CLASHINDARROCH II

WIND FARM

Collision Risk Model Calcs

Prepared for: Vattenfall Wind Power Ltd

Technical Appendix 8.2

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Clashindarroch II Wind Farm EIA Report

Chapter 8 Technical Appendix:

8.2 Collision Risk Model Results

November 2019

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1. INTRODUCTION

1.1 Purpose and Scope of this Document

1.1.1 This a technical appendix to Chapter 8 (Ornithology) of the Clashindarroch II wind farm (the 'proposed development') EIA Report. The potential for birds to collide with wind turbines is one of the key potential impacts considered within the EIA. This appendix provides further background information on the bird collision risk model (CRM) that has been used to inform the impact assessment for the key ornithological receptors.

1.1.2 The CRM follows the method known as the Band (Band *et al*. 2007[1]) or SNH model (SNH 2000[2]). This method is based on the analysis of observational data collected from timed bird flight activity surveys at fixed vantage points overlooking the proposed wind farm development site. It provides an estimate of the number of birds that would collide with a proposed wind farm. Because birds may take action to avoid a wind farm, or to avoid collision with individual wind turbines, an avoidance rate is applied to the output from the CRM. Details of the methods, assumptions, parameters and avoidance rates used in this case are provided in this report.

1.1.3 Further details of the flight activity survey (FAS) methods, survey effort and results are provided in Technical Appendix 8.1. The FAS vantage points and estimated viewsheds are shown on Figure 8.2 to Chapter 8 (Ornithology).

1.2 The Proposed Wind Farm & Wind Turbine Model

1.2.1 Details of the proposed wind farm are provided in Chapter 3: description of the Proposed Development. Table 8.2.1 provides the assumed wind farm / wind turbine parameters relevant to the CRM calculations. Most of the parameters are based on the wind turbine models Senvion 3.6 114 or Senvion 4.2M140EBC.

Table 8.2.1: Wind farm and wind turbine parameters

Parameter	Value
No. turbines (no. of blades per turbine)	14 (3)
Wind farm area [i]	545.76 ha
Blade length [ii]	70 m
Rotor diameter [ii]	140 m
Hub height [ii]	110 m
Max blade height [ii]	180 m
Min blade height [ii]	40 m
Max chord [iii]	4.01 m
Pitch [iv]	5 degs

[1] Band, W, Madders, M, & Whitfield, D.P. (2007). Developing field and analytical methods to assess avian collision risk at wind farms. In: Janss, G, de Lucas, M & Ferrer, M (eds.) Birds and Wind Farms. Lynx edicions, Barcelona.

[2] SNH (2000). Wind Farms and Birds: Calculating a theoretical collision risk assuming no avoiding action. Guidance Note Series, Scottish Natural Heritage.

Parameter	Value
Rotation period (fastest) [v]	5.7 secs
Turbine operation time [vi]	100%

1.2.2 The assumptions underlying the parameters listed in Table 8.2.1 are as follows:

i. The wind farm area is defined by a boundary around the outermost turbines plus a 500 m wide buffer (based on turbine Layout 046).

ii. Hub height, blade length, rotor diameter and max/min blade tip height are based on details provided by Vattenfall for Layout 046 (August 2019).

iii. Max chord assumed to be 4.01 m based on wind turbine model Senvion 3.6 114.

iv. Pitch is variable but was assumed to be 5 degrees (this is the maximum pitch).

v. Based on details provided for turbine model Senvion 4.2M140EBC[3] the maximum rotational period was assumed to be 5.7 seconds (i.e. 4.6-10.5 revs min^{-1} = rotation period 13.0-5.7 secs)

vi. The turbine operation time was assumed to be 100%, i.e. the CRM calculations do not account for low wind speeds and periods of maintenance.

1.3 Key Species Considered

1.3.1 Table 8.2.2 lists the target bird species, which had activity recorded within the proposed wind farm area and at collision risk height, with the key species-specific metrics used in the CRM.

Table 8.2.2: Target Species for which CRM was applied and their key biometrics and avoidance rates

Common name	Scientific name	Bird length (m) [i]	Wingspan (m) [i]	Bird speed (m/s) [ii]	Avoidance rate (%) [iii]
Pink-footed goose	*Anser brachyrhynchus*	0.75	1.70	15.0	99.8
Osprey	*Pandion haliaetus*	0.58	1.70	12.0	98.0
Goshawk	*Accipiter gentilis*	0.62	1.65	10.0	98.0
Common gull	*Larus canus*	0.42	1.30	13.0	99.2
Common kestrel	*Falco tinnunculus*	0.35	0.80	13.0	95.0

i - Bird length / wingspan, largest reported size is used, most values taken from Snow, D. W. & Perrins, C. M. (1998). The Birds of the Western Palearctic Concise Edition.

ii – Bird flight speed values primarily from Alerstam T., Rosén M., Bäckman J., Ericson P.G.P., Hellgren O. (2007). Flight speeds among bird species: allometric and phylogenetic effects. PLoS Biol, 5, 1656-1662.

iii - Assumed avoidance rates taken from current SNH Guidance (i.e. Avoidance Rates for the onshore SNH Wind Farm Collision Risk Model, July 2017) and in the case of common gull from Furness, R.W. (2019). Avoidance rates of herring gull, great black-backed gull and common gull for use in the assessment of terrestrial wind farms in Scotland. Scottish Natural Heritage Research Report No. 1019.

[3] https://www.senvion.com/global/en/products-services/wind-turbines/4xm/42m140-ebc/

2. METHODS

2.1 Introduction

2.1.1 Wind turbine collision risk for key species has been estimated following the method developed by SNH (2000) and Band *et al*. (2007), commonly referred to as the Band Model. Estimates of collision risk/mortality have been calculated for key receptors where there was sufficient data to carry out the analysis are also given in Table 8.2.2. Species that are not included in the collision risk analysis are either not of conservation concern or are at low collision risk due to their flight behaviour, and/or are species which are infrequently present within the study area.

2.1.2 In summary, the Band / SNH model involves three stages:

- Stage one is the estimation of the number of bird transits through the proposed rotor swept volume per year based on observed flight activity data and parameters of the wind farm and wind turbine design.
- Stage two involves the estimation of the predicted proportion of transits through the rotor swept volume that would result in a collision. All predicted collisions are assumed to be fatal. This provides an estimate of the number of fatalities per year for the wind farm but assumes that birds take no avoiding action to prevent a collision.
- Finally, an assumed rate for collision avoidance is applied to the estimate.

2.1.3 In order to provide a biologically realistic estimate of collision risk it is necessary to assume that birds take action to avoid collision. The species-specific avoidance rates assumed in this assessment are given in Table 8.2.2.

2.1.4 The following sections provide further information on the methods and assumptions applicable to each stage of the CRM process.

2.2 Data Processing

2.2.1 The mapped bird flight activity data was digitised using MapInfo (version 11.5.4) GIS software and the recorded parameters entered into a pre-formatted spreadsheet (MS Excel). The data is used to derive an estimate of the occupancy of the proposed wind farm flight risk volume and from this an estimate of the number of annual collisions based on data collected during different seasons.

2.2.2 The vantage point viewsheds were created using OS Land-Form Panorama ® DTM data and MapInfo's Vertical Mapper Viewshed Analysis tool (viewpoint height = 1.5 m; viewshed off-set for turbines = 30 m; viewing radius = 2000 m); the viewshed was then cut to a maximum of 180° field of view and to the wind farm area (i.e. 500 m wind turbine buffer).

2.3 Directional or Non-directional Flight Activity

2.3.1 There are two approaches to CRM calculations the application of which depends on certain assumptions about the use of the flight risk volume by the species under consideration. The 'directional' flight CRM method is appropriate for species that regularly pass through a proposed wind farm area in a clear direction. A typical scenario where this method is appropriate are flights by geese or swans commuting across a site, moving regularly between habitually used night-time roosts and daytime feeding areas. The alternative method assumes that flight activity is non-directional (essentially random) within the flight risk volume. This method is generally applicable to species that are active across the site, such as raptors during the breeding season.

2.3.2 In this case, observations from the flight activity surveys indicated that the non-directional method was applicable for all species included in the CRM calculations, with the exception of pink-footed geese where the flightlines suggested a regular flight corridor across the site. Therefore the non-directional model, for estimating the number of birds flying through rotors, was used to estimate collision risk for all species, and in addition, the directional model was used for pink-footed geese as a comparison.

2.4 The Flight Risk Volume

2.4.1 Target or secondary species recorded during the FAS were considered to be at potential risk of collision if they were active within the ‘medium’ and ‘high’ height bands and within or near to the proposed wind turbines. This is known as the ‘flight risk volume’ (FRV).

2.4.2 In this case, the FRV is defined as the space between 40 to 180 m above ground level (the minimum and maximum blade tip heights) and within 500 m of the proposed wind turbines.

2.4.3 Due to differences between the height bands adopted during the surveys (which were completed when shorter wind turbines were proposed for the site) and the actual dimensions of the proposed model of wind turbine some adjustment has to be made to the bird flights activity data. The risk heights assumed during the FAS were as follows:

- Very high > 250 m (above ground level)
- High 150 - 250 m
- Medium 20 - 150 m
- Low 5 - 20 m
- Very Low < 5 m

2.4.4 For the collision risk analysis, the observed flight time, for each target species, allocated to the ‘high’ and ‘medium’ height bands was adjusted to account for the dimensions of the proposed wind turbines. The proposed wind turbine model has a blade length of 70 m and a hub height of 110 m, this gives an actual collision risk band of 40-180 m above ground level. Allowing a 10 m margin for height estimation error, this equates to a proportion of 0.4 (150-190 m) of the ‘high’ height band and 0.92 (30-150 m) of the ‘medium’ height band.

2.4.5 For the estimate of occupancy of the FRV, all of the medium height band flight activity data was included and this was augmented by 40% of the high height band data to account for the difference between the height bands and the proposed wind turbine hub height and blade dimensions.

2.5 Seasons and Active Hours

2.5.1 For each species, where there was sufficient data recorded, flight activity from various survey periods (seasons) was analysed separately in the CRM. These seasons and the assumed total hours of potential activity, extrapolated from data recorded in each period, for each species are detailed in 8.2.3 below.

2.5.2 The relevant periods / potential active hours for each species are based on the pattern of observed activity during the survey period (i.e. May 2015 to August 2017).

Table 8.2.3: Survey Periods and Assumed Active Hours for each Species for which CRM was undertaken

Species	Seasons / Potential Active Hours				
	Summer Apr. to Aug.	**Winter** Sep. to Mar.	**Spring** Mar. to May.	**Autumn** Sep. – Nov.	**Whole Year**
Pink-footed goose	n/a	n/a	2208 [ii]	n/a	n/a
Osprey	2616 [i]	n/a	n/a	n/a	n/a
Goshawk	n/a	n/a	n/a	n/a	4380 [iii]
Common gull	2616 [i]	n/a	n/a	n/a	n/a
Common kestrel	n/a	n/a	n/a	n/a	4380 [iii]

i – Dusk / daylight hours for the period April to August inclusive.

ii – Daylight and nocturnal hours for the Spring passage period March to May inclusive

iii – Daylight hours whole year.

2.6 Calculating Total Transits

Non-directional Flights

2.6.1 For non-directional flights (all species) the number of transits of the proposed wind turbines was calculated.

2.6.2 Total seconds of activity within the FRV (V_w) was derived from the survey data, accounting for survey effort, overlaps between vantage point viewsheds and any simultaneous watches from overlapping viewsheds, expressed as hours per hectare. This is then extrapolated for the relevant season and number of potentially active hours (see Table 8.2.3).

2.6.3 The combined volume swept by the wind turbine blades (V_r) is calculated as follows:

$$V_r = \text{no. turbines x rotor swept area } (\pi R^2) \text{ x (depth of the blade + bird length)}$$

2.6.4 The number of bird transits through the combined rotor swept volume is calculated from the ratio between V_r and V_w applied to the total seconds of activity within V_w.

Directional flights

2.6.5 For directional flights (pink-footed geese during the March – May 2016 period only), the following method was followed:

2.6.6 A 'risk window' (W) or cross-sectional area was calculated using the maximum width of the wind farm (the proposed turbines and a 500 m turbine buffer) across the general directional of flying birds and the maximum height (h) of the highest turbine.

Cross-sectional area W = wind farm width x height

2.6.7 The number of birds (n) flying through this risk window per annum was estimated. The total number of geese flying at medium height at some point within the 500 m turbine buffer during the March – May 2016 survey period were included as 'birds at risk height'. The number of risk height birds was then divided by the number of survey hours, then multiplied by the number of hours the geese are assumed to be active during the year to calculate 'n'. An adjustment was made to the number of risk height geese to account for the difference between the medium height band category and the dimensions of the proposed turbine model (see Table 8.2.6b for details).

2.6.8 The area (A) presented by the wind farm rotors was then calculated. The rotors were assumed to be aligned in the plane of the risk window as, to a first approximation, any reduction in cross-sectional area because the rotors are at an oblique angle is offset by the increased risk to birds which have to make a longer transit through the rotors:

$A = N \times \pi R^2$ where N is the number of rotors and R is the rotor radius

2.6.9 The rotor area was then expressed as a proportion of the risk window (A/W).

2.6.10 The number of birds passing through the rotors equals the number of birds though risk window multiplied by the proportion of the area occupied by rotors:

Number of transits through the rotors = n x (A / W)

2.7 Collision Probability

2.7.1 The probability that a transit through the rotors would result in a collision was calculated for each species using a spreadsheet provided by SNH. The spreadsheet models collision risk based on species specific biometrics (i.e. wingspan and bird length), assumed flight speed, whether the bird is gliding or using flapping flight, wind direction and various parameters associated with the design and operation of the proposed wind turbines. Where there was a range of potential values (e.g. for bird biometrics or wind turbine parameters) the value that results in an increased collision probability was used. For example, rotor speed is variable and has a strong influence on collision probability, in this case the maximum rotor speed was used based on the reported specifications of the model of wind turbine proposed (or most similar model where the required parameters were unavailable, see Table 8.2.1).

2.7.2 The predicted number of collisions per season (or year), assuming that birds take no avoiding action, is calculated by applying the collision probability to the number of estimated transits through the rotor swept volume (V_r).

2.8 Assumed Avoidance Rates

2.8.1 The predicted number of collisions is then adjusted by an assumed avoidance rate, which is typically between 95 and >99%. The avoidance rates, based on current SNH guidance, are species-specific where there is sufficient empirical data available from published wind farm monitoring studies or are generic, and precautionary, for other species. The avoidance rates assumed in this case are provided in Table 8.2.2.

3. RESULTS

3.1 Introduction

3.1.1 The tables presented in this appendix provide further detail on the methods and calculations, following the SNH / Band Model, used to determine estimates of annual collision risk for key bird species based on the observed flight activity recorded at the study area between May 2015 and August 2017.

3.2 Summary Calculations to Estimate Flight Risk

3.2.1 Table 8.2.4 provides a summary of the flight activity data within the FRA for the species considered in the CRM analysis.

3.2.2 Table 8.2.5 provides a summary of the background calculations to estimate mean flight time at all heights and at risk height per hectare per hour within the wind farm area. This is based on 2 km radii cut-off for vantage point viewsheds, and data from May 2015 to July 2016 and April 2017 to August 2017.

3.2.3 Table 8.2.6 provides the results of the calculations to determine the number of bird transits through the wind farm rotors per year or season.

3.3 Estimated Number of Collision per Year

3.3.1 Table 8.2.7 gives the estimated number of collisions per year for each relevant species, the estimated total number of collisions over the 25-year lifetime of the proposed development and the estimated rate of collision. This is adjusted by an assumed avoidance rate (following current published guidance) for each species, as detailed in Table 8.2.2.

3.4 Band Model Outputs

3.4.1 Tables 8.2.8 a-e provide the raw output from SNH Band model collision probability spreadsheet for each species considered in the CRM.

Table 8.2.4 Summary Flight Activity Data for all Species considered in the CRM Analysis

Species	Survey Period	Total Flights (Birds) Recorded	Flights (Birds) within FRA	Duration at 'Low / V. Low' (secs) [i]	Duration at 'Medium' [ii] (secs) [i]	Duration at 'High [ii] / V. High' (secs) [i]	Total Duration (secs) [i]	% Low/ V. Low	% Med.	% High/ V. High
Osprey	May – Aug. 2015	1	1	0	206	106	312	0.00	65.93	34.07
	Apr. – Aug. 2017	1	1	29	132	17	178	16.32	73.89	9.79
	Totals	2	2	29	338	123	490	5.92	68.98	25.10
Pink-footed goose	Mar. – May 2016	1546	1305	0	17144	101304	118448	0.00	14.47	85.53
	Apr. – Aug. 2017	92	92	0	629	7251	7880	0.00	7.98	92.02
	Totals	1638	1397	0	17773	108555	126328	0.00	14.07	
Goshawk	May – Aug. 2015	0	0	-	-	-	-	-	-	-
	Sep. 2015 – Mar. 2016	18	12	22	567	592	1182	1.89	47.99	50.12
	Apr. – Jul. 2016	4	4	50	126	0	176	28.50	71.50	0.00
	Apr. – Aug. 2017	2	0	-	-	-	-	-	-	-
	Totals	24	16	72	693	592	1358	5.30	51.03	43.59
Common gull	Apr. – Aug. 2017	24	2	85	65	0	150	56.67	43.33	0.00
	Totals	24	2	85	65	0	150	56.65	43.35	0.00
Common kestrel	May – Aug. 2015	18	13	101	730	19	851	11.90	85.84	2.26
	Sep. 2015 – Mar. 2016	17	12	93	63	12	168	55.31	37.65	7.04
	Apr. – Jul. 2016	1	0	-	-	-	-	-	-	-
	Apr. – Aug. 2017	5	2	74	19	10	104	71.20	18.74	10.06
	Totals	41	27	268	812	41	1121	23.90	72.44	3.66

i. Duration = recorded time x proportion of flightline within FRA x number of birds.

ii. Activity recorded within the 'medium' and 'high' height bands has been adjusted so that 40% of the 'high' time (seconds) has been included in 'medium' height band. This is to account for differences between the height band categories for the flight activity survey and the dimensions of the proposed wind turbine model.

Table 8.2.5: Summary calculations to estimate flight activity at all heights and at risk height per hectare per hour within the wind farm area, based on data from May 2015 to July 2016 and April 2017 to August 2017 (only species with >1 flight line recorded within 500 m of the proposed wind turbines are included)

Species (data set) [ii]	VP	Viewshed area (ha) [i]	Total VP observation time (hr)	Viewshed area x observation time (ha/hr)	Time species observed, all heights (secs)	Time species observed at risk height (secs)	Total time all heights (hr hahr^{-1})	Total time risk height (hr hahr^{-1})	Mean activity all heights (hr hr^{-1})	Mean activity at risk height (hr hr^{-1})
Osprey (Summer 2015)	1	302.40	36.00	10886.49			0	0		
	2	303.79	39.00	11847.90	312.42	205.97	7.32489E-06	4.82903E-06		
	3	179.51	39.00	6909.17			0	0		
	Total	785.71	114.00	29643.56	312.42	205.97	7.32489E-06	4.82903E-06		
	1	302.40	36.00				2.44163E-06	1.60968E-06	0.001332548	0.000878499
Pink-footed goose (Spring 2016)	1	302.40	48.00	14515.32	53466.38	7841.27	0.001023179	0.000150057		
	2	303.79	48.00	14582.03	64981.78	9302.70	0.001237859	0.00017721		
	3	179.51	48.00	8616.68			0	0		
	Total	785.71	144.00	37714.03	118448.17	17143.97	0.002261038	0.000327267		
	Mean						0.000753679	0.000109089	0.411329117	0.059536655
Goshawk (2015-16)	1	302.40	162.00	48154.71	586.01	199.55	3.38036E-06	1.15107E-06		
	2	303.79	167.00	50733.31	710.35	450.83	3.88936E-06	2.46842E-06		
	3	179.51	165.00	29527.97	61.50	42.60	5.78505E-07	4.00733E-07		
	Total	785.71	494.00	128415.99	1357.86	692.98	7.84822E-06	4.02022E-06		
	Mean						2.61607E-06	1.34007E-06	0.001427752	0.000731361

Table 8.2.5: Summary calculations to estimate flight activity at all heights and at risk height per hectare per hour within the wind farm area, based on data from May 2015 to July 2016 and April 2017 to August 2017 (only species with >1 flight line recorded within 500 m of the proposed wind turbines are included)

Species (data set) [ii]	VP	Viewshed area (ha) [i]	Total VP observation time (hr)	Viewshed area x observation time (ha/hr)	Time species observed, all heights (secs)	Time species observed at risk height (secs)	Total time all heights (hr hahr^{-1})	Total time risk height (hr hahr^{-1})	Mean activity all heights (hr hr^{-1})	Mean activity at risk height (hr hr^{-1})
Common kestrel (2015-16)	1	302.40	162.00	48154.71	838.87	738.27	4.83899E-06	4.25868E-06		
	2	303.79	167.00	50733.31	130.05	40.61	7.1205E-07	2.22373E-07		
	3	179.51	165.00	29527.97	49.81	14.49	4.68543E-07	1.36322E-07		
	Total	785.71	494.00	128415.99	1018.73	793.38	6.01958E-06	4.61737E-06		
	Mean						2.00653E-06	1.53912E-06	0.001095085	0.000839995
Common gull (summer 2017)	1	302.40	36.00	8035.29	94.53	14.21	3.26802E-06	4.91264E-07		
	2	303.79	36.00	10936.52	56.08	51.08	1.42438E-06	1.29739E-06		
	3	179.51	36.00	6462.51	0.00	0.00	0	0		
	Total	785.71	108.00	25434.32	150.61	65.29	4.6924E-06	1.78865E-06		
	Mean						1.56413E-06	5.96217E-07	0.000853644	0.000325392
Common kestrel (summer 2017)	1	302.40	36.00	8035.29	14.94	4.48	5.16587E-07	1.54976E-07		
	2	303.79	36.00	10936.52	89.01	15.00	2.26076E-06	3.80986E-07		
	3	179.51	36.00	6462.51	0.00	0.00	0	0		
	Total	785.71	108.00	25434.32	103.95	19.48	2.77735E-06	5.35962E-07		

Table 8.2.5: Summary calculations to estimate flight activity at all heights and at risk height per hectare per hour within the wind farm area, based on data from May 2015 to July 2016 and April 2017 to August 2017 (only species with >1 flight line recorded within 500 m of the proposed wind turbines are included)

Species (data set) [ii]	VP	Viewshed area (ha) [i]	Total VP observation time (hr)	Viewshed area x observation time (ha/hr)	Time species observed, all heights (secs)	Time species observed at risk height (secs)	Total time all heights (hr hahr^{-1})	Total time risk height (hr hahr^{-1})	Mean activity all heights (hr hr^{-1})	Mean activity at risk height (hr hr^{-1})
	Mean						9.25782E-07	1.78654E-07	0.000505256	9.75025E-05
Osprey (Summer 2017)	1	302.40	36.00	8035.29	178.15	131.6308848	6.15875E-06	4.55044E-06		
	2	303.79	36.00	10936.52			0	0		
	3	179.51	36.00	6462.51			0	0		
	Total	785.71	108.00	25434.32	178.15	131.63	6.15875E-06	4.55044E-06		
	Mean						2.05292E-06	1.51681E-06	0.001120403	0.000827819

i - The viewshed was created using OS land-Form Panorama ® DTM data and MapInfo's Vertical Mapper Viewshed Analysis tool (viewpoint height = 1.5 m; viewshed off-set for turbines = 30 m; viewing radius = 2000 m); the viewshed was then cut to a maximum of 180^{O} field of view and to the Flight Risk Area (500 m turbine buffer).

ii - Common kestrel was recorded as a secondary species, therefore target species were recorded in preference when both were in view.

Table 8.2.6a: Results of calculations to determine the number of transits through the wind farm rotors for non-directional flights

Data set	Species	Combined volume swept by rotors (V_r) (m^3) [i]	Occupancy of the flight risk volume (hr) [ii]	Occupancy of rotor swept volume (secs) [iii]	Time taken to clear rotors (secs) [iv]	Number of transits through rotors [v]	Average collision risk [vi]
Summer 2015	Osprey	989205.01	2.30	10.71	0.38	28.00	6.4
March to May 2016	Pink-footed goose	1025842.232	131.46	635.38	0.32	2002.26	6.5
2015 to 2016 (12 months)	Goshawk	997825.53	3.20	15.06	0.46	32.53	7.0
	Common kestrel	939637.00	3.68	16.29	0.34	48.57	5.0
Summer 2017	Common gull	954722.92	0.85	3.83	0.34	11.24	5.6
	Common kestrel	939637.00	0.43	1.89	0.34	5.64	5.0
	Osprey	989205.01	2.17	10.09	0.38	26.39	6.4

i - Total rotor sweep area (m^2) multiplied by (d+l) i.e. the width of the rotor (max chord) and bird length, (m).

ii - Occupancy of the flight risk volume in hours per year, derived from the mean risk-height flight time (hr $hahr^{-1}$) multiplied by the flight risk area (ha) multiplied by the potential active hours (hr).

iii - Occupancy of rotor swept volume, derived from the occupancy of the flight risk volume (secs) divided by the flight risk volume (m^3) multiplied by the combined rotor volume (Vr) (m^3).

iv - Time taken for the bird to clear the rotors (secs), derived from maximum rotor depth (max chord) and bird length (d+l) (m), divided by the assumed flight speed ($m\ s^{-1}$).

v – Number of transits through the rotors is derived from the occupancy of the rotor swept volume divided by the time taken for the bird to clear the rotors, multiplied by operation time.

vi - Average collision risk derived from the SNH probability spreadsheet (see Tables 8.2.8 a-e below). The figure is based on an average between the upwind and downwind flight collision risk values. Flapping rather than gliding flight has been assumed in all cases.

Table 8.2.6b: Results of calculations to determine the number of transits through the wind farm rotors for directional flights

Data set	Species	Risk window (W) (m^2) [i]	Estimate of number of birds flying through risk window per annum (n) [ii]	Area presented by the wind farm rotors (A) (m^2) [iii]	Total rotor area as a proportion of risk window [iv]	Number of transits through rotors [v]	Average collision risk [vi]
March to May 2016	Pink-footed goose	531000	3864	215513.256	0.40586	1568.25	6.5

i – Risk window (W) is the width of the wind farm across the general flight direction of the birds (2950 m) multiplied by the maximum height of the highest turbine (180 m).

ii – Number of birds flying through the risk window per annum (n) = number of birds at risk height / number of survey hours (March – May 2016 = 144 hours of survey), multiplied by the potential active hours (2208 hrs = daylight and nocturnal hours for the Spring passage period March to May inclusive). All birds associated with medium height flightlines within 500 m of proposed turbines (L046) during the March – May 2016 period were counted as 'at risk height' (134 birds). In addition, 40% of the birds recorded as flying at 'high' within the 500 m of proposed turbines have been included in the 'number of birds at risk height' (118 birds). This is to account for differences between the height band categories for the flight activity survey and the dimensions of the proposed wind turbine model. (N.B. no geese were recorded flying at 'low' or 'very low' height bands).

iii – Area presented by the wind farm rotors (A) assumes the rotors are aligned in the plane of the risk window, and assumes no overlapping rotors when viewed in cross-section. A = number of rotors (N = 14) x πR^2 (where R = rotor radius = 70 m).

iv – Total rotor area as a proportion of risk window = A/W

v – Number of transits through the rotors = number of birds through the risk window x proportion occupied by rotors = n x (A/W)

vi - Average collision risk derived from the SNH probability spreadsheet (see Tables 8.2.8e below). The figure is based on an average between the upwind and downwind flight collision risk values. Flapping rather than gliding flight has been assumed.

Table 8.2.7a: Estimated collisions per year at the assumed collision avoidance rates for non-directional flights (NB these figures do not account for wind farm non-operational time)

Data set	Species	No Avoidance collisions	Avoidance rate (%)	Collisions per season/year	Total over 25 years	Years between collisions
Summer 2015	Osprey	1.79	98.0	0.036	0.90	27.90
March to May 2016	Pink-footed goose	130.15	99.8	0.260	6.51	3.84
2015 to 2016 (12 months)	Goshawk	2.28	98.0	0.046	1.14	21.96
	Common kestrel	2.43	95.0	0.121	3.04	8.24
Summer 2017	Common gull	0.63	99.2	0.005	0.13	198.65
	Common kestrel	0.28	95.0	0.014	0.35	70.95
	Osprey	1.69	98.0	0.034	0.84	29.61

Table 8.2.7b: Estimated collisions per year at the assumed collision avoidance rates for directional flights (NB these figures do not account for wind farm non-operational time)

Data set	Species	No Avoidance collisions	Avoidance rate (%)	Collisions per season/year	Total over 25 years	Years between collisions
March to May 2016	Pink-footed goose	101.94	99.8	0.204	5.10	4.91

Table 8.2.8a: Output from SNH Band model collision probability spreadsheet for common gull.

K: [1D or [3D] (0 or 1)	1	
NoBlades	3	
MaxChord	4.01	m
Pitch (degrees)	5	
BirdLength	0.42	m
Wingspan	1.3	m
F: Flapping (0) or gliding (+1)	0	
Bird speed	13	m/sec
RotorDiam	140	m
RotationPeriod	5.70	sec
Bird aspect ratioo: β	0.32	

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)	contribution from radius r	collide length	p(collision)	contribution from radius r
0.025	0.575	6.74	24.44	0.99	0.00124	24.04	0.97	0.00122
0.075	0.575	2.25	8.28	0.34	0.00251	7.88	0.32	0.00239
0.125	0.702	1.35	5.77	0.23	0.00292	5.28	0.21	0.00267
0.175	0.860	0.96	4.86	0.20	0.00344	4.26	0.17	0.00302
0.225	0.994	0.75	4.30	0.17	0.00391	3.60	0.15	0.00328
0.275	0.947	0.61	3.44	0.14	0.00383	2.78	0.11	0.00310
0.325	0.899	0.52	2.85	0.12	0.00375	2.22	0.09	0.00292
0.375	0.851	0.45	2.41	0.10	0.00366	1.81	0.07	0.00275
0.425	0.804	0.40	2.07	0.08	0.00356	1.51	0.06	0.00259
0.475	0.756	0.35	1.80	0.07	0.00345	1.27	0.05	0.00244
0.525	0.708	0.32	1.58	0.06	0.00335	1.08	0.04	0.00230
0.575	0.660	0.29	1.42	0.06	0.00331	0.96	0.04	0.00224
0.625	0.613	0.27	1.29	0.05	0.00327	0.87	0.04	0.00219
0.675	0.565	0.25	1.18	0.05	0.00323	0.79	0.03	0.00215
0.725	0.517	0.23	1.08	0.04	0.00317	0.72	0.03	0.00211
0.775	0.470	0.22	0.99	0.04	0.00311	0.66	0.03	0.00208
0.825	0.422	0.20	0.91	0.04	0.00305	0.62	0.02	0.00206
0.875	0.374	0.19	0.84	0.03	0.00297	0.58	0.02	0.00204
0.925	0.327	0.18	0.77	0.03	0.00289	0.54	0.02	0.00204
0.975	0.279	0.17	0.71	0.03	0.00280	0.52	0.02	0.00203
	Overall p(collision) =			**Upwind**	**6.3%**		**Downwind**	**4.8%**
					Average	**5.6%**		

Table 8.2.8b: Output from SNH Band model collision probability spreadsheet for goshawk.

Parameter	Value	Unit
K: [1D or [3D] (0 or 1)	1	
NoBlades	3	
MaxChord	4.01	m
Pitch (degrees)	5	
BirdLength	0.62	m
Wingspan	1.65	m
F: Flapping (0) or gliding (+1)	0	
Bird speed	10	m/sec
RotorDiam	140	m
RotationPeriod	5.70	sec
Bird aspect ratioo: β	0.38	

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

r/R	c/C	α	Upwind: collide			Downwind: collide		
radius	chord	alpha	length	p(collision)	contribution from radius r	length	p(collision)	contribution from radius r
0.025	0.575	5.18	20.66	1.00	0.00125	20.26	1.00	0.00125
0.075	0.575	1.73	7.02	0.37	0.00277	6.62	0.35	0.00261
0.125	0.702	1.04	4.86	0.26	0.00320	4.37	0.23	0.00288
0.175	0.860	0.74	4.07	0.21	0.00375	3.47	0.18	0.00319
0.225	0.994	0.58	3.59	0.19	0.00425	2.89	0.15	0.00342
0.275	0.947	0.47	2.89	0.15	0.00418	2.23	0.12	0.00323
0.325	0.899	0.40	2.40	0.13	0.00411	1.78	0.09	0.00304
0.375	0.851	0.35	2.09	0.11	0.00413	1.50	0.08	0.00296
0.425	0.804	0.30	1.88	0.10	0.00420	1.32	0.07	0.00295
0.475	0.756	0.27	1.71	0.09	0.00427	1.18	0.06	0.00295
0.525	0.708	0.25	1.57	0.08	0.00433	1.07	0.06	0.00296
0.575	0.660	0.23	1.45	0.08	0.00437	0.98	0.05	0.00298
0.625	0.613	0.21	1.34	0.07	0.00441	0.91	0.05	0.00300
0.675	0.565	0.19	1.25	0.07	0.00444	0.86	0.05	0.00304
0.725	0.517	0.18	1.17	0.06	0.00447	0.81	0.04	0.00309
0.775	0.470	0.17	1.10	0.06	0.00448	0.77	0.04	0.00314
0.825	0.422	0.16	1.03	0.05	0.00448	0.74	0.04	0.00320
0.875	0.374	0.15	0.97	0.05	0.00448	0.71	0.04	0.00327
0.925	0.327	0.14	0.92	0.05	0.00446	0.69	0.04	0.00335
0.975	0.279	0.13	0.87	0.05	0.00444	0.67	0.04	0.00344

Overall p(collision) = Upwind 8.0% Downwind 6.0%

Average 7.0%

Table 8.2.8c: Output from SNH Band model collision probability spreadsheet for common kestrel.

K: [1D or [3D] (0 or 1)	1	
NoBlades	3	
MaxChord	4.01	m
Pitch (degrees)	5	
BirdLength	0.35	m
Wingspan	0.8	m
F: Flapping (0) or gliding (+1)	0	
Bird speed	13	m/sec
RotorDiam	140	m
RotationPeriod	5.70	sec
Bird aspect ratioo: β	0.44	

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

r/R	c/C	α	Upwind: collide		contribution	Downwind: collide		contribution from radius r
radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	
0.025	0.575	6.74	21.07	0.85	0.00107	20.67	0.84	0.00105
0.075	0.575	2.25	7.16	0.29	0.00217	6.76	0.27	0.00205
0.125	0.702	1.35	5.10	0.21	0.00258	4.61	0.19	0.00233
0.175	0.860	0.96	4.38	0.18	0.00310	3.78	0.15	0.00268
0.225	0.994	0.75	3.92	0.16	0.00357	3.23	0.13	0.00294
0.275	0.947	0.61	3.14	0.13	0.00349	2.48	0.10	0.00276
0.325	0.899	0.52	2.59	0.10	0.00341	1.96	0.08	0.00258
0.375	0.851	0.45	2.18	0.09	0.00332	1.59	0.06	0.00241
0.425	0.804	0.40	1.90	0.08	0.00327	1.34	0.05	0.00231
0.475	0.756	0.35	1.69	0.07	0.00324	1.16	0.05	0.00222
0.525	0.708	0.32	1.51	0.06	0.00320	1.01	0.04	0.00215
0.575	0.660	0.29	1.35	0.05	0.00315	0.89	0.04	0.00208
0.625	0.613	0.27	1.22	0.05	0.00310	0.80	0.03	0.00201
0.675	0.565	0.25	1.11	0.04	0.00304	0.72	0.03	0.00196
0.725	0.517	0.23	1.01	0.04	0.00297	0.65	0.03	0.00191
0.775	0.470	0.22	0.92	0.04	0.00289	0.59	0.02	0.00186
0.825	0.422	0.20	0.84	0.03	0.00281	0.55	0.02	0.00183
0.875	0.374	0.19	0.77	0.03	0.00272	0.51	0.02	0.00180
0.925	0.327	0.18	0.70	0.03	0.00263	0.47	0.02	0.00177
0.975	0.279	0.17	0.64	0.03	0.00253	0.45	0.02	0.00176
	Overall p(collision) =			**Upwind**	**5.8%**		**Downwind**	**4.2%**
					Average	**5.0%**		

Table 8.2.8d: Output from SNH Band model collision probability spreadsheet for osprey.

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

Parameter	Value	Unit	r/R radius	c/C chord	α alpha	Upwind: collide length	Upwind: p(collision)	Upwind: contribution from radius r	Downwind: collide length	Downwind: p(collision)	Downwind: contribution from radius r
K: [1D or [3D] (0 or 1)	1										
NoBlades	3										
MaxChord	4.01	m									
Pitch (degrees)	5										
BirdLength	0.58	m	0.025	0.575	6.22	25.06	1.00	0.00125	24.66	1.00	0.00125
Wingspan	1.7	m	0.075	0.575	2.07	8.49	0.37	0.00279	8.09	0.35	0.00266
F: Flapping (0) or gliding (+1)	0		0.125	0.702	1.24	5.85	0.26	0.00321	5.36	0.23	0.00294
			0.175	0.860	0.89	4.86	0.21	0.00373	4.26	0.19	0.00327
Bird speed	12	m/sec	0.225	0.994	0.69	4.27	0.19	0.00421	3.57	0.16	0.00353
RotorDiam	140	m	0.275	0.947	0.57	3.43	0.15	0.00414	2.77	0.12	0.00334
RotationPeriod	5.70	sec	0.325	0.899	0.48	2.85	0.12	0.00406	2.22	0.10	0.00316
			0.375	0.851	0.41	2.41	0.11	0.00397	1.82	0.08	0.00299
			0.425	0.804	0.37	2.08	0.09	0.00387	1.52	0.07	0.00283
			0.475	0.756	0.33	1.83	0.08	0.00382	1.30	0.06	0.00272
Bird aspect ratioo: β	0.34		0.525	0.708	0.30	1.67	0.07	0.00383	1.17	0.05	0.00270
			0.575	0.660	0.27	1.52	0.07	0.00384	1.06	0.05	0.00268
			0.625	0.613	0.25	1.40	0.06	0.00385	0.97	0.04	0.00267
			0.675	0.565	0.23	1.30	0.06	0.00384	0.90	0.04	0.00267
			0.725	0.517	0.21	1.20	0.05	0.00383	0.84	0.04	0.00268
			0.775	0.470	0.20	1.12	0.05	0.00381	0.79	0.03	0.00269
			0.825	0.422	0.19	1.05	0.05	0.00378	0.75	0.03	0.00271
			0.875	0.374	0.18	0.98	0.04	0.00375	0.71	0.03	0.00274
			0.925	0.327	0.17	0.91	0.04	0.00371	0.69	0.03	0.00278
			0.975	0.279	0.16	0.86	0.04	0.00366	0.66	0.03	0.00282
				Overall p(collision) =			**Upwind**	**7.3%**		**Downwind**	**5.6%**
								Average	**6.4%**		

Table 8.2.8e: Output from SNH Band model collision probability spreadsheet for pink-footed goose.

K: [1D or [3D] (0 or 1)	1	
NoBlades	3	
MaxChord	4.01	m
Pitch (degrees)	5	
BirdLength	0.75	m
Wingspan	1.7	m
F: Flapping (0) or gliding (+1)	0	
Bird speed	15	m/sec
RotorDiam	140	m
RotationPeriod	5.70	sec
Bird aspect ratioo: β	0.44	

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

r/R	c/C	α	Upwind:			Downwind:		
radius	chord	alpha	collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r
0.025	0.575	7.78	31.28	1.00	0.00125	30.88	1.00	0.00125
0.075	0.575	2.59	10.56	0.37	0.00278	10.16	0.36	0.00267
0.125	0.702	1.56	7.25	0.25	0.00318	6.76	0.24	0.00296
0.175	0.860	1.11	6.01	0.21	0.00369	5.40	0.19	0.00332
0.225	0.994	0.86	5.25	0.18	0.00414	4.55	0.16	0.00359
0.275	0.947	0.71	4.21	0.15	0.00406	3.54	0.12	0.00342
0.325	0.899	0.60	3.48	0.12	0.00397	2.85	0.10	0.00325
0.375	0.851	0.52	2.94	0.10	0.00387	2.35	0.08	0.00309
0.425	0.804	0.46	2.53	0.09	0.00377	1.97	0.07	0.00293
0.475	0.756	0.41	2.25	0.08	0.00375	1.72	0.06	0.00287
0.525	0.708	0.37	2.04	0.07	0.00377	1.55	0.05	0.00286
0.575	0.660	0.34	1.87	0.07	0.00378	1.41	0.05	0.00285
0.625	0.613	0.31	1.73	0.06	0.00378	1.30	0.05	0.00284
0.675	0.565	0.29	1.60	0.06	0.00378	1.20	0.04	0.00285
0.725	0.517	0.27	1.48	0.05	0.00378	1.12	0.04	0.00286
0.775	0.470	0.25	1.38	0.05	0.00377	1.06	0.04	0.00287
0.825	0.422	0.24	1.29	0.05	0.00375	1.00	0.04	0.00289
0.875	0.374	0.22	1.21	0.04	0.00372	0.95	0.03	0.00292
0.925	0.327	0.21	1.14	0.04	0.00369	0.91	0.03	0.00295
0.975	0.279	0.20	1.07	0.04	0.00366	0.87	0.03	0.00299
	Overall p(collision) =			**Upwind**	**7.2%**		**Downwind**	**5.8%**
					Average	**6.5%**		

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