Bats flying at dusk. *Photo from Getty Images 1263413793*

Ultrasonic Deterrents To Reduce Bat Mortality at Wind Turbines—Short Science Summary

Background

In North America, several bat species commonly collide with operating turbines. Although the ultimate cause of collisions is unknown, studies suggest bats may be attracted to turbines because they often approach turbine structures and spend extended periods of time (seconds to minutes) near them. To reduce bat mortality at wind farms, operators seek to reduce the amount of time bats spend near spinning turbine blades (known as exposure). Current approaches to reduce exposure include both curtailment, in which turbine operators stop turbine rotors from spinning during periods when bats are expected to be at the highest risk of collision, and deterrent technologies that seek to discourage bats from entering the rotor-swept area or at least limit the amount of time spent there.

The use of ultrasonic deterrent devices that emit one or more high-frequency sounds has been the most tested technique. The idea behind using ultrasound as a deterrent is it disrupts the ability of bats to effectively echolocate (sometimes referred to as signal jamming). According to this idea, introducing ultrasonic noise in the environment in the same frequency ranges that bats use to echolocate makes it difficult for bats to reliably interpret their own ultrasonic vocalizations. Bats are expected to vacate environments where echolocation is required but becomes unreliable. To test this hypothesis, researchers have investigated the behavioral responses of bats in laboratory (Spanjer 2006) and natural settings (Szewczak and Arnett 2007; Gilmour et al. 2020; Fritts et al. 2024).

In one of the earliest studies on the topic, Szewczak and Arnett (2007) used ultrasonic deterrents at a natural pond that bats frequented for drinking and foraging. Szewczak and Arnett demonstrated that ultrasonic deterrents greatly reduced the overall bat activity rates within a distance of approximately 20 meters (m). Despite relatively consistent results using ultrasound deterrents in natural settings (Szewczak and Arnett 2007; Gilmour et al. 2020) and as a tool to discourage bats (at least temporarily) from approaching buildings and bridges (Zeale et al. 2016; Aldemir Bektas et al. 2022), researchers' ability to reduce bat mortality rates around wind turbines has been inconsistent (Table 1). For example, Weaver et al. (2020) found that ultrasonic deterrents reduced hoary bat (*Lasiurus cinereus*) and Brazilian free-tailed bat (*Tadarida brasiliensis*) fatalities but found no difference in the number of northern yellow bat (*Lasiurus intermedius*) carcasses between turbines with and without ultrasonic deterrents. Despite overall reductions in bat fatalities, several studies reported increased fatalities when considering species-specific effects.

Potential Drivers of Variable Responses to Ultrasonic Deterrents

Ultrasound Attenuates (Reduces Sound Pressure Level) Rapidly in the Atmosphere

Ultrasonic deterrents may be ineffective at times because of how rapidly ultrasound attenuates. In general, low-frequency calling species (species that have a characteristic echolocation frequency less than 35 kHz) appear to have more consistent mortality reduction from ultrasonic deterrents. The lower-frequency channels of an ultrasonic deterrent travel farther than

Table 1. Ultrasonic Deterrent Studies Investigating Mortality Reduction at Wind Farms. *(Data derived from publicly available studies that investigated deterrent-only treatments)*

Study	Location	Technology	Percent Change in Fatalities (All Species)	Species-Specific Trends*
Arnett et al. 2013	Columbia and Schuylkill Counties, Pennsylvania, USA	Continuous broadband ultrasound from 20 to 100 kilohertz (kHz); 8 total nacelle-mounted deterrents	-62% to -18%	Hoary bat: **-** Silver-haired bat: **-** Eastern red bat: **-**
Romano et al. 2019	Champaign and Vermilion Counties, Illinois, USA	Air-jet ultrasonic emitters emitting broadband ultrasound from 30 to 100 kHz; ultrasound was continuous in 2014 and 2015 and pulsed in 2016	-32.5% to -29.2%	Hoary bat: **-** Silver-haired bat: **-** Eastern red bat: **-** in 2014 & 2015 **+** in 2016
Weaver et al. 2020	Starr County, Texas, USA	Continuous broadband ultrasound from 20 to 50 kHz; four top and two bottom nacelle-mounted units	-61.2% to -38.5%	Mexican free-tailed bat: **-** Hoary bat: **-** Northern yellow bat: **+**
Schirmacher et al. 2020	Van Wert and Paulding Counties, Ohio	Continuous broadband ultrasound from 20 to 50 kHz; four top and two bottom nacelle-mounted units	-23.0% to +73.0%	Hoary bat: **-** Silver-haired bat: **-** Eastern red bat: **+** Big brown bat: **-**

** The **-** symbol signifies that bat mortality trended toward decreasing with the use of ultrasonic deterrents, and the **+** symbol signifies that bat mortality trended toward increasing with the use of ultrasonic deterrents.*

high-frequency channels (Figure 1). Therefore, high-frequency calling species must enter the rotor-swept area, where risk of collision occurs, before they are exposed to deterrent noise. Conversely, low-frequency calling species may encounter noise and be able to avoid the rotor-swept area altogether. If attenuation is the primary driver of mixed efficacy, then we must consider how to emit all frequency channels outside the rotor-swept area while accounting for trends in increasing turbine blade sizes. Research on blade-mounted ultrasonic deterrents seeks to overcome the challenges of attenuation by adhering or integrating ultrasonic devices along the length of the turbine blade (Sharma and Zeng 2022).

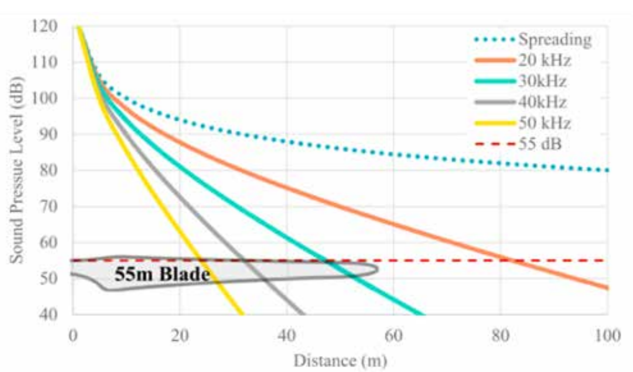

Figure 1. Sound pressure levels at distances away from source for different ultrasonic frequencies. Sound pressure levels attenuate more rapidly the higher the sound frequency. *Image from Weaver et al. (2020)*

Bats Rely on More Than Echolocation When Navigating in the Open Air

Because bats are known for their echolocation, most research has focused on using ultrasonic deterrent devices. Though bats rely on echolocation at close range (<100 m), they use vision to see objects at much greater distances (>2,000 m) (Boonman et al. 2013). Bats rely on vision to aid navigation during migratory flights, commuting flights, and even foraging flights. Furthermore, even at close range, vision may be prioritized over echolocation. For example, when exiting a tree hollow or cave, bats may find light a more reliable cue than echolocation, especially when many other bats are exiting at the same time, masking echo returns. The reliance on vision during flight means visual cues produced by turbines may act as potential drivers of bats' attraction to turbines. Technologies that disrupt visual cues are of interest as deterrent technologies.

Bats May Become Habituated to Static Ultrasound Signals

In situations in which bats are deterred by ultrasound, the magnitude of the effect may diminish over time. Bats have been known to habituate relatively quickly to anthropogenic noises at busy bridges and buildings. Bats may quickly compensate for any echolocation-jamming effects caused by ultrasonic emissions by adjusting their echolocation strategy. Ultrasonic deterrent devices have a fixed set of ultrasound characteristics (e.g., signal frequency, signal intensity, and signal modulation). If bats become habituated to a fixed ultrasound signal, future devices should aim to incorporate more dynamic signaling to keep bats from becoming desensitized.

Recommended Next Steps

The inconsistency in bat mortality reduction and, in some cases, the increased bat mortality have limited the application of ultrasonic deterrents. Identifying the driver(s) of variable efficacy is critical to determine the most efficient pathway toward developing effective ultrasonic deterrent devices. For example, if variability is driven solely by the limited range of ultrasound travel, then blade-mounted deterrents should be prioritized. However, if variable efficacy is related to species-specific differences in responses and/or habituation, we need to begin developing ultrasonic deterrents capable of more dynamic signaling.

The future of ultrasonic deterrents may not entail a one-size-fits-all approach. The ability to consistently deter bats of different species across different spatial and temporal scales may rely on the improved ability to both transmit and adapt ultrasonic signals. Further, ultrasonic deterrents may only serve as one layer of intervention in a larger, comprehensive approach to bat mortality reduction.

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NREL/FS-5000-90840 • November 2024