NRG White Paper

Developing an Ultrasonic Acoustic Bat Deterrent System for the Wind Industry

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1/31/20

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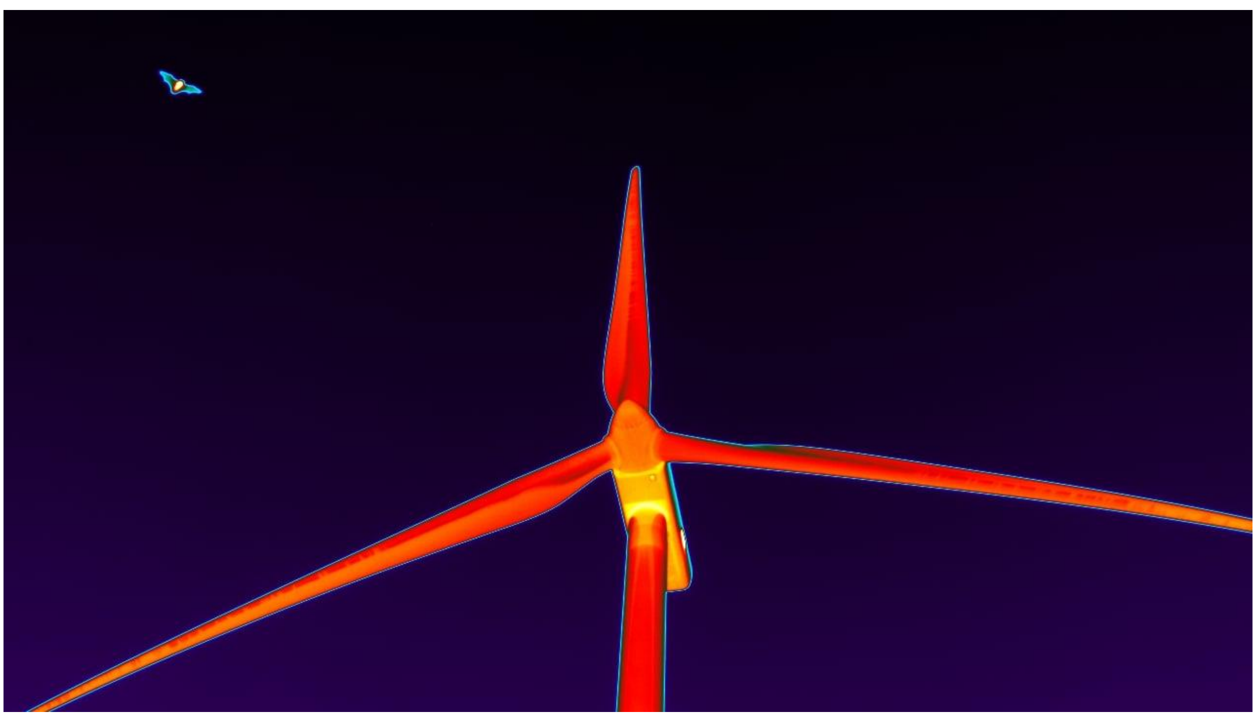
Overview

The wind industry takes great pride in contributing to a clean energy future and protecting species across the globe from climate change. However, there is no perfect energy solution. Even wind turbines, which produce an abundance of clean power, carry their own risks. For example, turbines have been shown to cause direct mortality to bat species, with bat deaths documented at wind energy facilities around the world (Kunz et al. 2007, Rydell et al. 2012, Arnett et al. 2016). This mortality is particularly concerning because of its potential impact on bat populations that are already in decline due to white-nose syndrome (WNS). Recent research suggests that even migratory tree bat populations, which are not affected by WNS but make up a large portion of the fatalities at wind plants, may be at risk due to the direct mortality caused by wind turbines (Frick et al. 2017). The wind industry takes these impacts seriously and is continuously working to minimize them.

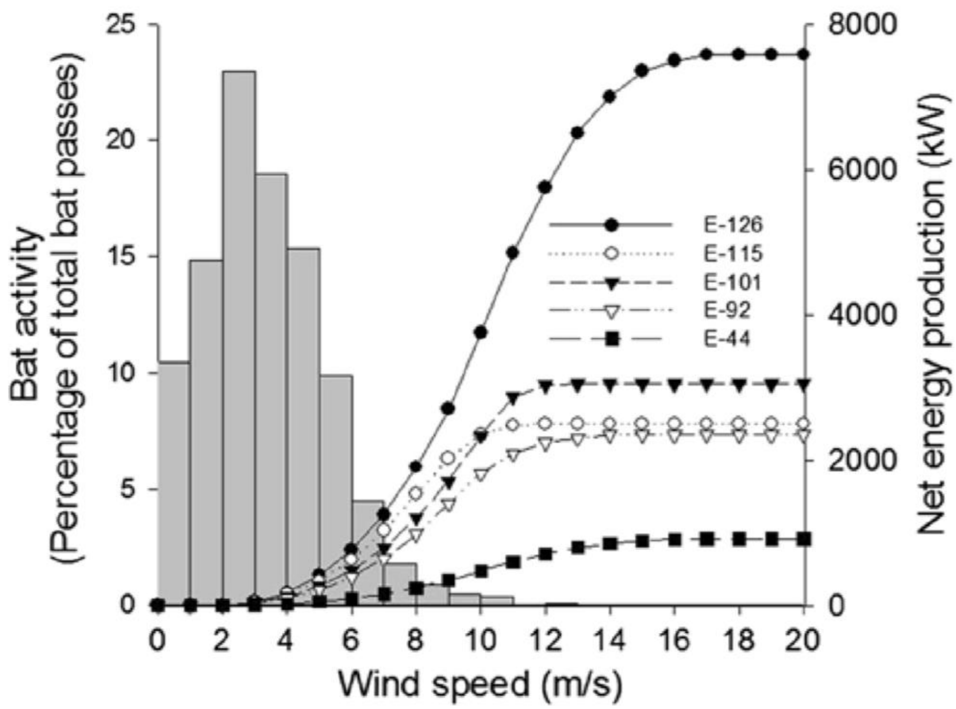
The discovery of direct mortality on bats drove significant research into how and why bats interact with wind turbines in the first place. From these studies it is now known that bats are attracted to turbines (Kunz et al. 2007, Cryan et al. 2014). This attraction causes increased bat activity around the turbine and consequently in the turbine's rotor swept area (the airspace through which the turbine's blades pass). Increased activity in this area increases the likelihood of a direct strike compared to the likelihood of strike if they were flying through the airspace by random chance. Proposed reasons for this attraction vary – some suggest that turbines look like trees, possibly explaining why tree-roosting bats are so highly impacted (Cryan & Barclay 2009), while others have suggested that bats are foraging for insects that are attracted to the turbine (Rydell et al. 2010).



Thermal image of a bat near a wind turbine. Photo courtesy of Michael Schirmacher, Bat Conservation International.

Current Solution

Research of bat mortality at wind plants has revealed that relatively higher bat mortality occurs during nights of low wind speeds (Arnett et al. 2008). It is also evident that bat activity around turbines directly relates to the wind speed, as seen in the figure below (Voigt et al. 2015), with the highest amount of activity occurring in lower wind speeds. Studies of bat interactions with turbines also revealed that bats did not collide with stationary, or very slow moving, blades (Cryan et al. 2014). Combining this knowledge with the relationship between wind speed and bat activity, stopping (or significantly slowing) the rotation of wind turbines' blades during periods of low wind speed has become the wind industry's primary mortality reduction strategy. The slowing/stopping of the rotation of the blades is commonly referred to as low wind speed curtailment and is accomplished by pitching the blades out of the wind. Curtailment has been demonstrated to reduce bat fatalities by 50% on average (Arnett et al. 2013).

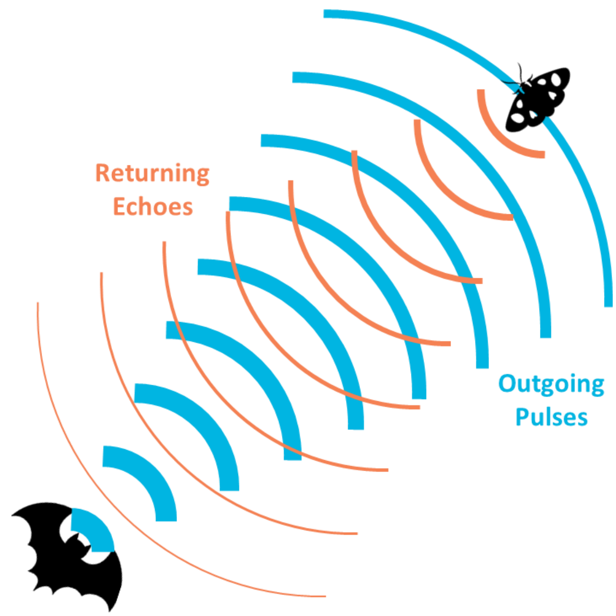


Overlap between bat activity and net energy production (kW) for selected wind turbines in relation to wind speed. Bat passes were assessed via acoustical recordings on wind turbines. (Voigt 2015)

The concern with this approach is that when the turbine is curtailed, it is not producing power. This results in annual losses in power production of 0.5% to 3.5% of the total annual energy production (Carl Ostridge & Chris Farmer 2018), making it economically unsustainable. As the wind speed set point used for curtailment is increased, the power losses increase by a power of ~2.6. Therefore, a severe financial penalty is incurred when increasing the curtailment speed in order to decrease bat mortality. This financial link creates a tension between conserving bats and being able to finance the wind plant. At present, an industry-wide equilibrium exists between a curtailment set point of 5 m/s and a reduced mortality of about 50%. Increasing the common curtailment speed of 5 m/s to further reduce bat mortality is not economically feasible.

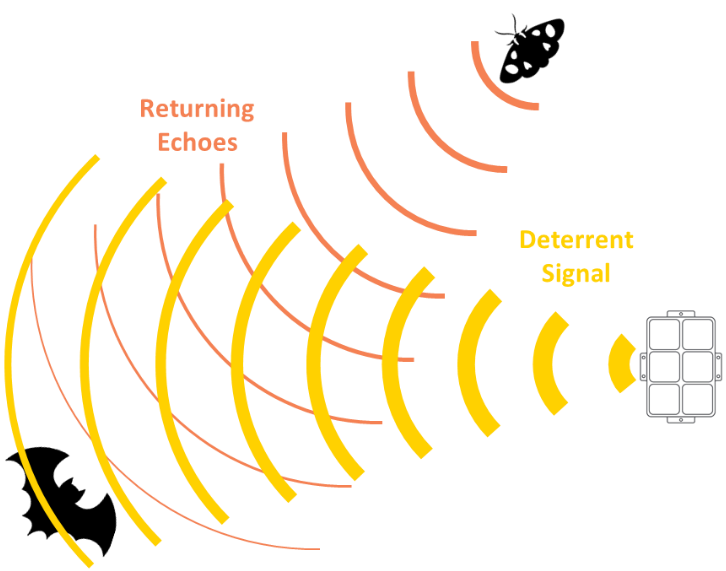
Deterrent Solution

Instead of stopping renewable power generation during low wind speeds, it would be more desirable to keep the bats out of the rotor swept area where there is a risk of mortality. To do this, we take advantage of the bat's unique sense of echolocation. Bats create a series of high frequency chirps that broadcast out through the air ahead of them. These chirps reflect off objects (e.g. insects, trees) creating echoes that return to the bat. By judging the time it took from emitting the chirp to the moment it returns, the bat can determine the range of the object that created the echo. Bats use echolocation for orientation in space, prey detection and capture, and obstacle avoidance.



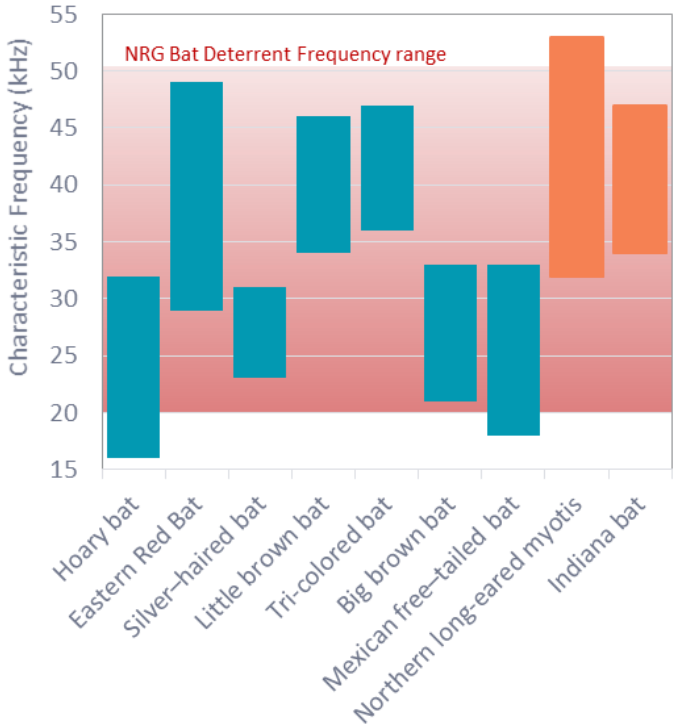
Bats emit high frequency pulses of sound that reflect off their prey and return to them as echoes.

Research from as far back as 2006 has proved the idea that you can reduce bat activity in an airspace by filling it with ultrasound in the same frequency range as the bat's echolocation calls (Szewczak & Arnett 2006). In fact, the idea of confusing a bat's sense of echolocation is even found in nature. When some species of tiger moth hear a bat's echolocation calls, they make ultrasonic clicks of their own (Corcoran et al. 2009). The moth clicks 'jam' the bat sonar, interfering with its ability to hear its own echo return, hindering its ability to track the moth (Corcoran et al. 2011).



By filling an airspace with ultrasound, the bats cannot hear their echo returns and avoid the airspace.

Building upon nature's creation and a great deal of previous research, NRG's bat deterrent technology is based on the principle of 'jamming' the echolocation capabilities of bats. The system does this by generating a



continuous ultrasonic acoustic signal in a frequency range that spans from 20 kHz to 50 kHz, covering the bat species that are most impacted by wind turbines in North America (Humboldt State University Bat Lab 2011). While some bats do echolocate below 20kHz, the top range of the human hearing threshold is also 20 kHz, so producing sound below this level introduces the possibility of human perception of the sound. To avoid this, NRG's Bat Deterrent System does not produce sounds lower than 20 kHz.

Each NRG Bat Deterrent System features multiple Bat Deterrent Units (BDU) that generate the ultrasound. Each BDU is composed of six individual, solid state 'speakers' which are sealed from the elements so they can survive the harsh environment on top of the turbine. These speakers create ultrasound in different frequency bands. The acoustic energy emitted is focused in front of the speakers, creating a 'cone' of incredibly loud ultrasonic noise.

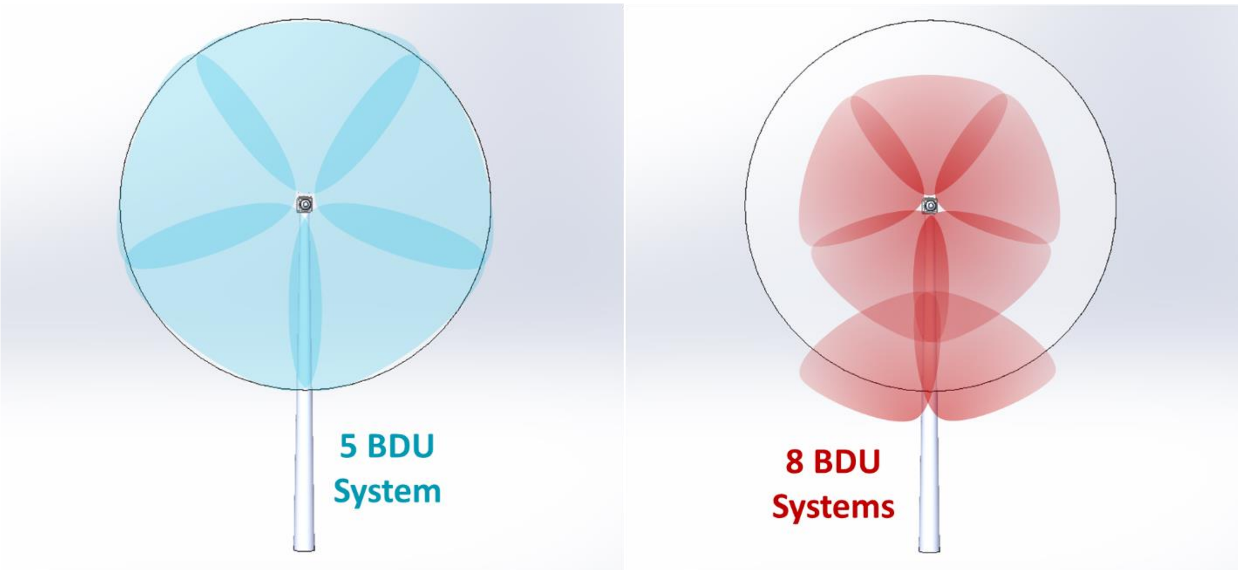
To accomplish full coverage of the rotor swept zone, multiple Bat Deterrent Units are mounted on the nacelle, projecting ultrasound outward. As a bat approaches this airspace, it is exposed to increasing levels of ultrasonic noise. The closer to the nacelle the bat gets, the greater the intensity of the noise, providing a dissuasion to remaining in the airspace. This dissuasion pushes bat activity away from the rotor swept area, reducing the probability of an unintended collision.

Bat Deterrent Units mounted on the nacelle of a wind turbine.

It is important to note that the ultrasonic noise does not extend beyond the rotor swept area of the turbine. Bats are only excluded from the airspace where there is risk of collision and are free to fly and forage below the rotor swept area, including around the base of the turbine.

System Configurations

To provide maximum coverage of the rotor swept area, two different configurations of the system have been created and tested: one system that has 5 BDU mounted on the nacelle of the turbine only, and another system with 5 BDU on the nacelle of the turbine and 3 additional BDU on the tower. Given each of the Bat Deterrent Unit's sound pattern, the effect is to provide overlapping acoustic coverage over the whole rotor plane, as seen in the illustration below.



The illustration on the left shows the sound pattern from the 5 BDU system with all the ultrasound emanating from the nacelle. The illustration on the right shows the sound pattern from the 8 BDU system where there is the same ultrasound emanating from the nacelle, but it is also supplemented by ultrasound from tower-mounted BDU.

Deterrent Validation Testing

In 2018, NRG worked with operators and researchers on two operational wind plants to prove the effectiveness of the Bat Deterrent System at reducing bat mortality. These studies compared the direct mortality from control turbines and treatment turbines using the NRG Bat Deterrent System. All of the turbines included in the studies were searched for bat carcasses using large plots (80m-100m radius). The details of each study are outlined below.

Illinois Study

The study in Illinois compared 15 control turbines that were operating normally without curtailment to 15 treatment turbines that had the 8 BDU system installed plus a 5.0 m/s cut-in speed curtailment applied. The turbines were searched every three days for 10 weeks during the fall bat migration season. Fatality estimates that included corrections for searcher efficiency and carcass persistence were

Illinois - 8DU + 5 m/s	% Redux
TOTAL	67%
Eastern Red (LABO)	58%
Hoary (LACI)	71%
Silver-haired (LANO)	72%
Big Brown (EPFU)	94%

*based on >500 carcasses recovered

estimated and the reduction in mortality was then calculated. The reductions achieved are seen in the table above.

While the results of the Bat Deterrent Systems plus curtailment are interesting, it is important to determine the incremental benefit of the Bat Deterrent Systems. In this case, there was a curtailment study being performed at an adjacent wind plant the same year, so there is a reference study that can be used to separate the contribution of curtailment and Bat Deterrent System. The reduction achieved by curtailment alone can be found in the column labeled '5 m/s' in the table below.

Illinois	8DU + 5m/s Reduction	5 m/s Reduction	Incremental Reduction
TOTAL	67%	43%	42%
Eastern Red (LABO)	58%	39%	32%
Hoary (LACI)	71%	65%	17%
Silver-haired (LANO)	72%	15%	67%

Raising cut-in wind speed from 3.0 m/s to 5.0 m/s alone was shown to reduce bat mortality by approximately 43% at the site for all bat species. The combined 5.0 m/s cut-in plus Bat Deterrent System treatment reduced bat mortality by 68%, which is a 42% incremental reduction in mortality. This is of significant conservation value and provided larger gains with some species that are not greatly reduced by curtailment alone. For example, under the 5.0 m/s curtailment regime, the Silver-haired bat mortality was only reduced by 15%. The addition of the Bat Deterrent System provided an increase in effectiveness of 67%, leading to a reduction in mortality of 72%. The impact on the Eastern red bat was similarly improved from a reduction of 39% to a reduction of 58%, boosting effectiveness by 32%.

Texas Study

The study in Texas was not the common fixed control versus treatment model. Instead, it used a randomized block design with the turbine as the blocking factor and turbine-night as the sampling unit. Randomization was constrained to ensure that each turbine received each treatment the same number of times over the course of the study.

For this test design, all 16 turbines in the study had a 5 BDU system installed, but on any given night only 8 of the Bat Deterrent Systems were operational. This created 8 control turbines (Deterrent System off) and 8 treatment turbines (Deterrent System on) every night. This study design necessitates daily searches so that fatalities can be attributed to a specific treatment. The search plots had a 100m radius and transects were spaced 5m apart.

This study was also unique in that it was conducted over the course of two years on the same turbines. Because there was no statistical difference between the years, both datasets could be combined to provide higher statistical power. It is also important to note that it provided evidence that there was no habituation or reduction in deterrent effectiveness over the two years.

The Bat Deterrent Systems had a significant effect on fatalities, with an overall reduction of 50% across the two years. Notable statistically significant reductions for both Brazilian Free-tail bats (54%) and Hoary bats (78%) were observed. It is important to note that the reductions shown for the Northern and Southern Yellow bats are not statistically significant and should not be interpreted as showing no effect of deterrents for either bat.

Texas Site - 5DU (2017/2018)	Control	Deterrent	% Redux
TOTAL	**418**	**209**	**50%**
Brazilian Free-tail (TABR)	334	152	**54%**
Hoary (LACI)	36	8	**78%**
Northern Yellow (LAIN)	27	22	19%
Southern Yellow (LAEG)	11	14	-27%

Conclusions

The development of an effective ultrasonic acoustic deterrent is incredibly important for the wind industry, both in terms of conservation efforts and optimizing energy production. The aforementioned studies show that NRG's Bat Deterrent System is a proven minimization tool for bats in North America and provides wind developers and operators with a powerful alternative to curtailment alone. The Illinois study proves that the Bat Deterrent Systems have a significant additive effect when used in conjunction with a low level of curtailment. Meanwhile, the Texas study is important because it proves that Brazilian Free-tail bats respond better to ultrasound than curtailment, which has had little effect on the species (Arnett et al. 2013), making the Bat Deterrent System the first proven minimization tool for this specific bat. The Hoary bat results from both studies are especially exciting because high levels of reduction were achieved at both sites, lessening concern over the potential population level impacts on this species caused by wind plants (Frick et al. 2017).

Commercial installation of NRG's Bat Deterrent Systems is taking place at wind farms across the United States. By keeping bats out of harm's way at wind turbines, this technology allows wind operators and developers to produce renewable energy while protecting the financial viability of their projects through mitigating the need for higher curtailment wind speeds. This is crucial to combatting climate change and creating a safer environment for all.

For more information about NRG Systems or its Bat Deterrent System, please contact bats@nrgsystems.com.

REFERENCES

Arnett, E.; Brown, W.; Erickson, W.; Fiedler, J.; Hamiltons, B.; Henry, T.; Jain, A.; Johnson, G.; Kerns, J.; Koford, R.; Nicholson, C.; O'Connell, T.; Piorkowski, M.; Tankersley, R. Jr. (2008). Patterns of Bat Fatalities at Wind Energy Facilities in North America. The Journal of Wildlife Management, 72(1), 61-78. DOI: 10.2193/2007-221

Arnett, E.; Johnson, G.; Erickson, W.; Hein, C. (2013). A Synthesis of Operational Mitigation Studies to Reduce Bat Fatalities at Wind Energy Facilities in North America. Report by Bat Conservation International and Western Ecosystems Technology Inc (WEST). pp 38.

Arnett, E.; Baerwald, E.; Mathews, F.; Rodrigues, L.; Rodríguez-Durán, A.; Rydell, J.; Villegas-Patraca, R.; Voigt, C. (2016). Impacts of Wind Energy Development on Bats: A Global Perspective. Bats in the Anthropocene: Conservation of Bats in a Changing World (pp. 295-323). Springer International Publishing.

Carl Ostridge & Chris Farmer (2018) "Understanding The Costs of Bat Curtailment." AWEA Wind Project Siting & Environmental Compliance Conference, 20 March 2018, The Guest House at Graceland, Memphis, TN

Corcoran, A. J., Barber, J. R. and Conner, W. E. (2009). Tiger moth jams bat sonar. Science 325, 325-327.

Corcoran, A.J., Jesse R. Barber, Nickolay I. Hristov, William E. Conner. Journal of Experimental Biology 2011 214: 2416-2425

Cryan, P.; Barclay, R. (2009). Causes of Bat Fatalities at Wind Turbines: Hypotheses and Predictions. Journal of Mammalogy, 90(6), 1330-1340.

Cryan et al. (2014) "Behavior of bats at wind turbines" PNAS | October 21, 2014 | vol. 111 | no. 42

Frick, W.; Baerwald, E.; Pollock, J.; Barclay, R.; Szymanski, J.; Weller, T.; Russell, A.; Loeb, S.; Medellin, R.; McGuire, L. (2017). Fatalities at Wind Turbines may Threaten Population Viability of a Migratory Bat. Biological Conservation, 209, 172-177. DOI: 10.1016/j.biocon.2017.02.023

Humboldt State University Bat Lab (2011) Echolocation Call Characteristics of Eastern US Bats, retrieved: http://www.sonobat.com/download/EasternUS_Acoustic_Table_Mar2011.pdf

Kunz, T.; Arnett, E.; Erickson, W.; Hoar, A.; Johnson, G.; Larkin, R.; Stickland, M.; Thresher, R.; Tuttle, M. (2007). Ecological Impacts of Wind Energy Development on Bats: Questions, Research Needs, and Hypotheses. Frontiers in Ecology and the Environment, 5(6), 315-324.

Rydell, J.; Bach, L.; Dubourg-Savage, M.; Green, M.; Rodrigues, L.; Hedenstrom, A. (2010). Mortality of Bats at Wind Turbines Links to Nocturnal Insect Migration?. European Journal of Wildlife Research, 56(6), 823-827.

Rydell, J.; Engstrom, H.; Hedenstrom, A.; Larsen, J.; Pettersson, J.; Green, M. (2012). The Effect of Wind Power on Birds and Bats - A Synthesis. Report by Vindval. pp 152.

Szewczak, J.; Arnett, E. (2006). Preliminary Field Test Results of an Acoustic Deterrent with the Potential to Reduce Bat Mortality from Wind Turbines. Report by Bat Conservation International and Humboldt State University. pp 7.

Voigt, C.; Lehnert, L.; Petersons, G.; Adorf, F.; Bach, L. (2015). Wildlife and Renewable Energy: German Politics Cross Migratory Bats. European Journal of Wildlife Research, 61(2), 213-219. DOI: 10.1007/s10344-015-0903-y