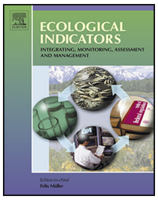
Ecological Indicators 34 (2013) 428–440

Contents lists available at SciVerse ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind



A new stochastic dynamic tool to improve the accuracy of mortality estimates for bats killed at wind farms

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ARTICLE INFO

Article history:
Received 25 September 2012
Received in revised form 20 March 2013
Accepted 6 June 2013

Keywords:
Mortality estimators
Bat fatalities
Wind farms
Stochastic dynamic modelling
Environmental impact assessment
General ecological monitoring

ABSTRACT

Although generally considered environmentally friendly, wind power has been associated with extensive mortality of birds and bats. In this perspective, there is a need for reliable estimates of fatalities at wind farms, where the heterogeneity of the basic information, used among environmental assessment studies, is unlikely to support an accurate universal estimation method. We tested the applicability of the Stochastic Dynamic Methodology (StDM) to estimate bat fatalities, based on multifactorial cause–effect relationships (by integrating multi-model inference statistical analysis and dynamic modelling) between mortality estimates, detected fatalities and the selected key-components of the reality, such as the real number of bat mortalities simulated, the rate of carcasses removal, the searcher efficiency, the monitoring periodicity and the number of turbines for different realistic scenarios associated with particular wind farm conditions. Although some existing mortality estimators are considered accurate, the choice of a given universal formula for all mortality assessments, based on deterministic parameters and assumptions, may originate unsuspected errors. Therefore, we propose a flexible dynamic modelling framework, the StDM estimator, where the obtained algorithms are adaptable to the universe of application intended. The StDM estimator takes into account random, non-constant and scenario dependent parameters, providing bias-corrected estimates. The StDM estimator was applied for the European wind farm context and validated in the most cases tested, through the confrontation with independent data. Overall, this approach is considered a valuable tool to improve the quality of mortality estimates at onshore wind facilities, within the local, environmental and methodological gradients (including the cases where no mortality is detected), namely in the scope of environmental impact assessments and general ecological monitoring programmes.

1. Introduction

In the last decades, renewable energies, and specially wind energy, have received a huge investment. Wind energy is considered as one of the strategies to deal with global warming and accomplishment of goals set by the Kyoto Protocol, however the entire balance of cost-benefits, including the direct and indirect local impacts of wind farms on wildlife and nature conservation, has not been made (e.g. Carrete et al., 2009; Everaert and Stienen, 2007; Lucas et al., 2005; Rabin et al., 2006; Santos et al., 2010; Söderholm et al., 2007). In this perspective environmental impact assessments (EIAs) and general ecological monitoring (GEM) programmes may provide mechanisms to support sustainable development and the conservation of biological diversity (OJEC, 1992, 1993; Söderman, 2006; Treweek, 1996, 1999). The universal application of EIA and GEM are the basis to implement national and international strategies of sustainable development, considering that EIA is used to foresee the environmental consequences of proposed human actions and GEM is used to implement corrections and adaptations to reduce the ecological impacts of human progresses (Gontier et al., 2006; Jay et al., 2007; Lindenmayer and Likens, 2010; MacNeely, 1994). Although the ecological inputs to environmental statements are considered in EIA, criticisms have arisen due to the lack of scientific rigour and failure to evaluate the real ecological impacts induced by the wind farms construction and operation (e.g. Slootweg, 2005; Slootweg and Kolhoff, 2003; Toro et al., 2012). In fact, the monitoring process of bat populations and bat mortality is based on field expert knowledge and labour-intensive work (Arnett et al., 2008), where the heterogeneity of the basic information used among different studies is unlikely to support an accurate universal estimation method (Rydell et al., 2010).

Mortality monitoring at wind farms is based in periodic carcass searches around the turbines, from where two primary sources of bias must be accounted to improve the accuracy of

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http://dx.doi.org/10.1016/j.ecolind.2013.06.003

fatality estimates: (1) the proportion of carcasses removed by scavengers between search intervals and (2) the proportion of carcasses present in the search plot but not detected by the observer (Anderson et al., 1999; Morrison, 2002), which is driven by the observer performance (e.g. Gutzwiller and Marcum, 1997) and the environmental variables that affect the observer efficiency, such as wind velocity, precipitation, temperature, cloud cover, light intensity, topography and vegetation characteristics (e.g. Philibert et al., 1993; Verner, 1985). Therefore, the correction of these parameters was recognized as critical to ensure the mortality estimators accuracy in contexts of imperfect detection (e.g. Erickson et al., 2000; Huso, 2010; Jain et al., 2007; Johnson et al., 2003; Jones et al., 2009). Whereas the first simple estimators did not account for non-detected carcasses persistence between searches (e.g. Johnson et al., 2003), the more recent and sophisticated estimators have been developed to account this requirement (e.g. Erickson et al., 2004; Korner-Nievergelt et al., 2011). Nevertheless, as far these estimators are closer to be more accurate, also the accomplishment of their several assumptions makes them more complex and dependent of the uncertainty of pre-determined distributions, namely to simulate bat fatalities as well as carcasses persistence and searcher efficiency throughout the period of searches.

Since many of these phenomena have non-constant distributions in real conditions (Korner-Nievergelt et al., 2011), the goal of this work was to test the applicability of a Stochastic Dynamic Methodology (StDM) in order to estimate bat fatalities at wind farms. The fundamentals of StDM, a sequential modelling process based on statistical parameter estimation methods (Santos and Cabral, 2004), were applied for bat mortality estimates using relevant cause–effect relationships between simulated fatalities, contextual characteristics of the wind farms and the performance of mortality detections.

The main objectives of the present paper were: (1) to develop a dynamic model providing realistic simulations of the bat mortality phenomena, attributable to collisions with wind turbines, using different conditions associated to monitoring designs and wind farm characteristics for a particular region and (2) to assess the final performance of the proposed framework in estimating the number of bat fatalities by quantifying the lack of the respective accuracy and validating the obtained results.

2. Methods

2.1. Conceptualization of the StDM estimator framework

The StDM estimator was based on a sequential modelling procedure (Fig. 1), initiated by the construction of a dynamic model (Fig. 1a) that provides realistic scenarios of bat fatalities from where the respective detections were forecasted. Considering the parameterization of the dynamic model, different scenarios within the European wind farm “data space” were considered, namely by changing the searcher conditions (carcasses persistence and searcher efficiency), the monitoring schemes (monitoring period and periodicity of searches) and the wind farms characteristics (number of wind turbines). The resulting simulations allowed us to generate a database (Fig. 1b) from the simulations of the fatalities time distribution and respective detections performance, considering the related relevant parameters as correction factors for imperfect detection. This information, when submitted to a robust information-theoretic approach based on Generalized Linear Models (GzLMs; Fig. 1c), the multi-model inference method (Burnham and Anderson, 2002), enable us to establish the interaction criteria between the obtained parameters, supporting the calculation of the more appropriated algorithm for the StDM estimator (Fig. 1d). Finally, based on new simulated independent scenarios (Fig. 1e), the proposed estimator was submitted to a validation procedure (Fig. 1f) by the confrontation between “Simulated real mortality” and the respective “StDM estimated mortality”. Furthermore, we assessed the bias and accuracy of our flexible estimator by calculating the relative error of the estimates for each simulated scenario. After the validation process, the performance of the StDM estimator was compared with other conventional known estimators, regarding realistic scenarios simulated for hypothetical wind farms in Europe.

2.2. Construction of the dynamic model

The dynamic model construction (Fig. 1a) was based on parameters calculated from the characterization of the wind farms and bat mortality monitoring schemes described in European wind farm studies (Appendix A; Fig. 2). These parameters are associated to the processes that lead to possible sources of imprecision,

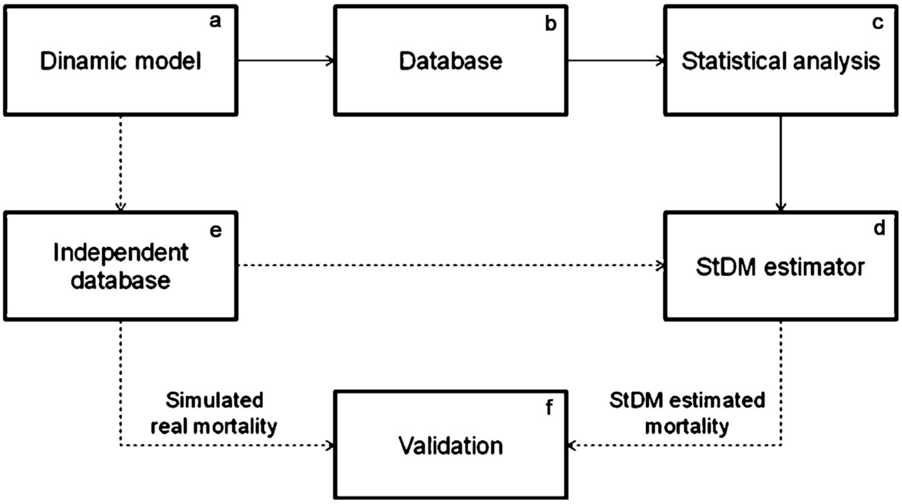

Fig. 1. The StDM estimator framework for the estimation of bat mortalities at wind farms facilities: (a) construction of a dynamic model for realistic simulations of the bat mortality phenomena attributable to collisions with wind turbines; (b) creation of a virtual database with the real fatalities simulated and the respective probable detections, considering the relevant parameters necessary to adjust for imperfect detection; (c) statistical analysis to test for relationships between response and explanatory variables; (d) calculation of the StDM estimator algorithm; (e) independent database creation for validation purposes; (f) statistical validation of the StDM estimates.