Short title: ***Variability in collision rate predictions***

Modelled sensitivity of avian collision rate at wind turbines varies with number of hours of flight activity input data

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Collision risk modelling of birds at wind turbines typically requires vantage point (VP) data to quantify bird flight activity. The number of VP observation hours required to provide such data, and the associated error in predicted collision rate, have not been formally assessed. Using the Band model and a randomisation procedure, we examine the sensitivity of collision rate predictions for the White tailed Eagle *Haliaeetus albicilla* to varying hours of input data on flight activity. Variability in collision rate decreased with increasing number of observation hours. However, at the asymptote in variability (about 62 observation hours) there was still considerable variability in predicted collision rate. VP watches are likely to be inherently variable, and collision rate predictions should assess the potential error associated with such results.

Keywords: Avian flight activity, Band model, collision risk modelling, onshore wind, renewable energy, vantage point watches, wind farms.

A variety of models has been developed to predict avian collision risk at wind turbines, typically requiring input data on bird flight activity and turbine specifications (e.g. Tucker 1996, Podolsky 2003, Smales 2006). In the UK and elsewhere (e.g. Norway, May *et al.* 2010), the model developed by Band *et al.* (2007, see also SNH 2000) remains the standard method for predicting collision rate for a range of bird species, including raptors and wildfowl, at proposed wind farms. The model requires various stages of input data which are then multiplied to calculate collision rate: (1) bird flight activity within the rotor swept zone (RSZ), determined from surveys; (2) site- and species-specific collision probabilities, determined by the structure and operation of the turbines and relevant bird size and flight (Table S1); and, (3) collision rate can be further refined by the inclusion of avoidance rate (Band *et al.* 2007). Key parameters in determining collision probability in Stage 2 are bird flight speed, rotor diameter and rotation speed, and predicted collision rate is highly sensitive to avoidance rate (Chamberlain *et al.* 2005, 2006).

A key knowledge gap remaining is the unknown sensitivity of the model outputs to varying levels of input data relating to flight activity in the RSZ (i.e. Stage 1). These are the data on which the calculations are based, and are often treated as providing definitive knowledge regarding flight activity at a site, but are only estimates, with associated error that is rarely considered in Environmental Impact Assessments (EIA). At onshore sites, bird flight activity is typically recorded using vantage point (VP) watches, conducted by either a single observer or multiple observers operating simultaneously. Flight activity observed during VP watches can be highly variable, and sufficient hours must be conducted to quantify flight activity at a site. As an example, Scotland's statutory government agency Scottish Natural Heritage (SNH) recommends a minimum of 36 observation hours per season (e.g. breeding season) to provide input data for calculating collision rate (SNH 2005), on the assumption that this level of observation will provide a reasonable estimate of true flight activity. However, this assumption has not been formally tested, although such testing is advocated by SNH (SNH 2005), partly because of a lack of larger datasets from which to draw sample subsets of observation hours to assess the change in variability with increasing observation hours.

Here we utilise an extensive dataset on flight activity of a large raptor species of high conservation concern, the White-tailed Eagle *Haliaeetus albicilla,* at an operational wind farm. We examine the sensitivity of collision rate calculations from the Band model to varying hours of input data on flight activity, predicting that variability in collision rate decreases with increasing observation hours. Using current SNH guidelines for VP watches as an example (SNH 2005), we use our results as a test of whether these are adequate in quantifying flight activity and the variability associated with collision rate predictions.

METHODS

Site details and vantage point data

Flight activity of White-tailed Eagles was recorded over a single breeding season in 2006 at the 68-turbine Smøla wind farm, Norway (Follestad *et al.* 2007). The coincidence of the wind farm with an area of high breeding density of White-tailed Eagles has led to a study of the response of large raptors to wind farm development, including VP watches to record flight activity. VP data from 2006 comprised 175 observation hours between March and August. Sessions ranged from 1 – 6 hours~~ duration~~. Although the duration of individual flights within a session was recorded, the precise time of day these occurred was not; ~~As precise flight time was not recorded, w~~we therefore required input data from sessions of equal length, and thus standardised observation period, ~~as~~ with ‘session’ forming~~forms~~ the minimum unit of analysis possible. For this reason ~~W~~we ~~therefore~~ utilised data from the session length with the largest sample size (2 hours, *n* = 51 sessions), retaining only those conducted using comparable methods between sessions (two observers operating simultaneously from the same two VPs). This yielded a sample of 47 2-hr sessions conducted between 13 March and 341 July 2006, between 06:00 – 19:00, representing the diurnal variation in flight activity and flight type (moving flight, soaring, spiralling etc, May *et al.* 2010) and consistent with recommended VP methodology (SNH 2005). Observations followed the Focal-Animal Sampling method (see May *et al.* 2010) and flight activity was summarised as the total flight time of all individual eagles at rotor height per session.

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Randomisation procedure and calculation of collision rate

We selected subsets of observation sessions, increasing incrementally by one session at a time, ranging from 1 to 47 (2 – 94 observation hours). For each number of observation hours, we used a resampling procedure (with replacement) with 10000 permutations, to select a random sample of observation sessions summing to the relevant total number of observation hours, with the output value of each permutation being the total flight time within the RSZ across all sessions. For each permutation, we calculated the predicted number of White-tailed Eagle collisions using the Band *et al.* (2007) model, assuming no turbine avoidance (see Discussion). Data on flight activity from the randomisation procedure provided Stage 1 data, and we incorporated relevant input parameters specific to the wind farm site and White-tailed Eagles for Stage 2 (Table S1).

We examined the effect of varying the number of observation hours upon the accuracy of (variability in) our collision rate predictions. We first calculated the mean and 95% confidence intervals (CI) of the 10000 permutations for each number of observation hours. The values of the upper and lower 95% CI were also calculated as the percentage difference of each relative to the mean. We assessed whether the variability in collision rate predictions reached asymptote with increasing number of observation hours. The calculated range between the upper and lower 95% CI was modelled as a response variable against the number of observation hours. Modelling was conducted using nonlinear regression (3-parameter exponential decay model) in SigmaPlot 12 (Systat Software Inc 2011) which yielded an estimate of the asymptote in the range of 95% CI. We then examined the probability of a single set of observations (i.e. percentage of the 10000 permutations) at each number of observation hours yielding a predicted collision rate outside the asymptotic range of the 95% CI.

RESULTS

The predicted number of collisions during the study period, calculated using our sample of 94 observation hours (n = 47 x 2 hour sessions) and assuming no avoidance, was 22.9 collisions, which was matched by the mean number of collisions calculated from random resamples with varying number of observation hours (range 22.6 – 23.1 collisions, Figure. 1a). As expected, there was a marked reduction in the variability of calculated collision rate, as measured by the range of 95% CI around the mean, with increasing number of observation hours (Fig. 1a, b). This variability decreased predictably with increasing effort, reaching an asymptote of y = 20.3 ± 0.7 (the range between the upper and lower 95% CI of number of collisions) at about 62 hours of observation (Fig. 1c), when the predicted number of collisions was 22.9 (95 % CI of 13.4 – 33.8; -41.7 to +47.2 % variation around the mean). The probability of a single set of observations yielding a calculated collision rate outside the asymptotic range of 95% CI also decreased predictably with increasing effort (Fig. 1d). Consistent with the calculated asymptote in variability for this particular dataset, 62 hours was the minimum observation period for which the calculated probability reaches 5% (5.0, Fig. 1d).

DISCUSSION

Increasing numbers of observation hours of flight activity markedly reduced the variability in the predicted number of eagle collisions, with an asymptote in variability at about 62 hours for this particular dataset. Whilst drawn from a much larger sample of VP data than are normally collected to quantify flight activity at a site, these results are however based on only one season in one year, and should not be treated as definitive. Furthermore, the extent to which this asymptote in observer effort is site- and species-specific is not assessed. Eagle activity at Smøla may be relatively high, and lower flight activity at other sites may lead to greater variability in collision rate predictions, which would likely raise the asymptote in observation hours above that calculated for this dataset. Even at 62 hours' observation of flight activity, there is still considerable variability in the predicted number of collisions, which varied from 13.4 – 33.8, a 2.5 fold range. Vantage point watches are likely to be inherently variable, and the results of a single set of observation hours from the field should not be treated as definitive in impact assessments, with no consideration of the potential error. Instead, EIAs should include an assessment of the likely variability in their predictions from a resampling procedure. Our predicted collision rate (22.9 eagles, using the sample dataset of 94 observation hours) assumes no turbine avoidance by flying eagles. The high sensitivity of predicted collision rate to avoidance rate (Chamberlain *et al.* 2006) could potentially outweigh the sensitivity of collision rate predictions to observer effort. However, a simultaneous assessment of sensitivity to both observer effort and avoidance rate was outside the scope of this study. Although not considered here, additional factors may affect estimates of flight activity within the RSZ, including the level of missed observations and the accuracy of estimating flight height of birds, particularly at distance (Madders & Whitfield 2006).

As a comparison with our results, Scotland's statutory government agency SNH recommends a minimum of 36 hours of vantage point observations per season to quantify flight activity at a proposed wind farm site and predict collision rate using the Band model (SNH

2005). Our calculations suggest that with 36 observation hours, the 95% CI of predicted collision rate range from 10.8 to 37.0 collisions (equivalent to -53.0 – 61.8% below and above the mean value of 22.9 collisions respectively), compared to 95% CI of 13.4 – 33.8 at the asymptote of 62 hours. Thus the range between the upper and lower 95% CI at the asymptote of 62 hours (20.4) is *c*. 22% lower than at 36 hrs (26.3). The probability of a single set of 36 hours of observations yielding a predicted collision rate outside the range of 95% CI at the asymptote is 14.4%, compared to 5.0% at 62 hours. Statistical power analyses typically aim for an 80% probability of detecting a significant result for a particular test. Here, this could be defined as an 80% probability of a single set of observations yielding a collision rate prediction within the 95% CI at the asymptotic range in variability. For our results this occurs at a minimum of 28 hours of observations (80.6%). Therefore deciding whether current guidelines for predicting collision rate need refinement requires consideration as to the acceptable level of uncertainty associated with such calculations. The results presented here provide a first attempt at quantifying such variability, and we would encourage the randomisation methods employed here to be repeated on additional VP datasets of avian flight activity, for a range of species vulnerable to collision with wind turbines. These methods could be further extended to examine the sensitivity of collision rate predictions within spatial subunits or individual turbines at a site and the influence of weather during VP watches (May *et al.* 2010, Ferrer *et al.* 2011).

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REFERENCES

Band, W., Madders, M. & Whitfield, D.P. 2007. Developing field and analytical methods to assess avian collision risk at wind farms. In De Lucas, M., Janss, G. & Ferrer, M. (eds) *Birds and Wind Power*: 259-275. Barcelona: Lynx Edicions.

Chamberlain, D.E., Freeman, S.N., Rehfisch, M.R., Fox. T. & Desholm, M. 2005. *Appraisal of Scottish Natural Heritage's Wind Farm Collision Risk Model and its Application*. BTO Research Report 401. Thetford: British Trust for Ornithology.

Chamberlain, D.E., Rehfisch, M.R., Fox, A.D., Desholm, M. & Anthony, S.J. 2006. The effect of avoidance rates on bird mortality predictions made by wind turbine collision risk models. *Ibis* **148**: 198-202.

Ferrer, M., de Lucas, M., Janss, G.F.E., Casado, E., Muñoz, A.R., Bechard, M.J., & Calabuig, C.P. 2011. Weak relationship between risk assessment studies and recorded mortality in wind farms. *J. Appl. Ecol.* http://dx.doi.org/10.1111/j.1365-2664.2011.02054.x

Follestad, A., Flagstad, Ø., Nygård, T.,Reitan, O. & Schulze, J. 2007. *Vindkraft og fugl på Smøla 2003-2006*. NINA Rapport 248. Trondheim: Norsk institutt for naturforskning.

Madders, M. & Whitfield, D.P. 2006. Upland raptors and the assessment of wind farm impacts. *Ibis* **148**: 43-56.

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May, R., Hoel, P.L., Langston, R., Dahl, E.L., Bevanger, K., Reitan, O., Nygård, T., Pedersen, H.C., Røskaft, E. & Stokke, B.G. 2010. *Collision risk in white-tailed eagles: Modelling collision risk using vantage point observations in Smøla wind-power plant*. NINA Report 639. Trondheim: Norwegian Institute for Nature Research.

Podolsky, R. 2003. *Avian Risk of Collision (ARC) Model*. NWCC Biological Significance Workshop, November 17–18, 2003. Washington, DC. National Wind Coordinating Committee.

Scottish Natural Heritage 2000. *Windfarms and birds: Calculating a theoretical collision risk assuming no avoiding action*. SNH, Edinburgh.

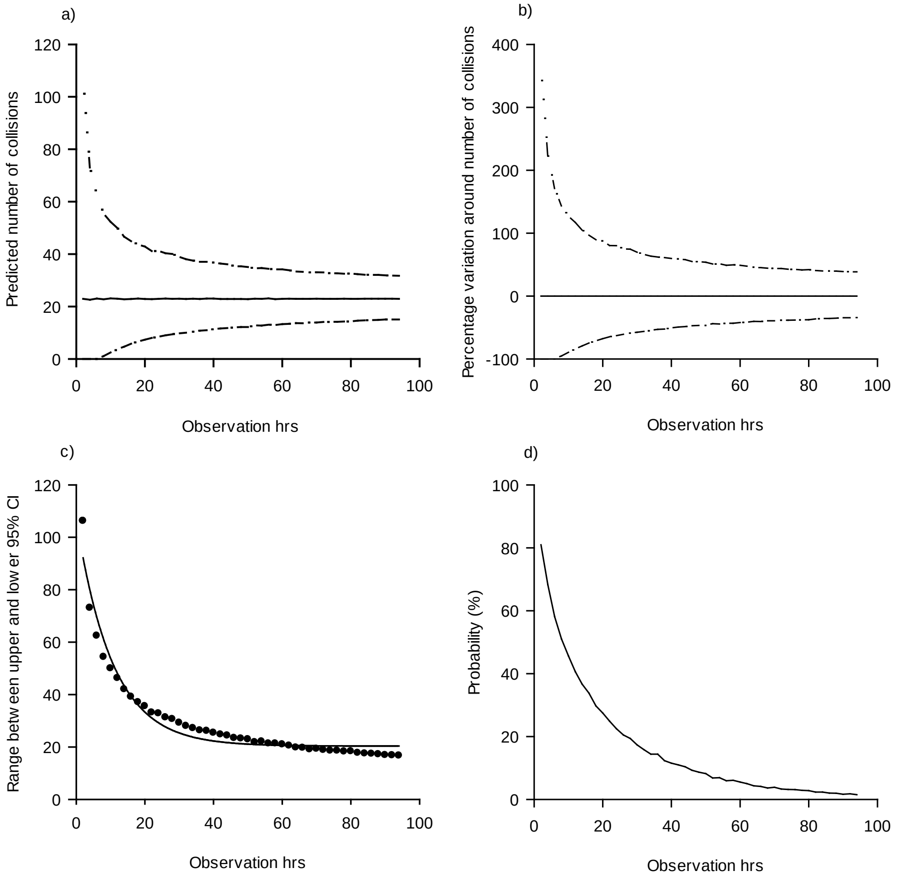
Scottish Natural Heritage. 2005. *Survey methods for use in assessing the impacts of onshore windfarms on bird communities*. SNH, Edinburgh.

Smales, I. 2006. *Impacts of avian collisions with wind power turbines: an overview of the modelling of cumulative risks posed by multiple wind farms*. Biosis Research Pty Ltd.

Systat Software Inc. 2011. SigmaPlot 12. London.

Tucker, V.A. 1996. A mathematical model of bird collisions with wind turbine rotors. *J. Solar Energy Engineering*. **118**: 253–262.

Figure.1. Effect of varying observation hours of vantage point watches on predictions of collision rate of White-tailed Eagles at Smøla wind farm from March – July 2006, calculated using the Band model: (a) Predicted number of collisions with varying observation hours (solid line = mean, dotted lines = 95% confidence intervals (CI)) from randomisation procedure; (b) Percentage variation in upper and lower 95% CI around the predicted number of collisions from randomisation procedure; (c) variation in the range between upper and lower 95% CI (circles = raw data from randomisation procedure with fitted line from modelling calculated range as the response variable against number of observation hours using non-linear regression); (d) probability of a single set of observations at each number of total observation hours yielding a collision rate prediction outside the asymptotic range in 95% CI at *c*. 62 hours.


a)
Predicted number of collisions
0
20
40
60
80
100
120
0
20
40
60
80
100
Observation hrs
b)
Percentage variation around number of collisions
-100
0
100
200
300
400
0
20
40
60
80
100
Observation hrs
c)
Range betw een upper and low er 95% CI
0
20
40
60
80
100
120
0
20
40
60
80
100
Observation hrs
d)
Probability (%)
0
20
40
60
80
100
0
20
40
60
80
100
Observation hrs