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Avian collision risk models for wind energy impact assessments

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ABSTRACT

With the increasing global development of wind energy, collision risk models (CRMs) are routinely used to assess the potential impacts of wind turbines on birds. We reviewed and compared the avian collision risk models currently available in the scientific literature, exploring aspects such as the calculation of a collision probability, inclusion of stationary components e.g. the tower, angle of approach and uncertainty. 10 models were cited in the literature and of these, all included a probability of collision of a single bird colliding with a wind turbine during passage through the rotor swept area, and the majority included a measure of the number of birds at risk. 7 out of the 10 models calculated the probability of birds colliding, whilst the remainder used a constant. We identified four approaches to calculate the probability of collision and these were used by others. 6 of the 10 models were deterministic and included the most frequently used models in the UK, with only 4 including variation or uncertainty in some way, the most recent using Bayesian methods. Despite their appeal, CRMs have their limitations and can be 'data hungry' as well as assuming much about bird movement and behaviour. As data become available, these assumptions should be tested to ensure that CRMs are functioning to adequately answer the questions posed by the wind energy sector.

1. Introduction

As wind energy developments increase globally both onshore and offshore (Lewis and Wiser, 2007; Snyder and Kaiser, 2009; Bilgili et al., 2011; Wang et al., 2012), the potential associated environmental impacts are receiving considerable attention, particularly avian impacts. Typically, wind energy developments require an environmental impact assessment to quantify the potential risk to the environment. The potential impacts of wind farms on bird populations can be grouped into three main types: direct mortality due to collision with turbines/infrastructure; physical habitat modification and/or loss; and avoidance responses of birds to turbines (Fox et al., 2006; Langston, 2013). Avian collision has received much attention as it is considered a very real threat to bird populations (Johnson et al., 2002; Krijgsveld et al., 2009) and a variety of methods have been developed to aid the assessment of the risk of collision. The methods can be categorised as those that measure and assess collisions empirically including direct and remote observations of bird flights in the development area (pre- and post-construction of the wind turbines) to assess flight behaviour, habitat use and flux of birds (Desholm and Kahlert, 2005; Desholm et al., 2006; Douglas et al., 2012) and corpse searches to document actual collisions (Winkelman, 1992; Huso and Dalthorp, 2014), and those which are more theoretical such as collision risk models which predict likely collisions (Holmstrom et al., 2011; Eichhorn et al., 2012; Smales et al., 2013). In addition to estimating collisions between birds and wind turbines, collision risk models (CRMs) are used in a range of other situations including marine mammals and marine renewable energy devices i.e. tidal stream turbines (Wilson et al., 2006), fish and turbines (Hammar and Ehnberg, 2013) and shipping collisions with moving and stationary objects (Montewka et al., 2010).

At their core, most avian collision risk models include a calculation of the probability of a collision occurring (assuming no evasive action or behaviour) and a measure of the number of birds within a risk window in order to estimate the likely number of collision events. The probability of collision is generally based on the probability of a turbine blade occupying the same space as the bird during the time that the bird takes to pass through the rotor. This therefore relies upon information on both bird and wind turbine characteristics including but not limited to bird morphometrics and flight speed, turbine rotor speed and turbine size. In addition to the probability of collision, an understanding of bird avoidance behaviour is required if realistic estimates of collision events are to be predicted. In the UK, the most frequently used avian collision risk model is commonly known as 'the Band model' (Band et al., 2007). Since its original development, it has undergone several iterations with the most recent associated with the Strategic Ornithological Support Services (SOSS) (Band, 2012a, 2012b). However, it is not the only collision risk model available to predict potential collisions of birds with wind turbines, and others are used outside of the UK and vary in their approach to assessing avian collision risk.

The aim of this review therefore is to discuss the range of avian collision risk models in order to raise awareness of those available, their

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strengths and limitations. In addition we qualitatively compare models, and highlight when it may be appropriate to use different models, as well as discussing the interpretation of results. Finally, we also suggest where future efforts should be focussed to advance collision risk modelling.

2. The collision risk models

The peer-reviewed scientific literature and the grey literature were extensively reviewed for references to avian collision models. Using Web of Science, Google and Google Scholar we searched for relevant peer-reviewed papers, reports, conference proceedings and book chapters relating to wind farms and collision risk models. The search terms used were "collision risk model or CRM or collision model" refined by "bird or avian or ornithology or ornithological" and "wind farm or wind turbine or windmill". We identified 10 distinct collision risk models referring to birds and wind turbines, the earliest dating back to 1996 (Tucker, 1996a). We defined the Band model and its various options and iterations as one model, though we will discuss the different versions below. We are aware other models are available, but following our literature review we were unable to find any documentation for these models, and were unable to contact the model developers. In this section we present brief descriptions of the collision risk models available, ordered chronologically in an effort to show the development and history of this field of research. We do not provide the fine mechanistic detail required to reproduce any single model but rather an overview of the methods available. The original intention of the project was to quantitatively compare models, but this was not possible as insufficient details were provided to do so. Although commercial confidentially is often given as the reason for a lack of detail regarding collision risk models, increased transparency would increase confidence in the final model outputs.

2.1. Tucker (1996a, 1996b)

Tucker (1996a) was the first to publish a complete analysis of bird–rotor collisions and went on to show how rotors could be designed so fewer birds collide for an equivalent energy generation (Tucker, 1996b). "The model analyses the motions and dimensions of both birds and propeller-type rotor blades, and predicts the probability of a collision when the bird flies through the area swept by the blades." (Tucker, 1996a). However, it does not estimate a likely number of collisions as a measure of bird density or flux through the turbine is not included. The probability of collision is calculated as a ratio of the time taken for a bird to move through the rotor swept area compared to the time taken for the turbine blades to complete a single revolution. In the model the theoretical blades are either one, or three dimensional consisting of length, chord and twist but no thickness. Collision with the static turbine tower is not considered in the calculations. The bird moves on fixed wings i.e. gliding not flapping, and is two-dimensional and rectangular with wingspan being greater than body length (Fig. 1b). It is therefore the corners of the rectangle which collide with either the leading or trailing edges the blades. The bird always moves perpendicular or parallel to the turbine rotor but flight can be parallel or oblique to the wind direction and the model can accommodate upwind or downwind flight. Avoidance behaviour of the bird is mostly not included in this model though it assumes that there is an inner radius at the turbine hub where birds will always avoid collision with the blades as it is a slow moving object.

2.2. Band (2012a, 2012b)

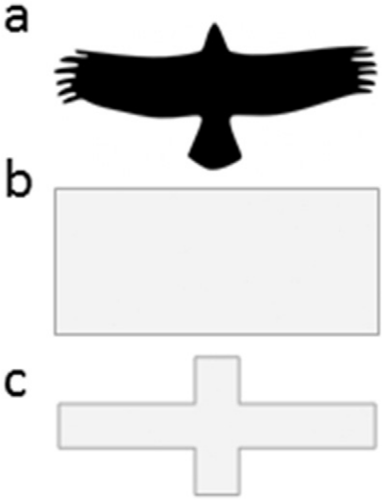

Fig. 1. Modelled representation of bird (a) as either rectangular (b) or cruciform (c).

The approach was originally developed for onshore wind turbines and promoted as guidance by Scottish Natural Heritage (Scottish Natural Heritage, 2000). It has been further developed by Band et al. (2007) and more recently for application in the offshore environment by Band (2012a, 2012b). Similar to Tucker (1996a) this model is based on the probability of a turbine blade occupying the same space as a bird during the time it takes the bird to pass through the rotor swept volume of the turbine. The probability of collision relies on information about the bird (wing span, body length, flight speed, flight height, nocturnal flight activity) and the turbine (blade width, blade length, blade pitch, rotor speed, hub height, operational time). The bird is assumed to be cruciform i.e. cross-shaped (Fig. 1c), though this simplification may underestimate collision risk and the turbine blade is assumed to have a width (chord) and a pitch angle but no thickness. The model only considers flights that are parallel to the wind i.e. perpendicular to rotation of turbine and assumes that the effects of approaching the turbine at oblique angles will cancel each other out though this may underestimate collision risk (Band, 2012b). It also only considers the moving rotor excluding the stationary elements such as the tower.

2.2.1. 'Basic' Band model

The approach of the original model (Band et al., 2007) had two stages for estimating the number of collisions per annum which included calculating: i) the number of birds flying through the rotor and ii) the probability of collision from a single transit of a rotor. The probability of collision is calculated at fixed intervals along the rotor blade and then averaged over the rotor swept area. The more recent offshore iteration of the model (Band, 2012b) includes a method to use boat-based survey data i.e. densities, rather than vantage point data to calculate the number of birds flying through the rotor. This modification is necessary due to the different data collection techniques applied in the onshore and offshore environments. The most recent version also includes a measure of avoidance behaviour, allowing for a proportion of birds to avoid collision.

2.2.2. 'Extended' Band model

The extended model is built on the basic model. The basic model assumes a uniform distribution of birds across the rotor swept area of the turbine. However, it was recognised that the distribution of birds, as well as the width of the turbine, all vary with height within the rotor swept area, thus affecting the collision risk. It is not possible to consider each of these individually due to covariance, however it is possible to use flight height curves (Johnston et al., 2014) to calculate the probability of a bird flying at a particular height within the turbine rotor sweep and colliding with a turbine blade. These individual probabilities are then integrated to gain the collision integral. Although the extended Band model is considered a more realistic model than the basic model, it is potentially more sensitive to uncertainty, particularly in relation to flight height estimates (Cook et al., 2014).