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A modelling framework to predict bat activity patterns on wind farms: An outline of possible applications on mountain ridges of North Portugal

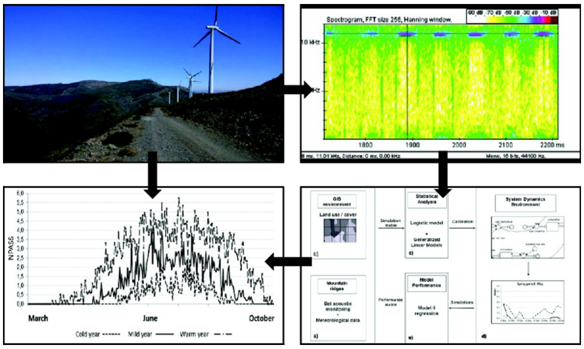
Carmen Silva [a], João Alexandre Cabral [a], Samantha Jane Hughes [b], Mário Santos [a,*]

[a] Laboratory of Applied Ecology, CITAB - Centre for the Research and Technology of Agro-Environment and Biological Sciences, University of Trás-os-Montes e Alto Douro, 5000-911 Vila Real, Portugal
[b] Fluvial Ecology Laboratory CITAB, Centre for Research and Technology of Agro-Environment and Biological Sciences, University of Trás-os-Montes and Alto Douro, 5000-911 Vila Real, Portugal

HIGHLIGHTS

- A holistic methodology was developed to predict bat activity on windfarms.
- Bat activity was associated with specific environmental conditions and scenarios.
- Model framework outputs could estimate the attractiveness of wind turbines.
- Attractiveness could support management of windfarms for conservation.

GRAPHICAL ABSTRACT



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ABSTRACT

Worldwide ecological impact assessments of wind farms have gathered relevant information on bat activity patterns. Since conventional bat study methods require intensive field work, the prediction of bat activity might prove useful by anticipating activity patterns and estimating attractiveness concomitant with the wind farm location. A novel framework was developed, based on the stochastic dynamic methodology (StDM) principles, to predict bat activity on mountain ridges with wind farms. We illustrate the framework application using regional data from North Portugal by merging information from several environmental monitoring programmes associated with diverse wind energy facilities that enable integrating the multifactorial influences of meteorological conditions, land cover and geographical variables on bat activity patterns. Output from this innovative methodology can anticipate episodes of exceptional bat activity, which, if correlated with collision probability, can be used to guide wind farm management strategy such as halting wind turbines during hazardous periods. If properly calibrated with regional gradients of environmental variables from mountain ridges with windfarms, the proposed methodology can be used as a complementary tool in environmental impact assessments and ecological monitoring, using predicted bat activity to assist decision making concerning the future location of wind farms and the implementation of effective mitigation measures.

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[*] Corresponding author.
E-mail address: mgsantos@utad.pt (M. Santos).

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1. Introduction

Declines in bat population result from several factors mostly associated with land use intensification (Fuentes-Montemayor et al., 2011), such as degradation of foraging habitats and shelters (Battersby, 2010) but also hunting pressure, diseases, pesticides and the decline of prey populations (O'Shea et al., 2016). Despite the clear benefits of wind energy, the overall balance of direct and indirect local impacts of wind farms on bats has not been determined (Santos et al., 2013a). Studies carried out in North America and Europe show that bat populations are particularly susceptible to impacts from these relatively recent infrastructures, with high mortality rates recorded near wind turbines in late summer and early autumn (Arnett et al., 2016). Specific carcass searches conducted at wind farms provide important information on mortality patterns (ICNB, 2012). Conversely, bat acoustic monitoring is a non-invasive method that can be used to monitor bat activity patterns (Bat Conservation Trust, 2007). Monitoring data derived from disperse wind farm environmental monitoring programmes can contribute to the implementation of mitigation measures such as increasing turbine cut-in speed (raising turbine cut-in speed above the manufacturer's set cut-in speed), placing acoustic deterrents on wind-turbines or even stopping wind turbines at specific periods such as nocturnal periods with high levels of bat activity, that can occur during situations correlated with attractiveness and collision probability (Johnson et al., 2012; Arnett et al., 2011; Arnett et al., 2013; Arnett et al., 2016). On the other hand, correlations between pre-construction measurements of bat activity with similar measurements made post-construction are weak. This could be because bats may be attracted to turbines once they are built and sites appear to be used differently by species afterwards (Arnett et al., 2016; O'Shea et al., 2016). Integrated post-construction measurements derived from a variety of wind farms could be used to produce reliable predictions of bat activity patterns for particular wind farm conditions. This could potentially contribute to identifying more suitable future locations of wind turbines, thereby reducing the occurrence of future potential attractiveness/collision probability for bats (Roscioni et al., 2014). This is particularly important for mountain ridges with wind farms in Iberia where most bat activity is associated with passing behaviour but rarely with regular feeding behaviour which tends to occur under specific environmental conditions and periods of insect emergence (Amorim et al., 2012; Ferreira et al., 2015).

Ecological modelling requires knowledge on ecosystem function and predominant environmental problems (Jørgensen and Bendoricchio, 2001). These requirements are necessary for developing models capable of simulating output from relevant scenarios for solving problems and producing quantitative tools from cause-effect relationships (Santos and Cabral, 2004; Santos et al., 2010; Santos et al., 2013b; Santos et al., 2016). It is fundamental that predictive tools integrate pertinent environmental data with explicatory relevance for bat occurrence and activity to support credible environmental impact assessments (EIA) and bat specific conservation programmes at wind farms located on mountain ridges (Kunz et al., 2007a, 2007b; Roscioni et al., 2014).

The recently developed Stochastic Dynamic Methodology (StDM) is a mechanistic protocol designed to recreate holistic ecological cause-effect relationships, by combining robust information-theoretic methods with contemporary dynamic modelling techniques (Santos et al., 2011; Santos et al., 2013b; Santos et al., 2016). StDM is based on the premise that general statistical patterns of ecological phenomena are emergent indicia of complex ecological processes (Santos and Cabral, 2004). Use of the StDM methodology minimizes several problems associated with model development such as model parameterization, structural complexity and variable selection processes (Bastos et al., 2012). The StDM protocol applies univariate and multivariate statistical techniques to extract the most pertinent relationships between response and explanatory variables. Usually, the response variables in StDM applications correspond to indicators or other relevant attributes under study. Explanatory variables, modelled as state variables in a system dynamics platform, represent the principal environmental factors or drivers considered in the scope of a specific problem. The basic unit of a StDM model is a state variable/response variable based on the balances described by difference equations or converters, whose coefficients, explaining the influence of the dynamic explanatory variables are estimated by prior statistical analyses. Since the statistical test outputs are static, one of the central requirements of StDM is that the founding data set captures the most relevant gradients of change under study (Santos and Cabral, 2004; Santos et al., 2016). This results in realistic simulations that take into account spatial and temporal dimensionality of the relevant parameters (Santos et al., 2013b). Obtained partial regression coefficients represent the global influence of selected significant environmental variables on several complex ecological processes. The latter processes are not included explicitly in the model, but are taken into consideration within the “data-space” of the environmental gradients assessed in changed ecosystems.

A StDM holistic model able to accurately predict bat activity for different wind farms located in mountain ridges would be a valuable tool for evaluating potential attractiveness associated with areas with more bat activity, particularly for EIA carried out to evaluate areas projected for windfarm installations or environmental management plans (EMP) for existing wind farms. Using the north of Portugal as demonstration site, this methodological demonstration paper (1) illustrates how to determine the main cause-effect relationships between environmental variables and bat activity patterns on mountain ridges with windfarms, (2) develops a novel StDM framework to predict bat activity in mountain ridges with wind farms across different spatiotemporal scales and environmental conditions and (3) illustrates the applicability of the methodology in future wind energy developments to support EIA and EMP decision-making in wind farm management.

2. Material and methods

2.1. Study area

The study area encompassed ten mountain ridges with wind farms, located in North Portugal (Fig. 1). Most of them coincide with the Natura 2000 network (http://www.protectedplanet.net/). The altitudinal gradient of the study sites varies between 770 and 1350 m a.s.l. and the prevailing bioclimates are temperate oceanic sub Mediterranean and Mediterranean pluviseasonal oceanic regions (Worldwide Bioclimatic Classification System, 1996–2009). The main habitat types, defined using CORINE land cover maps (CLC) were ground-truthed during specific field campaigns and comprise Mediterranean shrublands, Mediterranean dwarf scrublands combined with rock outcrops, woodlands and agriculture. Detailed information on the mountain ridges and windfarms information is given in Silva (2015).

2.2. Bat acoustic monitoring and environmental conditions

Bat activity and meteorological conditions were monitored once a month, from March until October (2007–2011) in the centre of the selected plots (sampling points) of each wind farm, in accordance to recommendations of EMP and national authorities (ICNF, 2009) (Table 1). One hundred and thirty five sampling points within 10 wind farms (minimum distance between sampling points 200 m) were used for monitoring acoustically assessed bat passes and meteorological conditions from pre-sunset (Table 1 and Fig.1). The precise number of sampling points per wind farm was dependent on the number of wind turbines present (minimum 3, maximum 32) and the distances of the sampling points from the closest wind turbine were varied (Table 1 and Fig. 1). Bat passes are defined as a sequence of >2 echolocation pulses of search-phase (Boughey et al., 2011; Broders, 2003; Kunz et al., 2007b), which can be described as an increase in amplitude of bat sound followed by a sudden decrease. The number of bat passes per 10 min was counted for each sample plot using the heterodyne system from the D240X detector (Pettersson Elektronik AB) scanned up and

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