NATURAL RESEARCH INFORMATION NOTE 7

DERIVATION OF AN AVOIDANCE RATE FOR RED KITE *MILVUS MILVUS* SUITABLE FOR ONSHORE WIND FARM COLLISION RISK MODELLING

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ABSTRACT

The Band Collision Risk Model (CRM) described by Band *et al*. (2007) attempts to estimate the number of fatalities at an operational wind farm that will result from birds colliding with rotating turbine blades due to given levels of flight activity (Stage 1) and the probability of a bird passing through spinning rotor blades actually being hit by the blades (Stage 2).

The Band CRM is essentially a 'no avoidance' model, and to bring predictions towards a semblance of reality a correction factor must be applied as a final element in the calculations ('Stage 3'). Stage 3 is a heavily influential aspect of the CRM process despite it not being formally part of the CRM process, and is termed the "avoidance rate".

Currently, according to Scottish Natural Heritage (SNH 2016) guidance the recommended avoidance rate for red kite *Milvus milvus* under the Band CRM is 98 %. This recommendation is based on a simplistic comparator argument presented by a previous NRIN 3 (Whitfield & Madders 2006). There has been much recent interest in the possible consequences of collision mortality at wind farms for this European endemic species.

The objective of the present NRIN 7 was to evaluate the most suitable value for an avoidance rate for red kites under the Band CRM, using empirical data derived before and after the construction of a wind farm. Our approach mimicked the most common usage of the Band CRM: the model is primarily, and in origin, a predictive tool (applied pre-construction and in assessment of proposed wind farms). Our approach therefore also followed the SNH recommended procedure by which avoidance rates should preferentially be derived.

Analysis of pre-construction flight activity of red kite and post-construction turbine searches was undertaken at the Braes of Doune wind farm in central Scotland. Coupled with this analysis, correction factors for searcher detection error, carcass persistence and the proportion of carcasses that may have fallen outside the turbine search area were derived, allowing adjusted estimates of collision mortality to be made. This is the only known study of avoidance rate, incorporating both pre- and post- construction data, to have been completed in the UK, and possibly in Europe.

The initial collision risk modelling was based on flight activity data gathered by Natural Research (Projects) Ltd during vantage point observations totalling 199.1 hours between September 2004 and May 2006, i.e. before construction of the wind farm. During this period a total of 11.6 hours of red kite activity was observed (c.6 % of total observation time) within 500 m of the proposed turbine envelope.

Based on a layout of 36 turbines, which operate 87 % of the time, the Band CRM, populated by the empirical flight data, predicted there was 1518 red kite transits through the rotor swept area per year. Thus, without avoidance, the model predicted there would be 165.68 collisions per year.

Turbine searches were carried out between February 2007 and March 2012. Three red kites were documented as collision fatalities during 50 months' monitoring.

A Monte-Carlo approach based on ballistics to model the proportion of carcasses that could be thrown outside of the search area was used. Based on the Braes of Doune turbine specifications, a 60 m high nacelle and 33 m long blades, it was predicted that 80 % of mid-sized birds would land within 61 - 70 m of the turbine base after being struck by a blade. Therefore the total number of red kite fatalities, corrected for those birds that may have fallen out with the search area and not found, was 0.9 kites per annum.

A total of 40 carcasses were used during staged persistence trials. Of these, only 6 carcasses were removed by scavengers with the remaining carcasses persisting until the end of the lengthy observation period. Parametric survival analyses, based on the distributional assumptions of four probability distributions suitable for survival data, indicated the model with the lowest AICc value, and considered to have the best fit, was the Log-normal distribution. Assuming that the number of collisions was uniformly distributed over time, the scavenging correction factor (*R*) based on parametrically estimated risk was defined at 0.88.

A total of seven searcher efficiency trials utilising 72 trial carcasses were conducted as part of the fatality monitoring program. Mean searcher efficiency rates across all seasons was estimated as 0.81 (95% CI = 0.65 – 0.95).

Using the method of Jain *et al.* (2007) the adjusted total number of fatalities, *m*, at the Braes of Doune wind farm was estimated. The final reported estimate of *m* and associated 90% confidence intervals were calculated using Monte-Carlo methods. The lower 5^{th} and upper 95^{th} percentiles of the 5000 iterations were estimates of the lower limit and upper limit of 90% confidence intervals. The adjusted annual fatality estimate for red kite at the Braes of Doune wind farm was 1.28 (90 % CI = 1.11, 1.55).

Using pre-construction flight activity data to predict the number of fatalities with no avoidance and adjusted observed annual fatalities, Monte-Carlo methods were employed to account for the range of estimated fatalities, the mean avoidance rate and associated confidence intervals were calculated. The lower 5^{th} and upper 95^{th} percentiles of the 5000 iterations are estimates of the lower limit and upper limit of 90 % confidence intervals.

The derived avoidance rate for red kite at the Braes of Doune wind farm was estimated to be 0.992 (90 % CI = 0.991, 0.993).

In assessments of wind farm proposals where red kites are flying within a proposed development area **our analyses recommend that an avoidance rate of 99 % should be used** and not 98 % (SNH 2016). Our recommended avoidance rate is applicable only to the original Band CRM and not to any subsequent model extensions.

INTRODUCTION

1. The Band Collision Risk Model (CRM) described by Band *et al*. (2007) attempts to estimate the number of fatalities at an operational wind farm that will result from birds colliding with rotating turbine blades due to given levels of flight activity (Stage 1) and the probability of a bird passing through spinning rotor blades actually being hit by the blades (Stage 2).

2. The Band CRM is essentially a 'no avoidance' model, and to bring predictions towards a semblance of reality (based on empirical studies) a correction factor must be applied as a final element in the calculations ('Stage 3'). Stage 3 is a heavily influential aspect of the whole CRM process (e.g. Chamberlain *et al*. 2006) despite it not being formally part of the CRM process, and is termed the "avoidance rate".

3. Previous guidance on the application of avoidance rates (following Band *et al*. (2007)), provided by Scottish Natural Heritage (SNH), was based on expert opinion rather than on evidence and that a precautionary default avoidance rate of 95 % should be used for all species. However, evidence obtained from reported mortality rates, mostly for geese and raptors in the USA (e.g. Pendlebury 2006; Whitfield & Madders 2006; Whitfield 2009) suggested that this value was overly precautionary and a revised default rate of 98 % was subsequently recommended (SNH 2010).

4. SNH made a number of other changes to avoidance rates since the original precautionary default rate of 95 % (e.g. changing the avoidance rate for geese to 99.8 % in May 2013 and for diver species to 99.5 % in October 2016: SNH 2013, 2016).

5. SNH (2010) recommended a change in the avoidance rate for red kite *Milvus milvus* from the previous recommendation of 95 % to one of 98 %. This change was largely made as a result of Whitfield & Madders (2006) who argued that the previous SNH recommendation for a 95 % avoidance rate had no evidential basis. Whitfield & Madders (2006) pointed to studies from Spain which indicated that red kites (and black kites *Milvus migrans*) were not relatively vulnerable to collision strikes compared with some other birds of prey and concluded that empirically derived avoidance rates should be sought through work at operational wind farms.

6. Current guidance on the application of avoidance rates under the Band CRM is provided by SNH (SNH 2016). Accordingly, an avoidance rate of 98 % has been recommended for use in wind farm collision modelling under the Band CRM for red kite, after Whitfield & Madders (2006).

7. The importance of deriving an empirically robust estimate of avoidance for red kite is pertinent to many evaluations of the species' conservation status; nationally and internationally. As a species that is endemic to Europe, collision mortality at wind farms has been identified by several authors as a potential threat at the population level (e.g. Eichhorn *et al* 2012, Schaub 2012, Bellebaum *et al* 2013). In Scotland, a recent SNH commissioned report, primarily examining the effect of persecution on the north Scotland red kite population, used a 98 % avoidance rate in considering potential strike-rates at wind farms as

a possible source of additional mortality (Sansom *et al.* 2016). Any change in potential strike-rates at wind farms, through a revision of a Band CRM avoidance rate may, therefore, also have implications for the scaling of other potential sources of mortality on population trends, such as those caused by persecution (Sansom *et al.* 2016).

8. The objective of the present report is to evaluate the most suitable value for an avoidance rate for red kite that may encounter operational onshore wind farms. In meeting this objective, analysis of pre-construction flight activity of red kite and post-construction turbine searches has been undertaken at the Braes of Doune wind farm in central Scotland. Coupled with this analysis, correction factors for searcher detection error, carcass persistence and the proportion of carcasses that may have fallen outside the turbine search area have been derived allowing adjusted estimates of collision mortality to be made. This is the only known study of an avoidance rate, incorporating both pre- and post- construction data, to have been completed in the UK, and possibly in Europe.

EMPIRICAL DERIVATION OF AN AVOIDANCE RATE FOR RED KITE

9. The collision risk model (CRM) described by Band *et al.* (2007) offers a crude mechanism for predicting potential avian collision rates which proposed wind farms may generate (Chamberlain *et al*. 2006, Madders & Whitfield 2006). Modelling collision risk under the Band CRM is a two-stage process. Stage 1 estimates the number of birds that fly ('transits') through the rotor swept disc, empirically derived from field observation. Stage 2 predicts the proportion of these birds that will be hit by a rotor blade. Combining both stages produces an estimate of collision fatality in the absence of any avoiding action (Band *et al*. 2007).

10. Derivation of an avoidance rate estimate essentially follows the same method as described by Band *et al*. (2007) in deriving an estimate of predicted collision rate, with one exception. Instead of using an assumed avoidance rate to correct a predicted 'no avoidance' pre-construction fatality estimate, an observed post-construction fatality estimate after avoidance was used to derive the avoidance rate which was necessary as a correction of the 'no avoidance' pre-construction fatality estimate resulting from Stages 1 and 2 of the calculations.

11. The present study followed the process described by Band *et al*. (2007) for clarity and ease for the reader to follow the steps in calculations (see also Whitfield and Madders, 2006). Under Stage 1 of this process, the rate of transits through the rotors is calculated, and under Stage 2 the proportion of these transits which result in collision is calculated. Combining the two stages gives *N* predicted collisions (no avoidance). The parameters required under Stage 1 are shown in Appendix 1. The following section describes how values for these parameters and for *N* observed collisions (with avoidance) were calculated for the wind farm in the study.

12. To derive a species-specific avoidance rate requires knowledge of how many birds, of the target species, have actually collided with turbine blades. Then, by comparing the number of birds that *actually* collide with turbine blades at an operational wind farm with the number of

birds *predicted* to collide, assuming no avoiding action, an 'observed' avoidance rate, i.e. one that is exhibited in practice, can be calculated by (Madders & Whitfield 2006)

$$\text{avoidance rate} = (1 - a), \qquad \text{[equation 1]}$$

where a = number of observed collision mortalities / number of predicted collision mortalities assuming no avoidance.

13. Despite searching for carcasses of birds killed in collisions being technically straightforward, several factors can influence the reliability of the collision mortality count. At onshore facilities the estimation of bird mortality is generally based on carcass searches around wind turbines. Within a pre-defined plot, trained searchers look for carcasses walking along parallel transects and then repeated over time. However, the number of carcasses found during the searches does not typically correspond to the actual number of birds killed by wind turbines. Carcass searches are only expected to find some of the birds killed by turbines. Some carcasses may be removed by scavengers; others may fall outside the search area, while others may be overlooked by the searcher.

14. This value must be adjusted by the proportion of carcasses left undetected, carcass removal (e.g. by scavengers or decay) and searcher efficiency rates, which can in turn be influenced by site- and carcass-specific variables, such as carcass size, species, season, vegetation cover and topography. Provided these factors are corrected for, through properly conducted search methodology and the calculation of carcass persistence rates, then accurate figures for collision mortality can be compiled.

Study site

15. The Braes of Doune Wind Farm is 10 km north-west of Dunblane centred on the eastern slopes of Beinn Odhar. Proposals to build a wind farm at the Braes of Doune were first made in 2001. A formal application to build 49 turbines was made by Airtricity Developments (Scotland) Ltd in October 2002, with planning permission and consent granted in October 2004 (Scottish Executive 2004). The consented wind farm consists of 36 V80 2.0 MW (megawatts) turbines with a total nominal output of 72 MW. Construction began in June 2006 and the Braes of Doune Wind Farm was completed and commissioned in February 2007.

16. In 1996 a project to re-establish a central Scotland red kite population began. Between 1996 and 2001, 103 red kites were imported from Germany and released in the area. The nearest set of release cages were only 4 km from the most southerly turbine and the wind farm is located within the kites' core geographical range in central Scotland.

17. Successful breeding as a result of the central Scotland reintroduction project first occurred in 1998 when two pairs reared five young. Breeding has occurred in every subsequent year. By 2007 there had been 165 breeding attempts with 121 of these successful and at least 259 young reared locally (RSPB Scotland data).

18. In considering potential ornithological impacts of the project the Scottish Executive (now the Scottish Government) identified the requirement to monitor red kite on and around the wind farm site as a species listed in Annex 1 of the EU Directive on the Conservation of Wild Birds (79/409/EEC; revised later as 2009/147/EC). Natural Research Projects Ltd (NRP) has been involved in the monitoring of red kite at the Braes of Doune since 2002 and intensively since 2004.

Source data

19. Estimation of an avoidance rate first considered pre-construction data from the Braes of Doune wind farm. The initial collision risk modelling was based on time budget data gathered by Natural Research (Projects) Ltd during vantage point observations totalling 199.1 hours between September 2004 and May 2006, i.e. before construction of the wind farm. During this period a total of 11.6 hours of red kite activity was observed (c.6 % of total observation time) within 500 m of the proposed turbine envelope.

20. The area within which timed observations were recorded measured 796 hectares (ha). Observations were undertaken from three vantage points (VPs) that between them covered c.99 % of the survey area. There was overlap in parts of the survey area visible from each VP such that the cumulative visible area totalled 1845 ha. The locations of two of the VPs had to be moved in January 2006 due to access issues.

21. The red kite input data are the number of seconds that red kite were recorded flying at rotor strike height (RSH), i.e. 10 – 100 m above ground level, expressed as a proportion of the total observation area and time. Red kite activity varied between VPs, with the greatest activity recorded from VP 5 (Table 1). The mean activity at RSH was 4.44×10^{-5} seconds per hectare per hour.

Table 1. Summary of red kite flight activity at 10 – 100m elevation above ground level recorded from six VPs at Braes of Doune, 2002 – 2003.

VP	Observation Area (ha)	Observation Time (hrs)	Observation effort (HaHr)	Flight time at 'risk height' (s)	Flying time ha^{-1} hr^{-1} at 'risk height'
4	385.4	49.0	18882.64	2125.0	3.126E-05
5	274.9	63.0	17316.18	7421.0	1.190E-04
6	168.8	66.1	11154.96	2753.0	6.855E-05
4A	318.2	3.0	954.57	0.0	0
4B	424.7	15.0	6370.50	0.0	0
5A	273.2	3.0	819.48	140.0	4.746E-05
Totals	**1845.1**	**199.1**	**55498.33**	**12439.0**	**4.439E-05**

22. Data from each VP were then weighted by hectare hours (Table 2). Thus observations from VP 4 exert a strong influence in the model whereas observations from VP 4A exert relatively little influence. Overall, the weighted flying time indicated that red kites spent 0.623 % of their flying time at 10 – 100 m within each kilometre square surveyed.

Table 2. Red kite flight activity at 10 – 100m elevation weighted by area and duration of observation. Adjusted values are expressed as percentage flying time per km^2 per hour.			
VP	**Weighting**	**Adjusted time at 'risk height' (Hahr^{-1})**	**Adjusted time at 'risk height'(km^{-2} hr^{-1})**
4	0.340	1.064E-05	0.106
5	0.312	3.714E-05	0.371
6	0.201	1.378E-05	0.138
4A	0.017	0	0.000
4B	0.115	0	0.000
5A	0.015	7.007E-07	0.007
Overall	**1.000**	**6.226E-05**	**0.623**

23. The wind farm covers an area approximately 3.57 km^2. Therefore the data predict that red kites will spend 0.623 x 3.57 = 2.22 % of the flying time at 10 – 100 m elevation within the wind farm. The turbine rotors have a diameter of 66 m and therefore occupy 73 % of the 10 – 100 m height band. Therefore red kite were predicted to spend 1.63 % of the time at RSH within the wind farm.

24. It was assumed that red kites are 0.65 m long (Snow & Perrins 1998) and fly at 11 ms^{-1} (Provan & Whitfield 2006). Day length was estimated, for each day, using the method of Forsythe *et al*. (1995) for a latitude of 56.2761° N. Based on a layout of 36 turbines, which operate 87 % of the time, the model of Band *et al.* (2007) populated by the empirical flight data predicts there will be 1518 red kite transits through the rotor swept area per year. Thus, without avoidance, the model predicts there will be 1518 x 0.125 x 0.87 = 165.68 collisions per year (see Appendix 2).

Carcass searches

25. Carcass searches were conducted within square plots established around each of the 36 turbines. Search plot dimensions measured 65 m from the turbine to the nearest plot edge for a total plot size of 130 x 130 m. A square plot 130 x 130 m was considered appropriate as the hub height of the turbines at Braes of Doune is 60 m, with 33 m long blades. This was consistent with the height of the turbines and consequent search plot area recommended by USA studies at the time of our study design (Johnson *et. al.* 2003). Subsequently, it has become apparent that the employed search plots may have been slightly too small to recover every possible collision victim that died immediately through blade-collision-trauma (e.g. Hull & Muir 2010).

26. Carcass searches were carried out February 2007 – January 2011 and October 2011 – March 2012. Each square plot was searched using transects 10 m apart, with the searcher looking 5 m on either side. This transect interval was considered suitable to detect a bird the size of a red kite. Plots took two to three hours to search methodically in this manner. A searcher was employed one day per week to carry out turbine searches. All 36 turbines were searched, in rotation, approximately once every 90 days.

27. Hull & Muir (2010) used a Monte-Carlo approach based on ballistics to model the proportion of carcasses that would be thrown various distances from a turbine, assuming that birds acquire a forward momentum based on the speed of the blade and are equally likely to be hit anywhere along the length of the blade. Based on the Braes of Doune turbine specifications, a 60 m high nacelle and 33 m long blades, Hull & Muir predict that 80 % of mid-sized birds would land within 61 - 70 m of the turbine base.

Searcher Efficiency

28. The objective of the searcher efficiency trials was to determine the proportion of carcasses that searchers detected, and the trial results were used to adjust bird fatality estimates for detection bias.

29. Trials were not conducted within the wind farm site to minimize the risk of attracting red kites to the area and prevent any risk of turbine related mortality. An area sufficiently distant from the turbines was chosen, being of similar altitude and habitat composition to that of the wind farm.

30. Three trial plots were identified and marked, each 130 x 130 m. The plots were searched using the same methodology as turbine searches. Carcasses were placed randomly in the trial plots by one field-worker and searched for by another later the same day. The searcher was unaware of the position and number of carcasses placed. In total seven searcher efficiency trials were conducted using 72 carcasses.

31. Common buzzard *Buteo buteo* and female pheasants *Phasianus colchicus* were chosen as an appropriate species to use due to their broadly similar size, weight and colouration to that of red kite. Pheasant carcasses were readily available from local sources during the winter and were frozen for use throughout the year. Buzzard carcasses were provided The Scottish Agricultural Science Agency.

Carcass Removal Trials

32. The objective of carcass removal trials was to determine the length of time a carcass remained in the search plot and was available for detection by searchers, and the trial results were used to adjust red kite fatality estimates for removal bias resulting from scavengers.

33. Smallwood (2007) reported that carcass persistence varied substantially amongst bird species, and highlighted a mismatch in carcass persistence between large raptors and any of the frequently used non-raptor surrogates. Similar results were obtained, on site, during comparison persistence trials between buzzard and pheasant carcasses (Urquhart *et al.* 2015).

34. Urquhart *et al* (2015) found a significant difference in carcass persistence rates between the buzzard and pheasant surrogates used to calibrate red kite mortality at the Braes of Doune wind farm. Buzzard carcasses persisted significantly longer than pheasant, regardless of season.

35. As such, buzzards were chosen as an appropriate surrogate species and were left in the search plots to establish how long they persisted. The GPS location of each carcass was noted to establish if any carcasses had been moved by scavengers. Each carcass was marked with a leg ring or metal tag to prevent confusion if they were moved from their original position.

36. Carcass removal trials were conducted throughout the year to incorporate seasonal variability in weather, vegetation and scavenger densities. Field-workers monitored the trial carcasses over a 95-day trial period. Carcasses were checked at Days 1, 3, 5, 8, 10, then every 5 days until Day 45 and then every 10 days until Day 95.

STATISTICAL ANALYSIS

Searcher Efficiency

37. Searcher efficiency rate is expressed as p, the proportion of carcasses that were detected. The standard error (square of variance) and 95 % confidence limits were estimated from a bootstrap sample (with replacement) of searcher efficiency data. A total of 5,000 bootstrap iterations were used.

Empirical Removal Time Distribution

38. Assuming that carcass removal occurs independently of one another, the empirical probability of being removed beyond the time t can be determined using the Kaplan-Meier estimator (Kaplan & Meier 1958) given by

$$\hat{S}(t) = \prod_{j=1}^{k} \frac{n_j - d_j}{n_j} \qquad \text{[Equation 2]}$$

where nj $(j = 1, ..., r)$ denote the number of carcasses not removed and dj denote the number of removed carcasses at time $t\,j$, for $t(k) \leq t < t(k+1)$ (k = 1, 2,…., r) with r being the number of not censored observations. However, when censored observations occur, this estimator can be biased. The approximate estimated standard error of the Kaplan-Meier estimator is given by

$$se\{\hat{S}(t)\} \approx \hat{S}(t) \left\{\sum_{j=1}^{k} \frac{dj}{nj(nj - dj)}\right\} \qquad \text{[Equation 3]}$$

Parametric Removal Time Distribution

39. Parametric survival procedures are based on a distributional assumption. There are several probability distributions described in the literature as suitable for survival data. The exponential, Weibull, log-logistic and log-normal distributions are among the most frequently used (e.g. Kalbfleisch and Prentice 2002; Lawless 2003).

40. As the persistence trials were conducted throughout all season, using only one species of carcass and in heterogeneous habitat there was no need to model dependency on these covariates.

41. Carcass persistence rates should be estimated upon the best-fit model. Different lifetime distributions may be fitted to data and the model fit analysed using Akaike Information Criterion (AIC). Carcass persistence data was fitted to a series of four distribution models: 1) Weibull, 2) exponential, 3) log-logistic and 4) log-normal using no covariates. The model with the lowest AICc value was considered to have the best fit.

42. Assuming that the number of collision-caused deaths is uniformly distributed over time, the scavenging correction factor (*R*) can be defined, based on parametrically estimated risk, by

$$R_i(t) = \frac{1}{t_i - t_{(t-1)}} \sum_{i=1}^{t_i - t_{(t-1)}} \hat{S}\,(t) \qquad \text{[Equation 4]}$$

where t_i is the time (number of days) at the *i*-th search. R_i expresses the average carcass persistence rate at the *i*-th search. This estimator assumes that the fatalities caused by collision occur with the same probability at any time *t* in the interval $t_{(i-1)} < t \le t_i$, i.e., at any time t between two consecutive searches.

Fatality Estimate

43. The estimated total number of red kite fatalities for the Braes of Doune wind farm, m, was calculated by (Jain *et al.* 2007)

$$m_i = \sum_{i=1}^{n} C_i \,/ (p * R_i) \qquad \text{[Equation 5]}$$

where C_i and R_i denote the observed mortality and the scavenging correction factor (here defined by equation 4) for the *i*-th search. The detection probability is expressed as *p*.

44. The final reported estimate of *m* and associated 90% confidence intervals were calculated using Monte-Carlo methods (Manly 1997). Monte-Carlo analysis is a computer simulation technique that is useful for calculating confidence intervals for complicated test statistics. A total of 5,000 iterations were used. The reported estimates are the means of the 5,000 estimates. The lower 5th and upper 95th percentiles of the 5000 iterations are estimates of the lower limit and upper limit of 90% confidence intervals.

RESULTS

Carcass searches

45. A total of 536 turbine searches were carried out between February 2007 and March 2012. There was an eight month gap in coverage in 2011 and frequent gaps of up to a month due to snow cover, especially in the 2009-10 winter, totalling 50 months of effort. Every turbine was searched 15 times except for four which received 14 searches. The dedicated searches detected one red kite carcass in April 2010.

46. In total, three red kites were found dead as a result of turbine strike. The first was discovered on 2 July 2007 at Turbine 44 during one of several ad hoc visits to the site. The second fatality was found as a result of the systematic turbine search method. It was found on 27 April 2010

during a routine search at Turbine 17. The third red kite was first discovered at the wind farm on 1 November 2010 by a facility maintenance employee, at Turbine 5, while doing routine site inspections. Given the timings of these records, in relation to the pre-set systematic search protocol, it is highly likely that these these carcasses would have been discovered by the systematic search programme. Reporting from ad hoc searches and from maintenance technicians did, however, allow a more rapid discovery of carcasses and so a more accurate necropsy on the cause of death; for example.

Searcher efficiency

47. A total of seven searcher efficiency trials utilising 72 trial carcasses were conducted as part of the fatality monitoring program (Table 3). Mean searcher efficiency rates across all seasons was 0.81 (95% CI = 0.65 – 0.95).

Table 3. Results of searcher efficiency trials.

Trial	No. carcasses placed	No. carcasses found	% found
1	9	7	78
2	9	9	100
3	9	4	44
4	9	5	56
5	9	8	89
6	20	20	100
7	7	7	100

Carcass persistence

48. A total of 40 buzzard carcasses were used throughout the persistence trials. Of these, only six carcasses were removed by scavengers with the remaining carcasses persisting until the end of the observation period.

49. Table 4 presents AIC values for the fitted models. Akaike's information measure was lowest for the log-normal model, however differences between AIC values regarding log-logistic and Weibull models were minimal, suggesting similar goodness of fit. For buzzard carcasses, persistence was modelled assuming a log-normal distribution, which was the model with the minimum AICc.

Table 4. Akaike's information criterion for the fitted parametric survival models

Model	AIC	ΔAIC
Log Normal	82.78649	0.00
Log Logistic	83.74906	0.96257
Weibull	84.01604	1.22955
Exponential	86.44012	3.65363

50. Figure 1 shows the empirical survivor distributions (step functions) of carcass persistence and the best-fit parametric model. The analysis of the empirical distribution shows that the

removal rates were slow and censored observations were registered. Overall, plots illustrated in Figure 1 show a good agreement between the observed and the fitted survivorship function.

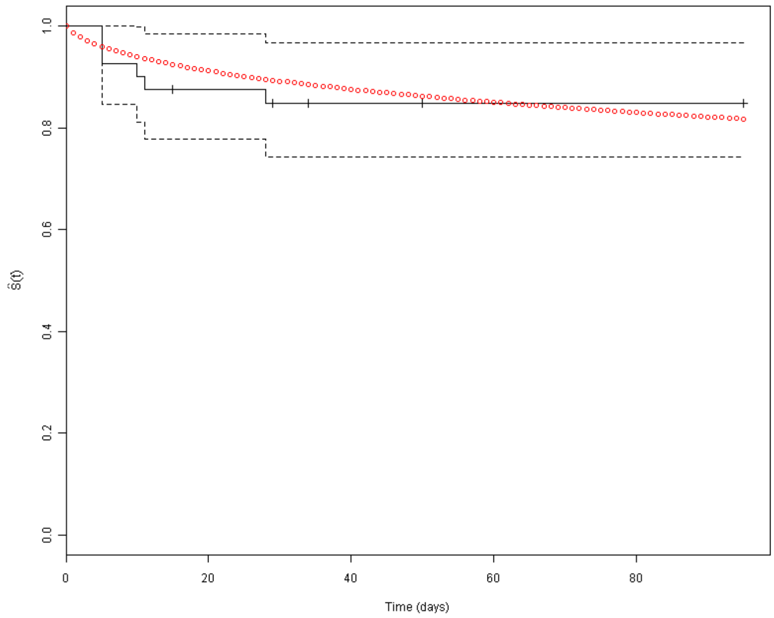

Figure 1. Empirical survivorship function results (stepwise) superimposed on the smoothed best fit model (in red). The symbol (+) at the end of the step functions indicates the existence of right censored observations. Dashed lines represent the confidence interval bands for the empirical survivorship functions.

51. The value of the scavenger removal correction factor (*R*) calculated for a time interval of 90 days (from equation 4), *R* = 0.88.

Adjusted observed fatality estimate

52. Turbine searches were carried out between February 2007 and March 2012. Three red kites were documented as collision fatalities during 50 months monitoring (Duffy & Urquhart 2014). Hull & Muir (2010) predict that 80 % of mid-sized birds would land within 61 - 70 m of the turbine base. Therefore the total number of red kite fatalities, corrected for those birds that may have fallen out with the search area and not found, is 0.9 kites per annum.

53. A total of 40 carcasses were used throughout the persistence trials. Of these, only 6 carcasses were removed by scavengers with the remaining carcasses persisting until the end of the observation period. Parametric survival analyses, based on the distributional assumptions of four probability distributions suitable for survival data, indicated the model with the lowest AICc value, and considered to have the best fit, was the Log-normal distribution. Assuming that the number of collisions is uniformly distributed over time, the scavenging correction factor (*R*) based on parametrically estimated risk was defined at 0.88.

54. A total of seven searcher efficiency trials utilising 72 trial carcasses were conducted as part of the fatality monitoring program. Mean searcher efficiency rates across all seasons was estimated as 0.81 (95 % CI = 0.65 – 0.95).

55. Using the method of Jain *et al.* (2007) the adjusted total number of fatalities, *m*, at the Braes of Doune wind farm can be estimated. The final reported estimate of *m* and associated 90 % confidence intervals were calculated using Monte-Carlo methods. The lower 5th and upper 95th percentiles of the 5000 iterations are estimates of the lower limit and upper limit of 90 % confidence intervals. The adjusted annual fatality estimate for red kite at the Braes of Doune wind farm is 1.28 (90 % CI = 1.11, 1.55).

DERIVATION OF AN AVOIDANCE RATE FOR RED KITE

56. The observed avoidance rate was calculated using only pre-construction data on flight activity, as these data take account of any proportion of birds which may have been displaced from the windfarm site post-construction. With this in mind the derived avoidance rate, for use within the SNH collision risk model, has been derived using pre-construction activity levels and post-construction collision mortality figures[1].

57. Using Equation 1 and employing Monte-Carlo methods, to account for the range of estimated fatalities, the mean avoidance rate and associated confidence intervals were calculated. The lower 5th and upper 95th percentiles of the 5000 iterations are estimates of the lower limit and upper limit of 90 % confidence intervals.

58. The derived avoidance rate for red kite at the Braes of Doune wind farm is estimated to be 0.992 (90 % CI = 0.991, 0.993).

RECOMMENDATION

59. In assessments of wind farm proposals where red kites are flying within a proposed wind farm development area our analyses recommend that an avoidance rate of 99 % should be used and not 98 % (SNH 2016). Our recommendation is based on a measure less than the lower 5th percentile of the given confidence intervals thus allowing for an element of precaution to be incorporated into any subsequent collision risk analysis using the Band CRM.

60. Our recommended avoidance rate is applicable only to the original Band CRM and not to any subsequent model extensions (Band 2012, 2013).

[1] A separate analysis (Fielding & Urquhart 2013, unpublished report) concluded that it is unlikely that there would have been any background change in post-construction potential for flight activity, due to an expanding population.

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Appendix 1

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA

K: [1D or [3D] (0 or 1)	1	
NoBlades	3	
MaxChord	2.80	m
Pitch (degrees)	15.0	
BirdLength	0.65	m
Wingspan	1.65	m
F: Flapping (0) or gliding (+1)	0	
Bird speed	11	m/sec
RotorDiam	66	m
RotationPeriod	2.82	sec
integration interval	0.05	
Bird aspect ratio: β	0.39	

Calculation of alpha and p(collision) as a function of radius

			Upwind:			Downwind:		
r/R radius	c/C chord	α alpha	collide length	p(collision)	y(x)	collide length	p(collision)	y(x)
0				1.00	0.000		1.00	0.000
0.05	0.575	2.99	10.01	0.97	0.097	9.17	0.89	0.089
0.1	0.622	1.50	5.44	0.53	0.105	4.54	0.44	0.088
0.15	0.781	1.00	4.32	0.42	0.125	3.19	0.31	0.092
0.2	0.939	0.75	3.82	0.37	0.148	2.45	0.24	0.095
0.25	0.971	0.60	3.26	0.32	0.158	1.85	0.18	0.090
0.3	0.923	0.50	2.74	0.26	0.159	1.40	0.14	0.081
0.35	0.875	0.43	2.35	0.23	0.159	1.08	0.10	0.073
0.4	0.827	0.37	2.09	0.20	0.161	0.89	0.09	0.069
0.45	0.780	0.33	1.92	0.19	0.167	0.79	0.08	0.068
0.5	0.732	0.30	1.77	0.17	0.171	0.71	0.07	0.069
0.55	0.684	0.27	1.65	0.16	0.175	0.66	0.06	0.070
0.6	0.637	0.25	1.54	0.15	0.179	0.68	0.07	0.079
0.65	0.589	0.23	1.44	0.14	0.181	0.71	0.07	0.089
0.7	0.541	0.21	1.36	0.13	0.183	0.73	0.07	0.099
0.75	0.494	0.20	1.27	0.12	0.185	0.74	0.07	0.108
0.8	0.446	0.19	1.20	0.12	0.185	0.75	0.07	0.116
0.85	0.398	0.18	1.13	0.11	0.185	0.75	0.07	0.123
0.9	0.350	0.17	1.06	0.10	0.185	0.75	0.07	0.130
0.95	0.303	0.16	1.00	0.10	0.183	0.74	0.07	0.136
1	0.255	0.15	0.94	0.09	0.181	0.73	0.07	0.142

Overall p(collision) = **Upwind** **15.9%** **Downwind** **9.2%**

Average **12.5%**

Appendix 2

WIND FARM PARAMETERS		
Size of windfarm envelope*	357	ha
Number of turbines	36	
Rotor diameter	66	m
Hub height	60	m
Max. rotor depth in metres	2.0	m
Max. chord	2.80	m
Pitch	15.0	degrees
Rotation period	2.82	s
Turbine operation time	87	%

BIRD PARAMETERS		
Length	0.65	m
Wingspan	1.65	m
Flapping (0) or gliding (+1)	0	
Assumed flight speed	11	ms^-1
Number of daylight hours available	4499	per year

BAND USED TO DEFINE 'RISK HEIGHT'		
Max height	100	m
Min height	10	m

	Watch Data		Bird Flight Data
VP	**Area (ha)**	**Time (hrs)**	**'Risk height' (s)**
4	385.4	49.0	2125.0
5	274.9	63.0	7421.0
6	168.8	66.1	2753.0
4A	318.2	3.0	0.0
4B	424.7	15.0	0.0
5A	273.2	3.0	140.0
Totals	*1845.1*	*199.1*	*12439.0*

Flight Activity Per Unit Time & Area			Weighted By Observation Effort		
VP	**Observation effort (HaHr)**	**Flying time at 'risk height' (Hahr^-1)**	**VP**	**Weighting**	**Adjusted time at 'risk height' (Hahr^-1)**
4	18882.64	3.126E-05	4	0.340	1.064E-05
5	17316.18	1.190E-04	5	0.312	3.714E-05
6	11154.96	6.855E-05	6	0.201	1.378E-05
4A	954.57	0.000E+00	4A	0.017	0.000E+00
4B	6370.50	0.000E+00	4B	0.115	0.000E+00
5A	819.48	4.746E-05	5A	0.015	7.007E-07
Totals	*55498.33*	*4.439E-05*	*Totals*	1.000	6.226E-05

Mean activity hr^-1 in wind farm	
Risk height	2.22016%
Rotor height	1.62812%

MORTALITY ESTIMATE		
Flight risk volume (Vw)	2.35E+08	m^3
Rotor radius^2	1089	m
Combined rotor swept area (Va)	123163	m^2
Vr = Va * (d + l)	326382	m^3
Bird occupancy (n)	73.25	hrs / yr
Bird occupancy of rotor swept vol (b)	365.69	bird-secs
Bird transit time (t)	0.24	secs
No. of transits through rotors	1517.98	per year
Estimated no. of collisions	165.68	per year