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Do habitat characteristics determine mortality risk for bats at wind farms? Modelling susceptible species activity patterns and anticipating possible mortality events

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ABSTRACT

Worldwide efforts to develop sustainable methods of energy production have been increasing the use of renewable sources, with special emphasis on wind energy. Despite the clear environmental benefits associated with this type of technology, many studies have confirmed bat fatalities at wind farms, which raise concerns about the long-term effects of these structures on bat populations. To investigate the impact of windmills on bat species, we developed a spatially explicit agent-based model (ABM) to replicate the underlying behavioural mechanisms for individuals of the species *Nyctalus leisleri* involved when navigating their habitats at a landscape level, and to simulate the associated mortality events. A set of environmental data layers was used to develop a grid representing a real landscape in terms of habitat types, foraging availability and collision-risk. The model variables were estimated using values from literature. The simulations confirmed the species predominant selection of specific foraging areas and its high mobility, evidenced by the maximum distances to roosts and home range sizes, highly correlated with the habitats coniferous forests and broadleaf forests. High wind speeds (≥4 m/s) were associated with a decrease in the number of expected fatalities, due to the behavioural limitations imposed to bat activity. Additionally, there was a clear relationship between mortality events and the proximity between roosts and the location of the wind turbines. Overall, these results elucidate the most likely foraging habitats used by the species and the relative risk of the location of windmills. They can inspire future studies of how bat species respond to the infrastructural impacts related with wind farms in mountain areas and/or to the pertinent mitigation measures implemented.

1. Introduction

Climate change caused by the increasing emission of greenhouse gases (GHG) is generally accepted as the greatest environmental threat of our time (GWEC, 2008). The EU member states committed to reduce emissions while responding to increased energy needs by developing sustainable energy production methods (EWEA, 2011). The environmental benefits of renewable energies are evident, and wind energy production is considered one of the cleanest energy sources, not implying the emission of GHG or other air pollutants. In fact, in contrast to fossil fuels, the use of wind energy prevents the emission of 600 t CO_2 per GWh (GWEC, 2006). Despite the obvious environmental benefits of wind energy, its impacts should be thoroughly analysed (Barclay et al., 2007; Berkhuizen and Postma, 1991). The increasing number of wind farms and the progressive implementation of larger wind turbines may worsen the impacts on wildlife (Barclay et al., 2007; Santos et al., 2010). The concerns about the possible impact of wind farms on wildlife began with birds (Erickson et al., 2001). However in the late 1990s several studies also pointed to negative effects of these structures on bats, namely mortality and behavioural changes (e.g., Bach et al., 1999; Johnson et al., 2001; Kerns and Kerlinger, 2004; Rhamel et al., 1999). In recent years, considerable progress has been made especially due to the estimation of mortality rates, behavioural studies of bats in areas surrounding wind turbines and the description of weather conditions associated with collisions (e.g., Bastos et al., 2013). Nevertheless and despite of the numerous hypotheses formulated, the factors leading to mortality of bats associated with these structures are not yet acknowledged (Cryan and Barclay, 2009).

In this study, we used the Leisler's bat, *Nyctalus leisleri* (Kuhl, 1817), a medium-sized migratory bat of the Vespertilionidae family (Palmeirim, 1990) as a model species, considering the high incidence of mortality events for several wind farms (ICNB, 2010; LEA, 2009, 2011). The species is labelled as "data deficient", and studies focusing on its ecology and conservation are important for determining the actual status and trends (Cabral et al., 2006). *N. leisleri* is distributed predominantly in the Western Palearctic, occurring throughout the

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European continent (Schober, 1997; Stebbings, 1988; Stebbings and Griffith, 1986). It seems to be associated with broadleaf forests, roosting primarily in old tree cavities (Ruczyński et al., 2010). Roost may also occur in buildings (Corbet and Harris, 1991; Mitchell-Jones et al., 1999; Shiel et al. 1999; Waters et al., 1999) or in bat boxes in both coniferous and broadleaf forests (Corbet and Harris, 1991). *N. leisleri* usually presents a nightly foraging pattern with two distinct periods of activity, as reported for other species of the genus *Nyctalus* (Russ et al., 2003; Shiel et al., 1998). According to Waters et al. (1999) the displayed pattern during a foraging night is similar to that described by Catto et al. (1995) for *Eptesicus serotinus*, with a well defined initial emergence, just after sunset, followed by a less clearly defined second emergence period, later in the evening. Their long and narrow wings, with high aspect ratio, enable swift flights but limited manoeuvrability, comparing to other slow flying species (Fleming, 2010; Norberg and Rayner, 1987). Several studies have also shown that this species uses a wide diversity of foraging habitats (Russ et al., 2003; Shiel et al., 1999; Vaughan et al., 1997; Walsh and Harris, 1996; Waters et al., 1999), commuting relatively large distances between roosts and foraging areas (Waters et al., 1999). Although the habitat selection may depend on its availability and resources, the species forages preferably in wide open spaces as they execute high flights primarily away from cluttered areas (Norberg and Rayner, 1987), above tree crowns, lakes and pastures. This bat is also commonly found foraging along boundary areas such as in between woodland and open fields or along linear features, such as roads and riparian galleries (Shiel et al., 1999; Szentkuti, 2006; Vaughan et al., 1997; Walsh and Harris, 1996; Waters et al., 1999). This species seems to be particularly susceptible to the clearing of mature deciduous woodland stands, due to the reduction of foraging grounds and the absence of trees with ideal characteristics for roosting. Due to its migratory nature, there is also a risk of collision with man-made structures in their migration routes (Amorim, 2009; Rydell et al., 2010). Considering the high number of fatalities recorded at wind farms, it is imperative to carry out robust exploratory studies to mitigate the scarcity of local data on the distribution, behaviour, risk of collision and actual population trends, in order to establish more universal and suitable measures for its conservation (Cabral et al., 2006). A promising possibility to gain insight into the large-scale effects of species behaviour in specific landscapes involves the development and implementation of spatiotemporal models using agent-based modelling platforms (ABM) (DeAngelis and Mooij, 2005; Eichhorn et al, 2012; Grimm and Railsback, 2005).

ABMs are computer simulation tools able to incorporate intelligence, combining elements of learning, adaptation, evolution and fuzzy logic (Grimm, 1999). Such models use the basic constituents of a system (i.e., individual agents), trying to demonstrate how system properties emerge from the interactions between its various components (Grimm, 1999; Grimm and Railsback, 2005). Therefore, the primary characteristic of an ABM is the use of the individual as the basic component, ceasing to represent the population as a continuous variable, but rather as the set of discrete entities of which it is composed (Jorgensen, 1994). ABMs allow effective understanding of a complex set of behaviours and interactions, and are therefore highly suitable for simulating the emergent population responses to complex phenomena (Grimm et al., 2005). Although its occasional use began in the 1970s (Kaiser, 1979), since the late 1980s ABMs have been used in a wide range of issues related to the management of environmental resources (Bousquet and Le Page, 2004; Grimm et al. 2010). This type of modelling approach has also been widely used in ecology, especially in population dynamics studies due to its flexibility allowing the use of detailed parameters with greater biological significance (DeAngelis and Mooij, 2005). More recently ABMs have been used in interdisciplinary approaches to address issues relating the interactions between humans and wildlife (An et al., 2005; Anwar et al., 2007). The recent increase of ABMs in ecological studies, mainly in animal behaviour and mobility fields (Stillman, 2008; Wang and Grimm, 2007), suggests that its application may have a key role in understanding habitat selection processes and evaluating conservation plans.

To address the issue of understanding bat habitat selection and the risk of collision with windmills, we have developed a spatially explicit ABM, using the species *N. leisleri* to demonstrate the simulation of a bat habitat foraging behaviour and roosting selection. The use of an ABM for our research purposes is advantageous since the interaction between agents and their environment is readily accommodated and realistic conditions can be approximated (such as movements across the landscape). We simulated the activity of *N. leisleri* in a real landscape in order to determine how habitat features influence its behaviour. Agents modify their foraging behaviours based on the known principles that govern animal movement and roost selection, and therefore to understand and predict the main factors that lead to mortality events at wind farms.

2. Methods

2.1. Study site description

The model was developed for a 22,500 ha landscape (Fig. 1B, simulation area), centred in the Negrelo and Guilhado wind farm, located in a mountain of northern Portugal (Fig. 1A). The wind farm consists of 10 wind turbines (Fig. 1C) with 82 m rotation diameter, installed along a ridge line between 1000 m and 1100 m of altitude (EDP, 2006). The landscape is dominated by grasslands and scrublands of low complexity and reduced biomass (LEA, 2011). Eight bat species are confirmed in the study area (*N. leisleri*, *Rhinolophus ferrumequinum*, *Pipistrellus kuhlii*, *Pipistrellus pipistrellus*, *Hypsugo savii*, *E. serotinus*, *Barbastella barbastellus*, *Tadarida teniotis*) although other species probably may also occur in the region (*Myotis myotis*, *Myotis blythii*, *Plecotus auritus*, *Plecotus austriacus*, *Miniopterus schreibersii* and *Pipistrellus pygmaeus*) (Ecosfera, 2007, 2008; LEA, 2009; Moreira, 2006).

2.2. Modelling procedure

The conceptual description of the model follows the specifications of the standard protocol ODD (overview, design concepts and details) to describe ABMs, proposed by Grimm et al. (2006) and reviewed in 2010 (Grimm et al., 2010).

2.2.1. Overview

2.2.1.1. Purpose. The agent based model investigates how the interplay of several variables determines the mortality events of *N. leisleri* in a studied wind farm. Using this context as a demonstration, we intend to reproduce the species foraging patterns (foraging focused simulations — FFS), identifying areas of high activity, in order to anticipate possible mortality events imputable to the wind turbine location (mortality focused simulations — MFS).

2.2.1.2. Entities, state variables and scales. The model included three types of conceptual entities described briefly in Table 1, the patches (unit cells) that make up the landscape of the study area (22,500 ha), the wind turbines and the bats (the only mobile entities in the model). The description of all state variables associated with these entities is also available in Table 1. All model parameters are listed in Appendix D.

The time unit used during the simulations was the second as it is the discrete unit that better adjusts to bat flight speeds, thus allowing the virtual individuals to adapt their flight route according to the variables of their position in small time intervals and therefore short spatiotemporal scale movements. Each simulation represented a typical foraging night with an average duration of 10 h (36,000 s) and all activity was updated and recorded discretely so the output data could be obtained in every second of the simulation if needed.