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Bat flight height monitored from wind masts predicts mortality risk at wind farms

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ABSTRACT

Bat fatalities by collision or barotrauma at wind farms currently raise high conservation concerns. In many countries, pre-installation acoustic surveys are mandatory in order to assess the impacts of wind farm projects. In this purpose, the use of wind masts to estimate bat activity and hence predict collision risk is highly recommended by conservation committees worldwide. Yet, the degree to which collisions may be predicted from acoustic monitoring at wind masts has been strongly debated.

To assess this relationship, microphone arrays were installed on 23 wind masts in order to record and locate bat activity on the vertical axis during 3260 nights. For each species, we also calculated a collision susceptibility index, based on fatality data gathered in the literature and corrected for species abundance. We demonstrate that the collision susceptibility index is correlated with the percentage of bat passes at blade height.

The acoustic recordings allowed us to establish a reference for the ratios of flight activity above heights of 20–45 m high for more than 16 European bat species. The correlation we demonstrate here between the percentage of bat passes at height – recorded from acoustic surveys on wind masts – and bat fatalities strongly supports that activity estimates from wind masts are appropriate for wind turbine impact assessments.

1. Introduction

Green energy development is today one of the top priorities of European governments. To answer this requirement, wind farm implantations have increased tremendously over the last years (Leung and Yang, 2012). Meanwhile, their impact has been proven lethal for numerous bird and bat species (Rydell et al., 2010a; Drewitt and Langston, 2006; Frick et al., 2017; Hammerson et al., 2017). In Europe, cases of fatalities by collision or barotrauma around wind turbines (WT) have been reported in 27 bat species over the 51 extant European species for a total amount of circa 7000 individuals and France alone has an impact on at least 17 species (Rodrigues et al., 2015). Since a very small proportion of wind farms were surveyed and for a limited period of time, this number is only the tip of the iceberg. Estimates show that in Germany alone, wind turbines may account for more than two million bats killed over the past 10 years, if mitigation measures were not practiced (Voigt et al., 2015).

All European bat species are under strict protection (Habitat Directive, Annex IV - Council Directive 92/43/EEC, 1992), hence the necessity to develop proper tools to assess as accurately as possible the impacts of human activities before their occurrence on bat populations. Today, European impact assessment studies monitor bat activity with methods ranging from evening transects with ultrasound detectors or autonomous overnight recordings from the ground to long-term recordings with microphones at height (Rodrigues et al., 2015).

To explain bat fatalities at WT and in the hope of predicting them, numerous hypotheses have emerged concerning the ultimate causes of collisions (Cryan and Barclay, 2009). The simplest explanation would be that mortality is directly linked to specific activity rates on site, independently from altitudinal distributions. However, uncommon species are sometimes more impacted than others (e.g. Georgiakakis et al., 2012). Some hypotheses suggest that species mostly impacted are annual migrants that might be seasonally maneuvering at heights with collision risks, or that they are tree roosting species that might mistake wind towers for trees (Cryan and Barclay, 2009; Cryan et al., 2014; Jameson and Willis, 2014). Rydell et al. (2010b, 2016) doubt that migration is the only explanation for collisions because resident species are very often the most impacted species, and because insects resting on WT were identified in the stomach contents of bat carcasses found at wind farms. They conclude that there might not be a single explanation

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to the complex phenomenon of bat collisions at wind farms.

Before investigating complex hypotheses, it is important to focus on straightforward relationships. In all simplicity, bats spending most of their time foraging and commuting at similar heights as blade heights should be more susceptible to collisions. This assumption of coincidental collisions (Cryan and Barclay, 2009) has never been thoroughly investigated because of the lack of appropriate tools, i.e. tools that would not produce any attraction phenomenon.

Yet, in order to estimate impacts before the setting up of wind farms, the more the setting resembles a WT, the easier it will be to estimate future impacts and draw conclusions. Hence it is not necessarily desirable to free the survey material from any effect on bat behaviour. Korner-Nievergelt et al. (2013) demonstrated that bat activity at WT nacelles is correlated with the number of carcasses found at their foot. But it has never been formally proven that this correlation is also valid for pre-construction acoustic surveys from wind masts, which are recommended for impact assessment studies (Rodrigues et al., 2015). An attempt by Hein et al. (2013) was not conclusive because of the variability in the methods of the studies that were available. Yet, this relationship most probably exists, notably because there is evidence that tall anthropogenic structures engender an attraction phenomenon toward tree roosting/migratory bats at the same time of the year where mortality peaks at WT are found (Jameson and Willis, 2014). Those bats are not the only species affected by WT collisions and others such as exclusive cave roosting species are also implicated although at much lower rates (e.g. *Miniopterus schreibersii*, Rodrigues et al., 2015). It might be that specific differences in flight behaviour play an important role in explaining differences in collision susceptibility among tree roosting/migratory species but more generally among all bats, and this concomitantly to an attraction phenomenon. Müller et al. (2013) showed that wind turbine fatality counts are numerous for most species flying more often around tree canopy than close to the ground. But a clear identification of the role played by bat flight height distribution in species susceptibilities to collisions, independently of species relative densities, is still missing. This distinction is for instance essential in order to rank species susceptibility. To perform this distinction between species behaviour and density, the latter must be corrected by using a reference scale for species activity levels (see Haquart, 2013).

Our study aims at testing the relevance of using activity data from wind masts in wind farm impact assessment studies. Our hypotheses are that (1) WT collision susceptibility is strongly linked to the preference of species flying at altitudes similar to those of WT blades, and that (2) this correlation can be established from observations at wind masts, as they act as a similar stimulus as WT toward bats.

2. Material and methods

2.1. Acoustic recordings

Recordings were conducted at 23 sites in France and Belgium (see Fig. 1) between 2011 and 2016. Habitats consisted in pine, spruce and mixed forest clearings (11 sites), bocage (3 sites), wetlands (1 site) and cultivated fields (8 sites). Sites in Southern and Eastern France were either located in mountainous areas or in plains while the remaining sites were in plains only. Months between April and October cumulated the maximum number of sites surveyed per night (Fig. 2). In total, bat activity was monitored on 3260 nights ($\mu = 142$, $\sigma = 72$ nights per site). The recording period at each site did not exceed one year.

In order to establish a link between bat behaviour before the presence of WT and the collision risk after their activation, a proper manner to assess bat flight height distribution had to be chosen. Collins and Jones (2009) obtained differences between bat activity at ground level and at height by mounting one microphone at ground level and one at 30 m on a mast. With two unsynchronised microphones however, the most detectable species might be counted twice (i.e. at both microphones). Some species can indeed be acoustically detected at more than 90 m (Holderied and von Helversen, 2003; Barataud, 2015). Here, we performed a binary location of the bat position (i.e. near the nacelle height or near the ground), without any double count, while at the same time enabling a specific identification through the echolocation calls.

We installed microphones on lattice or monopole wind masts of 50–100 m high that all had aviation lighting at night. Arrays with two microphones were achieved with two SMX-US microphones plugged to an SM2BAT (all models, Wildlife Acoustics, Massachusetts, USA). Microphones were inserted into aluminium tubes, facing downward, in protection from weather alterations. The omnidirectionality of the setting was ensured by a custom-made round shaped 6 cm diameter aluminium reflector placed below the microphone with a 45° angle. Microphones were respectively installed at heights ranging from 4 to 85 m (see Fig. 3). Recorders were programmed to start each day 30 min before sunset and stop 30 min after sunrise. For study sites between 2013 and 2016 (13 sites), whole night recordings were performed. On study sites from before 2013 (10 sites), samplings were collected during 10 min every 20 min. Gain was set at 36 dB, sampling rate at 192 kHz, trigger at 6 dB above background noise and trigger window at 2.5 s. A 1 kHz high pass filter was used. Files were compressed in WAC4 format and analysed in WAV format.

2.2. Species identification and flight height classification

Files were decompressed using the WAC2WAV (Wildlife Acoustics, Massachusetts, USA) software. When longer, files were automatically cut in 5 s bouts after each triggered recording to be used as a proxy for a bat pass, according to Barataud's method (2015). Species identifications were performed on SonoChiro (Biotope, France) (Newson et al. 2015). The verification of acoustic sequences was done on Syrinx (John Burt, USA) or BatSound (Pettersson Elektronik AB, Sweden) with spectrogram representations, allowing to measure acoustical parameters. Identification criteria are based on the association between acoustic call type, call shapes and measurable parameters (initial frequency, terminal frequency, signal length, maximum energy and its repartition …), their rhythms (interval duration between calls) and the environment (distance to obstacles). With the knowledge accumulated today, this method born from Barataud's work (2015) allows the identification, in good recording conditions, of 29 species from the 33 extant in France and Belgium. Yet, sonar calls of certain species are sometimes very close, even identical in certain flight circumstances. Hence, they are assembled in species groups. In the present case, *Myotis* were grouped in two categories: *Myotis myotis* and *M. blythii* in a “large *Myotis*” group and all others in a “small *Myotis*” group, and all *Plecotus* individuals in the *Plecotus* sp. group. Within those two groups, species present flight heights comparable to the other species of their group (Rodrigues et al., 2015). It was however not acceptable to group unidentified species from *Pipistrellus* or *Nyctalus/Eptesicus/Vespertilio* genera, because they display very different flight heights within their group. These unidentified bat passes (2.95% of all bat passes) were not used for further analyses.

In order to classify flight heights, SonoChiro was used to automatically determine the time at which each call starts on each microphone. Then, using the find.matches function of Hmisc package (Harrell, 2014) from R (R Development Core Team, 2008), we obtained the time differences of arrival for each call detected.

For each site, a height threshold was defined as the median height between the two microphones (see Fig. 3). This threshold corresponds for each site to the lowest height at which the planned WT blade would operate and therefore the altitude above which collisions can occur. This means that in forests also, the median height represents the height above which bats would be at collision risk. This threshold was used to assign bat calls to two classes: “at height” if the source of the signal is above the threshold and “at ground level” if it is below the threshold. If a bat call is detected by the highest or the lowest microphone only, the