at nacelle-height can provide a reliable and sensitive metric to design and evaluate curtailment programs, whether they involve straightforward blanket strategies or complex smart curtailment strategies combining multiple parameters. The overall goal of this research is to demonstrate that curtailment can be optimized using data that can be collected readily by wind farm operators, enabling costs associated with implementation and energy loss to be reduced while strategically reducing exposure of target species. The framework we envision includes a built-in validation procedure using the same methods and metrics and relieves the need to rely solely on carcass monitoring, which is prohibitively costly as a long-term strategy and fails to address the relationship between fatality risk and conditions at a temporal scale sufficient to design and evaluate curtailment with precision. Our hope is that these results will encourage broader consideration and implementation of curtailment within the wind industry to enable continued expansion of this important source of renewable energy generation while simultaneously protecting the viability of vulnerable bat species.

4.0 METHODS

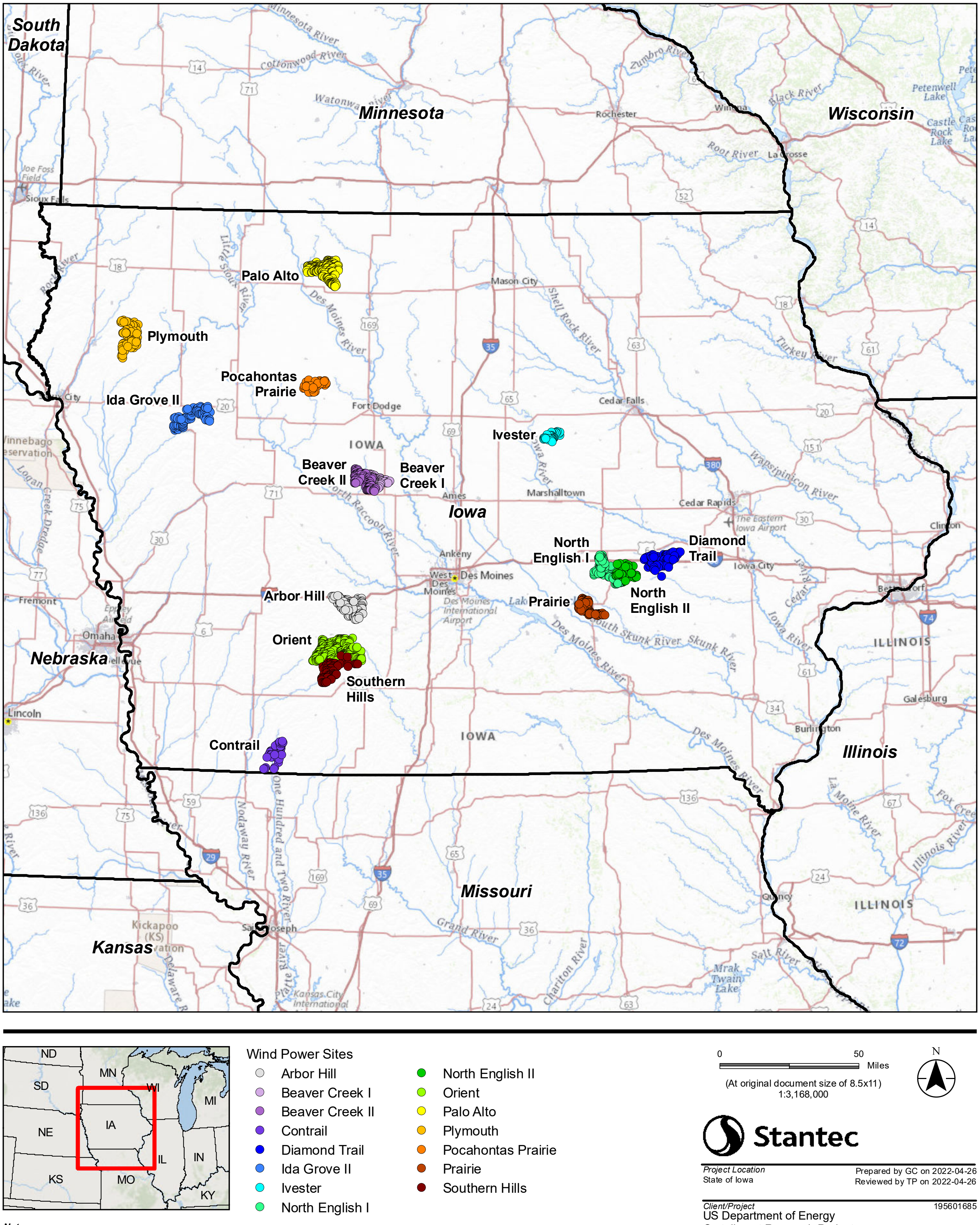
4.1 HOST SITE DESCRIPTIONS

The study will occur at up to 13 wind energy facilities owned and operated by MEC and located throughout Iowa (Figure 4-1). Of these, the two “original” sites (Orient and Arbor Hill) are considered as phase one, with monitoring occurring in 2021 and 2022 with a potential third monitoring period in 2023. The remaining 11 phase-two sites will be monitored in 2022 and 2023 and are referred to as the “expansion sites”. Project range in size from 35 to 244 turbines and represent a variety of turbine designs and manufacturers (Table 4-1). The wind projects in this study occur in the Rolling Loess Prairies of the Western Corn Belt Plains Ecoregion, which includes much of Iowa and is characterized by glaciated till plains and undulating loess plains. Land use in the region consists primarily of commercial agriculture dominated by corn (*Zea mays*), soybeans (*Glycine max*), and livestock (Baumgartner *et al.* 2020a & 2020b).

Stantec will coordinate with operations staff and consultants performing standardized post-construction studies (described below) to select 15 turbines at each site to be equipped with acoustic detectors and included in the study. Study turbines will be distributed evenly throughout each project area within various constraints such as landowner permissions. Barring unexpected issues with individual turbines or changes in access agreements, the same turbines will be monitored during each monitoring period. The manufacturer’s cut-in speed for wind projects included in the study range from 3.0–3.5 m/s, and MidAmerican plans to feather turbine blades to prevent turbine rotation below this wind speed at night from 15 March–15 November at each site.

4.2 TURBINE OPERATIONS

During the first year of the study, turbines equipped with acoustic detectors (15 per site) will be categorized as either an operational control (feathered below manufacturer’s cut-in) or blanket curtailment (as described in Table 4-1) for the duration of the monitoring period. For sites with multiple treatments during year 1 (phase one; Orient and Arbor Hill) operational treatments will be assigned to ensure spatially even distributions for each category at each site, with 7–8 turbines assigned to each category (15 total per site). All turbines at 11 expansion will be operated according to the same site-specific parameters during the first year of the study; 6 sites will be operated with blanket curtailment and 5 will have turbines feathered below manufacturer's normal cut-in speed (Table 3-1). During the second year of the study, an additional treatment consisting of a smart curtailment alternative based on acoustic data collected during the first year will be added at each site implementing blanket turbine curtailment. For Orient and Arbor Hill, the smart curtailment treatment will be applied to a subset of 5 turbines per site, and for the 6 curtailed expansion sites, smart curtailment will be applied to 50% of turbines at each site. Orient and Arbor Hill will also include an operational control at a subset of 5 turbines during year 2. The remaining 5 expansion sites that are operated without blanket curtailment will serve as operational controls at the site level. Parameters of the smart curtailment alternatives will be negotiated with host sites and designed within site-specific constraints imposed by turbine manufacturers, warranties, permitting requirements, or other factors such as SCADA control algorithms. Treatments will be assigned to ensure even spatial distributions of turbines with and without acoustic detectors for each treatment.



Revised: 2022-04-26 By: gcarpentier

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Notes

1. Coordinate System: NAD 1983 UTM Zone 15N
2. Background: The USGS National Map

Stantec

Project Location
State of Iowa

Prepared by GC on 2022-04-26
Reviewed by TP on 2022-04-26

Client/Project
US Department of Energy
Curtailment Research Project

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Figure No.
4-1

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Title
Project Location Map

Table 4-1. Site information for MidAmerican's Wind XI/XII facilities included in the expanded acoustic activity-based smart curtailment study.

Site	County	Manufacturer (per-turbine output)	# Turbines	Standard Cut-in Speed	Hub Height	Rotor Diameter	Blanket 5.0 m/s curtailment	Indiana Bat Range*	Carcass Monitoring
Arbor Hill I/II	Adair	Vestas (2 MW)	130	3	95	110	Yes	Yes	Full plots 2x/week at 20% of turbines; weekly road/pad at remaining turbines
		Vestas (4.2 MW)	12	3	105	150	Yes	Yes	
Beaver Creek I/II	Boone/Greene	Vestas (2 MW)	56	3	95	110	Yes	Yes	Road/pad weekly at all turbines
		Vestas (2.05 MW)	1	3	95	110	Yes	Yes	
		Vestas (2.2 MW)	28	3	95	110	Yes	Yes	
		Vestas (2 MW)	56	3	95	110	Yes	No	
		Vestas (2.05 MW)	1	3	95	110	Yes	No	
		Vestas (2.2 MW)	28	3	95	110	Yes	No	
Contrail	Taylor	GE (2.3 MW)	5	3.5	80	116	Yes	Yes	Road/pad weekly at all turbines
		GE (2.72 MW)	6	3	90	116	Yes	Yes	
		GE (2.82 MW)	30	3	89	127	Yes	Yes	
Diamond Trail	Iowa	Vestas (2 MW)	8	3	95	110	Yes	Yes	Road/pad weekly at all turbines
		Vestas (2.2 MW)	11	3	95	110	Yes	Yes	
		GE (2.82 MW)	25	3	89	127	Yes	Yes	
		Vestas (4.2 MW)	4	3	105	136	Yes	Yes	
		Vestas (4.3 MW)	32	3	105	136	Yes	Yes	
Ida Grove II	Ida	GE (2.3 MW)	8	3.5	80	116	No	No	Road/pad weekly at all turbines
		GE (2.52 MW)	73	3	80	127	No	No	
Ivester	Grundy	Siemens (2.415 MW)	5	3	80	108	No	No	Road/pad weekly at all turbines
		Siemens (2.625 MW)	30	3	85.1	120	No	No	
North English I/II	Poweshiek	Vestas (2 MW)	75	3	95	110	Yes	Yes	Road/pad weekly at all turbines
		Vestas (2.15 MW)	21	3	95	110	Yes	Yes	
		Vestas (2.2 MW)	4	3	95	110	Yes	Yes	
		Vestas (2 MW)	46	3	95	110	Yes	Yes	
		Vestas (2.15 MW)	19	3	95	110	Yes	Yes	
		Vestas (2.2 MW)	5	3	95	110	Yes	Yes	
Orient I/II	Adair	Vestas (2 MW)	77	3	95	110	Yes	Yes	Full plots 2x/week at 20% of turbines; weekly road/pad at remaining turbines
		Vestas (2.15 MW)	11	3	95	110	Yes	Yes	
		Vestas (2.2 MW)	92	3	95	110	Yes	Yes	
		Vestas (2.2 MW)	64	3	95	120	Yes	Yes	
Palo Alto I/II	Palo Alto	Vestas (2 MW)	125	3	95	110	No	No	Road/pad weekly at all turbines
		Vestas (2 MW)	45	3	95	110	No	No	
Plymouth County	Plymouth	GE (2.3 MW)	6	3.5	80	116	No	No	Full plots 2x/week at 20% of turbines; weekly road/pad at remaining turbines
		GE (2.82 MW)	67	3	89	127	No	No	
Pocahontas Prairie	Pocahontas	Vestas (2 MW)	24	3	100	110	No	No	Full plots 2x/week at 20% of turbines; weekly road/pad at remaining turbines
		Vestas (2.2 MW)	16	3	100	110	No	No	
Prairie	Mahaska	Vestas (2 MW)	49	3	95	110	Yes	Yes	Road/pad weekly at all turbines
		Vestas (2.15 MW)	7	3	95	110	Yes	Yes	
		Vestas (2.2 MW)	28	3	95	110	Yes	Yes	
Southern Hills	Adair/Union/Adams	Vestas (2 MW)	2	3	95	110	Yes	Yes	Road/pad weekly at all turbines
		Vestas (2.2 MW)	19	3	95	110	Yes	Yes	
		Vestas (4.3 MW)	25	3	105	136	Yes	Yes	
		Siemens (4.8 MW)	21	3	107	145	Yes	Yes	

* As listed in the draft Habitat Conservation Plan for Wind XI - XII

4.3 ACOUSTIC BAT MONITORING AND ANALYSIS

4.3.1 Acoustic Data Collection

During both field seasons, Stantec will deploy acoustic bat detectors on nacelles of 15 turbines at each study site, selecting turbines that are distributed throughout the wind farm and that are included in standardized fatality monitoring programs. For sites implementing curtailment treatments, we will allocate acoustic detectors evenly among treatments, such that a minimum of 5–8 turbines with acoustic detectors will be within each operational treatment. At Orient and Arbor Hill, we will deploy an additional 15 acoustic detectors of the same type and configuration at the base of 50% of study turbines to compare bat activity patterns at nacelle height and ground level and determine whether ground-level data are applicable for assessing fatality risk and evaluating curtailment. Acoustic detectors will be deployed in spring or early summer, before standardized fatality monitoring begins at each site. Stantec will program detectors to operate from 30 minutes before sunset until 30 minutes after sunrise each night throughout the survey period.

Stantec will use Wildlife Acoustics SM4BAT FS bat detectors equipped with SMM-U1 omnidirectional ultrasonic microphones to monitor bat activity at nacelle height. The detector and microphone are weather resistant and do not require weather proofing. However, microphones will be outfitted with a grounding bracket and grounded to the tower when possible to limit the effects of electrostatic damage to microphone components. Detectors will be powered by sealed lead-acid batteries recharged with a small solar panel and charge controller system or connected to an accessory AC power outlet in the turbine nacelle. We will coordinate with operations staff at each host site to design custom brackets for mounting the power supply, solar panel, detector, and microphone to each turbine.

Nacelle-mounted detectors will be oriented to record bat activity at the downwind side of the turbine nacelle, with detector microphones pointed away from the turbine rotor to minimize wind noise and aim towards the anticipated flight direction of bats approaching turbines from the downwind side, where they may be recorded more readily. Ground-mounted detectors at Orient and Arbor Hill will be attached to the external turbine stairs at the base of the turbine, with the microphone oriented horizontally away from the tower. Based on field tests using these detectors in open environments, we estimate that detectors could record bats up to a range of approximately 30 m. We have mounted detectors in this configuration on a variety of turbine models with satisfactory results (Figure 4-2). Detectors will be self-contained and will not be connected to the communications network of host site turbines. Data will be recorded on removable SD cards with up to 512 GB capacity (2 per detector). Stantec will coordinate with operations staff at each host site who will mobilize and demobilize detectors and perform periodic checks coordinated with routine turbine maintenance activities during the field season, to offload data ideally 1–3 times during the monitoring period and replace system components in the event of malfunction. Ground level detectors will be checked on roughly the same schedule.

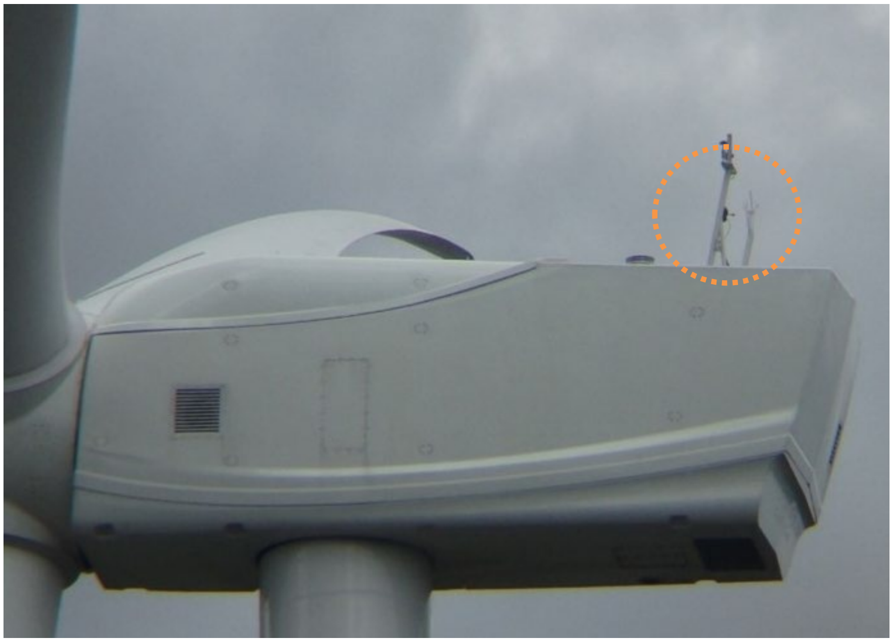

Figure 4-2. Photo of a SM4 acoustic bat detector (circled in orange) as deployed on the anemometer mast of a Gamesa G97 turbine at the New Creek Wind Farm in West Virginia, 2017.

Stantec will provide replacement detector components as necessary in case of equipment malfunction. Acoustic detectors will remain in place until fall migration has ended (typically mid-October to mid-November), and Stantec will coordinate with host sites to remove acoustic detectors and associated peripheral equipment at the end of the monitoring period. We will inspect detectors and associated hardware and conduct a post-season microphone sensitivity test for each detector. Stantec has deployed detectors in this manner on nacelles, with 1–3 checks per season, and detectors have typically operated during ~70% of attempted survey nights. Our proposed 15 nacelle-height detectors per site includes sufficient redundancy assuming similar rates of data loss.

4.3.2 Acoustic Data Analysis

After each bat activity season, Stantec will compile acoustic data, review detector performance based on system status files and inspection of equipment, and process data using the most current available versions of Kaleidoscope Pro (Wildlife Acoustics Inc., Maynard, MA) and/or SonoBat© software. Stantec has analyzed acoustic datasets collected previously at turbine nacelles and determined that these programs differ substantially in terms of species identifications and differentiation between bats and static when default settings are used. Comparisons to date have not identified one program or the other as superior but instead highlight differences among methods. Accordingly, we will also visually inspect a subset of data to help resolve differences among software programs and ensure accurate differentiation between bat activity and static and evaluate which method is preferable for analyzing acoustic data for purposes of designing and evaluating curtailment programs. We will use the set of visually vetted identifications for characterizing relationships between bat activity and conditions at nacelle height (visualized using heat maps), calculating exposure of bat activity to turbine operation (passes occurring when turbine RPM > 1) on a per-turbine basis and overall per curtailment treatment, and simulating exposure under alternative curtailment treatments.

4.3.3 Aligning Acoustic Data and Turbine Data

Timestamps of acoustic bat passes will be rounded to the nearest 10-minute interval and aligned with wind speed, temperature, and turbine rpm data recorded by the corresponding turbine in the same interval. We may use temperature data from permanent meteorological (met) towers at each site and/or apply correction factors to the nacelle-based measurements if advised to do so by operations staff. We will tally the number of bat passes per 10-minute period in which acoustic data were available to generate a dataset representative of the full monitoring period. We will categorize bat passes recorded when turbine rpm exceeds 1 based on 10-minute data as exposed to turbine operation.

4.4 STANDARDIZED CARCASS MONITORING

Comparing the effectiveness of curtailment strategies using carcass studies is often limited by sample sizes of carcasses and uncertainty introduced by imperfect carcass detection, carcass removal, and the imprecise temporal resolution of fatality data. The precision of fatality estimates depends on many factors, some of which cannot be controlled for, but more frequent monitoring (e.g., daily or weekly searches) at large numbers of turbines and in large search plots (e.g., radius equal to the height of turbines) tend to yield more precise estimates. However, such monitoring programs require extensive field effort and can be extremely expensive. Even when conducted at the highest level of intensity (e.g., daily searches at large, cleared plots) fatality studies cannot determine the precise timing of fatality, limiting their utility for fine-tuning curtailment programs.

Rather than focus resources on increasing the intensity of carcass studies, our study uses the standard post-construction surveys being conducted at host sites as part of MEC's permitting requirements. For the two original sites (Orient, Arbor Hill) and two of the expansion sites (Pocahontas Prairie, and Plymouth County), these protocols include full-plot searches at a biweekly interval (~3-days) at 20% of turbines and weekly road/pad searches at the remaining 80% of turbines. The remaining 9 expansion sites will have road/pad searchers at a weekly interval at all turbines (Table 4-1). In all cases, monitoring protocols are designed to generate empirical fatality estimates corrected for searcher efficiency and carcass removal, will follow consistent methods and levels of effort between years (within sites; methods will vary among wind farms), and apply consistent monitoring effort at turbines operating under different curtailment regimes. We have designed our study to rely primarily on acoustic data for differentiating curtailment plans in terms of acoustic exposure and will rely on fatality estimates only to establish the relationship between exposed bat activity and fatality risk. Therefore, the standardized fatality monitoring programs to be conducted at each site will be suitable for our purposes.

Each host site will conduct standardized fatality monitoring during both field seasons following methods and level of effort previously negotiated as part of the permitting process for each host site. Methods will include bias trials to account for imperfect carcass detection, carcass removal by scavenger, search area correction factors, and multipliers to adjust for search interval. We have summarized methods to be followed at each site below.

Standardized carcass searches will occur between 1 July and 15 October at each site, as outlined in Table 4-1. WEST, Inc. (WEST) will conduct the fatality monitoring at each site, as previously contracted under separate agreements between MidAmerican and WEST. “Full” search plots will be cleared out to a 100m x 100m square centered on each turbine, with parallel transects spaced at 5 m intervals and will occur twice per week. “Road and pad” search plots will be limited to gravel turbine pads and access roads, out to a maximum distance of 150 m, and will occur weekly. The number of turbines with full plots vary between Orient, Arbor Hill, and the two expansion sites with full plots, but all 15 turbines with acoustic detectors will include full plots at each of these sites. Biologists trained in proper search techniques will walk transects at a slow, steady pace, scanning visually on either side of transects. Surveyors will record standard measurements for each search including start/stop time, initials, and information on whether carcasses were found (Baumgartner *et al.* 2020). Alternatively, trained dogs may be used to supplement human searchers, in which case transects would be surveyed at wider spacing (20 m).

Bat carcasses found by surveyors will be marked temporarily during a search, after which the surveyor will return to record standardized information including date, time, turbine, species/sex/age (when possible), distance/azimuth from turbine, carcass condition, and estimated time since death (Baumgartner *et al.* 2020). WEST will photograph each carcass and will collect bat carcasses in labeled plastic bags and confirm species identifications made in the field. WEST will conduct all carcass documentation and reporting as required by corresponding collection/salvage permits including reporting fatalities or injuries of federally or state protected bird or bat species found during carcass searches. Carcasses found outside standardized search times or plots will be documented similarly to those found during regular searches but will be categorized as incidental and not included in bat fatality estimates.

Searcher efficiency trials will occur throughout the monitoring period without the surveyor’s knowledge and will involve placing ~80 bat carcasses in a variety of cover types and locations. Trials will use bats found on site, although no threatened or endangered species will be used. Carcass persistence trials using bats found on site will also be conducted throughout the survey period to quantify carcass retention time. Persistence trials will last for up to 30 days and will be conducted independently of searcher efficiency trials. Trials will be monitored daily for the first 4 days, then on days 7, 10, 14, 20, and 30 (Baumgartner *et al.* 2020).

Empirical bat fatality estimates will be generated separately for each site and operational strategy using the “Huso method” and/or GenEst estimator, each of which incorporates results of searcher efficiency and carcass persistence trials, the total number of carcasses found per turbine within each treatment, search interval, and a density-weighted area correction factor (Huso 2010). Bat fatality data will also be tabulated per turbine and per search interval for comparison with acoustic exposure at various scales.

4.5 BAT FATALITY ESTIMATES

Stantec will obtain results from standardized fatality monitoring at each host wind farm, including carcass information, survey effort data, search area information, and results of bias trials, and process these data using a common fatality estimator. Fatality estimates will be calculated separately for subsets of turbines in each operational treatment and will incorporate site-specific results of searcher efficiency and carcass persistence trials, the total number of carcasses found per turbine within each treatment, search interval, and a density-weighted area correction factor (Huso 2010). Fatality estimates will be calculated for a common time period between the two host sites (e.g., 1 July–15 October) to improve inter-site comparability. Bat fatality data will also be tabulated per turbine and per search interval for comparison with acoustic exposure at various scales. We anticipate performing most analyses based on all-bat fatality rates, although species-specific comparisons may be considered should sufficient sample sizes be available.

4.6 CURTAILMENT EVALUATIONS

4.6.1 Curtailment Effectiveness

We will categorize every 10-minute period as meeting or not meeting the corresponding curtailment parameters specific to each treatment/turbine and use the 10-minute rpm to determine whether each turbine was effectively curtailed (rpm < 1) when conditions were met. These evaluations will be compared against SCADA output or other event logs (where available) tracking periods where curtailment was triggered. Accordingly, we will generate an independent assessment of how closely turbine performance aligned with the parameters of each operational treatment. In other words, this analysis will compare actual turbine operation to how turbines should have performed under each curtailment strategy. This metric will also provide the basis of comparing the actual amount of curtailment for each treatment and quantifying differences among the treatments.

4.6.2 Calculating Energy Loss and Annual Energy Production

Stantec will use the power curve for each type of turbine at each host site to establish potential energy generation during each 10-minute period, based on wind speeds rounded to align with the resolution of the power curve. To calculate energy loss due to curtailment, we will sum potential energy generation for each turbine across intervals meeting curtailment conditions and in which rpm was less than 1. By excluding periods in which turbines were off (rpm < 1) but that curtailment conditions were not triggered, this calculation omits energy loss attributable to factors other than curtailment (e.g. maintenance, grid-mandated shutdowns, etc.).

We will use similar methods to calculate annual theoretical energy production, summing potential energy generation across 10-minute intervals for each turbine for the full year. From this total, we will subtract potential energy generation during intervals in which turbines were feathered (rpm < 1) for reasons other than curtailment (e.g., intervals when curtailment conditions were not met but rpm was less than 1). For Orient and Arbor Hill, energy loss from curtailment will also be evaluated as a percentage of annual energy production (AEP), following methods developed by the Electric Power Research Institute (EPRI) in collaboration with the DOE and National Renewable Energy Laboratory (NREL) (EPRI 2020).

We will also calculate the proportion of energy loss occurring during periods with and without bat activity as a metric of curtailment efficiency, which will be compared among treatments. Calculation of energy loss using this method provides an important baseline to which curtailment simulations can be compared. To design and optimize curtailment, it is critical to be able to predict energy loss associated with curtailment programs that have not yet been implemented. Comparing predicted and measured energy losses will help determine the reliability of energy loss forecasts and provide context in which to evaluate predictions.

4.6.3 Calculating Acoustic Exposure

Stantec will calculate for each turbine the proportion and number of bat passes exposed to turbine operation per sampled 10-minute period and summarize exposure per site and treatment as a mean among turbines and as an aggregate, pooling data among turbines. The difference in exposed bat activity between control and blanket curtailment, calculated after the first field season, will establish a target reduction in risk to bats for each host site. After the second year of the study, smart strategies will be evaluated alongside blanket curtailment and uncurtailed turbine operation using similar methods. After the second year, we will also compare exposed bat activity among sites and treatments using general linear models (e.g., ANOVA) to determine whether exposure differed significantly among treatments and sites, considering each turbine as an independent sample and including site and year as categorical factors.

4.6.4 Curtailment Simulations and Optimization

After the first year of the study, Stantec will load acoustic, wind speed, temperature, and rpm data from each host site into an interactive data visualizer built in the R software environment using R package *shiny* (Chang et al. 2018). This viewer enables the user to set parameters of a customized curtailment treatment such as cut-in speed and temperature threshold on a monthly or bi-weekly basis and simulate the associated energy loss and exposure of bat activity. Using the acoustic exposure of the blanket curtailment strategy implemented during the first year of the study as a benchmark, we will design one or more smart curtailment alternatives for each site that target an equivalent or reduced level of acoustic exposure with minimal energy loss. Stantec will work with operations staff for each host site to ensure the plausibility of smart curtailment strategies. This approach represents a manual optimization based on patterns of bat activity and fatality documented on site during the first year of monitoring.

Stantec will use the data visualization tool to predict the proportion of exposed bat activity for uncurtailed (control) operation, blanket curtailment, and the smart curtailment alternative for each host site based on results of the first year of monitoring. For sites operating without curtailment, we will simulate blanket and smart curtailment alternatives to enable comparisons across all projects. We will aggregate acoustic data from all available turbines at each host site to generate predictions. We will then use the acoustic and turbine operation data recorded during the second field season to calculate the amount of exposed activity and will compare measured (based on second field season) versus predicted (based on the first field season) exposure using linear regression. We will combine data from each host site and compare models with and without site as a factor using likelihood ratio tests. We will compare predicted versus estimated energy loss for each curtailment strategy using the same methods.

Accordingly, the second year of monitoring will provide an opportunity to explicitly test the predictions and evaluate how successfully each curtailment treatment prevented turbine operation during periods with bat activity. After the second year, the results of both years of monitoring from will be aggregated among host sites to evaluate relationships between exposed bat activity and fatality and measure consistency of seasonal activity trends and the relationship between bat activity and conditions.

4.7 EXPOSED BAT ACTIVITY AND BAT FATALITY

We will evaluate the relationship between exposed bat activity and fatality at three scales including fatality rates estimated per operational treatment, carcass totals per turbine, and whether carcasses were found during individual turbine searches. At the treatment scale, we will compare fatality estimates per treatment to the number of exposed bat passes per 10-minute period, aggregating data among turbines within each treatment using linear regression. For comparison, we will also test the relationship between total bat activity and bat fatality using similar methods. We will also compare the reduction in estimated bat fatality and the reduction in measured exposure of bat activity for each treatment relative to the operational control. As above, we will compare models with and without site using likelihood ratio test to evaluate whether the relationship between exposed activity and fatality varied among sites.

To compare fatality patterns and acoustic data at a finer spatial scale, we will compare the total number of bat carcasses found per turbine as a function of bat activity measured per turbine using generalized linear models assuming a Poisson error distribution. Because the number of searches and search area affect the number of carcasses, we will include survey effort and search area as offsets or continuous variables in the model structure. Individual turbine searches represent bat fatality on a finer temporal as well as spatial scale. Because most turbine searches result in discovery of 1 or fewer bat carcasses, we will use logistic regression (generalized linear model assuming a binomial distribution) to test whether the amount of bat activity recorded during intervals between turbine searches explained variation in the binary probability of finding or not finding a fresh bat carcass during the subsequent turbine search. As for the treatment level, we will again run separate models for all bat activity and the subset of activity exposed to turbine operation and evaluate the significance of site using likelihood ratio tests for the per turbine and per search interval tests.

4.8 BAT ACTIVITY AND CONDITIONS

Improved understanding of relationships between bat activity and conditions in the aerosphere is vital to evaluate various approaches to smart curtailment. Stantec's method of designing smart curtailment programs is based on the distribution of bat activity throughout the year in the conditions space defined by temperature and wind speed. While other variables could be included, temperature and wind speed are typically recorded by all commercial wind turbines and together explain a large extent of fine-scale variation in bat activity. Based on ongoing analysis of nacelle-height acoustic and weather data collected at Laurel Mountain and New Creek wind farms in West Virginia between 2011 – 2018, bats responded predictably to changing temperature and wind speed at nacelle height. We will further explore relationships between bat activity and conditions using the acoustic and weather datasets collected in this study by generating heat maps (example provided in Figure 4-3) representing distribution of activity in the conditions space defined by wind speed (binned at 0.5 m/s increments) and temperature (binned at 2.5°C increments). We will compare heat maps among sites, years, species, turbines, and seasons using qualitative visual inspection and by calculating the Hellinger distance between pairs of heat maps following methods outlined in Wilson (2011). This quantitative metric will allow us to partition variance across different axes to help determine appropriate levels of extrapolation in predicting the behavioral response of bats to changing conditions in the aerosphere.

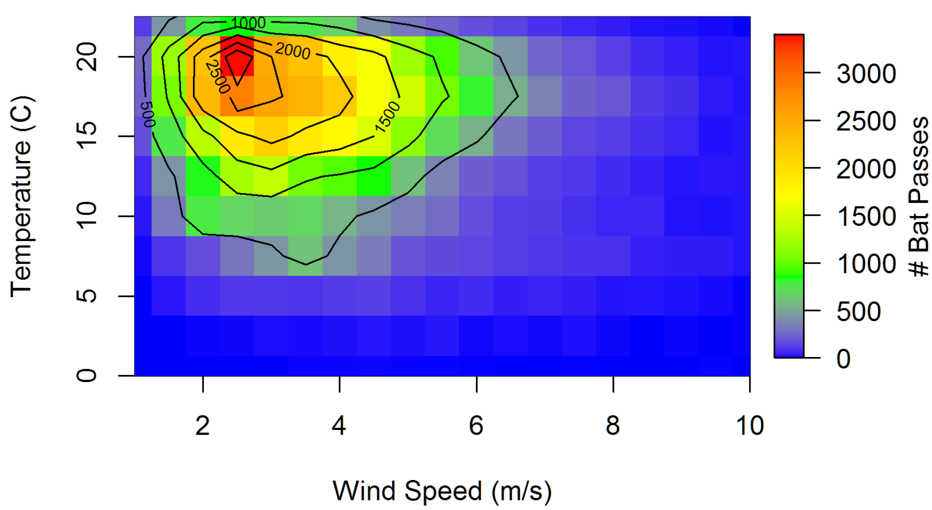

Figure 4-3. Example heat map displaying number of bat passes in the conditions space representing wind speed and temperature.

4.9 REPORTING

At the conclusion of each field season, Stantec will prepare an annual report summarizing survey effort and preliminary study results. At the conclusion of the study, Stantec will have independent sets of acoustic, turbine operation, and fatality data from up to 13 operating wind farms and will have an opportunity to compare these results to similar datasets collected previously at the Laurel Mountain and New Creek wind farms in West Virginia. This combined dataset will provide an unprecedented evaluation of exposed bat activity's sufficiency as a metric for informing curtailment and, we expect, will alleviate the necessity for over-strenuous post-construction monitoring efforts. Given the temporal coarseness of post-construction monitoring fatality data we do not expect that more intensive post-construction monitoring endeavors will yield a significantly better ability to inform fine-tuned curtailment, particularly considering the economic infeasibility of intense fatality studies over multiple successive years. By relying on acoustics to quantify exposure and compare treatments, Stantec will be able to characterize variation in bat activity as a function of temperature and wind speed more precisely than would be possible using traditional fatality survey methods.

Final deliverables at the culmination of the study will include a technical report summarizing and discussing project objectives, methods, and results. The report will include an evaluation of our framework for smart curtailment as well as recommendations and tools for designing, implementing, and evaluating smart curtailment programs. In the spirit of encouraging widespread evaluation and adoption of smart curtailment by the wind industry, we anticipate making portions of our source code for data visualization and optimizing curtailment publicly available and are committed to publishing results of our study in peer-reviewed journals.

5.0 LITERATURE CITED

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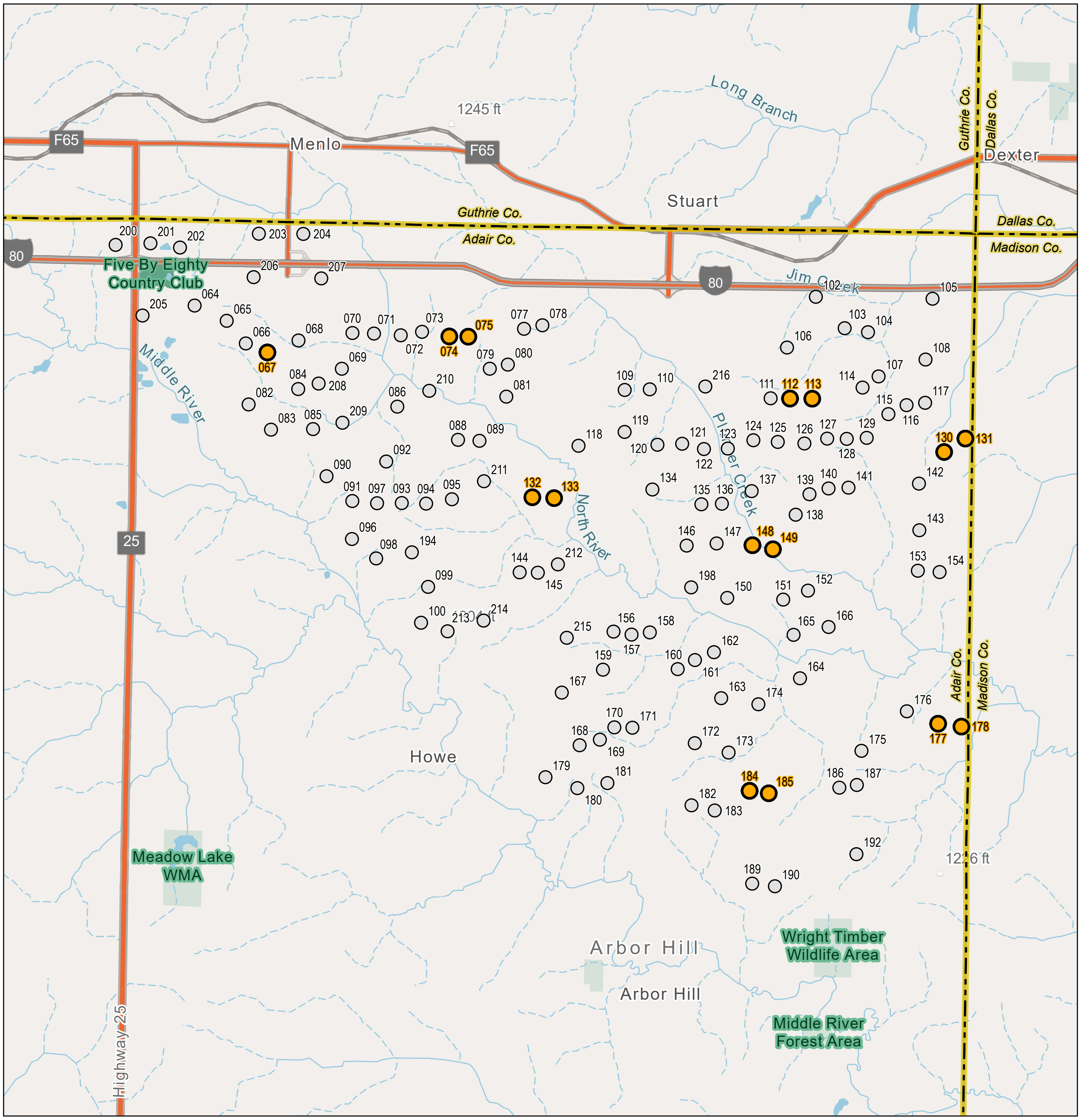
Appendix C



Legend

- County Boundary
- Wind Turbine

Wind Turbine with Detector

- Vestas V110

0 2 Miles

(At original document size of 8.5x11)
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N

Stantec

Project Location
Adair County, Iowa

Prepared by GC on 2024-09-30
Reviewed by TP on 2024-09-30

Client/Project 195601686
Department of Energy
MidAmerican Wind Energy Facilities

Figure No.
1

DRAFT

Title
Arbor Hill Wind Detector Locations

Notes
1. Coordinate System: NAD 1983 UTM Zone 15N
2. Data Sources: Stantec, USGS USWTDB
3. Background: Esri World Vector Base Map

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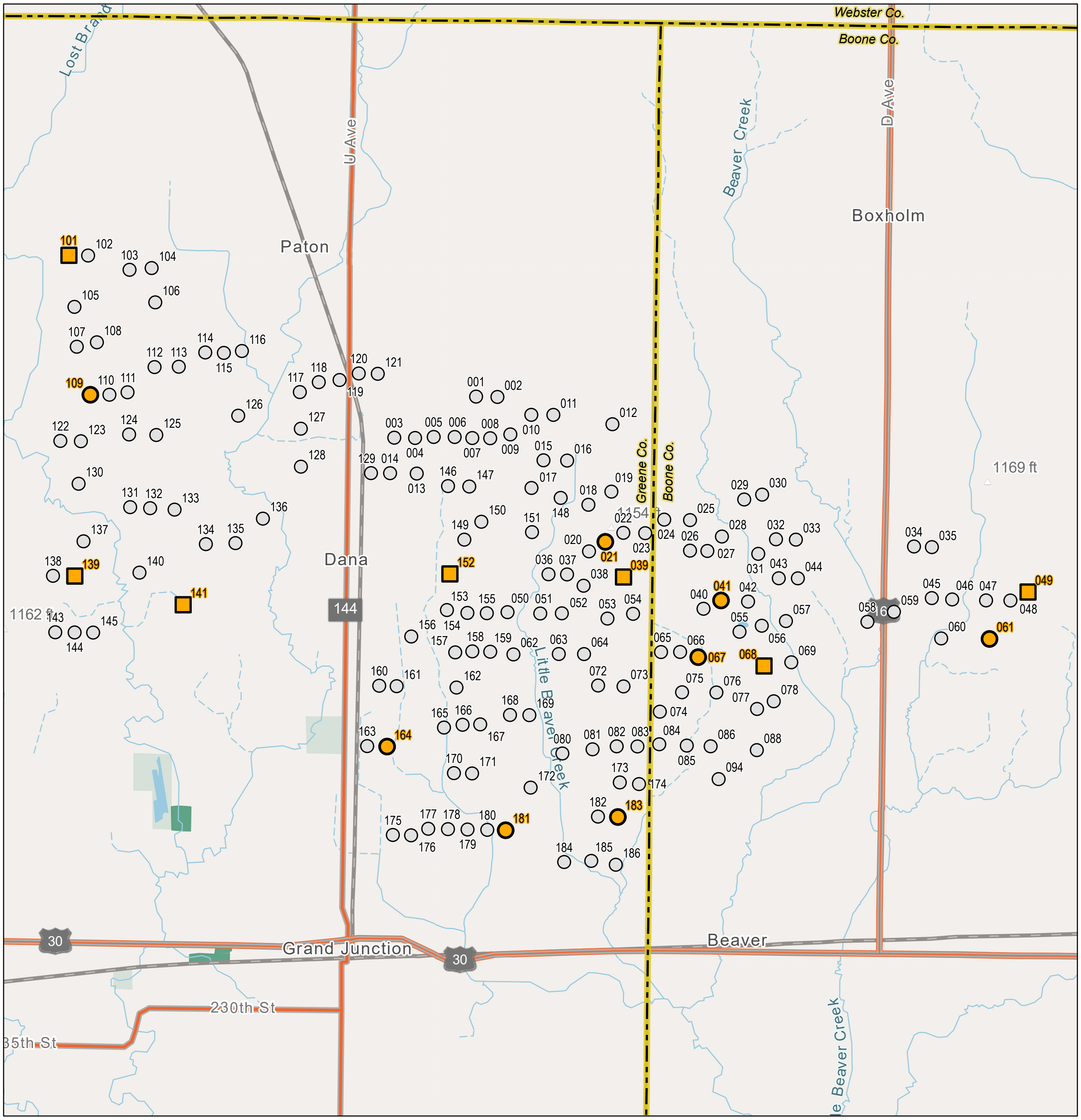

Legend

- County Boundary
- Wind Turbine

Wind Turbine with Detector

- Vestas 2.0-110
- Vestas 2.2-110

0 2 Miles

(At original document size of 8.5x11)
1:126,720

N

Notes

1. Coordinate System: NAD 1983 UTM Zone 15N
2. Data Sources: Stantec, USGS USWTDB
3. Background: Esri World Vector Base Map

Stantec

Project Location
Greene and Boone Counties
Iowa

Prepared by GC on 2024-09-30
Reviewed by TP on 2024-09-30

Client/Project
Department of Energy
MidAmerican Wind Energy Facilities

195601686

Figure No.
2

DRAFT

Title
Beaver Creek Wind Detector Locations

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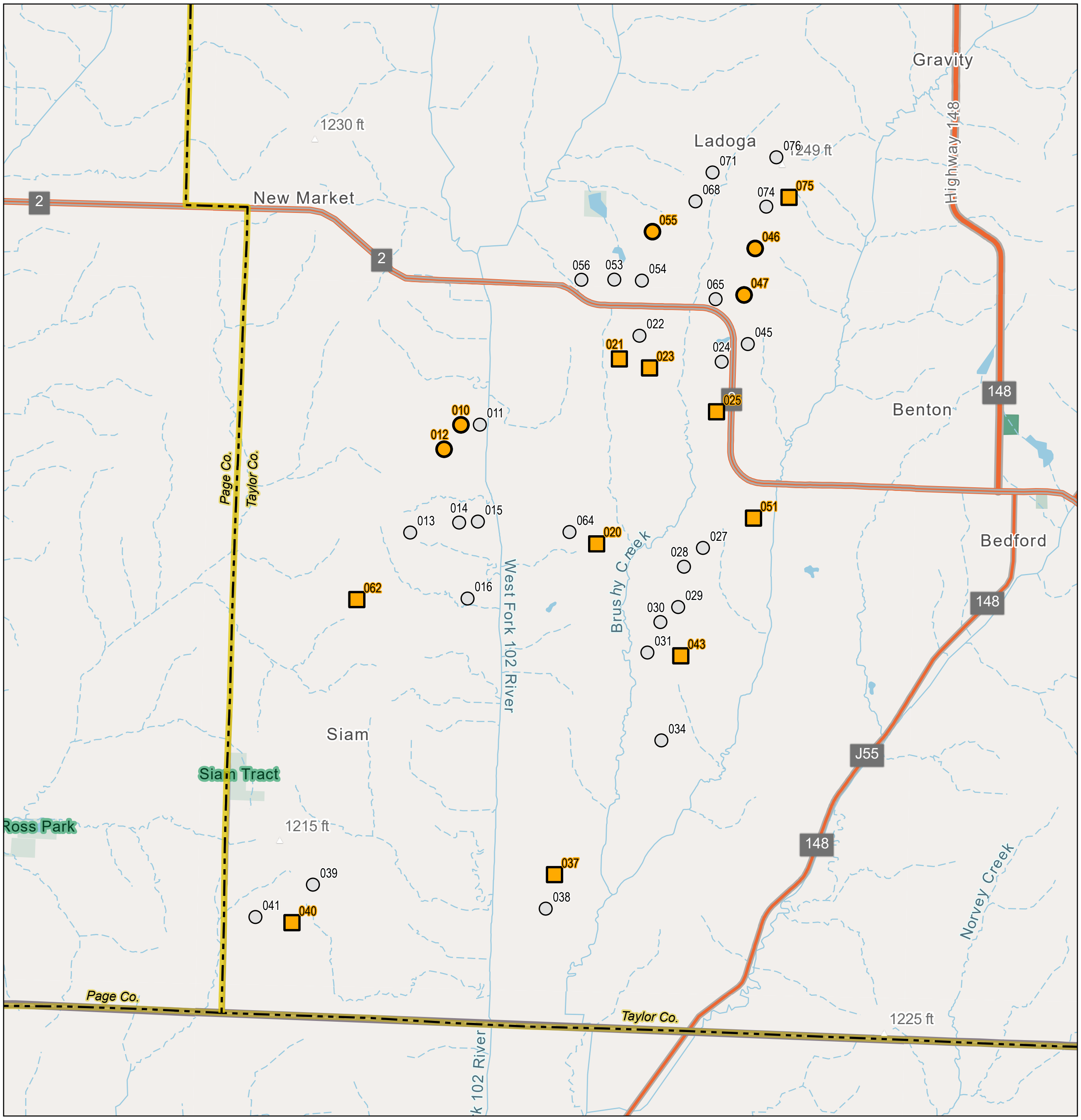

Legend

- County Boundary
- Wind Turbine

Wind Turbine with Detector

- GE 2.72 ESS-116
- GE 2.82 ESS-127

0 2 Miles

(At original document size of 8.5x11)
1:126,720

N

Stantec

Project Location
Taylor County, Iowa

Prepared by GC on 2024-09-30
Reviewed by TP on 2024-09-30

Client/Project
Department of Energy
MidAmerican Wind Energy Facilities

195601686

Figure No.
3

DRAFT

Title
Contrail Wind Detector Locations

Notes
1. Coordinate System: NAD 1983 UTM Zone 15N
2. Data Sources: Stantec, USGS USWTDB
3. Background: Esri World Vector Base Map

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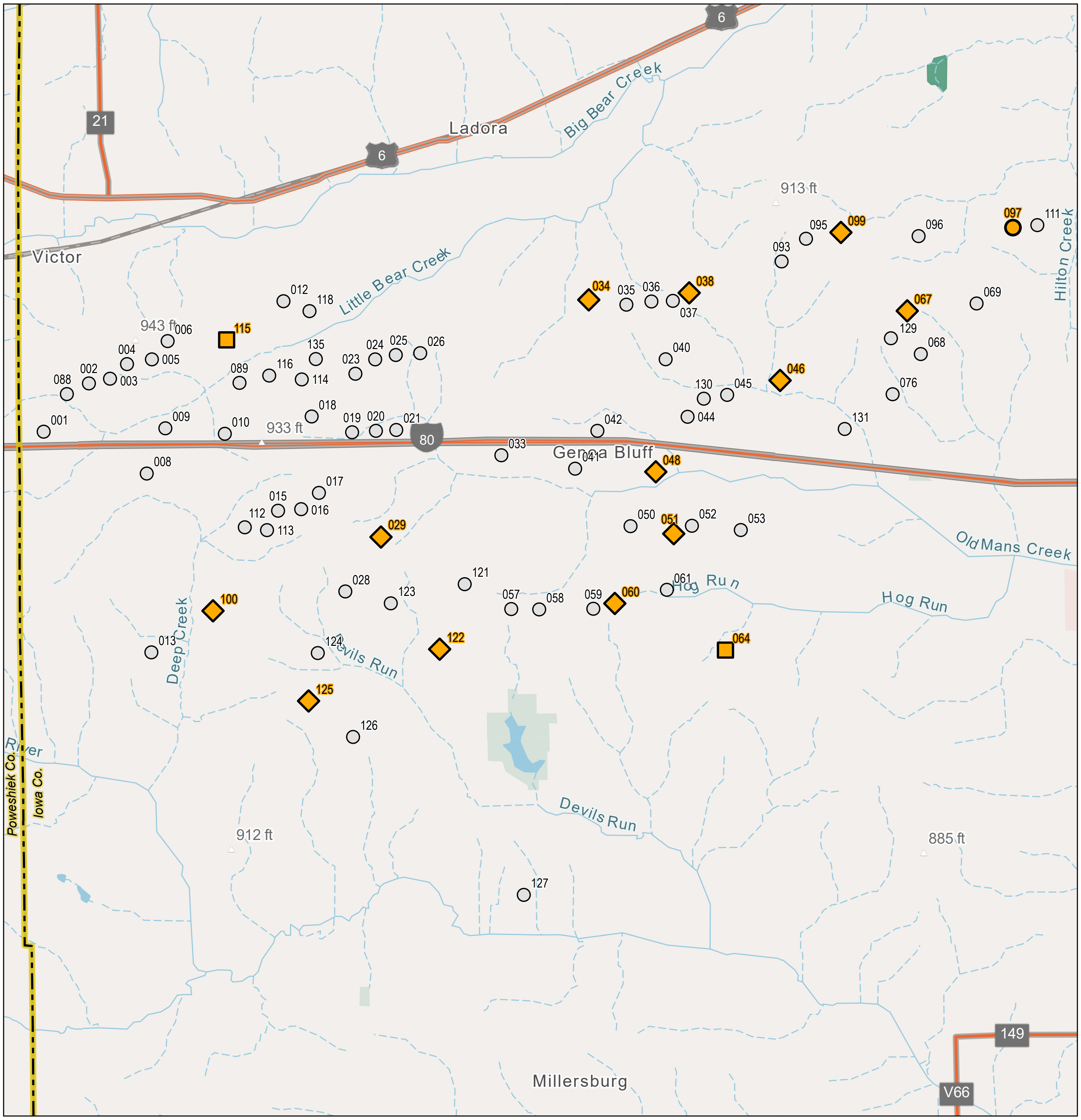

Legend
- County Boundary
- Wind Turbine

Wind Turbine with Detector
- Vestas 2.0-110
- Vestas 2.2-110
- Vestas 4.3-136

0 2 Miles
(At original document size of 8.5x11)
1:126,720

N

Stantec

Project Location
Iowa County, Iowa

Prepared by GC on 2024-09-30
Reviewed by TP on 2024-09-30

Client/Project
Department of Energy
MidAmerican Wind Energy Facilities

195601686

Figure No.
4

DRAFT

Title
Diamond Trail Wind Detector Locations

Notes
1. Coordinate System: NAD 1983 UTM Zone 15N
2. Data Sources: Stantec, USGS USWTDB
3. Background: Esri World Vector Base Map

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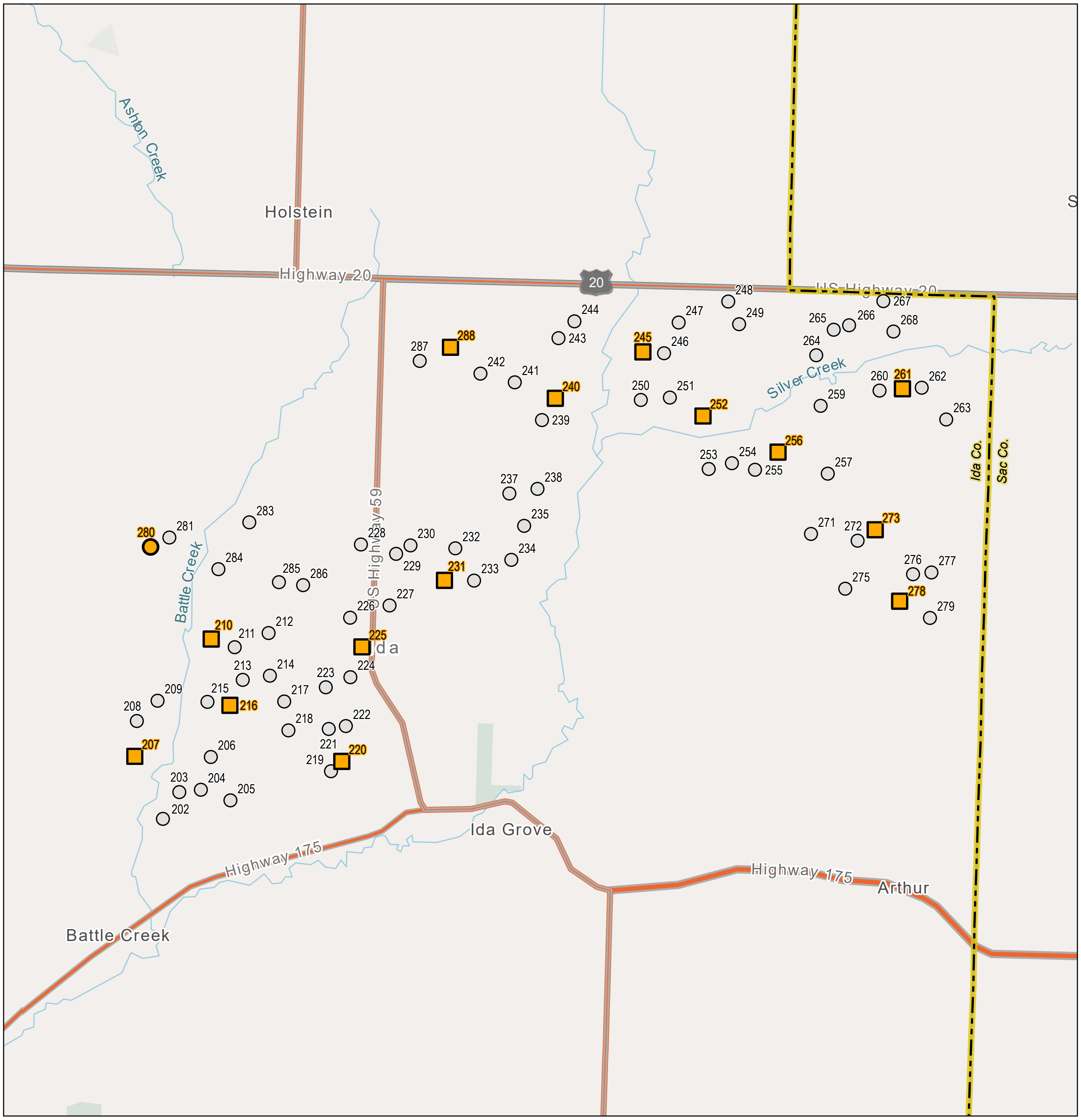

Legend

County Boundary

Wind Turbine

Wind Turbine with Detector

GE 2.3 ESS-116

GE 2.52 ESS-127

0 2.5 Miles

(At original document size of 8.5x11)
1:158,400

N

Stantec

Project Location
Ada County, Iowa

Prepared by GC on 2024-09-30
Reviewed by TP on 2024-09-30

Client/Project
Department of Energy
MidAmerican Wind Energy Facilities

195601686

Figure No.
5

DRAFT

Title
Ida Grove Wind Detector Locations

Notes
1. Coordinate System: NAD 1983 UTM Zone 15N
2. Data Sources: Stantec, USGS USWTDB
3. Background: Esri World Vector Base Map

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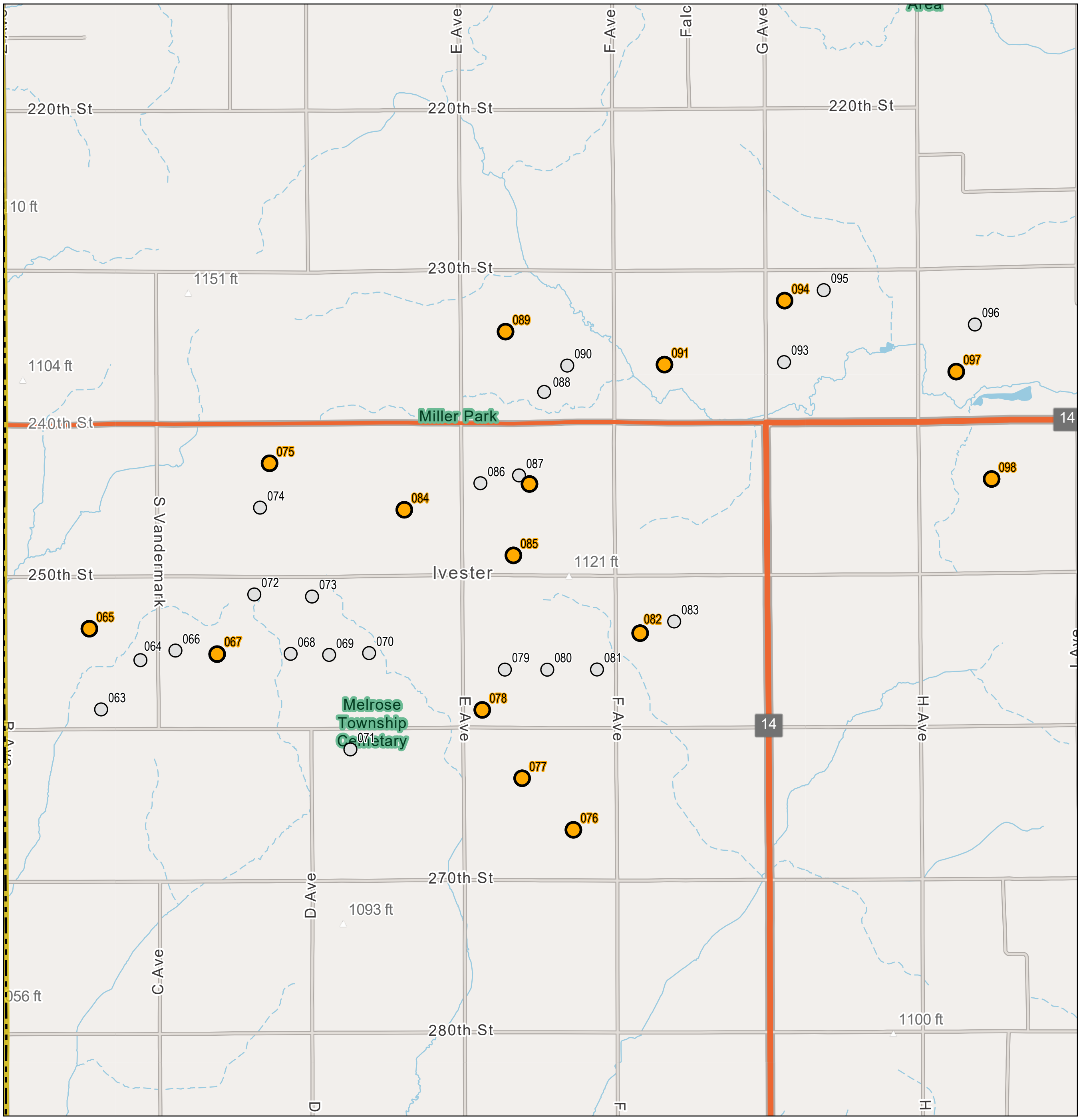

Legend
- County Boundary
- Wind Turbine

Wind Turbine with Detector
- Siemens 2.625-120

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(At original document size of 8.5x11)
1:63,360

Stantec

Project Location
Grundy County, Iowa

Prepared by GC on 2024-09-30
Reviewed by TP on 2024-09-30

Client/Project 195601686
Department of Energy
MidAmerican Wind Energy Facilities

Figure No.
6

DRAFT

Title
Ivestor Wind Detector Locations

Notes
1. Coordinate System: NAD 1983 UTM Zone 15N
2. Data Sources: Stantec, USGS USWTDB
3. Background: Esri World Vector Base Map

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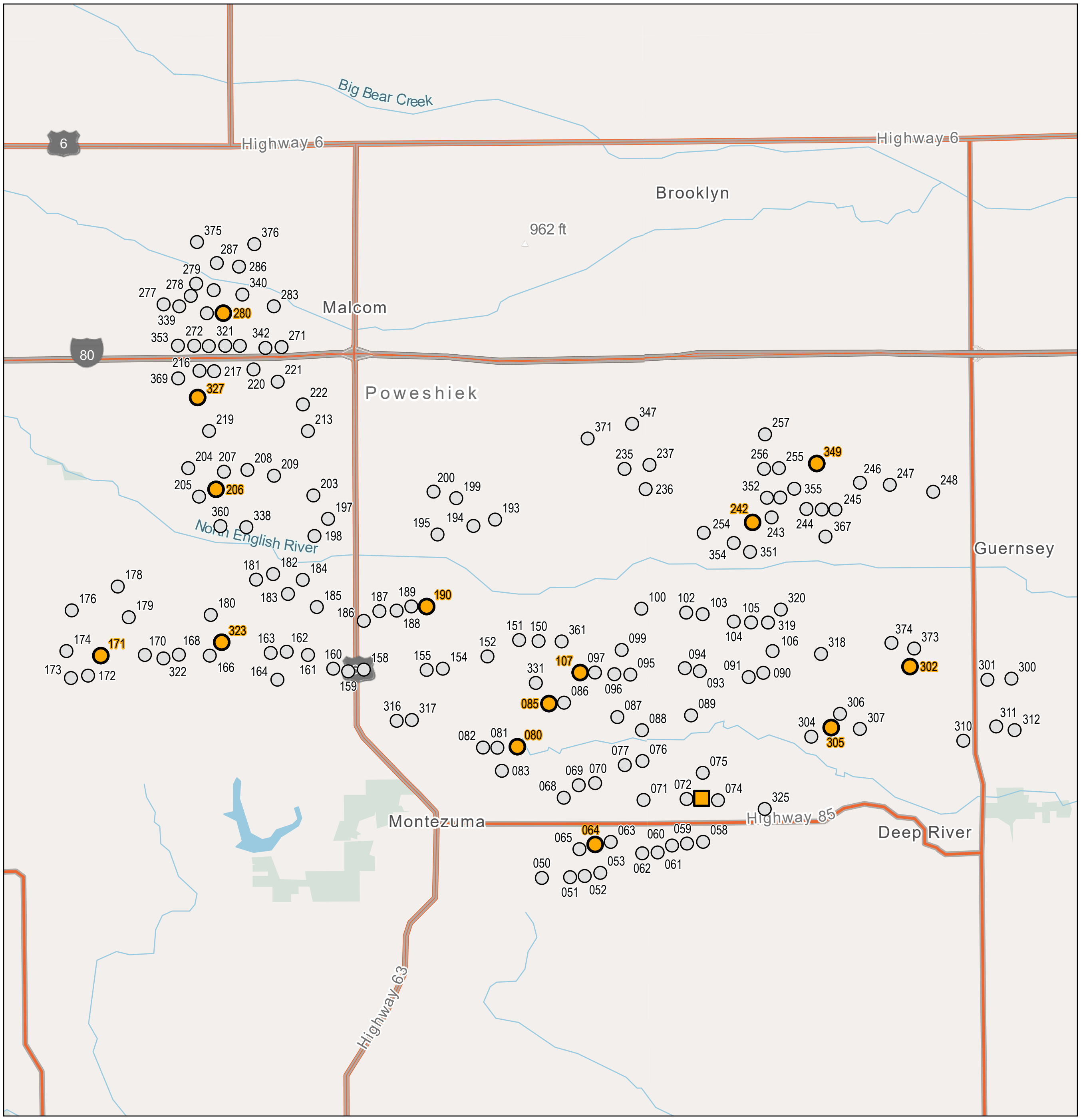

Legend

- County Boundary
- Wind Turbine

Wind Turbine with Detector

- Vestas 2.0-110
- Vestas 2.2-110

0 2.5 Miles

(At original document size of 8.5x11)
1:158,400

N

Stantec

Notes

1. Coordinate System: NAD 1983 UTM Zone 15N
2. Data Sources: Stantec, USGS USWTDB
3. Background: Esri World Vector Base Map

Project Location
Mahaska County, Iowa

Prepared by GC on 2024-09-30
Reviewed by TP on 2024-09-30

Client/Project
Department of Energy
MidAmerican Wind Energy Facilities

195601686

Figure No.
7

DRAFT

Title
North English Wind Detector Locations

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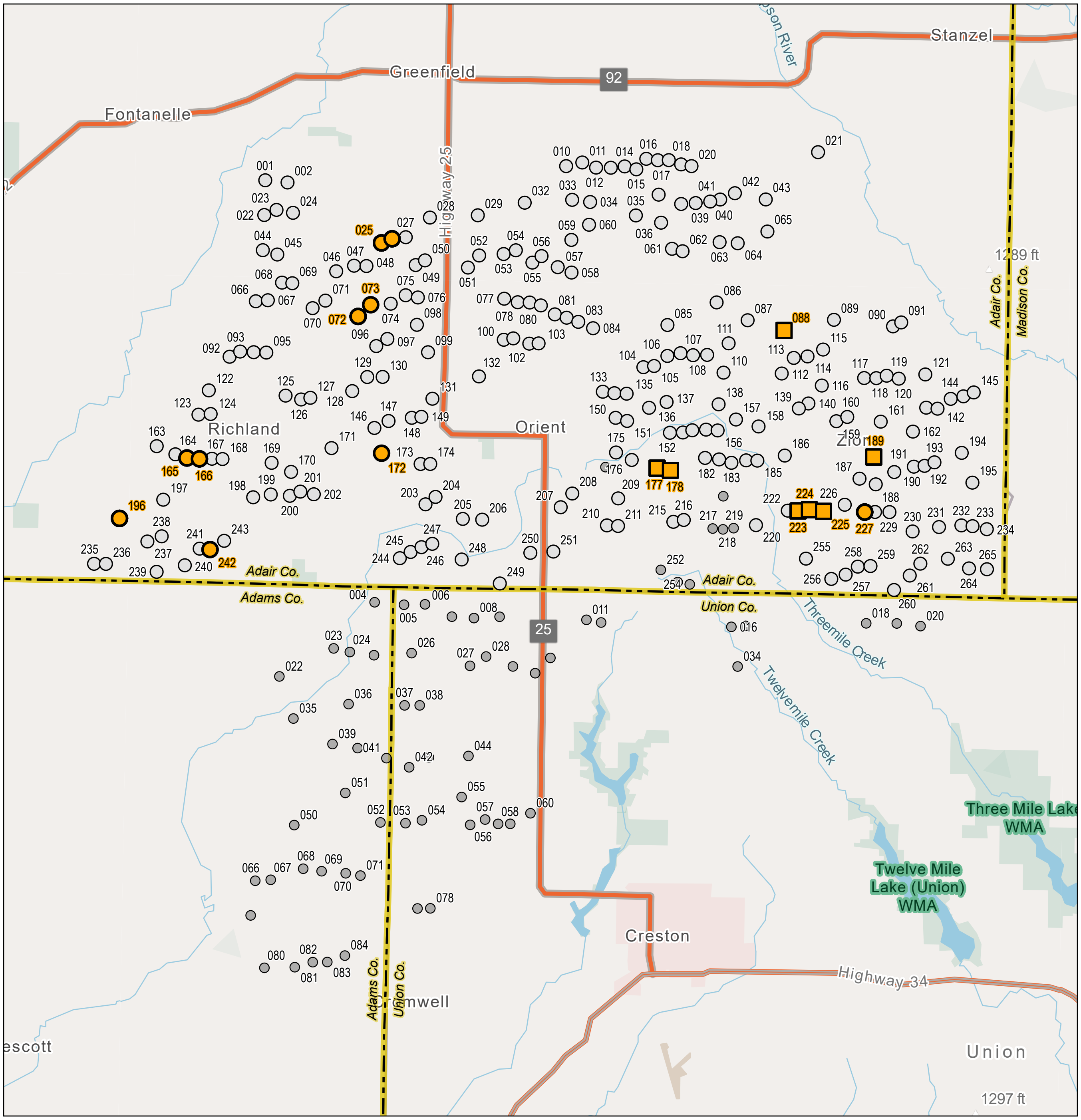

Legend
- County Boundary
- Southern Hills WTG
- Orient WTG

Orient Wind Turbine with Detector
- Vestas V110
- Vestas V120

0 3 Miles

(At original document size of 8.5x11)
1:190,080

Stantec

Project Location
Adair, Adams, and Union Counties, Iowa

Prepared by GC on 2024-10-03
Reviewed by TP on 2024-10-03

Client/Project
Department of Energy
MidAmerican Wind Energy Facilities

195601686

Figure No.
8

DRAFT

Title
Orient Wind Detector Locations

Notes
1. Coordinate System: NAD 1983 UTM Zone 15N
2. Data Sources: Stantec, USGS USWTDB
3. Background: Esri World Vector Base Map

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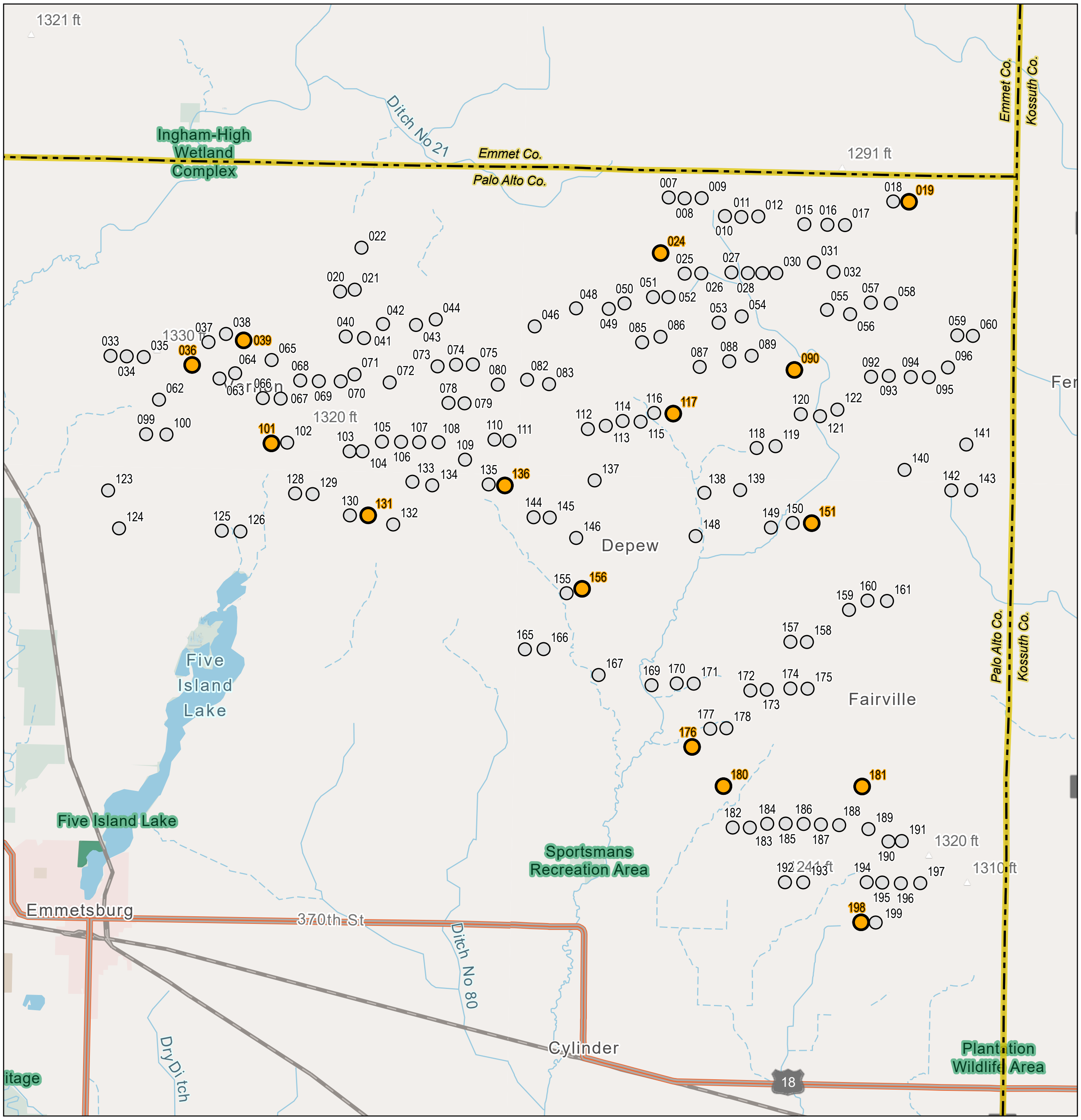

Legend

County Boundary

Wind Turbine

Wind Turbine with Detector

Vestas 2.0-110

0 2 Miles

(At original document size of 8.5x11)
1:126,720

N

Stantec

Project Location
Palo Alto County, Iowa

Prepared by GC on 2024-09-30
Reviewed by TP on 2024-09-30

Client/Project 195601686
Department of Energy
MidAmerican Wind Energy Facilities

Figure No.
9

DRAFT

Title
Palo Alto Wind Detector Locations

Notes
1. Coordinate System: NAD 1983 UTM Zone 15N
2. Data Sources: Stantec, USGS USWTDB
3. Background: Esri World Vector Base Map

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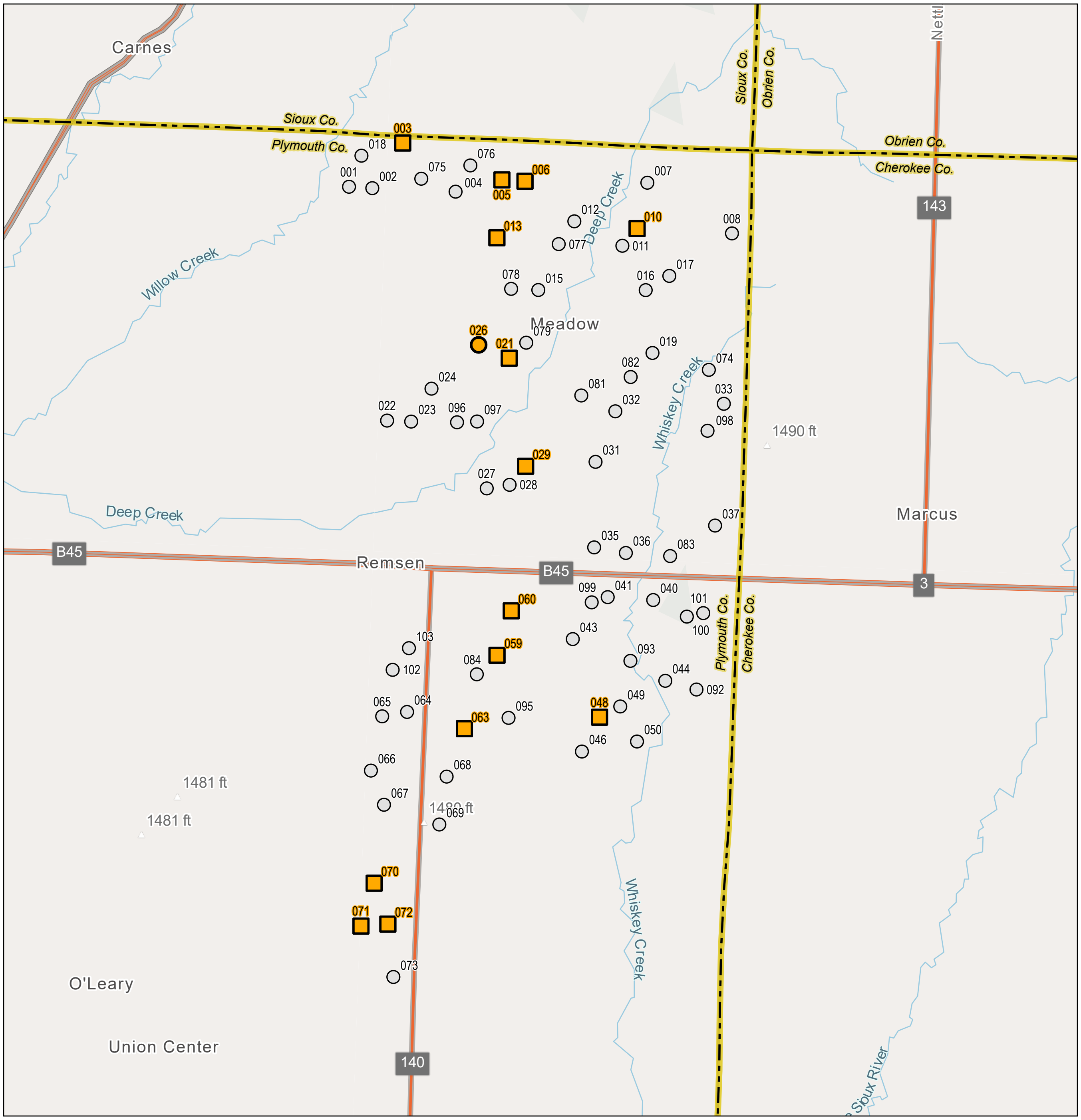

Legend

- County Boundary
- Wind Turbine

Wind Turbine with Detector

- GE 2.3 ESS-116
- GE 2.82 ESS-127

0 2.5 Miles

(At original document size of 8.5x11)
1:158,400

N

Notes

1. Coordinate System: NAD 1983 UTM Zone 15N
2. Data Sources: Stantec, USGS USWTDB
3. Background: Esri World Vector Base Map

Stantec

Project Location
Plymouth County, Iowa

Prepared by GC on 2024-09-30
Reviewed by TP on 2024-09-30

Client/Project
Department of Energy
MidAmerican Wind Energy Facilities

195601686

Figure No.
10

Title
Plymouth Wind Detector Locations

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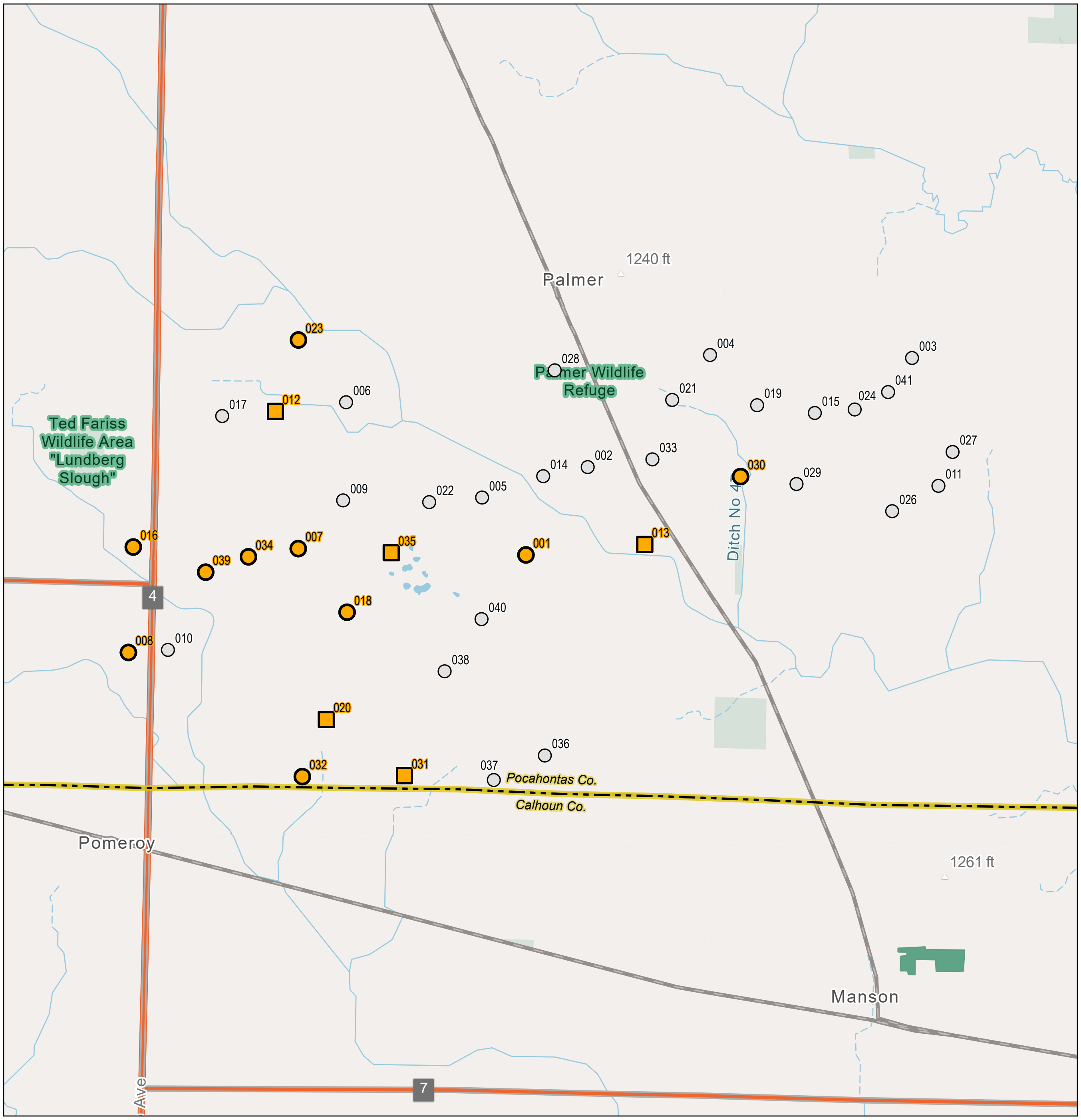


Legend
- County Boundary
- Wind Turbine

Wind Turbine with Detector
- Vestas 2.0-110
- Vestas 2.2-110

0 1.5 Miles
(At original document size of 8.5x11)
1:95,040

N

Stantec

Project Location
Pocahontas County, Iowa

Prepared by GC on 2024-09-30
Reviewed by TP on 2024-09-30

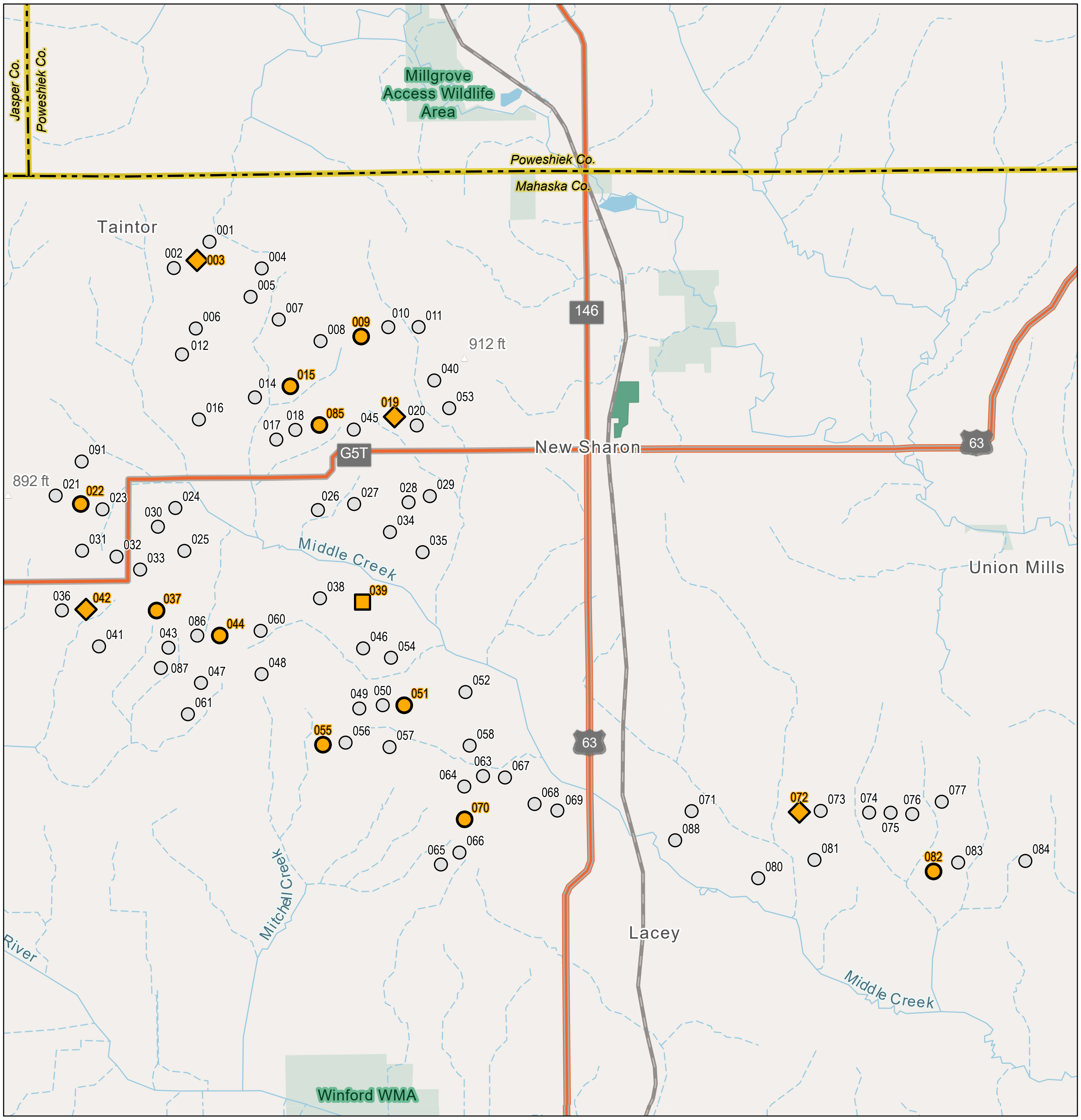
Client/Project
Department of Energy
MidAmerican Wind Energy Facilities

195601686

Figure No.
11

Title
Pocahontas Wind Detector Locations

Notes
1. Coordinate System: NAD 1983 UTM Zone 15N
2. Data Sources: Stantec, USGS USWTDB
3. Background: Esri World Vector Base Map



Legend

- County Boundary
- Wind Turbine

Wind Turbine with Detector

- Vestas 2.0-110
- Vestas 2.2-110

Notes

1. Coordinate System: NAD 1983 UTM Zone 15N
2. Data Sources: Stantec, USGS USWTDB
3. Background: Esri World Vector Base Map

0 1.5 Miles

(At original document size of 8.5x11)
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N

Stantec

Project Location
Mahaska County, Iowa

Prepared by GC on 2024-09-30
Reviewed by TP on 2024-09-30

Client/Project
Department of Energy
MidAmerican Wind Energy Facilities

195601686

Figure No.
12

Title
Prairie Wind Detector Locations

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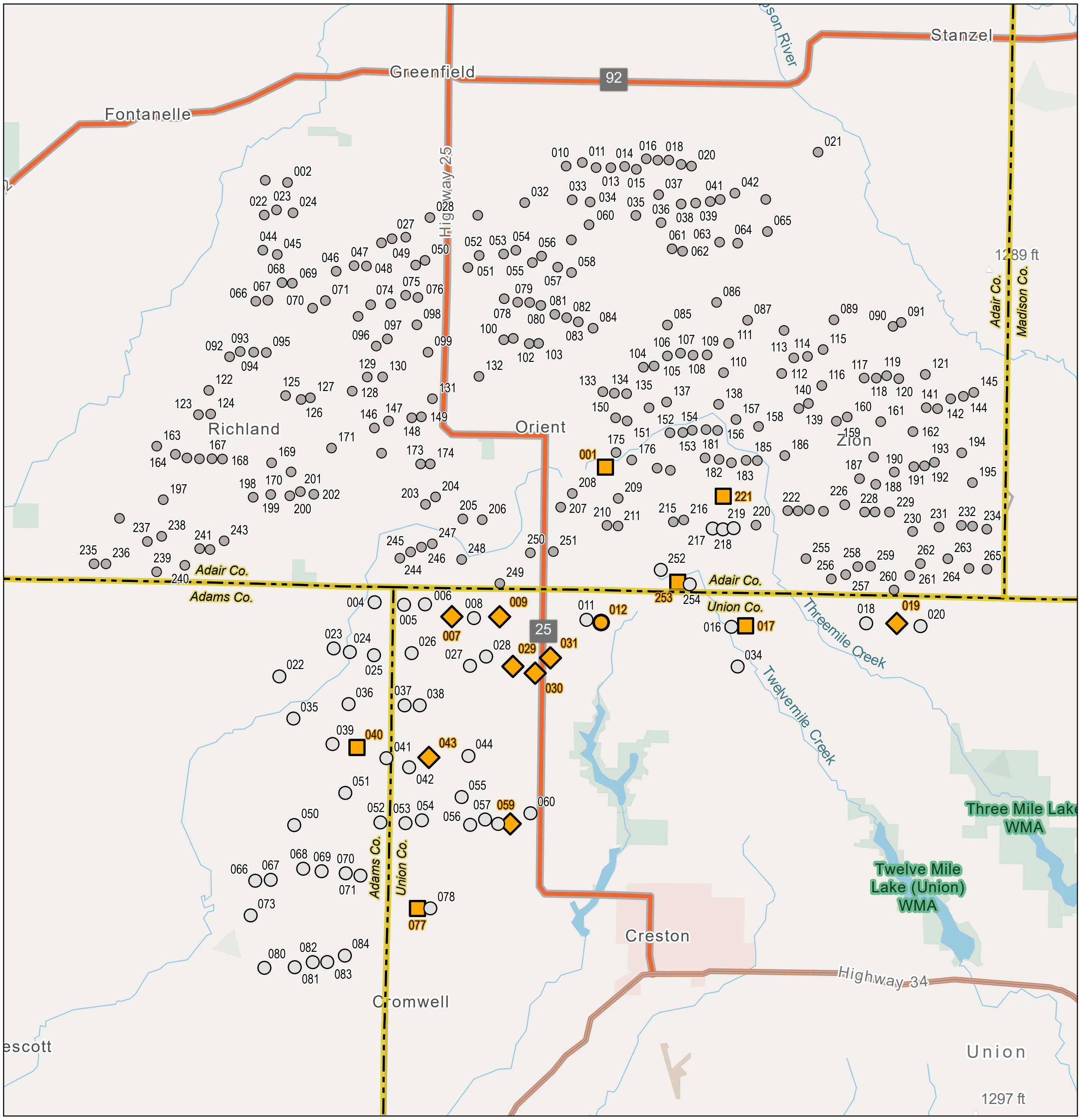

Legend

- County Boundary
- Orient WTG
- Southern Hills WTG

Souther Hills Wind Turbine with Detector

- Vestas 2.0-110
- Vestas 2.2-110
- Vestas 4.3-136

0 3 Miles

(At original document size of 8.5x11)
1:190,080

N

Stantec

Notes
1. Coordinate System: NAD 1983 UTM Zone 15N
2. Data Sources: Stantec, USGS USWTDB
3. Background: Esri World Vector Base Map

Project Location
Adair, Adams, and Union Counties, Iowa

Prepared by GC on 2024-10-03
Reviewed by TP on 2024-10-03

Client/Project
Department of Energy
MidAmerican Wind Energy Facilities

195601686

Figure No.
13

Title
Southern Hills Wind Detector Locations

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Appendix D

Appendix D Table 1. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Arbor Hill, Adair County, Iowa, 2021.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
ground	Blanket	067	5/1/2021	12/31/2021	Battery/Solar	245 (216)	23,824	7,897	2,867	2,867	78 (78)	2,220	1,333 (46.5)	1,341 (46.8)
ground	Blanket	075	5/1/2021	12/2/2021	Battery/Solar	216 (216)	15,838	3,043	2,752	2,635	78 (78)	2,010	1,181 (44.8)	1,218 (46.2)
ground	Blanket	131	5/1/2021	12/2/2021	Battery/Solar	216 (216)	32,968	9,584	3,511	3,509	78 (78)	2,825	1,835 (52.3)	1,780 (50.7)
ground	Blanket	184	5/1/2021	12/2/2021	Battery/Solar	216 (216)	47,800	6,517	4,244	4,241	78 (78)	3,107	1,695 (40)	1,886 (44.5)
ground	Control	112	5/1/2021	12/2/2021	Battery/Solar	216 (192)	129,190	64,975	2,965	2,941	78 (78)	2,282	2,002 (68.1)	1,993 (67.8)
ground	Control	148	5/1/2021	12/2/2021	Battery/Solar	216 (211)	55,937	16,216	5,236	4,999	78 (78)	3,238	3,020 (60.4)	2,670 (53.4)
ground	Control	177	6/11/2021	12/2/2021	Battery/Solar	175 (175)	38,219	8,824	4,392	4,374	78 (78)	3,331	3,092 (70.7)	2,749 (62.8)
nacelle	Blanket	067	6/10/2021	12/31/2021	Battery/Solar	205 (200)	83,290	23,276	653	653	78 (78)	561	314 (48.1)	354 (54.2)
nacelle	Blanket	075	6/15/2021	12/31/2021	Battery/Solar	200 (200)	23,856	2,634	696	693	78 (78)	483	350 (50.5)	368 (53.1)
nacelle	Blanket	113	5/27/2021	12/31/2021	Battery/Solar	219 (219)	32,457	5,168	1,018	1,015	78 (78)	840	423 (41.7)	419 (41.3)
nacelle	Blanket	131	6/12/2021	12/31/2021	Battery/Solar	203 (203)	89,556	20,531	803	803	78 (78)	698	375 (46.7)	394 (49.1)
nacelle	Blanket	133	6/12/2021	12/10/2021	Battery/Solar	182 (182)	43,057	6,308	1,871	1,186	78 (78)	1,004	475 (40.1)	519 (43.8)
nacelle	Blanket	149	6/3/2021	12/12/2021	Battery/Solar	193 (193)	93,828	10,770	630	625	78 (78)	548	311 (49.8)	285 (45.6)
nacelle	Blanket	178	6/1/2021	12/4/2021	Battery/Solar	187 (187)	90,894	66,916	1,041	1,021	78 (78)	839	458 (44.9)	484 (47.4)
nacelle	Blanket	184	6/12/2021	12/8/2021	Battery/Solar	180 (180)	18,464	1,709	945	945	78 (78)	837	442 (46.8)	512 (54.2)
nacelle	Control	074	6/1/2021	12/31/2021	Battery/Solar	214 (170)	40,773	8,948	814	814	78 (78)	720	686 (84.3)	561 (68.9)
nacelle	Control	112	7/8/2021	12/31/2021	Battery/Solar	177 (177)	12,900	4,349	631	628	78 (78)	581	529 (84.2)	497 (79.1)
nacelle	Control	130	5/20/2021	12/31/2021	Battery/Solar	226 (79)	75,452	64,941	201	200	78 (23)	141	127 (63.5)	108 (54)
nacelle	Control	132	6/2/2021	12/31/2021	Battery/Solar	213 (212)	60,225	5,656	739	714	78 (78)	615	359 (50.3)	449 (62.9)
nacelle	Control	148	5/1/2021	12/26/2021	Battery/Solar	240 (0)	0	0	0	0	78 (0)	0	0 (0)	0 (0)
nacelle	Control	177	6/9/2021	12/31/2021	Battery/Solar	206 (151)	11,641	1,745	1,438	1,430	78 (78)	1,198	1,139 (79.7)	985 (68.9)
nacelle	Control	185	6/9/2021	11/15/2021	Battery/Solar	160 (143)	91,352	72,525	843	781	78 (78)	672	467 (59.8)	556 (71.2)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.

**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 2. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Arbor Hill, Adair County, Iowa, 2022.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
ground	Blanket	112	6/30/2022	1/14/2023	Battery/Solar	199 (187)	192,274	6,198	3,450	2,947	78 (78)	2,604	1,464 (49.7)	1,664 (56.5)
ground	Blanket	131	6/30/2022	1/14/2023	Battery/Solar	199 (199)	75,813	4,524	3,658	2,861	78 (78)	2,580	2,240 (78.3)	1,697 (59.3)*
ground	Blanket	177	6/28/2022	1/14/2023	Battery/Solar	201 (201)	17,241	1,442	5,241	4,066	78 (78)	3,639	3,146 (77.4)	2,243 (55.2)*
ground	Blanket	184	6/28/2022	1/14/2023	Battery/Solar	201 (200)	41,638	6,043	6,009	4,826	78 (78)	4,041	1,377 (28.5)	2,765 (57.3)**
ground	Control	067	6/30/2022	1/13/2023	Battery/Solar	198 (190)	32,430	3,351	2,598	1,474	78 (71)	1,311	975 (66.1)	1,111 (75.4)
ground	Smart	075	6/28/2022	1/13/2023	Battery/Solar	200 (0)	0	0	0	0	78 (0)	0	0 (0)	0 (0)
ground	Smart	148	6/28/2022	1/15/2023	Battery/Solar	202 (176)	47,732	4,718	4,464	3,486	78 (78)	2,894	2,563 (73.5)	1,035 (29.7)*
nacelle	Blanket	074	6/28/2022	1/13/2023	Battery/Solar	200 (154)	20,794	665	626	458	78 (78)	435	182 (39.7)	259 (56.6)
nacelle	Blanket	112	6/30/2022	1/15/2023	Battery/Solar	200 (200)	11,080	795	686	569	78 (78)	533	257 (45.2)	309 (54.3)
nacelle	Blanket	131	6/30/2022	1/14/2023	Battery/Solar	199 (151)	30,124	1,110	882	610	78 (78)	582	476 (78)	367 (60.2)*
nacelle	Blanket	177	6/28/2022	1/14/2023	Battery/Solar	201 (91)	14,269	5,238	1,191	891	78 (74)	849	749 (84.1)	482 (54.1)*
nacelle	Blanket	184	6/30/2022	1/14/2023	Battery/Solar	199 (0)	175,486	33,592	0	0	78 (0)	0	0 (0)	0 (0)*
nacelle	Control	067	6/30/2022	1/13/2023	Battery/Solar	198 (198)	16,442	593	532	305	78 (78)	290	218 (71.5)	276 (90.5)
nacelle	Control	113	6/30/2022	1/14/2023	Battery/Solar	199 (0)	0	0	0	0	78 (0)	0	0 (0)	0 (0)
nacelle	Control	132	6/30/2022	1/14/2023	Battery/Solar	199 (199)	42,934	569	520	423	78 (78)	396	260 (61.5)	344 (81.3)
nacelle	Control	149	6/30/2022	1/15/2023	Battery/Solar	200 (0)	0	0	0	0	78 (0)	0	0 (0)	0 (0)
nacelle	Control	185	6/28/2022	1/14/2023	Battery/Solar	201 (162)	0	0	762	493	78 (78)	458	406 (82.4)	416 (84.4)
nacelle	Smart	075	6/28/2022	1/13/2023	Battery/Solar	200 (138)	77,835	721	643	454	78 (78)	444	206 (45.4)	290 (63.9)
nacelle	Smart	130	6/28/2022	1/14/2023	Battery/Solar	201 (188)	26,885	957	751	547	78 (78)	494	441 (80.6)	296 (54.1)*
nacelle	Smart	133	6/30/2022	1/14/2023	Battery/Solar	199 (49)	37,726	527	513	444	78 (34)	414	139 (31.3)	203 (45.7)
nacelle	Smart	148	6/30/2022	1/15/2023	Battery/Solar	200 (0)	0	0	0	0	78 (0)	0	0 (0)	0 (0)*
nacelle	Smart	178	6/30/2022	1/15/2023	Battery/Solar	200 (0)	0	0	0	0	78 (0)	0	0 (0)	0 (0)*

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 3. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Arbor Hill, Adair County, Iowa, 2023.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Blanket	075	6/9/2023	11/9/2023	5V AC/DC	154 (57)	11,607	485	487	383	78 (24)	355	32 (8.4)	62 (16.2)**
nacelle	Blanket	112	6/7/2023	11/9/2023	5V AC/DC	156 (112)	18,393	483	483	348	78 (74)	315	73 (21)	93 (26.7)
nacelle	Blanket	131	6/9/2023	11/9/2023	5V AC/DC	154 (50)	7,534	308	308	219	78 (17)	175	85 (38.8)	92 (42)
nacelle	Blanket	132	6/7/2023	11/9/2023	5V AC/DC	156 (107)	76,624	360	359	254	78 (49)	230	100 (39.4)	117 (46.1)
nacelle	Blanket	149	6/9/2023	11/9/2023	5V AC/DC	154 (150)	68,904	1,179	1,178	870	78 (78)	792	307 (35.3)	302 (34.7)
nacelle	Blanket	177	6/9/2023	11/9/2023	5V AC/DC	154 (31)	4,473	164	164	117	78 (0)	0	0 (0)	0 (0)
nacelle	Blanket	185	6/9/2023	11/9/2023	5V AC/DC	154 (85)	40,114	5,482	1,136	751	78 (52)	701	332 (44.2)	323 (43)
nacelle	Smart	067	6/9/2023	11/9/2023	5V AC/DC	154 (43)	2,272	52	52	35	78 (8)	0	0 (0)	0 (0)
nacelle	Smart	074	6/10/2023	11/9/2023	5V AC/DC	153 (0)	0	0	0	0	78 (0)	0	0 (0)	0 (0)
nacelle	Smart	113	6/6/2023	11/9/2023	5V AC/DC	157 (121)	2,820	1,183	1,182	566	78 (78)	482	44 (7.8)	177 (31.3)
nacelle	Smart	130	6/7/2023	11/9/2023	5V AC/DC	156 (65)	6,482	102	102	74	78 (11)	0	0 (0)	0 (0)
nacelle	Smart	133	6/7/2023	11/9/2023	5V AC/DC	156 (113)	5,548	341	340	253	78 (75)	220	55 (21.7)	61 (24.1)**
nacelle	Smart	148	6/9/2023	11/9/2023	5V AC/DC	154 (150)	201	45	45	39	78 (78)	0	0 (0)	0 (0)
nacelle	Smart	178	6/9/2023	11/9/2023	5V AC/DC	154 (126)	12,570	1,689	1,684	1,050	78 (61)	932	368 (35)	339 (32.3)
nacelle	Smart	184	6/10/2023	11/9/2023	5V AC/DC	153 (88)	30,319	1,249	1,221	765	78 (56)	718	86 (11.2)	286 (37.4)**

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 4. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Beaver Creek, Boone and Greene Counties, Iowa, 2022.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Blanket	041	8/15/2022	1/15/2023	9V AC/DC	154 (16)	46,761	34,264	200	164	48 (17)	164	78 (47.6)	86 (52.4)
nacelle	Blanket	049	8/17/2022	1/15/2023	9V AC/DC	152 (16)	40,829	335	270	194	46 (17)	194	104 (53.6)	132 (68)
nacelle	Blanket	061	8/17/2022	1/15/2023	9V AC/DC	152 (23)	10,780	223	217	168	46 (24)	168	123 (73.2)	114 (67.9)
nacelle	Blanket	067	8/15/2022	1/15/2023	9V AC/DC	154 (51)	28,826	311	274	234	48 (33)	232	147 (62.8)	116 (49.6)
nacelle	Blanket	068	8/15/2022	1/15/2023	9V AC/DC	154 (14)	27,788	160	158	128	48 (15)	128	74 (57.8)	77 (60.2)
nacelle	Control	021	8/17/2022	1/15/2023	9V AC/DC	152 (7)	4,813	70	56	47	46 (8)	47	35 (74.5)	35 (74.5)
nacelle	Control	039	8/9/2022	1/15/2023	9V AC/DC	160 (0)	0	0	0	0	54 (1)	0	0 (0)	0 (0)
nacelle	Control	101	8/9/2022	1/15/2023	9V AC/DC	160 (146)	166,868	429	231	178	54 (46)	176	167 (93.8)	144 (80.9)
nacelle	Control	109	8/9/2022	1/15/2023	9V AC/DC	160 (152)	166,263	293	273	237	54 (46)	233	218 (92)	202 (85.2)
nacelle	Control	139	8/10/2022	1/15/2023	9V AC/DC	159 (55)	87,442	393	354	266	53 (53)	266	246 (92.5)	234 (88)
nacelle	Control	141	8/10/2022	1/15/2023	9V AC/DC	159 (56)	124,365	396	360	297	53 (53)	297	273 (91.9)	251 (84.5)
nacelle	Control	152	8/10/2022	1/15/2023	9V AC/DC	159 (128)	155,481	478	269	231	53 (53)	228	187 (81)	181 (78.4)
nacelle	Control	164	8/10/2022	1/15/2023	9V AC/DC	159 (18)	18,403	298	269	212	53 (19)	212	170 (80.2)	170 (80.2)
nacelle	Control	181	8/15/2022	1/15/2023	9V AC/DC	154 (43)	53,249	414	301	242	48 (44)	242	218 (90.1)	214 (88.4)
nacelle	Control	183	8/15/2022	1/15/2023	9V AC/DC	154 (58)	38,288	389	362	284	48 (48)	282	222 (78.2)	209 (73.6)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 5. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Beaver Creek, Boone and Greene Counties, Iowa, 2023.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Blanket	049	6/11/2023	11/21/2023	5V AC/DC	164 (5)	11,412	13	7	7	78 (0)	0	0 (0)	0 (0)
nacelle	Blanket	068	6/10/2023	11/21/2023	5V AC/DC	165 (32)	48,093	62	45	43	78 (0)	0	0 (0)	0 (0)
nacelle	Control	021	6/10/2023	11/21/2023	5V AC/DC	165 (110)	78,802	753	551	550	78 (75)	495	379 (68.9)	273 (49.6)
nacelle	Control	039	6/10/2023	11/21/2023	5V AC/DC	165 (120)	298,036	843	669	656	78 (78)	623	481 (73.3)	339 (51.7)
nacelle	Control	101	6/10/2023	11/21/2023	5V AC/DC	165 (99)	80,885	933	894	878	78 (64)	816	674 (76.8)	463 (52.7)
nacelle	Control	109	6/10/2023	11/21/2023	5V AC/DC	165 (108)	78,564	637	635	618	78 (73)	572	426 (68.9)	407 (65.9)
nacelle	Control	139	6/10/2023	11/21/2023	5V AC/DC	165 (154)	223,959	1,007	892	883	78 (78)	812	641 (72.6)	532 (60.2)
nacelle	Control	141	6/10/2023	11/21/2023	5V AC/DC	165 (32)	49,090	78	60	60	78 (0)	0	0 (0)	0 (0)
nacelle	Control	152	6/10/2023	11/21/2023	5V AC/DC	165 (66)	81,703	740	688	688	78 (31)	631	390 (56.7)	252 (36.6)
nacelle	Control	164	6/10/2023	11/21/2023	5V AC/DC	165 (154)	236,333	4,065	1,519	1,510	78 (78)	1,386	841 (55.7)	970 (64.2)
nacelle	Control	181	6/10/2023	11/21/2023	5V AC/DC	165 (96)	60,218	401	36	36	78 (64)	0	0 (0)	0 (0)
nacelle	Control	183	6/10/2023	11/21/2023	5V AC/DC	165 (37)	34,548	65	59	58	78 (2)	6	6 (10.3)	6 (10.3)
nacelle	Smart	041	6/10/2023	11/21/2023	5V AC/DC	165 (65)	173,823	144,512	479	468	78 (30)	419	272 (58.1)	123 (26.3)*
nacelle	Smart	061	6/11/2023	11/21/2023	5V AC/DC	164 (74)	35,147	875	837	825	78 (40)	733	447 (54.2)	278 (33.7)*
nacelle	Smart	067	6/11/2023	11/21/2023	5V AC/DC	164 (64)	46,816	575	494	491	78 (30)	450	275 (56)	90 (18.3)*

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 6. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Contrail, Taylor County, Iowa, 2022.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Blanket	010	7/19/2022	1/2/2023	9V AC/DC	168 (168)	203,279	3,767	2,151	2,151	75 (75)	2,139	1,887 (87.7)	1,302 (60.5)*
nacelle	Blanket	012	7/19/2022	1/2/2023	9V AC/DC	168 (108)	279,391	6,411	3,161	3,161	75 (75)	3,138	2,937 (92.9)	1,986 (62.8)*
nacelle	Blanket	020	7/25/2022	1/2/2023	9V AC/DC	162 (56)	175,314	13,094	861	861	69 (57)	861	789 (91.6)	488 (56.7)*
nacelle	Blanket	021	7/26/2022	1/16/2023	9V AC/DC	175 (108)	283,486	6,177	1,466	1,265	68 (68)	1,245	1,066 (84.3)	493 (39)*
nacelle	Blanket	023	7/25/2022	1/5/2023	9V AC/DC	165 (91)	28,133	2,578	176	176	69 (27)	175	137 (77.8)	74 (42)*
nacelle	Blanket	025	7/21/2022	1/5/2023	9V AC/DC	169 (169)	364,127	8,210	1,124	1,021	73 (73)	1,007	900 (88.1)	496 (48.6)*
nacelle	Blanket	037	7/18/2022	1/16/2023	9V AC/DC	183 (85)	170,159	1,815	1,375	1,375	76 (76)	1,368	1,130 (82.2)	627 (45.6)*
nacelle	Blanket	040	7/14/2022	1/8/2023	9V AC/DC	179 (168)	131,262	1,379	1,070	1,070	78 (74)	1,057	810 (75.7)	552 (51.6)*
nacelle	Blanket	043	7/20/2022	1/9/2023	9V AC/DC	174 (167)	149,384	14,802	1,330	1,330	74 (74)	1,330	1,221 (91.8)	674 (50.7)*
nacelle	Blanket	046	7/26/2022	11/30/2022	9V AC/DC	128 (127)	379,587	27,898	1,057	1,057	68 (68)	1,047	830 (78.5)	508 (48.1)*
nacelle	Blanket	047	7/25/2022	1/10/2023	9V AC/DC	170 (170)	281,819	5,098	1,321	1,321	69 (69)	1,294	1,176 (89)	712 (53.9)*
nacelle	Blanket	051	7/21/2022	1/16/2023	9V AC/DC	180 (81)	246,762	82,983	4,795	4,795	73 (73)	4,780	4,497 (93.8)	3,542 (73.9)*
nacelle	Blanket	055	7/27/2022	12/20/2022	9V AC/DC	147 (147)	190,090	1,507	1,181	1,181	67 (67)	1,154	806 (68.2)	565 (47.8)*
nacelle	Blanket	062	7/18/2022	1/16/2023	9V AC/DC	183 (95)	219,833	3,856	1,364	1,364	76 (76)	1,346	1,195 (87.6)	589 (43.2)*
nacelle	Blanket	075	7/14/2022	1/16/2023	9V AC/DC	187 (101)	332,040	11,401	1,326	1,326	78 (78)	1,312	1,164 (87.8)	751 (56.6)*

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 7. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Contrail, Taylor County, Iowa, 2023.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Blanket	012	6/19/2023	11/8/2023	5V AC/DC	143 (94)	226,575	12,694	5,315	5,315	78 (68)	4,167	3,397 (63.9)	2,304 (43.3)*
nacelle	Blanket	020	6/19/2023	11/8/2023	5V AC/DC	143 (57)	158,717	14,949	1,058	1,058	78 (31)	860	465 (44)	258 (24.4)*
nacelle	Blanket	023	6/19/2023	11/8/2023	5V AC/DC	143 (11)	20,188	791	15	15	78 (0)	0	0 (0)	0 (0)*
nacelle	Blanket	040	6/19/2023	11/8/2023	5V AC/DC	143 (142)	106,532	1,393	1,305	1,305	78 (78)	1,072	689 (52.8)	515 (39.5)*
nacelle	Blanket	043	6/19/2023	11/8/2023	5V AC/DC	143 (54)	153,701	16,422	1,291	1,291	78 (28)	954	507 (39.3)	313 (24.2)*
nacelle	Blanket	047	6/19/2023	11/8/2023	5V AC/DC	143 (35)	69,062	2,018	442	442	78 (9)	187	123 (27.8)	68 (15.4)*
nacelle	Blanket	062	6/19/2023	11/8/2023	5V AC/DC	143 (31)	56,645	1,784	309	309	78 (5)	107	24 (7.8)	22 (7.1)*
nacelle	Smart	010	6/19/2023	11/8/2023	5V AC/DC	143 (116)	282,858	17,651	6,428	6,428	78 (78)	5,010	4,315 (67.1)	3,018 (47)*
nacelle	Smart	021	6/19/2023	11/8/2023	5V AC/DC	143 (142)	45,245	899	75	75	78 (78)	0	0 (0)	0 (0)*
nacelle	Smart	025	6/19/2023	11/8/2023	5V AC/DC	143 (33)	19,089	278	39	39	78 (10)	0	0 (0)	0 (0)*
nacelle	Smart	037	6/19/2023	11/8/2023	5V AC/DC	143 (139)	277,664	4,292	3,533	3,533	78 (78)	2,794	1,676 (47.4)	985 (27.9)*
nacelle	Smart	046	6/19/2023	11/8/2023	5V AC/DC	143 (99)	225,129	10,911	1,438	1,438	78 (73)	1,179	824 (57.3)	481 (33.4)*
nacelle	Smart	051	6/19/2023	11/8/2023	5V AC/DC	143 (71)	132,696	3,609	2,839	2,833	78 (45)	2,404	1,859 (65.6)	1,356 (47.9)*
nacelle	Smart	055	6/19/2023	11/8/2023	5V AC/DC	143 (142)	208,798	2,017	1,330	1,330	78 (78)	1,032	602 (45.3)	369 (27.7)*
nacelle	Smart	075	6/19/2023	11/8/2023	5V AC/DC	143 (20)	53,184	1,813	104	104	78 (0)	0	0 (0)	0 (0)*

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 8. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Diamond Trail, Iowa County, Iowa, 2022.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Blanket	029	8/9/2022	1/21/2023	9V AC/DC	166 (166)	100,845	1,449	641	605	54 (54)	595	242 (40)	255 (42.1)
nacelle	Blanket	034	8/10/2022	1/21/2023	9V AC/DC	165 (97)	293,070	76,752	662	648	53 (53)	628	317 (48.9)	337 (52)
nacelle	Blanket	038	8/11/2022	1/21/2023	9V AC/DC	164 (164)	307,137	2,630	682	670	52 (52)	646	303 (45.2)	320 (47.8)
nacelle	Blanket	046	8/5/2022	1/21/2023	9V AC/DC	170 (170)	219,472	5,147	747	728	58 (58)	720	393 (54)	387 (53.2)
nacelle	Blanket	048	8/9/2022	1/21/2023	9V AC/DC	166 (166)	168,674	1,098	497	483	54 (54)	462	192 (39.8)	206 (42.7)
nacelle	Blanket	051	8/10/2022	1/20/2023	9V AC/DC	164 (162)	193,634	1,617	642	631	53 (53)	619	250 (39.6)	244 (38.7)
nacelle	Blanket	060	8/8/2022	1/20/2023	9V AC/DC	166 (164)	188,741	1,249	748	734	55 (55)	715	374 (51)	382 (52)
nacelle	Blanket	064	8/8/2022	1/20/2023	9V AC/DC	166 (163)	195,969	2,524	718	709	55 (55)	698	287 (40.5)	323 (45.6)
nacelle	Blanket	067	8/12/2022	1/20/2023	9V AC/DC	162 (162)	258,546	1,705	583	564	51 (51)	558	270 (47.9)	294 (52.1)
nacelle	Blanket	097	8/8/2022	1/21/2023	9V AC/DC	167 (68)	191,245	2,729	995	977	55 (55)	950	379 (38.8)	458 (46.9)
nacelle	Blanket	099	8/17/2022	1/20/2023	9V AC/DC	157 (154)	276,834	1,664	545	526	46 (43)	514	239 (45.4)	260 (49.4)
nacelle	Blanket	100	8/10/2022	1/21/2023	9V AC/DC	165 (165)	50,103	932	742	725	53 (53)	713	251 (34.6)	257 (35.4)
nacelle	Blanket	115	8/8/2022	1/21/2023	9V AC/DC	167 (102)	224,940	1,207	689	670	55 (55)	656	243 (36.3)	253 (37.8)
nacelle	Blanket	122	8/9/2022	1/21/2023	9V AC/DC	166 (118)	328,239	7,842	699	683	54 (54)	672	288 (42.2)	299 (43.8)
nacelle	Blanket	125	8/12/2022	1/21/2023	9V AC/DC	163 (100)	290,459	32,134	578	568	51 (51)	555	261 (46)	293 (51.6)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 9. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Diamond Trail, Iowa County, Iowa, 2023.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Blanket	034	6/14/2023	11/3/2023	5V AC/DC	143 (13)	19,799	2,676	55	55	78 (0)	0	0 (0)	0 (0)
nacelle	Blanket	046	6/14/2023	11/3/2023	9V AC/DC	143 (142)	165,396	2,687	723	723	78 (78)	626	317 (43.8)	328 (45.4)
nacelle	Blanket	051	6/14/2023	11/4/2023	5V AC/DC	144 (61)	91,987	635	418	418	78 (30)	324	117 (28)	120 (28.7)
nacelle	Blanket	064	6/14/2023	11/4/2023	5V AC/DC	144 (115)	180,909	4,532	1,011	1,011	78 (78)	845	401 (39.7)	403 (39.9)
nacelle	Blanket	097	6/14/2023	11/5/2023	5V AC/DC	145 (106)	242,942	3,418	1,480	1,480	78 (74)	1,264	543 (36.7)	561 (37.9)
nacelle	Blanket	100	6/14/2023	11/5/2023	5V AC/DC	145 (144)	32,632	500	489	466	78 (78)	390	169 (36.3)	178 (38.2)
nacelle	Blanket	122	6/14/2023	11/5/2023	9V AC/DC	145 (27)	101,085	1,916	94	89	78 (0)	0	0 (0)	0 (0)
nacelle	Smart	029	6/14/2023	11/3/2023	5V AC/DC	143 (102)	147,956	2,463	583	583	78 (71)	491	264 (45.3)	246 (42.2)
nacelle	Smart	038	6/14/2023	11/3/2023	5V AC/DC	143 (112)	174,464	532	375	375	78 (50)	290	172 (45.9)	184 (49.1)
nacelle	Smart	048	6/14/2023	11/4/2023	5V AC/DC	144 (30)	29,751	354	86	86	78 (0)	0	0 (0)	0 (0)
nacelle	Smart	060	6/14/2023	11/4/2023	5V AC/DC	144 (22)	44,425	148	34	34	78 (0)	0	0 (0)	0 (0)
nacelle	Smart	067	6/14/2023	11/5/2023	5V AC/DC	145 (137)	74,708	538	524	522	78 (74)	466	210 (40.2)	200 (38.3)
nacelle	Smart	099	6/14/2023	11/5/2023	5V AC/DC	145 (141)	97,829	787	736	736	78 (75)	644	328 (44.6)	338 (45.9)
nacelle	Smart	115	6/14/2023	11/5/2023	5V AC/DC	145 (102)	213,389	14,369	760	738	78 (72)	661	219 (29.7)	252 (34.1)
nacelle	Smart	125	6/14/2023	11/5/2023	5V AC/DC	145 (48)	41,348	3,361	212	210	78 (17)	142	43 (20.5)	51 (24.3)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 10. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Ida Grove, Ida County, Iowa, 2022.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Control	207	6/23/2022	1/12/2023	9V AC/DC	204 (39)	81,473	1,224	261	261	78 (17)	178	0 (0)	155 (59.4)
nacelle	Control	210	7/5/2022	1/11/2023	9V AC/DC	191 (190)	188,123	1,297	1,082	1,082	78 (77)	1,055	924 (85.4)	878 (81.1)
nacelle	Control	216	7/1/2022	1/12/2023	9V AC/DC	196 (113)	345,469	9,698	578	578	78 (77)	542	388 (67.1)	470 (81.3)**
nacelle	Control	220	7/5/2022	1/12/2023	9V AC/DC	192 (185)	81,019	3,213	1,598	1,598	78 (77)	1,551	1,443 (90.3)	1,450 (90.7)
nacelle	Control	225	7/1/2022	1/12/2023	9V AC/DC	196 (171)	412,323	4,977	519	519	78 (77)	479	444 (85.5)	414 (79.8)
nacelle	Control	231	7/7/2022	1/12/2023	9V AC/DC	190 (180)	369,713	11,181	867	867	78 (78)	815	739 (85.2)	693 (79.9)
nacelle	Control	240	6/23/2022	1/12/2023	9V AC/DC	204 (129)	352,839	38,952	710	710	78 (77)	659	594 (83.7)	575 (81)
nacelle	Control	245	6/22/2022	1/9/2023	9V AC/DC	202 (187)	233,166	3,896	641	639	78 (65)	508	271 (42.4)	396 (62)**
nacelle	Control	252	6/22/2022	1/12/2023	9V AC/DC	205 (169)	414,225	2,545	705	705	78 (68)	683	319 (45.2)	659 (93.5)**
nacelle	Control	256	6/23/2022	1/9/2023	9V AC/DC	201 (199)	132,637	1,322	302	301	78 (78)	272	238 (79.1)	227 (75.4)
nacelle	Control	261	6/23/2022	1/10/2023	9V AC/DC	202 (108)	209,427	11,944	401	399	78 (63)	394	330 (82.7)	343 (86)
nacelle	Control	273	6/23/2022	1/11/2023	9V AC/DC	203 (197)	117,626	1,289	536	441	78 (75)	423	216 (49)	393 (89.1)**
nacelle	Control	278	6/24/2022	1/11/2023	9V AC/DC	202 (0)	70	0	0	0	78 (0)	0	0 (0)	0 (0)
nacelle	Control	280	6/24/2022	1/10/2023	9V AC/DC	201 (200)	319,203	2,783	1,345	1,340	78 (77)	1,145	1,054 (78.7)	1,021 (76.2)
nacelle	Control	288	6/21/2022	1/11/2023	9V AC/DC	205 (0)	17,886	0	0	0	78 (0)	0	0 (0)	0 (0)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 11. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Ida Grove, Ida County, Iowa, 2023.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Control	207	6/15/2023	11/1/2023	5V AC/DC	140 (85)	231,013	6,984	773	773	78 (60)	721	403 (52.1)	545 (70.5)
nacelle	Control	210	6/15/2023	11/1/2023	5V AC/DC	140 (99)	105,393	541	399	399	78 (43)	275	151 (37.8)	193 (48.4)**
nacelle	Control	216	6/15/2023	11/1/2023	5V AC/DC	140 (69)	148,742	2,689	722	722	78 (44)	656	448 (62)	445 (61.6)
nacelle	Control	220	6/15/2023	11/1/2023	5V AC/DC	140 (133)	136,061	2,170	1,690	1,689	78 (78)	1,498	1,159 (68.6)	1,202 (71.2)
nacelle	Control	225	6/15/2023	11/3/2023	5V AC/DC	142 (66)	161,992	5,245	631	631	78 (41)	529	347 (55)	330 (52.3)
nacelle	Control	231	6/15/2023	11/3/2023	5V AC/DC	142 (85)	169,411	2,375	871	871	78 (60)	767	539 (61.9)	496 (56.9)
nacelle	Control	240	6/15/2023	11/1/2023	5V AC/DC	140 (97)	203,181	12,605	787	786	78 (45)	678	472 (60.1)	509 (64.8)**
nacelle	Control	245	6/15/2023	11/1/2023	5V AC/DC	140 (110)	273,044	9,165	1,091	1,091	78 (78)	1,006	737 (67.6)	673 (61.7)
nacelle	Control	252	6/15/2023	11/3/2023	9V AC/DC	142 (62)	169,608	4,175	565	563	78 (37)	512	368 (65.4)	341 (60.6)
nacelle	Control	256	6/15/2023	11/1/2023	5V AC/DC	140 (134)	144,026	1,971	388	388	78 (78)	339	199 (51.3)	194 (50)
nacelle	Control	261	6/15/2023	11/1/2023	5V AC/DC	140 (87)	89,480	2,425	159	159	78 (62)	121	98 (61.6)	81 (50.9)
nacelle	Control	273	6/15/2023	11/1/2023	5V AC/DC	140 (134)	78,290	16,584	832	821	78 (78)	765	126 (15.3)	572 (69.7)**
nacelle	Control	278	6/15/2023	11/1/2023	5V AC/DC	140 (134)	129,521	673	483	483	78 (78)	437	304 (62.9)	342 (70.8)
nacelle	Control	280	6/15/2023	11/3/2023	5V AC/DC	142 (136)	237,671	2,730	1,857	1,855	78 (78)	1,620	1,139 (61.4)	1,241 (66.9)
nacelle	Control	288	6/15/2023	11/1/2023	5V AC/DC	140 (118)	97,754	2,256	981	981	78 (78)	858	0 (0)	611 (62.3)**

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 12. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Ivester, Grundy County, Iowa, 2022.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Control	065	6/22/2022	1/25/2023	9V AC/DC	218 (68)	10,597	384	372	330	78 (45)	324	284 (86.1)	246 (74.5)
nacelle	Control	067	6/22/2022	1/25/2023	9V AC/DC	218 (197)	6,682	558	488	448	78 (78)	431	415 (92.6)	325 (72.5)
nacelle	Control	075	6/22/2022	1/25/2023	9V AC/DC	218 (197)	1,378	339	315	252	78 (78)	247	232 (92.1)	187 (74.2)
nacelle	Control	076	6/22/2022	1/25/2023	9V AC/DC	218 (142)	519,342	4,322	705	614	78 (78)	596	449 (73.1)	511 (83.2)
nacelle	Control	077	6/23/2022	1/25/2023	9V AC/DC	217 (200)	7,710	504	496	401	78 (78)	395	351 (87.5)	320 (79.8)
nacelle	Control	078	6/27/2022	1/25/2023	9V AC/DC	213 (63)	1,202	369	366	284	78 (45)	278	266 (93.7)	238 (83.8)
nacelle	Control	082	6/23/2022	1/25/2023	9V AC/DC	217 (217)	8,225	1,276	499	422	78 (78)	397	339 (80.3)	294 (69.7)
nacelle	Control	084	6/27/2022	1/25/2023	9V AC/DC	213 (88)	825	471	424	393	78 (70)	389	361 (91.9)	323 (82.2)
nacelle	Control	085	6/22/2022	1/25/2023	9V AC/DC	218 (217)	3,731	467	412	364	78 (78)	354	294 (80.8)	257 (70.6)
nacelle	Control	087	6/23/2022	1/25/2023	9V AC/DC	217 (213)	6,879	550	540	457	78 (78)	446	300 (65.6)	361 (79)
nacelle	Control	089	6/23/2022	1/25/2023	9V AC/DC	217 (66)	23,634	385	389	365	78 (44)	345	225 (61.6)	239 (65.5)
nacelle	Control	091	6/22/2022	1/24/2023	9V AC/DC	217 (212)	2,122	452	452	379	78 (78)	362	304 (80.2)	259 (68.3)
nacelle	Control	094	6/27/2022	1/25/2023	9V AC/DC	213 (63)	1,089	262	261	229	78 (45)	222	208 (90.8)	152 (66.4)
nacelle	Control	097	6/24/2022	1/24/2023	9V AC/DC	215 (215)	5,968	928	914	812	78 (78)	719	636 (78.3)	596 (73.4)
nacelle	Control	098	6/24/2022	1/24/2023	9V AC/DC	215 (215)	24,160	737	417	363	78 (78)	342	284 (78.2)	253 (69.7)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 13. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Ivester, Grundy County, Iowa, 2023.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%) Measured	Exposed Passes (%) Simulated
nacelle	Control	065	7/5/2023	11/1/2023	5V AC/DC	120 (119)	1,665	606	604	603	78 (78)	576	261 (43.3)	214 (35.5)
nacelle	Control	067	7/5/2023	11/1/2023	5V AC/DC	120 (118)	847	458	460	460	78 (78)	397	262 (57)	231 (50.2)
nacelle	Control	075	7/6/2023	11/1/2023	5V AC/DC	119 (118)	11,320	267	270	270	78 (78)	251	137 (50.7)	116 (43)
nacelle	Control	076	7/6/2023	11/1/2023	5V AC/DC	119 (118)	10,343	2,939	297	297	78 (78)	268	170 (57.2)	170 (57.2)
nacelle	Control	077	7/6/2023	11/1/2023	5V AC/DC	119 (117)	6,067	777	770	770	78 (78)	699	119 (15.5)	543 (70.5)**
nacelle	Control	078	7/6/2023	11/1/2023	5V AC/DC	119 (118)	984	381	384	384	78 (78)	349	257 (66.9)	241 (62.8)
nacelle	Control	082	7/7/2023	11/1/2023	5V AC/DC	118 (117)	18,650	2,696	421	421	78 (78)	394	300 (71.3)	266 (63.2)
nacelle	Control	084	7/7/2023	11/1/2023	5V AC/DC	118 (117)	1,879	453	412	412	78 (78)	386	259 (62.9)	214 (51.9)
nacelle	Control	085	7/7/2023	11/1/2023	5V AC/DC	118 (117)	1,256	387	387	387	78 (78)	350	248 (64.1)	230 (59.4)
nacelle	Control	087	7/7/2023	11/1/2023	5V AC/DC	118 (117)	7,557	451	422	422	78 (78)	396	249 (59)	244 (57.8)
nacelle	Control	089	7/7/2023	11/1/2023	5V AC/DC	118 (117)	1,551	342	342	342	78 (78)	326	201 (58.8)	215 (62.9)
nacelle	Control	091	7/7/2023	11/1/2023	5V AC/DC	118 (117)	1,017	392	393	393	78 (78)	373	234 (59.5)	221 (56.2)
nacelle	Control	094	7/6/2023	11/1/2023	5V AC/DC	119 (118)	1,518	356	356	356	78 (78)	323	209 (58.7)	199 (55.9)
nacelle	Control	097	7/7/2023	11/1/2023	5V AC/DC	118 (117)	2,733	884	875	875	78 (78)	792	556 (63.5)	500 (57.1)
nacelle	Control	098	7/7/2023	11/1/2023	9V AC/DC	118 (117)	1,463	513	513	513	78 (78)	473	299 (58.3)	284 (55.4)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 14. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at North English, Poweshiek County, Iowa, 2022.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Blanket	064	8/9/2022	1/19/2023	9V AC/DC	164 (144)	24,393	463	438	250	54 (54)	244	159 (63.6)	149 (59.6)
nacelle	Blanket	073	8/9/2022	1/19/2023	9V AC/DC	164 (0)	0	0	0	0	54 (1)	0	0 (0)	0 (0)
nacelle	Blanket	080	8/8/2022	1/19/2023	9V AC/DC	165 (165)	17,638	488	482	294	55 (55)	287	134 (45.6)	109 (37.1)
nacelle	Blanket	085	8/8/2022	1/19/2023	9V AC/DC	165 (165)	37,075	504	505	260	55 (55)	255	150 (57.7)	148 (56.9)
nacelle	Blanket	107	8/9/2022	1/19/2023	9V AC/DC	164 (73)	331,681	11,722	404	281	54 (54)	277	176 (62.6)	203 (72.2)
nacelle	Blanket	171	8/9/2022	1/19/2023	9V AC/DC	164 (126)	375,279	3,623	444	274	54 (54)	270	183 (66.8)	198 (72.3)
nacelle	Blanket	190	8/10/2022	1/19/2023	9V AC/DC	163 (144)	149,440	1,596	509	294	53 (53)	286	117 (39.8)	136 (46.3)
nacelle	Blanket	206	8/10/2022	1/17/2023	9V AC/DC	161 (161)	75,606	542	433	300	53 (53)	289	143 (47.7)	155 (51.7)
nacelle	Blanket	242	8/10/2022	1/19/2023	9V AC/DC	163 (114)	90,169	430	391	299	53 (53)	294	138 (46.2)	108 (36.1)
nacelle	Blanket	280	8/4/2022	1/17/2023	9V AC/DC	167 (167)	37,122	504	499	322	59 (59)	314	168 (52.2)	205 (63.7)
nacelle	Blanket	302	8/11/2022	1/17/2023	9V AC/DC	160 (160)	50,908	766	688	408	52 (52)	404	201 (49.3)	218 (53.4)
nacelle	Blanket	305	8/11/2022	1/19/2023	9V AC/DC	162 (62)	51,756	634	610	369	52 (52)	359	157 (42.5)	202 (54.7)
nacelle	Blanket	323	8/16/2022	1/17/2023	9V AC/DC	155 (155)	18,817	353	348	245	47 (47)	236	136 (55.5)	141 (57.6)
nacelle	Blanket	327	8/11/2022	1/19/2023	9V AC/DC	162 (95)	203,282	798	707	452	52 (52)	445	201 (44.5)	214 (47.3)
nacelle	Blanket	349	9/15/2022	1/19/2023	9V AC/DC	127 (127)	103,301	282	27	19	17 (17)	12	11 (57.9)	9 (47.4)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 15. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at North English, Poweshiek County, Iowa, 2023.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%) Measured	Exposed Passes (%) Simulated
nacelle	Blanket	073	6/12/2023	11/7/2023	5V AC/DC	149 (147)	26,814	718	667	423	78 (77)	372	169 (40)	174 (41.1)
nacelle	Blanket	085	6/12/2023	11/7/2023	5V AC/DC	149 (125)	13,322	561	541	427	78 (55)	374	149 (34.9)	175 (41)
nacelle	Blanket	171	6/12/2023	11/7/2023	5V AC/DC	149 (103)	283,374	3,520	796	549	78 (70)	471	221 (40.3)	229 (41.7)
nacelle	Blanket	242	6/12/2023	11/9/2023	5V AC/DC	151 (107)	273,328	1,232	1,007	511	78 (74)	449	248 (48.5)	200 (39.1)
nacelle	Blanket	280	6/12/2023	11/8/2023	5V AC/DC	150 (117)	23,872	619	610	427	78 (78)	386	117 (27.4)	137 (32.1)
nacelle	Blanket	305	6/12/2023	11/8/2023	5V AC/DC	150 (59)	120,149	419	220	143	78 (17)	110	21 (14.7)	29 (20.3)
nacelle	Blanket	327	6/13/2023	11/9/2023	5V AC/DC	150 (149)	13,308	701	681	423	78 (78)	382	114 (27)	139 (32.9)
nacelle	Smart	064	6/12/2023	11/7/2023	5V AC/DC	149 (108)	42,426	570	527	341	78 (75)	302	144 (42.2)	124 (36.4)
nacelle	Smart	080	6/12/2023	11/7/2023	9V AC/DC	149 (139)	14,339	892	812	566	78 (78)	505	179 (31.6)	221 (39)
nacelle	Smart	107	6/12/2023	11/7/2023	5V AC/DC	149 (147)	134,391	2,468	538	339	78 (77)	304	103 (30.4)	119 (35.1)
nacelle	Smart	190	6/12/2023	11/8/2023	5V AC/DC	150 (14)	20,380	150	16	12	78 (0)	0	0 (0)	0 (0)
nacelle	Smart	206	6/12/2023	11/8/2023	5V AC/DC	150 (149)	158,534	830	670	466	78 (78)	412	145 (31.1)	131 (28.1)
nacelle	Smart	302	6/12/2023	11/8/2023	5V AC/DC	150 (149)	61,339	1,019	954	696	78 (78)	614	291 (41.8)	278 (39.9)
nacelle	Smart	323	6/12/2023	11/8/2023	5V AC/DC	150 (149)	24,923	855	824	577	78 (78)	495	125 (21.7)	179 (31)
nacelle	Smart	349	6/12/2023	11/9/2023	5V AC/DC	151 (122)	65,270	761	746	438	78 (78)	379	166 (37.9)	166 (37.9)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 16. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Orient, Adair County, Iowa, 2021.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
ground	Blanket	072	5/6/2021	12/2/2021	Battery/Solar	211 (199)	49,966	21,138	2,668	2,638	78 (78)	2,189	1,393 (52.8)	1,372 (52)
ground	Blanket	177	5/1/2021	12/2/2021	Battery/Solar	216 (208)	42,200	6,456	2,637	2,507	78 (78)	2,050	1,080 (43.1)	1,067 (42.6)
ground	Blanket	189	5/1/2021	12/2/2021	Battery/Solar	216 (216)	32,341	2,987	2,841	2,644	78 (78)	2,194	939 (35.5)	1,153 (43.6)
ground	Blanket	196	5/1/2021	12/2/2021	Battery/Solar	216 (216)	7,928	546	557	552	78 (78)	446	214 (38.8)	224 (40.6)**
ground	Control	025	5/1/2021	12/2/2021	Battery/Solar	216 (198)	31,011	621	158	157	78 (74)	154	138 (87.9)	125 (79.6)
ground	Control	088	5/1/2021	12/2/2021	Battery/Solar	216 (209)	49,479	8,876	4,526	4,504	78 (78)	3,327	2,348 (52.1)	2,954 (65.6)
ground	Control	223	5/1/2021	11/29/2021	Battery/Solar	213 (208)	81,592	13,715	2,950	2,277	78 (78)	2,047	1,447 (63.5)	1,793 (78.7)**
ground	Control	227	5/1/2021	12/2/2021	Battery/Solar	216 (192)	0	0	2,942	2,921	78 (78)	2,359	1,706 (58.4)	1,904 (65.2)
nacelle	Blanket	026	5/28/2021	12/31/2021	Battery/Solar	218 (218)	16,040	1,342	526	517	78 (78)	428	240 (46.4)	229 (44.3)
nacelle	Blanket	072	5/27/2021	11/24/2021	Battery/Solar	182 (181)	24,593	2,933	484	482	78 (78)	401	216 (44.8)	231 (47.9)
nacelle	Blanket	172	6/3/2021	10/16/2021	Battery/Solar	136 (68)	108,068	35,107	212	212	78 (26)	150	70 (33)	72 (34)
nacelle	Blanket	177	6/6/2021	9/27/2021	Battery/Solar	114 (113)	27,899	2,713	706	697	76 (75)	657	365 (52.4)	372 (53.4)
nacelle	Blanket	189	5/29/2021	12/31/2021	Battery/Solar	217 (217)	13,475	1,067	713	673	78 (78)	568	240 (35.7)	261 (38.8)
nacelle	Blanket	196	6/4/2021	11/18/2021	Battery/Solar	168 (166)	62,013	12,556	618	607	78 (78)	538	316 (52.1)	313 (51.6)
nacelle	Blanket	224	6/4/2021	12/31/2021	Battery/Solar	211 (211)	19,878	2,208	742	669	78 (78)	598	253 (37.8)	248 (37.1)
nacelle	Blanket	225	6/5/2021	12/28/2021	Battery/Solar	207 (206)	103,690	31,639	751	719	78 (78)	663	400 (55.6)	395 (54.9)
nacelle	Control	025	5/1/2021	12/31/2021	Battery/Solar	245 (205)	100,897	20,969	631	617	78 (78)	535	506 (82)	477 (77.3)
nacelle	Control	073	6/8/2021	12/31/2021	Battery/Solar	207 (184)	27,382	2,541	1,046	1,039	78 (78)	835	799 (76.9)	777 (74.8)
nacelle	Control	088	6/3/2021	12/31/2021	Battery/Solar	212 (183)	33,845	3,003	744	731	78 (78)	601	524 (71.7)	565 (77.3)
nacelle	Control	166	5/20/2021	12/31/2021	Battery/Solar	226 (226)	19,734	1,738	634	616	78 (78)	566	552 (89.6)	507 (82.3)
nacelle	Control	178	5/28/2021	12/31/2021	Battery/Solar	218 (218)	61,200	37,489	601	597	78 (78)	530	425 (71.2)	463 (77.6)
nacelle	Control	223	6/6/2021	9/3/2021	Battery/Solar	90 (15)	82	5	0	0	52 (8)	0	0 (0)	0 (0)
nacelle	Control	227	6/8/2021	10/13/2021	Battery/Solar	128 (91)	230,018	107,625	809	802	78 (75)	763	634 (79.1)	677 (84.4)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 17. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Orient, Adair County, Iowa, 2022.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
ground	Blanket	088	7/29/2022	1/13/2023	Battery/Solar	169 (169)	98,527	7,600	4,211	2,890	65 (65)	2,854	856 (29.6)	1,957 (67.7)**
ground	Blanket	177	5/26/2022	1/13/2023	Battery/Solar	233 (3)	5	0	0	0	78 (0)	0	0 (0)	0 (0)
ground	Blanket	223	5/26/2022	1/13/2023	Battery/Solar	233 (6)	9	0	0	0	78 (0)	0	0 (0)	0 (0)
ground	Blanket	227	6/29/2022	11/3/2022	Battery/Solar	128 (42)	35,416	4,205	1,063	714	78 (31)	707	526 (73.7)	520 (72.8)
ground	Control	025	6/29/2022	1/11/2023	Battery/Solar	197 (197)	142,807	2,591	2,271	1,803	78 (78)	1,685	1,559 (86.5)	1,552 (86.1)
ground	Smart	072	6/29/2022	1/13/2023	Battery/Solar	199 (198)	107,765	3,799	3,521	3,021	78 (78)	2,854	1,528 (50.6)	1,413 (46.8)
ground	Smart	189	6/29/2022	1/12/2023	Battery/Solar	198 (0)	93	65	0	0	78 (0)	0	0 (0)	0 (0)
ground	Smart	196	6/29/2022	1/12/2023	Battery/Solar	198 (198)	14,354	3,133	3,111	2,551	78 (78)	2,348	1,310 (51.4)	1,386 (54.3)
nacelle	Blanket	026	6/29/2022	1/13/2023	Battery/Solar	199 (0)	0	0	0	0	78 (0)	0	0 (0)	0 (0)
nacelle	Blanket	088	6/29/2022	1/13/2023	Battery/Solar	199 (199)	92,665	2,852	1,431	930	78 (78)	893	318 (34.2)	519 (55.8)**
nacelle	Blanket	177	6/29/2022	1/13/2023	Battery/Solar	199 (199)	18,613	976	696	516	78 (78)	502	278 (53.9)	285 (55.2)
nacelle	Blanket	223	6/29/2022	1/13/2023	Battery/Solar	199 (0)	0	0	0	0	78 (0)	0	0 (0)	0 (0)
nacelle	Blanket	227	6/29/2022	1/12/2023	Battery/Solar	198 (198)	46,215	3,349	736	580	78 (78)	563	365 (62.9)	368 (63.4)
nacelle	Control	025	6/29/2022	1/12/2023	Battery/Solar	198 (196)	18,342	815	527	459	78 (78)	442	420 (91.5)	419 (91.3)
nacelle	Control	165	6/29/2022	1/13/2023	Battery/Solar	199 (0)	0	0	0	0	78 (0)	0	0 (0)	0 (0)
nacelle	Control	178	5/20/2022	1/13/2023	Battery/Solar	239 (185)	11,319	1,004	572	420	78 (78)	394	363 (86.4)	369 (87.9)
nacelle	Control	224	6/29/2022	1/13/2023	Battery/Solar	199 (0)	0	0	0	0	78 (0)	0	0 (0)	0 (0)
nacelle	Control	242	6/29/2022	1/13/2023	Battery/Solar	199 (199)	36,215	802	685	557	78 (78)	526	479 (86)	480 (86.2)
nacelle	Smart	072	6/29/2022	1/12/2023	Battery/Solar	198 (0)	0	0	0	0	78 (0)	0	0 (0)	0 (0)
nacelle	Smart	166	6/29/2022	1/12/2023	Battery/Solar	198 (198)	11,572	574	517	453	78 (78)	437	409 (90.3)	242 (53.4)*
nacelle	Smart	189	6/29/2022	1/13/2023	Battery/Solar	199 (198)	109,833	1,192	666	438	78 (78)	415	232 (53)	211 (48.2)
nacelle	Smart	196	6/29/2022	1/12/2023	Battery/Solar	198 (197)	10,172	850	796	616	78 (77)	588	337 (54.7)	345 (56)
nacelle	Smart	225	6/29/2022	1/13/2023	Battery/Solar	199 (199)	104,868	1,498	884	625	78 (78)	599	299 (47.8)	329 (52.6)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 18. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Orient, Adair County, Iowa, 2023.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Blanket	026	6/7/2023	11/5/2023	5V AC/DC	152 (152)	7,185	821	819	577	78 (78)	521	196 (34)	203 (35.2)
nacelle	Blanket	072	6/9/2023	11/10/2023	5V AC/DC	155 (154)	12,694	827	826	620	78 (78)	554	174 (28.1)	190 (30.6)
nacelle	Blanket	166	6/7/2023	11/5/2023	5V AC/DC	152 (149)	87,328	750	646	467	78 (78)	431	165 (35.3)	170 (36.4)
nacelle	Blanket	177	6/7/2023	11/10/2023	5V AC/DC	157 (152)	8,176	1,074	1,071	687	78 (78)	617	191 (27.8)	241 (35.1)
nacelle	Blanket	196	6/7/2023	11/5/2023	5V AC/DC	152 (150)	40,350	1,025	1,020	742	78 (76)	670	146 (19.7)	304 (41)
nacelle	Blanket	223	6/9/2023	11/5/2023	5V AC/DC	150 (141)	20,882	870	855	470	78 (69)	413	132 (28.1)	137 (29.1)
nacelle	Blanket	225	6/7/2023	11/5/2023	5V AC/DC	152 (150)	9,708	931	930	520	78 (78)	458	120 (23.1)	168 (32.3)
nacelle	Blanket	242	6/9/2023	11/5/2023	5V AC/DC	150 (111)	0	0	293	240	78 (43)	179	100 (41.7)	102 (42.5)
nacelle	Smart	025	6/7/2023	11/5/2023	5V AC/DC	152 (152)	19,793	745	733	531	78 (78)	492	114 (21.5)	182 (34.3)
nacelle	Smart	088	6/9/2023	11/5/2023	5V AC/DC	150 (143)	11,703	3,057	3,045	2,061	78 (76)	1,915	362 (17.6)	480 (23.3)
nacelle	Smart	165	6/7/2023	11/5/2023	5V AC/DC	152 (0)	0	0	0	0	78 (0)	0	0 (0)	0 (0)
nacelle	Smart	178	6/7/2023	11/10/2023	5V AC/DC	157 (156)	38,341	1,133	968	643	78 (78)	584	208 (32.3)	214 (33.3)
nacelle	Smart	189	6/7/2023	11/5/2023	5V AC/DC	152 (109)	11,376	217	216	155	78 (37)	103	58 (37.4)	35 (22.6)
nacelle	Smart	224	6/7/2023	11/5/2023	5V AC/DC	152 (145)	13,351	1,062	1,053	686	78 (78)	632	60 (8.7)	284 (41.4)**
nacelle	Smart	227	6/9/2023	11/5/2023	5V AC/DC	150 (130)	27,365	1,311	1,018	806	78 (78)	745	191 (23.7)	198 (24.6)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 19. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Palo Alto, Palo Alto County, Iowa, 2022.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Control	019	8/2/2022	1/30/2023	9V AC/DC	182 (178)	15,704	249	245	161	61 (61)	160	135 (83.9)	136 (84.5)
nacelle	Control	024	7/27/2022	1/30/2023	9V AC/DC	188 (93)	156,605	192	187	164	67 (67)	163	136 (82.9)	134 (81.7)
nacelle	Control	036	7/27/2022	1/30/2023	9V AC/DC	188 (167)	59,618	253	240	188	67 (67)	180	149 (79.3)	146 (77.7)
nacelle	Control	039	8/1/2022	1/30/2023	9V AC/DC	183 (177)	188,076	505	225	168	62 (62)	163	144 (85.7)	142 (84.5)
nacelle	Control	090	8/1/2022	1/30/2023	9V AC/DC	183 (178)	26,492	201	194	150	62 (62)	148	129 (86)	136 (90.7)
nacelle	Control	101	7/25/2022	1/30/2023	9V AC/DC	190 (85)	144,968	281	222	183	69 (69)	181	173 (94.5)	151 (82.5)
nacelle	Control	117	7/29/2022	1/30/2023	9V AC/DC	186 (182)	127,155	425	248	187	65 (65)	182	145 (77.5)	164 (87.7)
nacelle	Control	131	7/25/2022	1/30/2023	9V AC/DC	190 (87)	27,390	283	280	197	69 (69)	194	167 (84.8)	153 (77.7)
nacelle	Control	136	7/26/2022	1/30/2023	9V AC/DC	189 (185)	28,613	228	225	172	68 (68)	171	156 (90.7)	142 (82.6)
nacelle	Control	151	7/26/2022	1/30/2023	9V AC/DC	189 (150)	11,974	225	211	173	68 (68)	170	162 (93.6)	145 (83.8)
nacelle	Control	156	8/1/2022	1/30/2023	9V AC/DC	183 (87)	96,207	277	246	194	62 (62)	190	171 (88.1)	165 (85.1)
nacelle	Control	176	7/25/2022	12/3/2022	9V AC/DC	132 (129)	11,536	269	262	200	69 (69)	194	173 (86.5)	165 (82.5)
nacelle	Control	180	7/26/2022	1/30/2023	9V AC/DC	189 (134)	220,426	2409	216	170	68 (68)	169	153 (90)	134 (78.8)
nacelle	Control	181	7/29/2022	1/30/2023	9V AC/DC	186 (159)	228,361	821	267	203	65 (65)	200	181 (89.2)	172 (84.7)
nacelle	Control	198	7/28/2022	1/30/2023	9V AC/DC	187 (111)	233,145	382	352	255	66 (66)	255	213 (83.5)	197 (77.3)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 20. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Palo Alto, Palo Alto County, Iowa, 2023.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Control	019	6/17/2023	11/5/2023	9V AC/DC	142 (138)	6,487	514	512	162	78 (75)	142	75 (46.3)	75 (46.3)
nacelle	Control	024	6/17/2023	11/5/2023	5V AC/DC	142 (129)	92,723	156	147	102	78 (73)	94	74 (72.5)	76 (74.5)
nacelle	Control	036	6/17/2023	11/5/2023	5V AC/DC	142 (116)	12,849	21	21	14	78 (63)	0	0 (0)	0 (0)
nacelle	Control	039	6/17/2023	11/5/2023	5V AC/DC	142 (109)	60,652	236	185	136	78 (66)	118	71 (52.2)	71 (52.2)
nacelle	Control	090	6/17/2023	11/5/2023	5V AC/DC	142 (137)	12,718	317	316	86	78 (74)	68	58 (67.4)	54 (62.8)
nacelle	Control	101	6/17/2023	11/5/2023	5V AC/DC	142 (95)	173,675	612	394	345	78 (67)	322	255 (73.9)	242 (70.1)
nacelle	Control	117	6/17/2023	11/5/2023	5V AC/DC	142 (138)	162,562	503	411	254	78 (75)	238	224 (88.2)	222 (87.4)
nacelle	Control	131	6/17/2023	11/5/2023	5V AC/DC	142 (137)	68,560	449	434	358	78 (74)	338	262 (73.2)	215 (60.1)
nacelle	Control	136	6/17/2023	11/5/2023	5V AC/DC	142 (117)	35,204	377	375	298	78 (73)	274	246 (82.6)	213 (71.5)
nacelle	Control	151	6/17/2023	11/5/2023	5V AC/DC	142 (6)	49	3	3	1	78 (0)	0	0 (0)	0 (0)
nacelle	Control	156	6/17/2023	11/5/2023	5V AC/DC	142 (3)	1,235	1	1	1	78 (0)	0	0 (0)	0 (0)
nacelle	Control	176	6/17/2023	11/5/2023	5V AC/DC	142 (98)	20,761	226	227	63	78 (70)	53	53 (84.1)	24 (38.1)
nacelle	Control	180	6/17/2023	11/5/2023	5V AC/DC	142 (18)	12,111	91	5	1	78 (4)	0	0 (0)	0 (0)
nacelle	Control	181	6/17/2023	11/5/2023	5V AC/DC	142 (133)	234,359	1,588	250	85	78 (74)	79	79 (92.9)	75 (88.2)
nacelle	Control	198	6/17/2023	11/5/2023	5V AC/DC	142 (13)	27,032	18	9	2	78 (0)	0	0 (0)	0 (0)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 21. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Plymouth, Plymouth County, Iowa, 2022.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Control	003	8/5/2022	1/31/2023	9V AC/DC	180 (3)	0	0	0	0	58 (3)	0	0 (0)	0 (0)
nacelle	Control	005	7/26/2022	1/31/2023	9V AC/DC	190 (105)	287,314	25,061	320	320	68 (68)	315	300 (93.8)	285 (89.1)
nacelle	Control	006	7/26/2022	1/31/2023	9V AC/DC	190 (190)	190,857	22,393	271	271	68 (68)	265	237 (87.5)	248 (91.5)
nacelle	Control	010	7/26/2022	1/31/2023	9V AC/DC	190 (169)	296,820	14,239	301	301	68 (66)	299	265 (88)	289 (96)
nacelle	Control	013	8/5/2022	1/31/2023	9V AC/DC	180 (163)	235,219	9,032	341	341	58 (58)	338	315 (92.4)	294 (86.2)
nacelle	Control	021	7/26/2022	1/31/2023	9V AC/DC	190 (149)	393,718	13,767	300	299	68 (67)	292	285 (95.3)	264 (88.3)
nacelle	Control	026	7/26/2022	1/31/2023	9V AC/DC	190 (0)	0	0	0	0	68 (1)	0	0 (0)	0 (0)
nacelle	Control	029	7/26/2022	1/31/2023	9V AC/DC	190 (77)	240,525	41,376	436	436	68 (67)	425	401 (92)	382 (87.6)
nacelle	Control	048	7/26/2022	1/31/2023	9V AC/DC	190 (174)	209,719	3,635	441	441	68 (68)	437	422 (95.7)	396 (89.8)
nacelle	Control	059	7/22/2022	1/31/2023	9V AC/DC	194 (109)	258,615	17,975	434	434	72 (72)	424	401 (92.4)	378 (87.1)
nacelle	Control	060	7/22/2022	1/31/2023	9V AC/DC	194 (194)	251,638	1,482	367	367	72 (72)	361	350 (95.4)	329 (89.6)
nacelle	Control	063	7/26/2022	1/31/2023	9V AC/DC	190 (142)	206,009	3,782	355	355	68 (68)	351	339 (95.5)	331 (93.2)
nacelle	Control	070	7/21/2022	1/31/2023	9V AC/DC	195 (195)	259,996	6,102	398	398	73 (73)	391	371 (93.2)	360 (90.5)
nacelle	Control	071	7/21/2022	1/31/2023	9V AC/DC	195 (40)	224,078	21,754	336	336	73 (41)	336	279 (83)	301 (89.6)
nacelle	Control	072	7/21/2022	1/31/2023	9V AC/DC	195 (85)	280,586	28,228	527	527	73 (73)	524	499 (94.7)	452 (85.8)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 22. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Plymouth, Plymouth County, Iowa, 2023.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Control	003	6/17/2023	11/6/2023	5V AC/DC	143 (138)	172,374	8,106	501	501	78 (77)	458	375 (74.9)	363 (72.5)
nacelle	Control	005	6/17/2023	11/6/2023	5V AC/DC	143 (80)	156,544	8,224	346	346	78 (55)	320	271 (78.3)	244 (70.5)
nacelle	Control	006	6/17/2023	11/6/2023	5V AC/DC	143 (48)	105,054	9,560	243	243	78 (24)	216	176 (72.4)	155 (63.8)
nacelle	Control	010	6/17/2023	11/6/2023	5V AC/DC	143 (109)	126,836	4,993	576	576	78 (78)	542	369 (64.1)	329 (57.1)
nacelle	Control	013	6/17/2023	11/6/2023	9V AC/DC	143 (129)	14,805	416	17	17	78 (72)	7	5 (29.4)	5 (29.4)
nacelle	Control	021	6/17/2023	11/6/2023	5V AC/DC	143 (13)	29,235	2,163	9	9	78 (0)	0	0 (0)	0 (0)
nacelle	Control	026	6/17/2023	11/6/2023	5V AC/DC	143 (130)	113,348	22,514	770	770	78 (77)	715	518 (67.3)	496 (64.4)
nacelle	Control	029	6/17/2023	11/6/2023	5V AC/DC	143 (75)	185,699	17,948	455	455	78 (52)	425	363 (79.8)	282 (62)
nacelle	Control	048	6/17/2023	11/6/2023	5V AC/DC	143 (4)	29,749	545	1	1	78 (0)	0	0 (0)	0 (0)
nacelle	Control	059	6/17/2023	11/6/2023	5V AC/DC	143 (136)	29,541	725	147	147	78 (77)	117	91 (61.9)	84 (57.1)
nacelle	Control	060	6/17/2023	11/6/2023	5V AC/DC	143 (13)	177,888	7,834	7	7	78 (0)	0	0 (0)	0 (0)
nacelle	Control	063	6/17/2023	11/6/2023	5V AC/DC	143 (119)	219,077	5,439	599	599	78 (77)	553	416 (69.4)	337 (56.3)
nacelle	Control	070	6/17/2023	11/6/2023	5V AC/DC	143 (38)	89,449	14,799	349	349	78 (22)	322	243 (69.6)	212 (60.7)
nacelle	Control	071	6/17/2023	11/6/2023	9V AC/DC	143 (34)	82,137	9,858	171	171	78 (12)	121	106 (62)	83 (48.5)
nacelle	Control	072	6/17/2023	11/6/2023	5V AC/DC	143 (25)	65,316	3,247	289	289	78 (22)	266	199 (68.9)	186 (64.4)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 23. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Pocahontas Prairie, Pocahontas County, Iowa, 2022.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Control	001	8/18/2022	1/25/2023	9V AC/DC	161 (73)	207,451	178,802	284	264	45 (45)	211	148 (56.1)	194 (73.5)*
nacelle	Control	007	8/18/2022	1/25/2023	9V AC/DC	161 (0)	0	0	0	0	45 (1)	0	0 (0)	0 (0)*
nacelle	Control	008	8/22/2022	1/25/2023	9V AC/DC	157 (157)	127,730	82	71	50	41 (41)	47	41 (82)	46 (92)*
nacelle	Control	012	8/22/2022	1/25/2023	9V AC/DC	157 (57)	170,454	72,652	78	56	41 (41)	54	48 (85.7)	53 (94.6)*
nacelle	Control	013	8/18/2022	1/25/2023	9V AC/DC	161 (161)	118,611	1,527	185	149	45 (45)	148	114 (76.5)	143 (96)*
nacelle	Control	016	8/22/2022	1/25/2023	9V AC/DC	157 (136)	371,295	229	104	79	41 (41)	75	55 (69.6)	75 (94.9)*
nacelle	Control	018	8/22/2022	1/25/2023	9V AC/DC	157 (157)	210,882	2,211	113	94	41 (41)	89	48 (51.1)	74 (78.7)*
nacelle	Control	020	8/22/2022	1/25/2023	9V AC/DC	157 (157)	129,456	1,280	135	112	41 (41)	112	102 (91.1)	111 (99.1)*
nacelle	Control	023	8/22/2022	1/24/2023	9V AC/DC	156 (22)	48,278	4,877	65	49	41 (18)	49	44 (89.8)	49 (100)*
nacelle	Control	030	8/18/2022	1/25/2023	9V AC/DC	161 (74)	211,435	117,644	173	165	45 (45)	165	135 (81.8)	160 (97)*
nacelle	Control	031	8/19/2022	1/25/2023	9V AC/DC	160 (160)	89,518	24,522	348	300	44 (44)	105	95 (31.7)	96 (32)*
nacelle	Control	032	8/19/2022	1/25/2023	9V AC/DC	160 (160)	143,247	849	166	126	44 (44)	123	94 (74.6)	122 (96.8)*
nacelle	Control	034	8/22/2022	1/24/2023	9V AC/DC	156 (156)	323,392	3,802	101	94	41 (41)	91	77 (81.9)	89 (94.7)*
nacelle	Control	035	8/18/2022	1/25/2023	9V AC/DC	161 (161)	319,279	3,646	1,578	1,131	45 (45)	609	540 (47.7)	593 (52.4)*
nacelle	Control	039	9/6/2022	1/24/2023	9V AC/DC	141 (141)	72,788	110	32	28	26 (26)	19	18 (64.3)	18 (64.3)*

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment.

Appendix D Table 24. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring at Pocahontas Prairie, Pocahontas County, Iowa, 2023.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Control	001	6/16/2023	11/4/2023	5V AC/DC	142 (141)	143,390	718	414	413	78 (78)	380	314 (76)	289 (70)
nacelle	Control	007	6/16/2023	11/3/2023	5V AC/DC	141 (54)	99,546	1,668	168	168	78 (25)	143	111 (66.1)	86 (51.2)
nacelle	Control	008	6/16/2023	11/4/2023	5V AC/DC	142 (79)	155,580	68	58	58	78 (16)	34	26 (44.8)	28 (48.3)
nacelle	Control	012	6/16/2023	11/4/2023	5V AC/DC	142 (51)	43,911	760	186	185	78 (22)	166	128 (69.2)	127 (68.6)
nacelle	Control	013	6/16/2023	11/4/2023	5V AC/DC	142 (48)	93,087	1,355	212	210	78 (19)	187	181 (86.2)	181 (86.2)
nacelle	Control	016	6/16/2023	11/3/2023	5V AC/DC	141 (46)	105,914	152	108	108	78 (17)	94	90 (83.3)	84 (77.8)
nacelle	Control	018	6/16/2023	11/4/2023	5V AC/DC	142 (141)	266,629	1,195	421	418	78 (78)	383	343 (82.1)	330 (78.9)
nacelle	Control	020	6/16/2023	11/4/2023	5V AC/DC	142 (141)	43,258	828	256	255	78 (78)	237	200 (78.4)	187 (73.3)
nacelle	Control	023	6/16/2023	11/4/2023	5V AC/DC	142 (79)	173,362	118,351	235	235	78 (50)	224	192 (81.7)	181 (77)
nacelle	Control	030	6/16/2023	11/4/2023	5V AC/DC	142 (84)	199,889	111,311	353	353	78 (55)	335	287 (81.3)	258 (73.1)
nacelle	Control	031	6/16/2023	11/4/2023	5V AC/DC	142 (25)	42,017	630	18	18	78 (0)	0	0 (0)	0 (0)
nacelle	Control	032	6/16/2023	11/4/2023	5V AC/DC	142 (135)	187,087	1,467	380	380	78 (72)	342	298 (78.4)	274 (72.1)
nacelle	Control	034	6/16/2023	11/3/2023	5V AC/DC	141 (90)	221,607	9,244	379	379	78 (61)	360	318 (83.9)	276 (72.8)
nacelle	Control	035	6/16/2023	11/4/2023	5V AC/DC	142 (122)	173,195	2,980	371	371	78 (78)	346	323 (87.1)	316 (85.2)
nacelle	Control	039	6/16/2023	11/3/2023	5V AC/DC	141 (57)	165,937	160,248	149	149	78 (28)	126	109 (73.2)	98 (65.8)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment

Appendix D Table 25. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring Prairie, Mahaska County, Iowa, 2022.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Blanket	003	8/5/2022	1/19/2023	9V AC/DC	168 (166)	13,433	923	919	688	58 (58)	673	311 (45.2)	315 (45.8)
nacelle	Blanket	009	8/8/2022	1/20/2023	9V AC/DC	166 (35)	5,801	615	616	484	55 (36)	484	152 (31.4)	173 (35.7)
nacelle	Blanket	015	9/15/2022	1/20/2023	9V AC/DC	128 (0)	234,768	1	0	0	17 (1)	0	0 (0)	0 (0)
nacelle	Blanket	019	9/15/2022	1/20/2023	9V AC/DC	128 (85)	24,539	70	71	67	17 (17)	56	36 (53.7)	50 (74.6)
nacelle	Blanket	022	8/15/2022	1/20/2023	9V AC/DC	159 (28)	2,914	437	437	347	48 (29)	347	99 (28.5)	167 (48.1)
nacelle	Blanket	037	8/8/2022	1/20/2023	9V AC/DC	166 (35)	17,562	474	467	336	55 (36)	336	202 (60.1)	188 (56)
nacelle	Blanket	039	9/15/2022	1/19/2023	9V AC/DC	127 (124)	22,355	504	495	492	17 (17)	459	450 (91.5)	434 (88.2)
nacelle	Blanket	042	8/4/2022	1/20/2023	9V AC/DC	170 (40)	3,922	212	211	109	59 (10)	109	52 (47.7)	65 (59.6)
nacelle	Blanket	044	9/15/2022	1/20/2023	9V AC/DC	128 (89)	12,119	37	37	33	17 (17)	19	19 (57.6)	18 (54.5)
nacelle	Blanket	051	8/15/2022	1/20/2023	9V AC/DC	159 (18)	3,615	462	462	337	48 (19)	337	144 (42.7)	171 (50.7)
nacelle	Blanket	055	8/15/2022	1/20/2023	9V AC/DC	159 (8)	516	319	321	184	48 (9)	184	75 (40.8)	61 (33.2)
nacelle	Blanket	070	8/15/2022	1/20/2023	9V AC/DC	159 (115)	220,450	119,521	370	244	48 (17)	243	127 (52)	130 (53.3)
nacelle	Blanket	072	8/15/2022	1/20/2023	9V AC/DC	159 (134)	28,211	663	662	431	48 (48)	406	183 (42.5)	217 (50.3)
nacelle	Blanket	082	8/15/2022	1/20/2023	9V AC/DC	159 (159)	30,560	2,543	586	470	48 (48)	444	230 (48.9)	279 (59.4)
nacelle	Blanket	085	8/15/2022	1/20/2023	9V AC/DC	159 (134)	13,953	565	554	445	48 (48)	434	181 (40.7)	217 (48.8)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment

Appendix D Table 26. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring Prairie, Mahaska County, Iowa, 2023.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Blanket	003	6/13/2023	11/7/2023	9V AC/DC	148 (144)	6,492	1,335	1,191	1,176	78 (78)	1,048	369 (31.4)	434 (36.9)
nacelle	Blanket	009	6/13/2023	11/7/2023	5V AC/DC	148 (144)	4,267	1,276	1,119	1,097	78 (78)	979	329 (30)	355 (32.4)
nacelle	Blanket	022	6/13/2023	11/7/2023	9V AC/DC	148 (26)	2,644	72	47	46	78 (0)	0	0 (0)	0 (0)
nacelle	Blanket	042	6/13/2023	11/8/2023	5V AC/DC	149 (145)	40,438	1,138	897	893	78 (78)	803	260 (29.1)	257 (28.8)
nacelle	Blanket	044	6/13/2023	11/8/2023	5V AC/DC	149 (142)	17,922	1,194	790	783	78 (76)	666	237 (30.3)	222 (28.4)
nacelle	Blanket	055	6/13/2023	11/9/2023	5V AC/DC	150 (145)	14,515	2,059	1,215	1,174	78 (78)	1,027	358 (30.5)	394 (33.6)
nacelle	Blanket	072	6/13/2023	11/9/2023	5V AC/DC	150 (130)	35,312	14,483	1,121	1,085	78 (78)	961	374 (34.5)	385 (35.5)
nacelle	Blanket	085	6/13/2023	11/9/2023	5V AC/DC	150 (93)	13,048	1,149	844	827	78 (61)	748	240 (29)	264 (31.9)
nacelle	Smart	015	6/13/2023	11/7/2023	5V AC/DC	148 (143)	6,713	961	829	819	78 (78)	742	217 (26.5)	233 (28.4)
nacelle	Smart	019	6/13/2023	11/7/2023	5V AC/DC	148 (144)	4,078	1,068	986	971	78 (78)	867	233 (24)	286 (29.5)
nacelle	Smart	037	6/13/2023	11/8/2023	5V AC/DC	149 (68)	19,531	947	549	529	78 (36)	449	98 (18.5)	153 (28.9)
nacelle	Smart	039	6/13/2023	11/8/2023	5V AC/DC	149 (8)	627	20	3	3	78 (0)	0	0 (0)	0 (0)
nacelle	Smart	051	6/13/2023	11/8/2023	5V AC/DC	149 (140)	23,487	8,075	1,220	1,195	78 (73)	1,116	353 (29.5)	430 (36)
nacelle	Smart	070	6/13/2023	11/9/2023	5V AC/DC	150 (128)	144,231	110,292	1,218	1,193	78 (78)	1,080	363 (30.4)	405 (33.9)
nacelle	Smart	082	6/13/2023	11/9/2023	5V AC/DC	150 (146)	55,899	1,323	1,098	1,071	78 (78)	939	386 (36)	407 (38)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment

Appendix D Table 27. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring Southern Hills, Adair, Union, and Adams Counties, Iowa, 2022.

Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Blanket	001	8/10/2022	1/26/2023	9V AC/DC	170 (0)	686	0	0	0	53 (1)	0	0 (0)	0 (0)
nacelle	Blanket	007	8/16/2022	1/26/2023	9V AC/DC	164 (164)	89,424	1,441	281	278	47 (47)	276	171 (61.5)	173 (62.2)
nacelle	Blanket	009	8/16/2022	1/26/2023	9V AC/DC	164 (65)	18,019	415	349	344	47 (47)	340	171 (49.7)	183 (53.2)
nacelle	Blanket	012	8/10/2022	1/26/2023	9V AC/DC	170 (110)	229,763	517	353	339	53 (53)	337	198 (58.4)	208 (61.4)
nacelle	Blanket	017	8/11/2022	1/26/2023	9V AC/DC	169 (144)	382,486	1,601	487	470	52 (52)	463	142 (30.2)	255 (54.3)
nacelle	Blanket	019	8/11/2022	1/26/2023	9V AC/DC	169 (81)	56,393	633	635	610	52 (52)	585	369 (60.5)	395 (64.8)
nacelle	Blanket	029	8/16/2022	1/26/2023	9V AC/DC	164 (154)	66,842	375	259	251	47 (47)	237	140 (55.8)	137 (54.6)
nacelle	Blanket	030	8/18/2022	1/26/2023	9V AC/DC	162 (127)	38,297	521	292	262	45 (45)	256	137 (52.3)	163 (62.2)
nacelle	Blanket	031	8/18/2022	1/26/2023	9V AC/DC	162 (152)	70,761	331	255	247	45 (45)	234	139 (56.3)	149 (60.3)
nacelle	Blanket	040	8/11/2022	1/26/2023	9V AC/DC	169 (140)	385,715	10,415	631	606	52 (52)	593	299 (49.3)	304 (50.2)
nacelle	Blanket	043	8/11/2022	1/26/2023	9V AC/DC	169 (159)	37,786	696	583	569	52 (52)	562	252 (44.3)	281 (49.4)
nacelle	Blanket	059	8/18/2022	1/26/2023	9V AC/DC	162 (138)	174,617	506	379	358	45 (45)	351	174 (48.6)	169 (47.2)
nacelle	Blanket	077	8/11/2022	1/26/2023	9V AC/DC	169 (2)	5,115	4,709	70	70	52 (3)	70	40 (57.1)	41 (58.6)
nacelle	Blanket	221	8/10/2022	1/26/2023	9V AC/DC	170 (159)	222,901	491	466	448	53 (53)	438	220 (49.1)	224 (50)
nacelle	Blanket	253	8/12/2022	1/26/2023	9V AC/DC	168 (167)	304,236	1,567	315	311	51 (50)	305	136 (43.7)	156 (50.2)

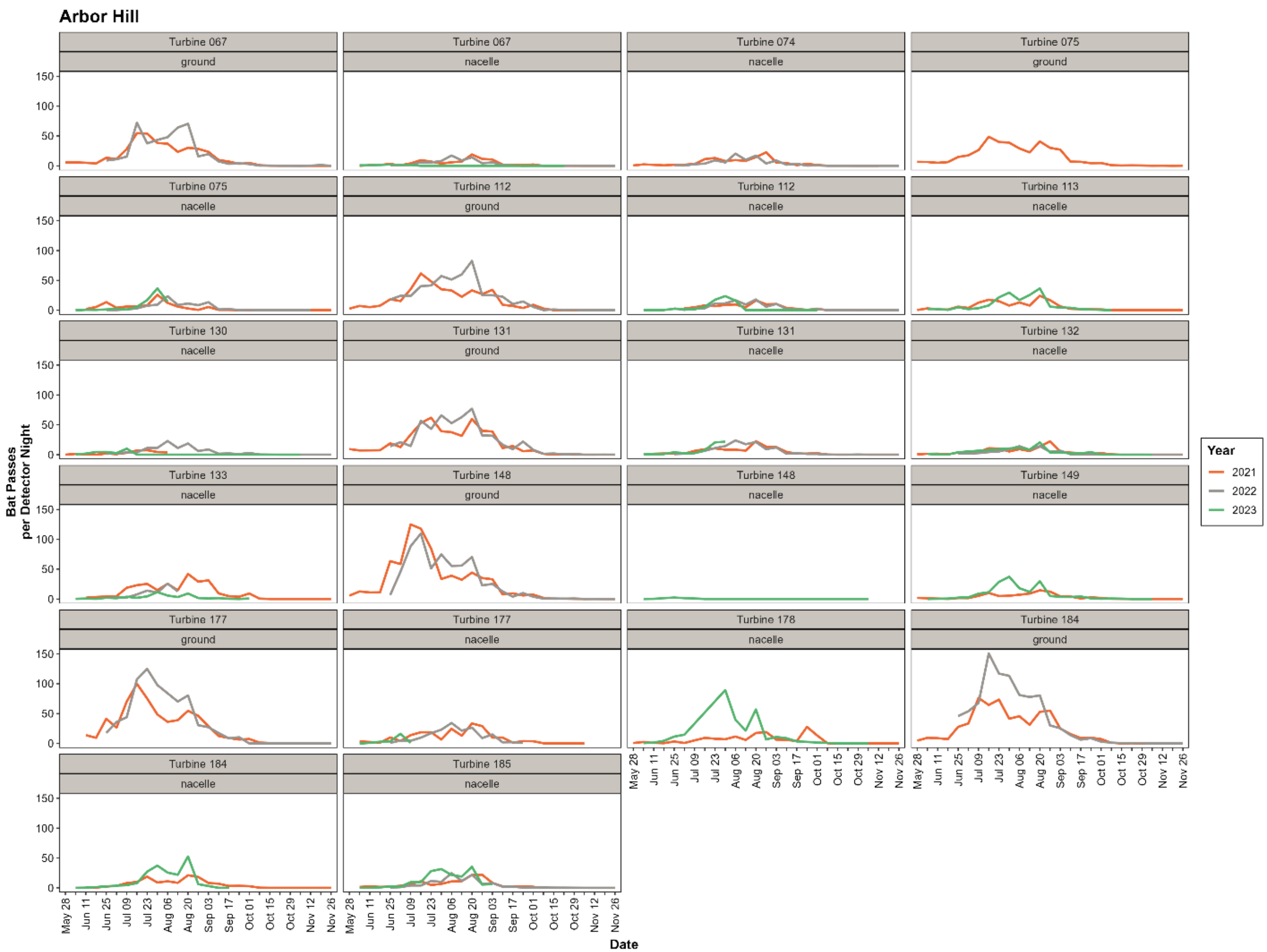
*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment

Appendix D Table 28. Bat data availability and acoustic exposure by position, treatment, and turbine during acoustic monitoring Southern Hills, Adair, Union, and Adams Counties, Iowa, 2023.

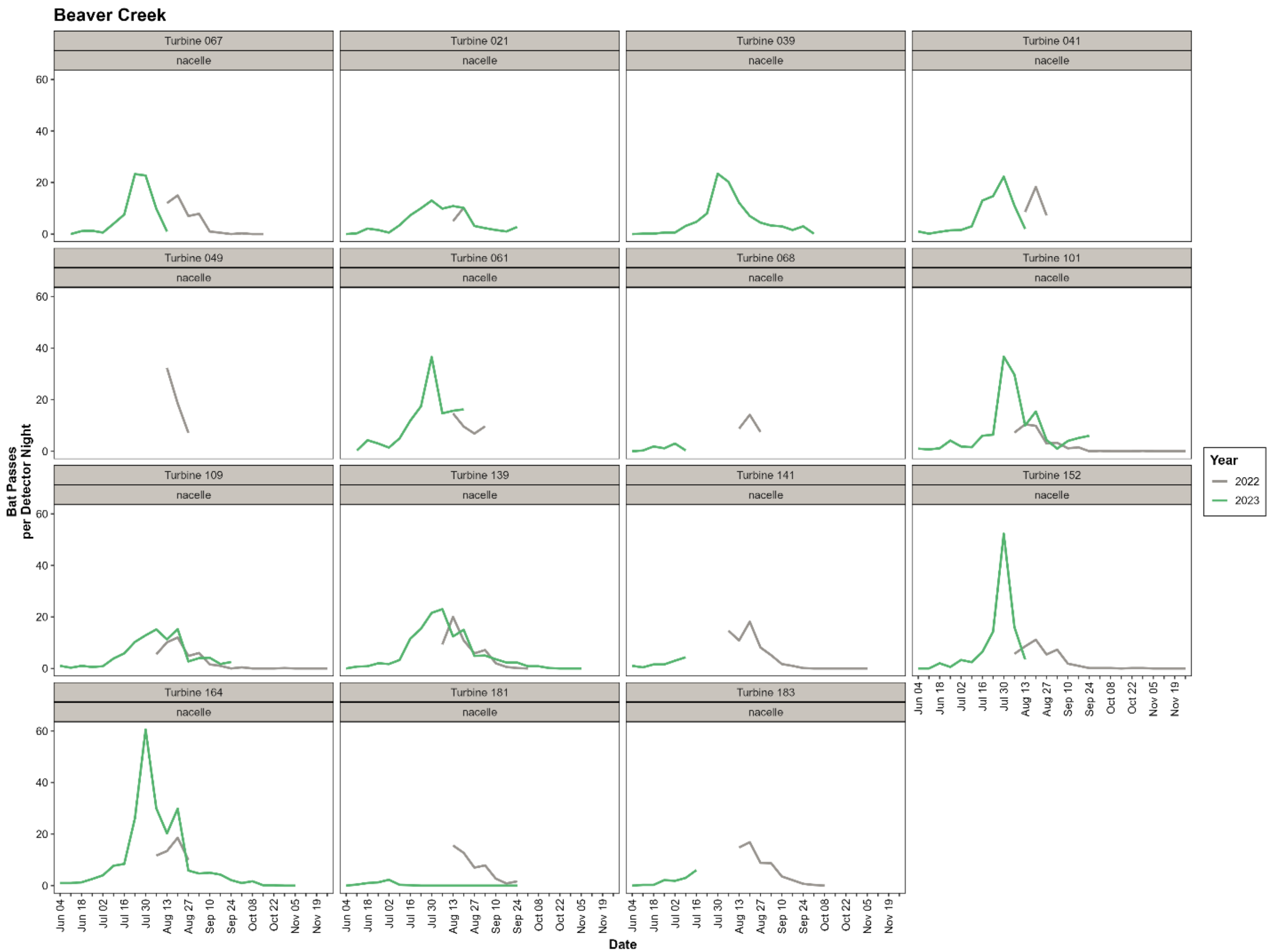
Detector Position	Assigned Treatment	Turbine	Deployment	Demobilization	Configuration	Attempted (Successful) Nights	Total Files (in id.csv)	KPro Passes (species ID + NoID)	Bat Passes (manually vetted)	Bat Passes with WX/Ops	15 July–30 September			
											Attempted (Successful) Nights	Bat Passes with WX/Ops	Exposed Passes (%)	
													Measured	Simulated
nacelle	Blanket	001	6/11/2023	11/7/2023	5V AC/DC	150 (111)	213,059	40,942	774	774	78 (76)	728	191 (24.7)	233 (30.1)
nacelle	Blanket	007	6/11/2023	11/7/2023	9V AC/DC	150 (29)	7,905	26	24	24	78 (0)	0	0 (0)	0 (0)
nacelle	Blanket	017	6/11/2023	11/7/2023	5V AC/DC	150 (45)	63,055	438	265	265	78 (11)	180	73 (27.5)	56 (21.1)
nacelle	Blanket	030	6/11/2023	11/7/2023	5V AC/DC	150 (0)	0	0	0	0	78 (0)	0	0 (0)	0 (0)
nacelle	Blanket	031	6/11/2023	11/7/2023	5V AC/DC	150 (106)	69,344	934	925	925	78 (72)	842	260 (28.1)	283 (30.6)
nacelle	Blanket	040	6/11/2023	11/7/2023	5V AC/DC	150 (39)	74,771	1,929	541	510	78 (13)	221	75 (14.7)	53 (10.4)
nacelle	Blanket	077	6/11/2023	11/7/2023	5V AC/DC	150 (48)	99,670	19,205	254	224	78 (14)	154	39 (17.4)	33 (14.7)
nacelle	Blanket	253	6/11/2023	11/7/2023	5V AC/DC	150 (147)	194,836	1,651	956	956	78 (76)	892	258 (27)	274 (28.7)
nacelle	Smart	009	6/11/2023	11/7/2023	5V AC/DC	150 (134)	14,410	852	807	807	78 (76)	730	241 (29.9)	249 (30.9)
nacelle	Smart	012	6/11/2023	11/7/2023	5V AC/DC	150 (87)	106,769	822	704	704	78 (53)	644	228 (32.4)	238 (33.8)
nacelle	Smart	019	6/11/2023	11/7/2023	5V AC/DC	150 (146)	6,667	711	713	713	78 (75)	625	236 (33.1)	226 (31.7)
nacelle	Smart	029	6/11/2023	11/7/2023	5V AC/DC	150 (147)	15,156	755	724	722	78 (76)	668	269 (37.3)	270 (37.4)
nacelle	Smart	043	6/11/2023	11/7/2023	5V AC/DC	150 (147)	130,105	1,076	1,058	1,058	78 (76)	950	287 (27.1)	290 (27.4)
nacelle	Smart	059	6/11/2023	11/7/2023	5V AC/DC	150 (146)	96,634	905	888	886	78 (75)	786	306 (34.5)	268 (30.2)
nacelle	Smart	221	6/11/2023	11/7/2023	5V AC/DC	150 (85)	72,468	825	800	800	78 (51)	747	136 (17)	141 (17.6)

*=Treatment reassigned based on review of turbine rotor speed versus wind speed.
**=Turbine non-operational for extended periods for reasons other than curtailment

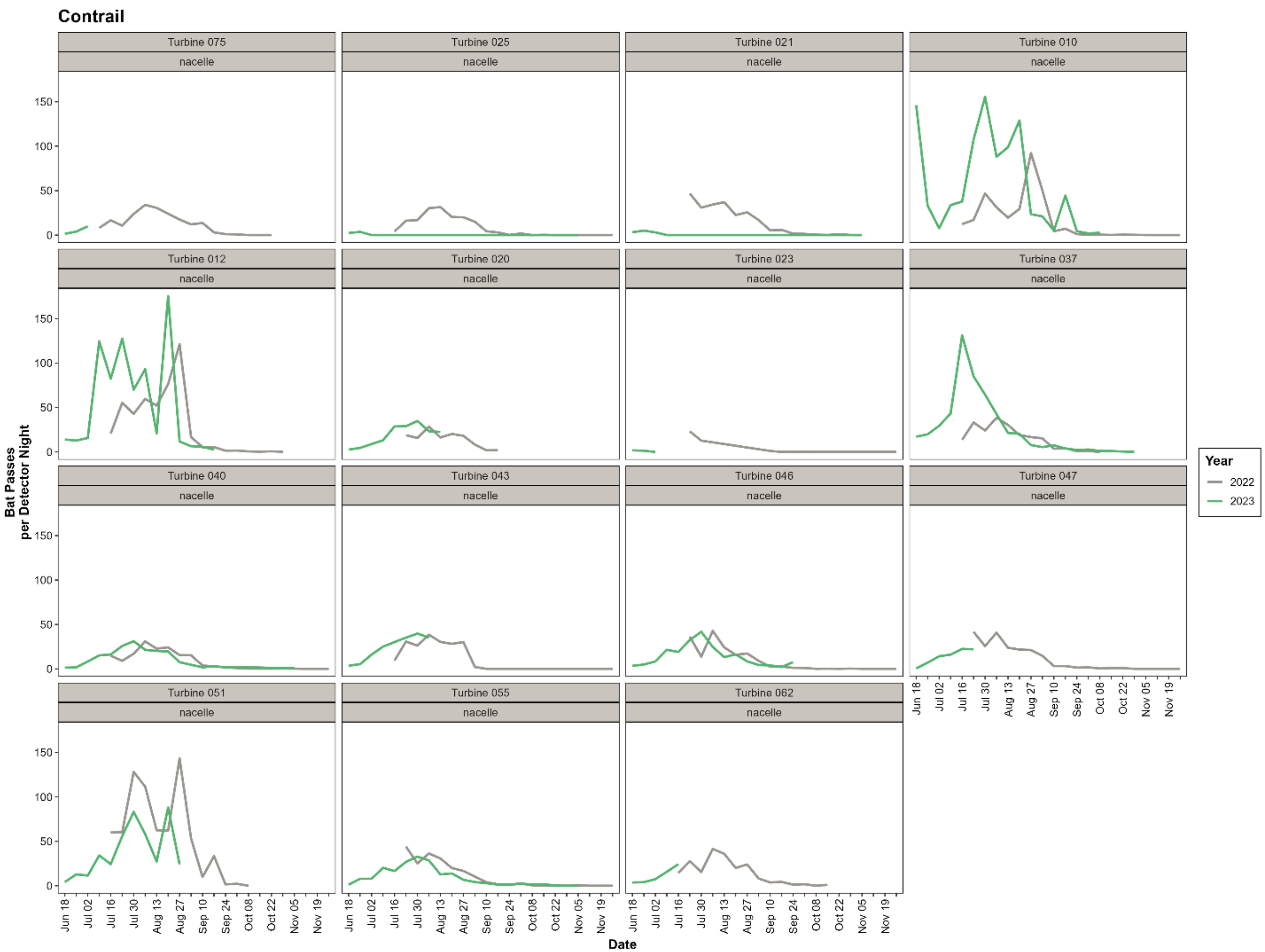
Appendix E



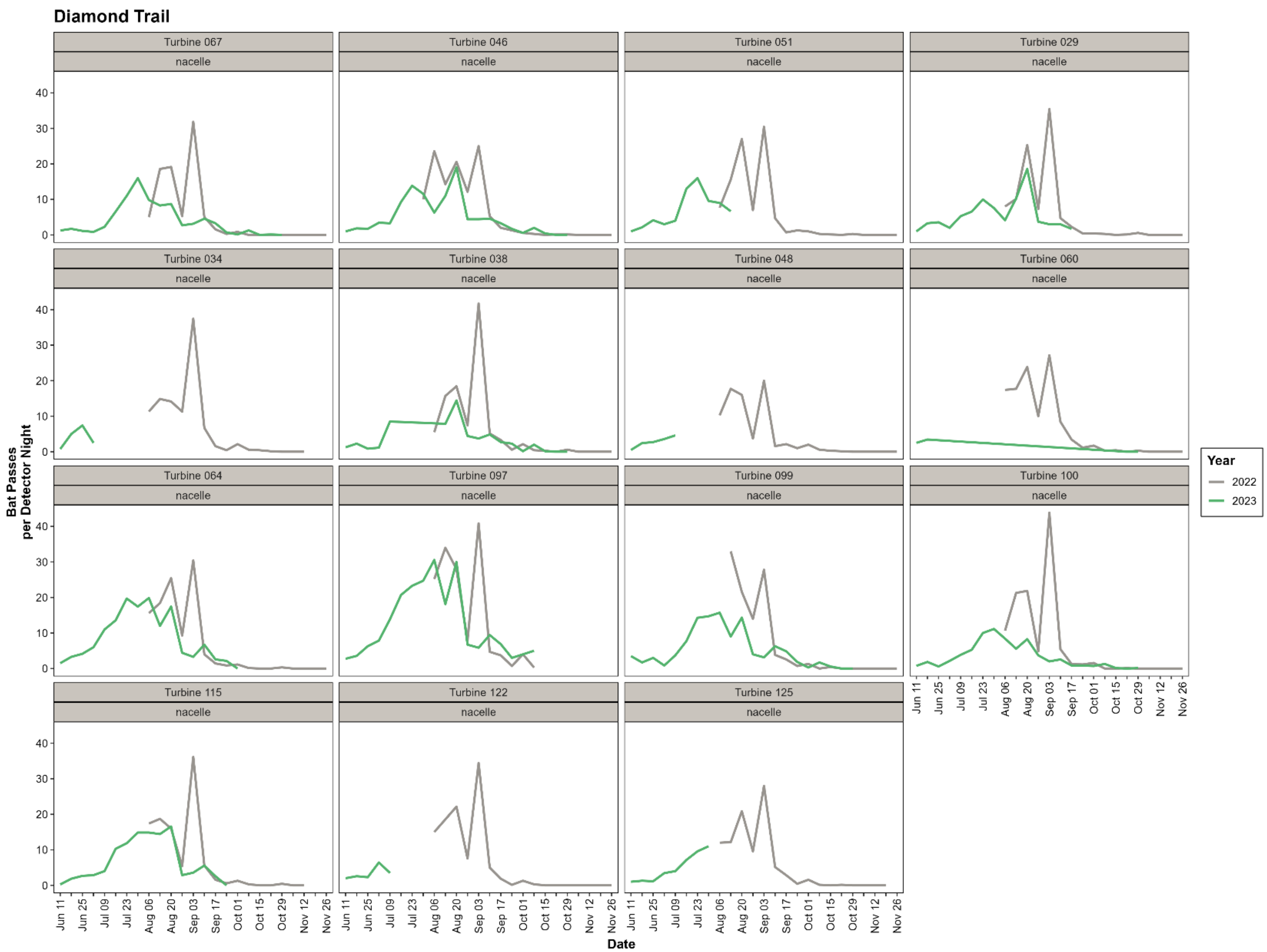
Appendix E Figure 1. Weekly distribution of bat passes by year recorded at nacelle-mounted and ground-level detectors at Arbor Hill, Adair County, Iowa, 2021–2023.



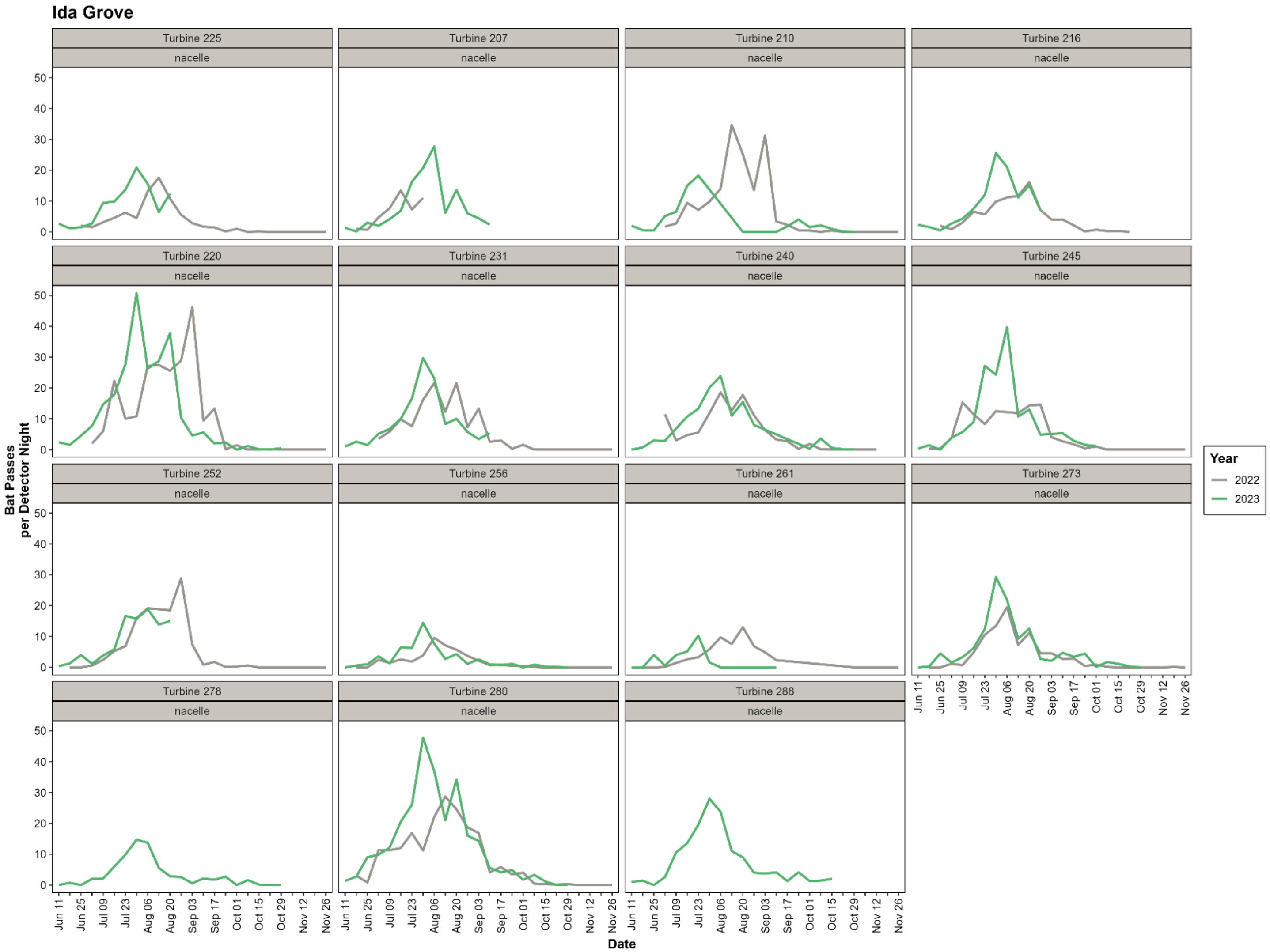
Appendix E Figure 2. Weekly distribution of bat passes by year recorded at nacelle-mounted detectors at Beaver Creek I and II, Boone and Greene Counties, Iowa, 2022–2023.



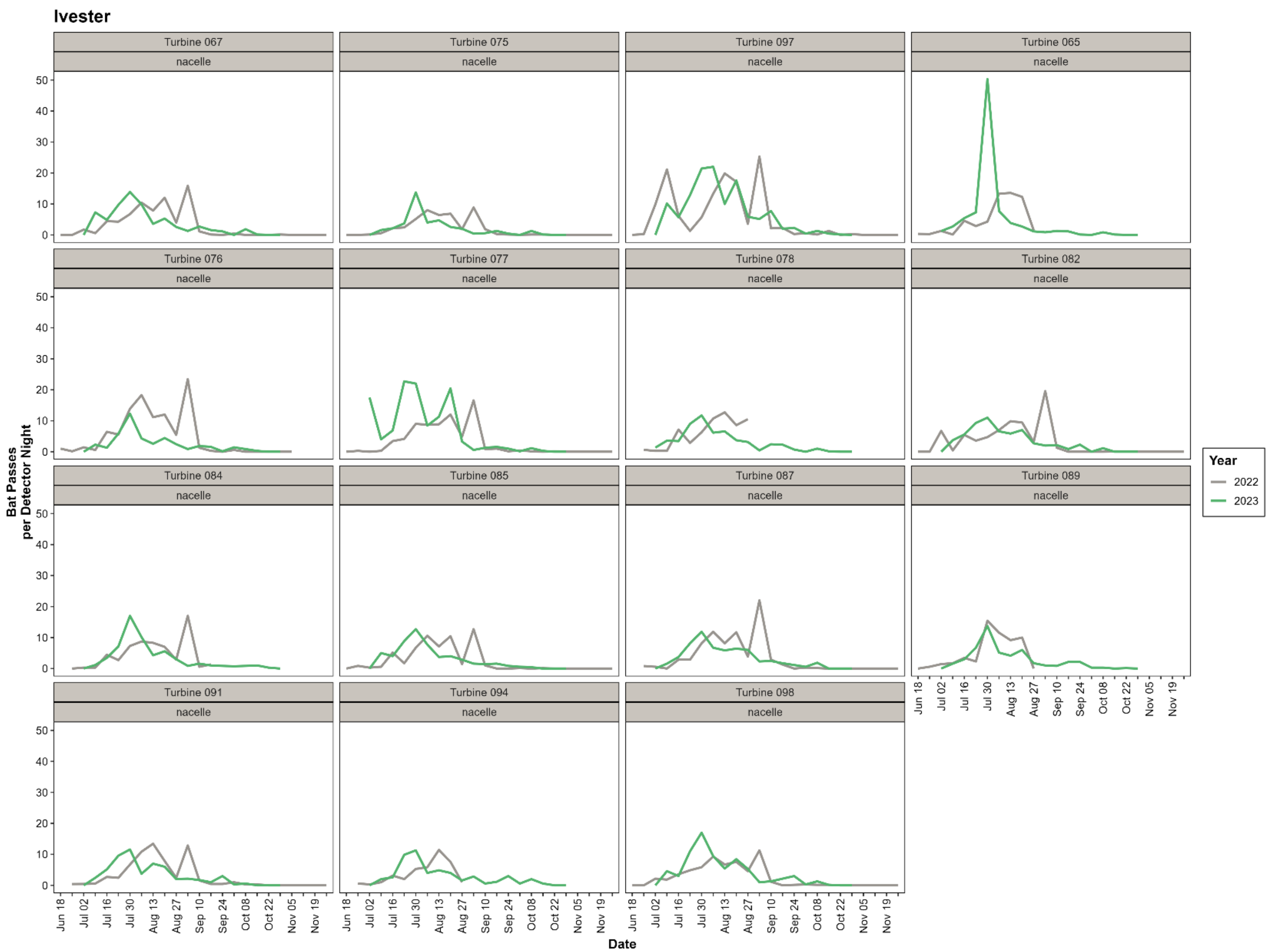
Appendix E Figure 3. Weekly distribution of bat passes by year recorded at nacelle-mounted detectors at Contrail, Taylor County, Iowa, 2022–2023.



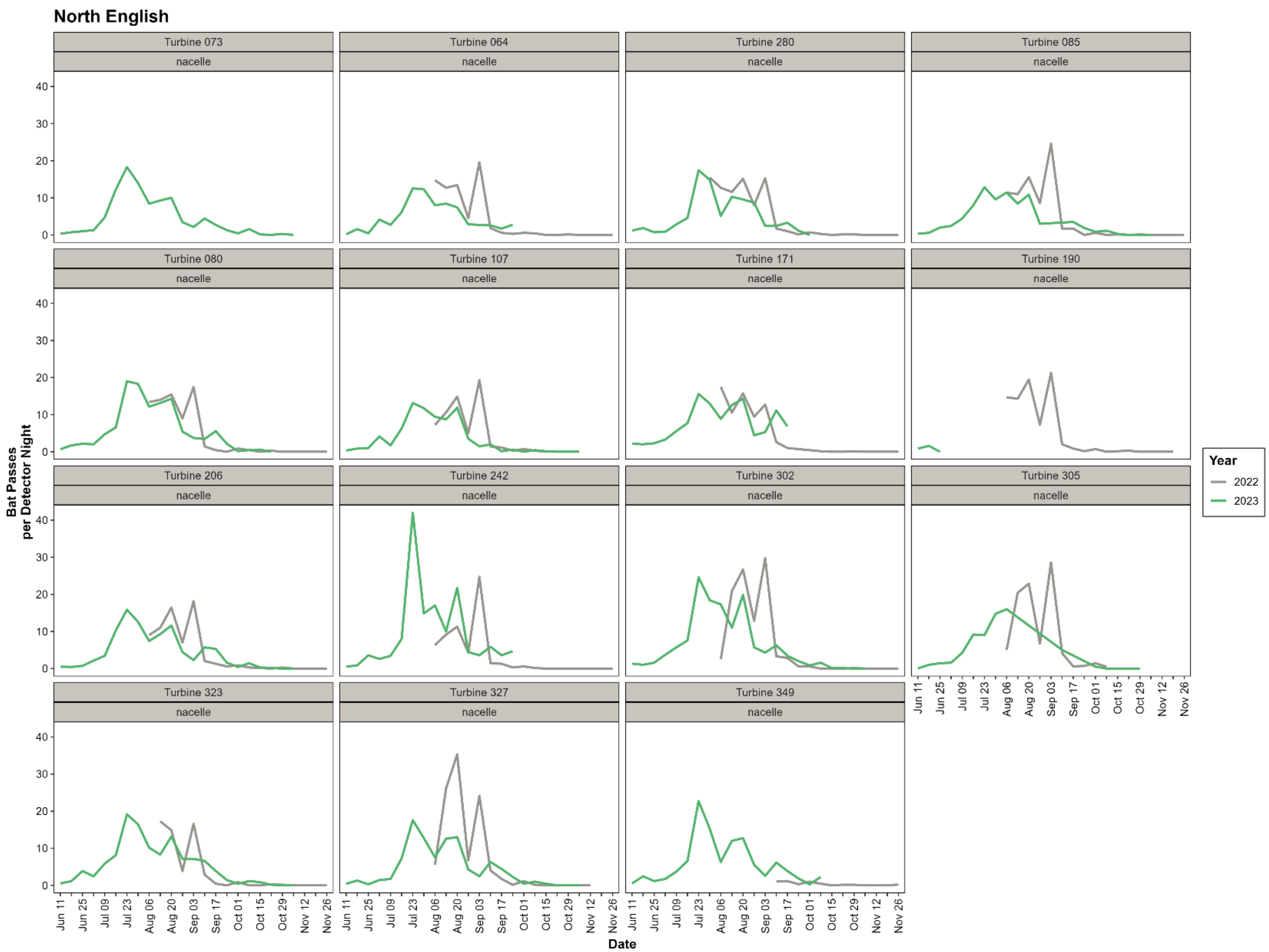
Appendix E Figure 4. Weekly distribution of bat passes by year recorded at nacelle-mounted detectors at Diamond Trail, Iowa County, Iowa, 2022–2023.



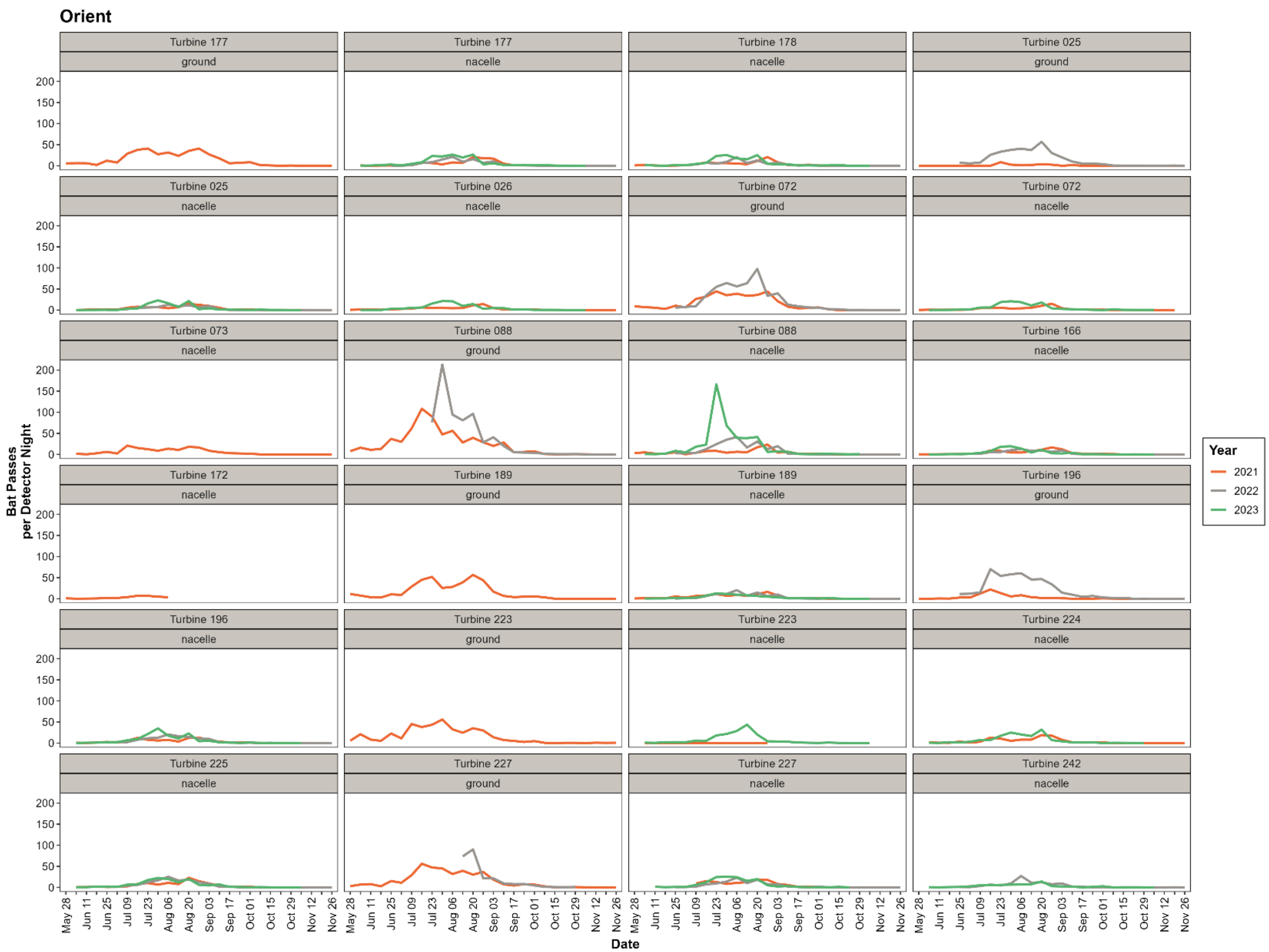
Appendix E Figure 5. Weekly distribution of bat passes by year recorded at nacelle-mounted detectors at Ida Grove II, Ida County, Iowa, 2022–2023



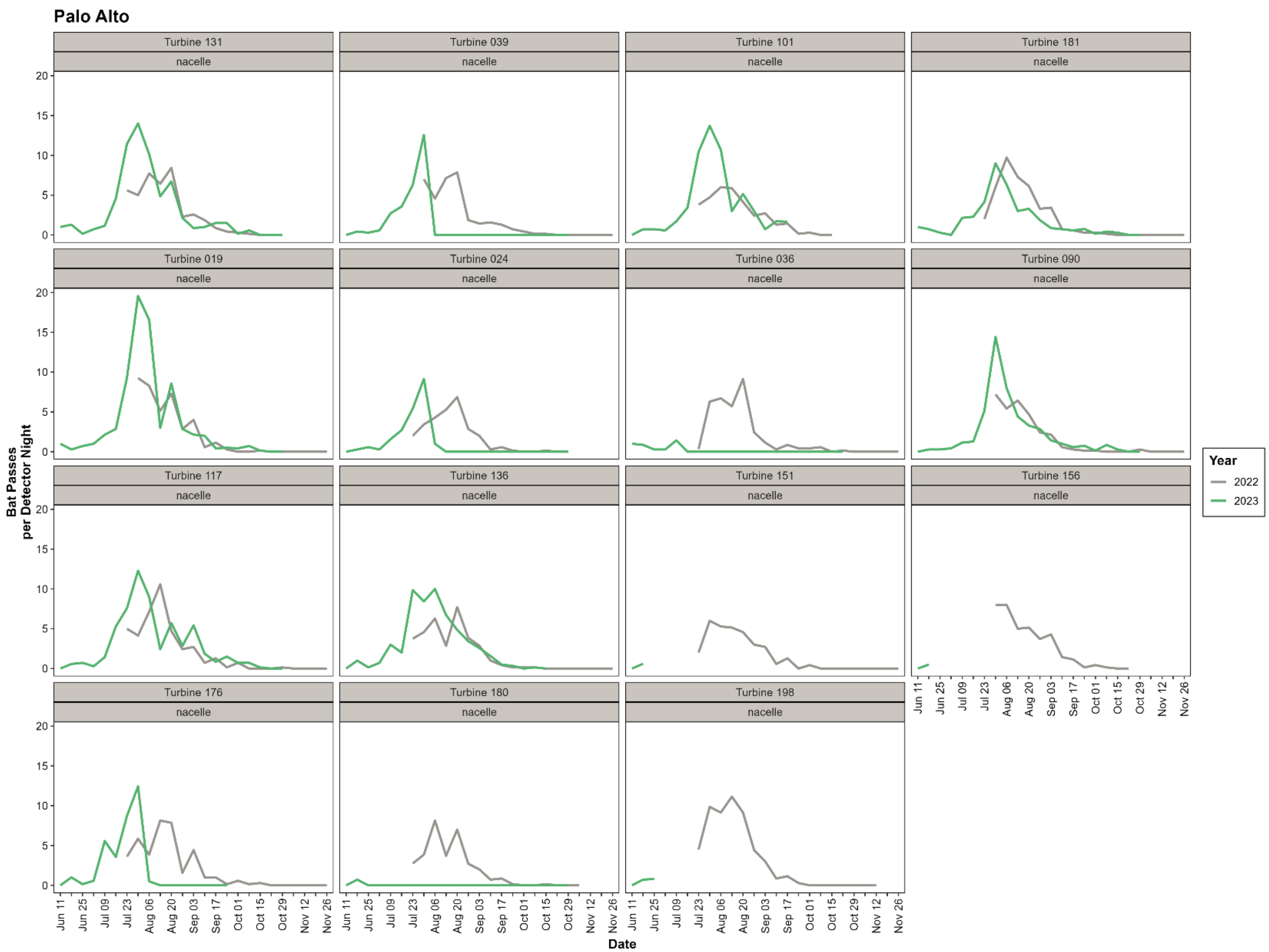
Appendix E Figure 6. Weekly distribution of bat passes by year recorded at nacelle-mounted detectors at Ivester, Grundy County, Iowa, 2022–2023.



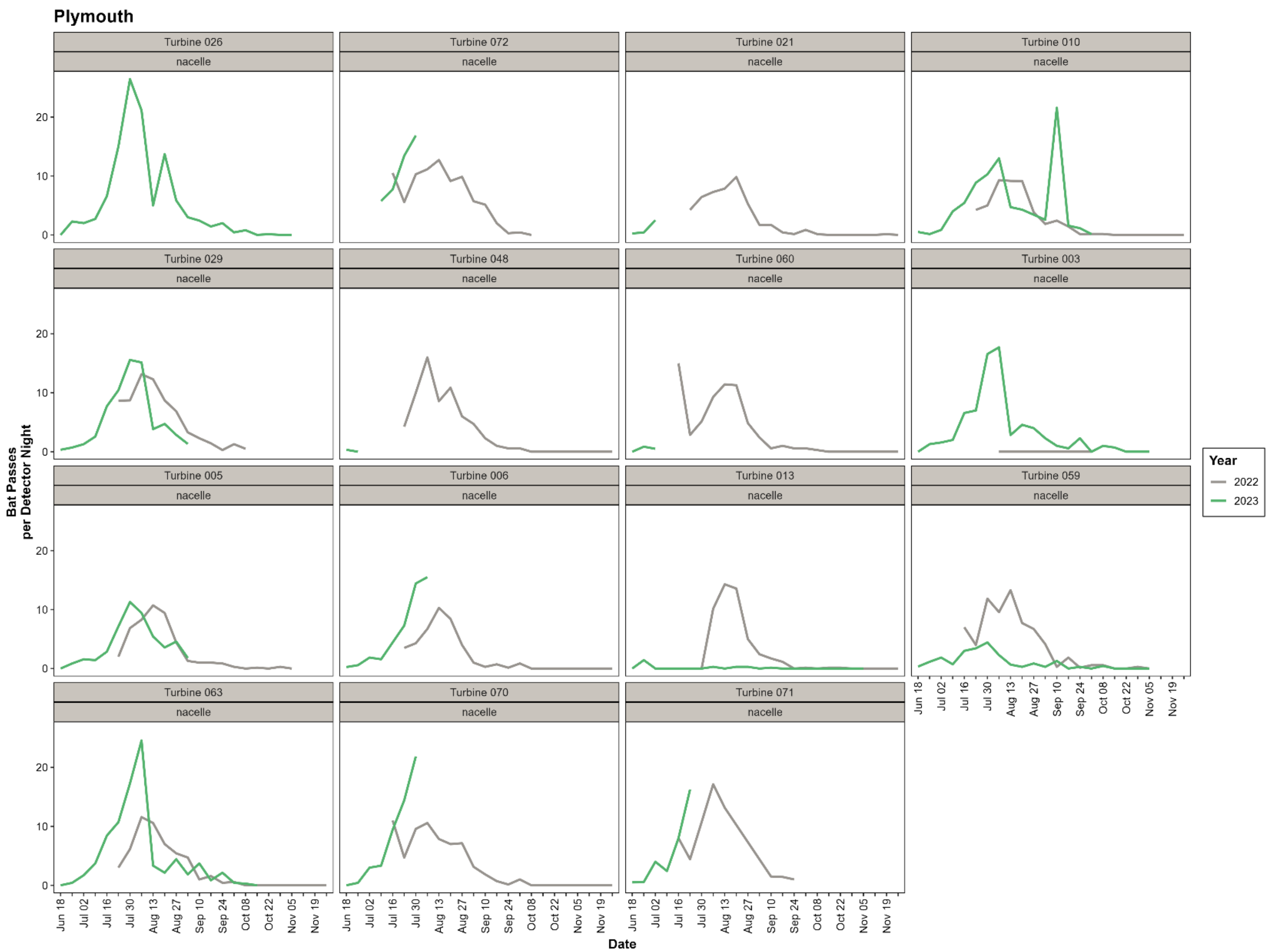
Appendix E Figure 7. Weekly distribution of bat passes by year recorded at nacelle-mounted detectors at North English, Poweshiek County, Iowa, 2022–2023.



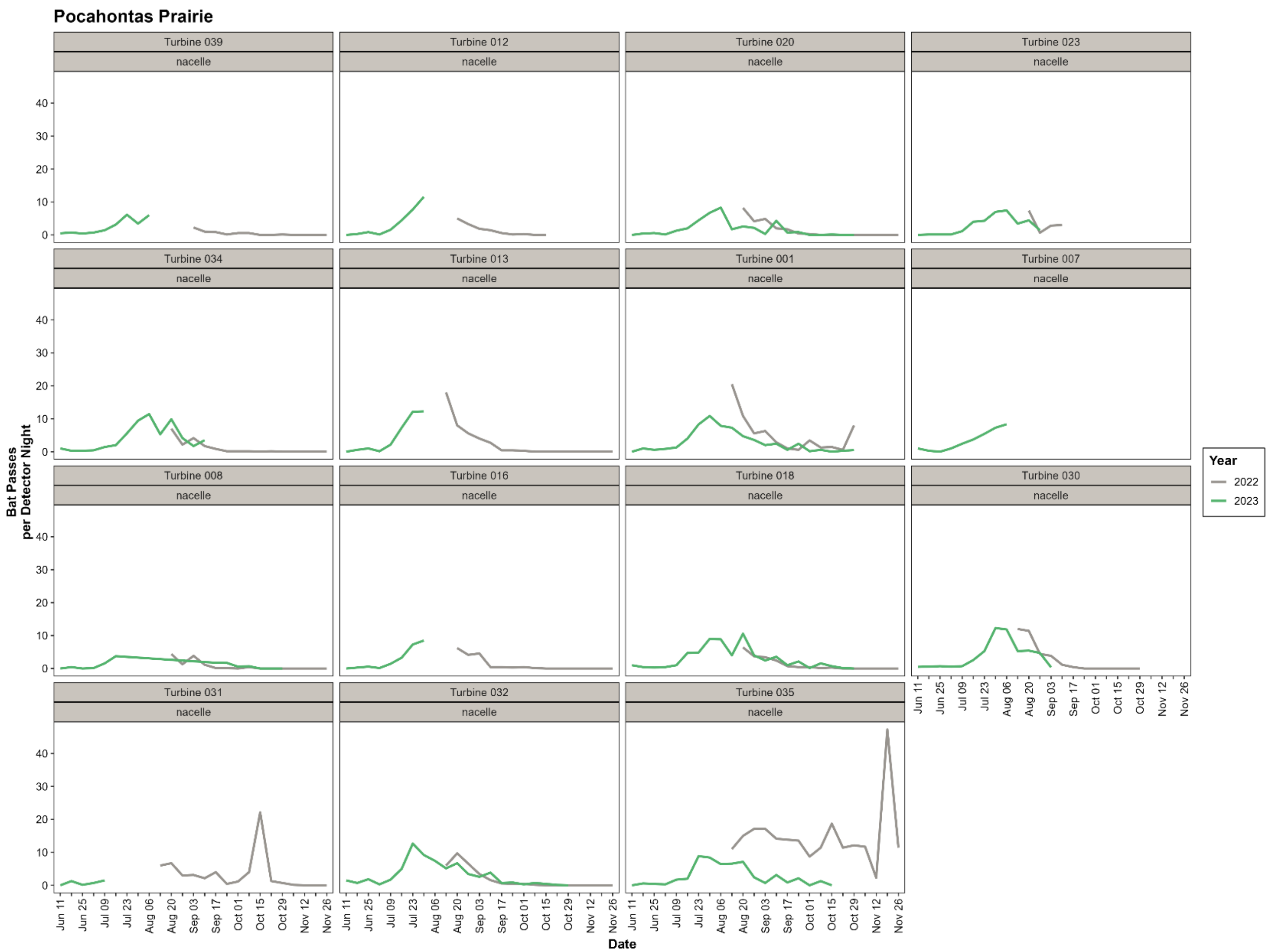
Appendix E Figure 8. Weekly distribution of bat passes by year recorded at nacelle-mounted and ground-level at Orient, Adair County, Iowa, 2021–2023.



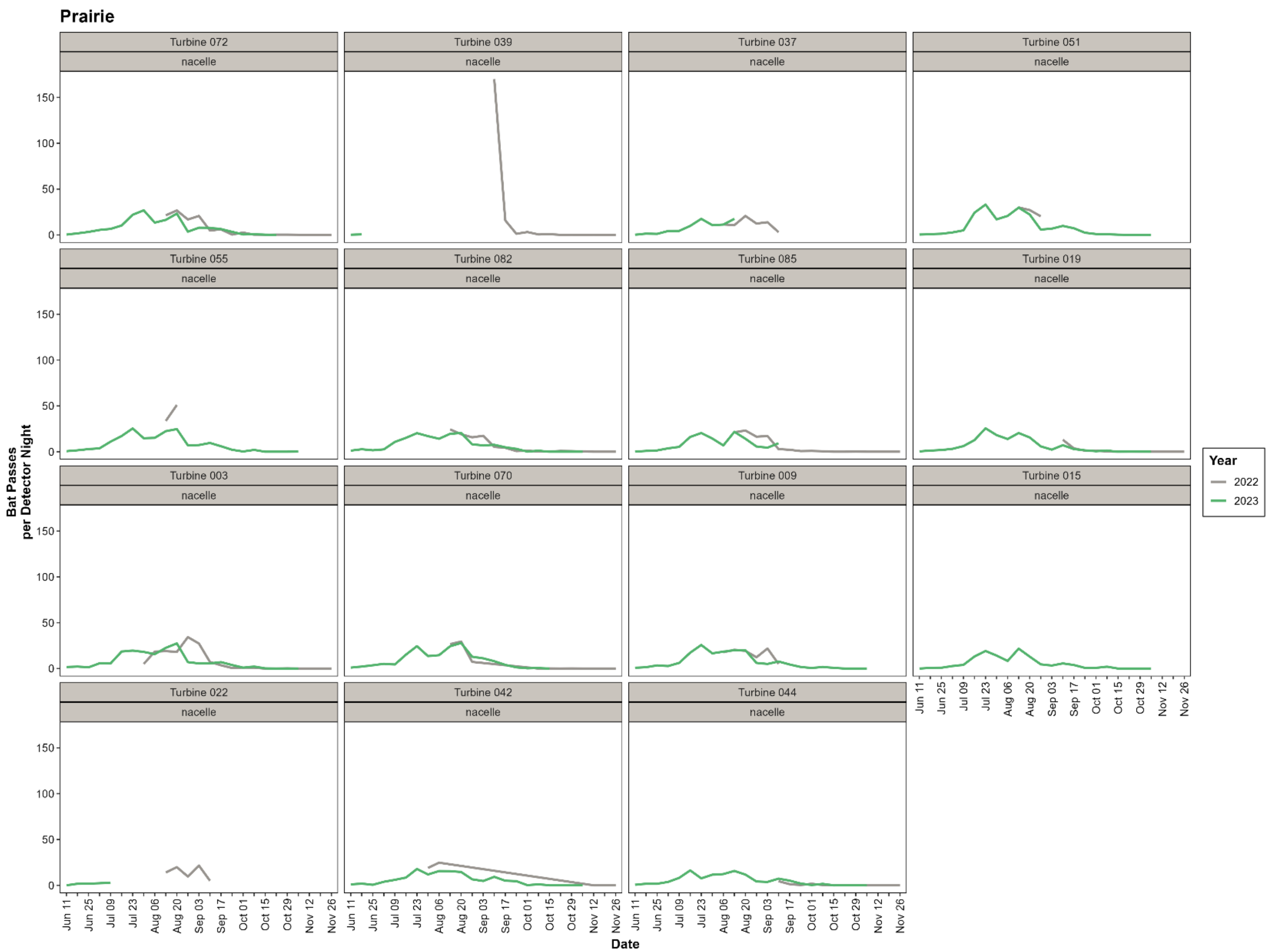
Appendix E Figure 9. Weekly distribution of bat passes by year recorded at nacelle-mounted detectors at Palo Alto, Palo Alto County, Iowa, 2022–2023.



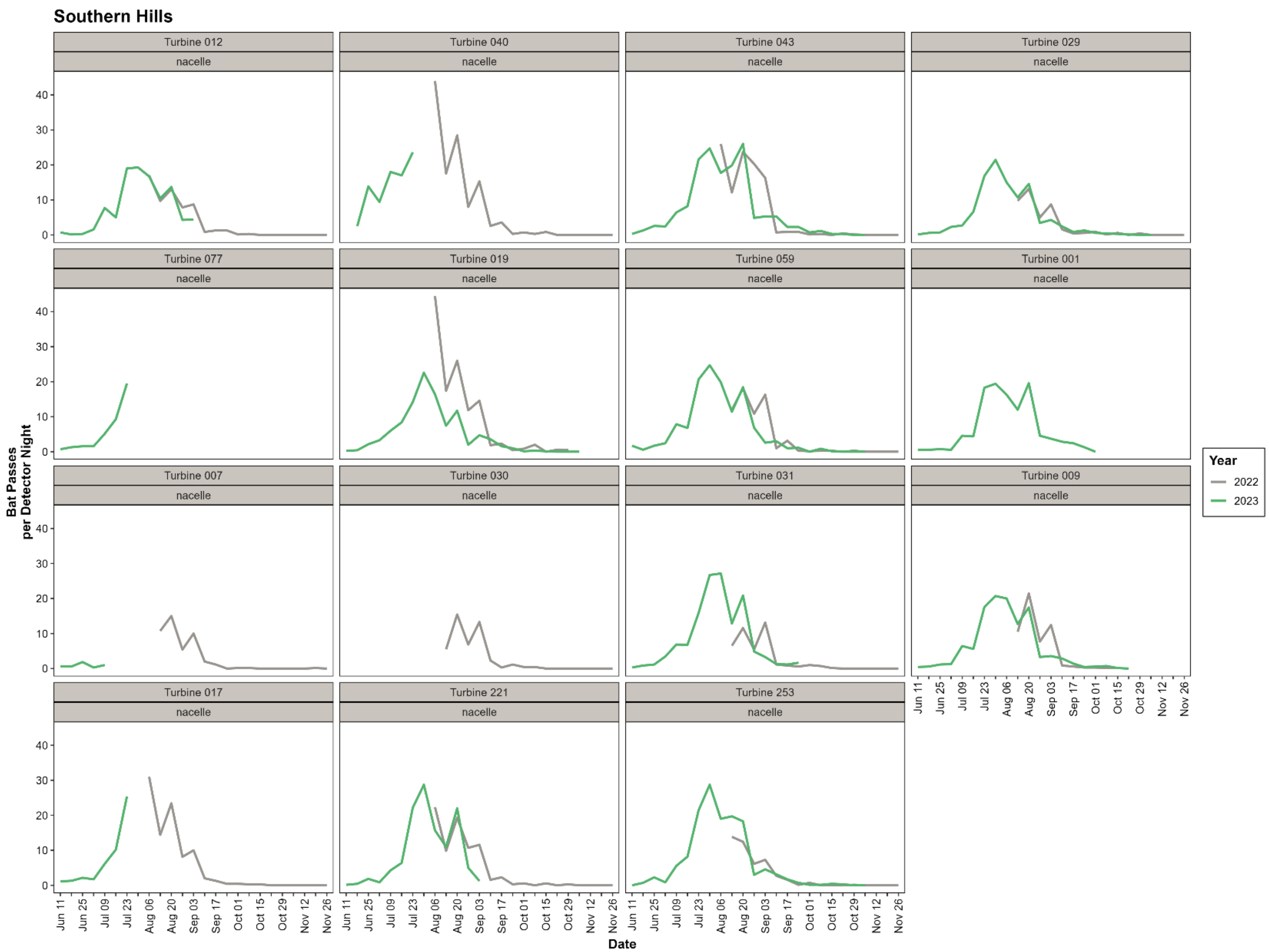
Appendix E Figure 10. Weekly distribution of bat passes by year recorded at nacelle-mounted detectors at Plymouth, Plymouth County, Iowa, 2022–2023.



Appendix E Figure 11. Weekly distribution of bat passes by year recorded at nacelle-mounted detectors at Pocahontas Prairie, Pocahontas County, Iowa, 2022–2023.

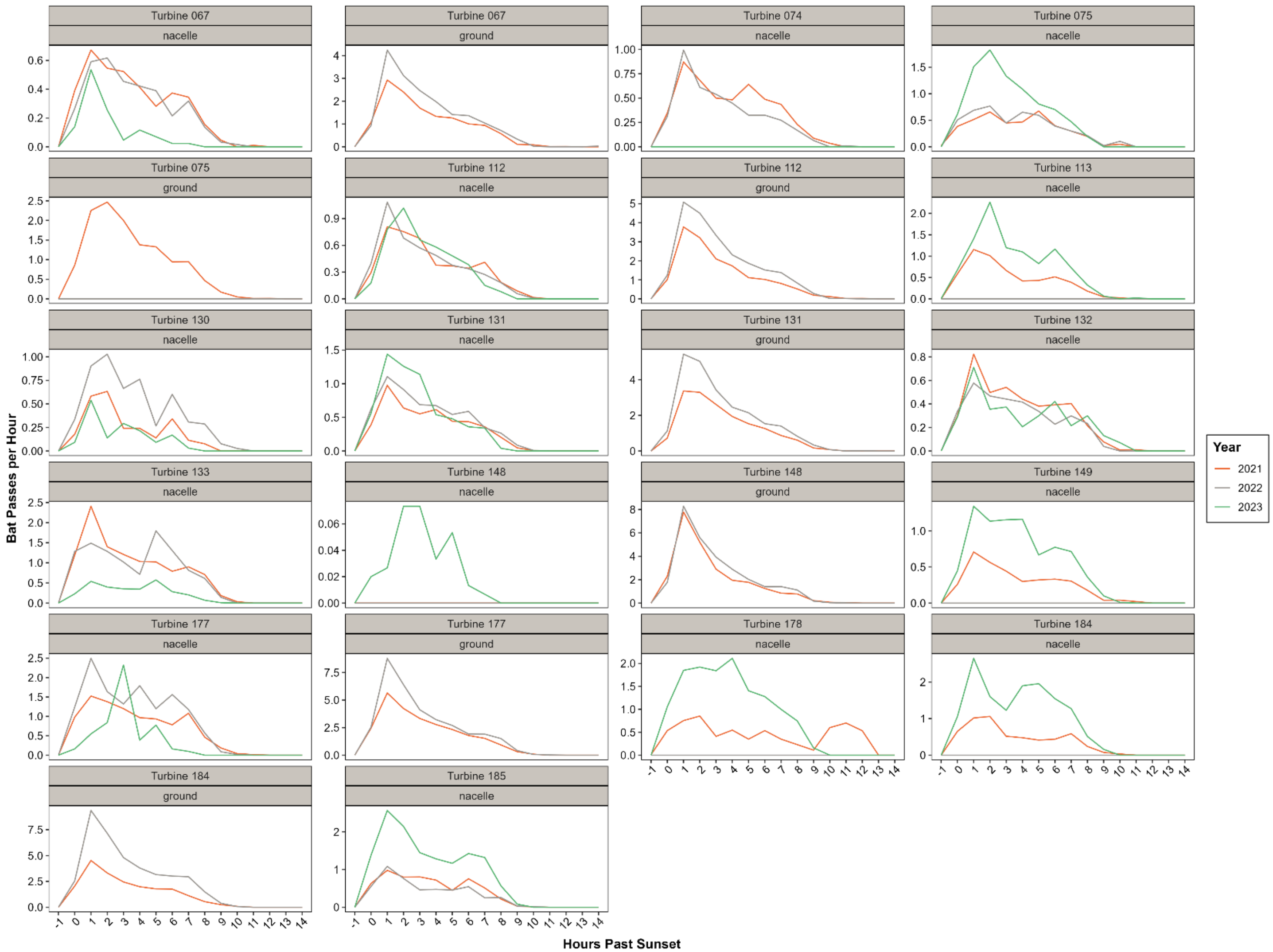


Appendix E Figure 12. Weekly distribution of bat passes by year recorded at nacelle-mounted detectors at Prairie, Mahaska County, Iowa, 2022–2023.

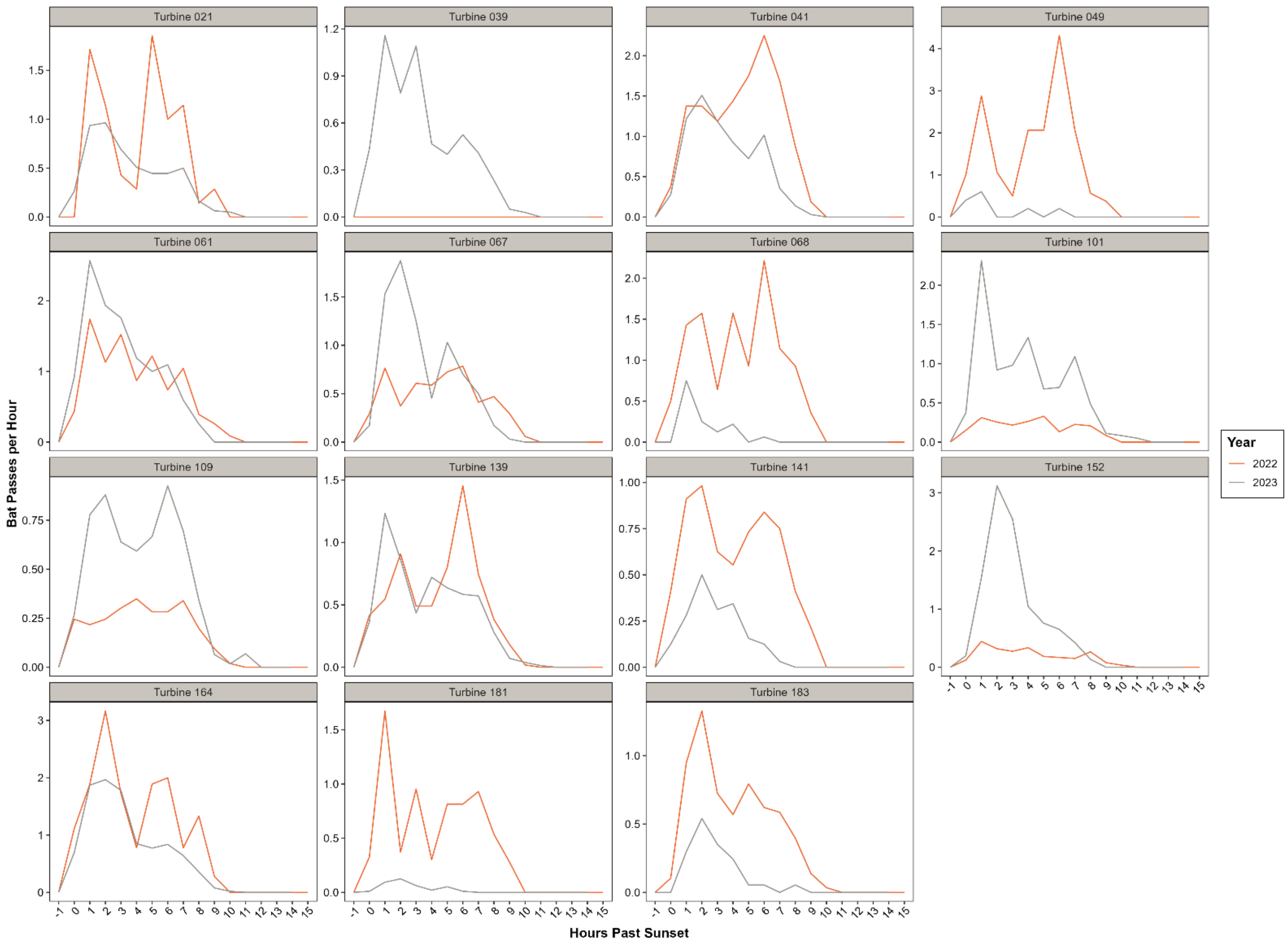


Appendix E Figure 13. Weekly distribution of bat passes by year recorded at nacelle-mounted detectors at Southern Hills, Adair, Union, and Adams Counties, Iowa, 2022–2023.

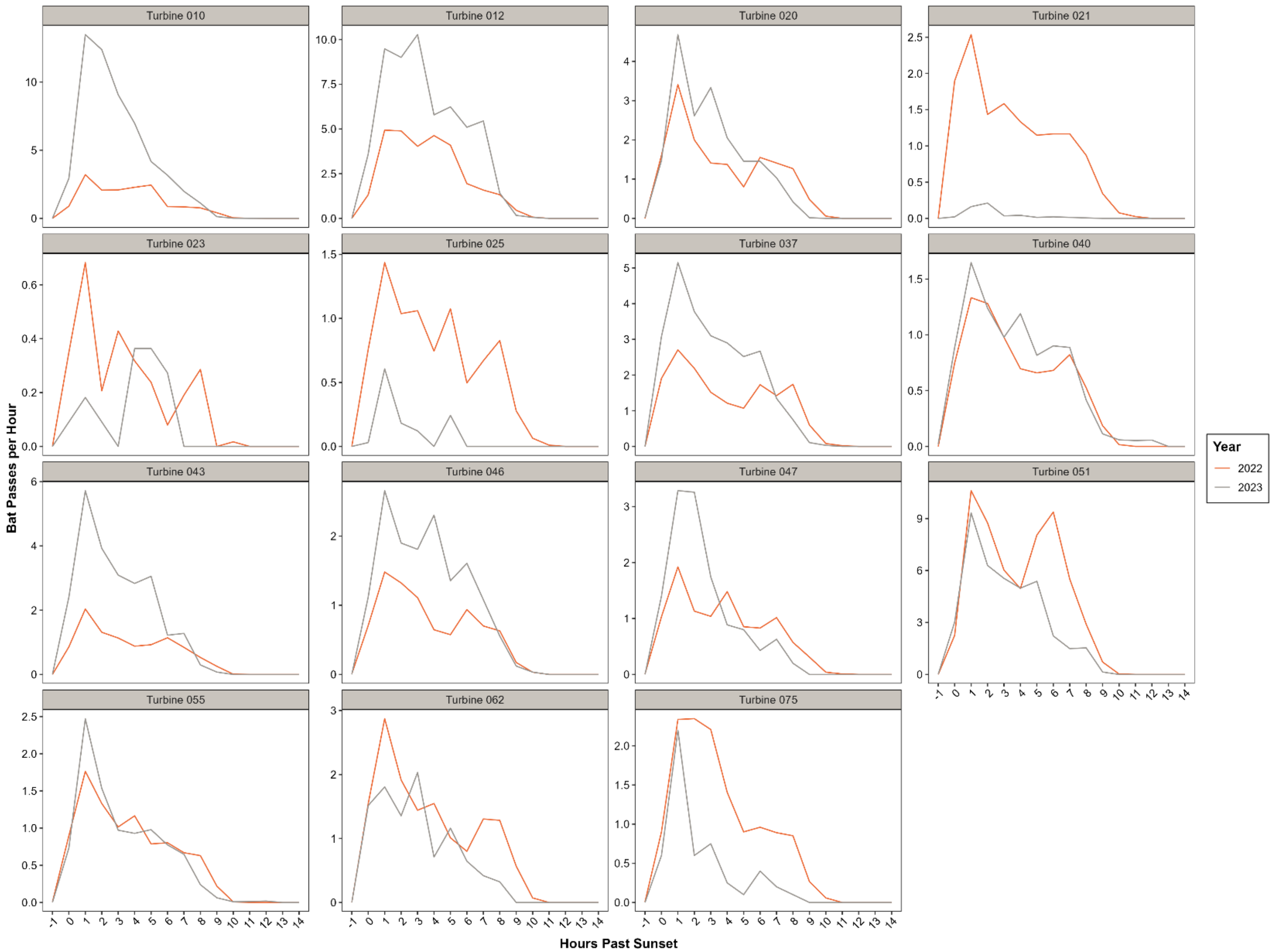
Appendix F



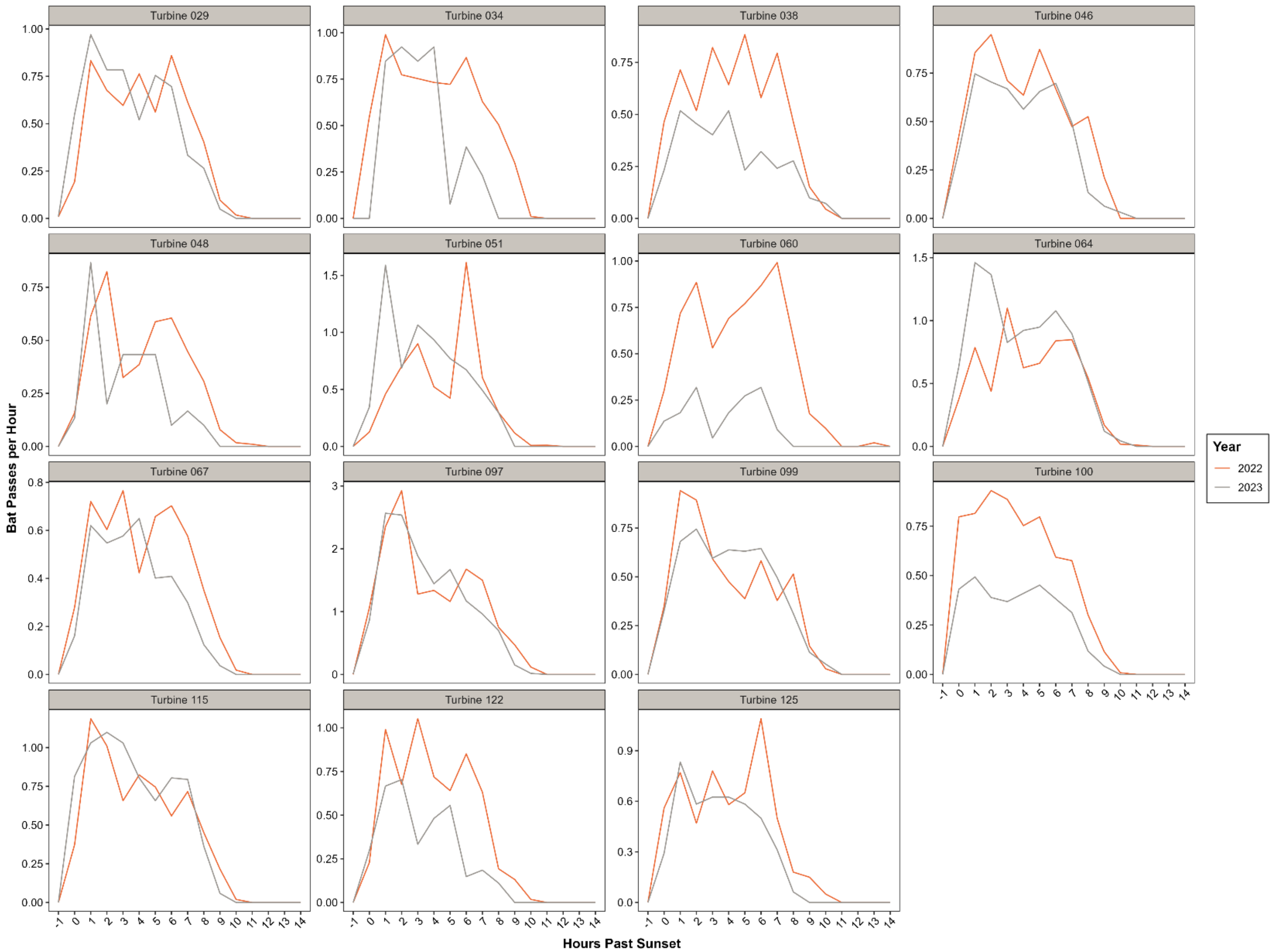
Appendix F Figure 1. Hourly distribution of bat passes by year recorded at nacelle-mounted and ground-level detectors at Arbor Hill, Adair County, Iowa, 2021–2023.



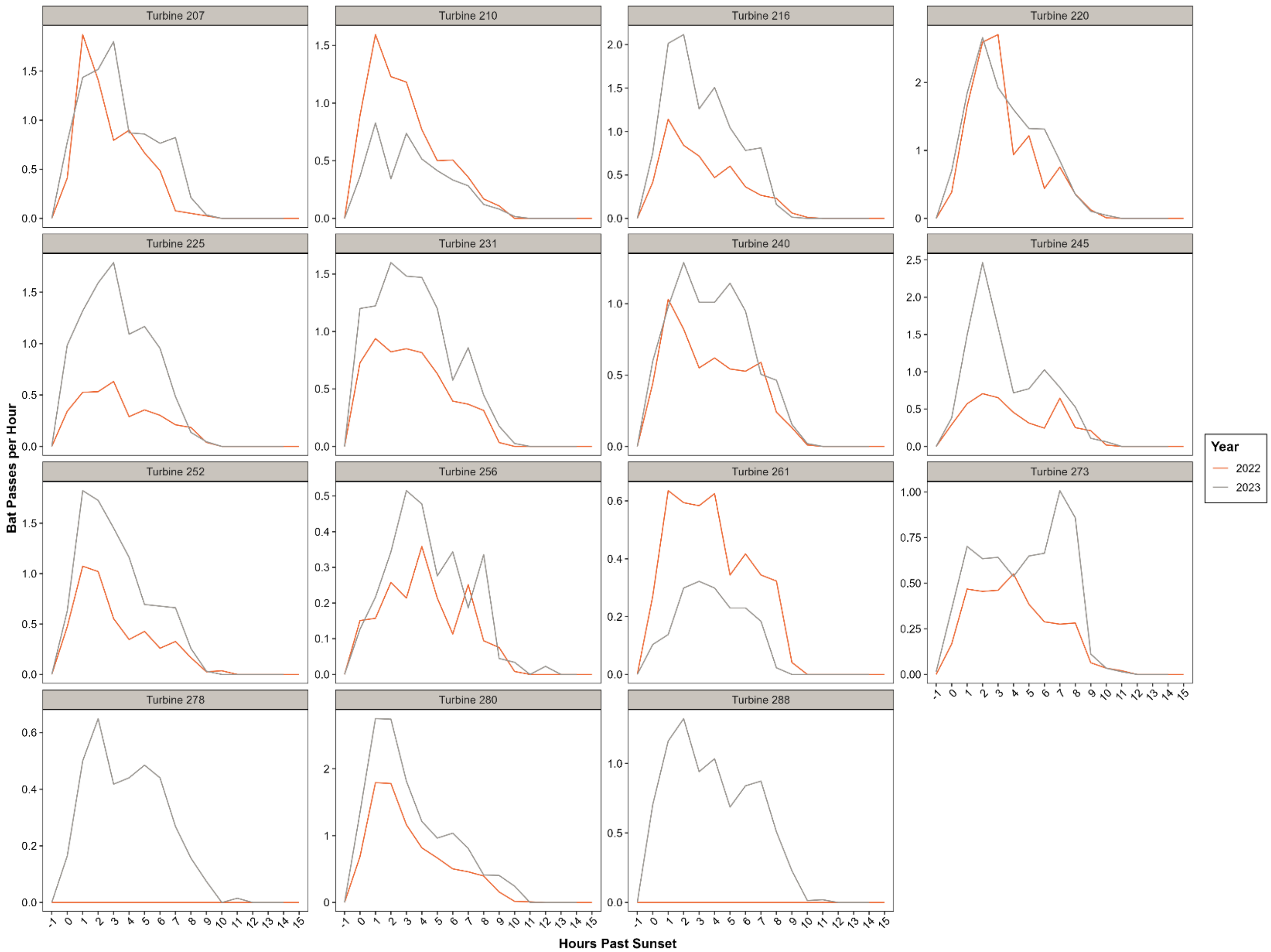
Appendix F Figure 2. Hourly distribution of bat passes by year recorded at nacelle-mounted detectors at Beaver Creek I and II, Boone and Greene Counties, Iowa, 2022–2023.



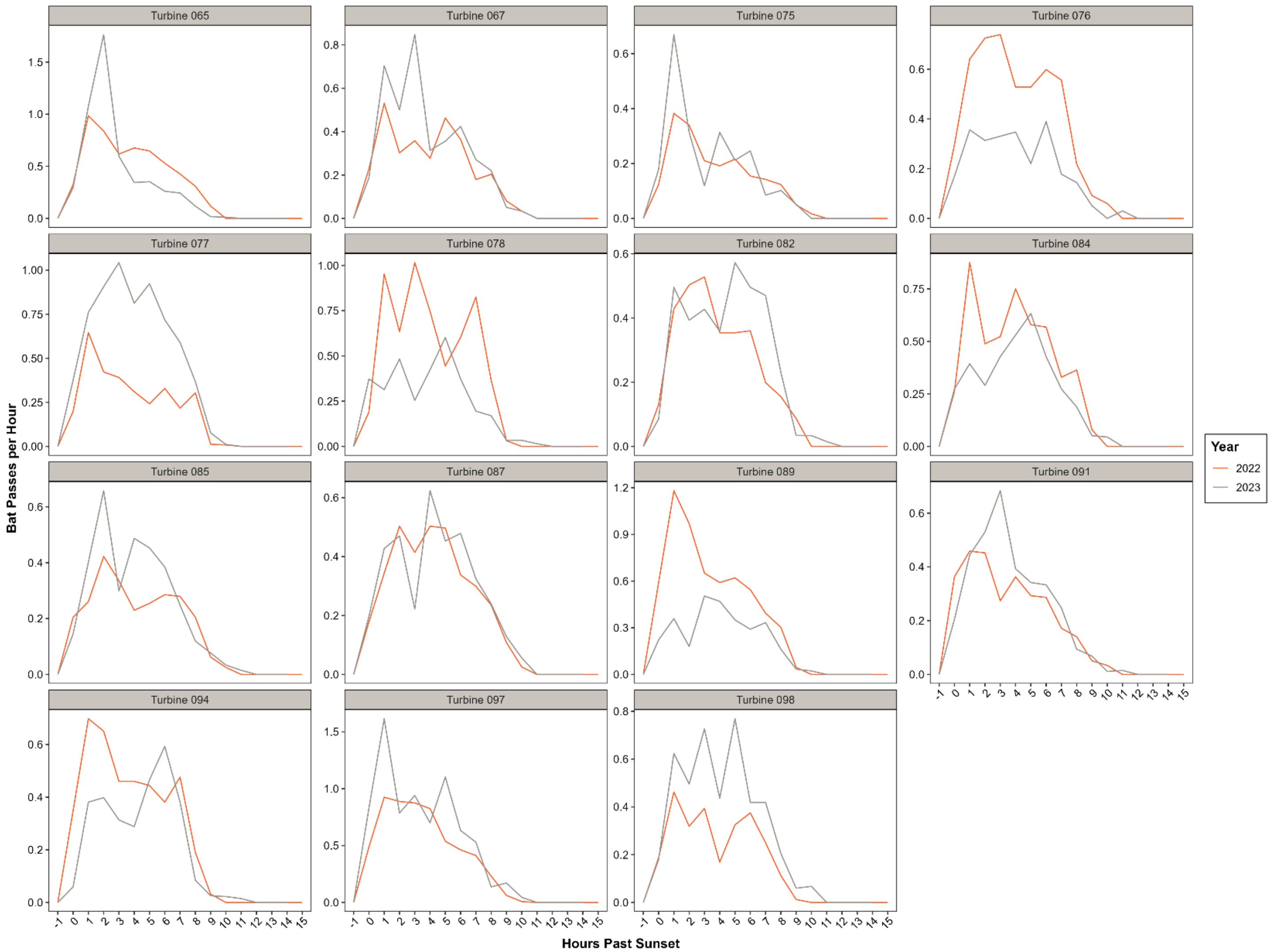
Appendix F Figure 3.Hourly distribution of bat passes by year recorded at nacelle-mounted detectors at Contrail, Taylor County, Iowa, 2022–2023.



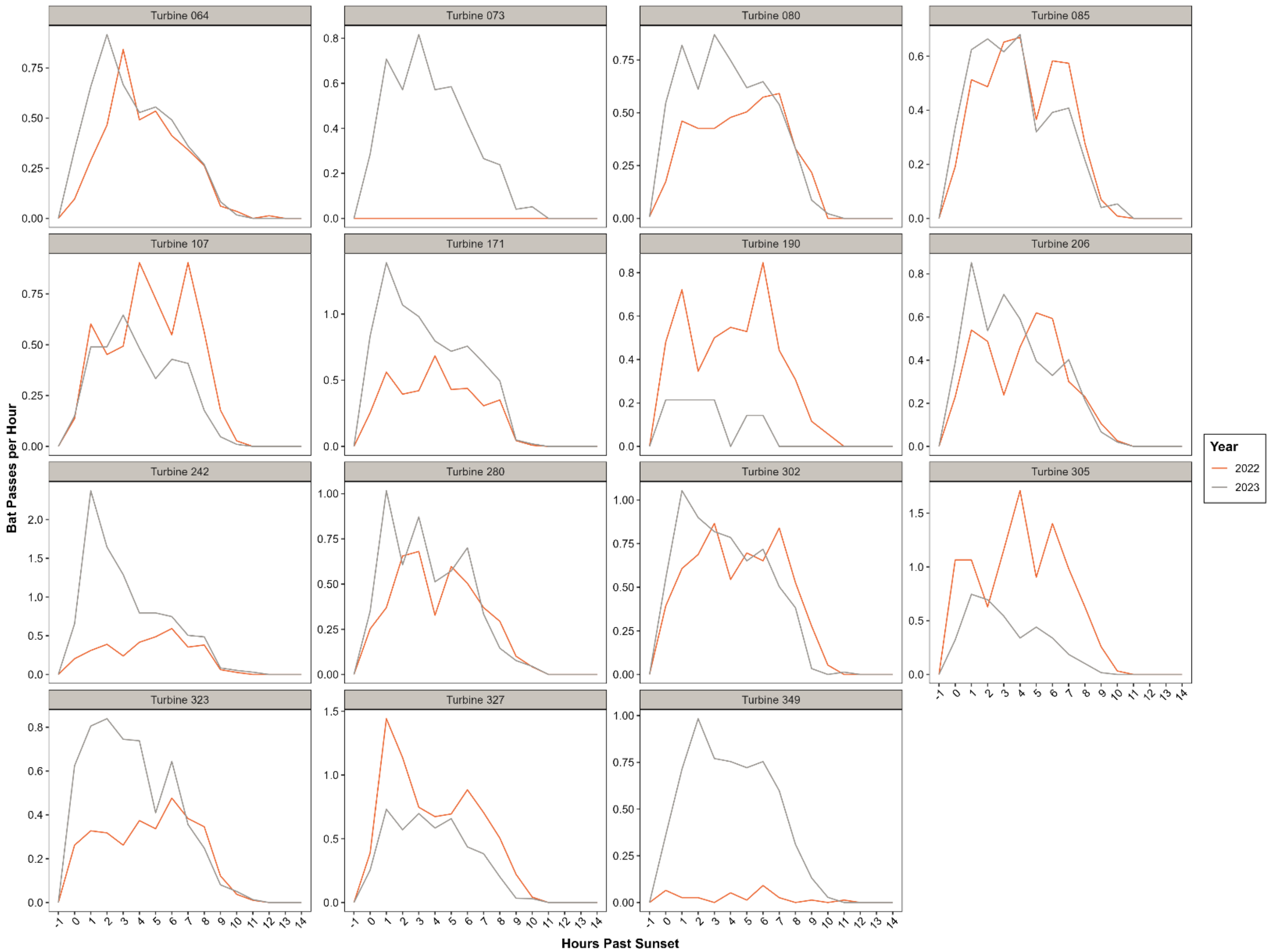
Appendix F Figure 4.Hourly distribution of bat passes by year recorded at nacelle-mounted detectors at Diamond Trail, Iowa County, Iowa, 2022–2023.



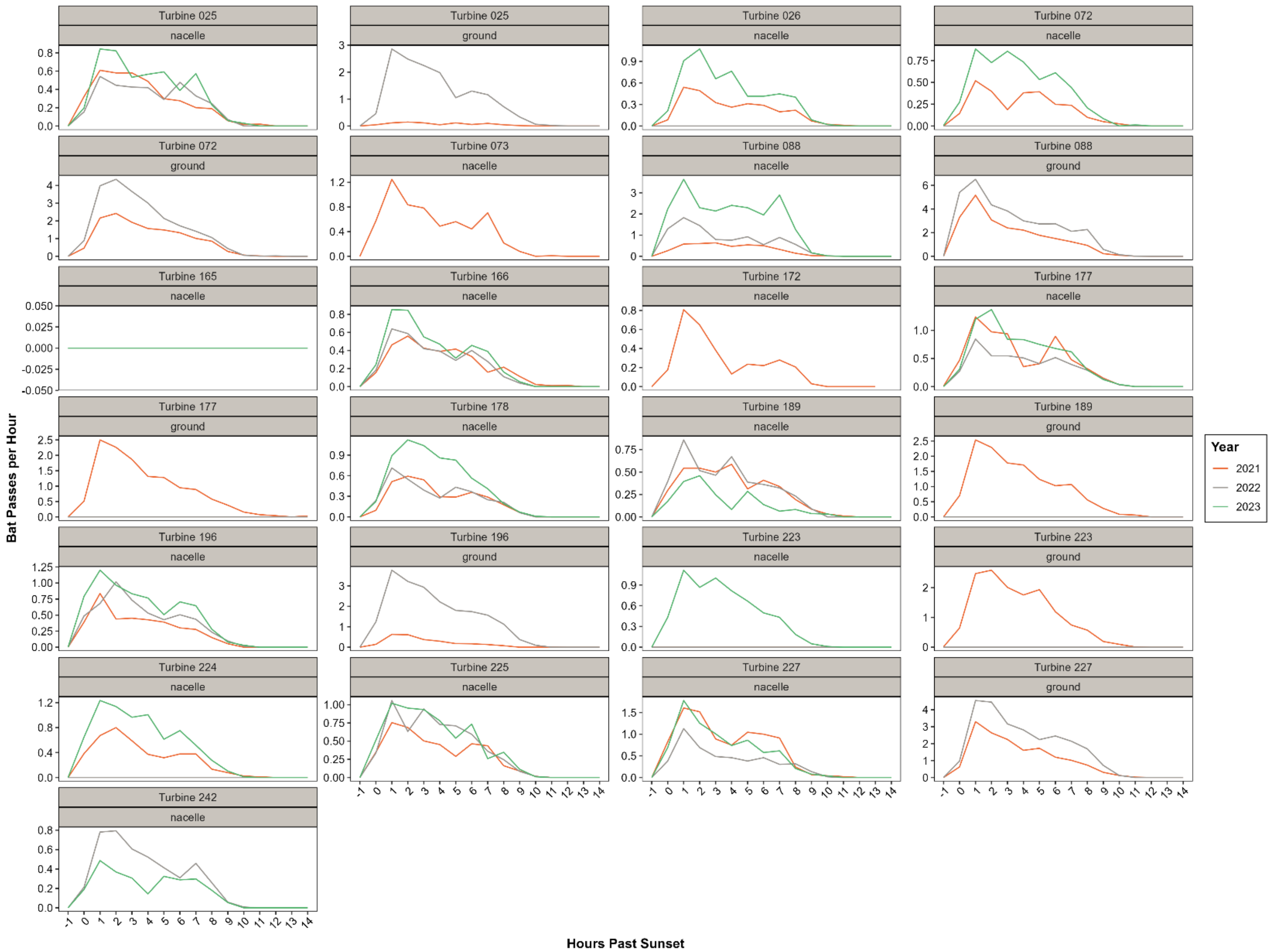
Appendix F Figure 5.Hourly distribution of bat passes by year recorded at nacelle-mounted detectors at Ida Grove II, Ida County, Iowa, 2022–2023.



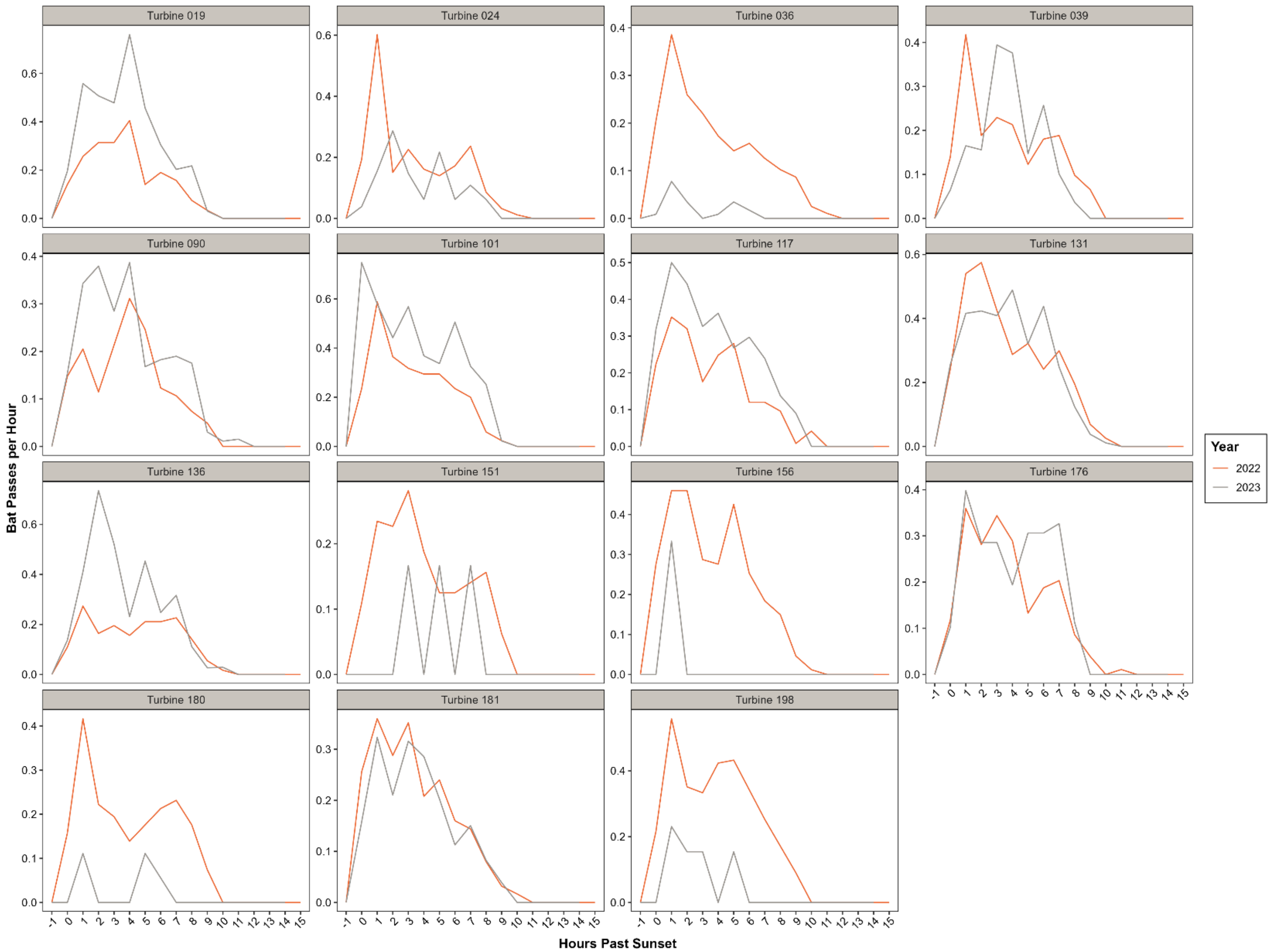
Appendix F Figure 6.Hourly distribution of bat passes by year recorded at nacelle-mounted detectors at Ivester, Grundy County, Iowa, 2022–2023.



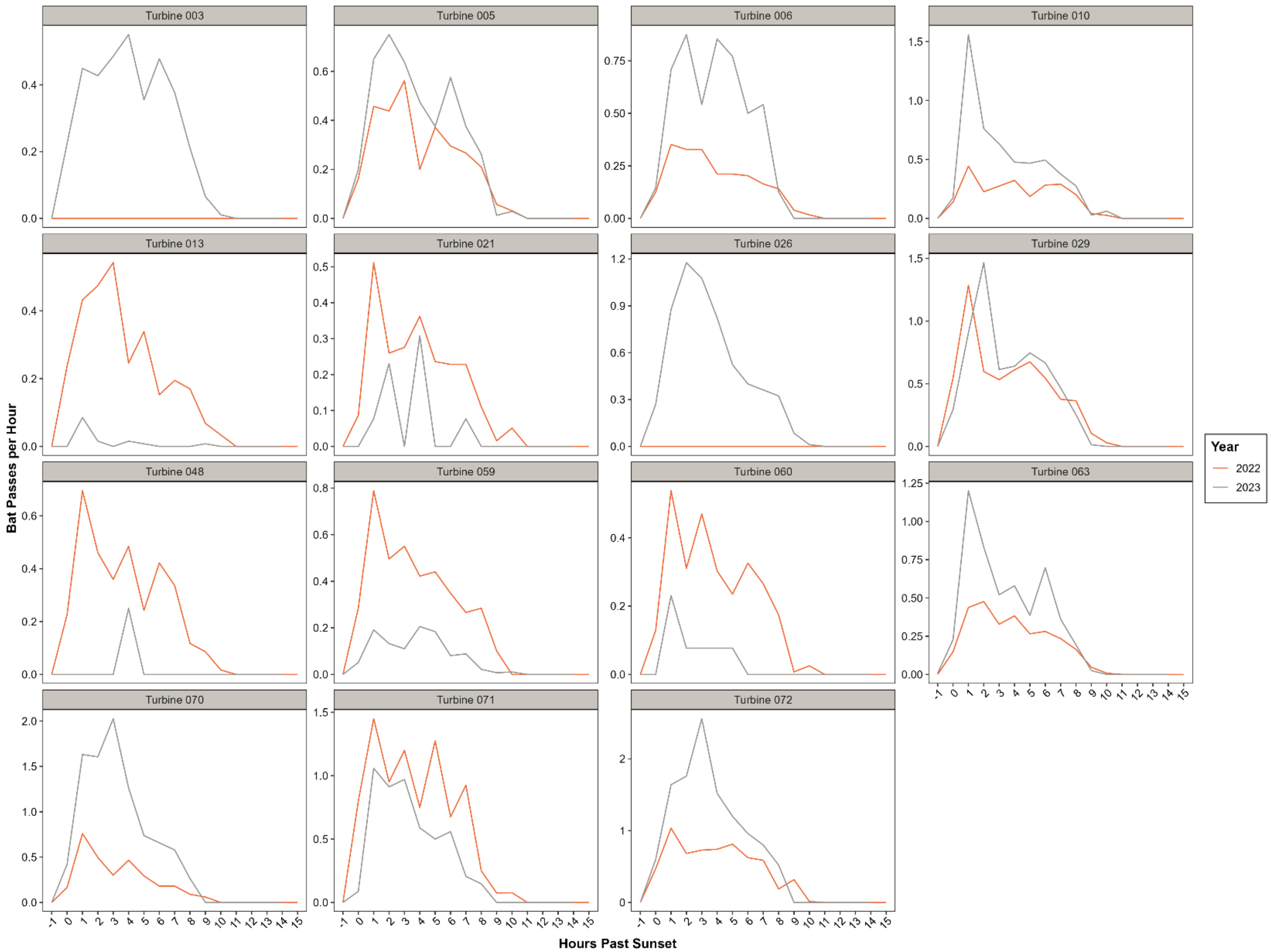
Appendix F Figure 7. Hourly distribution of bat passes by year recorded at nacelle-mounted detectors at North English, Poweshiek County, Iowa, 2022–2023.



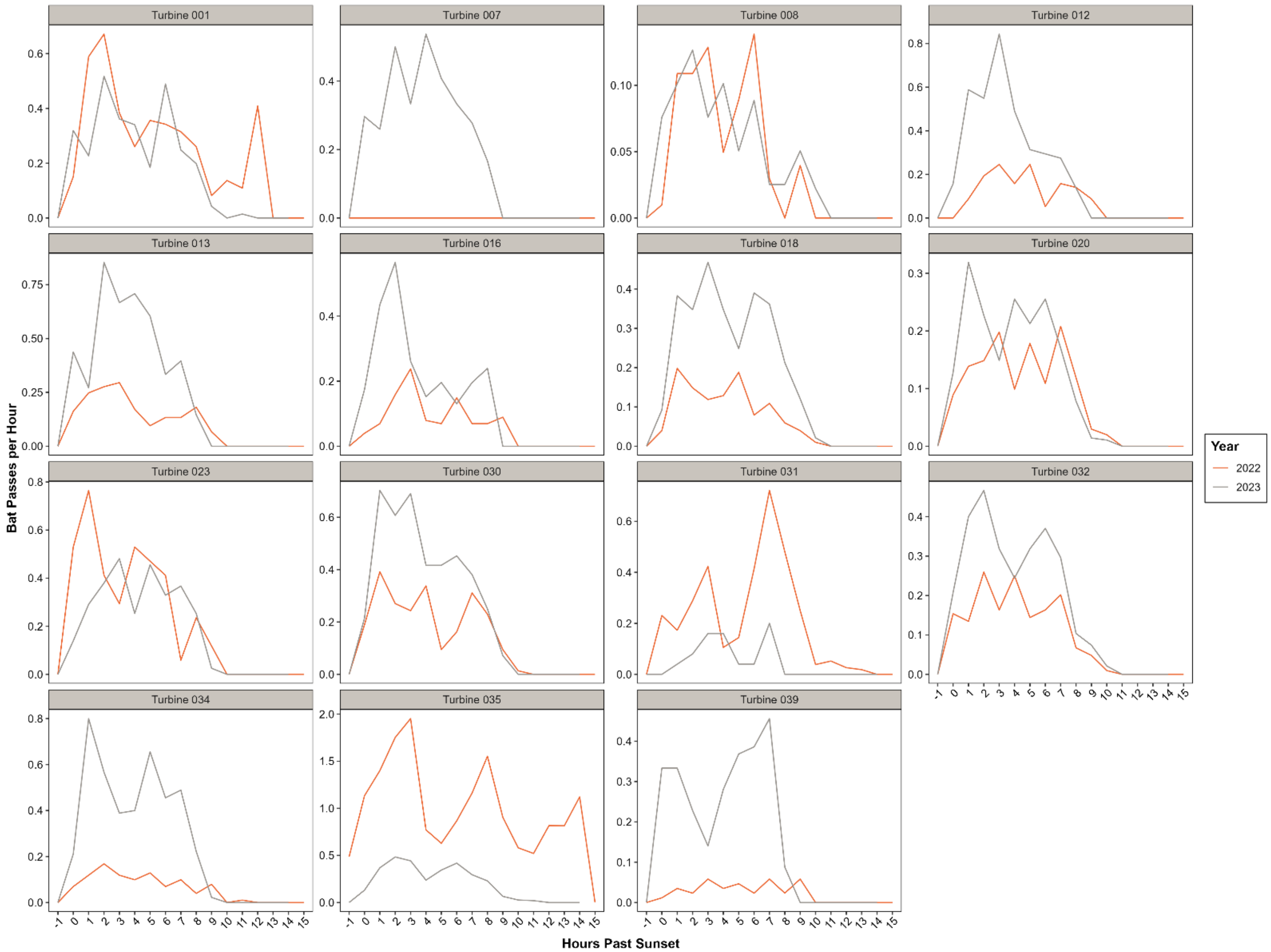
Appendix F Figure 8. Hourly distribution of bat passes by year recorded at nacelle-mounted and ground-level at Orient, Adair County, Iowa, 2021–2023.



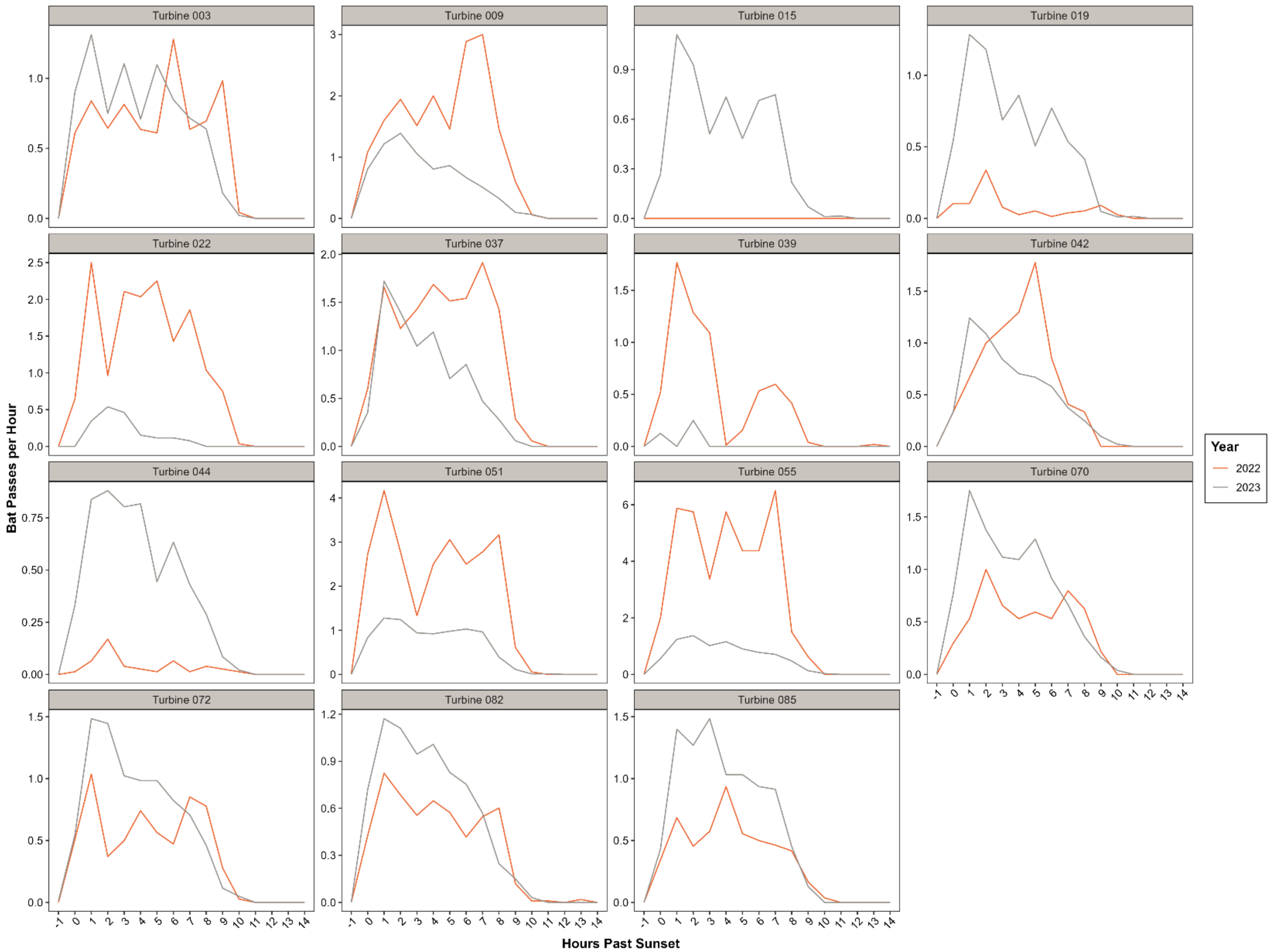
Appendix F Figure 9. Hourly distribution of bat passes by year recorded at nacelle-mounted detectors at Palo Alto, Palo Alto County, Iowa, 2022–2023.



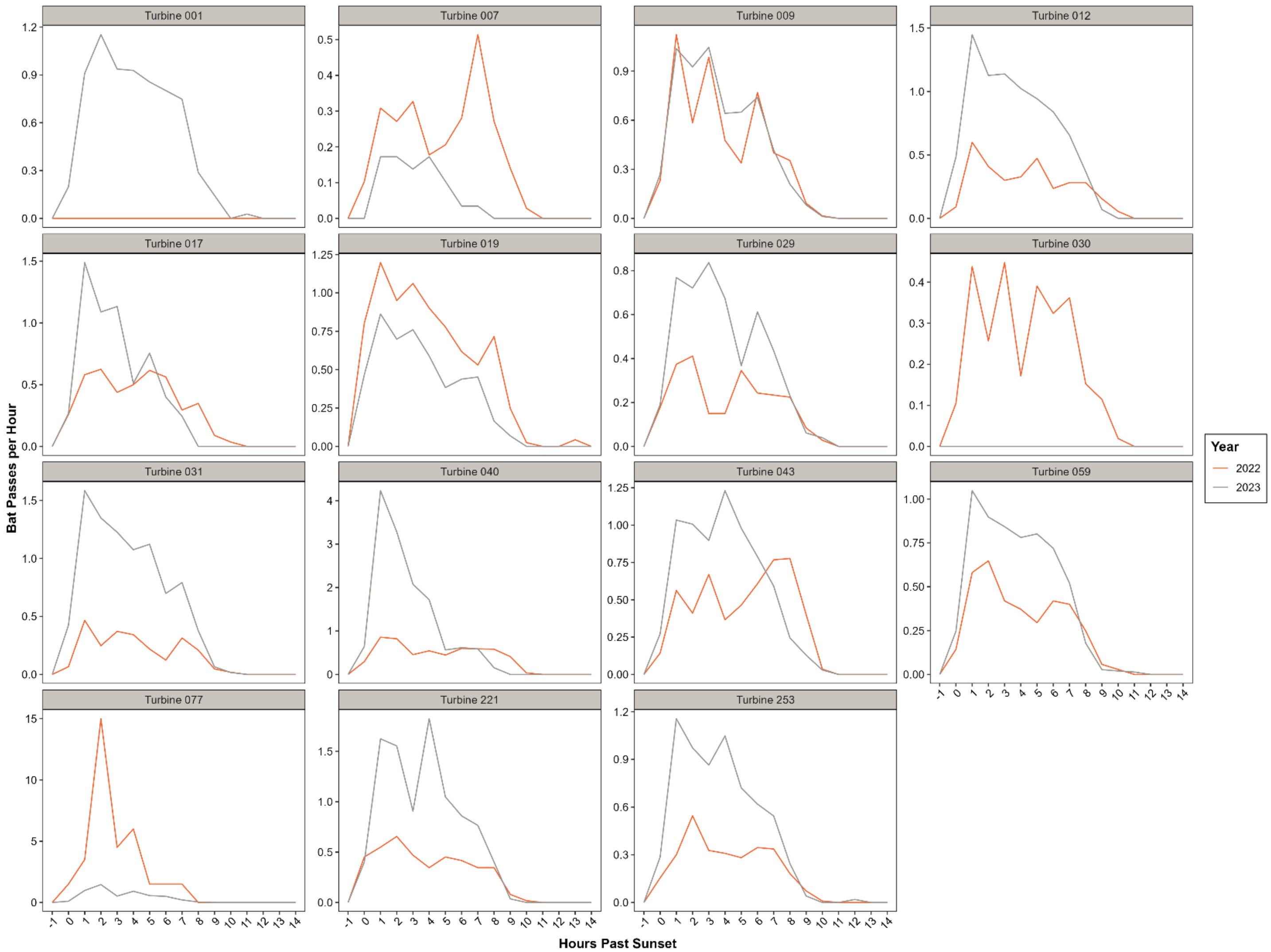
Appendix F Figure 10.Hourly distribution of bat passes by year recorded at nacelle-mounted detectors at Plymouth, Plymouth County, Iowa, 2022–2023.



Appendix F Figure 11.Hourly distribution of bat passes by year recorded at nacelle-mounted detectors at Pocahontas Prairie, Pocahontas County, Iowa, 2022–2023.

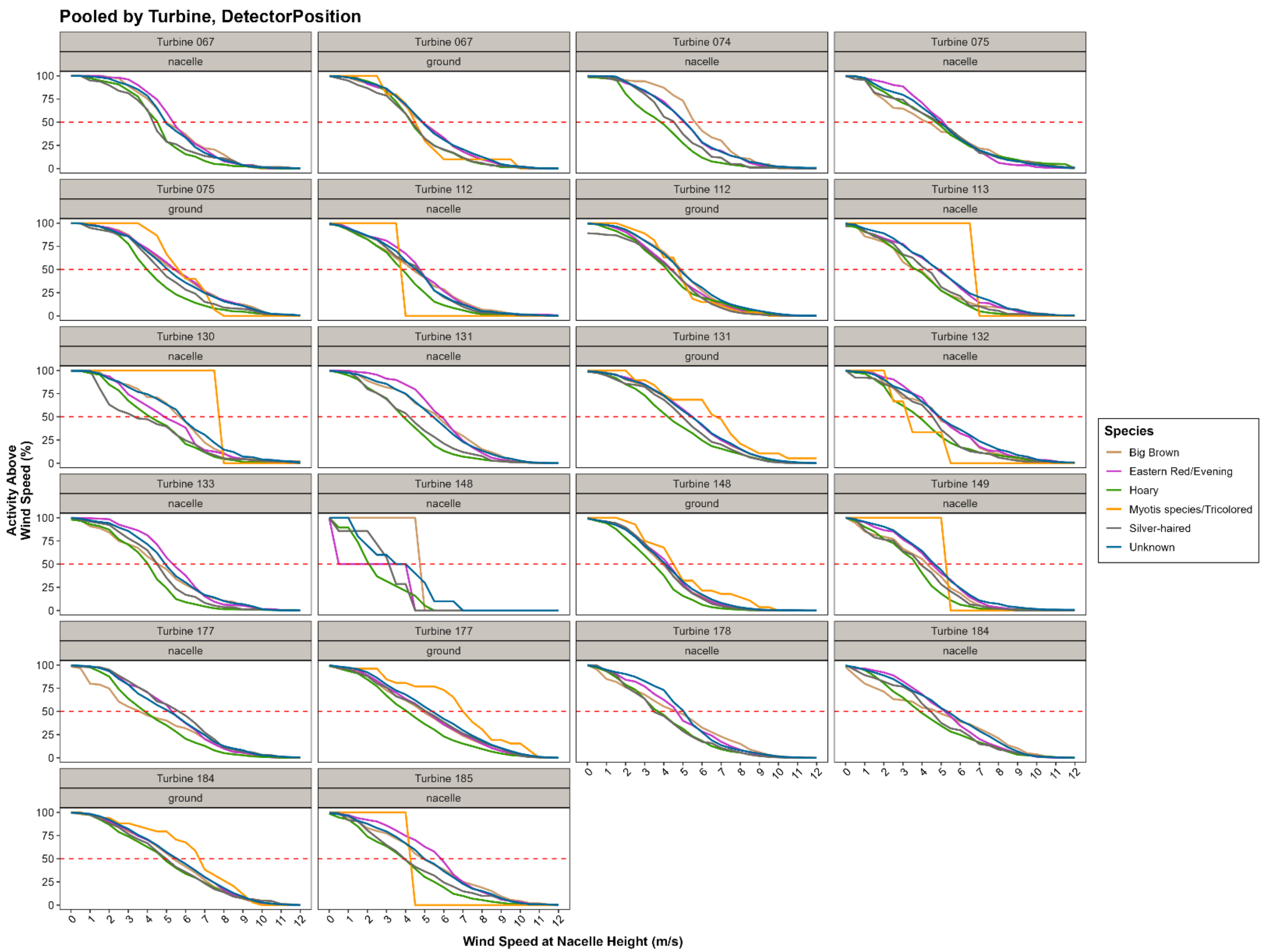


Appendix F Figure 12.Hourly distribution of bat passes by year recorded at nacelle-mounted detectors at Prairie, Mahaska County, Iowa, 2022–2023.

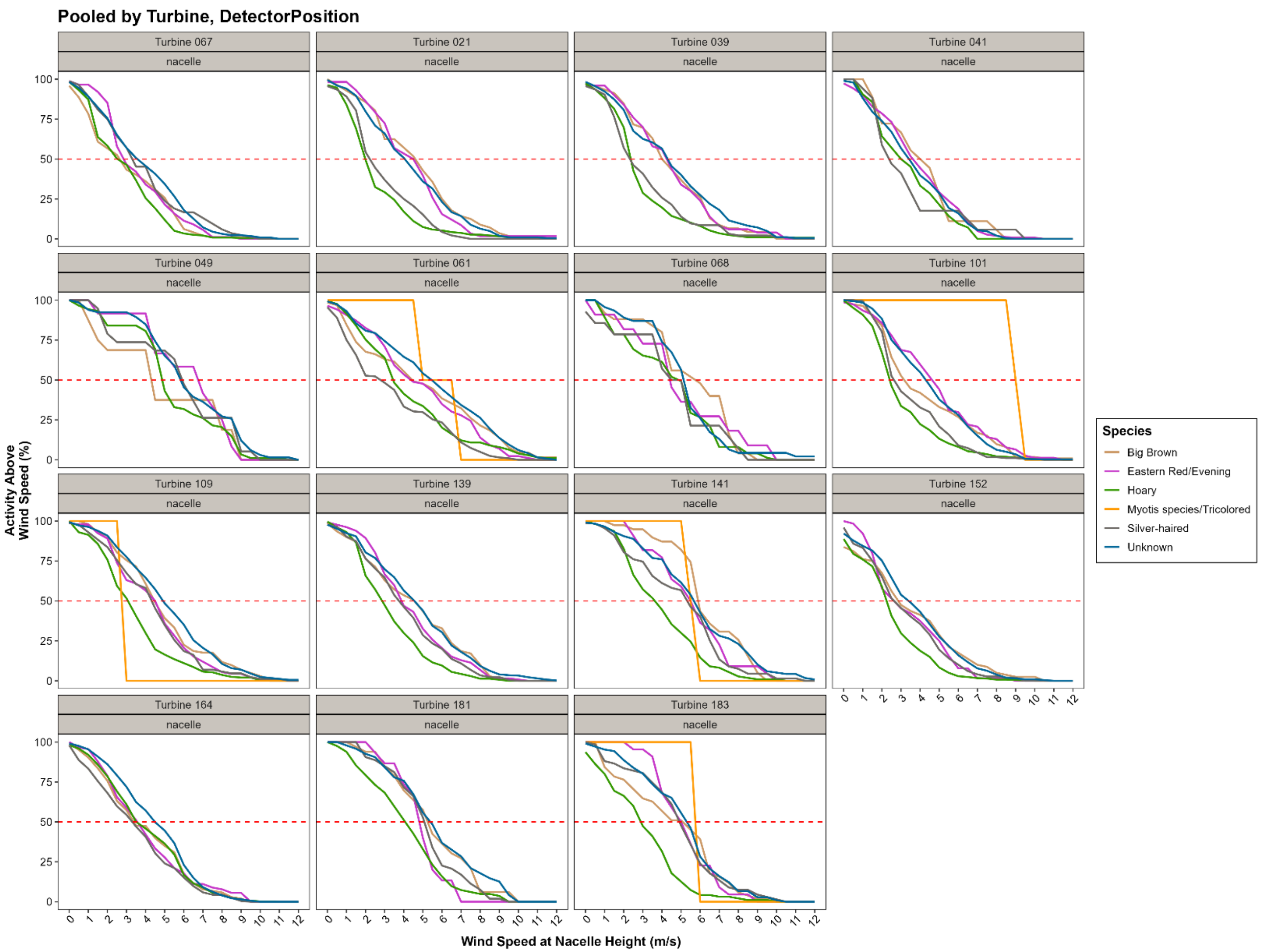


Appendix F Figure 13.Hourly distribution of bat passes by year recorded at nacelle-mounted detectors at Southern Hills, Adair, Union, and Adams Counties, Iowa, 2022–2023.

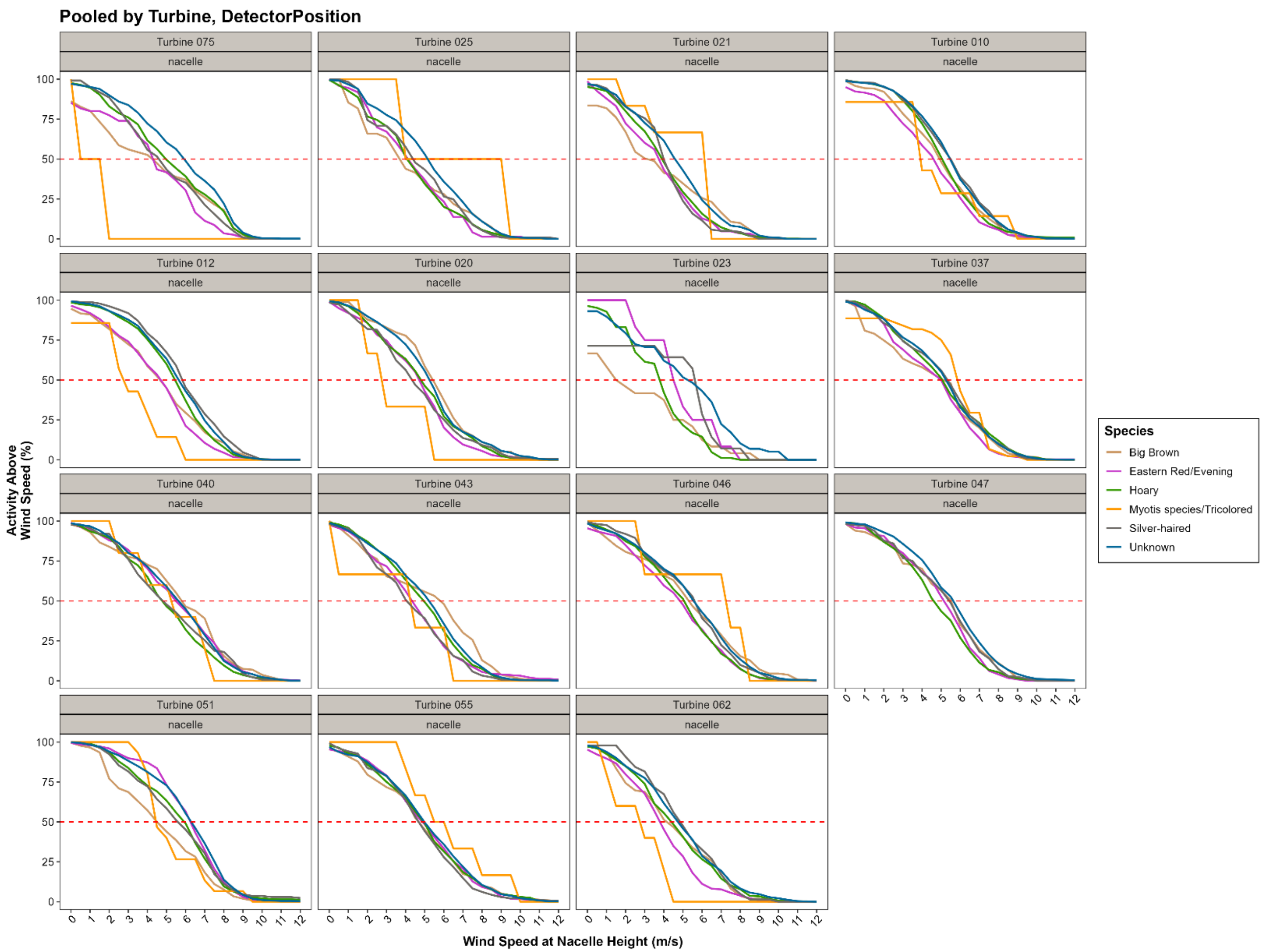
Appendix G



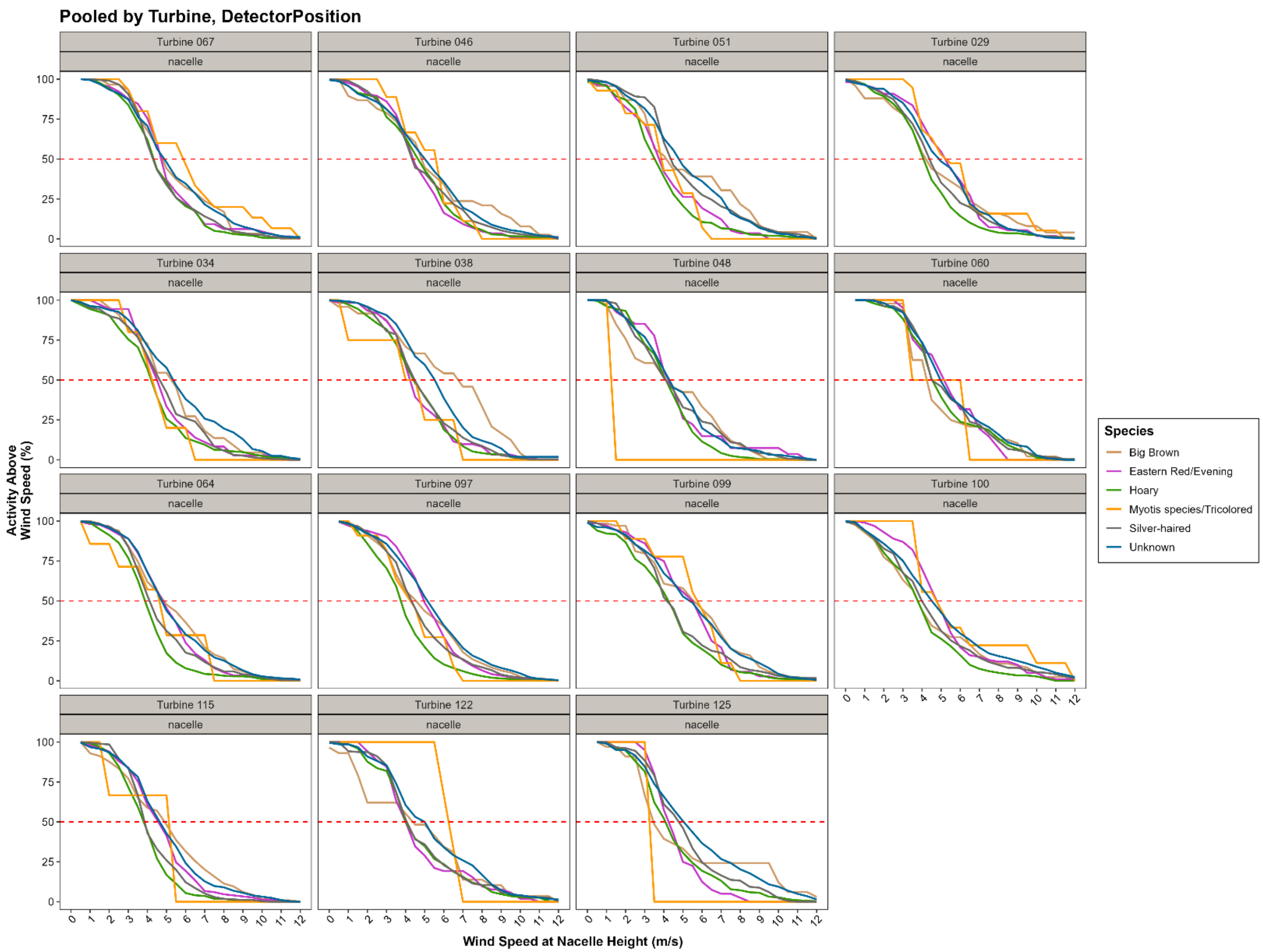
Appendix G Figure 1. Distribution of bat passes by species group as a function of wind speed at Arbor Hill during 2021–2023 monitoring.



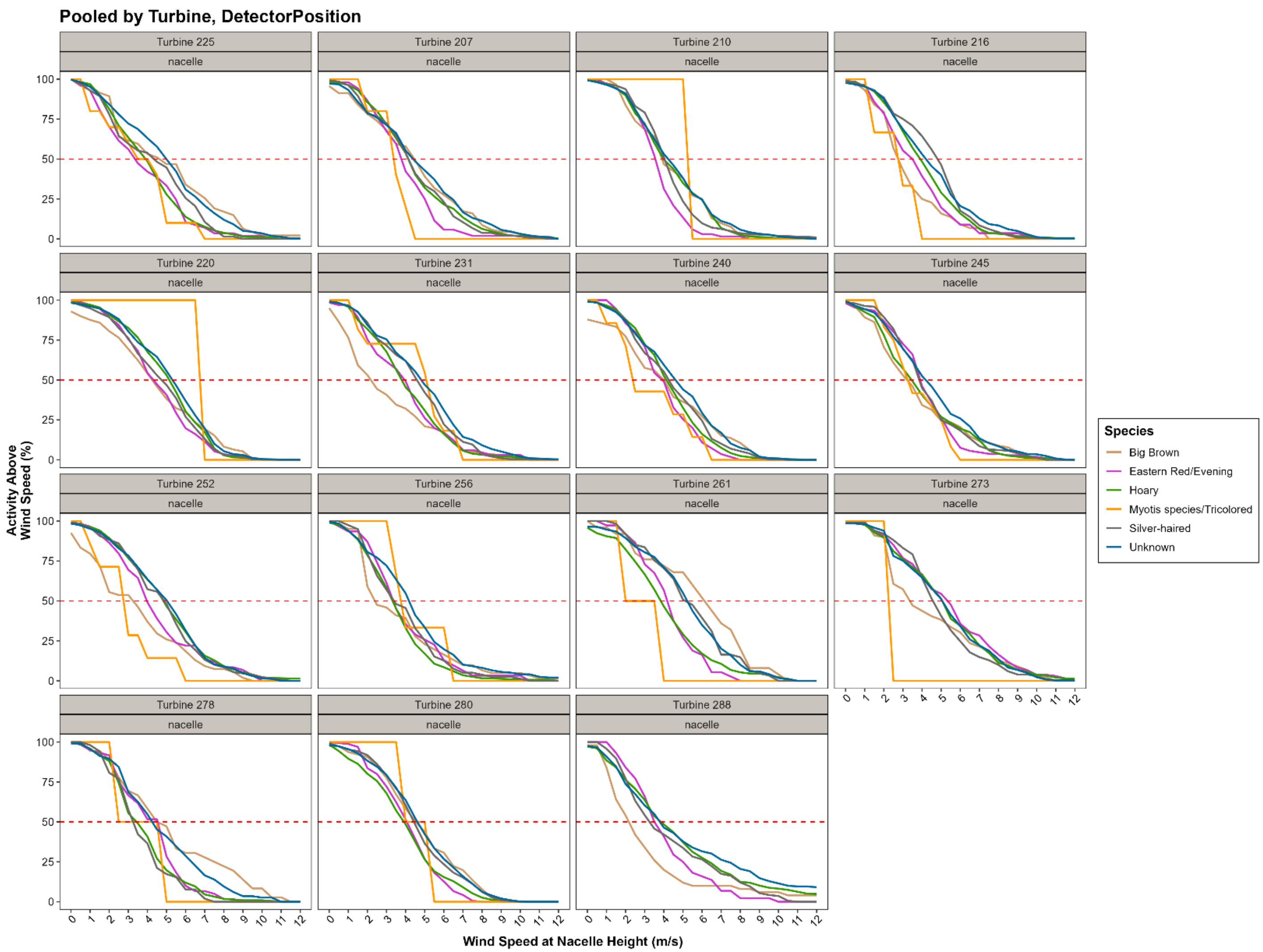
Appendix G Figure 2. Distribution of bat passes by species group as a function of wind speed at Beaver Creek during 2022–2023 monitoring.



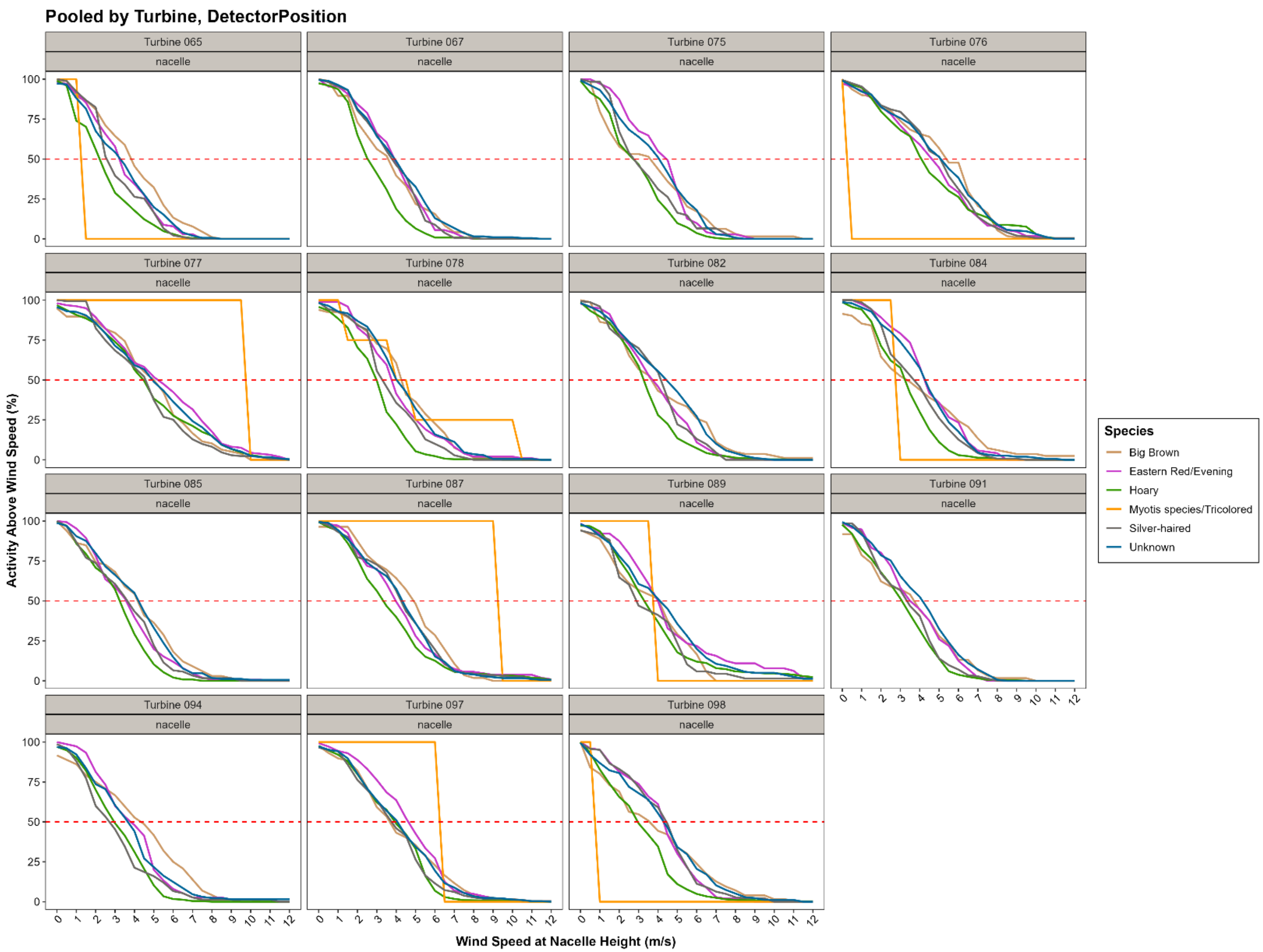
Appendix G Figure 3. Distribution of bat passes by species group as a function of wind speed at Contrail during 2022–2023 monitoring.



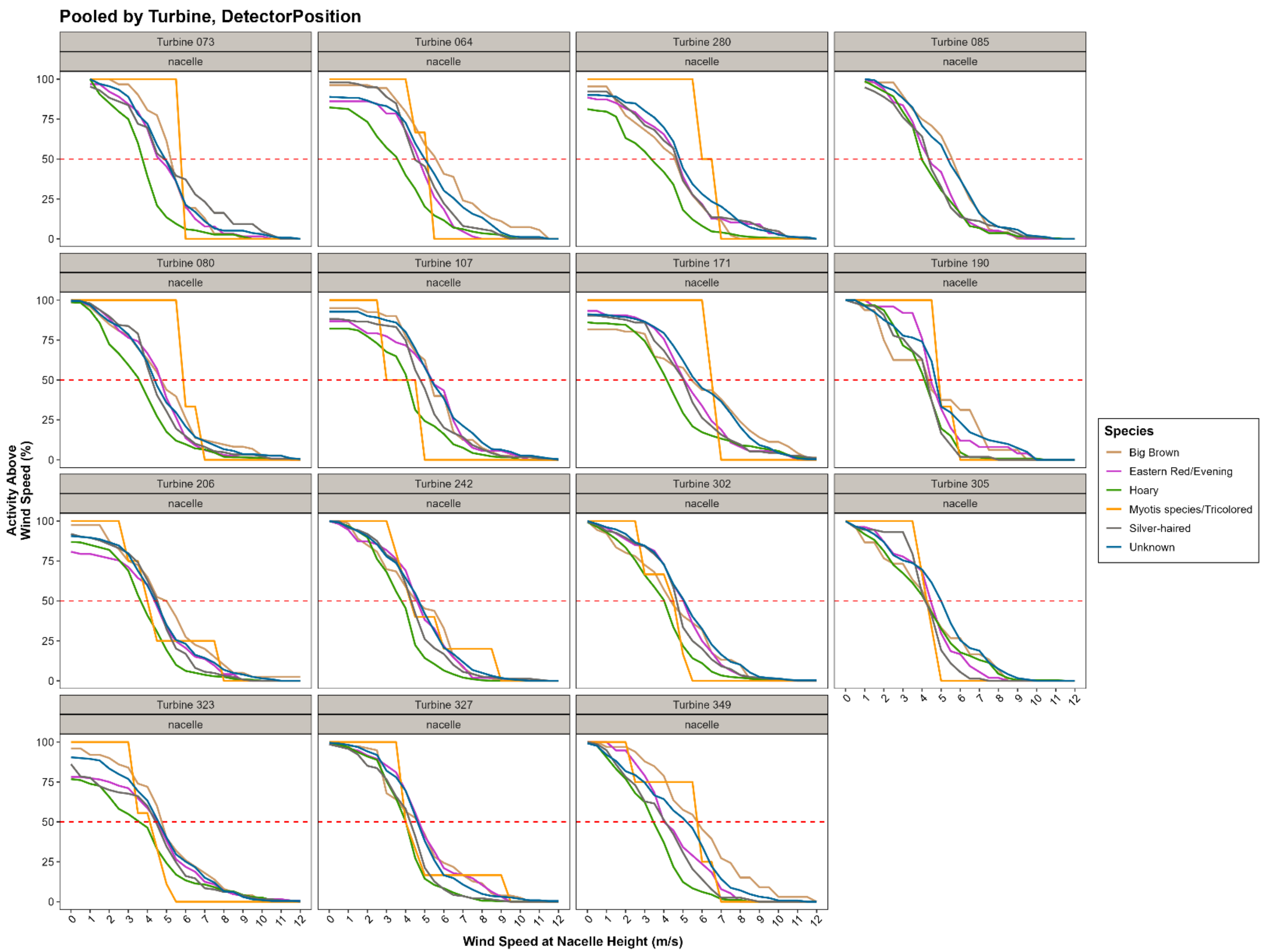
Appendix G Figure 4. Distribution of bat passes by species group as a function of wind speed at Diamond Trail during 2022–2023 monitoring.



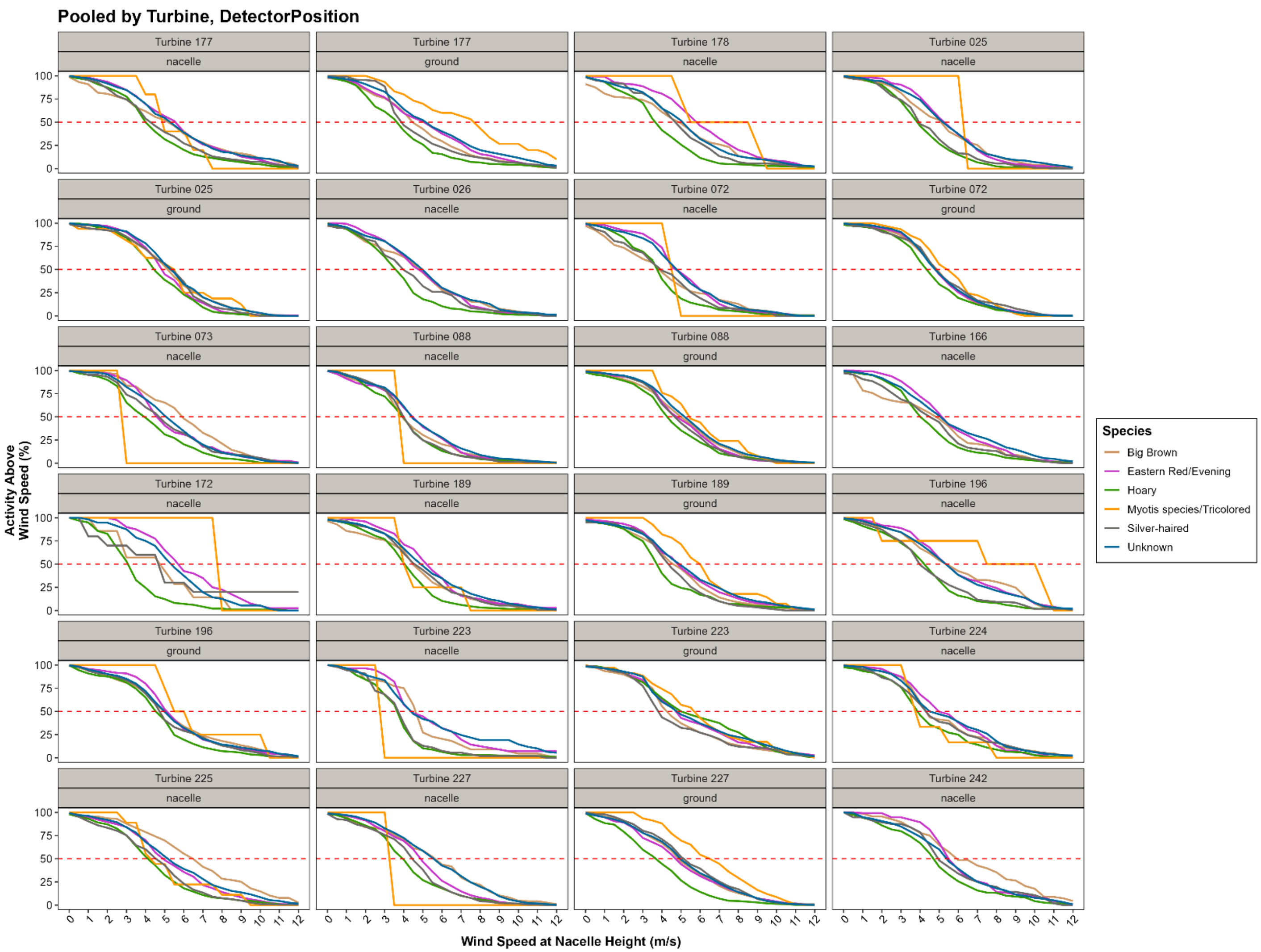
Appendix G Figure 5. Distribution of bat passes by species group as a function of wind speed at Ida Grove during 2022–2023 monitoring.



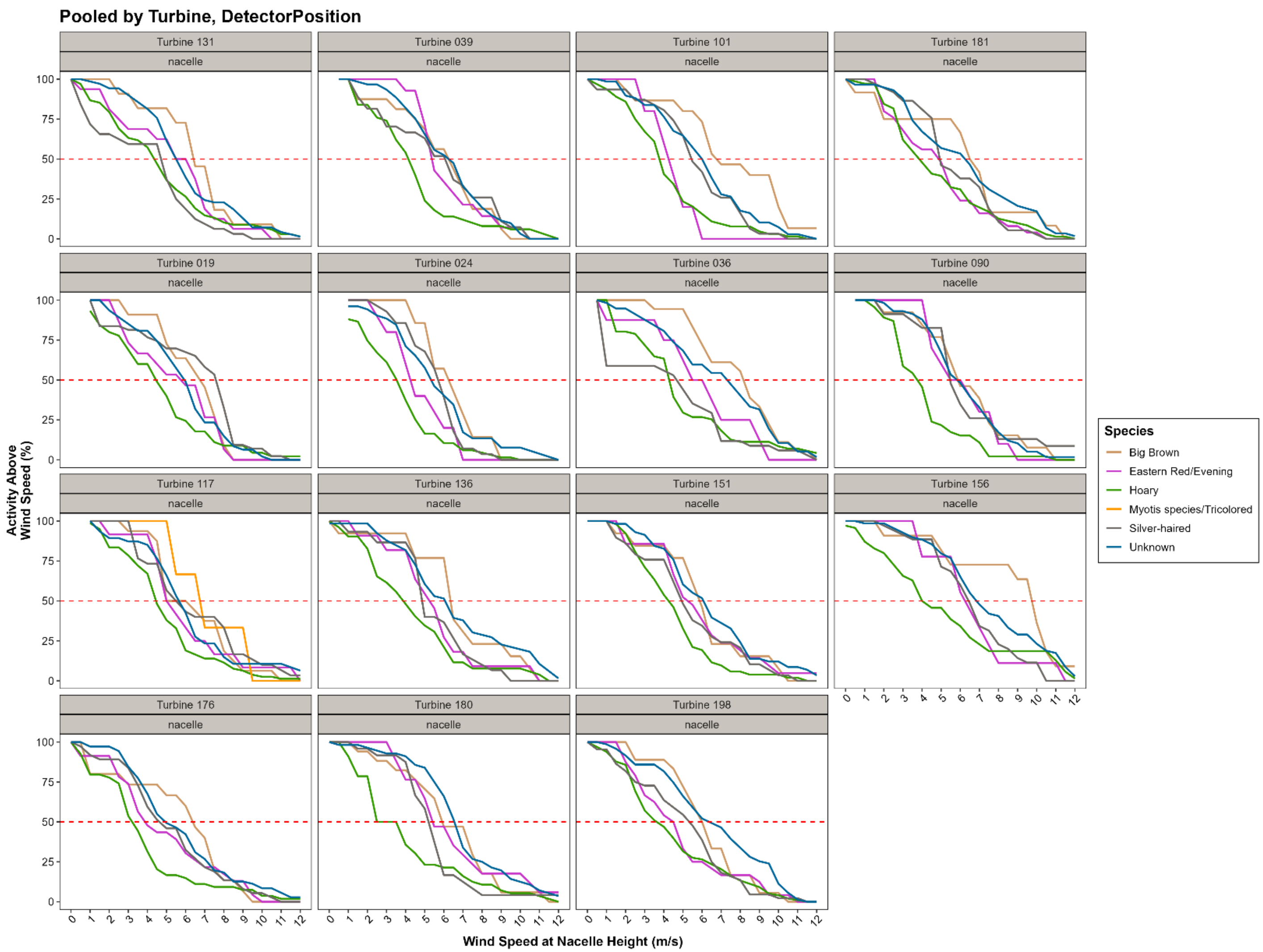
Appendix G Figure 6. Distribution of bat passes by species group as a function of wind speed at Ivester during 2022–2023 monitoring.



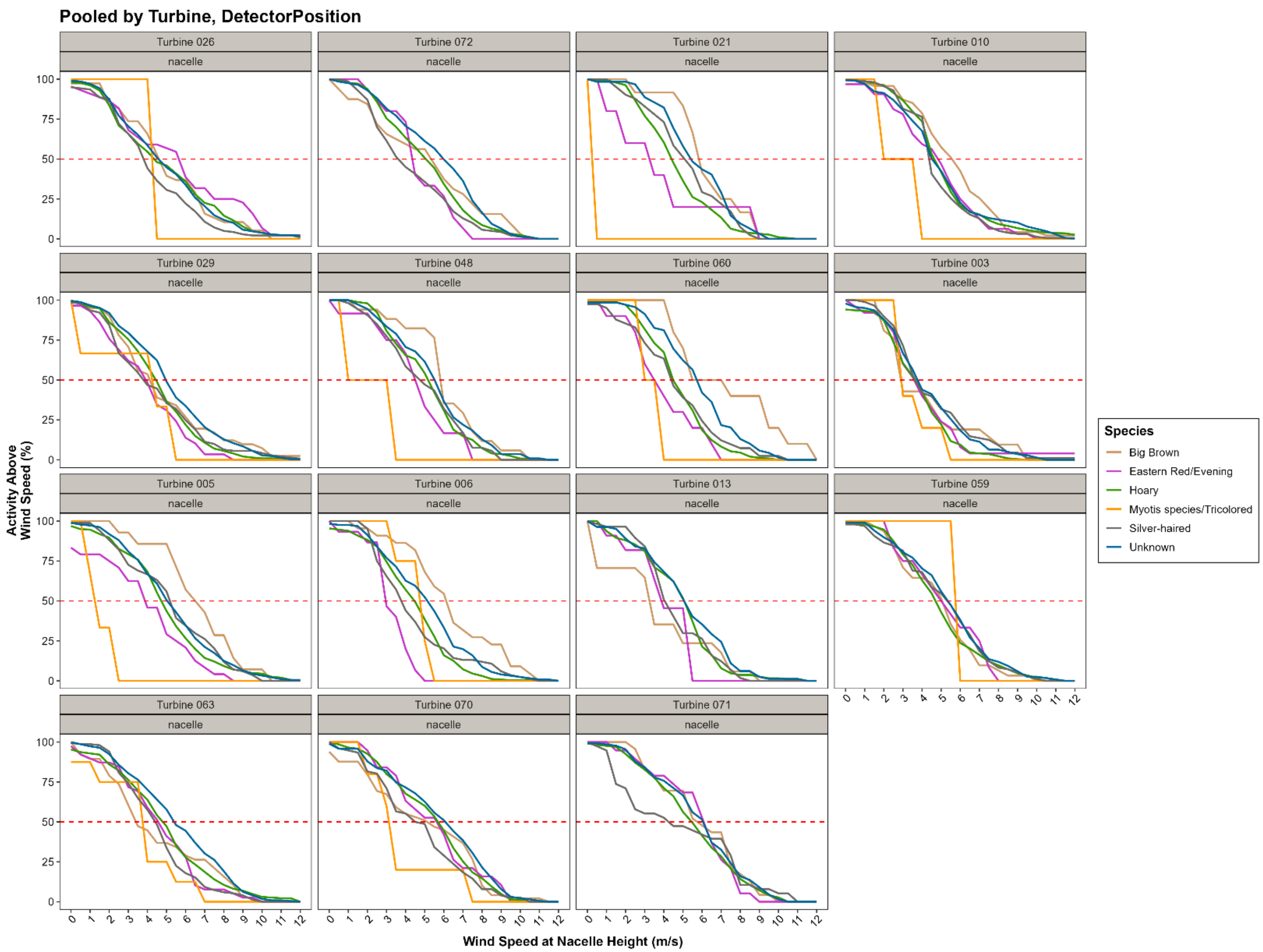
Appendix G Figure 7. Distribution of bat passes by species group as a function of wind speed at North English during 2022–2023 monitoring.



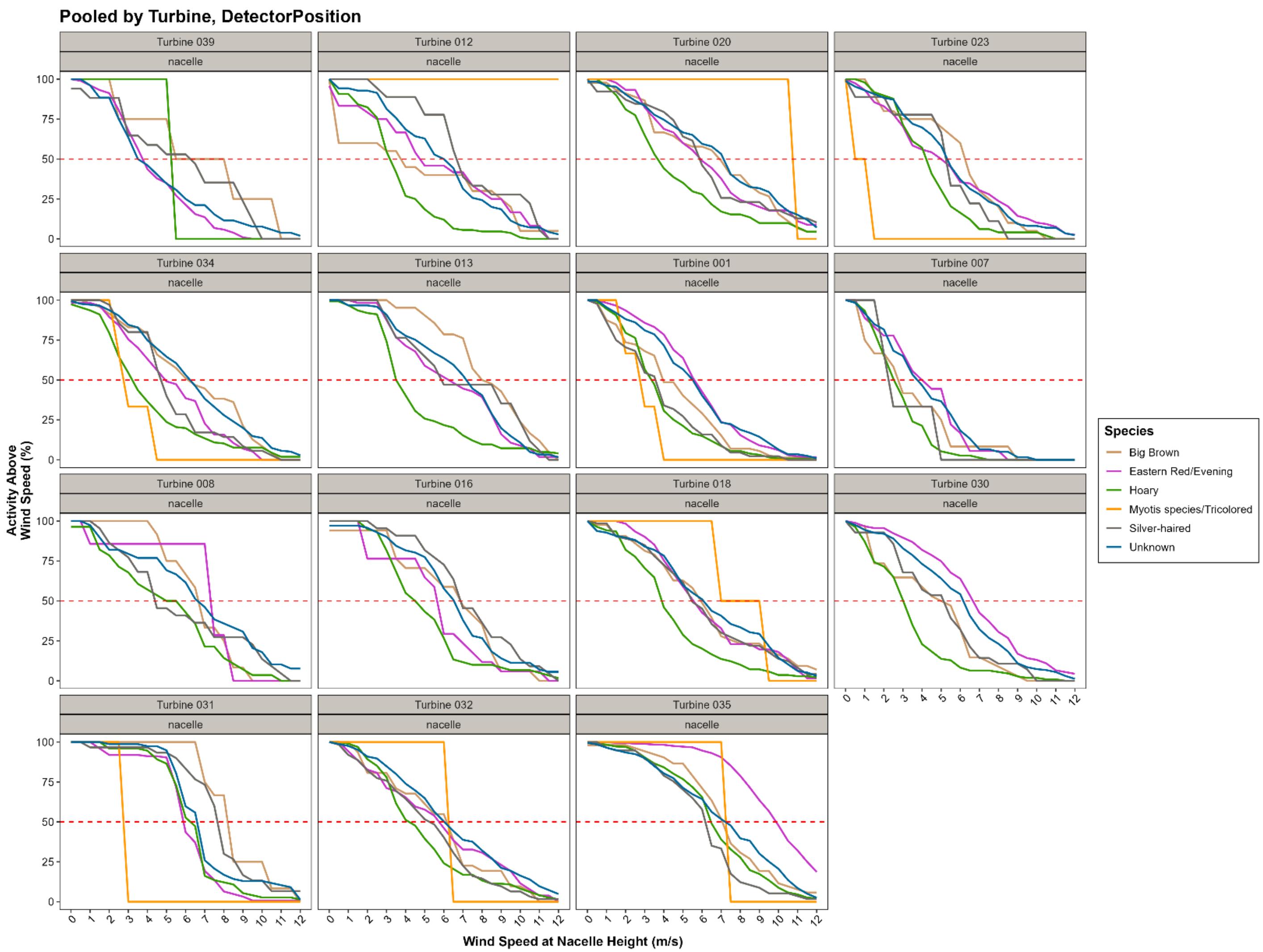
Appendix G Figure 8. Distribution of bat passes by species group as a function of wind speed at Orient during 2021–2023 monitoring.



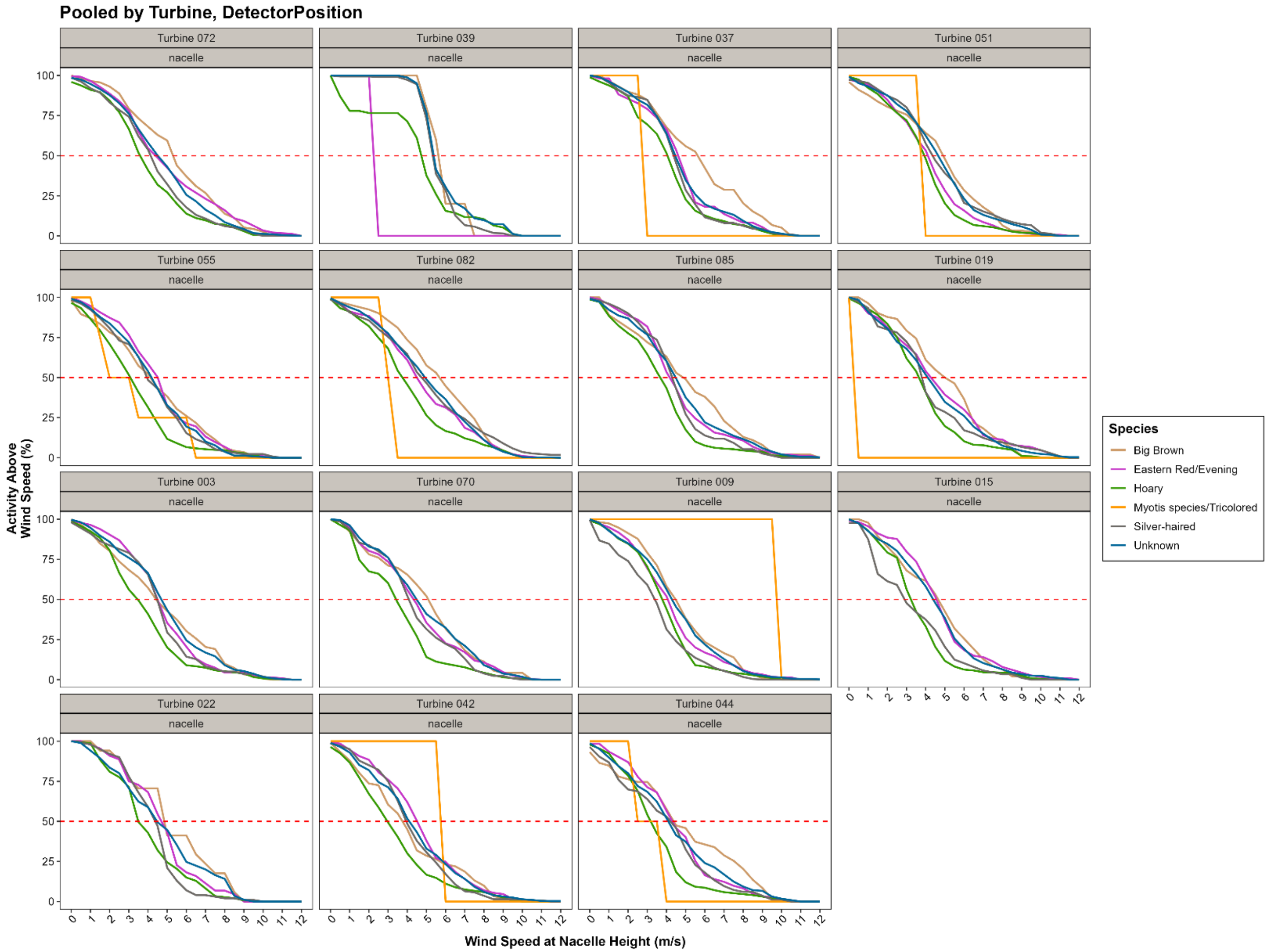
Appendix G Figure 9. Distribution of bat passes by species group as a function of wind speed at Palo Alto during 2022–2023 monitoring.



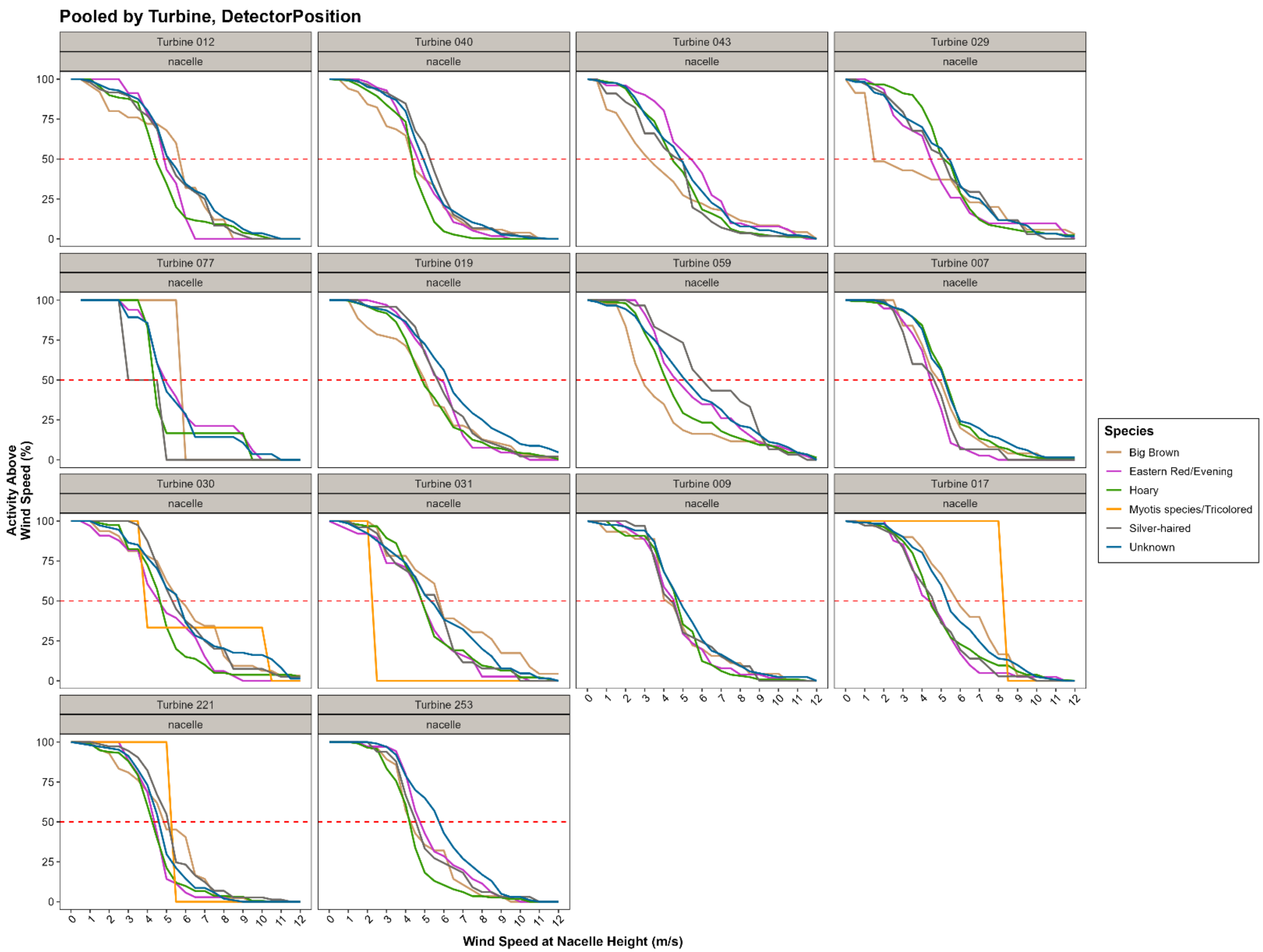
Appendix G Figure 10. Distribution of bat passes by species group as a function of wind speed at Plymouth during 2022–2023 monitoring.



Appendix G Figure 11. Distribution of bat passes by species group as a function of wind speed at Pocahontas Prairie during 2022–2023 monitoring.

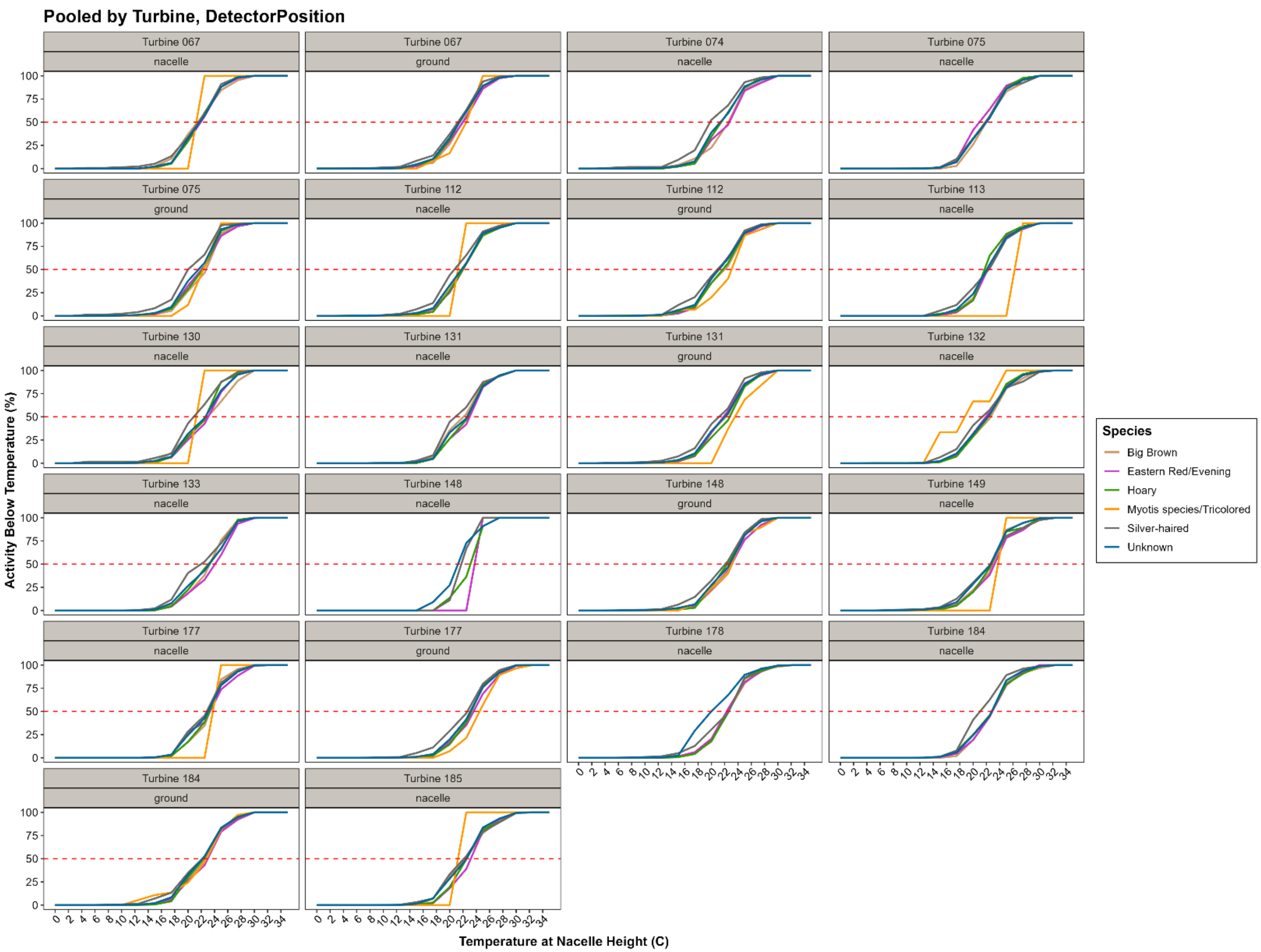


Appendix G Figure 12. Distribution of bat passes by species group as a function of wind speed at Prairie during 2022–2023 monitoring.

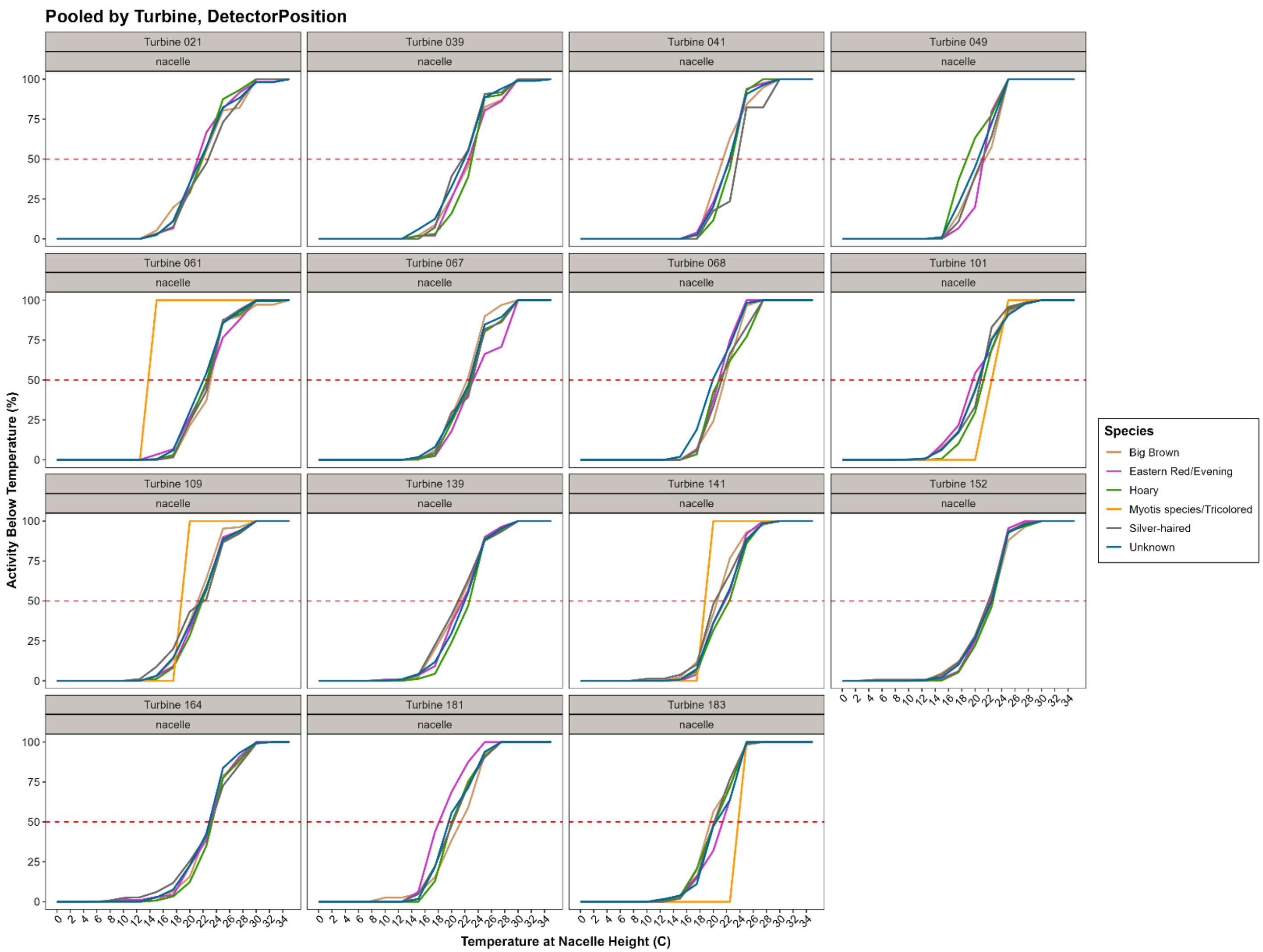


Appendix G Figure 13. Distribution of bat passes by species group as a function of wind speed at Southern Hills during 2022–2023 monitoring.

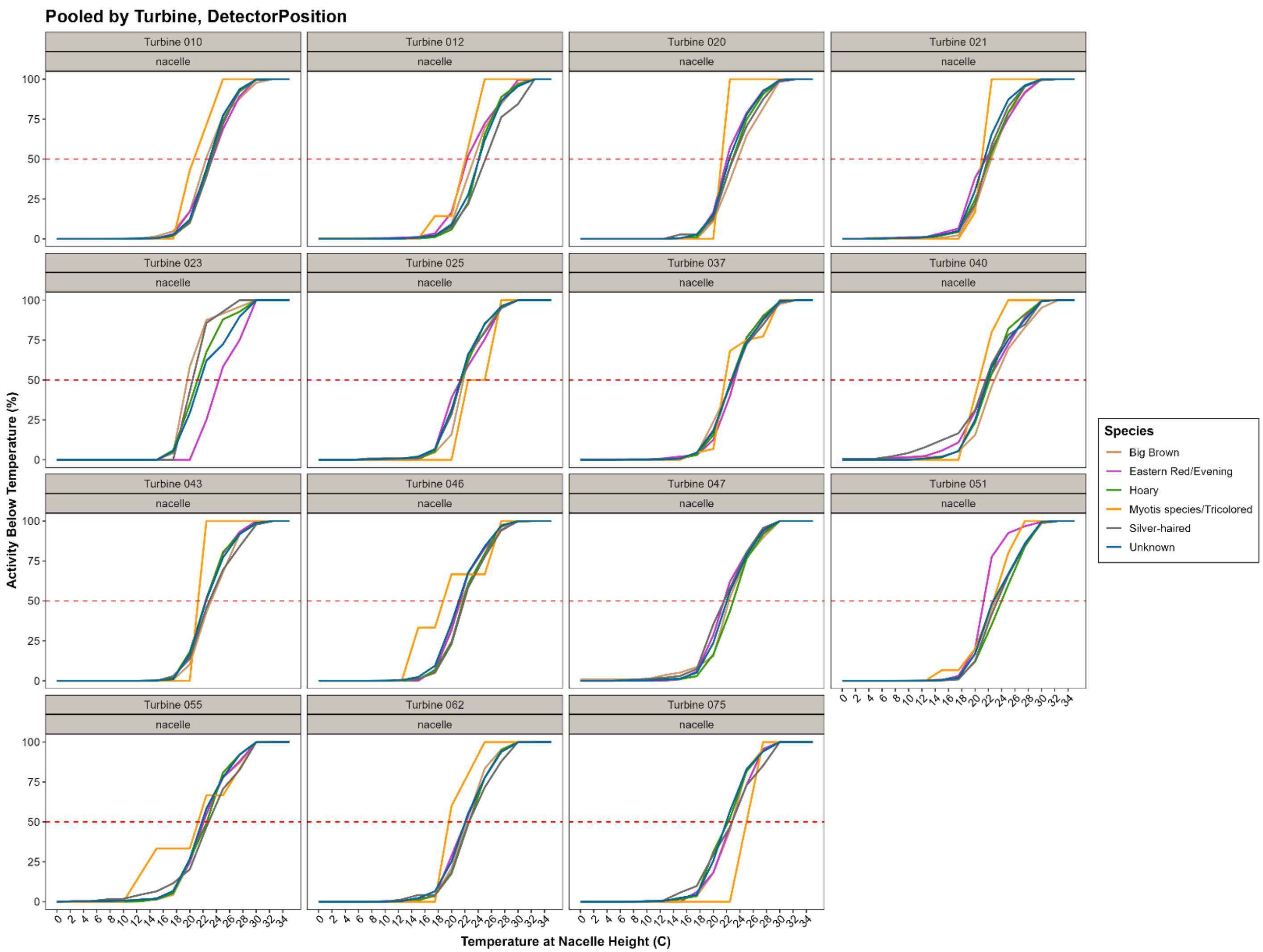
Appendix H



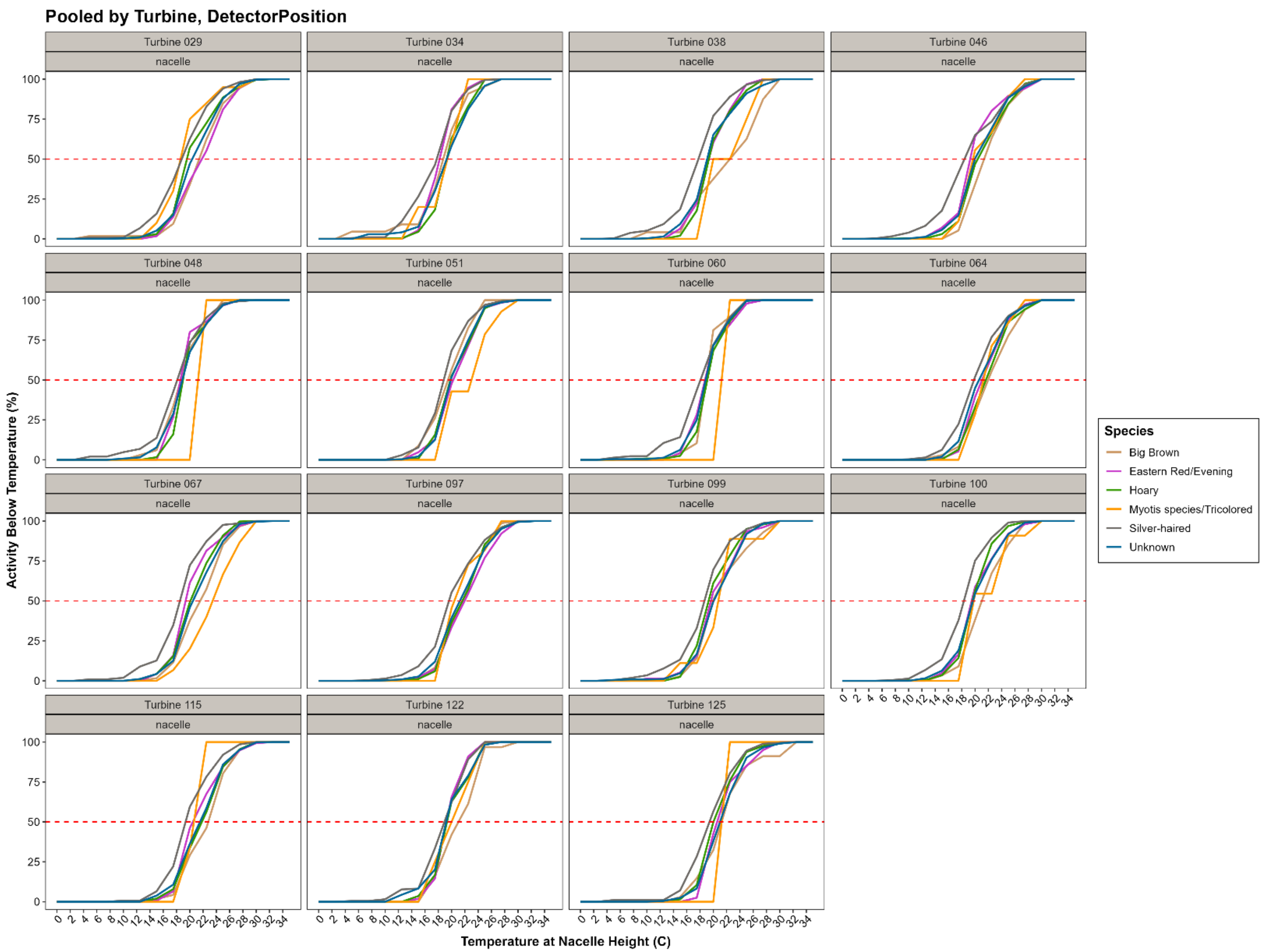
Appendix H Figure 1. Distribution of bat passes by species group as a function of temperature at Arbor Hill during 2021–2023 monitoring.



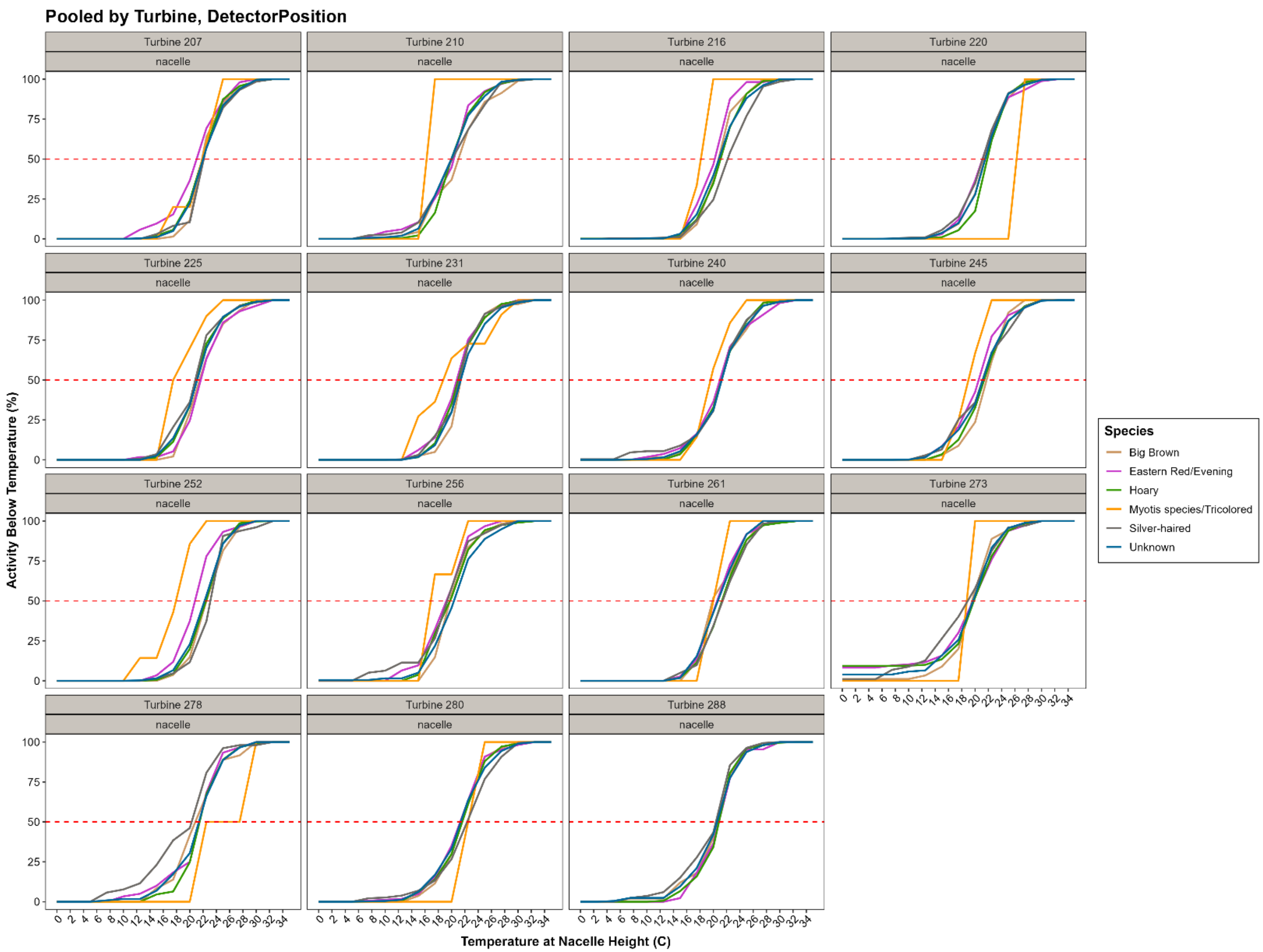
Appendix H Figure 2. Distribution of bat passes by species group as a function of temperature at Beaver Creek during 2022–2023 monitoring.



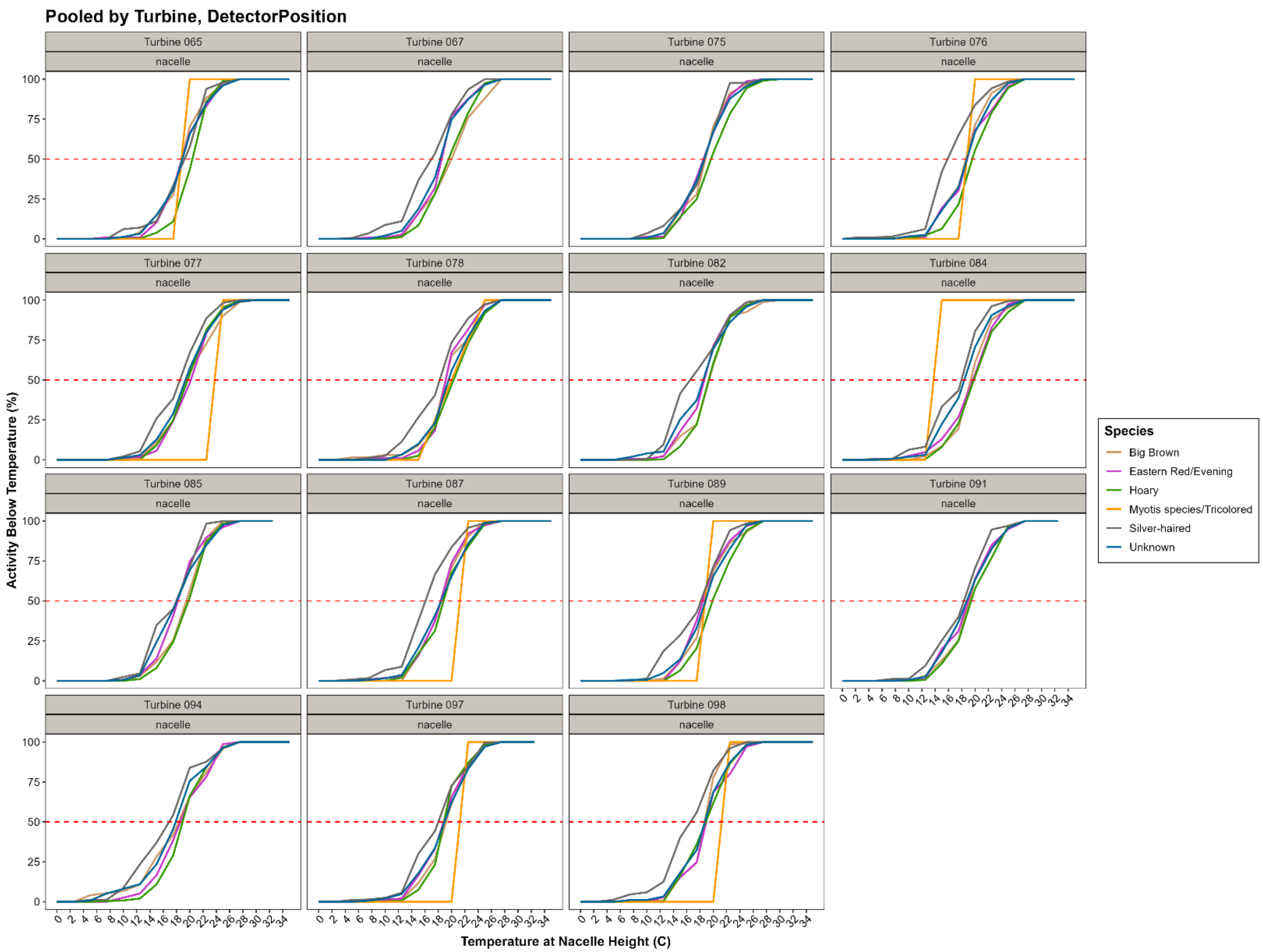
Appendix H Figure 3. Distribution of bat passes by species group as a function of temperature at Contrail during 2022–2023 monitoring.



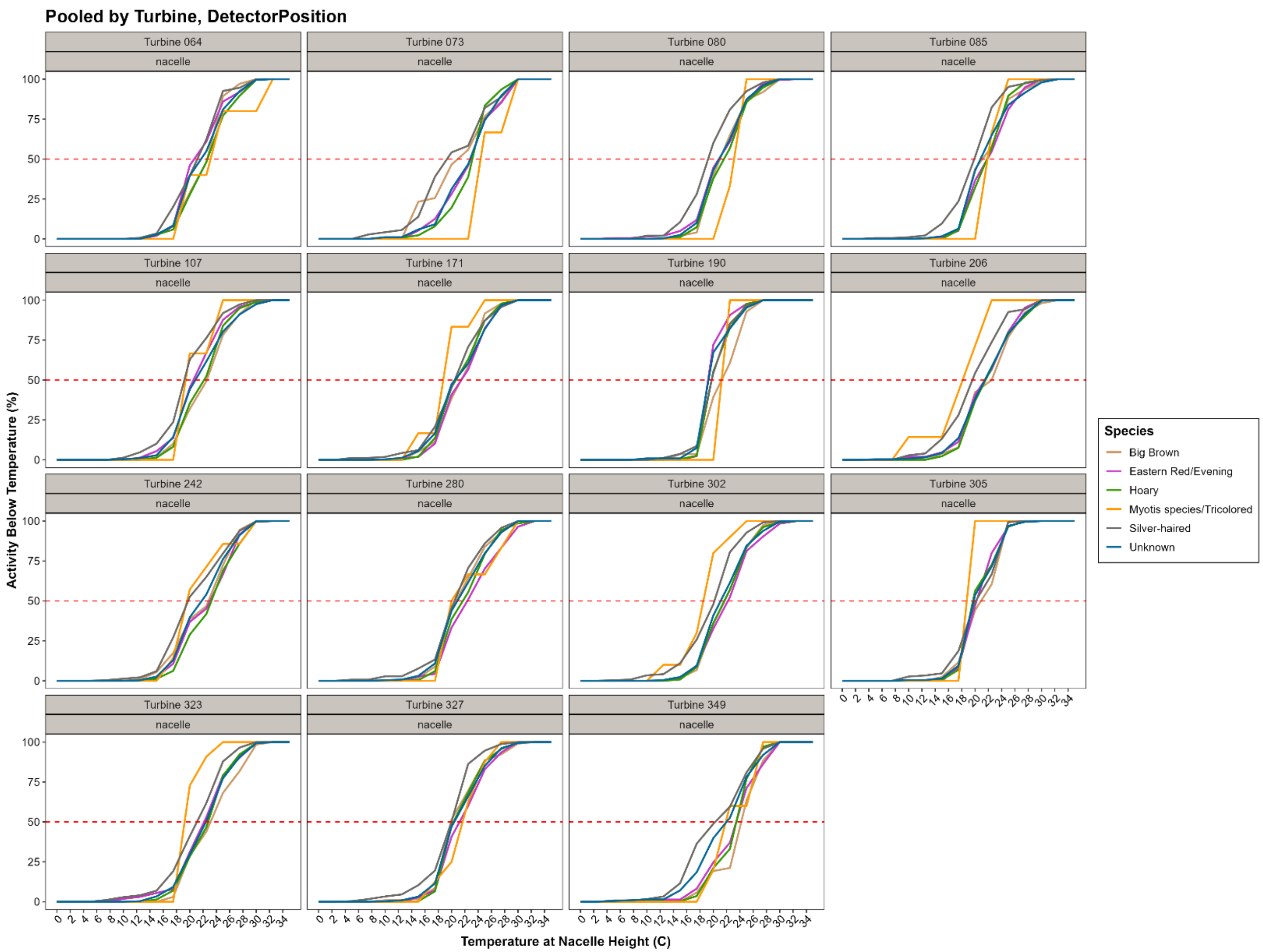
Appendix H Figure 4. Distribution of bat passes by species group as a function of temperature at Diamond Trail during 2022–2023 monitoring.



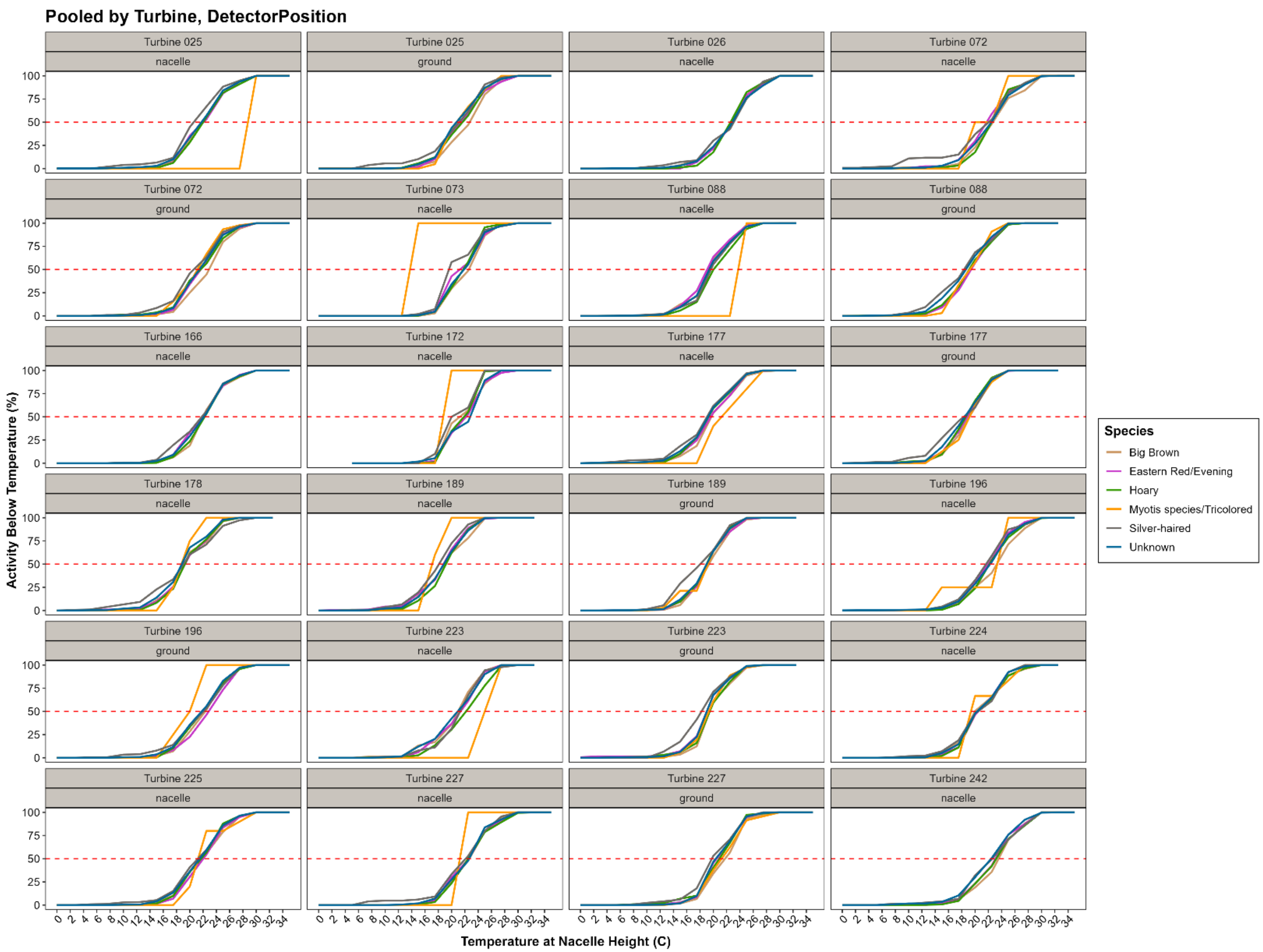
Appendix H Figure 5. Distribution of bat passes by species group as a function of temperature at Ida Grove during 2022–2023 monitoring.



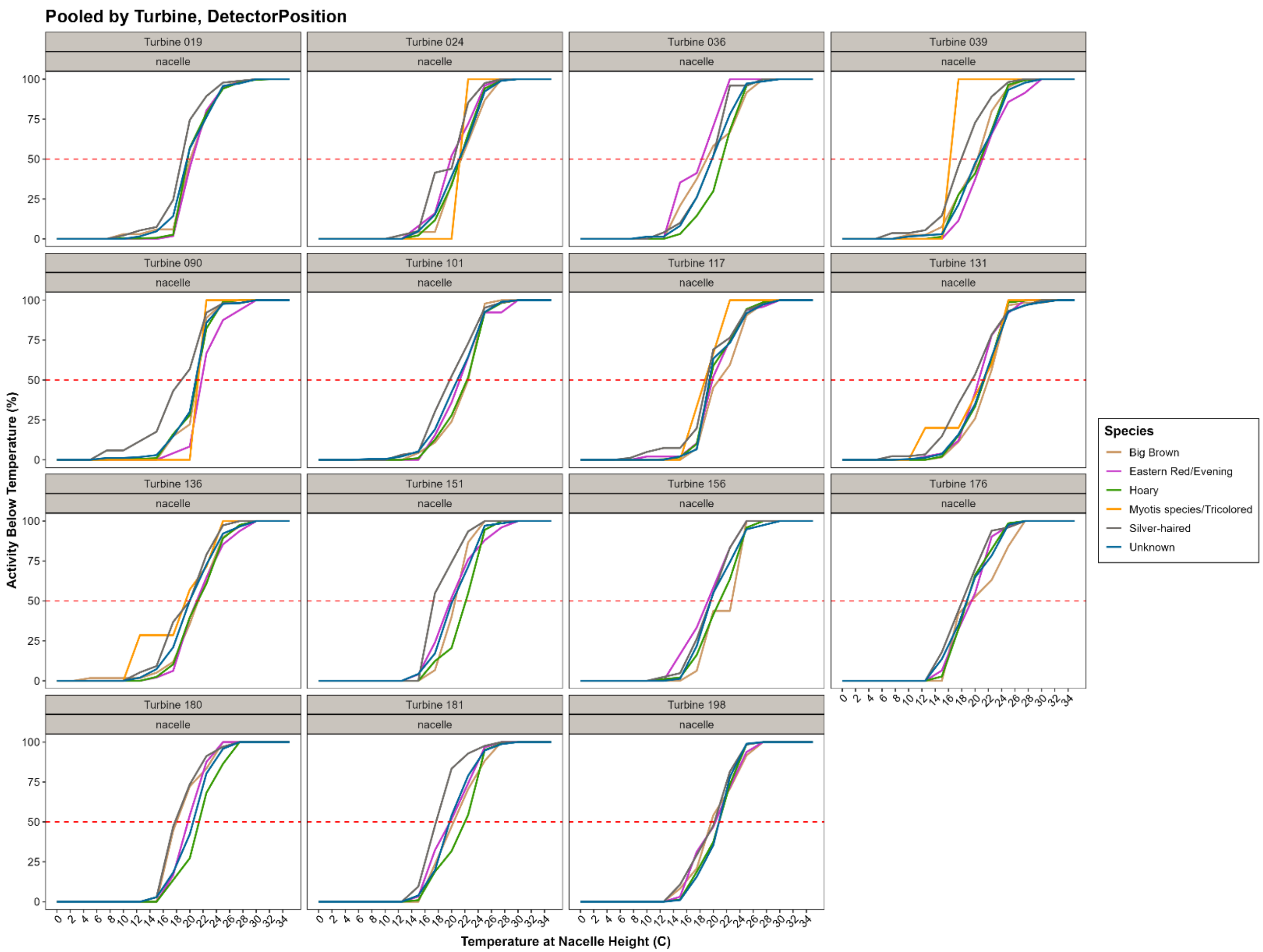
Appendix H Figure 6. Distribution of bat passes by species group as a function of temperature at Ivester during 2022–2023 monitoring.



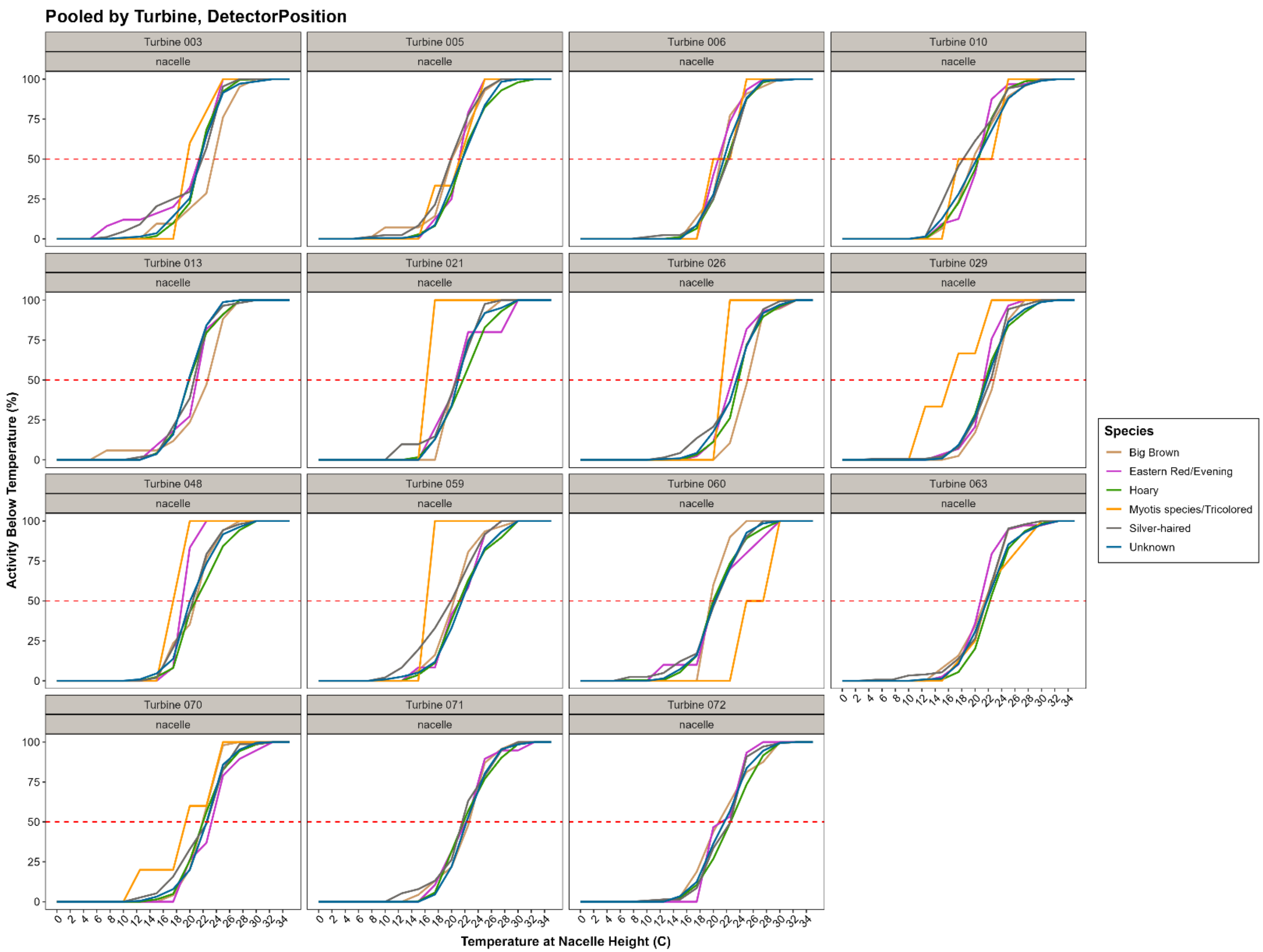
Appendix H Figure 7. Distribution of bat passes by species group as a function of temperature at North English during 2022–2023 monitoring.



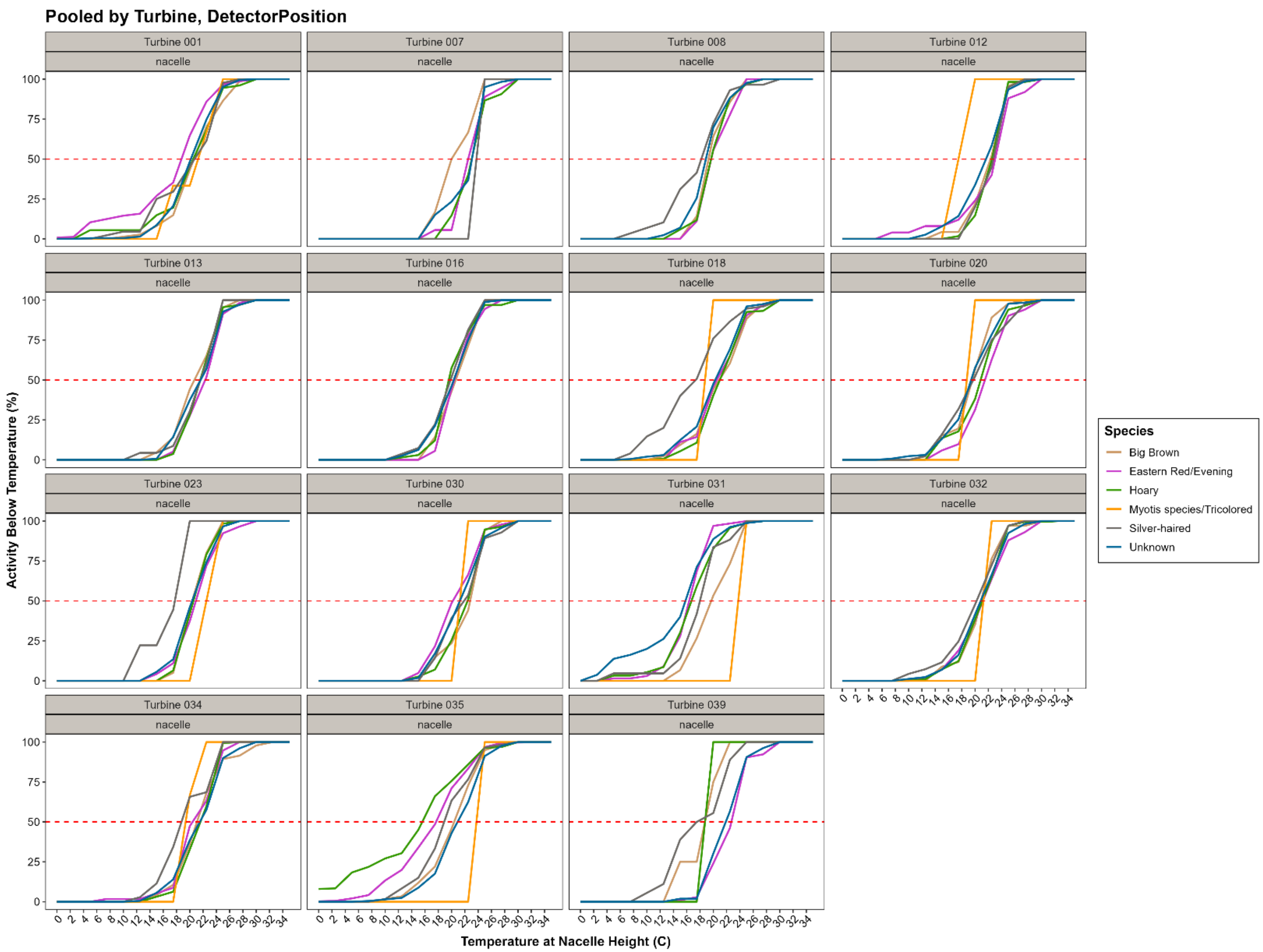
Appendix H Figure 8. Distribution of bat passes by species group as a function of temperature at Orient during 2021–2023 monitoring.



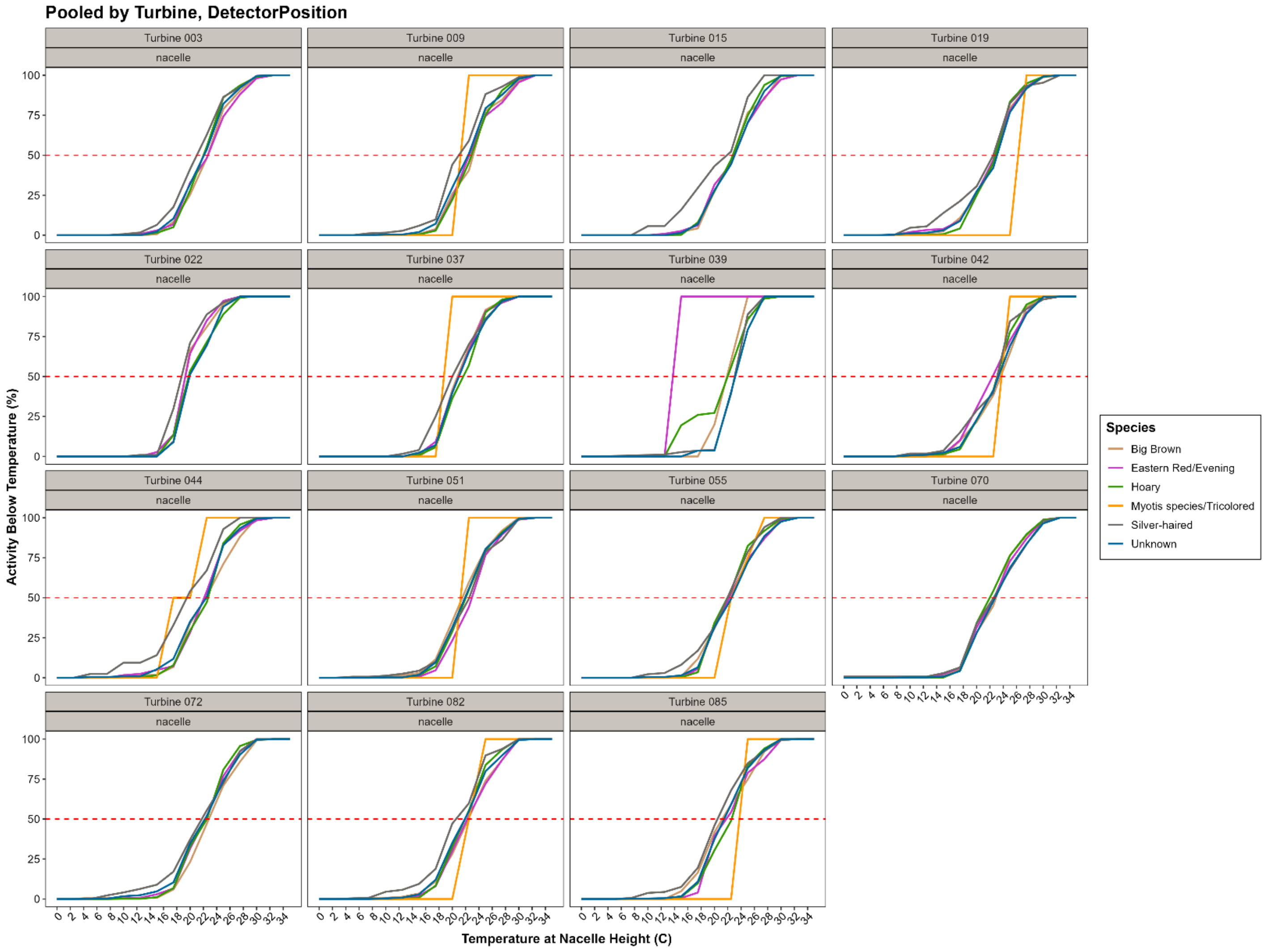
Appendix H Figure 9. Distribution of bat passes by species group as a function of temperature at Palo Alto during 2022–2023 monitoring.



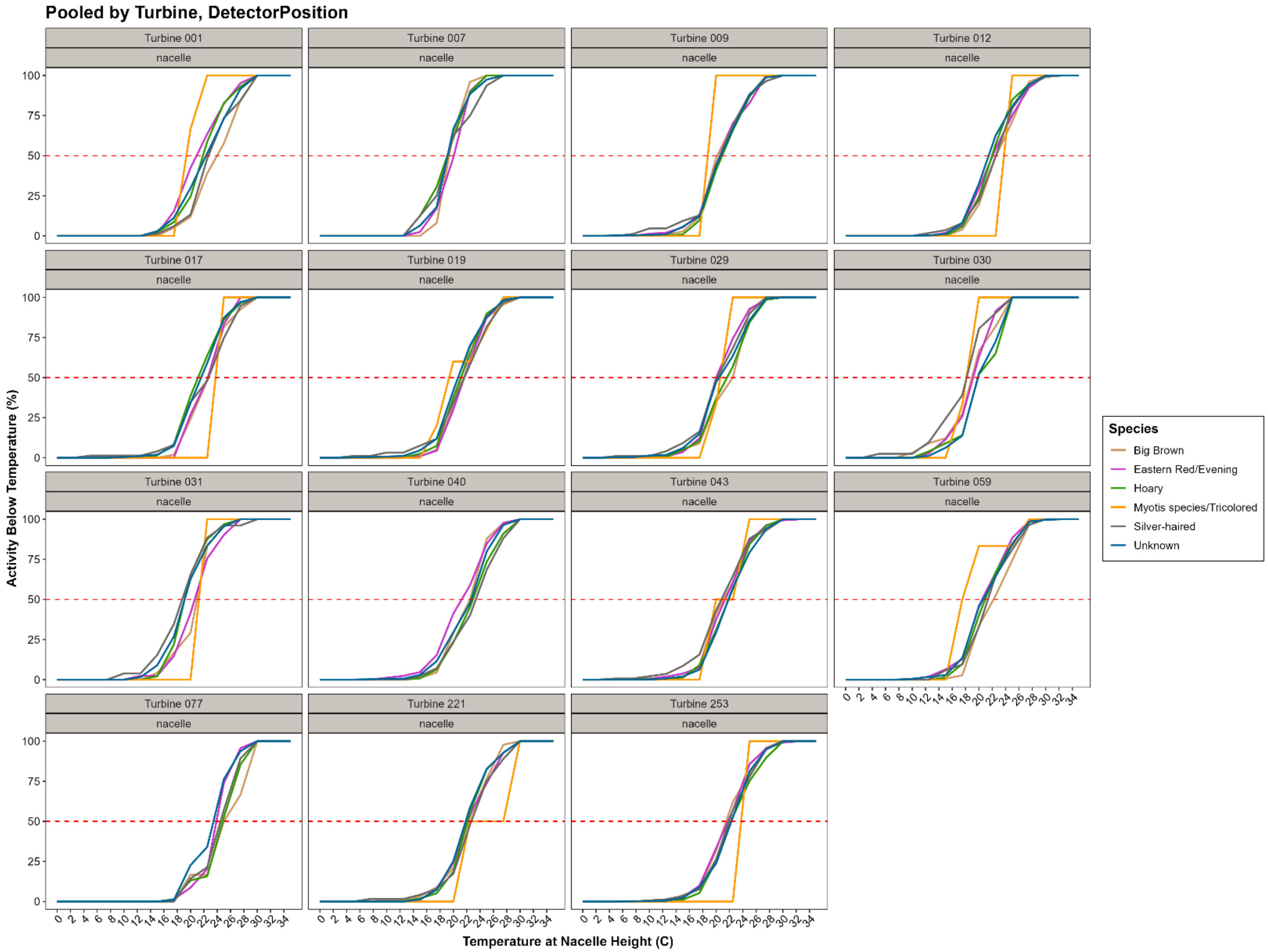
Appendix H Figure 10. Distribution of bat passes by species group as a function of temperature at Plymouth during 2022–2023 monitoring.



Appendix H Figure 11. Distribution of bat passes by species group as a function of temperature at Pocahontas Prairie during 2022–2023 monitoring.

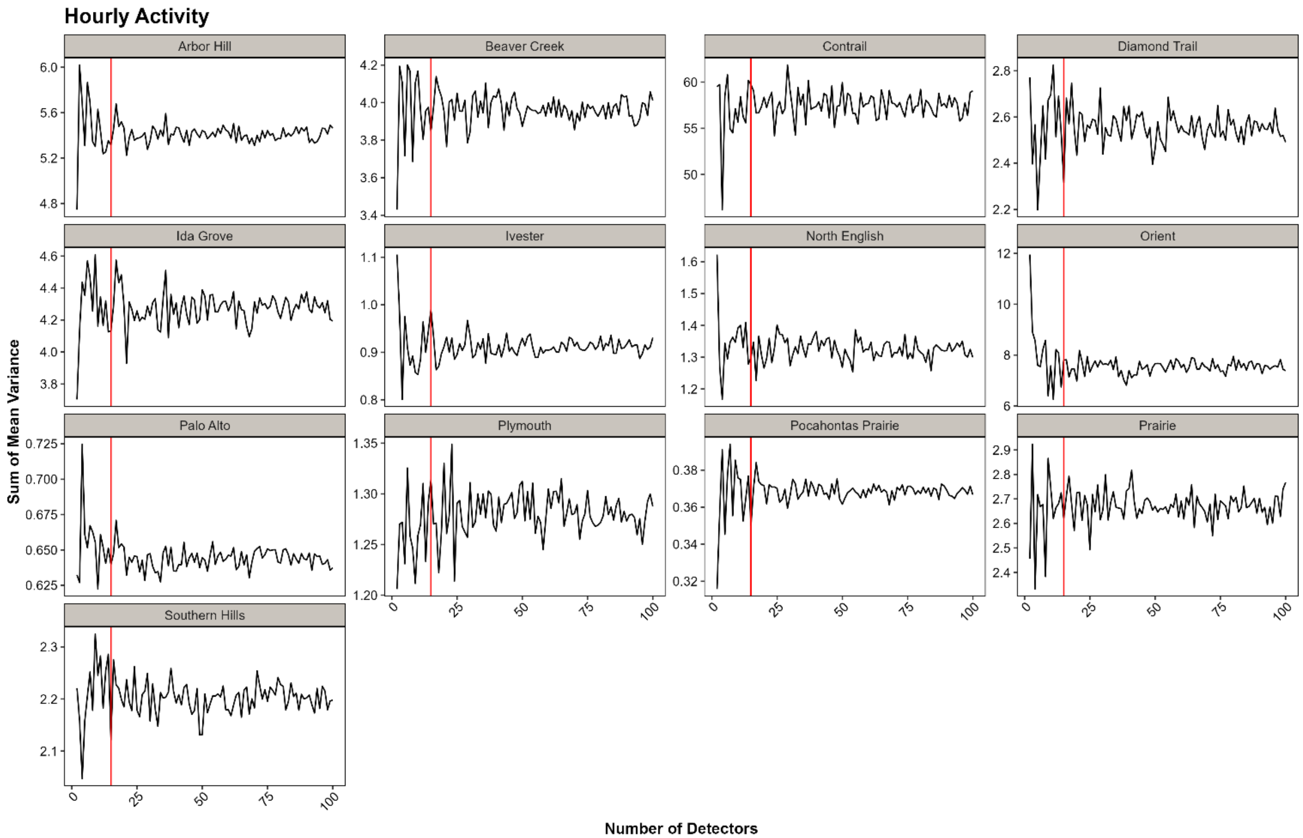


Appendix H Figure 12. Distribution of bat passes by species group as a function of temperature at Prairie during 2022–2023 monitoring.

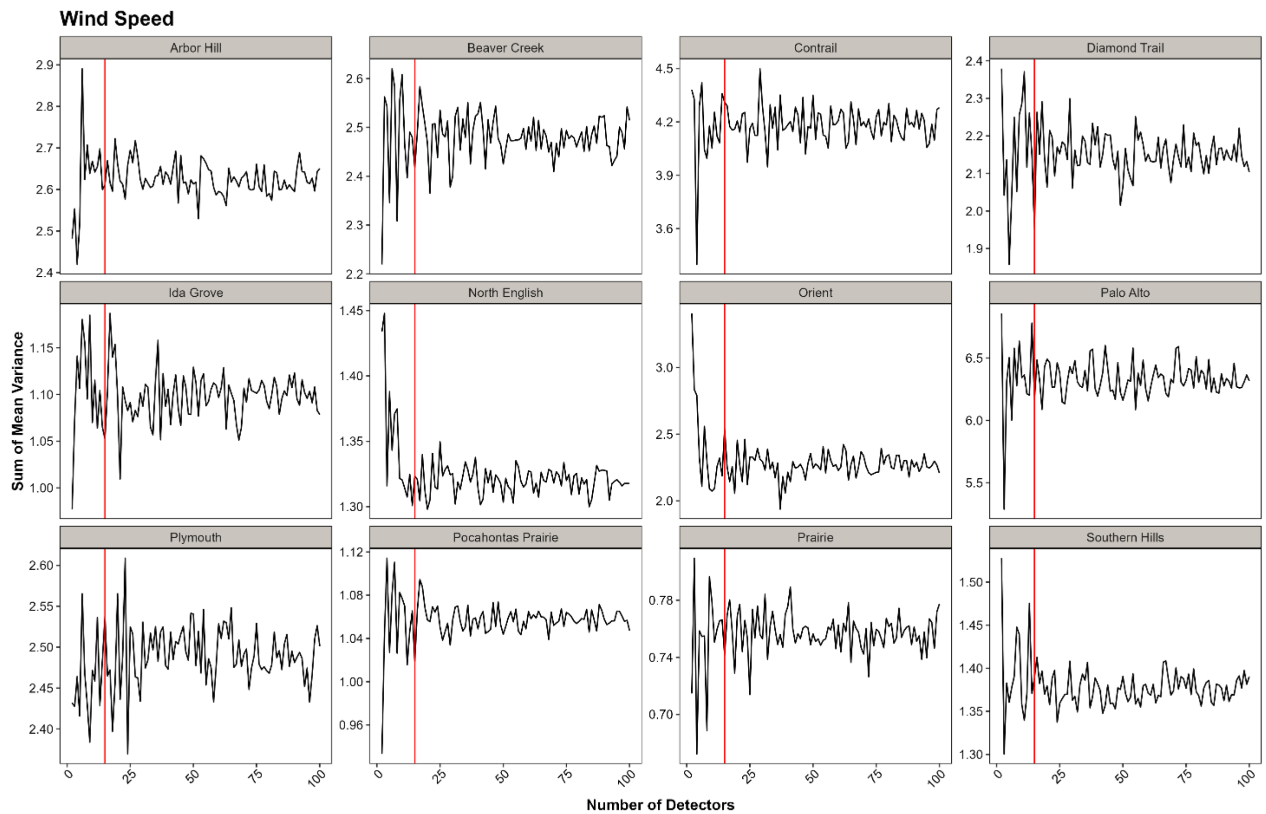


Appendix H Figure 13. Distribution of bat passes by species group as a function of temperature at Southern Hills during 2022–2023 monitoring.

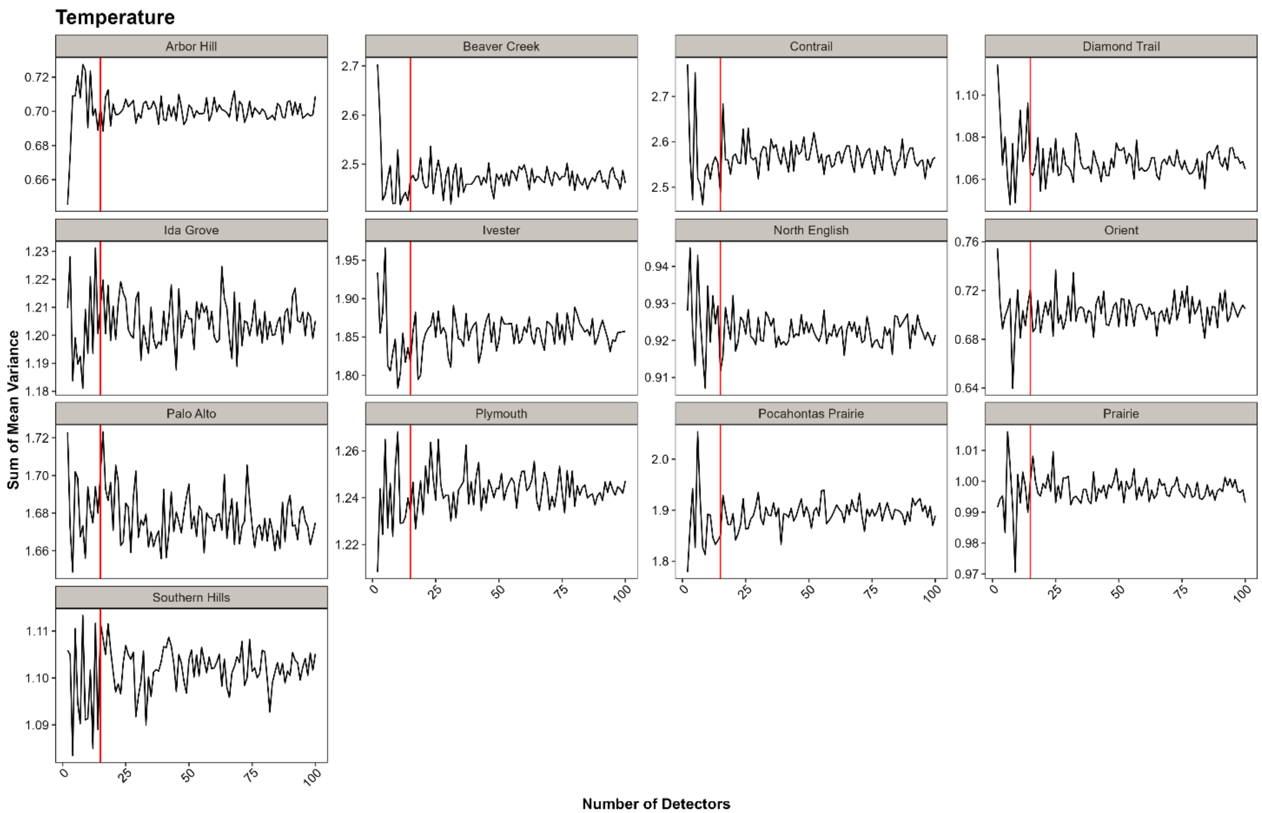
Appendix I



Appendix I Figure 1. Sum of mean variance in hourly distribution of bat activity as a function of bootstrapped number of samples (red line indicates 15 samples) drawn from nacelle-height detectors at MidAmerican wind energy facilities in Iowa from 2021–2023.



Appendix I Figure 2. Sum of mean variance in wind speed-related distribution of bat activity as a function of bootstrapped number of samples (red line indicates 15 samples) drawn from nacelle-height detectors at MidAmerican wind energy facilities in Iowa from 2021–2023.



Appendix I Figure 3. Sum of mean variance in temperature-related distribution of bat activity as a function of bootstrapped number of samples (red line indicates 15 samples) drawn from nacelle-height detectors at MidAmerican wind energy facilities in Iowa from 2021–2023.

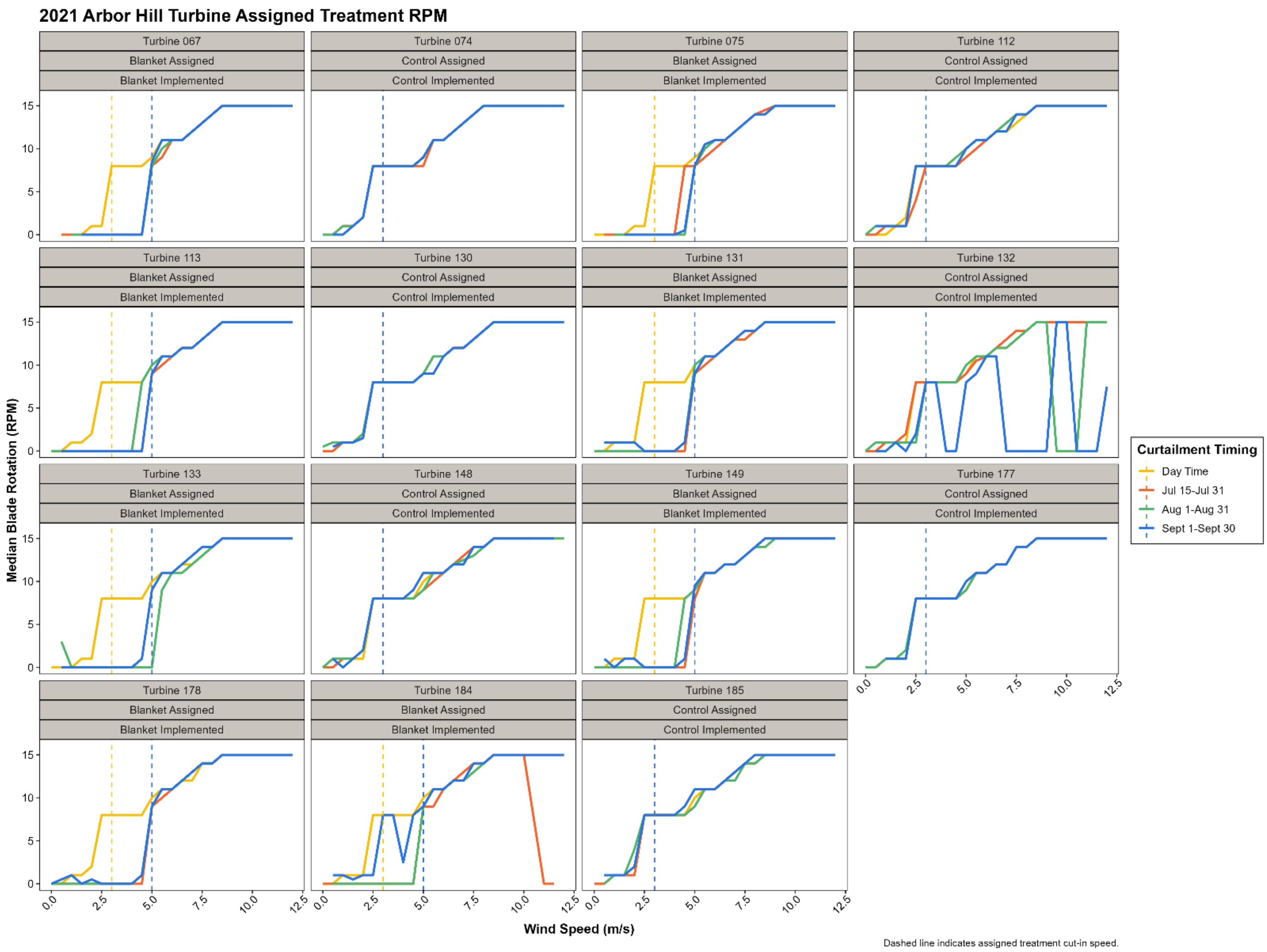
Appendix I Table 1. Number and percent of nightly 10-minute intervals where bats were present and absent at each wind energy facility.

Site	Present	Absent
Arbor Hill	12,678 (4.44%)	272,696 (95.56%)
Beaver Creek	5,938 (4.89%)	115,476 (95.11%)
Contrail	16,812 (8.82%)	173,804 (91.18%)
Diamond Trail	9,332 (4.74%)	187,456 (95.26%)
Ida Grove	10,987 (5.02%)	207,962 (94.98%)
Ivester	7,398 (3.03%)	237,005 (96.97%)
North English	6,258 (3.42%)	176,736 (96.58%)
Orient	13,634 (3.9%)	335,811 (96.1%)
Palo Alto	3,148 (1.86%)	166,244 (98.14%)
Plymouth	5,406 (3.14%)	166,599 (96.86%)
Pocahontas Prairie	4,298 (2.63%)	159,306 (97.37%)
Prairie	9,839 (5.71%)	162,397 (94.29%)
Southern Hills	8,070 (4.34%)	177,896 (95.66%)

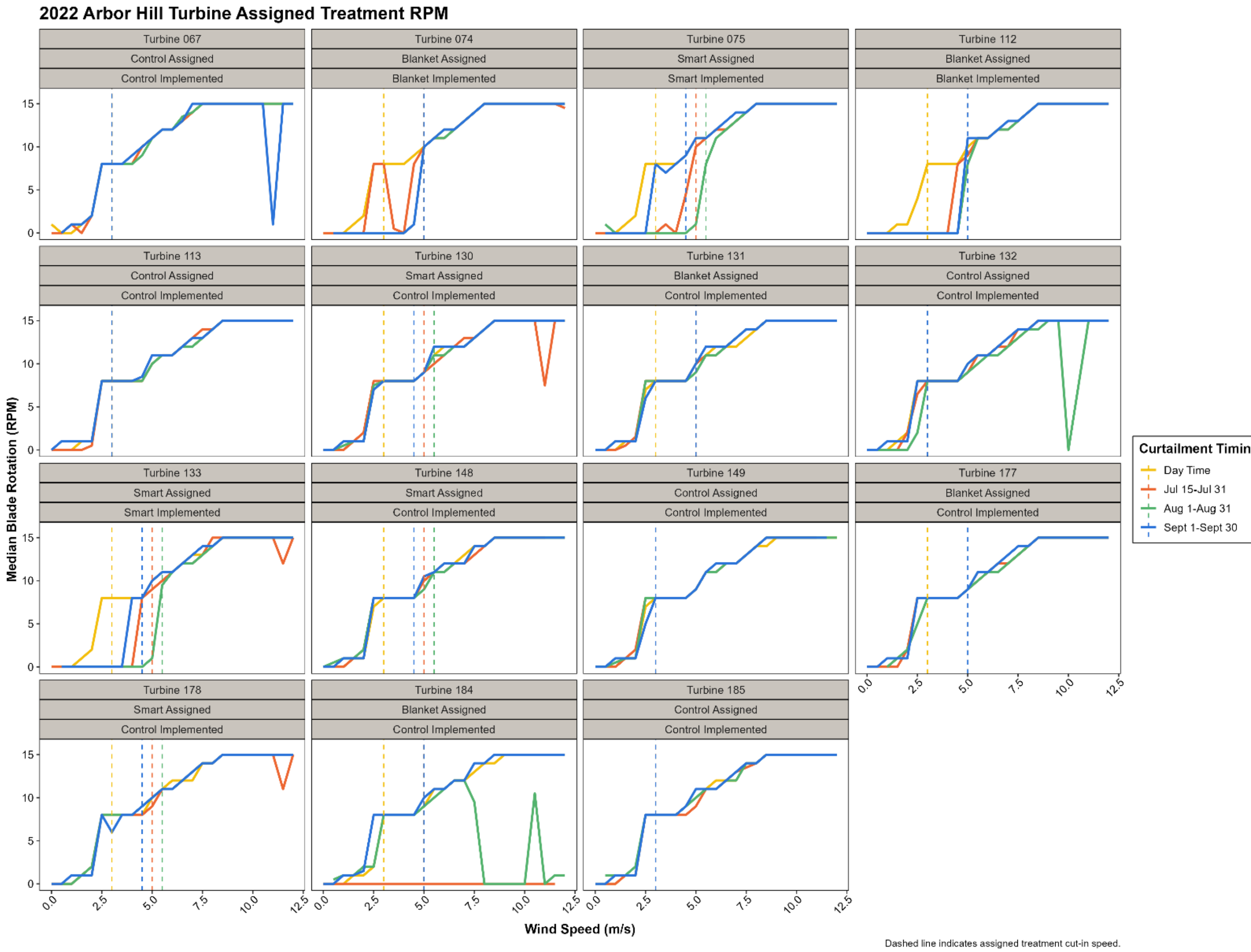
Appendix I Table 2. Random forest model classification error rates by site.

Site	Presence	Absence	Out of Bag
Arbor Hill	17.49%	24.26%	20.87%
Beaver Creek	18.58%	25.63%	22.10%
Contrail	15.69%	22.15%	18.92%
Diamond Trail	17.64%	24.05%	20.84%
Ida Grove	17.40%	24.67%	21.03%
Ivester	14.37%	19.67%	17.02%
North English	15.74%	22.04%	18.89%
Orient	17.72%	22.91%	20.32%
Palo Alto	16.14%	20.71%	18.42%
Plymouth	17.22%	23.10%	20.16%
Pocahontas Prairie	17.05%	23.55%	20.30%
Prairie	16.56%	24.57%	20.56%
Southern Hills	15.81%	20.41%	18.11%

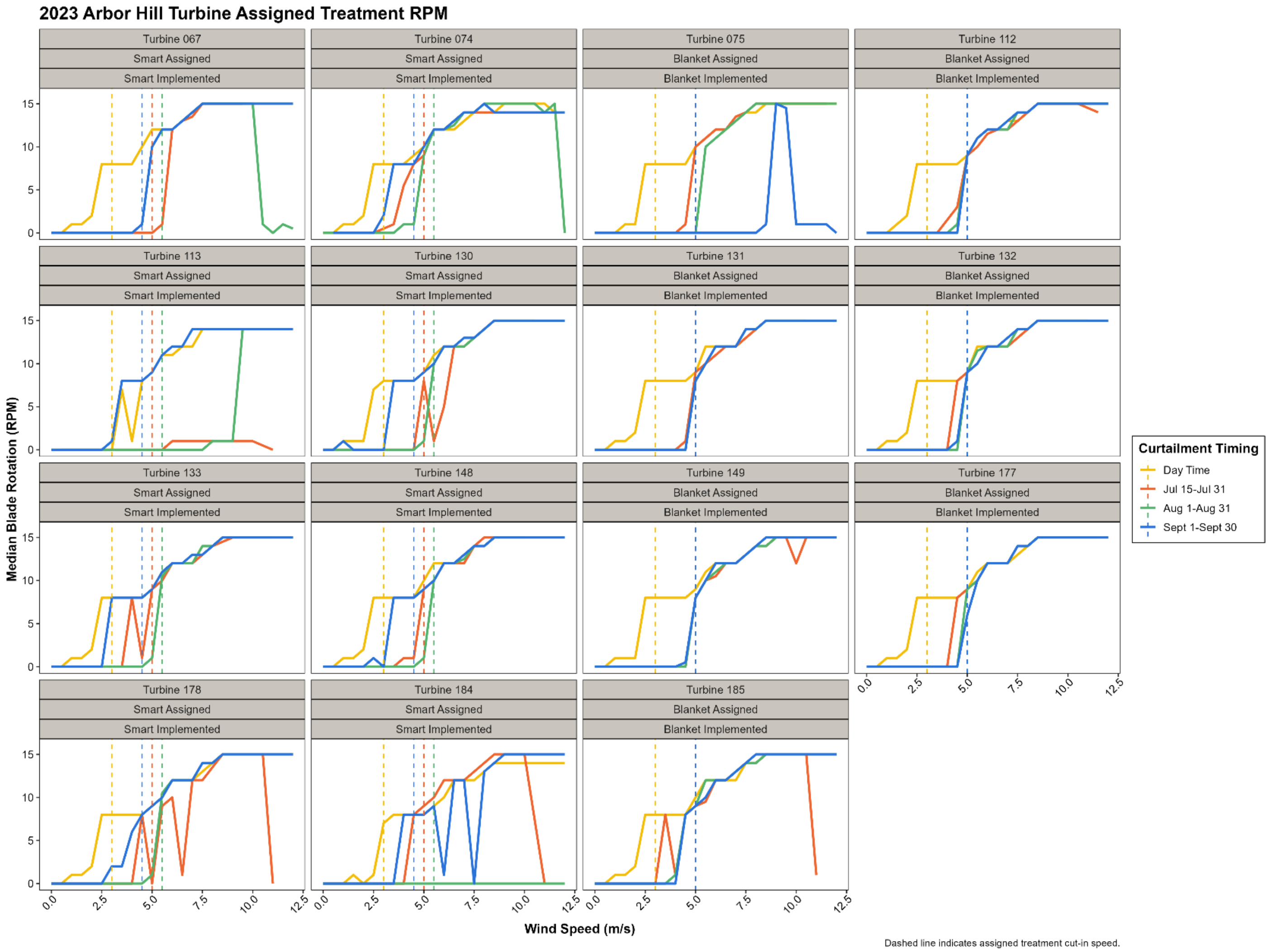
Appendix J



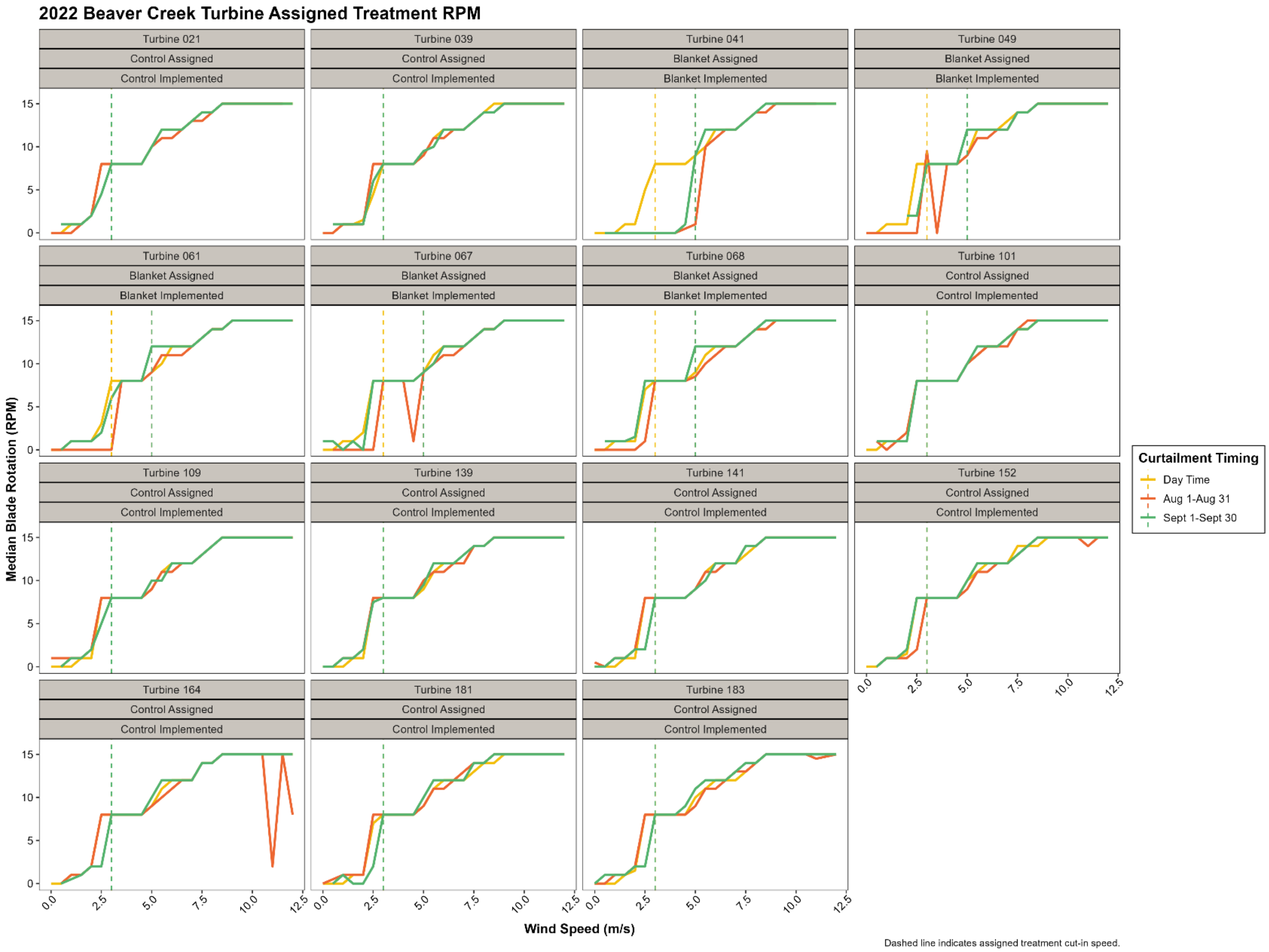
Appendix J Figure 1. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Arbor Hill in 2021.



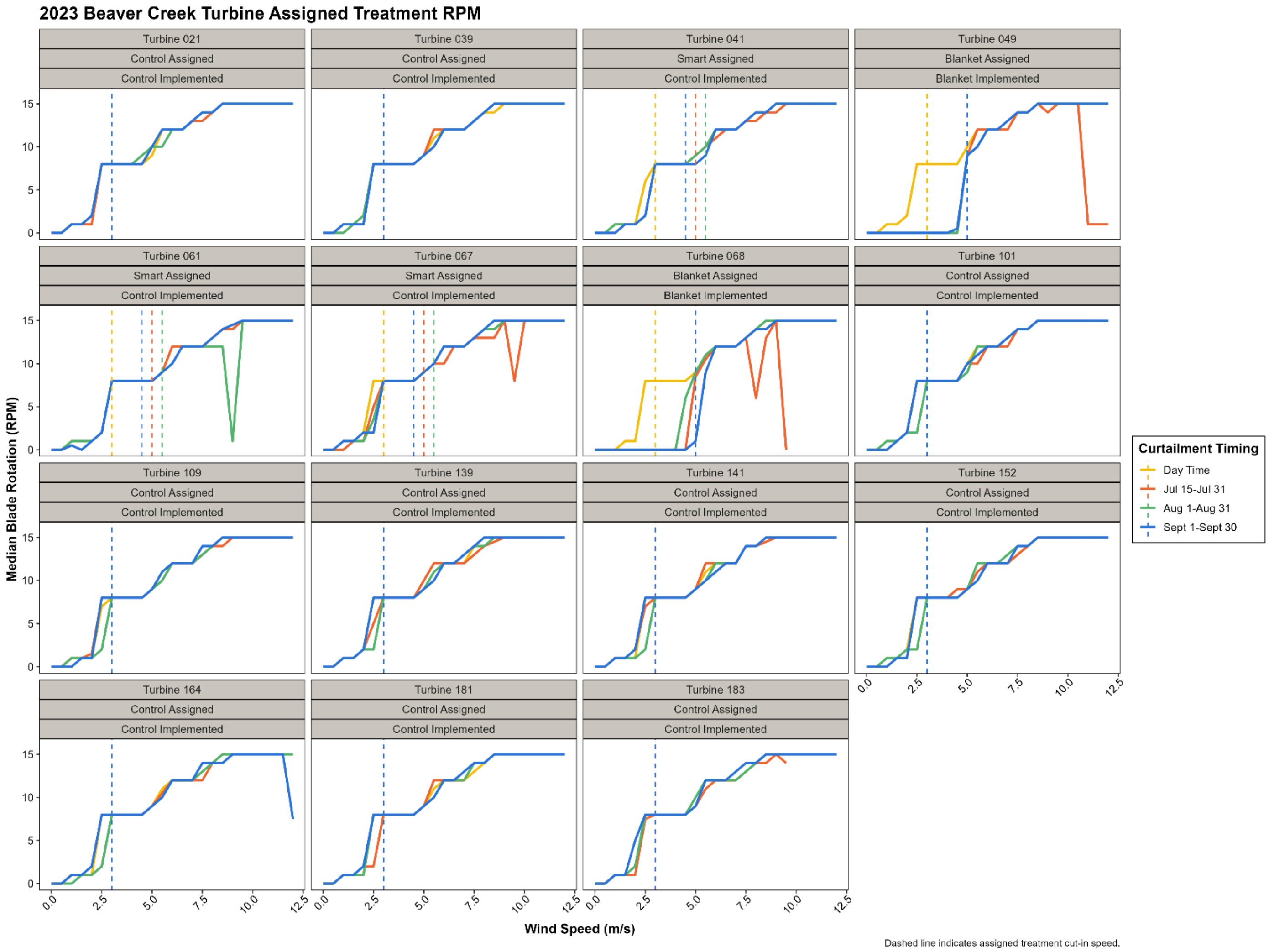
Appendix J Figure 2. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Arbor Hill in 2022.



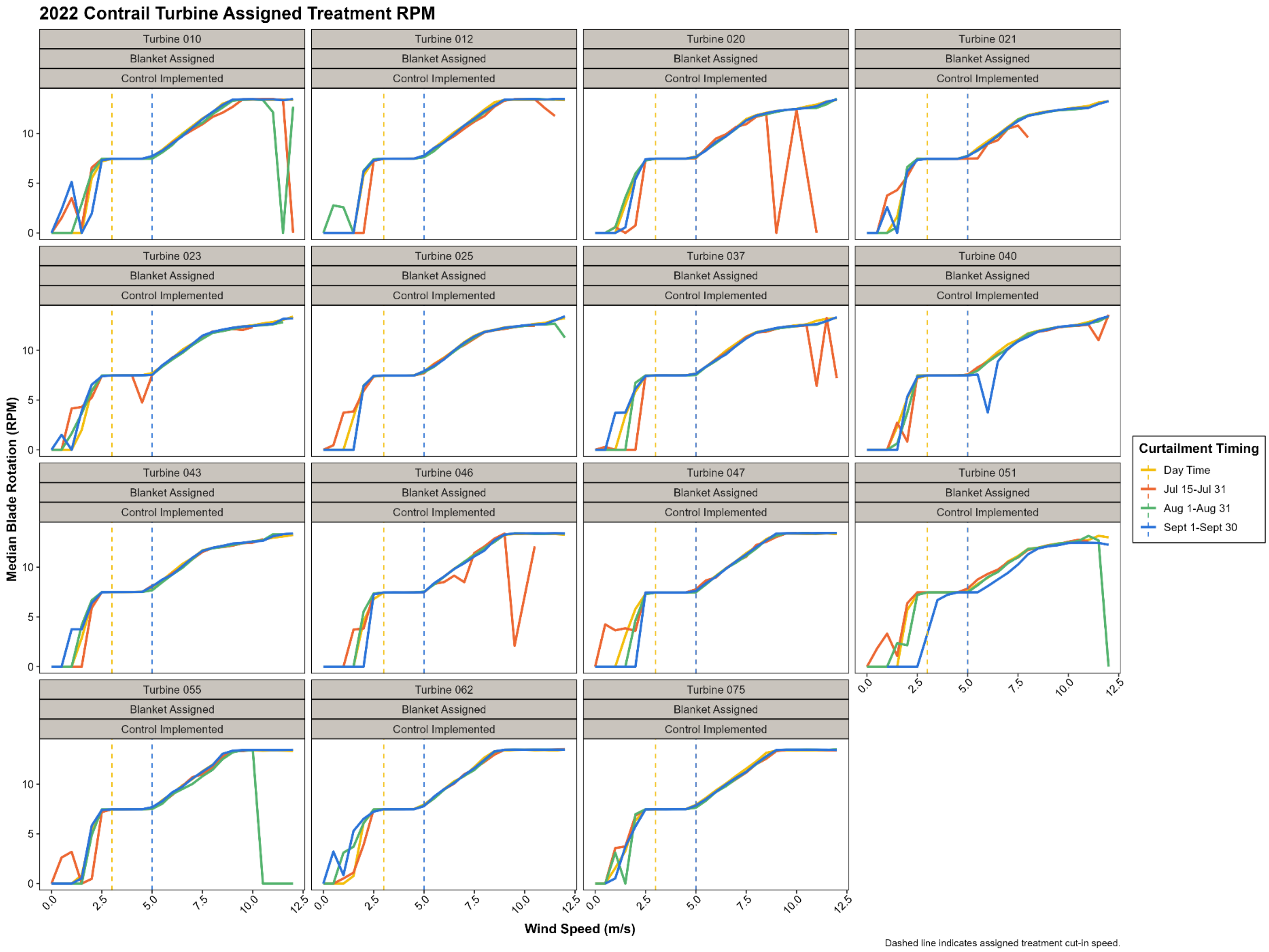
Appendix J Figure 3. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Arbor Hill in 2023.



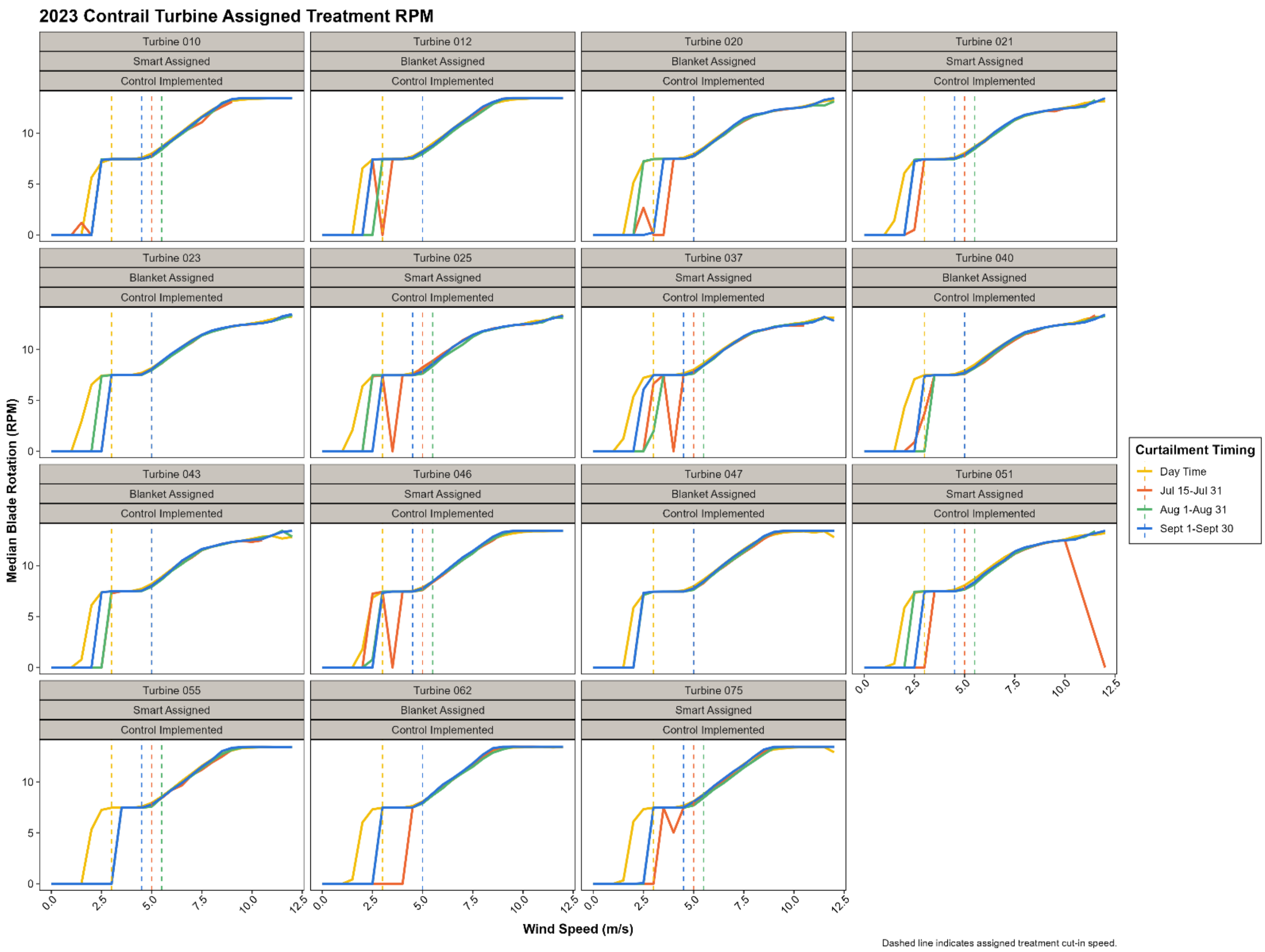
Appendix J Figure 4. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Beaver Creek in 2022.



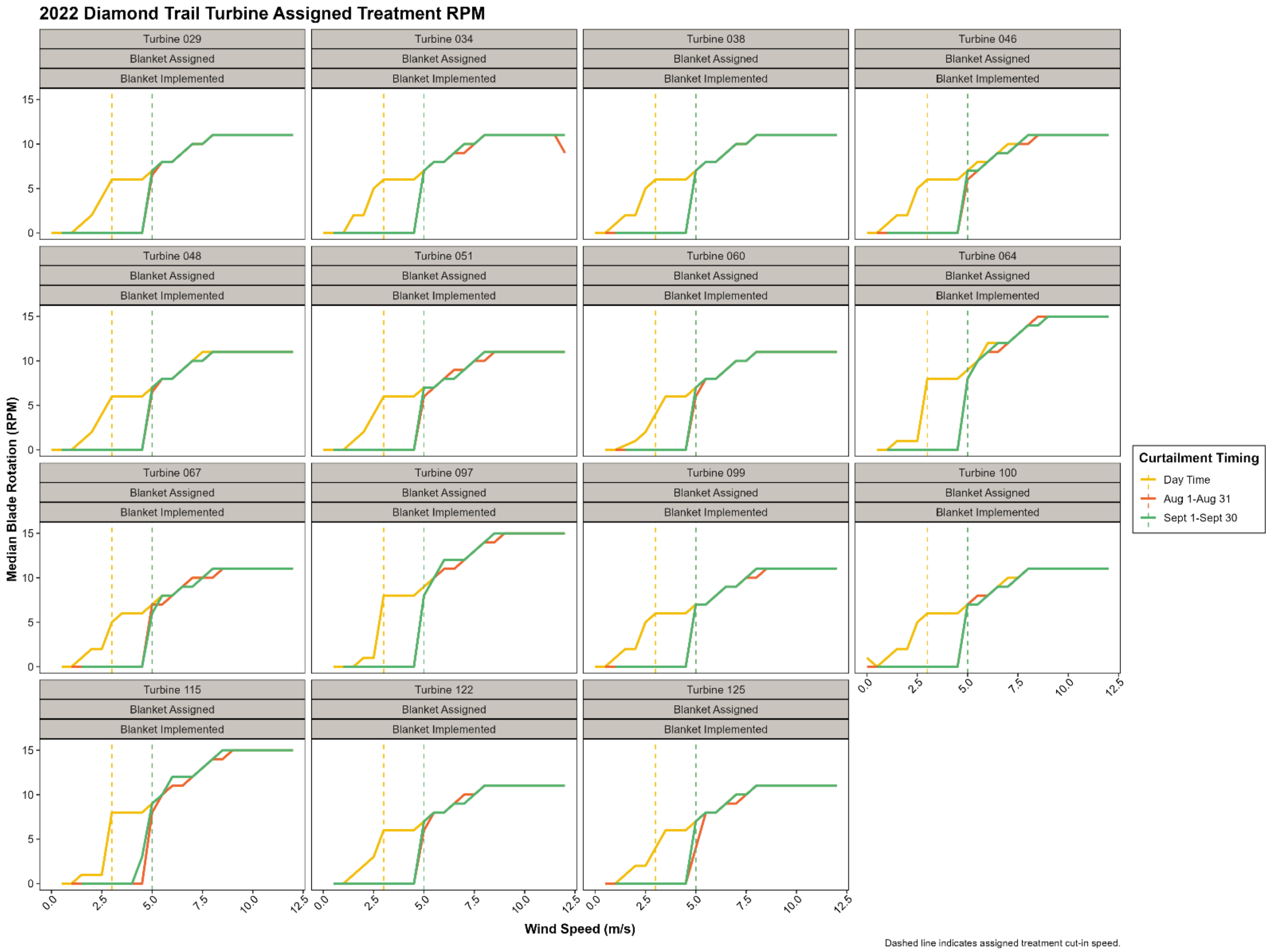
Appendix J Figure 5. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Beaver Creek in 2023.



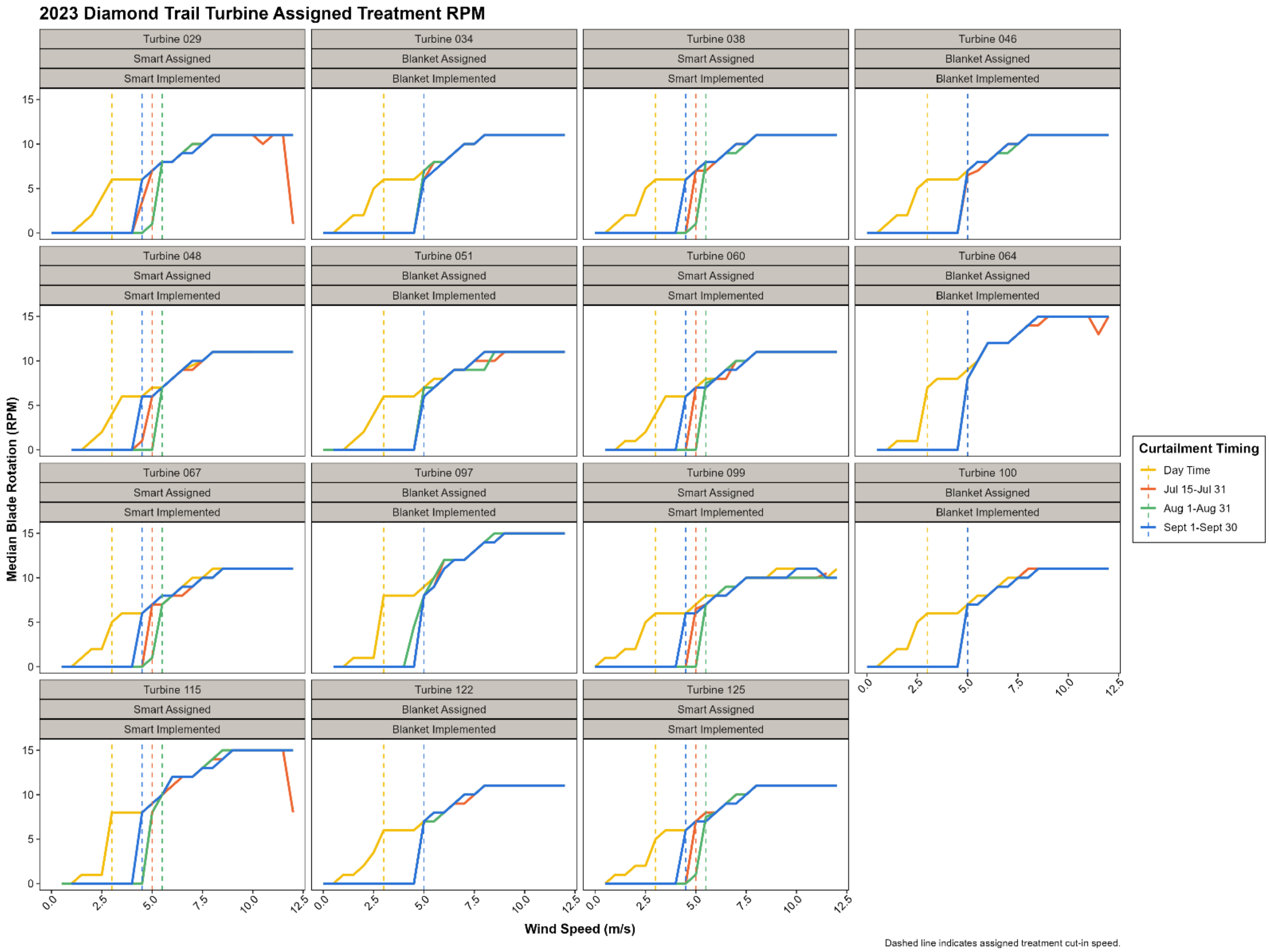
Appendix J Figure 6. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Contrail in 2022.



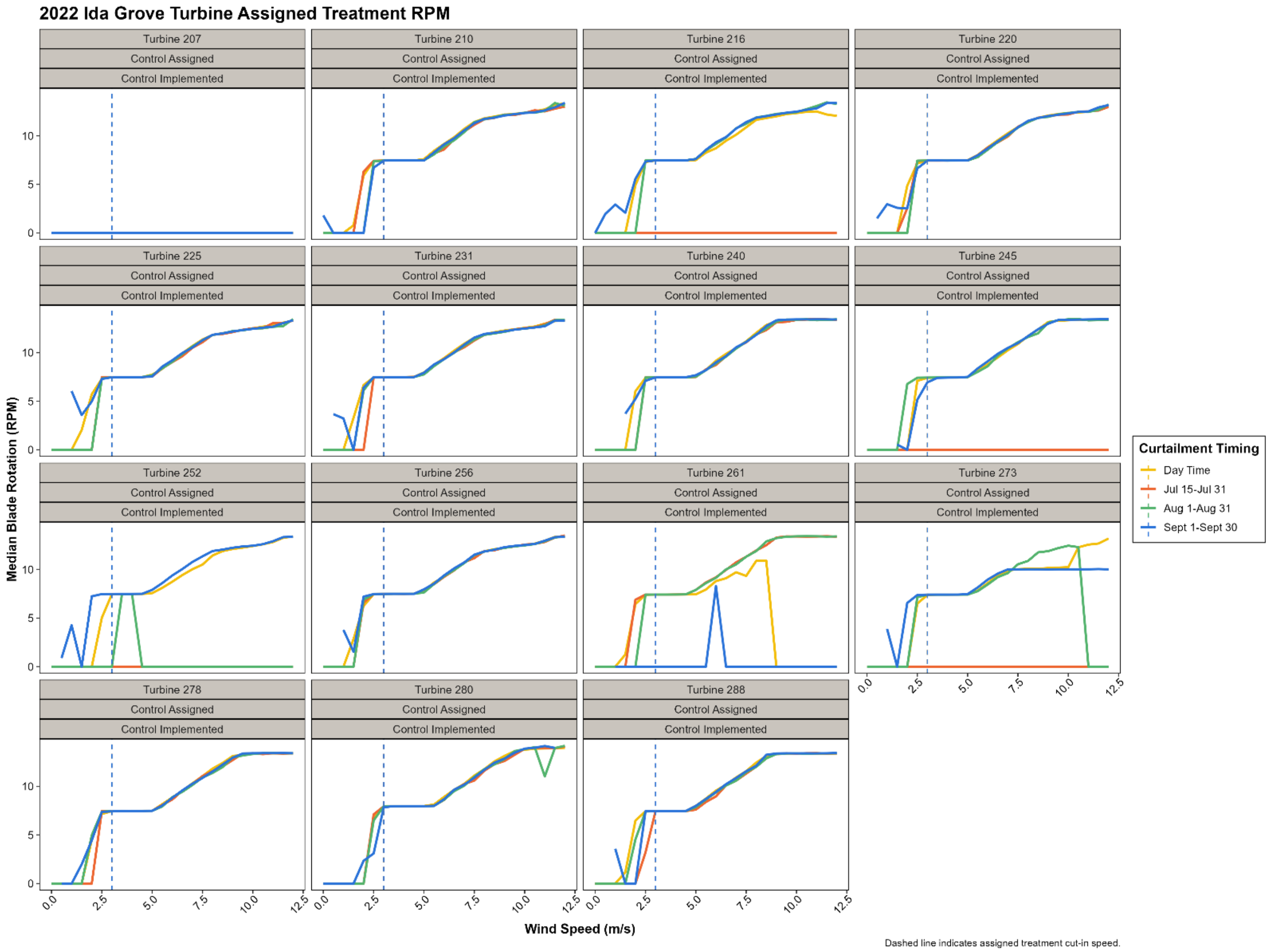
Appendix J Figure 7. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Contrail in 2023.



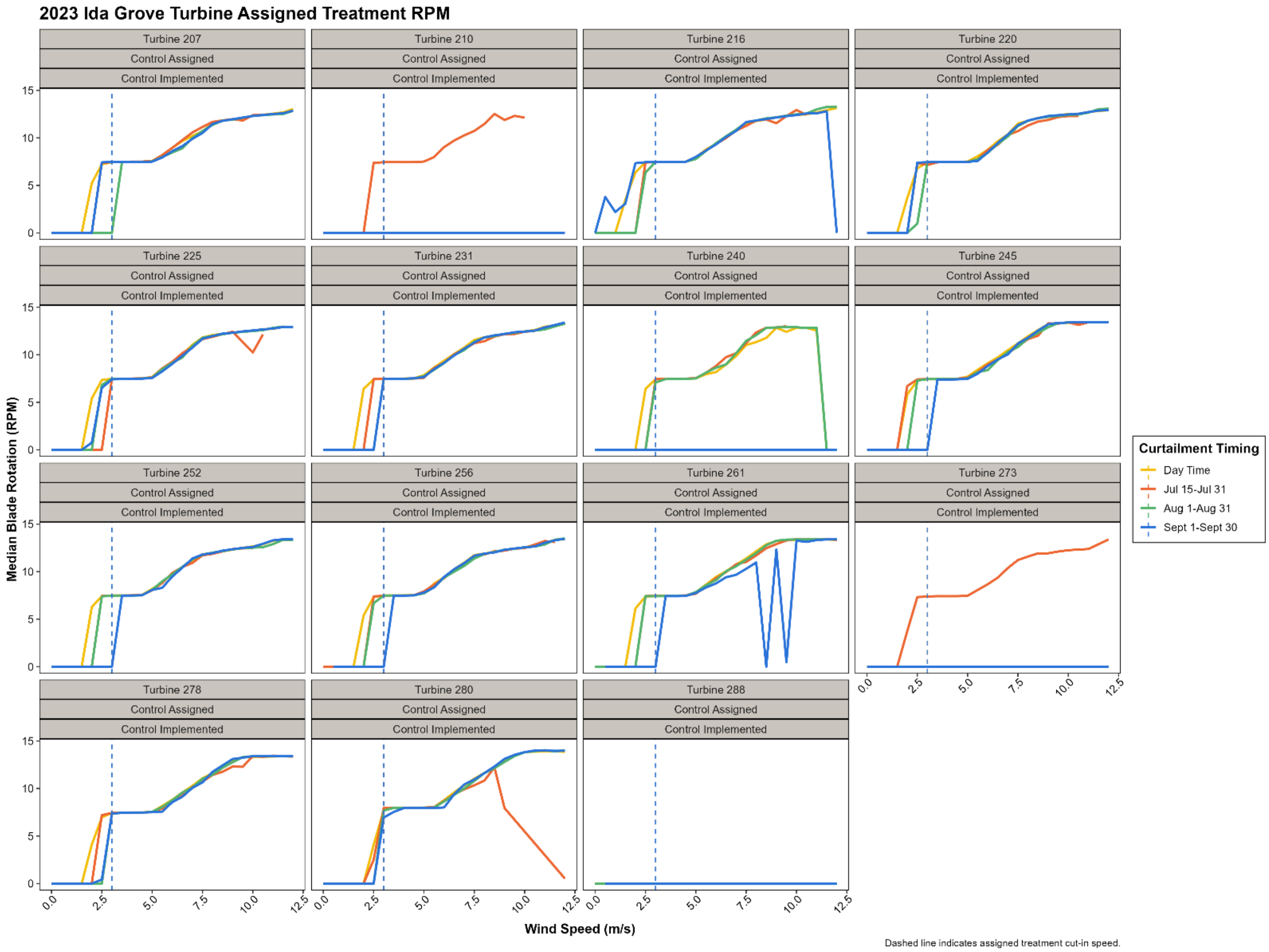
Appendix J Figure 8. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Diamond Trail in 2022.



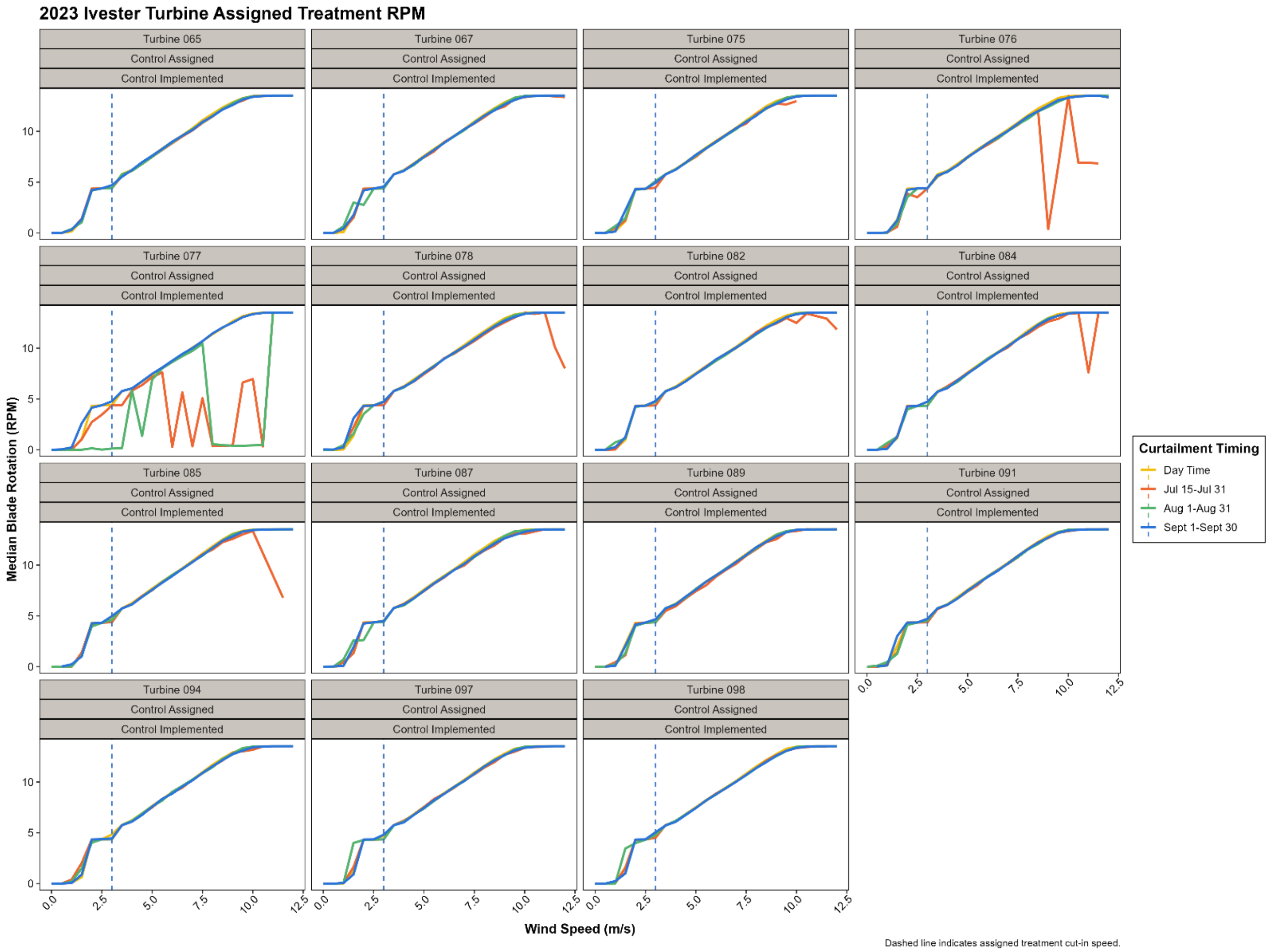
Appendix J Figure 9. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Diamond Trail in 2023.



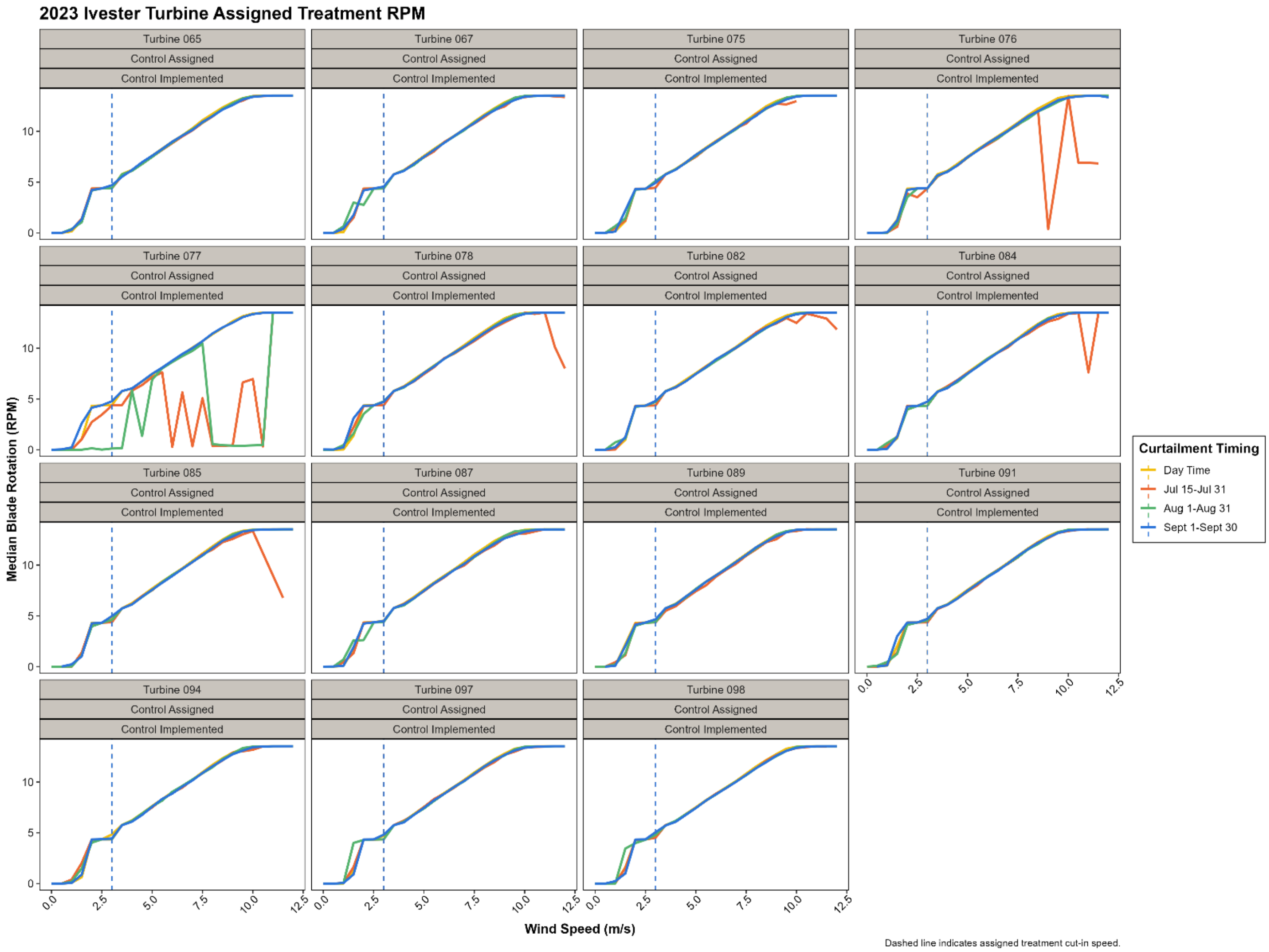
Appendix J Figure 10. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Ida Grove in 2022.



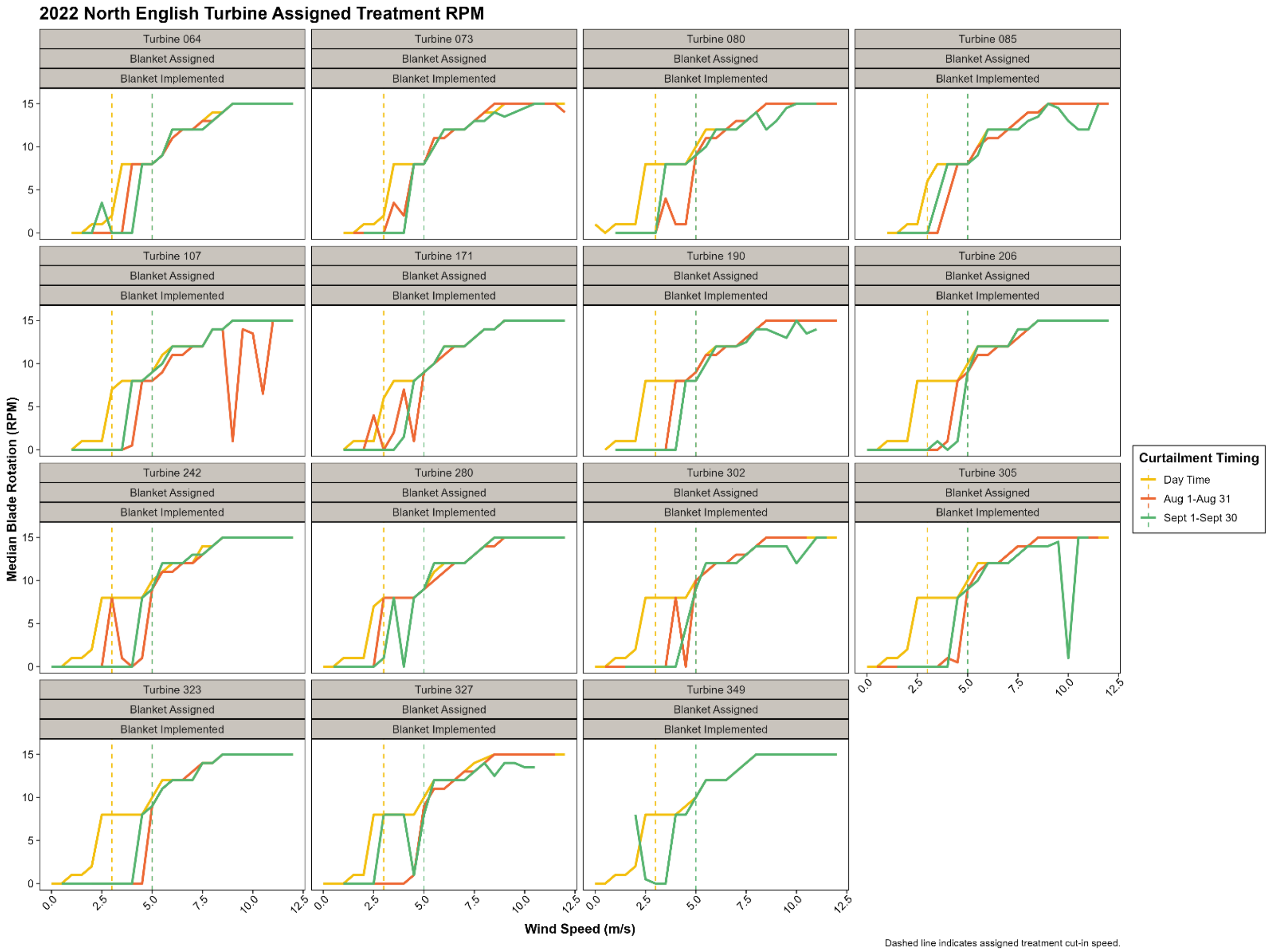
Appendix J Figure 11. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Ida Grove in 2023.



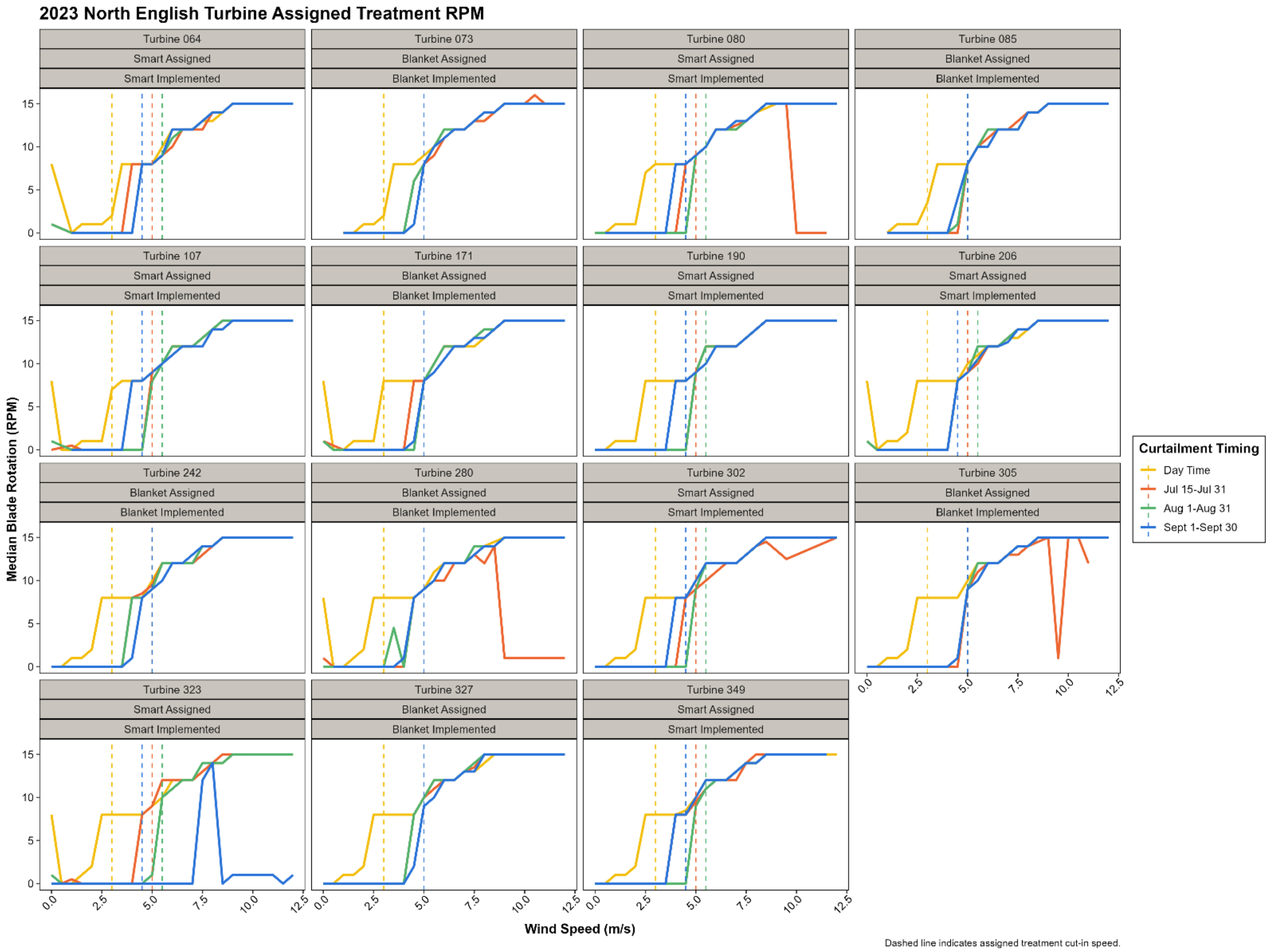
Appendix J Figure 12. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Ivester in 2022.



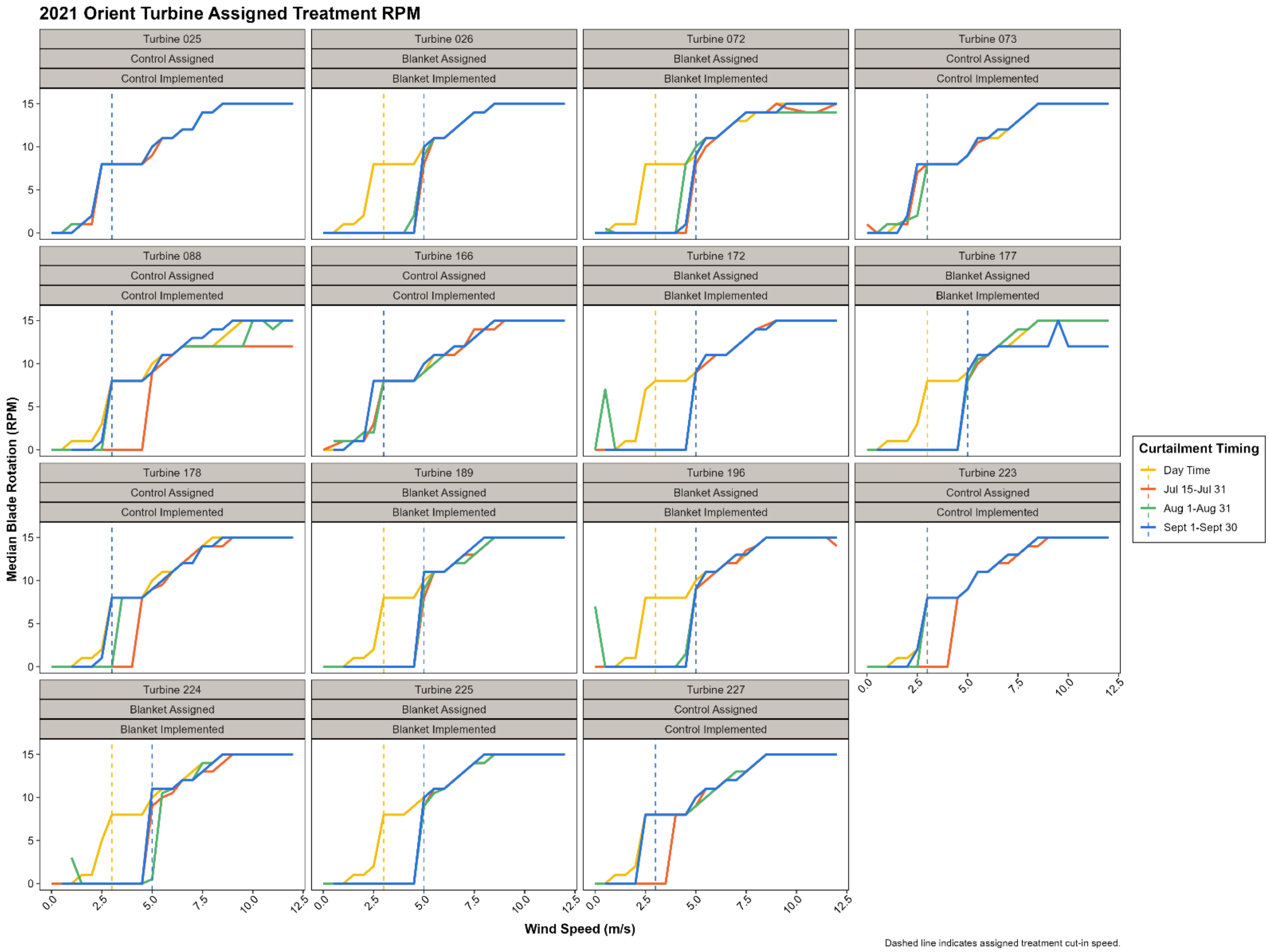
Appendix J Figure 13. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Ivester in 2023.



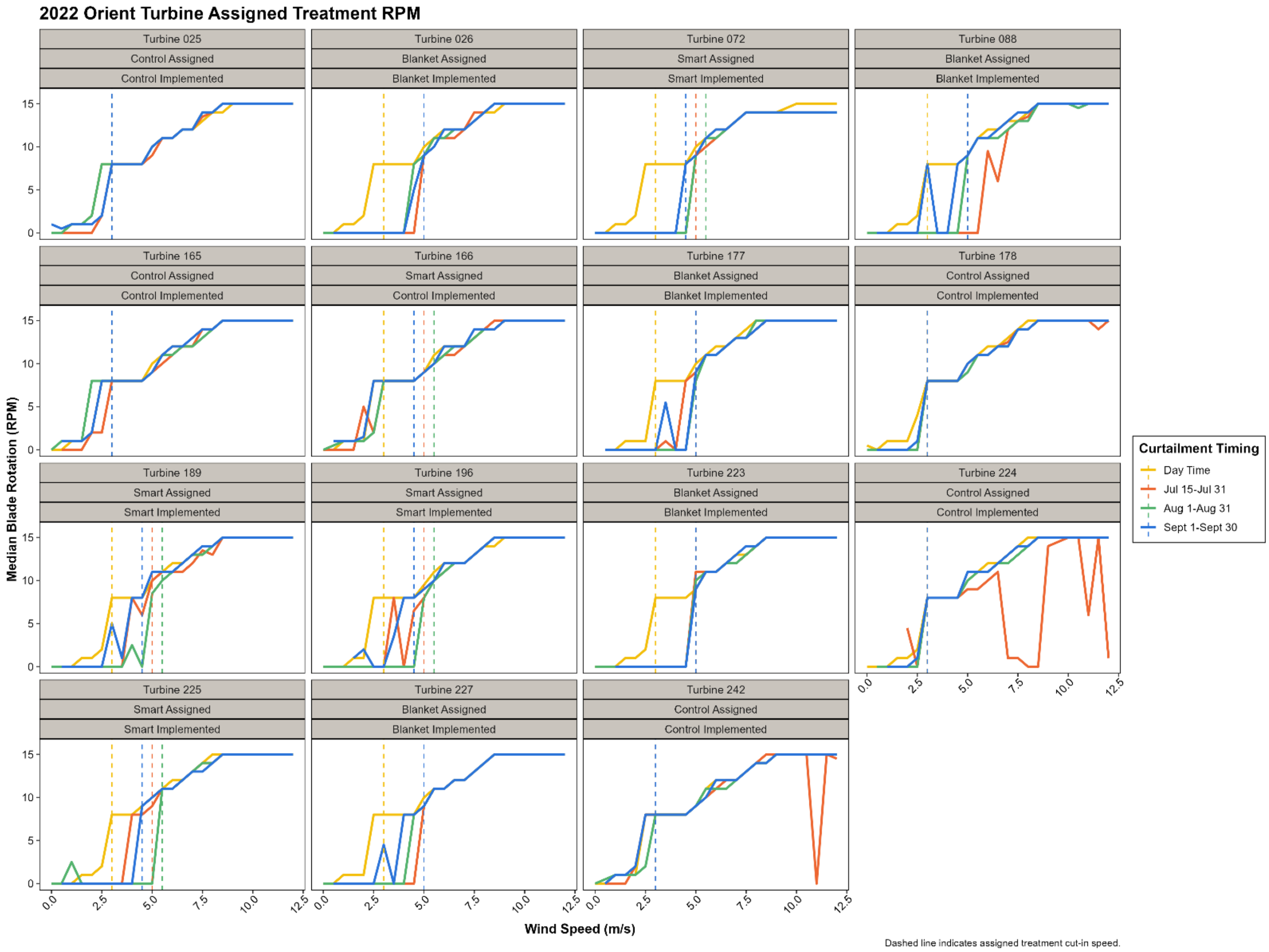
Appendix J Figure 14. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at North English in 2022.



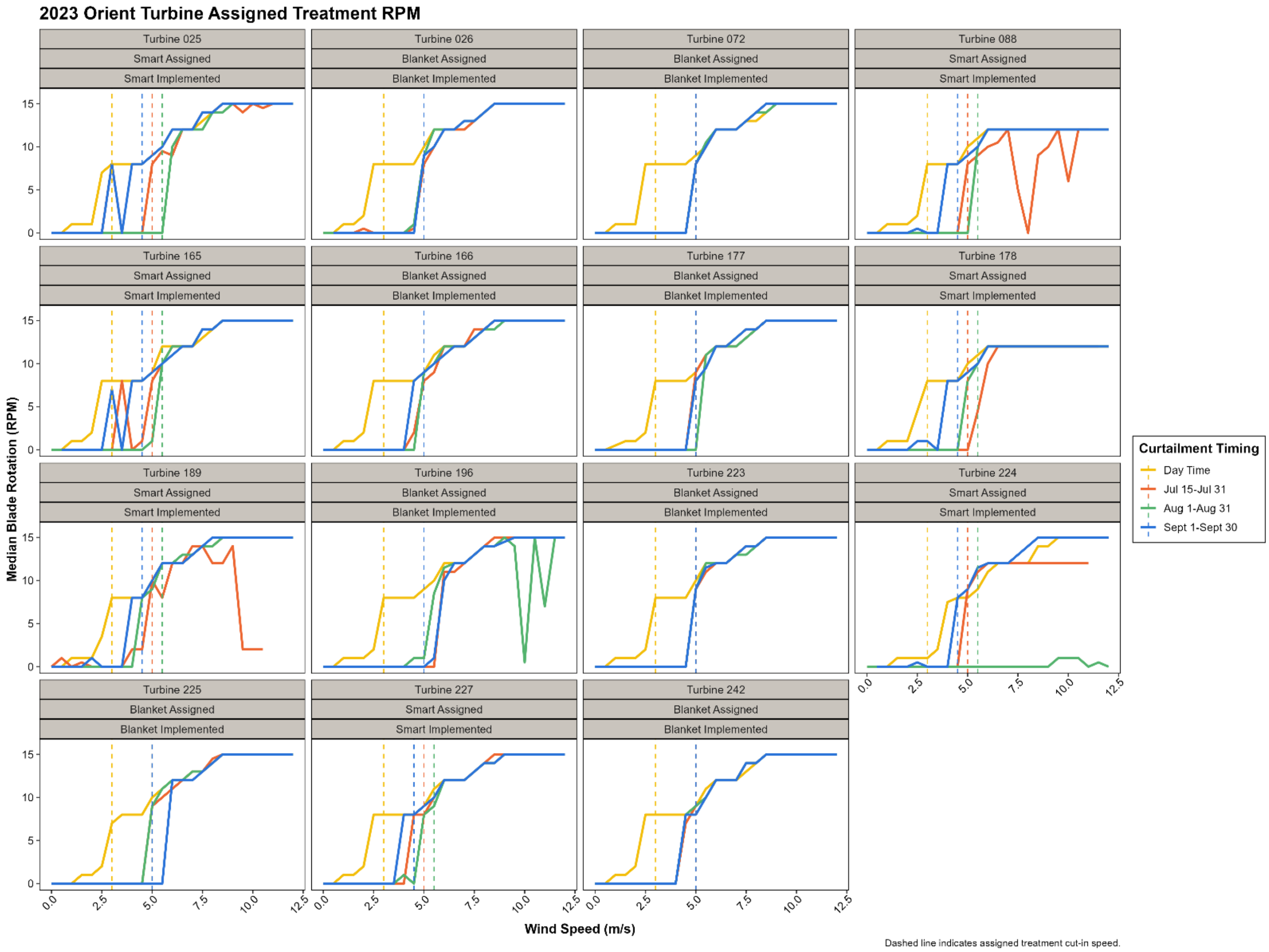
Appendix J Figure 15. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at North English in 2023.



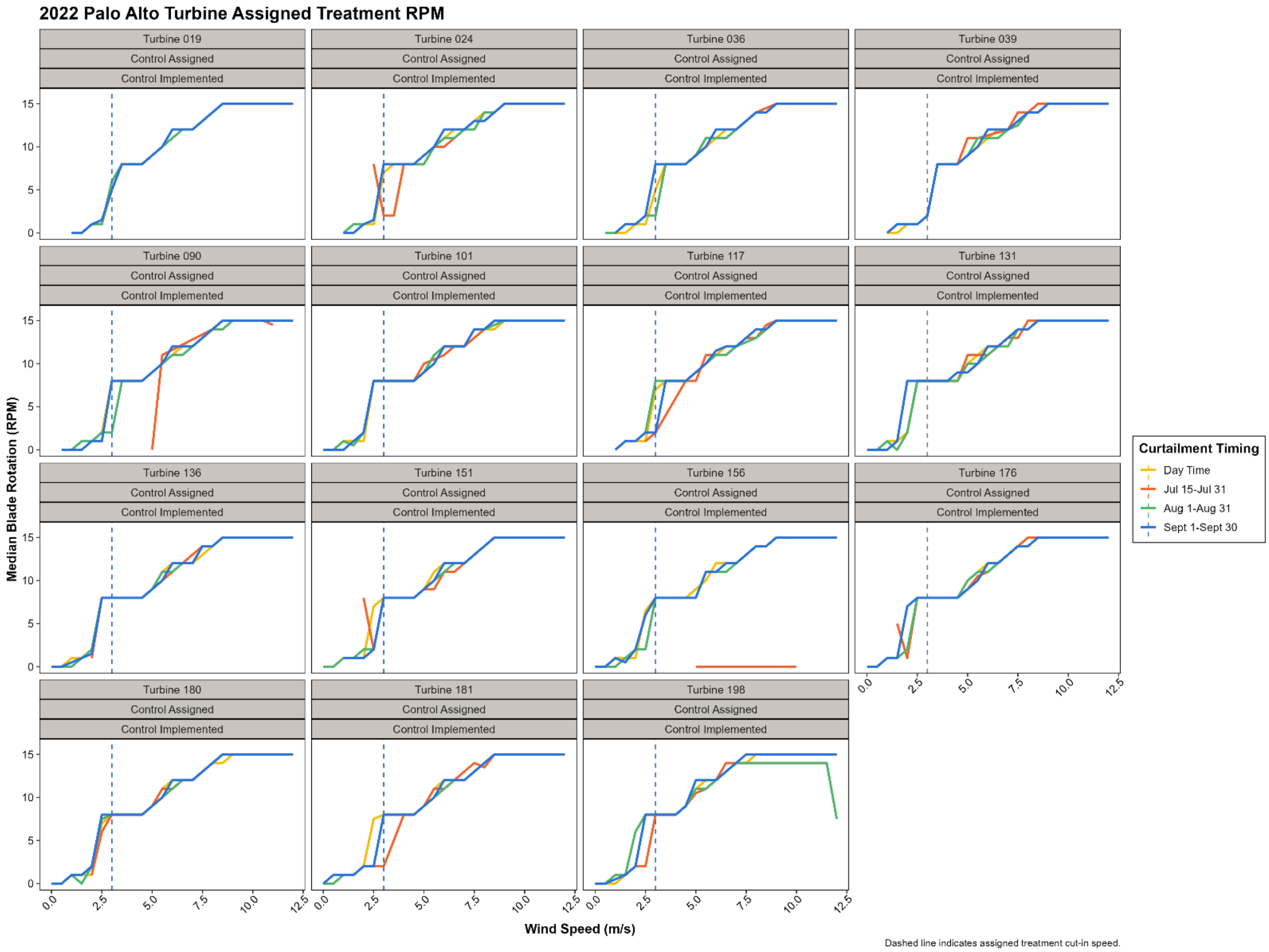
Appendix J Figure 16. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Orient in 2021.



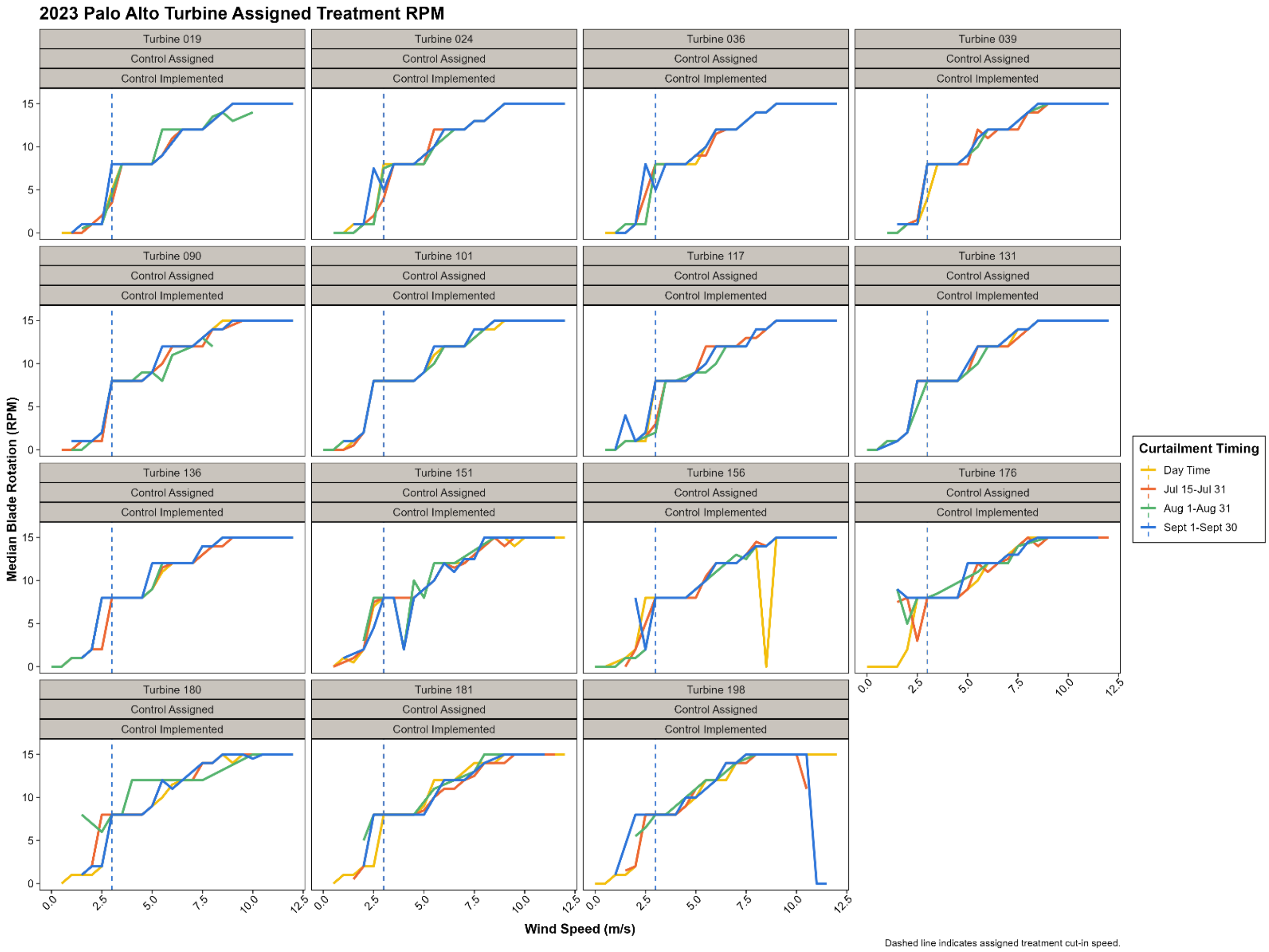
Appendix J Figure 17. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Orient in 2022.



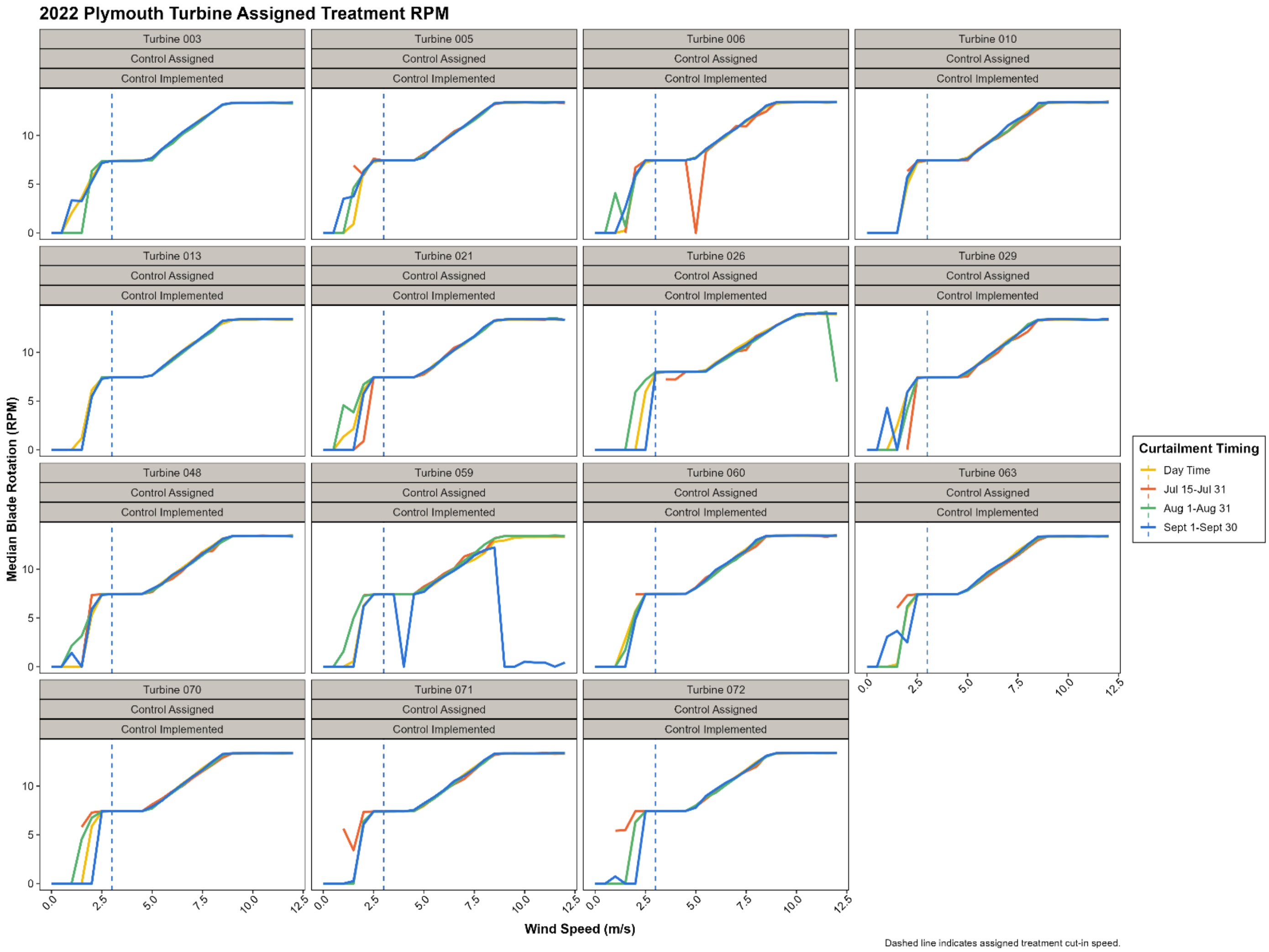
Appendix J Figure 18. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Orient in 2023.



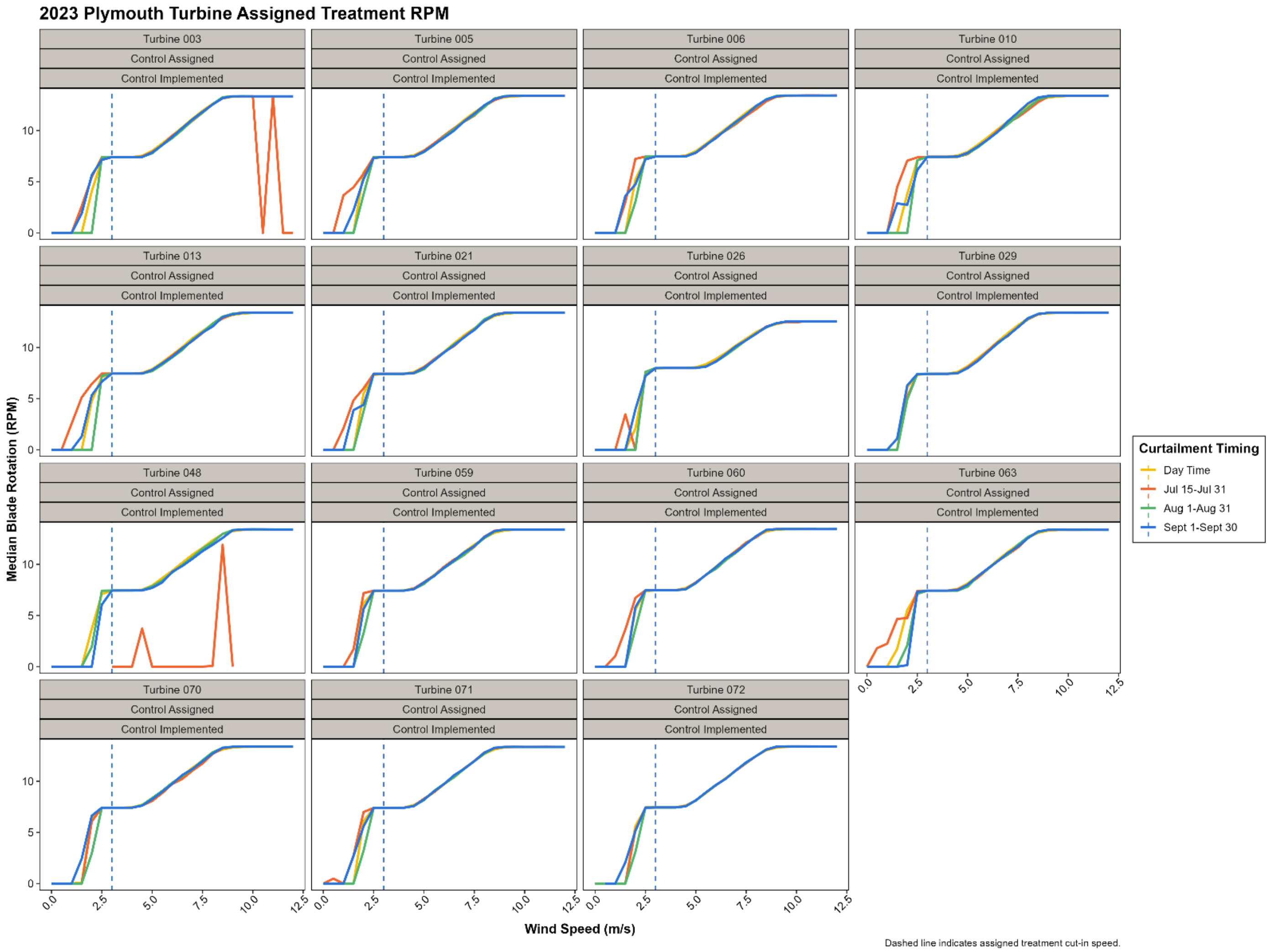
Appendix J Figure 19. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Palo Alto in 2022.



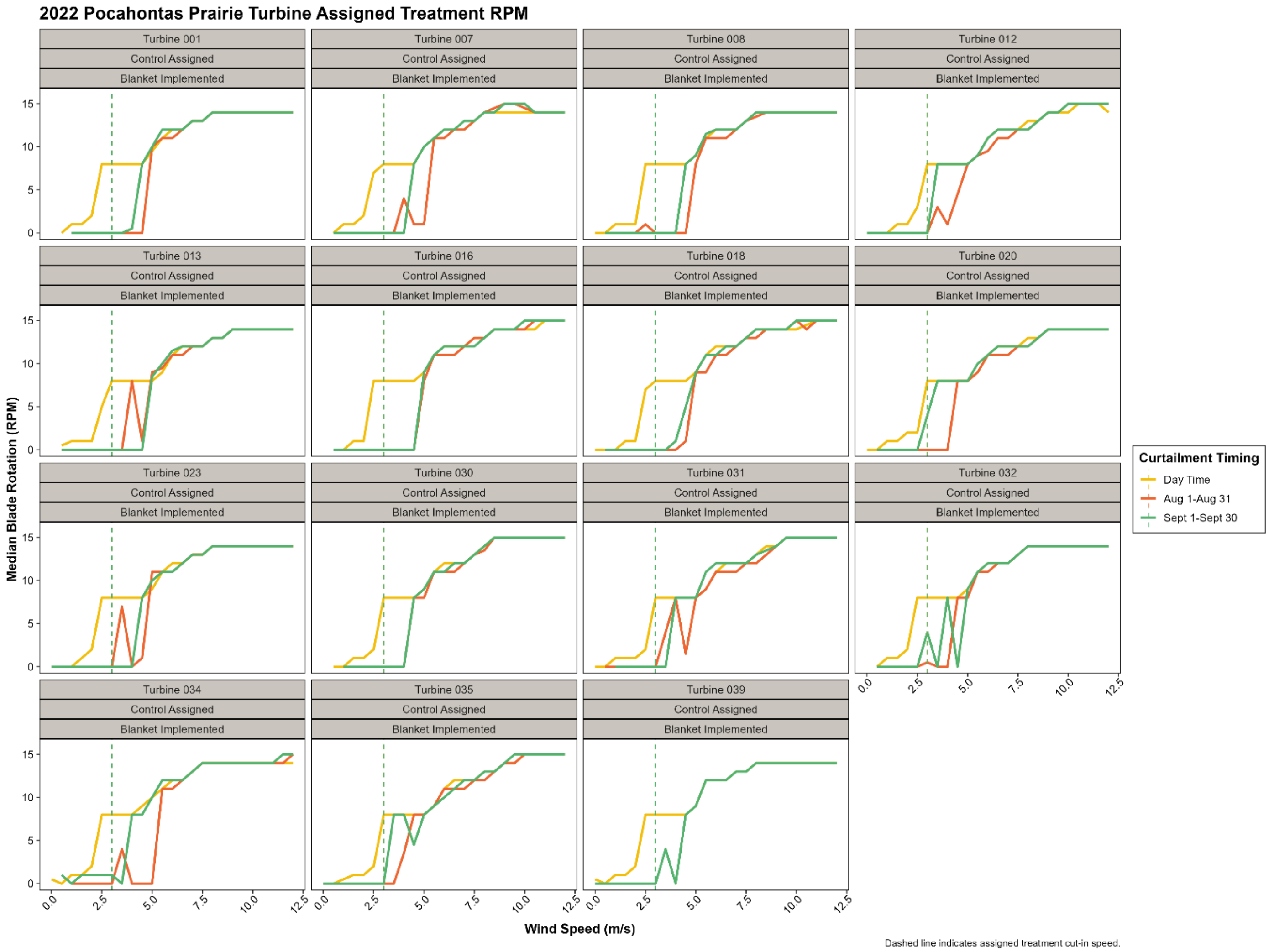
Appendix J Figure 20. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Palo Alto in 2023.



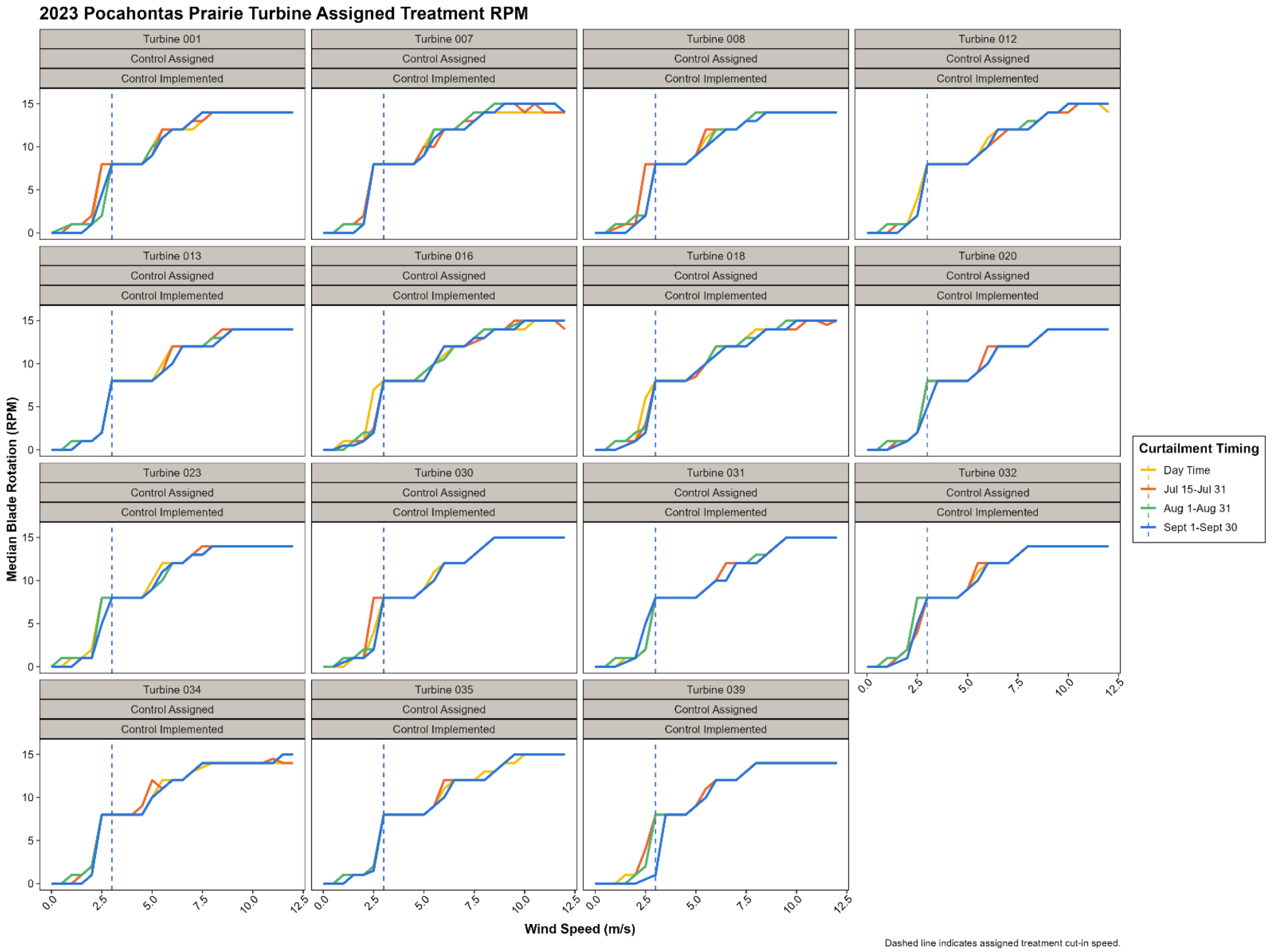
Appendix J Figure 21. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Plymouth in 2022.



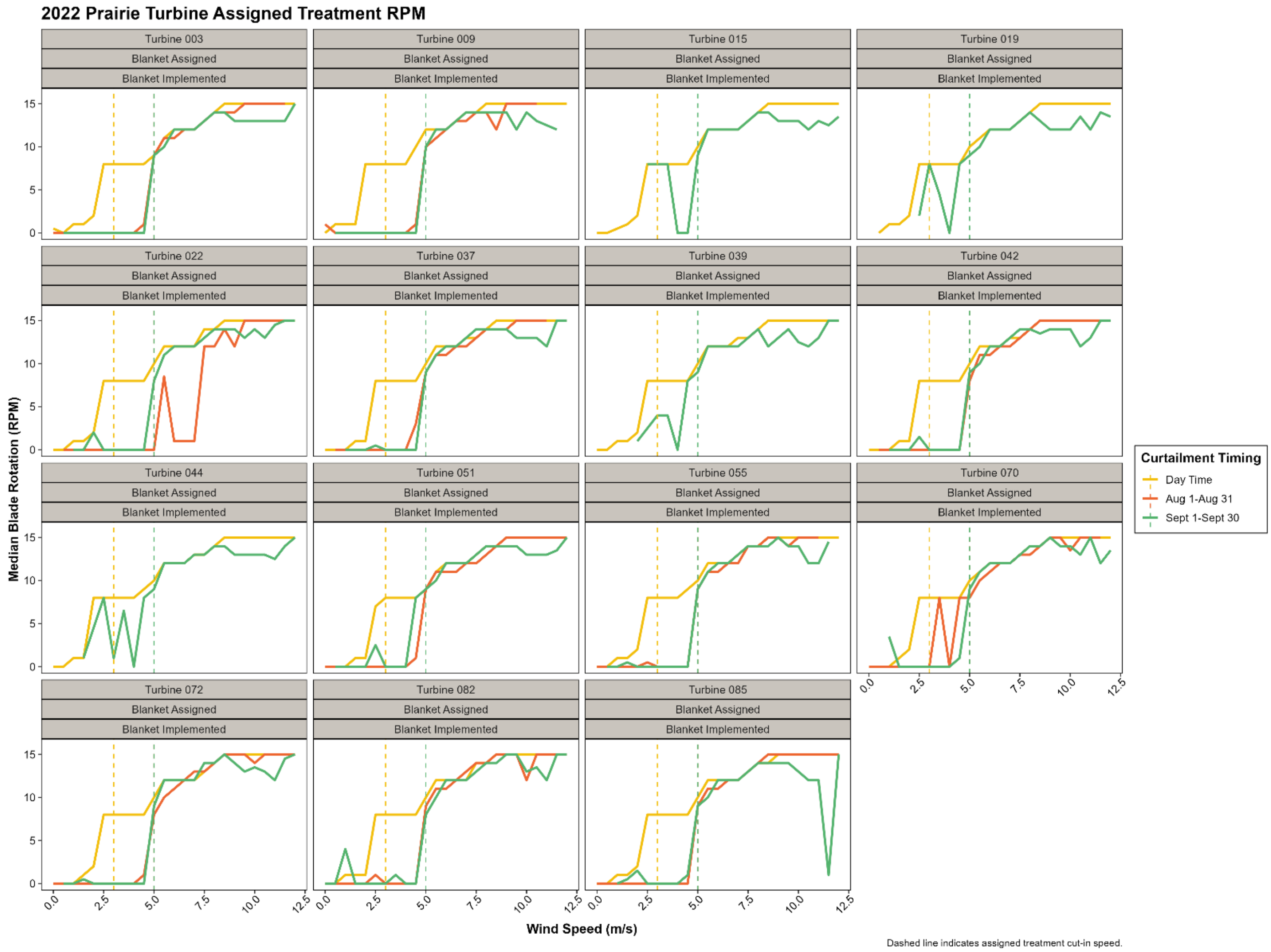
Appendix J Figure 22. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Plymouth in 2023.



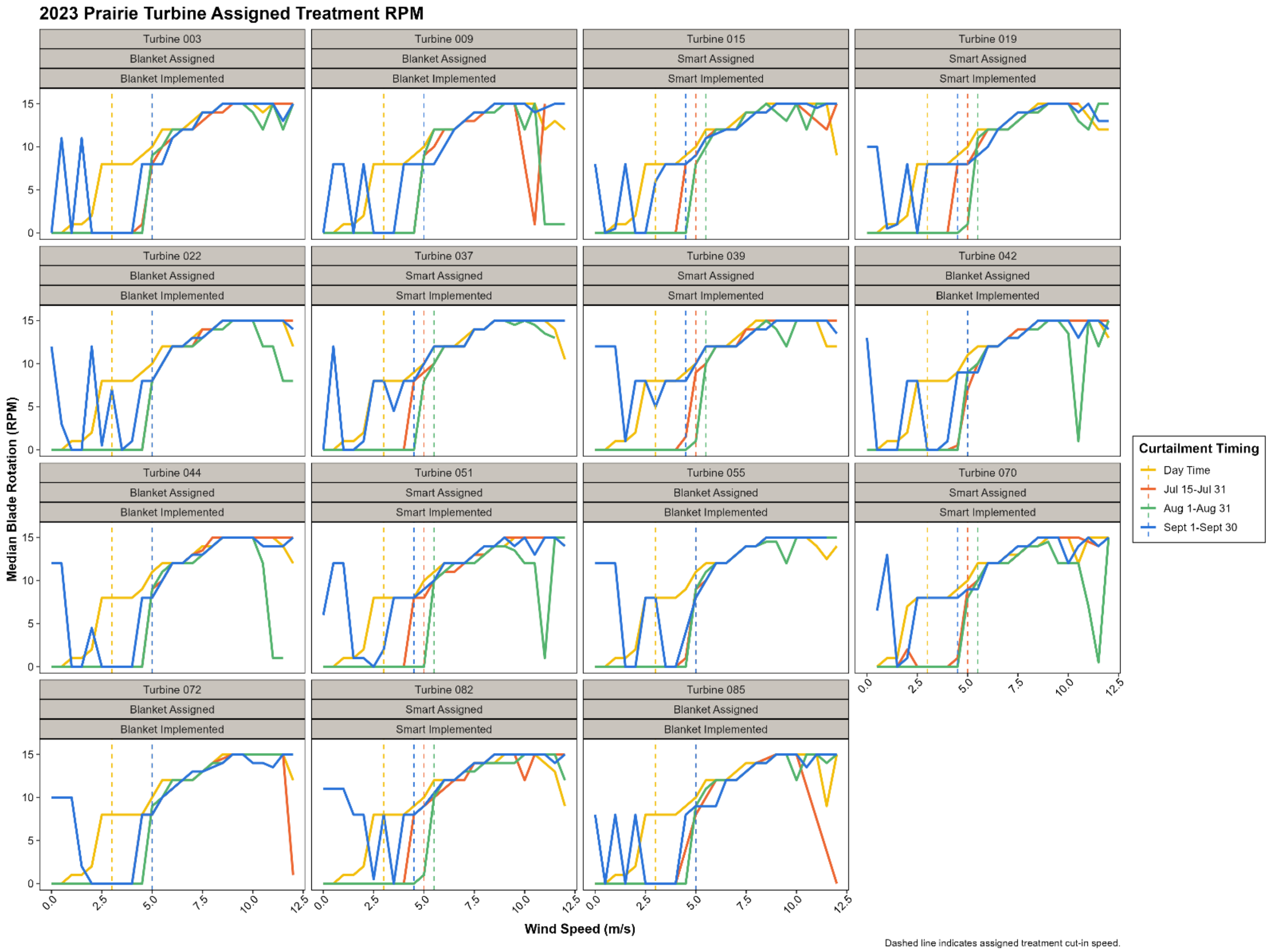
Appendix J Figure 23. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Pocahontas Prairie in 2022.



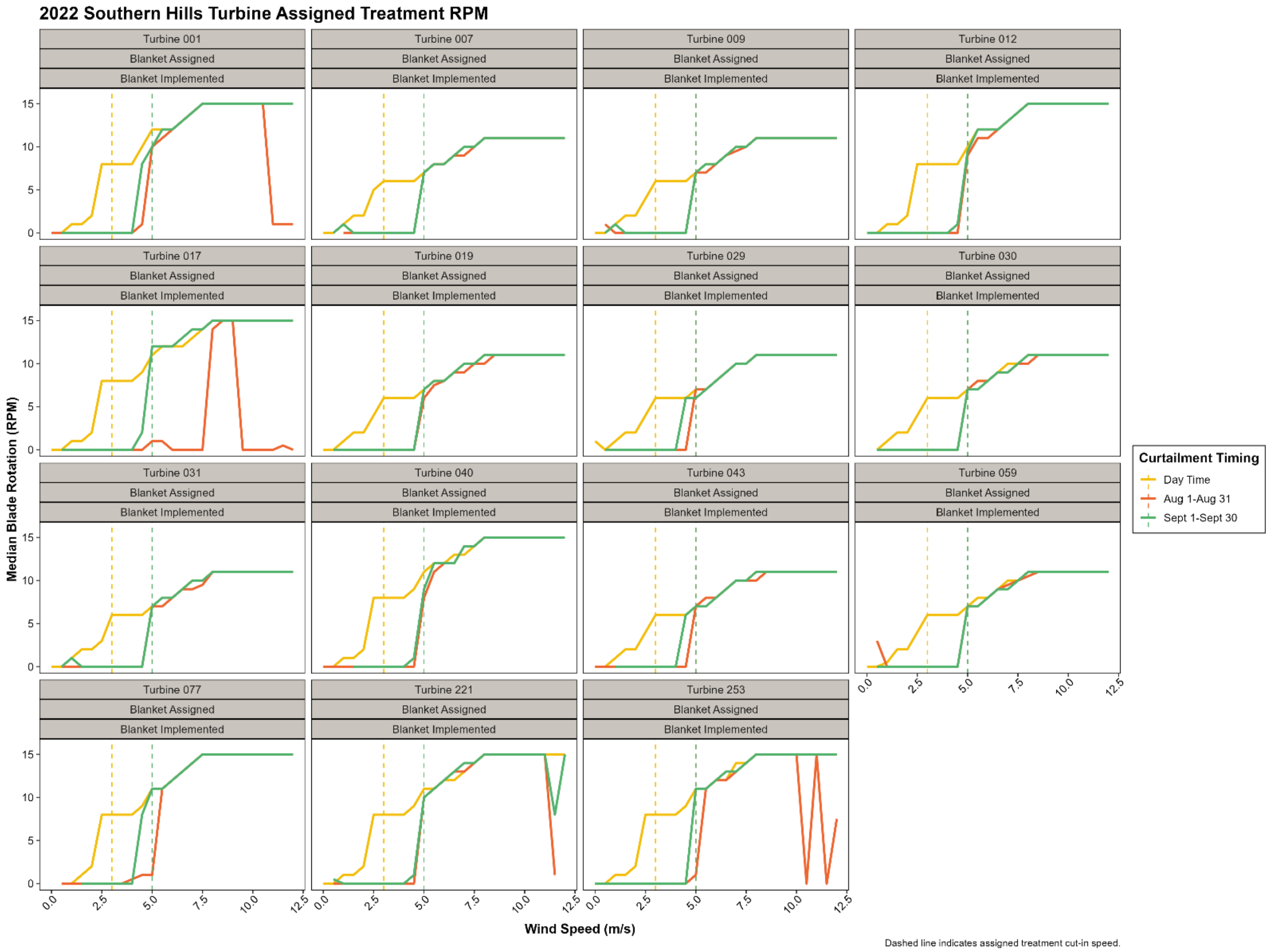
Appendix J Figure 24. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Pocahontas Prairie in 2023.



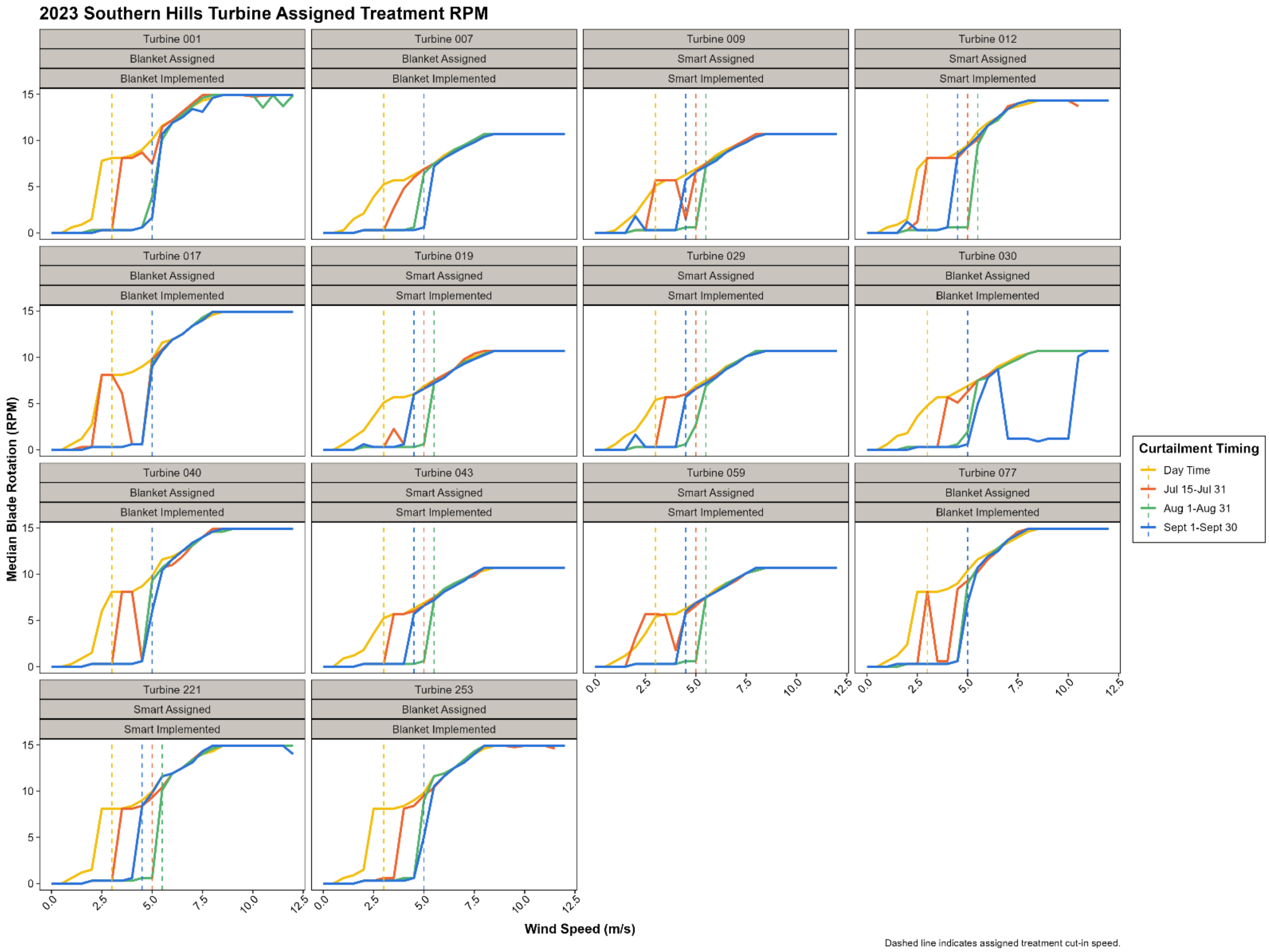
Appendix J Figure 25. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Prairie in 2022.



Appendix J Figure 26. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Prairie in 2023.

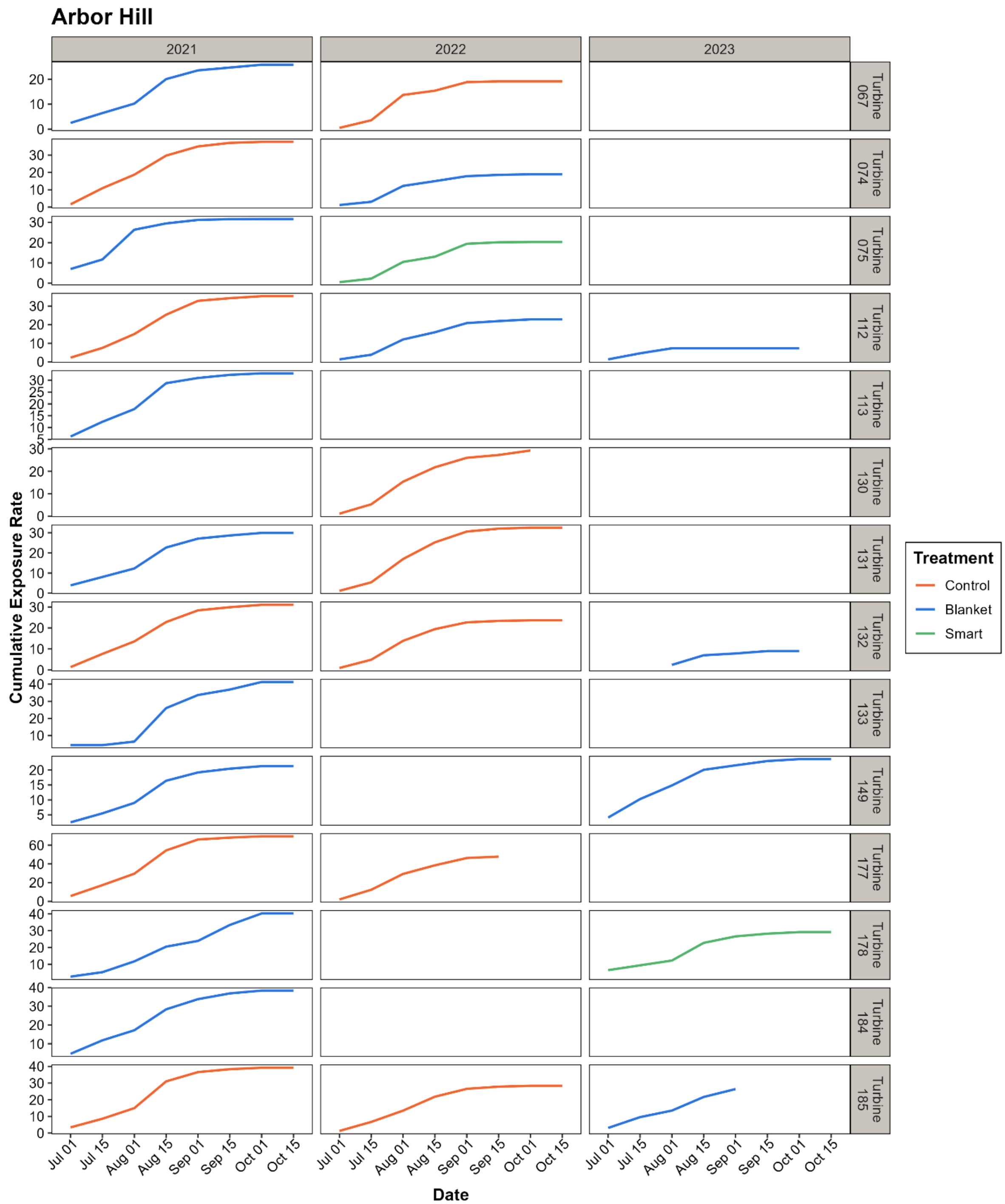


Appendix J Figure 27. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Southern Hills in 2022.

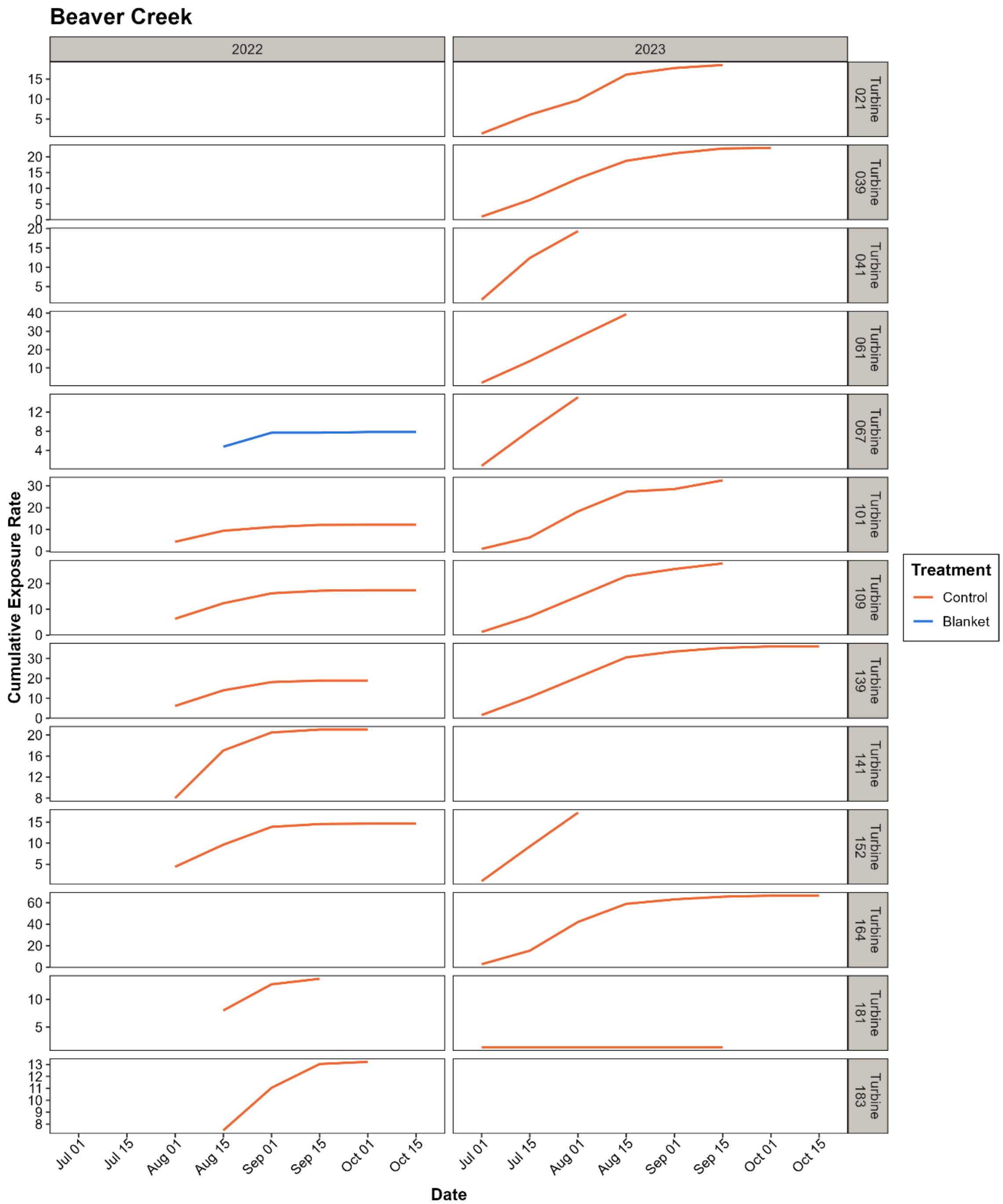


Appendix J Figure 28. Median turbine blade rotation (rpm) as a function of wind speed bin for daytime and date breaks according to curtailment treatment at Southern Hills in 2023.

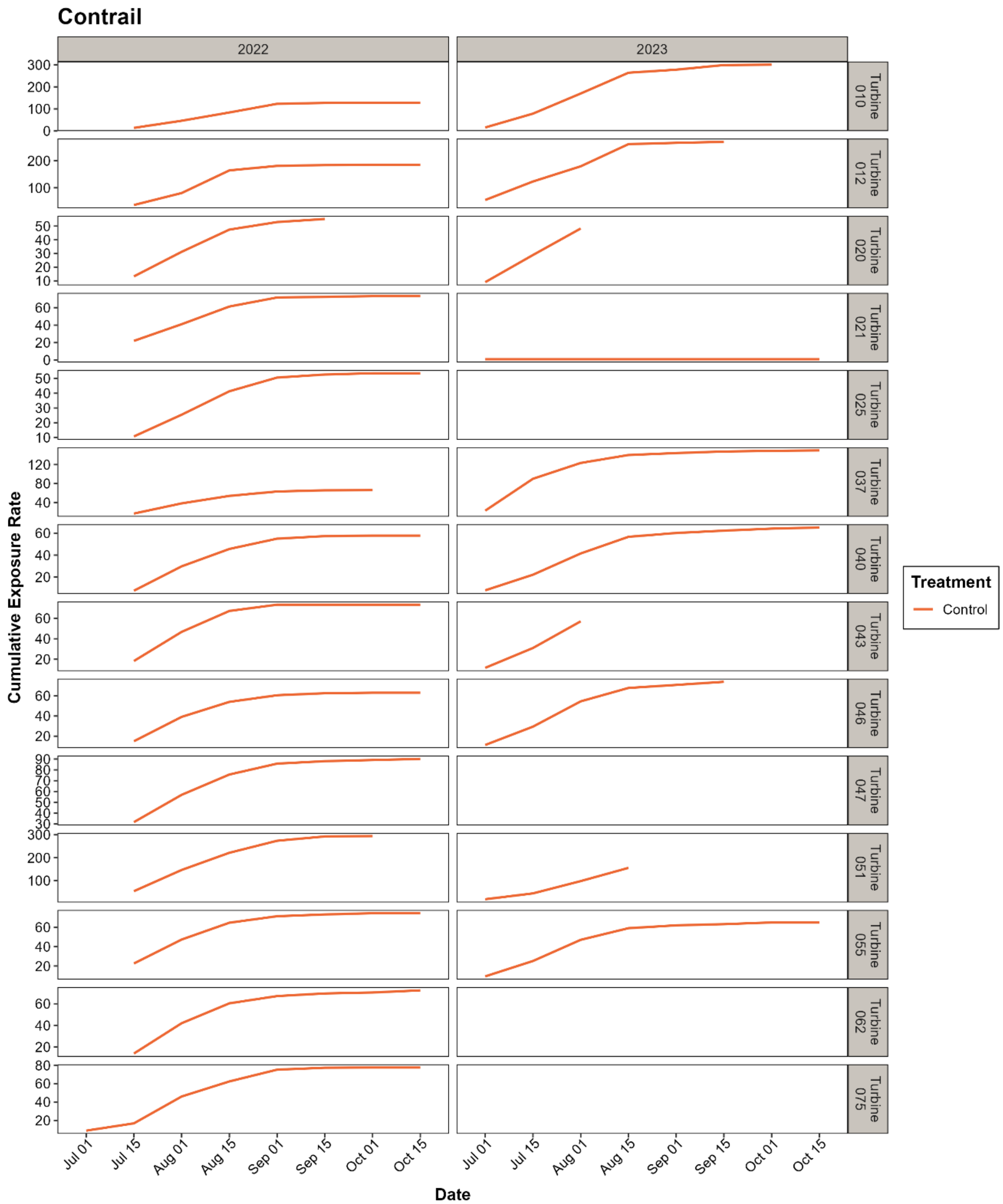
Appendix K



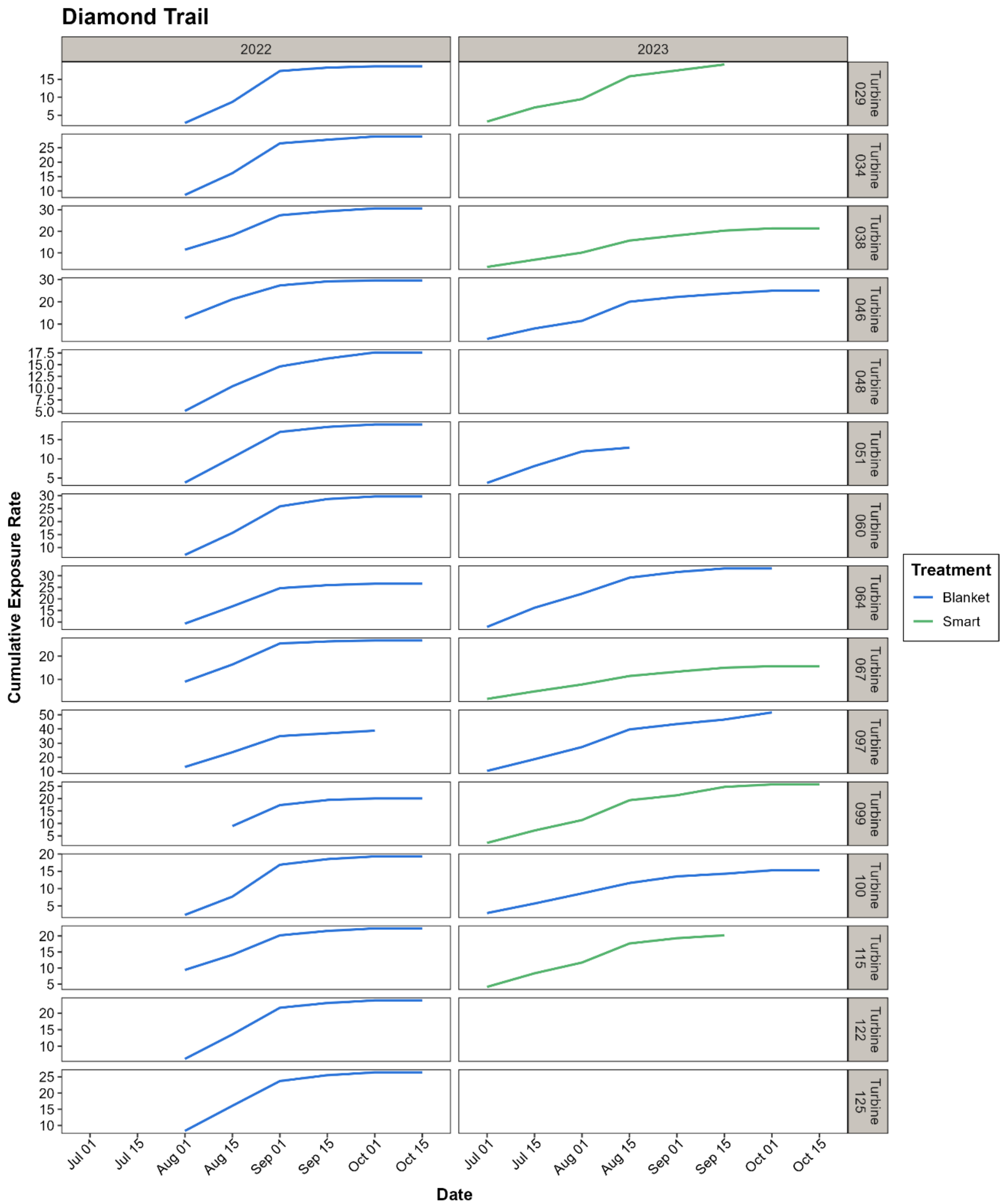
Appendix K Figure 1. Cumulative acoustic exposure measured per turbine by nacelle-mounted acoustic detectors at Arbor Hill, 2021–2023.



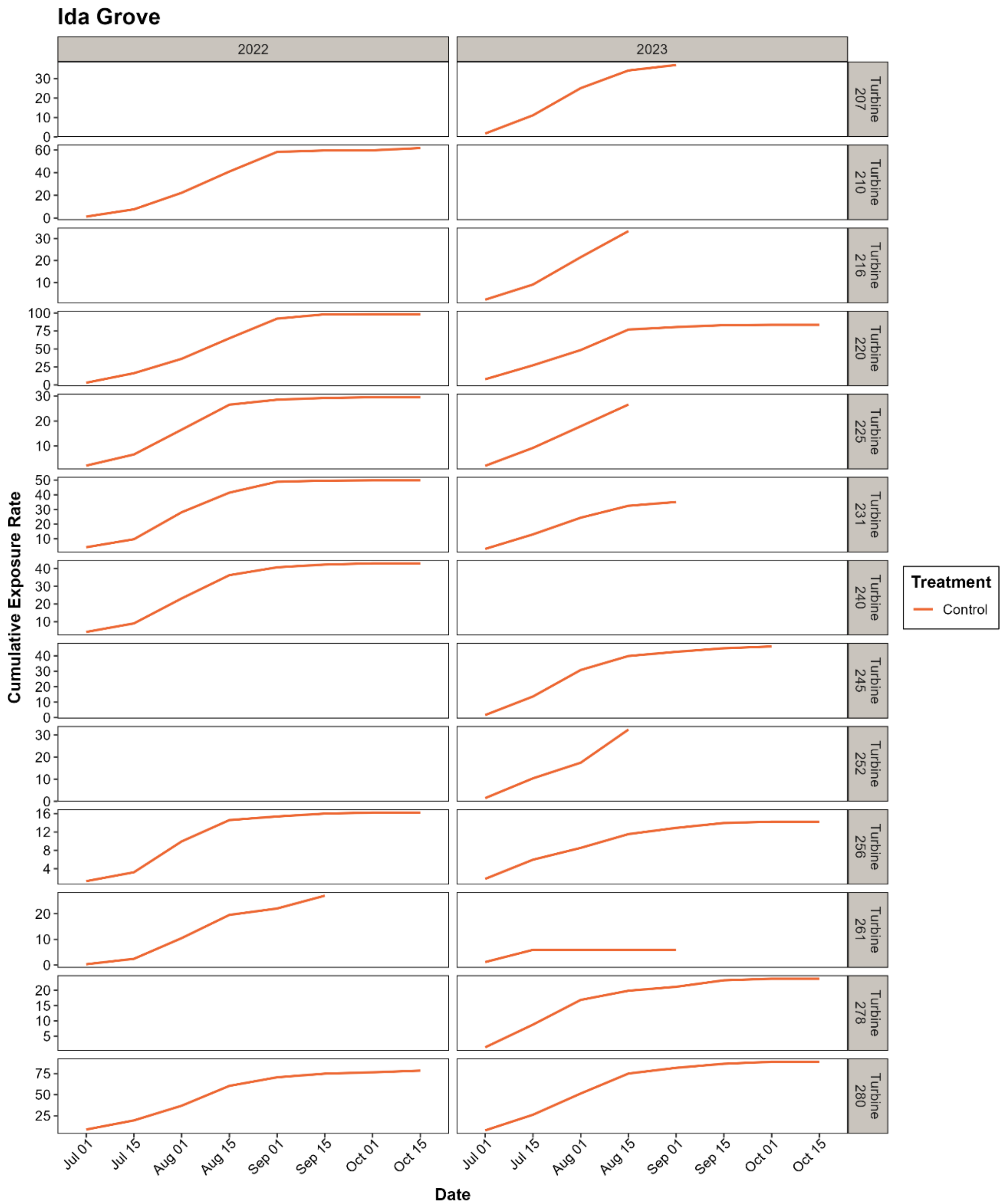
Appendix K Figure 2. Cumulative acoustic exposure measured per turbine by nacelle-mounted acoustic detectors at Beaver Creek, 2022–2023.



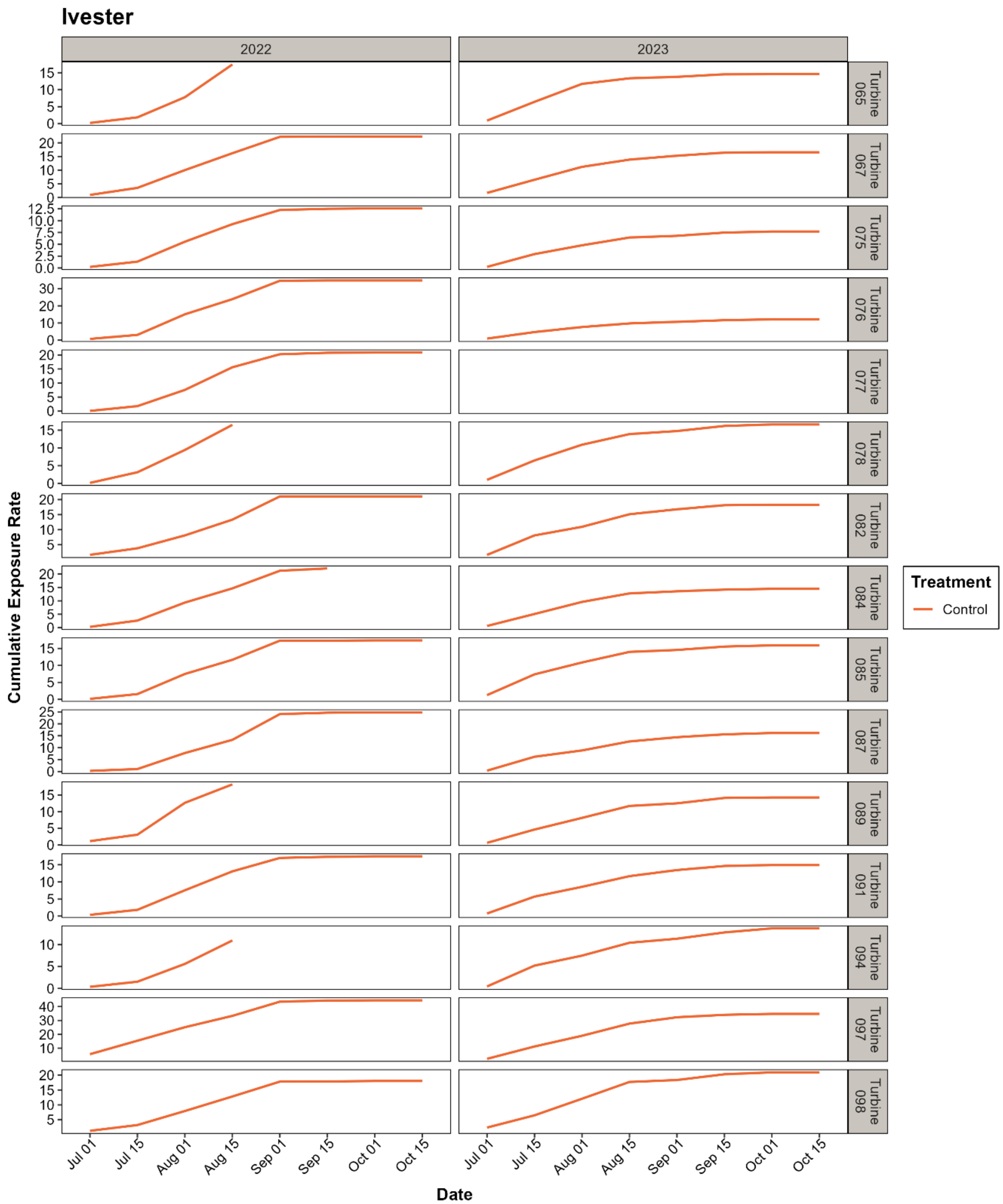
Appendix K Figure 3. Cumulative acoustic exposure measured per turbine by nacelle-mounted acoustic detectors at Contrail, 2022–2023.



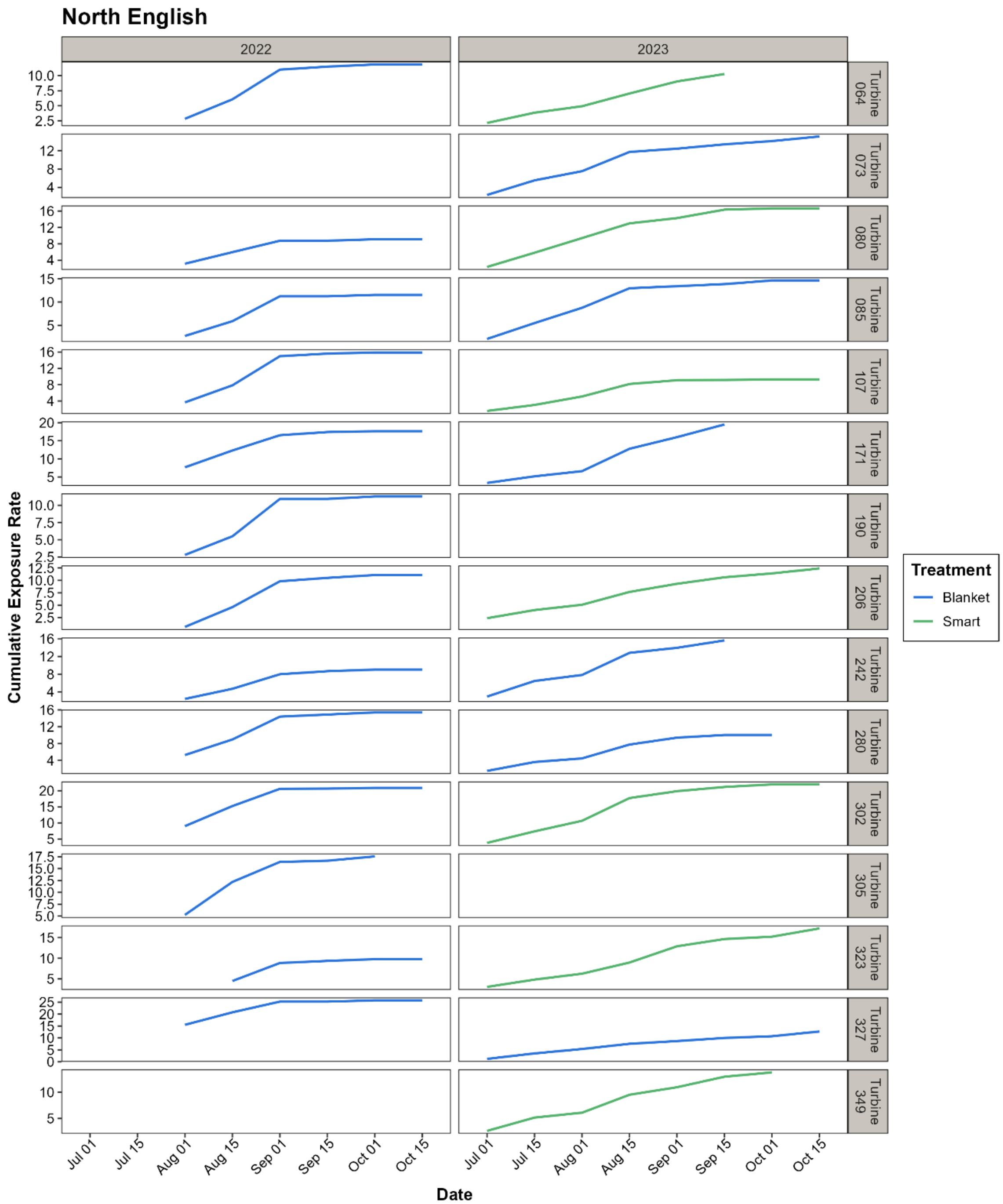
Appendix K Figure 4. Cumulative acoustic exposure measured per turbine by nacelle-mounted acoustic detectors at Diamond Trail, 2022–2023.



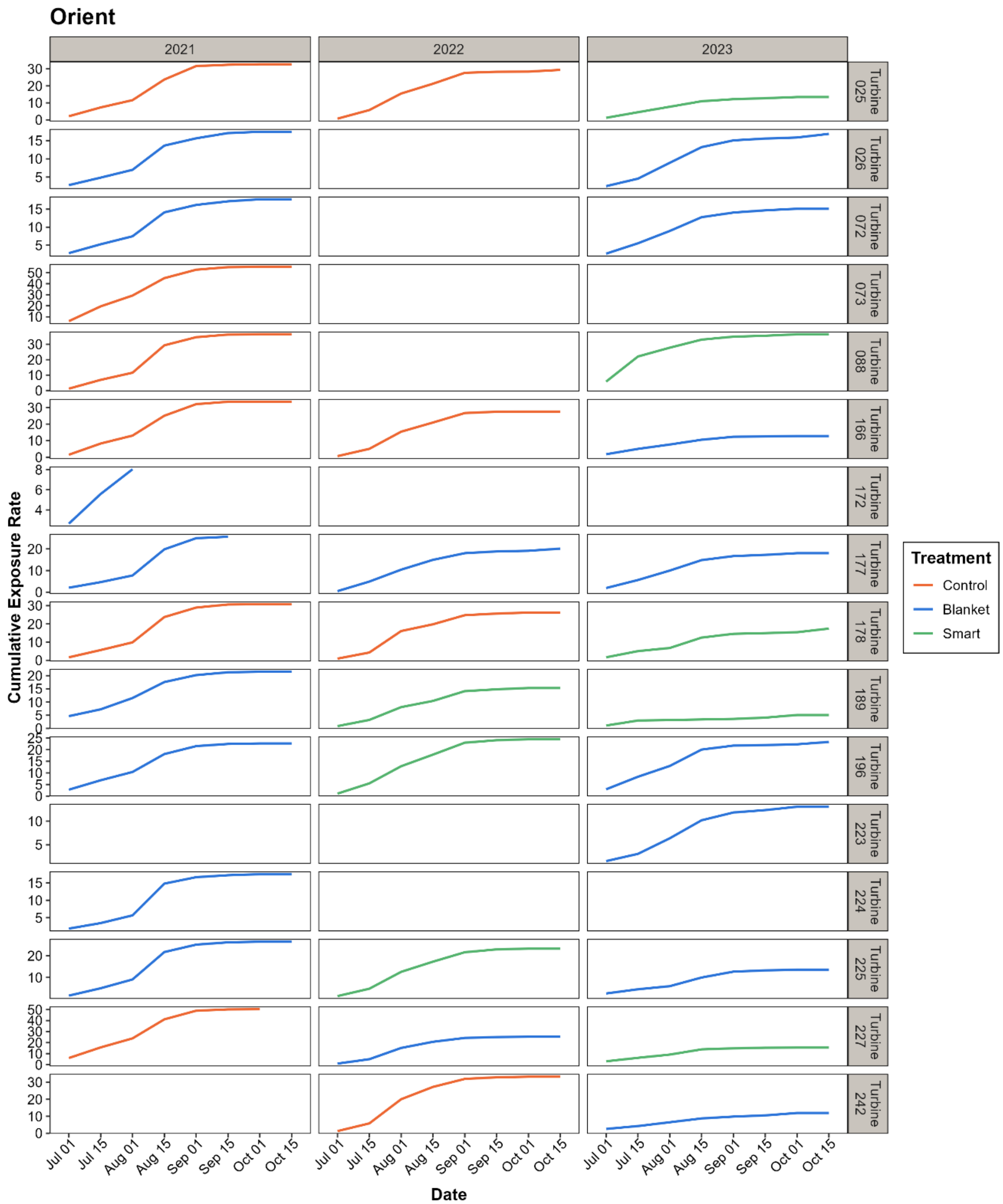
Appendix K Figure 5. Cumulative acoustic exposure measured per turbine by nacelle-mounted acoustic detectors at Ida Grove, 2022–2023.



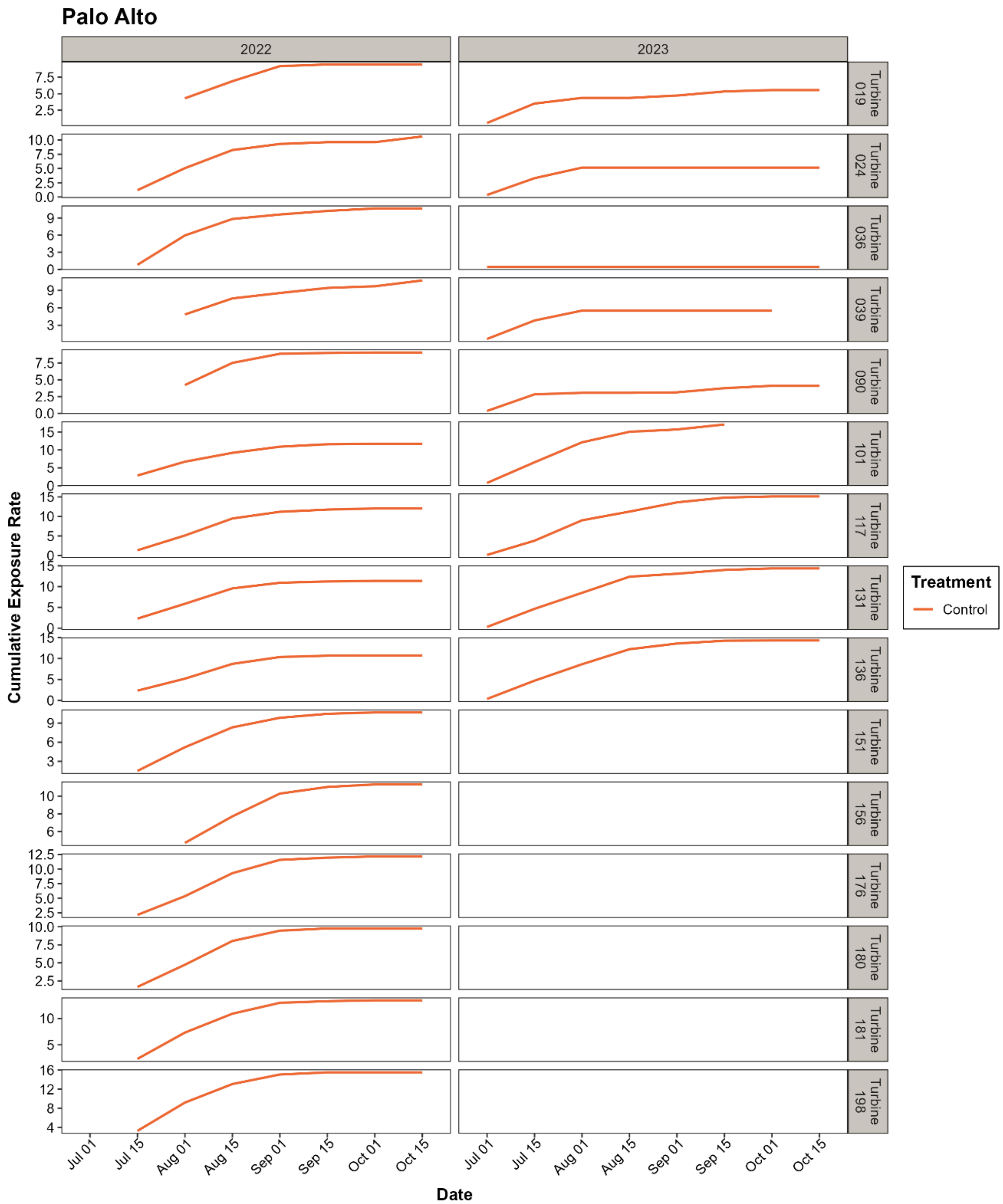
Appendix K Figure 6. Cumulative acoustic exposure measured per turbine by nacelle-mounted acoustic detectors at Ivester, 2022–2023.



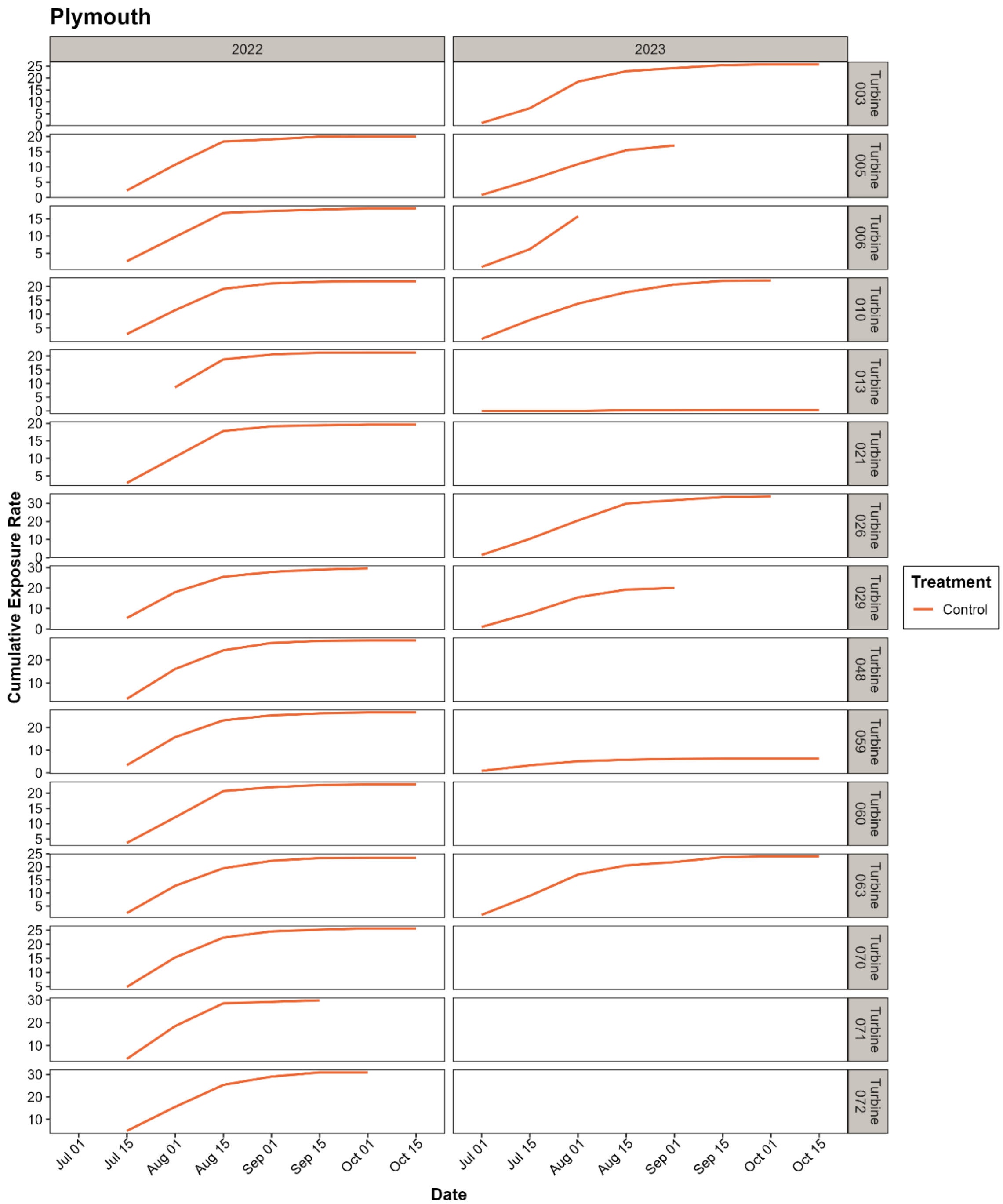
Appendix K Figure 7. Cumulative acoustic exposure measured per turbine by nacelle-mounted acoustic detectors at North English, 2022–2023.



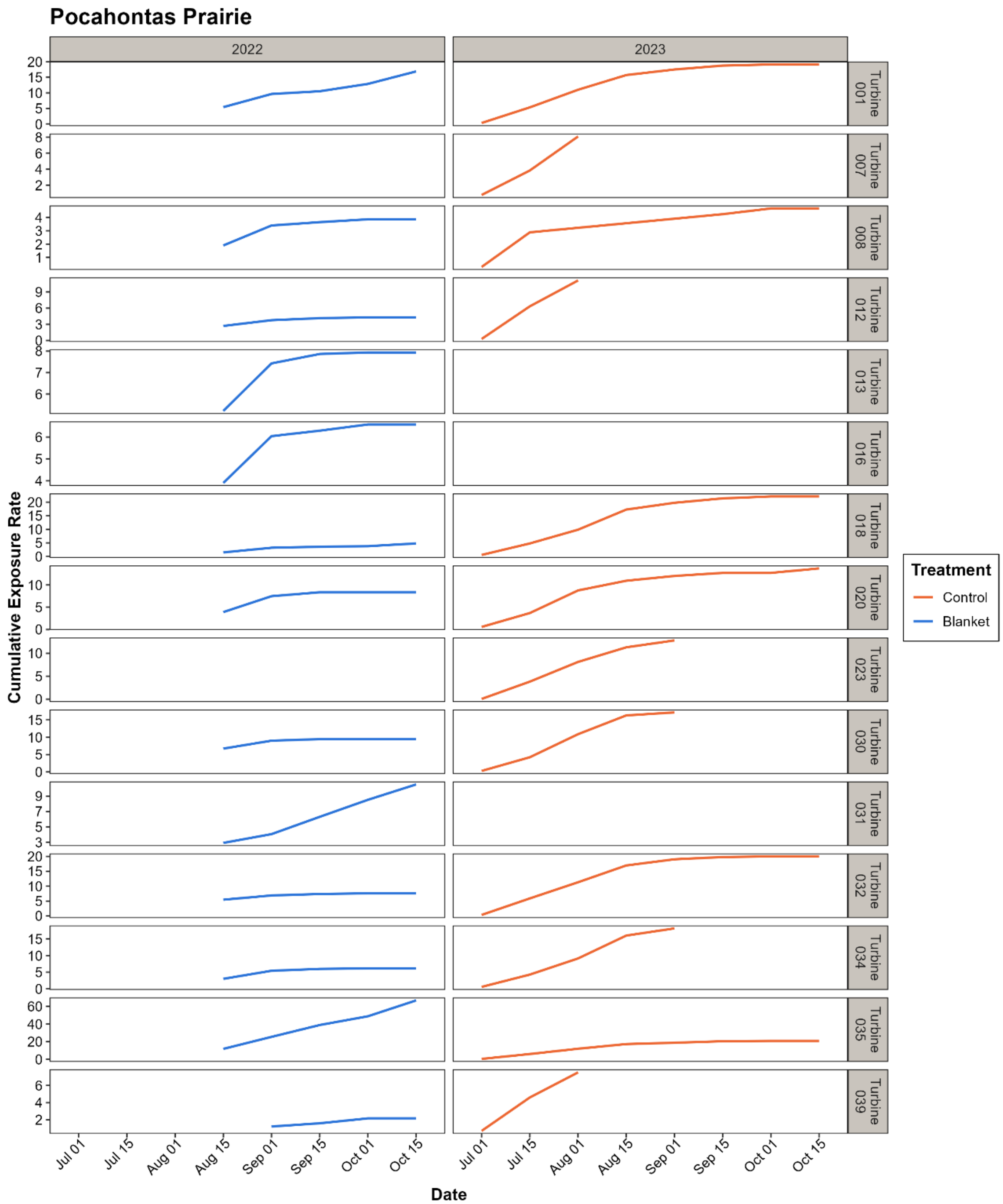
Appendix K Figure 8. Cumulative acoustic exposure measured per turbine by nacelle-mounted acoustic detectors at Orient, 2021–2023.



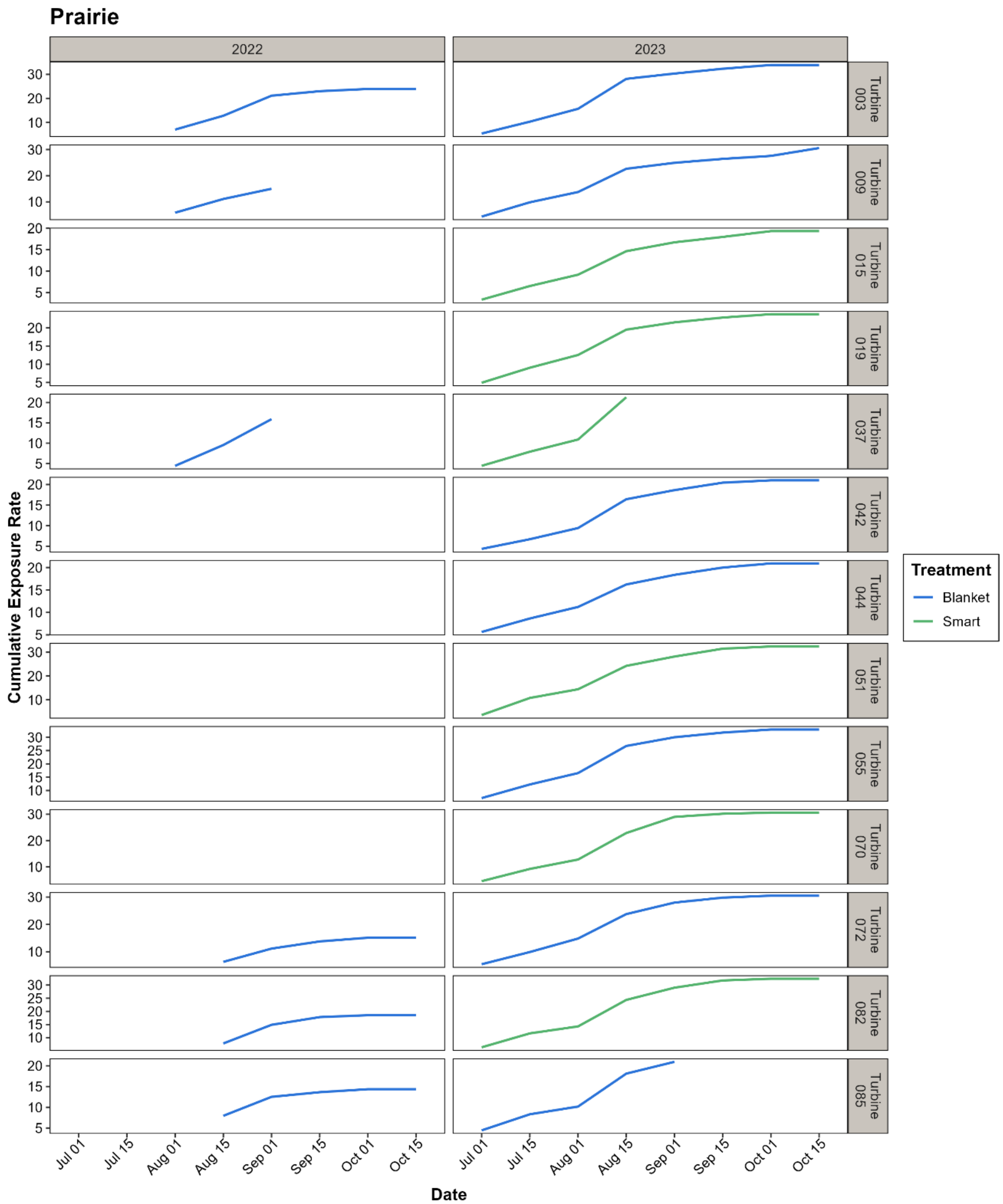
Appendix K Figure 9. Cumulative acoustic exposure measured per turbine by nacelle-mounted acoustic detectors at Palo Alto, 2022–2023.



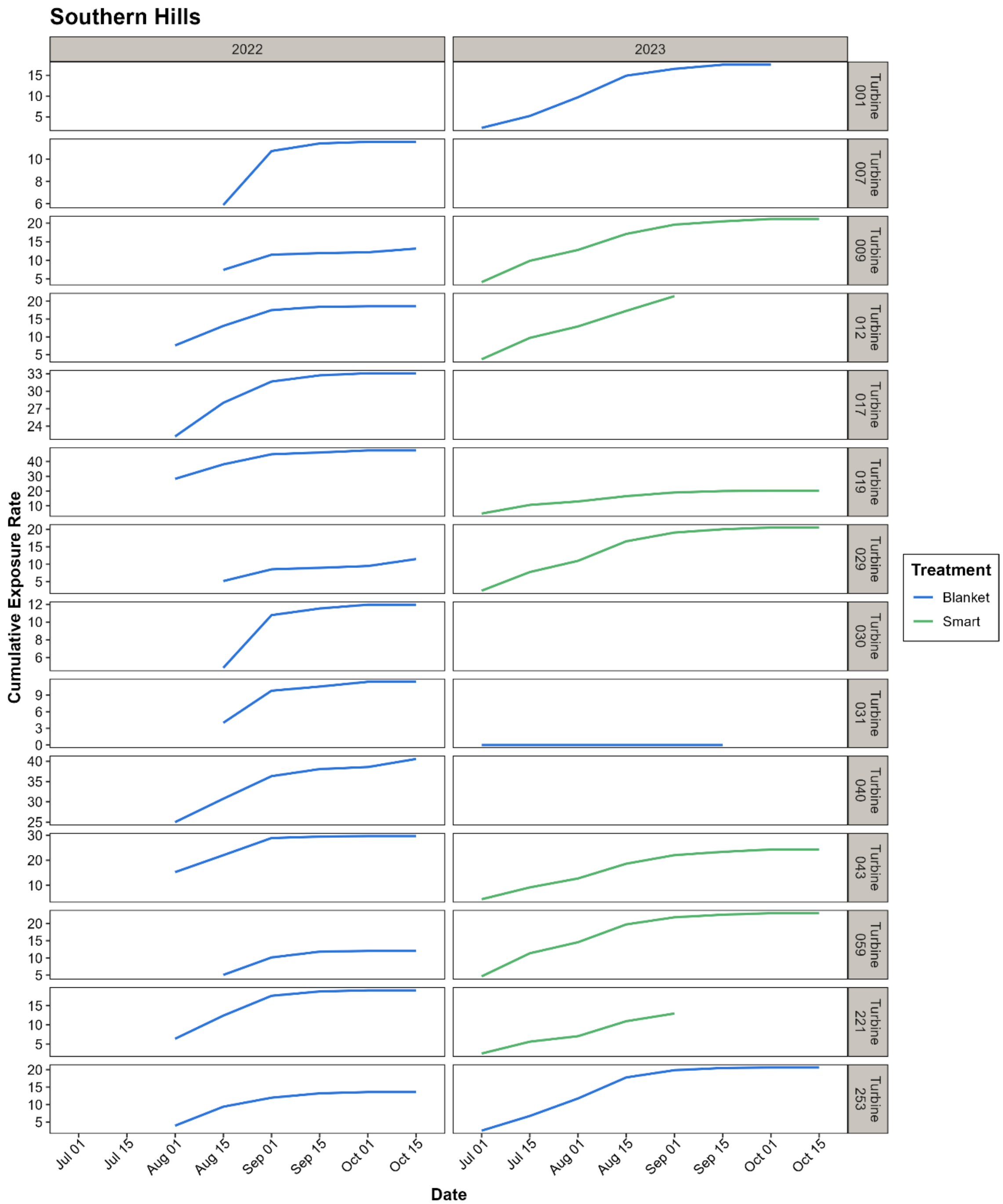
Appendix K Figure 10. Cumulative acoustic exposure measured per turbine by nacelle-mounted acoustic detectors at Plymouth, 2022–2023.



Appendix K Figure 11. Cumulative acoustic exposure measured per turbine by nacelle-mounted acoustic detectors at Pocahontas Prairie, 2022–2023.

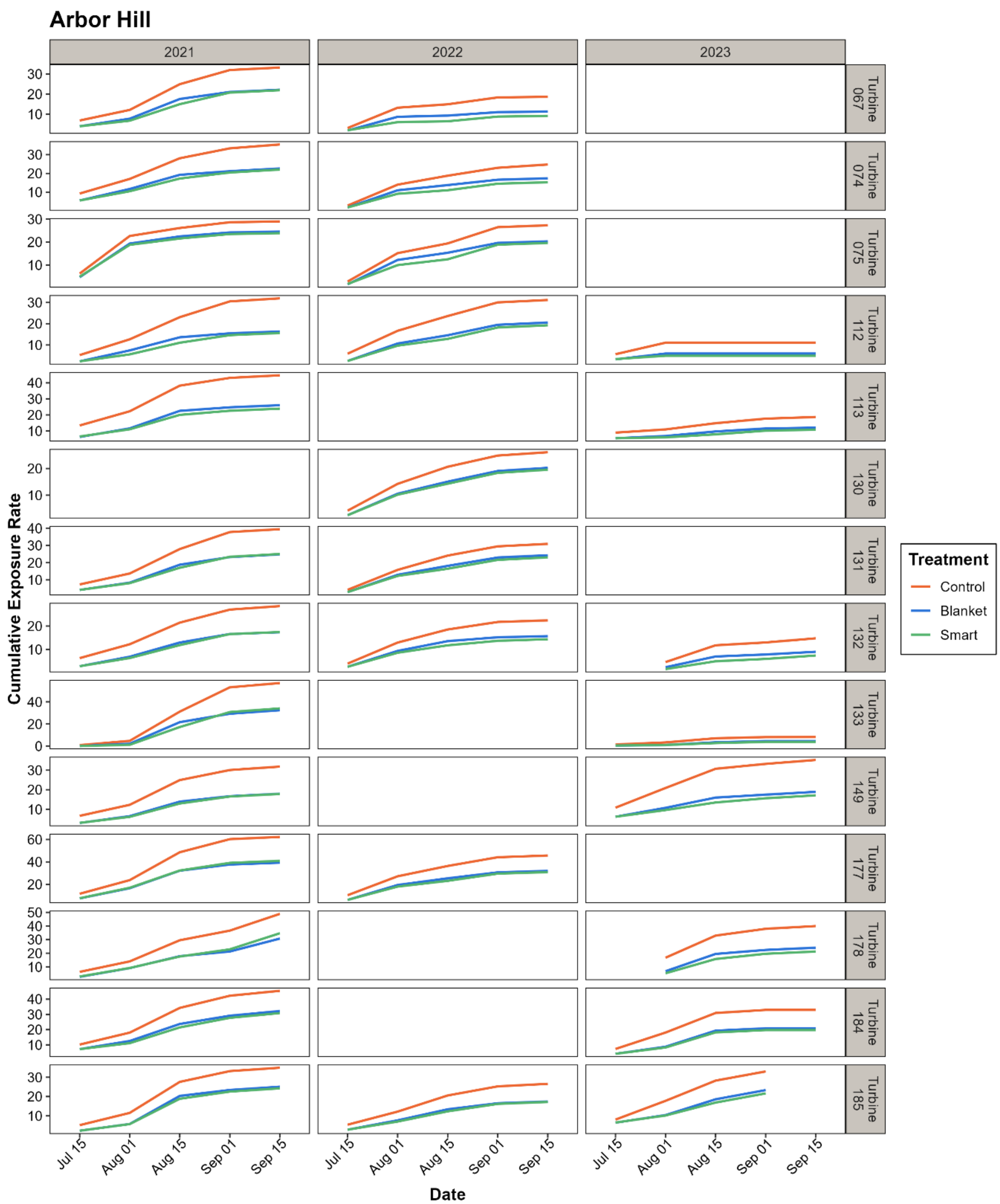


Appendix K Figure 12. Cumulative acoustic exposure measured per turbine by nacelle-mounted acoustic detectors at Prairie, 2022–2023.

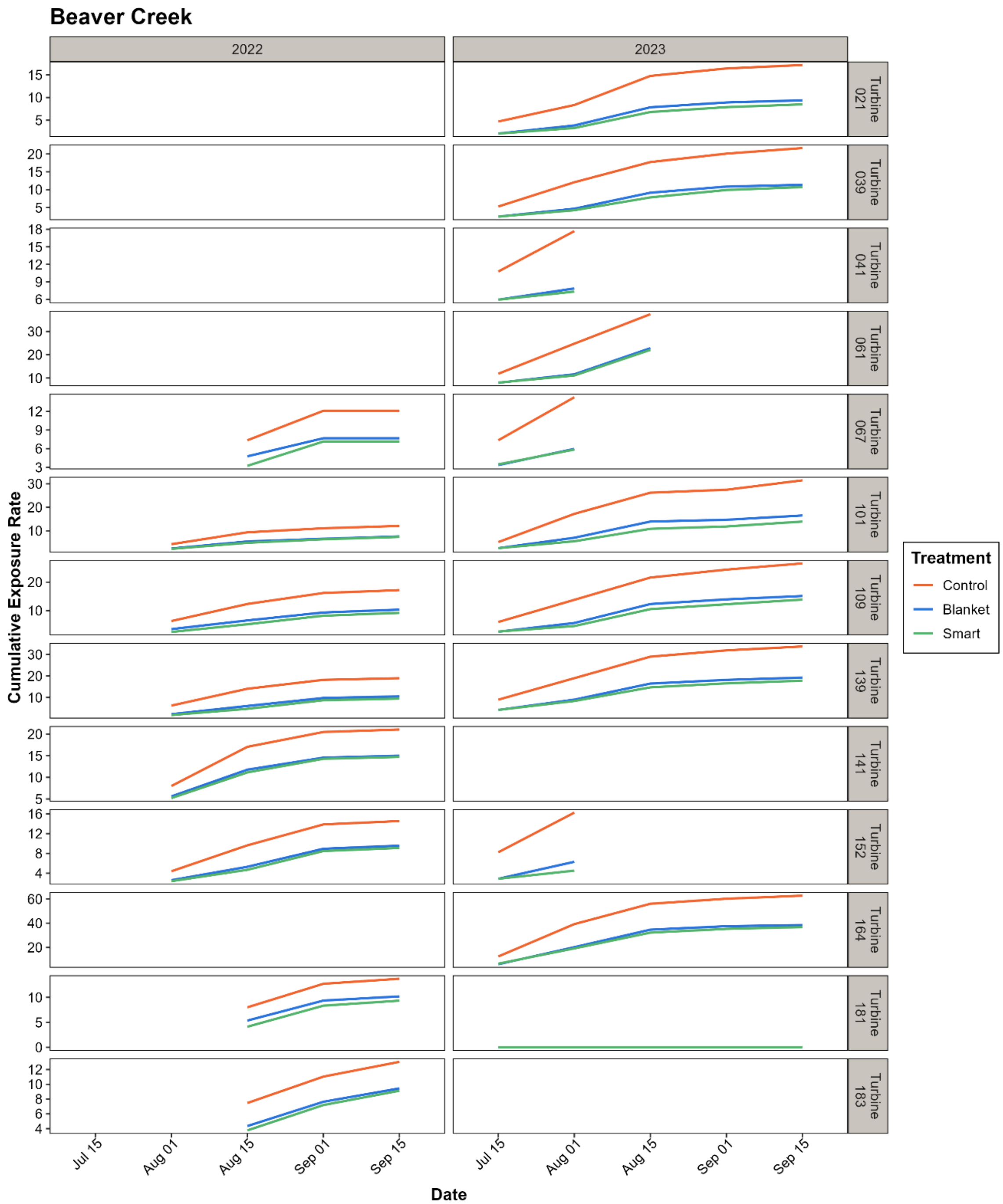


Appendix K Figure 13. Cumulative acoustic exposure measured per turbine by nacelle-mounted acoustic detectors at Southern Hills, 2022–2023.

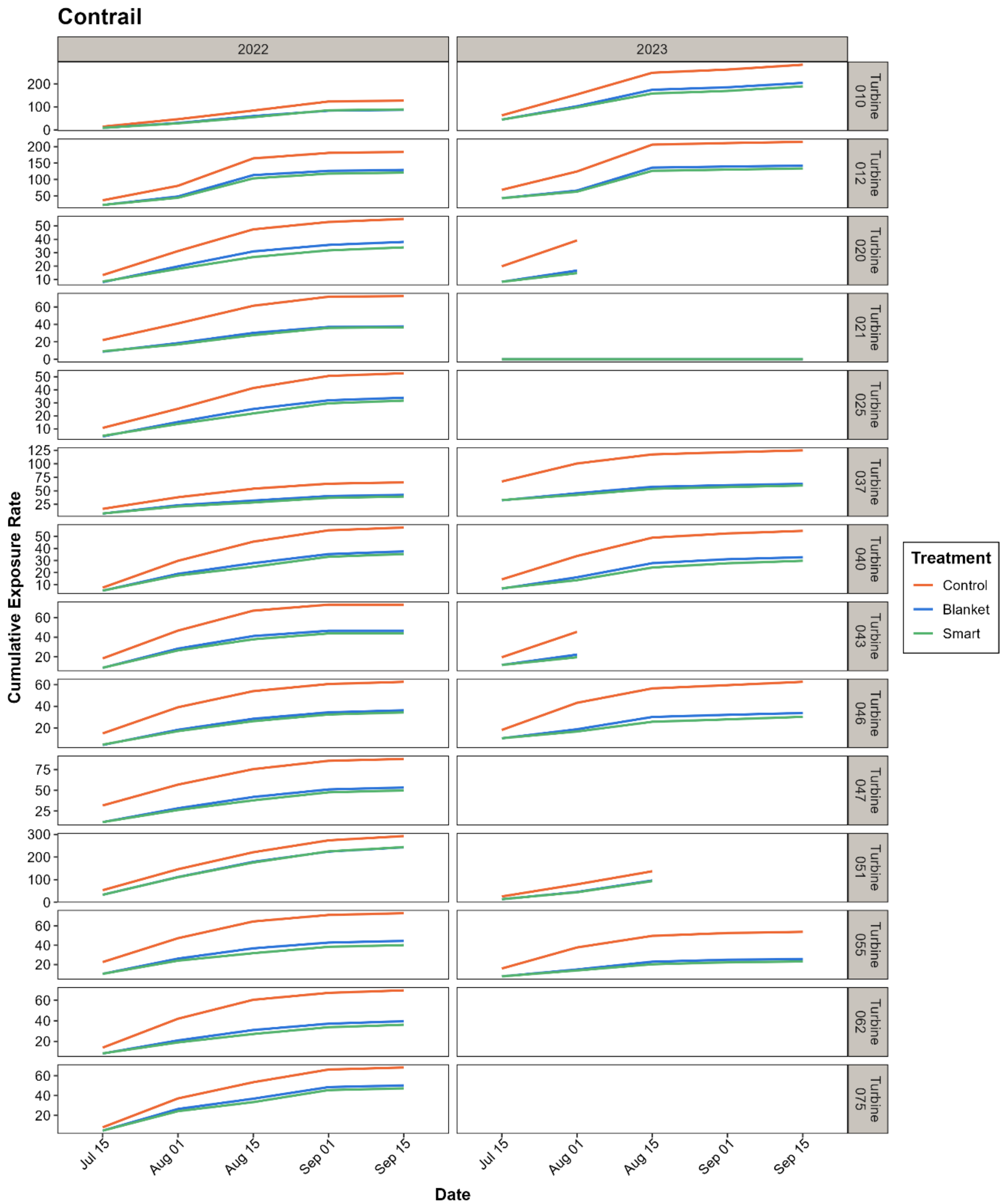
Appendix L



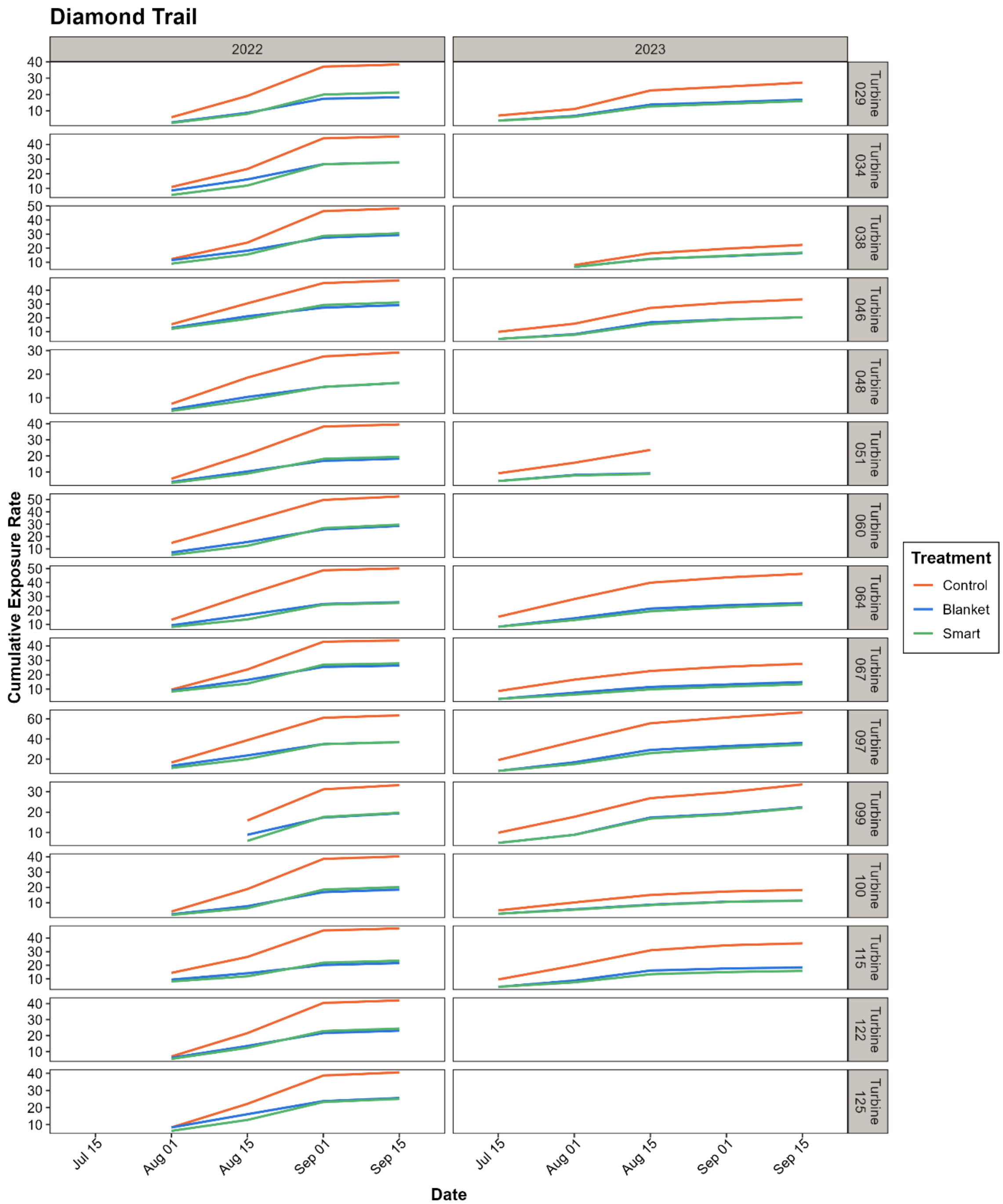
Appendix L Figure 1. Cumulative acoustic exposure simulated per turbine by nacelle-mounted acoustic detectors at Arbor Hill, 2021–2023.



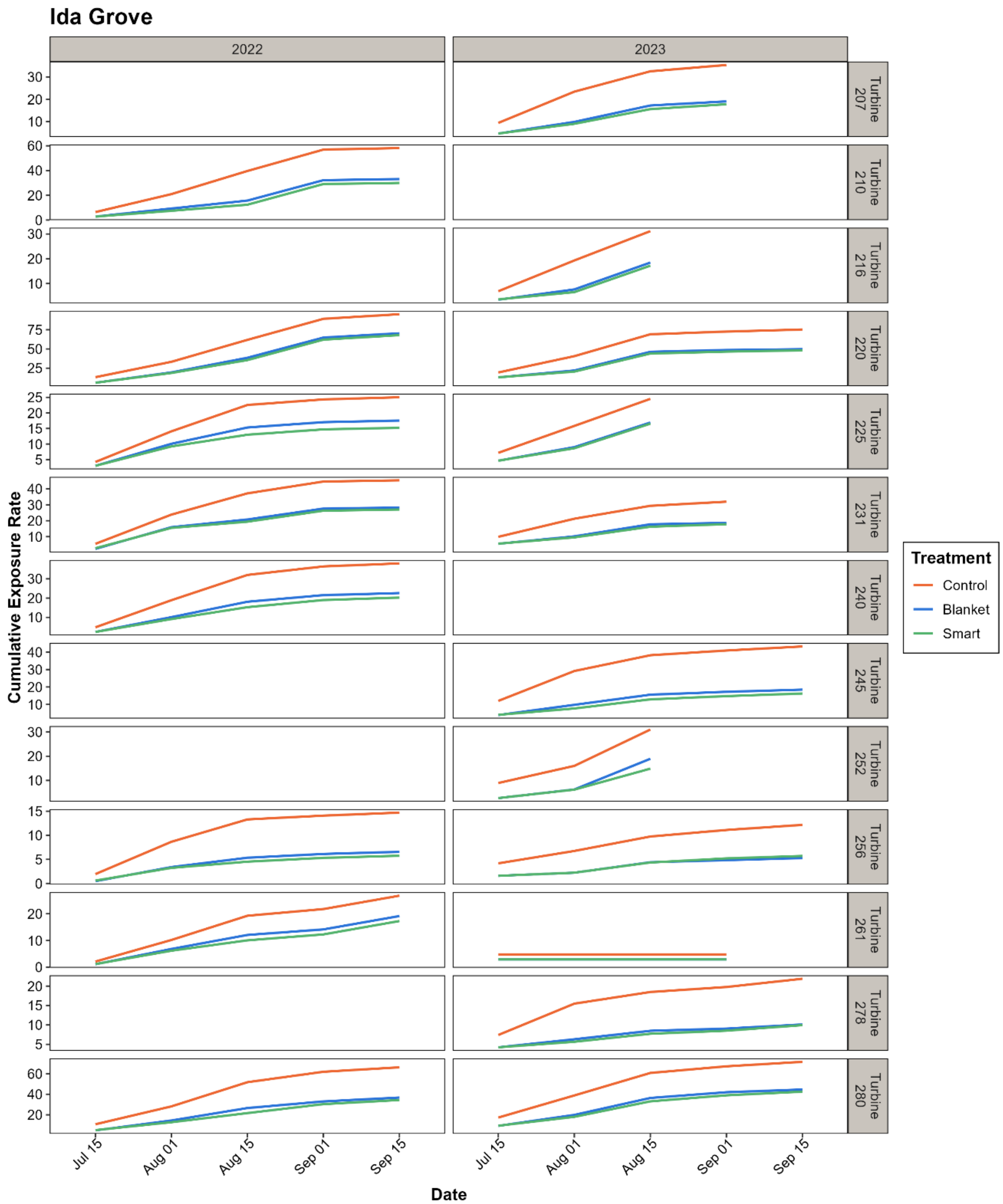
Appendix L Figure 2. Cumulative acoustic exposure simulated per turbine by nacelle-mounted acoustic detectors at Beaver Creek, 2022–2023.



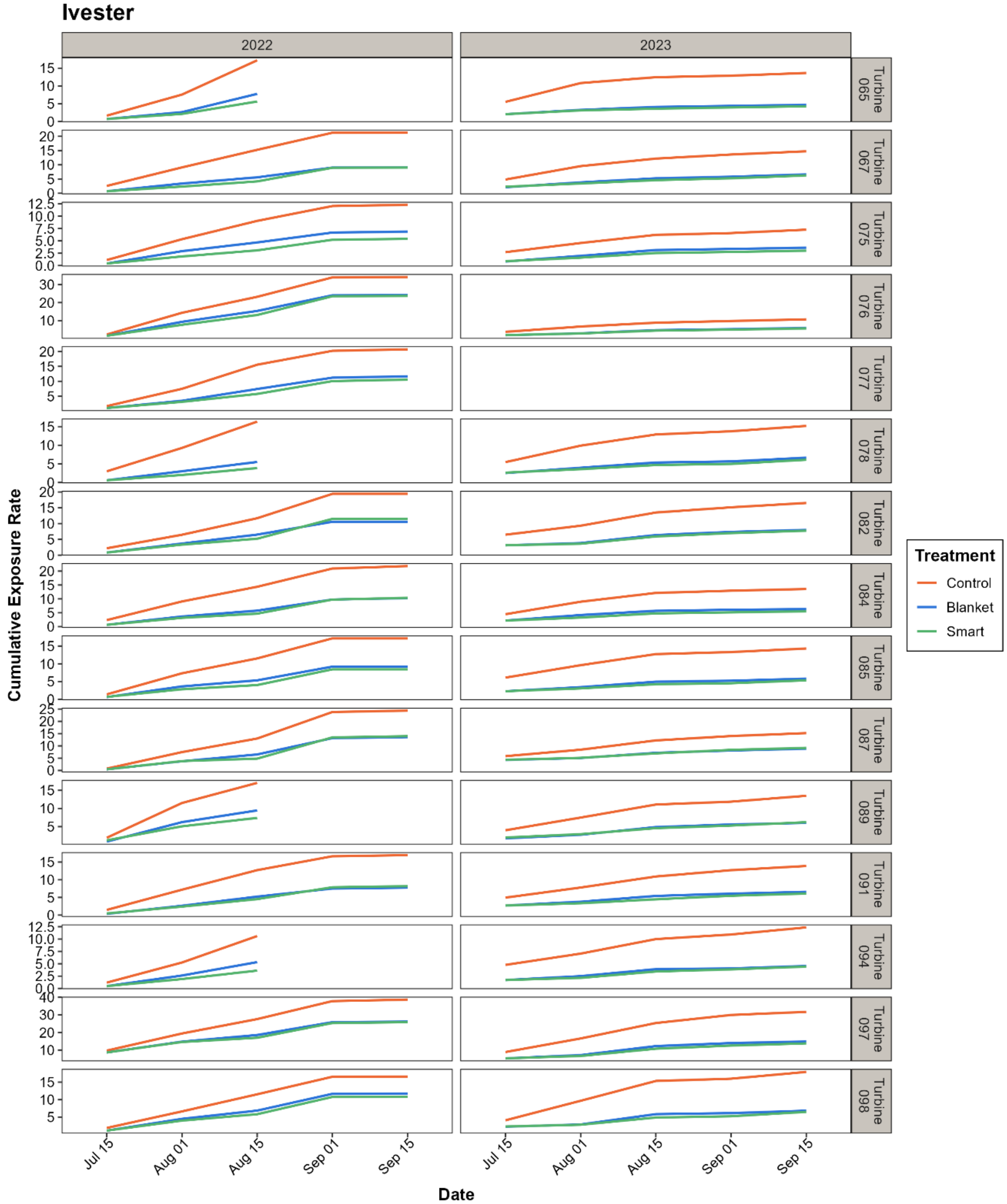
Appendix L Figure 3. Cumulative acoustic exposure simulated per turbine by nacelle-mounted acoustic detectors at Contrail, 2022–2023.



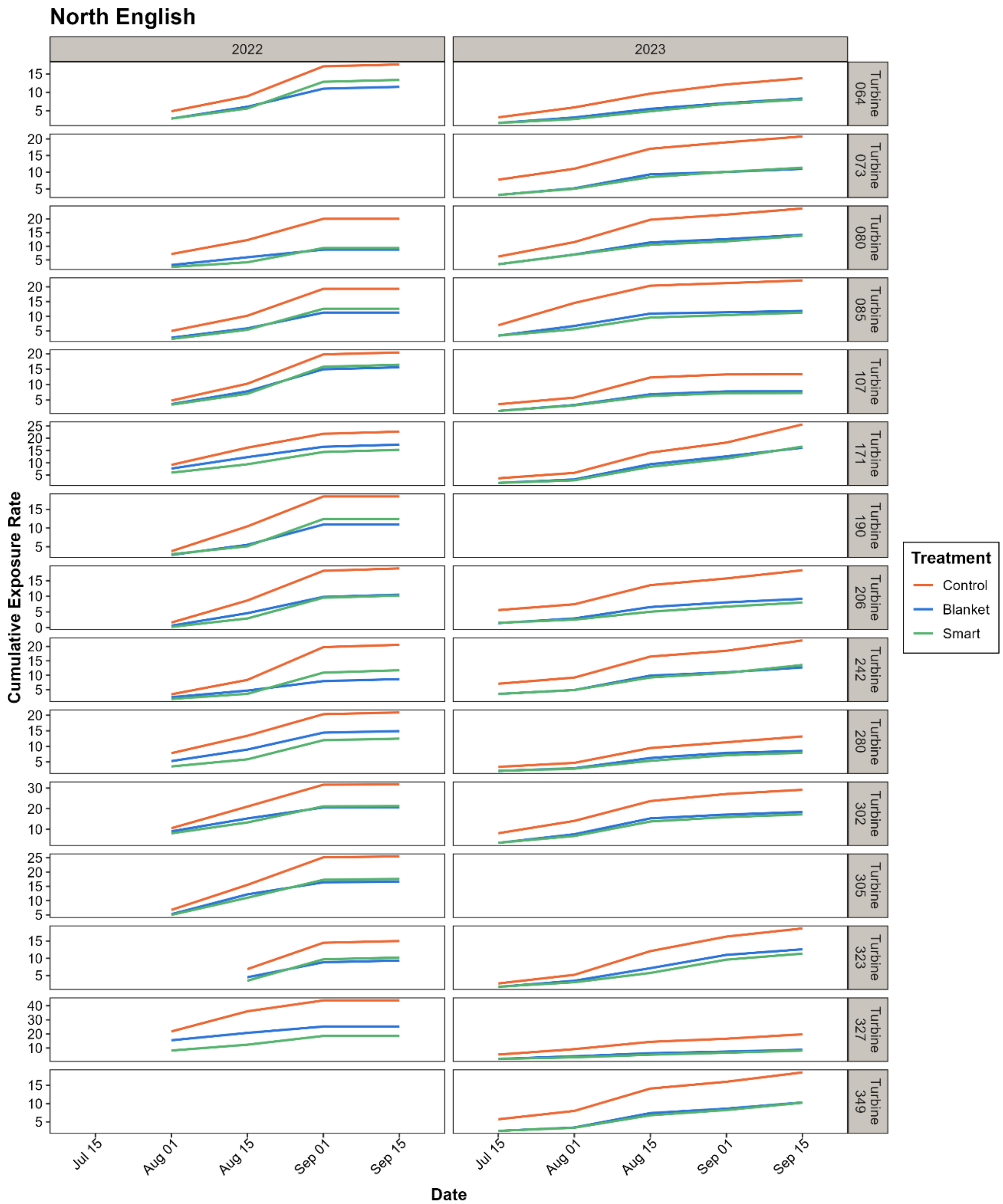
Appendix L Figure 4. Cumulative acoustic exposure simulated per turbine by nacelle-mounted acoustic detectors at Diamond Trail, 2022–2023.



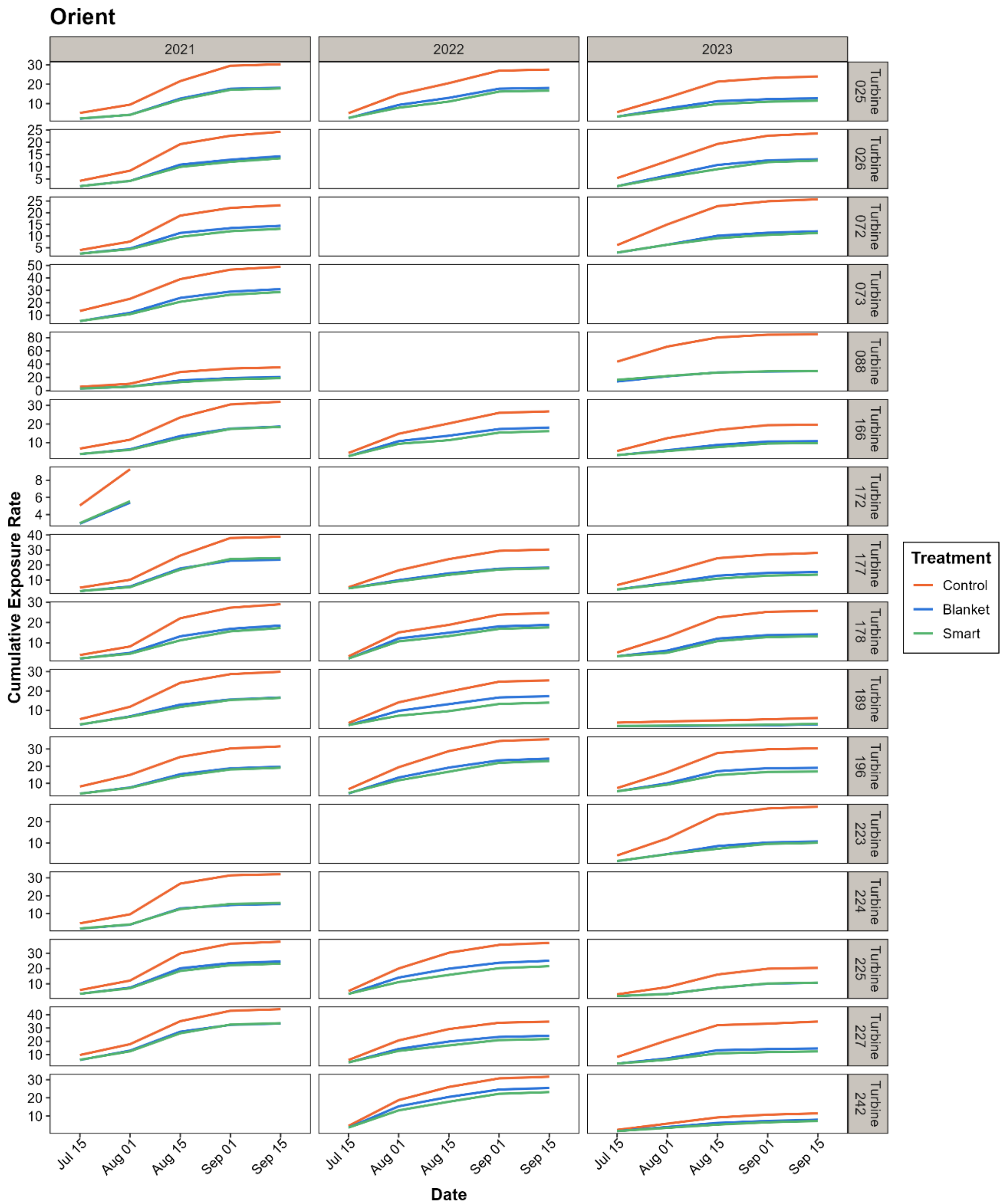
Appendix L Figure 5. Cumulative acoustic exposure simulated per turbine by nacelle-mounted acoustic detectors at Ida Grove, 2022–2023.



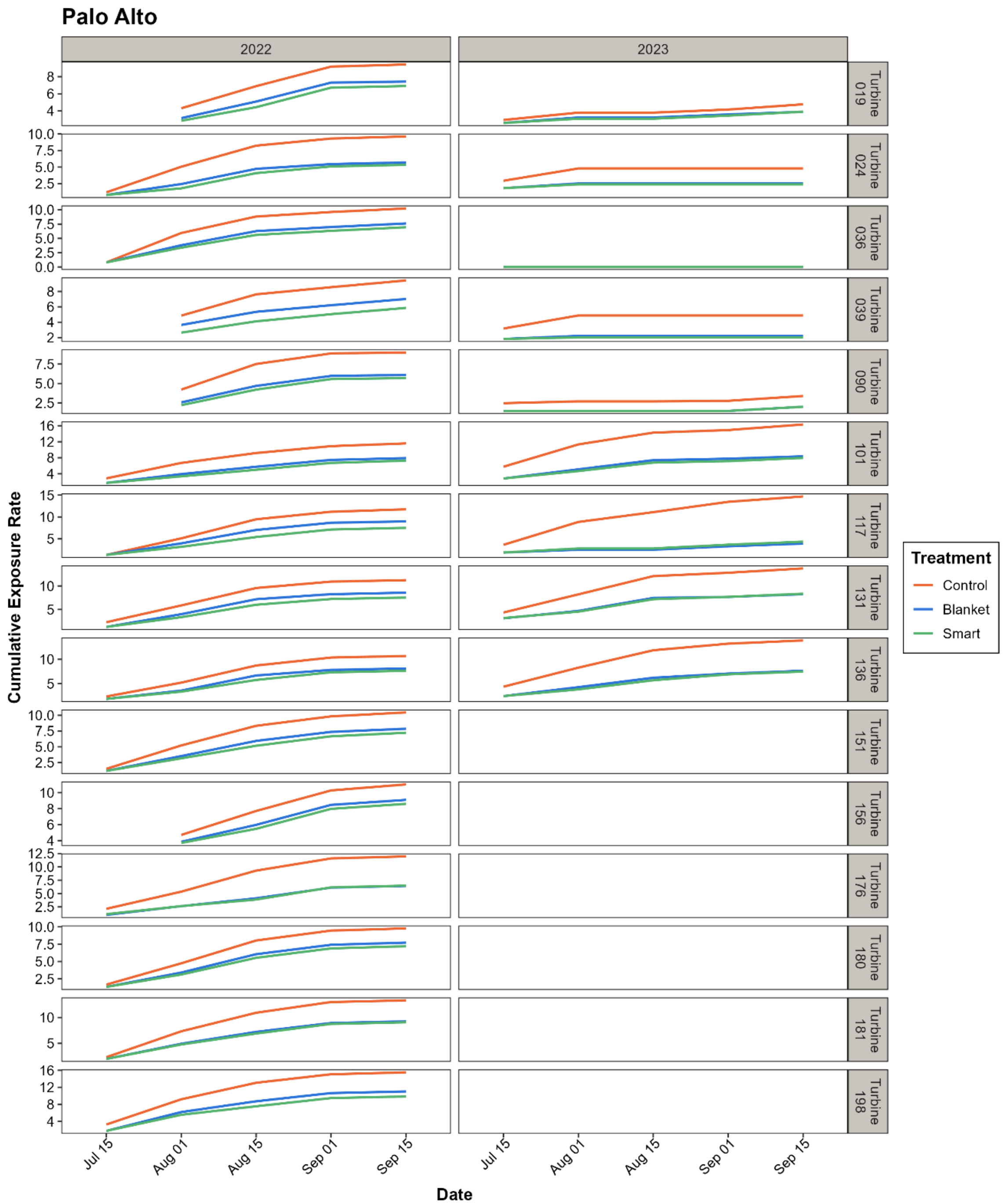
Appendix L Figure 6. Cumulative acoustic exposure simulated per turbine by nacelle-mounted acoustic detectors at Ivester, 2022-2023.



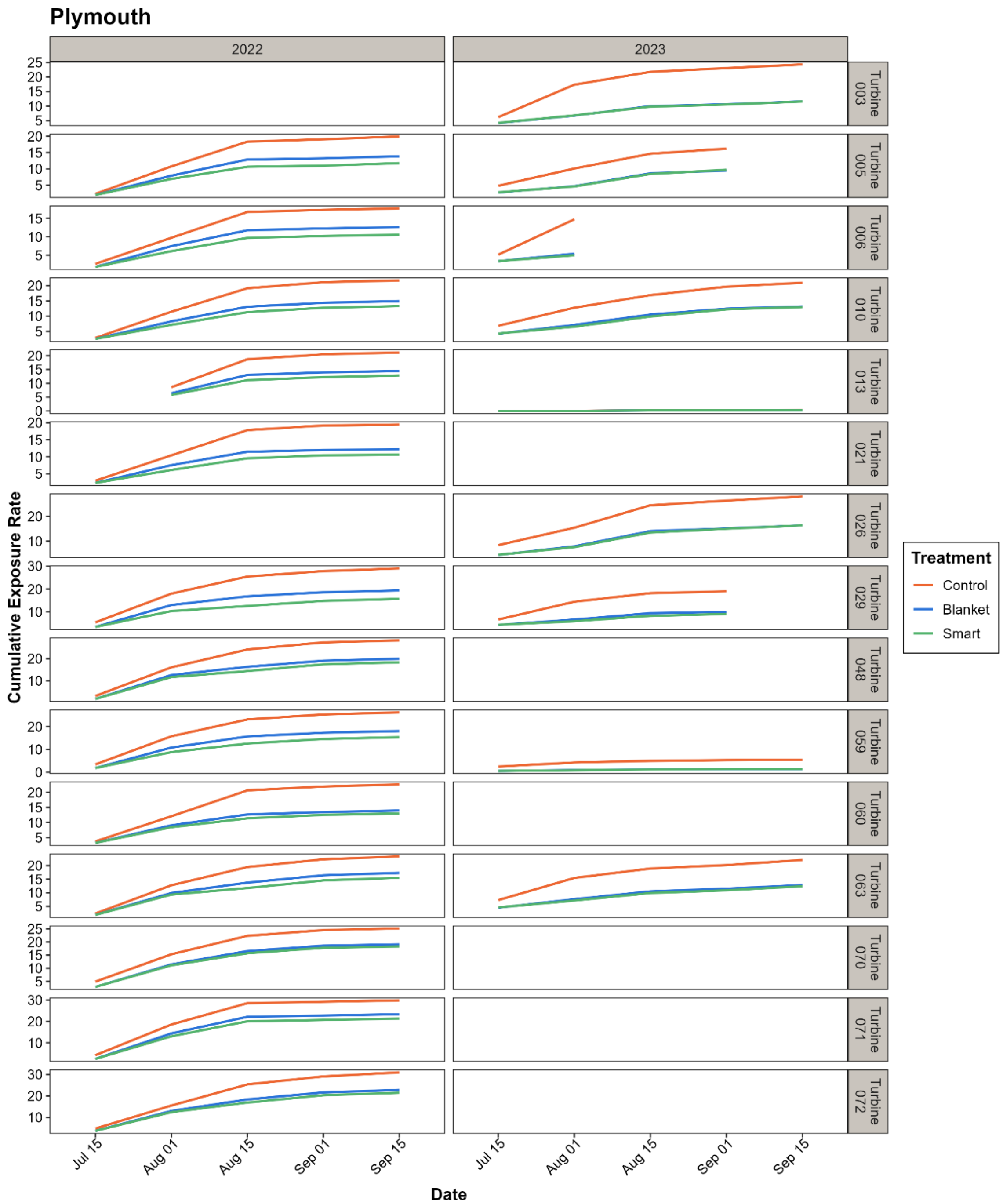
Appendix L Figure 7. Cumulative acoustic exposure simulated per turbine by nacelle-mounted acoustic detectors at North English, 2022–2023.



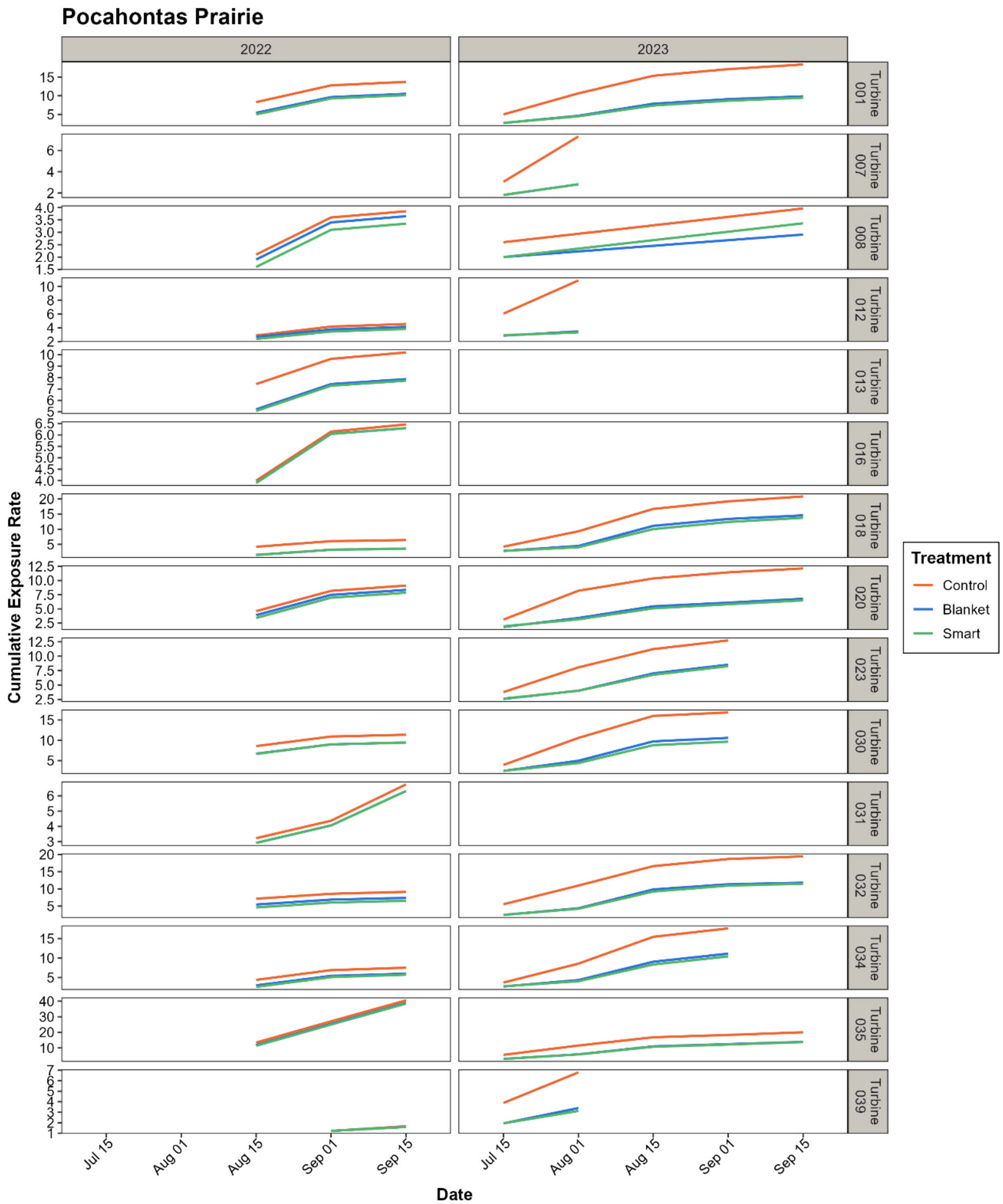
Appendix L Figure 8. Cumulative acoustic exposure simulated per turbine by nacelle-mounted acoustic detectors at Orient, 2021–2023.



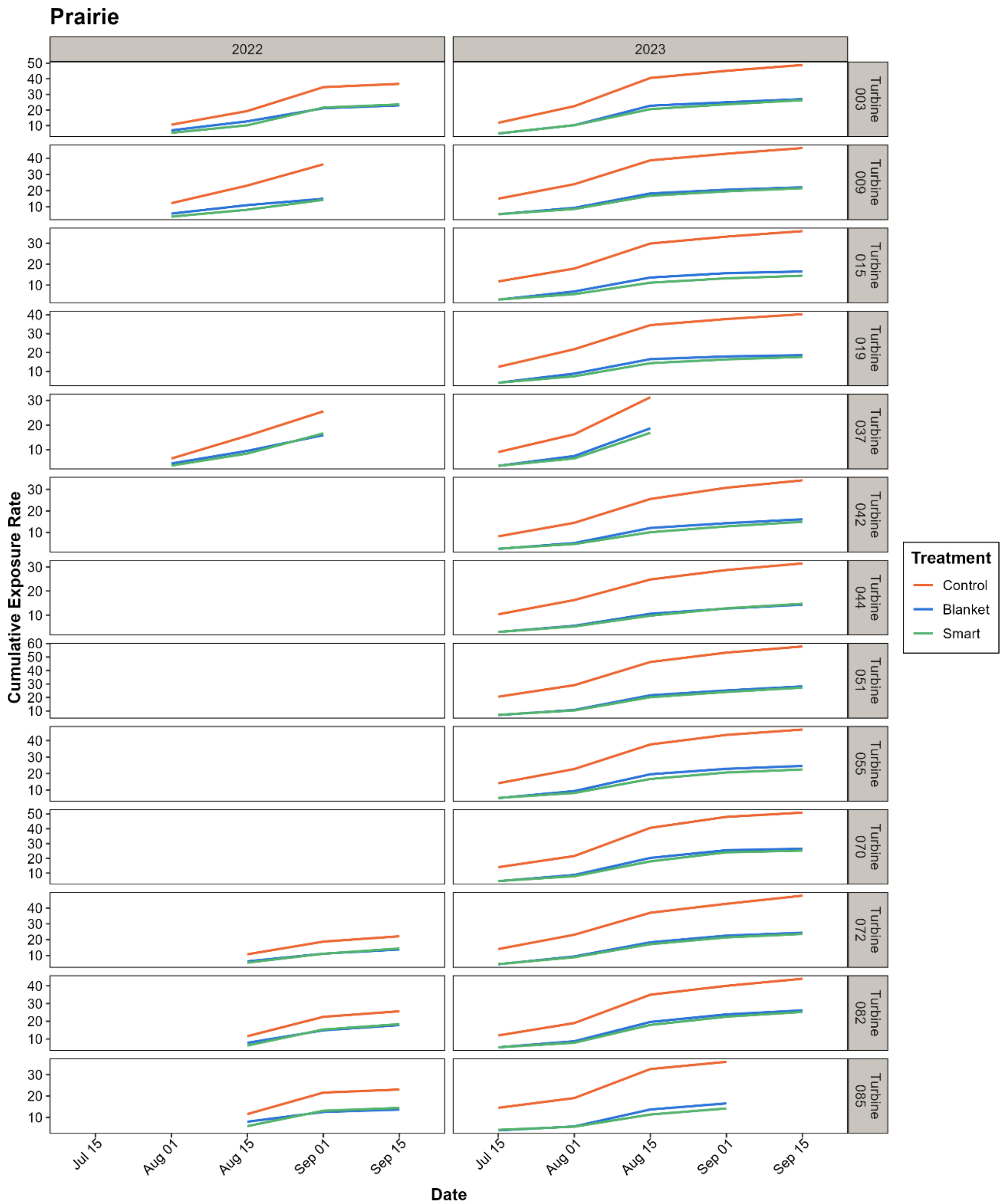
Appendix L Figure 9. Cumulative acoustic exposure simulated per turbine by nacelle-mounted acoustic detectors at Palo Alto, 2022–2023.



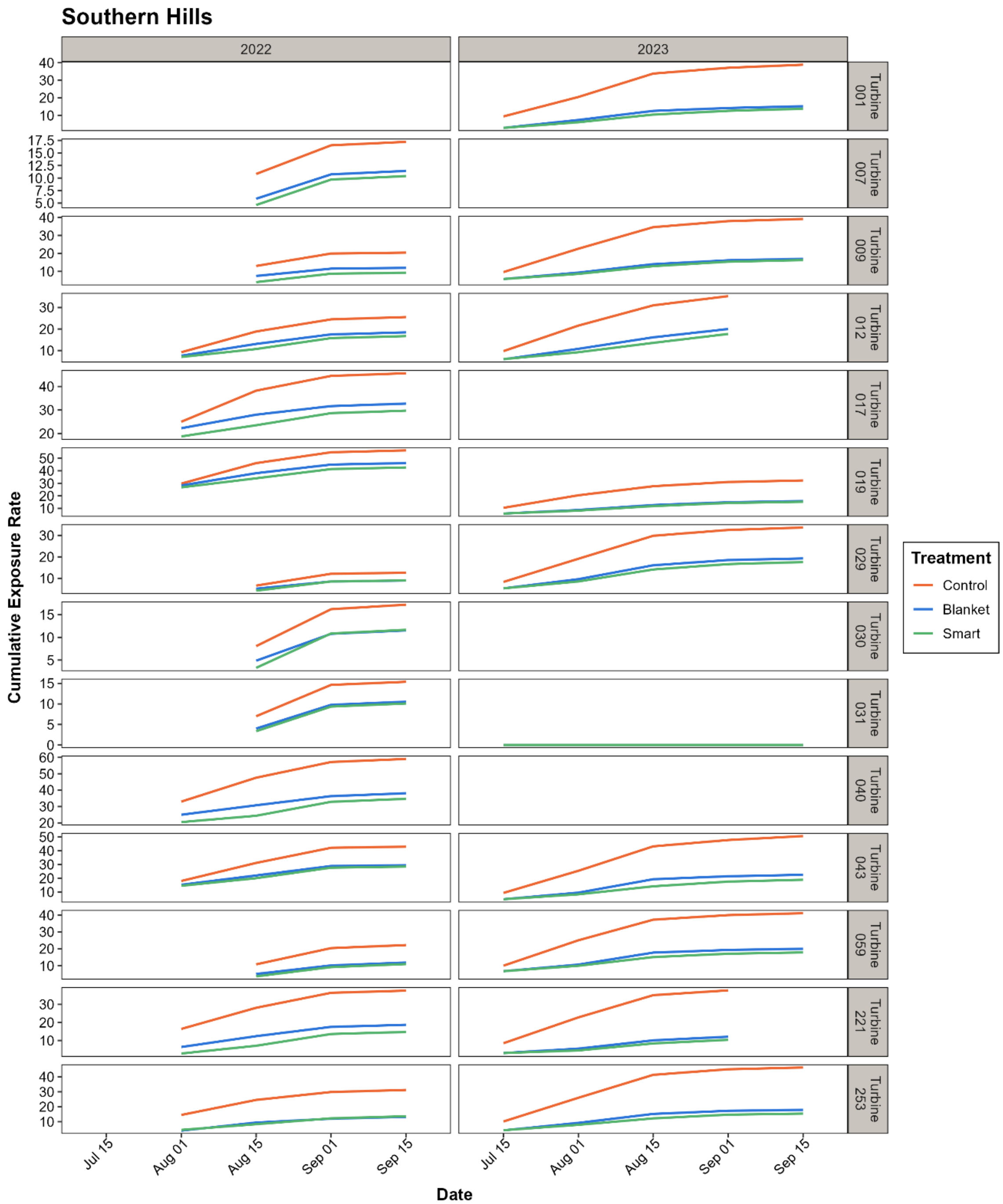
Appendix L Figure 10. Cumulative acoustic exposure simulated per turbine by nacelle-mounted acoustic detectors at Plymouth, 2022–2023.



Appendix L Figure 11. Cumulative acoustic exposure simulated per turbine by nacelle-mounted acoustic detectors at Pocahontas Prairie, 2022–2023.



Appendix L Figure 12. Cumulative acoustic exposure simulated per turbine by nacelle-mounted acoustic detectors at Prairie, 2022–2023.



Appendix L Figure 13. Cumulative acoustic exposure simulated per turbine by nacelle-mounted acoustic detectors at Southern Hills, 2022–2023.