# Ultrasonic noise emissions from wind turbines: Potential effects on bat species

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## ABSTRACT

The impact that wind turbines have on the environment, particularly with respect to wildlife such as bat species, has generated increasing concern over the last decade. Although the harnessing of wind power is becoming much more widespread as a clean, renewable energy resource, the increasing global turbine mortality rates for bats are thought to be significantly detrimental to susceptible species. Much research is still needed to fully understand the ways in which turbines affect bats, since they rely on echolocation and audible cues to hunt and navigate, therefore having a unique acoustic perspective of objects in their vicinity. Here we present an overview of what is currently known regarding ultrasonic emissions from operational wind turbine structures, including noise generated from the gearing mechanism, rotor, or through blade defects, and how such noise may be perceptible to some bat species in the local turbine habitat.

## INTRODUCTION

Wind energy is the fastest growing global energy technology, with a yearly growth rate of around 30–40 % (BWEA, 2001; EWEA, 2009). Wind power is seen as a clean, environmentally friendly renewable energy source; although wind turbines have undergone rapid development over the last 30 years (Twidell, 2003), it is only relatively recently that their impact on wildlife has been brought to scientific and public attention. This is perhaps due to their increasingly widespread deployment over a wider range of habitats than ever before, through increasing demand for ‘greener’ energy production. The phenomenon of wildlife-turbine mortality initially asserted itself with incidents of bird strike at early experimental large-scale turbine installations in the 1980’s (Erickson *et al*., 2002). It was not until early 2000 that bat-strike at wind plants began to be noticed during ground carcass surveys, with many hundreds of bat carcasses turning up, at some plants outnumbering bird carcasses by almost 7:1 (Kerns & Kerlinger, 2004). Further study over the last decade has revealed that the phenomenon of bat-turbine mortality is widespread throughout the US, Europe and other countries world-wide. The causality behind bat interactions at wind turbine installations still remains largely unclear, and it is widely recognized that much more study is required to investigate the underlying factors. However, it is recognised that direct blade-strike mortality may not be the only issue for bat populations in the vicinity of wind turbines.

Rather than a visual system, insectivorous bats rely on echolocation, producing high-frequency (ultrasonic) pulses of sound and interpreting reflected echoes to navigate and hunt. It is not yet clearly understood whether operational wind turbine rotors produce significant levels of ultrasonic emission that could be detected by bats, or potentially interfere with echolocation during bat-turbine interactions. This paper provides a brief overview of the current knowledge surrounding noise emissions from wind turbines, and the potential effects on local bat species.

## ULTRASONIC NOISE EMISSIONS FROM WIND TURBINES

Operational turbines are known to produce variable levels of human-audible noise (<20 kHz) from the blades and nacelle. Although turbine noise is predominantly low frequency with almost all acoustic contribution at 65 dB SPL from frequencies below 2 kHz (Dooling, 2002), it seems feasible there could also be an ultrasonic component (Johnson & Kunz, 2004). To date, there have been very few investigations into the ultrasonic emissions of different makes of turbine. Due to the nature of ultrasound being increasingly attenuated with distance, high-frequency sound emissions from turbines can be difficult to assess, particularly at large-scale installations. Some studies have been unable to detect any ultrasonic noise produced by active turbines, although it is possible that the distance between the turbine blades and ground level was large enough to prevent detection by the equipment used at the time (Johnson & Kunz, 2004). Schröder (1997) investigated the ultrasonic emissions of 47 turbines (19 types) in Germany, using a ‘Pettersson D980’ bat detector, at ground level, between the base to 100 m away. Many turbines were found to emit ultrasound at around 20–50 kHz, although levels were not provided. Although the turbines in this study ranged from 10–92 m tall, there did not appear to be a correlation between ultrasonic emission and turbine size, and the precise source of the ultrasonic noise could not be identified. A similar study by Szewczak & Arnett (2006) examined the ultrasonic emission components of 7 types of turbine at wind plants around the US, as measured by a ‘Pettersson D240x’ bat detector at ground level. In contrast with Schröder’s findings, Szewczak & Arnett found most turbines contributed little, if any, ultrasound above ambient noise level. There therefore appears to be no ‘standard’ type of ultrasound emission between different makes of turbine, with some structures emitting no ultrasound while others may emit significant levels of ultrasonic noise.

### Potential sources of ultrasonic noise production

According to Twidell (2003), although low-frequency noise can be generated from the turbine’s blades passing the tower and perturbing the wind, high-frequency noise may be primarily generated by the blade tips. Some blades are known to ‘whistle’ due to slight defects in the blade (Dooling, 2002), or previous damage. The rotational frequency of the rotor, and its harmonics, can produce unwanted vibrations (Twidell, 2003), which could play a part in ultrasonic emission. The internal machinery housed in and around the turbine’s nacelle is also reportedly a generic source of noise, and while Szewczak & Arnett (2006) found the electronic machinery of some turbine models to generate ultrasonic noise, in most cases this was not detectable more than 10 m from the nacelle. Such studies have noted that other sources of ultrasonic emissions from the turbines need further investigation.

## EXAMPLE TURBINE NOISE MEASUREMENTS

### Microturbine sound field measurement

Previous work by the authors (Long, 2011) assessed the ultrasonic noise emissions from a microturbine model (rotor diameter 0.91 m) previously linked with bat mortality. Measurements were taken with a high-frequency calibrated microphone (assessed frequency range 45–55 kHz), in an anechoic chamber, in 10° increments around the operational rotor (0.6 m from the hub). The microturbine was found not to produce appreciable ultrasonic noise above the undistorted noise floor of the microphone (see Fig. 1).

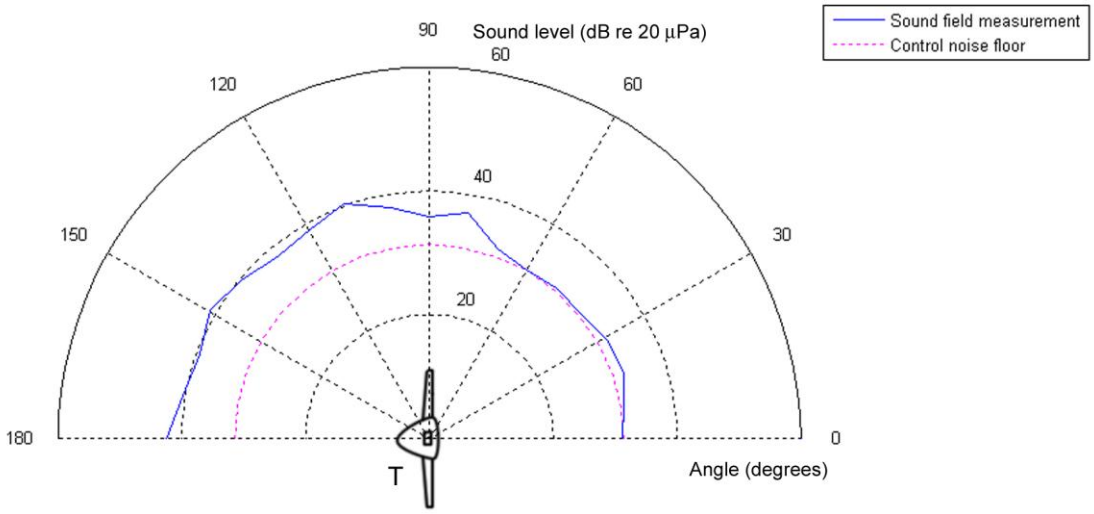


**Figure 1:** Polar sound map of microturbine sound field in the ultrasonic region between 45–55 kHz, as measured by calibrated ultrasonic microphone at a distance of 0.6 m. Solid line indicates the noise measurement, dotted line the control noise floor level for the microphone, while 'T' denotes the location of the microturbine.

It was therefore concluded that this particular model of microturbine did not contribute a high level of ultrasonic noise to the environment in the range of 45–55 kHz. In addition, sonograms of the ultrasonic frequency band recorded (20–100 kHz) revealed no other ultrasonic contribution in this range.

## Unusual turbine blade fault emission

As noted by Dooling (2002), minor blade structural discrepancies/faults can cause operational rotors to 'whistle', either in the human-audible or ultrasonic range. An interesting example of this was recorded from a 20 kW turbine (rotor diameter 11 m) by the authors (Long, 2011), using a calibrated high-frequency microphone (assessed frequency range 2 Hz–100 kHz). Ultrasonic FM sweeps were produced by the turbine, between around 22–30 kHz and lasting about 140 ms (see Fig. 2).

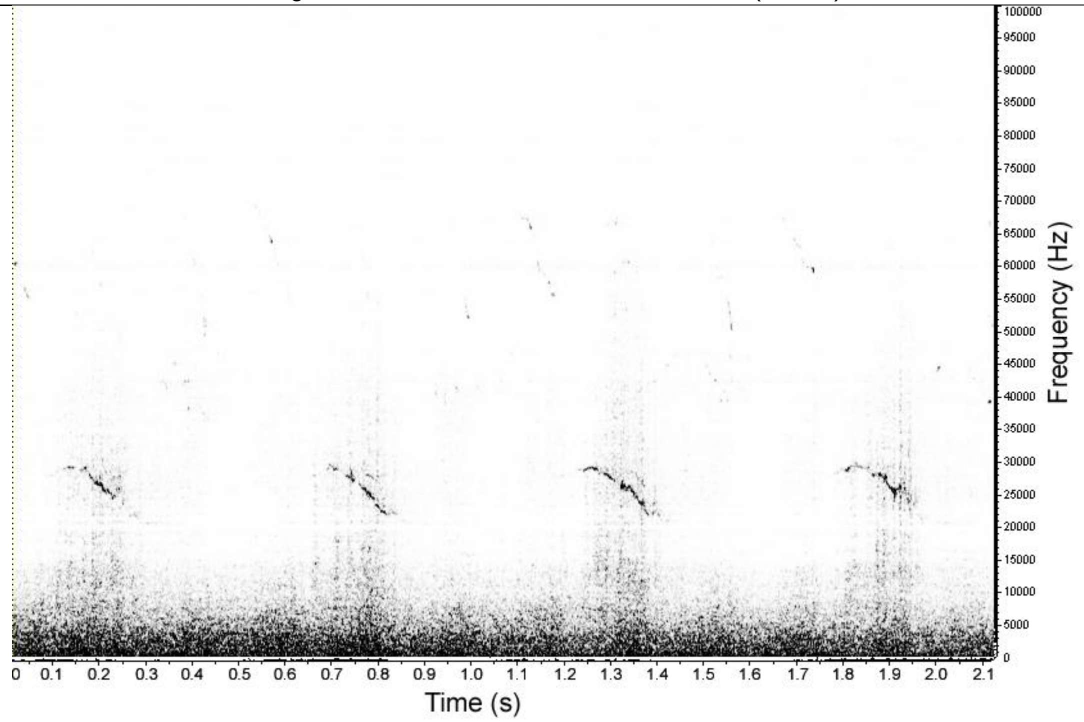


**Figure 2:** Acoustic emission spectral FFT profile from a 20 kW turbine with blade fault, recorded at 200 kS $s^{-1}$ at the turbine base, one metre above ground level (hub height 13 m). Hanning window, FFT length 1024 bands, 75 % overlap, 40 % linear energy scaling.

By analyzing video footage of the moving blades, these FM sweeps were confirmed to correlate with the passage of one of the turbine's three blades. The owners of the turbine reported that there was one damaged/defective blade that had previously been repaired, but not replaced. Fig. 3 highlights the overall amplitude difference between sound emission from the turbine and a control background noise measurement taken in the same location while the turbine was not operational, over the frequency range of the emitted sweep (22–30 kHz).

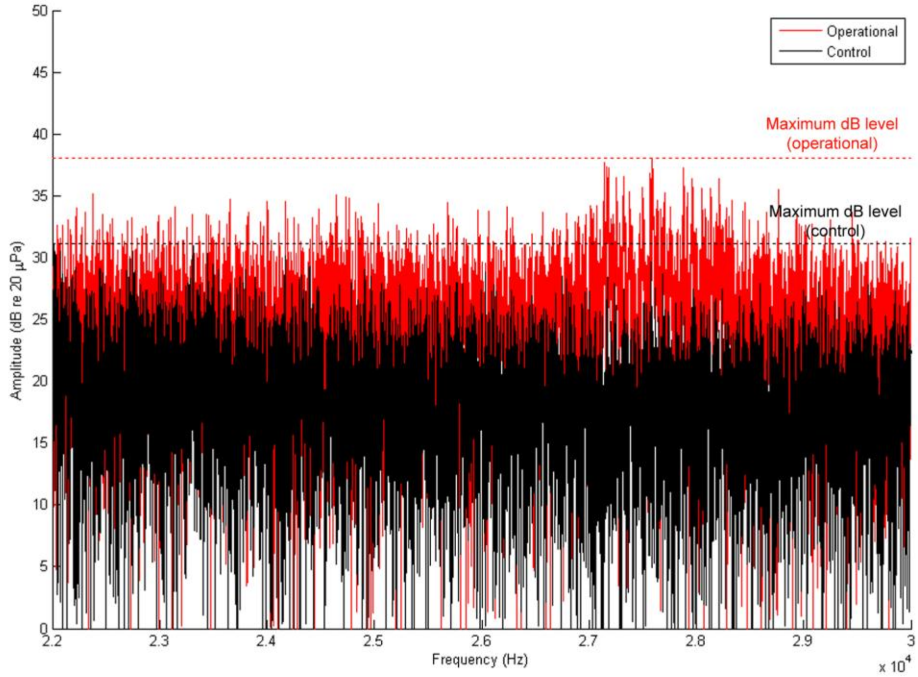

**Figure 3:** DFT trace of the recorded amplitude data comparing a control measurement to that taken during turbine operation, between 22–30 kHz (DFT calculated using MATLAB's FFT algorithm, sampled at 200 kS $s^{-1}$, FFT length 262144 bands). Red and black dotted lines indicate maximum dB levels for the operational and control recordings, respectively. Data taken from 600 ms samples of original recordings (one complete blade sweep cycle).

## POTENTIAL EFFECTS OF TURBINE NOISE ON LOCAL BAT SPECIES

Because bats rely heavily on using and interpreting ultrasound in their environment, potential disruption to their normal behavior patterns due to ultrasound disturbance must be investigated further. It might be speculated that ultrasonic noise emitted in the vicinity of the turbine rotor could potentially 'jam' the ultrasonic emissions of a bat, making it difficult for them to navigate and hunt effectively. Studies in the US have even attempted to deter bats from certain areas by emitting high-intensity broad-band ultrasound, in attempts to 'jam' the bats' echolocation calls (Szewczak & Arnett, 2007). The aim was to deploy these devices around turbines, but this method may also compromise the bats' already reduced capacity to interpret their own echoes from moving blades, and avoid them (Long *et al*., 2010). It has even been suggested that ultrasonic noise itself is attractive to bats (Johnson & Kunz, 2004), or at least attracts the curiosity of bats (Arnett *et al*., 2005), although investigations by Ahlén (2004) to this effect have demonstrated negative results and this hypothesis remains largely unverified (Arnett *et al*., 2005).

The majority of turbines in Schröder's study were found to produce ultrasound, typically between 20–50 kHz, which correlates well with frequencies used by European bat species for echolocation (although the sound intensity, and the relationship with bat mortality, were not investigated). Some turbines have a digital anemometer on top of the turbine rotor housing, and these have been found (in some cases) to emit ultrasound themselves in the region of 38 kHz (Arnett *et al*., 2005), well within the frequency range found to be used by bat species observed in the areas of the study. Arnett and colleagues disabled some of these anemometers and found that there was no effect on the bat mortality rate. The conclusion was reached that these emissions were too readily attenuated to have any effect on the bats present; however the intensity of the emissions from these devices was not measured.

Microturbine sound field assessment by Long (2011) revealed ultrasound levels only slightly above ambient noise (25–40 dB re 20 μPa). Experimental work by Griffin *et al*. (1960) concluded that sounds produced by small insects of 25–30 dB re 20 μPa at 15 cm were unlikely to be detectable by a bat over 50 cm away, so it seems unlikely that the similar noise level produced by this turbine could be acting as an acoustic lure or masking echolocation. Although this particular microturbine model had been previously linked to bat deaths, it seems unlikely that ultrasound emission played any critical role.

With regard to the ultrasonic noise produced by blade defect, although the predominant ultrasound emissions between 22–30 kHz may be below the detectable range of some of the more common UK bat species, serotine (*Eptesicus serotinus*), Leisler's (*Nyctalus leisleri*) and noctule (*Nyctalus noctula*) bats all echolocate at the lower end of the ultrasonic spectrum, within this range, and may therefore be able to detect this particular turbine's acoustic emission. While the peak amplitude of the emission over this range was over 5 dB re 20 μPa louder than the ambient background noise, the peak was less than 40 dB re 20 μPa in total as measured directly underneath the blades (12 m to hub), and degraded such that it was not discernible above background noise over 20 m away from the source. This can be compared with the relative sound levels produced by the same operational turbine within the human audible range (up to 20 kHz), with a peak of 96 dB re 20 μPa in the <1 kHz zone, as measured at the turbine's base. It is therefore conceivable that some bats could detect the ultrasonic emissions from this particular turbine which are caused by a blade fault. However, bats in the locality of the turbine may not be able to detect such emissions unless they were in the immediate vicinity, for example within a radius of 10 m, due to the low amplitude of the ultrasound emission and high attenuation.

The impact of ultrasonic emissions on bats is thought by some to be limited, particularly during the summer and during migration (Rodrigues *et al*., 2006), however this theory remains untested and the way bats react to turbine-produced ultrasound remains unknown (Bach & Rahmel, 2004; Bach, 2001). Some observations suggest that serotines actually avoid locations where ultrasonic emissions occur, but other bats (such as pipistrelles (*Pipistrellus* spp.)) do not (Bach, 2001). It is possible that serotines are able to use ultrasound produced by turbines as an 'acoustic landmark' and use this for orientation or avoidance (after Jensen *et al*., 2005). Dooling (2002) has also hypothesised that turbine-generated noise may help birds (and possibly bats) to better detect and avoid these blades. It is therefore possible that different bat species might detect and utilize ultrasonic noise from turbines in different ways, and that ultrasound emissions may therefore have a variable impact on each species in the locality.

## CONCLUSIONS

Ultrasonic emissions from wind turbines appear to be highly variable and not well investigated. Current research has revealed some turbines do generate ultrasound, either inherently through design or components, or acquired as a result of blade defects. Analysis of this noise has identified the possibility that the ultrasound emissions of such turbines could be perceptible by some bat species, although little is currently known on the long-term effects of ultrasound emission on bat behavior or local bat populations. Existing research suggests that ultrasonic noise produced by wind turbines may have variable effects depending on bat species, something that must be investigated in more detail in order to obtain further insight into potential effects on local bat ecology.

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