



## Research Article

## Up and down: *B. barbastellus* explore lattice towers

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### Abstract

During the last decade, wind turbine construction has become an issue of paramount importance for bat conservation. Several hypotheses have been proposed to explain why bats come close enough to the spinning rotor blades to get killed, some of which assuming that bats explore wind turbines. We test the hypothesis that the forest species *Barbastella barbastellus* explores tall towers (lattice towers). Echolocation calls were continuously recorded over a one-year period. At two study sites we analysed temporally linked consecutive echolocation recordings between neighbouring automated acoustic devices (batcorder) which were installed at 3.5 m (ground), 20 m (canopy), 35 m (above the canopy) and at 50 and 80 m (open airspace). We assigned 7–10% of all contacts to vertical movements. Bats moved along the lattice towers at heights of between 3.5 and 20 m at both sites and between 20 and 35 m at one site. Although the extent of this explorative behaviour may have been underestimated due to limited acoustic detection distance, and although we used a lattice tower (most wind turbine monopoles are made of a different material), the almost complete lack of echolocation calls above 50 m at the first study site and above 20 m at the second study site makes it unlikely that explorative behaviour may expose *B. barbastellus* to significant risk.

## Introduction

Bats are the most endangered mammals threatened by wind energy development (e.g., Rydell et al., 2016; Arnett et al., 2016; Voigt and Kingston, 2016): despite the use of a sophisticated biosonar, collisions still occur because the tips of rotor blades spin too fast (up to 300 km/h) for echo perception (Kunz et al., 2007). Mortality often reveals seasonal patterns: for instance, the majority of fatalities in the Northern Hemisphere occurs during late summer and early fall (Arnett et al., 2016). In 2003 and 2014, bats belonging to 27 out of the 37 species known for Europe were shown to be killed by wind turbines (Rodrigues et al., 2015), with *Pipistrellus pipistrellus*, *Nyctalus leisleri*, *Pipistrellus nathusii* and *Nyctalus noctula* being predominantly affected. While the latter three are known to migrate over long distances (Popalisseanu and Voigt, 2009; Dondini et al., 2013), *P. pipistrellus* is a locally abundant, resident species (Rydell et al., 2016).

Even rare species, such as *Barbastella barbastellus* and *Rhinolophus* spp., are occasionally found dead at wind turbines, albeit in lower numbers. In Europe, five fatalities involving *B. barbastellus* have been recorded (Rodrigues et al., 2015) — two in Germany and Spain, and three in France. However, such numbers have to be interpreted carefully since almost all published bat fatalities have been recorded from open landscapes, where the majority of wind turbines were built, and not from forests where species such as *B. barbastellus* predominantly occur (Russo et al., 2015).

It is currently unknown why and how resident forest bats come close enough to spinning wind turbine rotor blades to get killed. Several hypotheses have been put forward which are not mutually exclusive (Szewczak and Arnett, 2006; Kunz et al., 2007; Cryan and Barclay,

2009; Rydell et al., 2016; Cryan et al., 2012, 2014), i.e.: (i) bats may mistake the monopole towers of wind turbines and other tall structures for potential roosts (roost attraction hypothesis); (ii) tree-roosting species may seek shelter or mating roosts in tall trees (tallest-tree hypothesis / roost attraction hypothesis / reproductive landmark hypothesis); (iii) landscape modifications may guide foraging bats towards wind turbines (linear corridor hypothesis / landscape attraction hypothesis); (iv) bats may be attracted to prey insects that accumulate around turbines (feeding hypothesis); (v) sound (including ultrasonic noise) produced by wind turbines may attract bats (sound hypothesis). To the best of our knowledge, none of these assumptions has been confirmed.

Most of these hypotheses directly or implicitly assume that wind turbines attract bats and cause explorative behaviour. Some observations using thermal infrared imaging of flight activity of bats at wind turbines indicate that bats fly and forage in close proximity to wind turbine rotors (Ahlen, 2003; Horn et al., 2008). A recent study based on 3D reconstruction of infrared images of presumably aerial hawking bats active near a wind turbine nacelle showed movements that could be interpreted as explorative behaviour (Behr et al., 2016). However, it is still unclear whether wind turbine monopole towers in fact induce exploration flights among bats, guiding them upwards and eventually bringing them close to the rotor blades.

We here investigate whether flight activity of *Barbastella barbastellus* occurs high above the forest floor or even above the forest canopy as a consequence of vertical movements of bats up and down wind turbine monopole towers. We conducted a 1-year acoustic monitoring survey at two 83 m high lattice towers (as surrogates for wind turbine monopoles) placed inside forests. We used a vertical setting of consecutive automatic ultrasound recorders to detect temporally adjacent echolocation signals of *B. barbastellus* at two neighbouring recorders which would indicate vertical flight movements up or down the towers.

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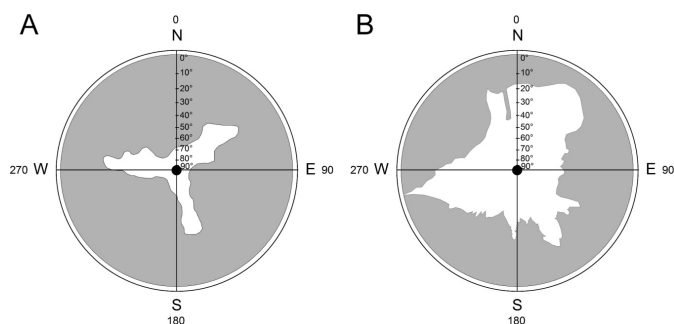
## Methods

### Species account

*Barbastella barbastellus* is highly dependent on the availability of natural forests (Rebello et al., 2012). The species sometimes roosts in buildings and rock crevices, but typically roosts under the loose bark of dead trees or in hollows (Russo et al., 2004; Hillen et al., 2010). Besides open grasslands and rocky landscapes, it hunts mainly in mature forests (Hillen et al., 2009; Ancillotto et al., 2014a,b) at habitat edges (along forest tracks, above the canopy, etc.) and is highly specialized to moths (99% of all prey insects consumed) (Rydell et al., 1996; Rydell and Bogdanowicz, 1997). The western barbastelle emits two types of search signals in different directions: downwards through the mouth for spatial orientation (type 1), or upwards through the nose for prey localization (type 2) (Seibert et al., 2015). The highly structured calls increase the probability of correct species identification and provide information on the behavioural context of sound production (Eklöv, 2003). In addition, *B. barbastellus* calls are relatively weak.

### Study sites

From November 2014 to October 2015, bat echolocation calls were continuously recorded at two sites in the Osburg upland forest area in the Western Hunsrück Mountains (Rhineland-Palatinate, Germany). The study site at Beuren (49°44' N, 6°52' E) was characterized by an old mature forest. Dominant tree species at the site were oak, beech and conifers (Norway spruce, Douglas fir). The presence of standing dead trees provided many potential roosts for tree-dwelling bats. The study site at Schöndorf (49°40' N, 6°46' E) was a clearing surrounded by forest (beech, Norway spruce, Douglas fir) and a wildlife food plot. The height of the canopy cover reached approximately 25 m at Beuren and 20–25 m at Schöndorf. The percentage and distribution of canopy cover around the towers, measured in accordance with Tonne (1954) by shading with a “Horizontoskop” (Institute for Daylight Technology, Stuttgart, Germany), characterized Beuren as a dense forest area (90% cover) and Schöndorf as a kind of clearing (66% cover) (Fig. 1). Both sites were chosen since extensive mist-netting, acoustic monitoring and radio telemetry in 2012, 2014 and 2015 had shown high activities of *B. barbastellus*, including the presence of nursery colonies.



**Figure 1** – Distribution of canopy coverage around the towers (black dots) at Beuren (A) and Schöndorf (B) as measured with a “Horizontoskop”.

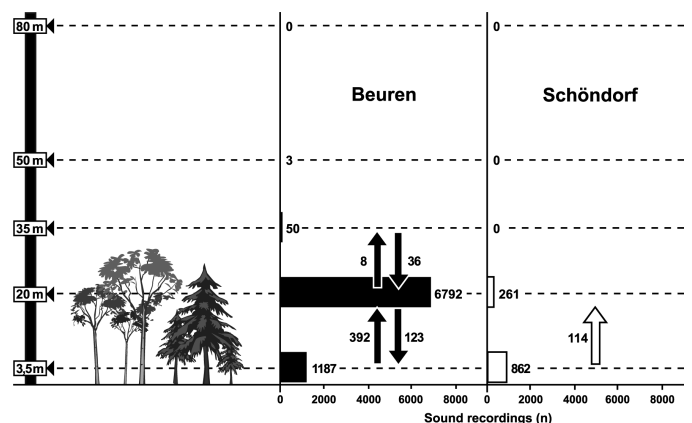
### Acoustic sampling and analysis

We installed 83 m high lattice-towers (Windhunter GmbH, Germany) at both sites to investigate the activity of *B. barbastellus* at different forest strata and in open airspace above the canopy. A lattice tower is a freestanding framework tower. We chose lattice towers because they were commonly used at wind turbines in the past. Besides they can be used as electricity transmission, radio or observation towers. Echolocation calls were recorded near the ground (3.5 m), in the canopy (20 m), above the canopy (35 m) and in open airspace (50 m, 80 m) (Fig. 2). Acoustic monitoring was conducted via automatic recording (batcorders, ecoObs, Erlangen, Germany). We used the box extension with automated solar panel. Bat calls were recorded from sunset to half an hour after sunrise and digitized in real-time at a rate of 500 kHz with 16-bit amplitude resolution.

We used post-trigger sound recordings as a measure unit (“records”) with the following parameters: quality=20, threshold=-36 dB re full scale, post-trigger=200 ms, critical frequency=16 kHz. Species identification was performed automatically using bcAdmin 3.0, bcAnalyze 2.0 and batIdent software (ecoObs, Erlangen, Germany). However, many bat species are difficult to identify using automatic software (especially some species of the genus *Myotis*), and a general cautionary note on automated identification of bat calls was recently published (Russo and Voigt, 2016). Fortunately, and in contrast to most other species, echolocation pulses of *B. barbastellus* are very easy to identify. Nevertheless, in order to eliminate analysis errors we manually checked and, where necessary, corrected the following assignments: Bbar = sound recordings that contained echolocation calls of *B. barbastellus*; spec. = recordings that contained calls of unassigned bat species; no calls = recordings that contained no echolocation calls (for example, birds or sometimes faint calls of *B. barbastellus* or other bat species).

### Analysis of vertical flight movements

To identify vertical flight movements of *B. barbastellus*, we calculated the time intervals between two consecutive sound recordings at neighbouring batcorder positions that contained either single echolocation calls or call sequences. Records were considered to be temporally connected if they were recorded within a 20 s time frame. This criterion was defined according to the empirical frequency distributions of time intervals between two correlated records (data not shown). *B. barbastellus* can fly very fast, up to 10 m/s (Runkel, 2008), but many biotic and abiotic factors can influence the duration of acoustic recordings, and hence the relevant timeframe between temporally related records (e.g., intra- and interspecific interactions, wind speed, rain, foraging, exploration or stationary flights). Two consecutive records with a corresponding time interval >20 s were considered to not be linked. We can be sure that our data do not include many errors of measurement (for example if two bats flew near different microphones just a few seconds apart) because the nursery colonies we investigated had only a few individuals. At Beuren we counted 17 individuals (15.07.2015) and at Schöndorf 16 (08.06.2015). Analyses were performed using ArcGIS 10.1 (Esri, California, USA) to convert the time and date of the call sequences into a spatio-temporal metric system. This allowed us to use GIS standard distance tools to calculate the observed time interval between two temporally correlated records. The data were not normally distributed (Shapiro-Wilk test) and thus subjected to non-parametric tests. To test the observed time interval distributions against our null hypothesis of no temporal correlation between sound records at neighbouring batcorders, we first determined the temporal distribution of sound records per night (hourly time intervals) and batcorder. We then randomly distributed an equal number of sound records across each night according to the nocturnal activity pattern (temporally strat-



**Figure 2** – Vertical arrangement of five acoustic devices and the distribution of *B. barbastellus* contacts (measured as the total number of relevant sound recordings during the study period of 1 year at Beuren and Schöndorf). Arrows and associated numbers indicate the direction and sum of up and down movements between neighbouring pairs of batcorders.

ified distribution), from which we determined time interval lengths for comparison with the observed interval lengths distribution ( $\chi^2$  homogeneity test). We tested the null hypothesis that the empirical and random intervals belong to the same distribution, which would indicate no exploration behaviour. When sample sizes were small ( $n \leq 5$ ), we used the Fisher's exact test instead of the  $\chi^2$ -test. Pairwise comparisons of calculated time intervals between two temporally correlated records (median) were calculated with the Mann-Whitney U test as a non-parametric test. All data were analysed using SigmaPlot 11 (Systat Software, San Jose, USA).

## Results

### Vertical flight activity of *B. barbastellus*

We collected a total of 8032 and 1123 sound records that contained echolocation calls of *B. barbastellus* at Beuren and Schöndorf, respectively. The vertical distribution differed significantly at the two study sites ( $\chi^2$ -test,  $p < 0.001$ ), with a maximum detection height of 50 m at Beuren and 20 m at Schöndorf (Fig. 2).

### Vertical movements of *B. barbastellus*

Time intervals between temporally adjacent sound recordings of neighbouring batcorders were not normally distributed (Shapiro-Wilk test), and thus subjected to non-parametric comparisons. The null hypothesis of intervals between observed and randomly distributed records showing the same distribution was rejected for all comparisons, except at Schöndorf between 20 m (canopy) and 3.5 m (ground) (Tab. 1). Hence, and according to our assumption, *B. barbastellus* movements were upwards near the towers at both study sites. Significant downward movements were only observed at Beuren, from 35 m (above canopy) to 20 m (canopy), and from 20 m (canopy) to 3.5 m (ground). We detected no vertical flight movements between 35 m and 50 m.

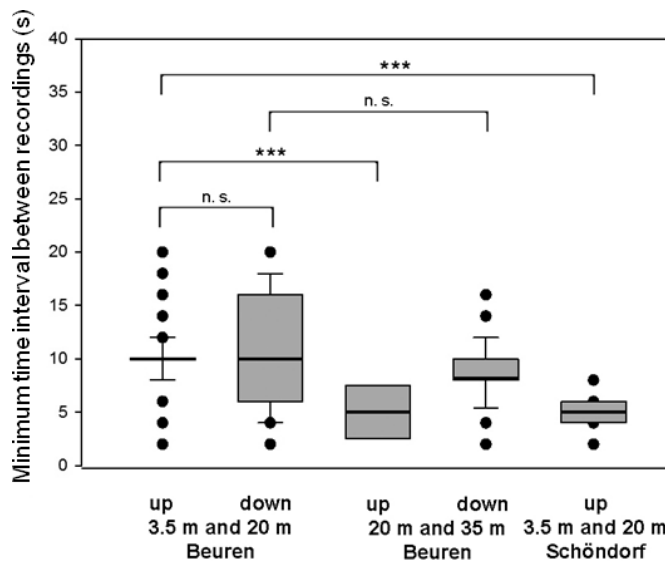
At Beuren, the median of upward and downward interval lengths between ground (3.5 m) and canopy (20 m) did not differ from one another (Fig. 3). In contrast, movements from the canopy (20 m) to above the canopy (35 m) were significantly faster than those from 3.5 m to 20 m. In addition, movements from the ground (3.5 m) to the canopy (20 m) were significantly faster at Schöndorf compared to Beuren (Fig. 3).

The percentage of vertical flight movements in relation to the total activity of *B. barbastellus* was 7.1% at Beuren and 10.8% at Schöndorf. The seasonal distribution of vertical movements differed at the two study sites (Fig. 4). At Beuren, vertical movements increased steadily from March to May and peaked in July, whereas vertical activity was low in spring and summer and increased in autumn at Schöndorf. Only in Schöndorf did we record vertical movements in late autumn. Vertical movements above the canopy were rare and only recorded at Beuren (7.9% of all vertical movements at Beuren). In April and June, the relative frequency of vertical movements was less than 5%. From June to October, vertical movements at the canopy and above the canopy (20 and 35 m) occurred continually (peak in August, 33.3%).

**Table 1** – Number and median of time intervals between temporally correlated records of *B. barbastellus* between neighbouring batcorders and comparison with intervals of randomly distributed echolocation calls ( $\chi^2$  homogeneity test, unless otherwise indicated) at Beuren and Schöndorf (df=1 for all tests); the arrows indicate upward and downward flight directions.

Vertical flight movements	Consecutive records (n)	Median	$\chi^2$	p-value
Beuren 3.5 to 20 m (↑)	392	10	201.41	<0.001
Beuren 20 to 3.5 m (↓)	123	10	5.48	0.019
Beuren 20 to 35 m (↑)	8	5	-	<0.001 <sup>a</sup>
Beuren 35 to 20 m (↓)	36	8	-	<0.001 <sup>a</sup>
Schöndorf 3.5 to 20 m (↑)	114	5	128.48	<0.001
Schöndorf 20 to 3.5 m (↓)	4	-	0.004	0.95

<sup>a</sup> Fisher's exact test



**Figure 3** – Box plots of interval length between two neighbouring batcorders and pairwise comparisons (the bold line indicates the median) using Mann-Whitney U test (n.s.=not significant= $p > 0.05$ , \*\*\*= $p < 0.001$ ).

## Discussion

We present the first evidence that *B. barbastellus* moves vertically (up and down) along human-made tall structures (lattice towers). However, the vertical flight movements at the two towers solely occurred close to the ground (3.5 m) and above the canopy (35 m), since flight activity was almost entirely absent above 35 m. We only recorded *B. barbastellus* three times at 50 m and never at 80 m. We interpret these vertical movements as exploration flights and discuss them in relation to previously mentioned hypotheses, according to which bats are attracted to wind turbines.

### Different vertical activity patterns at the two study sites

While ground activity of *B. barbastellus* at 3.5 m was similar for both sites (Fig. 2), the activity recorded at the canopy and high above it differed between the sites. This may be due to the completely different position of the towers in relation to the canopy, indicating the influence of habitat on the behaviour of *B. barbastellus*. At Beuren, the canopy was close to the tower (canopy cover 90%), while at Schöndorf the setup was more open (resembling a clearing), with the canopy up to 50 m away from the tower (Fig. 1). Bats foraging along the canopy at Beuren could easily cross the close gap between the canopy edges at the tower and hence be recorded. At Schöndorf, this gap may have been too large to be crossed during a foraging flight any more than occasionally.

### Exploration flights of *B. barbastellus* at the lattice towers

Cryan et al. (2014) assumed that tree bats are attracted to wind turbines since bats confuse them with trees. In contrast, we assume that bats can distinguish trees from towers or wind turbines because they are able to classify vegetation and other complex objects based on echo information (Yovel et al., 2008, 2009). In addition, visual cues may play a role in the discrimination of vertical objects within a bat's home range (Eklöv, 2003). Our bats in fact recognized the large lattice towers and seemed to explore them. Since *B. barbastellus* is not known to glean prey items from any kind of surface (Andreas et al., 2012), the vertical flight movements we observed at rates of about 10.8% (Schöndorf) and 7.1% (Beuren) of all recordings support this assumption. We assume that the frequency of such vertical movements is even systematically underestimated, since temporally correlated echolocation signals of *B. barbastellus* are difficult to detect due to low source levels and varying flight trajectories.

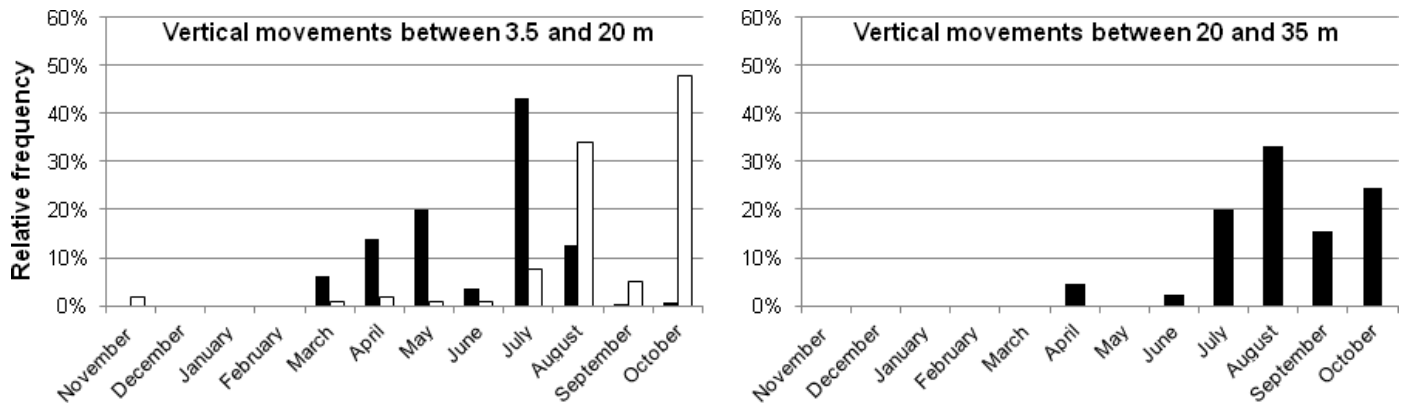


Figure 4 – Seasonal distribution of vertical movements of *B. barbastellus* at Beuren (black, n=559) and Schöndorf (white, n=118) from November 2014 to October 2015; upward and downward movements were added together.

### *B. barbastellus* does not fly high above the canopy

With the exception of three records at 50 m at Beuren, we did not record activity of *B. barbastellus* high above the canopy, and almost all records at 35 m at Beuren occurred in conjunction with vertical movements (44 out of 50). Hence, we conclude that *B. barbastellus* does not usually fly high above the canopy. Other authors found barbastelles at the canopy or tight above (Sierro, 1999; Müller et al., 2013). Consequently, *B. barbastellus* is able to fly in open airspace but at the same time it probably focuses the sonar beam on the canopy and edges of forests for spatial orientation.

Our results may be explained according to the highly specialised echolocation strategy of *B. barbastellus*. The low source level of the bifunctional echolocation system of *B. barbastellus* results in a limited detection distance: the detection distance of *B. barbastellus* for large moths is only about 3 m (Seibert et al., 2015), whereas for a tree in beam direction it is about 9 m (Stilz and Schnitzler, 2012). The echolocation signals of *B. barbastellus* are always frequency-modulated. In contrast, bats that forage in open airspace high above the canopy emit constant-frequency calls with high intensity (sound pressure level) to increase detection range and because no background echoes occur (Schnitzler et al., 2003). However, barbastelles are able to emit louder calls during transfer flights between roosts and foraging areas.

A recent long-term study at three different study sites in Germany also found that barbastelles were only occasionally detected at 30 m above the ground (Hurst et al., 2017). Only few contacts were recorded at 50 m, and above 50 m *B. barbastellus* was not detected at all. In addition, the species was never recorded in recent acoustic surveys at wind turbine nacelles (Reichenbach et al., 2015). Overall, our results and those of other studies demonstrate that *B. barbastellus* only occasionally flies at heights >30 m above the canopy. This congruence among study sites in different landscapes makes us conclude that these results are conferrable to other forest habitats with nursery colonies of barbastelles.

### Conclusions

Our data provide strong evidence that *B. barbastellus* does not fly high above the canopy; at least near human-made vertical structures. Although explorative behaviour may lead some individuals up the towers, in our study bats never reached a height that would bring them close enough to the spinning rotor blades of a wind turbine to get killed. In fact, inside forests such blades are usually located at heights far above 50 m. Rather, collisions are possible at low wind turbines when the distance between canopy and the tip of the turbine blade is small (<50 m). This was probably the case with the French wind farms that recorded barbastelle fatalities and where the blade tips rotate at 39 and 23 m above the ground (Rodrigues et al., 2015). Maybe this was also the case in Lower Saxony, where a dead barbastelle bat was found under a wind turbine with a hub height of only 64 m and the lower tip of turbine blade being less than 30 m from the ground (Manthey, 2015).

We wish to highlight that unlike wind turbines, lattice towers are static structures made of a different material so it cannot be fully ruled out that such characteristics may influence bat behaviour. Besides, even if *B. barbastellus* is not frequently involved, several other bat species are put at serious risk by wind turbines located near or inside forest areas. ☞

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