TECHNICAL APPENDIX 9.2:

Avian Collision Risk Assessment

Aultmore Wind Farm Redesign

Prepared for: **Vattenfall**

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BASIS OF REPORT

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DOCUMENT REFERENCES

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APPENDICES

1.0 Introduction

This report presents the results of Collision Risk Modelling (CRM) undertaken for three bird species to inform an assessment of potential ornithological impacts relating to the proposed redesign of the previously consented Aultmore Wind Farm located in Aultmore Forest, Moray, between Keith and Buckie (the Site). The CRM report is based on the EIA Report which comprises sixteen turbines in two arrays. These are treated separately and then combined to produce an overall collision risk.

Modelling for the two arrays was undertaken using parameters which considered the worst-case scenario for impacts on birds. The arrays and their parameters are as follow:

- Eastern array: 11 turbines with a rotor diameter of 170m, tip height of 200m and hub height of 115m.
- Western array: 5 turbines with a rotor diameter of 170m, tip height of 200m and hub height of 115m.

The CRM was undertaken in accordance with current NatureScot (NS) (formerly Scottish Natural Heritage (SNH)) guidance, which is recognised as standard best practice guidance through the UK and Ireland to inform impact assessment for onshore wind farms. Further details regarding the methodology used, including details of assumptions used and any corrections applied, are provided in Section 2. The monitoring results are presented in Section 3 and copies of the modelling calculations for each species modelled are included in Appendices 01-02.

Species summary accounts are presented in Section 3 of the report.

2.0 Primary Target Species

Target species for the surveys were defined by legal and/ or conservation status and vulnerability to impacts caused by wind turbines, as defined in NS Guidance (SNH 2017[1]).

Bird species of high conservation importance are those which are Annex I and Schedule 1 species and other species of high conservation importance which are considered to be vulnerable to impacts from wind farm developments.

The following species are therefore considered relevant as primary target species:

- Annex I raptor and owl species*;*
- Breeding and migratory wildfowl; and
- Breeding and migratory waders.

3.0 Methods

The standard Band CRM (Band *et. al.* 2007[2]) was used to estimate collision risk based on recorded target species activity levels and flight behaviour, proposed turbine numbers and specifications, and the relevant species biometrics and flight characteristics. Modelling collision risk under the Band CRM is a two-stage process. Stage 1 estimates the number of birds that fly through the rotor swept disc. Stage 2 predicts the proportion of these birds that have the potential to be hit by a rotor blade. Combining both stages produces

[1] Scottish Natural Heritage (SNH) (2017). *Recommended Bird Survey Methods to Inform Impact Assessment of Onshore Wind Farms. Version 2*.

[2] Band, W., Madders, M. and Whitfield, D.P. (2007) Developing Field and Analytical Methods to Assess Avian Collision Risk at Wind Farms. In: De Lucas, M., Janss, G. and Ferrer, M., Eds., Birds and Wind Power, Quercus Editions, Madrid, 259-275.

an estimate of collision mortality in the absence of any avoidance action/behaviour by birds. Avoidance rates are then applied to generate predicted rates of collision mortality.

3.1 Prediction of Rotor Transits from Vantage Point Survey Data

3.1.1 Aultmore Survey Data 2021 to 2022

In order to inform the assessment, updated baseline surveys were carried out during late March 2021 to February 2022. The number of birds that fly through the rotor swept area was estimated using flight data gathered using flight activity vantage point surveys during this period.

The surveys gathered data from four vantage points (VPs). The total number of hours are as shown in **Table 3-1**.

Table 3-1
VP Surveys undertaken at Aultmore, March 2021 – February 2022

VP Number	Grid Coordinates (x, y)	Hours of Survey Completed (hrs:mins)		
		Mar-Aug	Sep-Feb	Total
1	342377,858149	48	48	96
2	340257,856149	48	48	96
3	345925,859642	48	48	96
4	347359,857535	48	48	96

3.1.2 Viewshed Data

Viewshed data, i.e., the area visible from each VP within each of the two wind farm polygons (WP)[3], are summarised in **Table 3-2**.

The combined viewshed areas (minus overlap) of the western array (3,211,997m²) represents 98.2% of the survey WP (3,268,525m²).

The combined viewshed areas (minus overlap) of the eastern array (5,929,550m²) represents 91.1% of the survey WP (6,544,136m²).

Table 3-2
Aultmore VP Viewshed Data

VP/ Viewshed Number	Area of visibility (m²)*
Western Array	
VP 1 viewshed	2,899,963
VP 2 viewshed	1,810,190

[3] The survey wind farm polygon (WP) includes the area within 500m of the outermost turbine blades.

VP/ Viewshed Number	Area of visibility (m²)*
VP 1+2 viewshed combined (minus overlap)	3,211,997
Survey WP	3,268,525
Eastern Array	
VP 3 viewshed	4,211,072
VP 4 viewshed	3,916,992
VP 3+4 viewshed combined (minus overlap)	5,929,550
Survey WP	6,544,136
	* area calculated in GIS using offset of 25m above ground level

As such, the viewshed coverage is considered sufficient to inform this assessment.

3.1.3 Flight Selection for CRM

In order to select flights liable to incur a potential risk of collision, i.e., within the areas occupied by proposed turbines, the CRM used only observations collected within each WP – defined by a 500m buffer around the proposed outermost turbine locations. The size of buffer takes into account rotor blade length and potential spatial errors in flight recording accuracy. It is known that bird detection rates vary between species. To ensure the CRM used robust measures of flight activity, a 2km distance truncation was used in the viewshed from each VP, i.e., only flights within 2km of each VP were included (as per NS guidance).

Analysis in MS Excel and GIS identified those flights that were at Potential Collision Height (PCH) and within the WP. Flight times that were used in the CRM were derived from field data for each flight. Time spent at different flight heights was estimated in a database from interval data for flights that entered the WP. Flying time estimated to occur within the survey recording height bands (see following section) was used to determine the period that target species were at risk of collision with the rotors.

3.1.4 Correcting Survey PCH to Actual PCH

Baseline VP surveys were initiated before the current candidate turbine details were known. The baseline surveys utilised the following height bands:

- 1 = <25m
- 2 = 25-180m
- 3 = 180-200m
- 4 = >200m

As such, the height bands used to record flight activity do not correspond precisely to PCH for the proposed development (30-200m [4]), i.e., height band 2 overlaps slightly with the lower limit of the actual PCH (25-30m of the 25-180m band).

[4] Using the turbine data in Table 3-4

For the small difference outlined, an adjustment was included in the model. Assuming an equal distribution of heights within all height bands, it is assumed that a proportion of the flights within height band 2 will be below risk height. the model accounts for this by adjusting the proportion of flights included by rotor diameter/ survey risk height (170/175 (97.1%)).

3.1.5 Seasonal Definitions

CRMs were constructed using data based on the survey design (March 2021 to February 2022) and taking into account the relevant species seasonal periods, i.e., March – May 2021 (spring migration for geese), March – August 2021 (breeding season 2021), September – November 2021 (autumn migration for geese) and September 2021 – February 2022 (non-breeding season 2021/22).

The theoretical time that birds could be active with potential for turbine collisions was assumed to be the period between sunrise and sunset within each survey period using the latitude of the Site[5].

For geese, which could be active nocturnally, an additional 25% of nocturnal hours were added to the daylight hours to give a more accurate representation of the available hours for this species (as per Band *et al.*, 2007).

3.1.6 Undertaking CRM

Species with sufficient flight activity to be modelled[6] were as follows[7]:

- Pink-footed goose: Eastern Array March-May 2021;
- Pink-footed goose: Eastern Array September-November 2021;
- Pink-footed goose: Western Array March-May 2021;
- Pink-footed goose: Western Array September-November 2021;
- Greylag goose: Eastern Array September-November 2021;
- Common gull: Eastern Array March-August 2021;
- Common gull: Western Array March-August 2021.

Based on the regular and predictable flight behaviour of pink-footed and greylag goose, the regular (directional) model was used for these species during CRM. Similarly, the regular model was used for common gull, using the number of birds recorded flying within the Site[8].

The following parameters were entered into a bespoke modelling spreadsheet:-

- The number of birds flying through the survey risk window, within each viewshed (T_wV);
- The total observation effort within the risk window (*e*) within each viewshed;
- The length of the risk window viewed from each VP (*Y*), calculated as a proportion of viewshed (*X)* from each VP/ total size of WP[9] x total length of risk window;

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[5] https://www.timeanddate.com [Accessed in December 2022].
[6] Sufficient flight activity was defined as a minimum total of three flights or minimum ten individuals of each primary target species recorded in each array during each season of analysis. Numbers below these thresholds are likely to result in negligible predicted mortality. An exception was made for common gull for HRA purposes, which was recorded as a secondary species only.
[7] Flight activity data are presented in Table 3-5.
[8] In this case flight line data were not mapped as common gull was recorded as a secondary target species only.

[9] This is area covered by the outermost turbines plus 500m buffer

- An estimation of daylight minutes (plus 25% nocturnal minutes within the season of analysis for geese);
- Species-specific bird parameters (**Table 3-3)**; and
- Wind farm parameters (**Table 3-4**).

A map showing VP locations and viewsheds along with the 500m buffer around the outermost turbine blades is provided in **Technical Appendix 9:1: Bird Survey Report** (**Figure 9.1.2**).

The NS CRM spreadsheet[10] calculates the probability of collision for each particular species. The model then combines this probability of collision with the observed flight activity per unit area (birds per metre per minute) weighted for observation effort from each VP to produce an estimate of the number of transits through the rotor blades. Mortality estimates are then derived by applying species-specific avoidance rates.

3.1.7 Bird Biometrics and Avoidance Rates

Measurements and flight speeds of the species for which CRM was undertaken were derived from British Trust for Ornithology (BTO)[11], and Alerstram *et al.* (2007[12]). The avoidance rates for these species are taken from NS (2018[13]).

Table 3-3
Bird biometrics and avoidance rates used in CRM

Species name	Bird length (m)	Wingspan (m)	Flight speed (m/s)	Avoidance rate (%)
Pink-footed goose	0.65	1.53	17.0	99.8
Greylag goose	0.83	1.64	17.0	99.8
Common gull	0.42	1.30	13.4	98.0

3.1.8 Wind Farm and Turbine Parameters

The wind turbine parameters used in the CRM are detailed in **Table 3-4** and are based on the information provided by Vattenfall for the purposes of assessment. These parameters reflect the worst case scenario for impacts on birds.

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[10] https://www.nature.scot/wind-farm-impacts-birds-calculating-probability-collision [Accessed in December 2022].
[11] https://www.bto.org/understanding-birds/birdfacts [Accessed in December 2022].
[12] Alerstam T, Rosén M, Bäckman J, Ericson PG, Hellgren O. (2007). Flight speeds among bird species: allometric and phylogenetic effects. PLoS Biol.
[13] SNH (2018) Avoidance rates for the onshore SNH wind farm collision risk model. https://www.nature.scot/doc/wind-farm-impacts-birds-use-avoidance-rates-naturescot-wind-farm-collision-risk-model#:~:text=2.%20Recommended%20avoidance%20rates%20%20%20Species%20,%20SNH%20%282013%29%20%207%20more%20rows%20. [Accessed in December 2022].

Table 3-4
Wind farm & turbine parameters

Parameter	Value
Size of survey wind farm polygons (WP)	East Array: 654.4ha
	West Array: 326.9ha
Length of survey risk windows	East Array: 3368m
	West Array: 2144m
Number of turbines	East Array: 11
	West Array: 5
Rotor radius/ diameter	85.0m/ 170.0m
Hub height	115m
Max. chord	4.5m
Pitch	6°
Rotation period	6.5 s (max 9.23 rpm)
Turbine operation time	85%

3.2 Aultmore Flightline Data

Table 3-5 summarises the primary target species flightline data (plus common gull) from VP surveys conducted, presented for each array and season. **Table 3-6** to **Table 3-8** (inclusive) present the seasonal primary target species occupancy data within each height band, and the total at-risk occupancy data used in the CRM. Species with sufficient data to be taken forward to undertake CRM are highlighted in **bold** (i.e., pink-footed goose and greylag goose)**.** In addition, to inform the Habitats Regulation Appraisal (HRA), CRM was conducted for common gull, in order to inform further assessment (HRA) (See **Technical Appendix 8.7: Shadow HRA Screening**).

Table 3-5
Number of target species flights and individuals observed passing through each Aultmore WP during VP surveys (2021 to 2022)

Species name	Wind Farm Array	Period of analysis	Total number of birds recorded in flight	Flights through WP		Flights through WP at Potential Collision Height (PCH)	
				Flights	Individuals	Flights	Individuals
Whooper swan	East	Autumn 2021 (Sep-Nov)	3	1	3	1	3
	West	Spring 2021 (Mar-May)	2	0	0	0	0
Pink-footed goose	**East**	**Spring 2021 (Mar-May)**	**468**	**9**	**444**	**3**	**120**
		Autumn 2021 (Sep-Nov)	**840**	**3**	**575**	**2**	**325**
	West	**Spring 2021 (Mar-May)**	**1554**	**14**	**734**	**14**	**734**
		Autumn 2021 (Sep-Nov)	**227**	**3**	**170**	**3**	**170**
Greylag goose	**East**	**Autumn 2021 (Sep-Nov)**	**180**	**6**	**180**	**5**	**173**
	West	Spring 2021 (Mar-May)	11	1	1	1	1
		Breeding season 2021 (Apr-Aug)	2	0	0	0	0
		Autumn 2021 (Sep-Nov)	0	0	0	0	0
		Winter 2021/2022 (Dec-Feb)	6	1	6	1	6
Hen harrier	East	Breeding season 2021 (Mar-Aug)	2	1	1	0	0
		Non-breeding season 2021/2022 (Sep-Mar)	1	1	1	0	0
Goshawk	East	Breeding season 2021 (Mar-Aug)	5	5	5	2	2
	West	Breeding season 2021 (Mar-Aug)	7	3	4	0	0

Species name	Wind Farm Array	Period of analysis	Total number of birds recorded in flight	Flights through WP		Flights through WP at Potential Collision Height (PCH)	
				Flights	Individuals	Flights	Individuals
		Non-breeding season 2021/2022 (Sep-Mar)	1	1	1	1	1
Osprey	West	Breeding season 2021 (Mar-Aug)	2	1	2	1	2
Kestrel	East	Breeding season 2021 (Mar-Aug)	6	6	6	0	0
		Non-breeding season 2021/2022 (Sep-Mar)	2	2	2	0	0
	West	Breeding season 2021 (Mar-Aug)	6	2	2	0	0
		Non-breeding season 2021/2022 (Sep-Mar)	13	3	3	1	1
Peregrine	West	Breeding season 2021 (Mar-Aug)	1	0	0	0	0
Snipe	East	Non-breeding season 2021/2022 (Sep-Mar)	1	1	1	1	1
Curlew	West	Breeding season 2021 (Mar-Aug)	10	0	0	0	0
Common gull[14]	**East**	**Breeding season 2021 (Mar-Aug)**	**6**	**4**	**6**	**1**	**1**
	West	**Breeding season 2021 (Mar-Aug)**	**26**	**12**	**25**	**3**	**8**

[14] Derived from secondary species 5-minute summaries. All flights recorded were included. For the purposes of HRA, CRM was conducted using the non-random (directional) model.

Table 3-6
Details of Pink-footed Goose Flights Recorded within 500m Buffer of Turbines

Wind Farm Array	Period	VP No.	No. of flights	No. of birds	No. of birds at PCH
East	Spring 2021 (Mar-May)	3	9	444	120
	Autumn 2021 (Sep-Nov)	3	1	250	0
	Spring 2021 (Mar-May)	4	0	0	0
	Autumn 2021 (Sep-Nov)	4	2	325	325
West	Spring 2021 (Mar-May)	1	8	450	450
	Autumn 2021 (Sep-Nov)	1	2	125	125
	Spring 2021 (Mar-May)	2	6	312	312
	Autumn 2021 (Sep-Nov)	2	1	45	45

Table 3-7
Details of Greylag Goose Flights Recorded within 500m Buffer of Turbines

Wind Farm Array	Period	VP No.	No. of flights	No. of birds	No. of birds at PCH
East	Spring 2021 (Mar-May)	3	0	0	0
	Autumn 2021 (Sep-Nov)	3	5	173	173
	Spring 2021 (Mar-May)	4	0	0	0
	Autumn 2021 (Sep-Nov)	4	1	7	0
West	Spring 2021 (Mar-May)	1	1	1	1
	Autumn 2021 (Sep-Nov)	1	0	0	0
	Spring 2021 (Mar-May)	2	0	0	0
	Autumn 2021 (Sep-Nov)	2	0	0	0
	Winter 2021/2022	2	1	6	6

Table 3-8
Details of Common Gull Flights Recorded within 500m Buffer of Turbines

Wind Farm Array	Period	VP No.	No. of flights	No. of birds	No. of birds at PCH
East	April to August 2021	3	6	4	1
		4	0	0	0
West	April to August 2021	1	0	0	0
		2	12	25	8

4.0 Collision Risk Modelling Results

Table 4-1 summarises the predicted collision rates for the three species under consideration. Copies of the modelling calculations for each species are included in Appendices 01-02.

Table 4-1
Summary of CRM Output E Array

Species name	Period of analysis	Modelled collisions	Years per collision
Pink-footed goose	Spring 2021 (Mar to May)	0.18	5.4
	Autumn 2021 (Sep to Nov)	0.42	2.39
	Annual	0.60	1.67
Greylag goose	Autumn 2021 (Sep to Nov)	0.24	4.2
Common gull	Breeding season 2021 (Apr to Aug)	0.02	54.5

Table 4-2
Summary of CRM Output W Array

Species name	Period of analysis	Modelled collisions	Years per collision
Pink-footed goose	Spring 2021 (Mar to May)	0.74	1.35
	Autumn 2021 (Sep to Nov)	0.10	9.75
	Annual	0.84	1.19
Common gull	Breeding season 2021 (Apr to Aug)	0.08	12.8

Table 4-3
Summary of CRM Combined

Species name	Array	Modelled collisions	Years per collision
Pink-footed goose	East	0.60	1.67
	West	0.84	1.19
	Combined	1.44	0.69
Greylag goose	East	0.24	4.20
	Combined	0.24	4.20

Species name	Array	Modelled collisions	Years per collision
Common gull	East	0.02	54.5
	West	0.08	12.8
	Combined	0.10	10.0

4.1 Species Summary

4.1.1 Pink-footed goose

Pink-footed goose was recorded on passage or commuting over the Site only, during the months of March, April, October and November. The majority of flights followed a north/ south or south/ north orientation and varied in height between approximately 20m to >200m above ground level.

The peak in flight activity occurred during spring (March – April) when 36 flight events were recorded, with a cumulative total of 2,022 birds counted, which equates to a mean flock size of 56.2. In autumn (October – November), there were 9 flight events recorded with a cumulative total of 1,067 birds counted, which equates to a mean flock size of 118.6.

For reference, the Moray and Nairn Coast SPA qualifying population was based on the 5 year (1988/89-1992/93) mean peak of 7,538. This compares with the most recent 5 year (2017/18-2021/22) mean peak for the Inner Moray and Beauly Firths WeBS area (Austin et al. 2023[15]) of 31,492. Any impacts on the designated site should therefore be considered in the light of this increasing population.

4.1.2 Greylag goose

Greylag goose was recorded on passage or commuting over the Site only, during the months of March, April, June, October, November and December. The majority of flights followed a north/ south or south/ north orientation and varied in height between approximately 10m to 130m above ground level.

The peak in flight activity occurred during autumn (October – November) when 6 flight events were recorded, with a cumulative total of 180 birds counted, which equates to a mean flock size of 30 birds. Otherwise, numbers were low, with a mean flock size of 4 birds during the rest of the year.

For reference, the Moray and Nairn Coast SPA qualifying population was based on the 5 year (1988/89-1992/93) mean peak of 3,023. This compares with the most recent 5 year (2017/18-2021/22) mean peak for the Inner Moray and Beauly Firths WeBS area (Austin *et al*. 2023) of 468. Any impacts on the designated site should therefore be considered in the light of this decreasing population. This change is due to the fact that the majority of the Scottish wintering population moving north to Orkney.

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[15] Austin, G.E., Calbrade, N.A., Birtles, G.A., Peck, K., Shaw, J.M. Wotton, S.R., Balmer, D.E. and Frost, T.M. 2023.
Waterbirds in the UK 2021/22: The Wetland Bird Survey and Goose & Swan Monitoring Programme. BTO/RSPB/JNCC/NatureScot.Thetford.
"Contains Wetland Bird Survey (WeBS) data from Waterbirds in the UK 2021/22 © copyright and database right 2023. WeBS is a partnership jointly funded by the BTO, RSPB and JNCC, with fieldwork conducted by volunteers and previous support from WWT."
[*]including supplementary counts from the Goose and Swan Monitoring Partnership (GSMP)
http://www.bto.org/volunteer-surveys/webs/publications/webs-annual-report

4.1.3 Common gull

Common gull was recorded on passage or commuting over the Site only, during the months of March, April, June and August. Flights were in height bands 1 and 2 (between approximately >0m to 180m above ground level).

The peak in flight activity occurred during spring (March – April). Numbers were low, with a cumulative total of 32 and mean flock size of 1.9 birds.

APPENDIX 01

CRM Probability Calculations

Pink-footed Goose

K: [1D or [3D] (0 or 1)	1		**Calculation of alpha and p(collision) as a function of radius**								
NoBlades	3						Upwind:			Downwind:	
MaxChord	4.5	m	r/R	c/C	α	collide		contribution	collide		contribution
Pitch (degrees)	6		radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r
BirdLength	0.65	m	0.025	0.575	8.28	34.23	0.93	0.00116	33.69	0.91	0.00114
Wingspan	1.53	m	0.075	0.575	2.76	11.59	0.31	0.00236	11.05	0.30	0.00225
F: Flapping (0) or gliding (·	0		0.125	0.702	1.66	8.06	0.22	0.00273	7.40	0.20	0.00251
			0.175	0.860	1.18	6.76	0.18	0.00321	5.96	0.16	0.00283
Bird speed	17	m/sec	0.225	0.994	0.92	5.97	0.16	0.00364	5.03	0.14	0.00307
RotorDiam	170	m	0.275	0.947	0.75	4.78	0.13	0.00357	3.89	0.11	0.00291
RotationPeriod	6.50	sec	0.325	0.899	0.64	3.96	0.11	0.00349	3.11	0.08	0.00275
			0.375	0.851	0.55	3.35	0.09	0.00341	2.55	0.07	0.00259
			0.425	0.804	0.49	2.87	0.08	0.00332	2.12	0.06	0.00244
			0.475	0.756	0.44	2.50	0.07	0.00322	1.78	0.05	0.00230
Bird aspect ratioo: β	0.42		0.525	0.708	0.39	2.23	0.06	0.00318	1.57	0.04	0.00223
			0.575	0.660	0.36	2.02	0.05	0.00316	1.40	0.04	0.00219
			0.625	0.613	0.33	1.85	0.05	0.00313	1.27	0.03	0.00215
			0.675	0.565	0.31	1.69	0.05	0.00310	1.16	0.03	0.00212
			0.725	0.517	0.29	1.55	0.04	0.00306	1.07	0.03	0.00210
			0.775	0.470	0.27	1.43	0.04	0.00301	0.99	0.03	0.00208
			0.825	0.422	0.25	1.32	0.04	0.00296	0.93	0.03	0.00207
			0.875	0.374	0.24	1.22	0.03	0.00290	0.87	0.02	0.00207
			0.925	0.327	0.22	1.13	0.03	0.00284	0.82	0.02	0.00207
			0.975	0.279	0.21	1.05	0.03	0.00277	0.78	0.02	0.00207
				Overall p(collision) =			**Upwind**	**6.0%**		**Downwind**	**4.6%**
								Average	**5.3%**		

Greylag Goose

K: [1D or [3D] (0 or 1)	1		**Calculation of alpha and p(collision) as a function of radius**								
NoBlades	3						Upwind:			Downwind:	
MaxChord	4.5	m	r/R	c/C	α	collide		contribution	collide		contribution
Pitch (degrees)	6		radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r
BirdLength	0.83	m	0.025	0.575	8.28	35.14	0.95	0.00119	34.60	0.94	0.00117
Wingspan	1.64	m	0.075	0.575	2.76	11.89	0.32	0.00242	11.35	0.31	0.00231
F: Flapping (0) or gliding (·	0		0.125	0.702	1.66	8.24	0.22	0.00280	7.58	0.21	0.00257
			0.175	0.860	1.18	6.89	0.19	0.00328	6.09	0.17	0.00289
Bird speed	17	m/sec	0.225	0.994	0.92	6.07	0.16	0.00371	5.13	0.14	0.00314
RotorDiam	170	m	0.275	0.947	0.75	4.87	0.13	0.00363	3.98	0.11	0.00297
RotationPeriod	6.50	sec	0.325	0.899	0.64	4.03	0.11	0.00355	3.18	0.09	0.00281
			0.375	0.851	0.55	3.41	0.09	0.00347	2.61	0.07	0.00265
			0.425	0.804	0.49	2.96	0.08	0.00341	2.20	0.06	0.00254
			0.475	0.756	0.44	2.66	0.07	0.00343	1.95	0.05	0.00251
Bird aspect ratioo: β	0.51		0.525	0.708	0.39	2.41	0.07	0.00344	1.75	0.05	0.00249
			0.575	0.660	0.36	2.20	0.06	0.00344	1.58	0.04	0.00247
			0.625	0.613	0.33	2.03	0.06	0.00344	1.45	0.04	0.00246
			0.675	0.565	0.31	1.87	0.05	0.00343	1.34	0.04	0.00245
			0.725	0.517	0.29	1.73	0.05	0.00341	1.25	0.03	0.00246
			0.775	0.470	0.27	1.61	0.04	0.00339	1.17	0.03	0.00246
			0.825	0.422	0.25	1.50	0.04	0.00336	1.11	0.03	0.00248
			0.875	0.374	0.24	1.40	0.04	0.00333	1.05	0.03	0.00249
			0.925	0.327	0.22	1.31	0.04	0.00329	1.00	0.03	0.00252
			0.975	0.279	0.21	1.23	0.03	0.00325	0.96	0.03	0.00255
				Overall p(collision) =			**Upwind**	**6.5%**		**Downwind**	**5.0%**
								Average	**5.8%**		

Common Gull

K: [1D or [3D] (0 or 1)	1		**Calculation of alpha and p(collision) as a function of radius**								
NoBlades	3						Upwind:			Downwind:	
MaxChord	4.5	m	r/R	c/C	α	collide		contribution	collide		contribution
Pitch (degrees)	6		radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r
BirdLength	0.42	m	0.025	0.575	6.52	22.46	0.77	0.00097	21.92	0.75	0.00094
Wingspan	1.3	m	0.075	0.575	2.17	7.67	0.26	0.00198	7.12	0.25	0.00184
F: Flapping (0) or gliding (·	1		0.125	0.702	1.30	5.51	0.19	0.00237	4.85	0.17	0.00209
			0.175	0.860	0.93	4.76	0.16	0.00287	3.95	0.14	0.00238
Bird speed	13.4	m/sec	0.225	0.994	0.72	4.29	0.15	0.00333	3.36	0.12	0.00260
RotorDiam	170	m	0.275	0.947	0.59	3.45	0.12	0.00327	2.56	0.09	0.00242
RotationPeriod	6.50	sec	0.325	0.899	0.50	2.86	0.10	0.00320	2.01	0.07	0.00225
			0.375	0.851	0.43	2.42	0.08	0.00312	1.62	0.06	0.00209
			0.425	0.804	0.38	2.08	0.07	0.00304	1.32	0.05	0.00193
			0.475	0.756	0.34	1.80	0.06	0.00295	1.09	0.04	0.00178
Bird aspect ratioo: β	0.32		0.525	0.708	0.31	1.74	0.06	0.00314	1.07	0.04	0.00194
			0.575	0.660	0.28	1.57	0.05	0.00311	0.95	0.03	0.00188
			0.625	0.613	0.26	1.42	0.05	0.00306	0.85	0.03	0.00182
			0.675	0.565	0.24	1.30	0.04	0.00301	0.77	0.03	0.00178
			0.725	0.517	0.22	1.18	0.04	0.00296	0.70	0.02	0.00174
			0.775	0.470	0.21	1.08	0.04	0.00289	0.64	0.02	0.00171
			0.825	0.422	0.20	0.99	0.03	0.00282	0.59	0.02	0.00169
			0.875	0.374	0.19	0.91	0.03	0.00274	0.56	0.02	0.00168
			0.925	0.327	0.18	0.83	0.03	0.00265	0.52	0.02	0.00167
			0.975	0.279	0.17	0.76	0.03	0.00255	0.50	0.02	0.00167
				Overall p(collision) =			**Upwind**	**5.6%**		**Downwind**	**3.8%**
								Average	**4.7%**		

APPENDIX 02

CRM Calculations

Pink-footed Goose East Array; Spring

	Viewsheds							
	3	4						
STAGE 1: Number of rotor transits								
Step 1.1: Number of birds flying through the survey risk window[1], recorded within each viewshed (T_wV)	120	0						
Minutes survey effort (*e*)	1,900	1,800						
Windfarm area (ha) within viewshed (*v*)	421.1	391.7						
X, proportion of windfarm area (WP is 654.4ha)[2]	0.64	0.60						
Y, length of survey risk window viewed (X * 3368)	2167	2016						
Step 1.2: Unweighted rate of birds (flux) through risk window (*$T_wV$rate*) T_wV rate=$T_wV/e/v$	2.91E-05	0						
Step 1.3: Weighted flux (weighted TwV rate)								
Metre-minutes at VP (Y*e)	4,117,823	3,628,732						
Weight: proportion of total effort made at the VP	0.53	0.47						
Weighted T_wV rate)	1.55E-05	0						
Step 1.4: Total flux through risk window during surveys (z)				1.55E-05	birds per metre per minute			
Step 1.5: Estimated total birds through survey risk window during spring (*T_w*)								
Potentially active minutes: spring *(m)*[3]				92,365				
Total length of survey risk window (l)				3,368	m			
T_w =z**m**WP (seconds)				4,819				
Step 1.6: T_w adjusted from survey PCH band to actual PCH . adjT_w =T_w* (30-200m)/(25-200m)				4,681				
Step 1.7: Area of risk window *(W)*								
Length of risk window *(B)*				3,368	m			

Height of rotors *(h)*	170	m
Area of risk window: *W=B*h*	572,560	m^2

Step 1.8: Area swept by windfarm rotors *(A)*		
Number of turbines *(N)*	11	
π	3.1416	
Rotor radius *(R)*	85	m
Rotor-swept area: $A=N*\pi*R^2$	249,678	m^2
Step 1.9: Total birds through rotor-swept area during spring (T_r)		
$T_r=T_w*(A/W)$	2041.4	birds/transits
STAGE 2: Probability of Collision for a bird flying through rotors (*p*(collision))		
Step 2.1: *p*(collision) from SNH spreadsheet[4]	0.053	
STAGE 3: Predicted annual mortality during spring		
Step 3.1: With no avoidance, turbines operational 85% of the time		
*N*p*(collision)*0.85	91.96	
Step 3.2: Adjusted using a range of avoidance rates:		approx one collision every (years)
99.8%	0.18	5.436917498

[1] The survey risk window is based on the windfarm polygon and so includes a precautionary 500m buffer to either side of the outermost rotors

[2] These proportions sum to more than 1.0 due to extensive overlapping.

[3] The total number of daytime plus 25% nocturnal minutes during the period.

[4]Assumes bird length=0.65m, wingspan 1.53m, flight speed=17m/sec

Pink-footed Goose East Array; Autumn

	Viewsheds							
	3	4						
STAGE 1: Number of rotor transits								
Step 1.1: Number of birds flying through the survey risk window[1], recorded within each viewshed (T_wV)	0	325						
Minutes survey effort (*e*)	1,800	1,800						
Windfarm area (ha) within viewshed (*v*)	421.1	391.7						
X, proportion of windfarm area (WP is 654.4ha)[2]	0.64	0.60						
Y, length of survey risk window viewed (X * 3368)	2167	2016						
Step 1.2: Unweighted rate of birds (flux) through risk window (*T_wV*rate) T_wV rate=$T_wV/e/v$	0	8.96E-05						
Step 1.3: Weighted flux (weighted TwV rate)								
Metre-minutes at VP (Y*e)	3,901,095	3,628,732						
Weight: proportion of total effort made at the VP	0.52	0.48						
Weighted T_wV rate)	0	4.32E-05						
Step 1.4: Total flux through risk window during surveys (z)				4.32E-05	birds per metre per minute			
Step 1.5: Estimated total birds through survey risk window during autumn (*T_w*)								
Potentially active minutes: autumn season *(m)*[3]				75,560				
Total length of survey risk window (l)				3,368	m			
T_w =z**m**WP (seconds)				10,984				
Step 1.6: T_w adjusted from survey PCH band to actual PCH . adjT_w =T_w* (30-200m)/(25-200m)				10,670				
Step 1.7: Area of risk window *(W)*								
Length of risk window *(B)*				3,368	m			

Height of rotors *(h)*	170	m	
Area of risk window: *W=B*h*	572,560	m^2	

Step 1.8: Area swept by windfarm rotors *(A)*			
Number of turbines *(N)*	11		
π	3.1416		
Rotor radius *(R)*	85	m	
Rotor-swept area: $A=N*\pi*R^2$	249,678	m^2	
Step 1.9: Total birds through rotor-swept area during autumn (T_r)			
$T_r=T_w*(A/W)$	4653.0	birds/transits	
STAGE 2: Probability of Collision for a bird flying through rotors (*p*(collision))			
Step 2.1: *p*(collision) from SNH spreadsheet[4]	0.053		
STAGE 3: Predicted annual mortality during autumn			
Step 3.1: With no avoidance, turbines operational 85% of the time			
*N*p*(collision)*0.85	209.62		
Step 3.2: Adjusted using a range of avoidance rates:		approx one collision every (years)	
99.8%	0.42		2.385297376

[1] The survey risk window is based on the windfarm polygon and so includes a precautionary 500m buffer to either side of the outermost rotors

[2] These proportions sum to more than 1.0 due to extensive overlapping.

[3] The total number of daytime plus 25% nocturnal minutes during the period.

[4]Assumes bird length=0.65m, wingspan 1.53m, flight speed=17m/sec

Pink-footed Goose West Array; Spring

	Viewsheds							
	1	2						
STAGE 1: Number of rotor transits								
Step 1.1: Number of birds flying through the survey risk window[1], recorded within each viewshed (T_wV)	450	312						
Minutes survey effort (*e*)	1,800	1,800						
Windfarm area (ha) within viewshed (*v*)	290.0	181.0						
X, proportion of windfarm area (WP is 326.9ha)[2]	0.89	0.55						
Y, length of survey risk window viewed (X * 2144)	1902	1187						
Step 1.2: Unweighted rate of birds (flux) through risk window (*$T_wV$rate*) T_wV rate=$T_wV/e/v$	0.000131	0.000146						
Step 1.3: Weighted flux (weighted TwV rate)								
Metre-minutes at VP (Y*e)	3,423,461	2,137,022						
Weight: proportion of total effort made at the VP	0.62	0.38						
Weighted T_wV rate)	8.09E-05	5.61E-05						
Step 1.4: Total flux through risk window during surveys (z)				1.37E-04	birds per metre per minute			
Step 1.5: Estimated total birds through survey risk window during spring (*T_w*)								
Potentially active minutes: spring *(m)*[3]				92,365				
Total length of survey risk window (l)				2,144	m			
T_w =z**m**WP (seconds)				27,138				
Step 1.6: T_w adjusted from survey PCH band to actual PCH . adjT_w =T_w* (30 -200m)/(25-200m)				26,362				
Step 1.7: Area of risk window *(W)*								
Length of risk window *(B)*				2,144	m			

Height of rotors *(h)*	170	m
Area of risk window: *W=B*h*	364,480	m^2
Step 1.8: Area swept by windfarm rotors *(A)*		
Number of turbines *(N)*	5	
π	3.1416	
Rotor radius *(R)*	85	m
Rotor-swept area: $A=N*\pi*R^2$	113,490	m^2
Step 1.9: Total birds through rotor-swept area during autumn (T_r)		
$T_r=T_w*(A/W)$	8208.6	birds/transits
STAGE 2: Probability of Collision for a bird flying through rotors (*p*(collision))		
Step 2.1: *p*(collision) from SNH spreadsheet[4]	0.053	
STAGE 3: Predicted annual mortality during spring		
Step 3.1: With no avoidance, turbines operational 85% of the time		
*N***p*(collision)*0.85	369.80	
Step 3.2: Adjusted using a range of avoidance rates:		approx one collision every (years)
99.8%	0.74	1.352090049

[1] The survey risk window is based on the windfarm polygon and so includes a precautionary 500m buffer to either side of the outermost rotors

[2] These proportions sum to more than 1.0 due to extensive overlapping.

[3] The total number of daytime plus 25% nocturnal minutes during the period.

[4]Assumes bird length=0.65m, wingspan 1.53m, flight speed=17m/sec

Pink-footed Goose West Array; Autumn

	Viewsheds							
	3	**4**						
STAGE 1: Number of rotor transits								
Step 1.1: Number of birds flying through the survey risk window[1], recorded within each viewshed (T_wV)	0	325						
Minutes survey effort (*e*)	1,800	1,800						
Windfarm area (ha) within viewshed (*v*)	421.1	391.7						
X, proportion of windfarm area (WP is 654.4ha)[2]	0.64	0.60						
Y, length of survey risk window viewed (X * 3368)	2167	2016						
Step 1.2: Unweighted rate of birds (flux) through risk window (*T_wV*rate) T_wV rate=$T_wV/e/v$	0	8.96E-05						
Step 1.3: Weighted flux (weighted TwV rate)								
Metre-minutes at VP (Y*e)	3,901,095	3,628,732						
Weight: proportion of total effort made at the VP	0.52	0.48						
Weighted T_wV rate)	0	4.32E-05						
Step 1.4: Total flux through risk window during surveys (z)				4.32E-05	birds per metre per minute			
Step 1.5: Estimated total birds through survey risk window during autumn (*T_w*)								
Potentially active minutes: autumn season *(m)*[3]				75,560				
Total length of survey risk window (l)				3,368	m			
T_w =z**m**WP (seconds)				10,984				
Step 1.6: T_w adjusted from survey PCH band to actual PCH . adjT_w =T_w* (30-200m)/(25-200m)				10,670				
Step 1.7: Area of risk window *(W)*								
Length of risk window *(B)*				3,368	m			

Height of rotors *(h)*	170	m	
Area of risk window: *W=B*h*	572,560	m^2	
Step 1.8: Area swept by windfarm rotors *(A)*			
Number of turbines *(N)*	11		
π	3.1416		
Rotor radius *(R)*	85	m	
Rotor-swept area: $A=N*\pi*R^2$	249,678	m^2	
Step 1.9: Total birds through rotor-swept area during autumn (T_r)			
$T_r=T_w*(A/W)$	4653.0	birds/transits	
STAGE 2: Probability of Collision for a bird flying through rotors (*p*(collision))			
Step 2.1: *p*(collision) from SNH spreadsheet[4]	0.053		
STAGE 3: Predicted annual mortality outside breeding season			
Step 3.1: With no avoidance, turbines operational 85% of the time			
*N*p*(collision)*0.85	209.62		
Step 3.2: Adjusted using a range of avoidance rates:		approx one collision every (years)	
99.8%	0.42		2.385297376

[1] The survey risk window is based on the windfarm polygon and so includes a precautionary 500m buffer to either side of the outermost rotors

[2] These proportions sum to more than 1.0 due to extensive overlapping.

[3] The total number of daytime plus 25% nocturnal minutes during the period.

[4]Assumes bird length=0.65m, wingspan 1.53m, flight speed=17m/sec

Greylag Goose East Array; Autumn

	Viewsheds							
	3	**4**						
STAGE 1: Number of rotor transits								
Step 1.1: Number of birds flying through the survey risk window[1], recorded within each viewshed (T_wV)	173	0						
Minutes survey effort (*e*)	1,800	1,800						
Windfarm area (ha) within viewshed (*v*)	421.1	391.7						
X, proportion of windfarm area (WP is 654.4ha)[2]	0.64	0.60						
Y, length of survey risk window viewed (X * 3368)	2167	2016						
Step 1.2: Unweighted rate of birds (flux) through risk window ($T_wV$rate) T_wV rate=$T_wV/e/v$	4.43E-05	0						
Step 1.3: Weighted flux (weighted TwV rate)								
Metre-minutes at VP (Y*e)	3,901,095	3,628,732						
Weight: proportion of total effort made at the VP	0.52	0.48						
Weighted T_wV rate)	2.3E-05	0						
Step 1.4: Total flux through risk window during surveys (z)				2.30E-05	birds per metre per minute			
Step 1.5: Estimated total birds through survey risk window during autumn (T_w)								
Potentially active minutes: autumn *(m)*[3]				75,560				
Total length of survey risk window (l)				3,368	m			
T_w =z**m**WP (seconds)				5,847				
Step 1.6: T_w adjusted from survey PCH band to actual PCH . adjT_w =T_w* (30-200m)/(25-200m)				5,680				
Step 1.7: Area of risk window *(W)*								
Length of risk window *(B)*				3,368	m			

Height of rotors *(h)*	170	m	
Area of risk window: *W=B*h*	572,560	m^2	
Step 1.8: Area swept by windfarm rotors *(A)*			
Number of turbines *(N)*	11		
π	3.1416		
Rotor radius *(R)*	85	m	
Rotor-swept area: $A=N*\pi*R^2$	249,678	m^2	
Step 1.9: Total birds through rotor-swept area during autumn (T_r)			
$T_r=T_w*(A/W)$	2476.8	birds/transits	
STAGE 2: Probability of Collision for a bird flying through rotors (*p*(collision))			
Step 2.1: *p*(collision) from SNH spreadsheet[4]	0.057		
STAGE 3: Predicted annual mortality during autumn			
Step 3.1: With no avoidance, turbines operational 85% of the time			
*N***p*(collision)*0.85	120.00		
Step 3.2: Adjusted using a range of avoidance rates:		approx one collision every (years)	
99.8%	0.24		4.166590336

[1] The survey risk window is based on the windfarm polygon and so includes a precautionary 500m buffer to either side of the outermost rotors

[2] These proportions sum to more than 1.0 due to extensive overlapping.

[3] The total number of daytime plus 25% nocturnal minutes during the period.

[4]Assumes bird length=0.83m, wingspan 1.64m, flight speed=17m/sec

Common Gull East Array; Breeding Season

	Viewsheds							
	3	4						
STAGE 1: Number of rotor transits								
Step 1.1: Number of birds flying through the survey risk window[1], recorded within each viewshed (T_wV)	1	0						
Minutes survey effort (*e*)	2,620	2,340						
Windfarm area (ha) within viewshed (*v*)	421.1	391.7						
X, proportion of windfarm area (WP is 654.4ha)[2]	0.64	0.60						
Y, length of survey risk window viewed (X * 3368)	2167	2016						
Step 1.2: Unweighted rate of birds (flux) through risk window ($T_wV$rate) T_wV rate=$T_wV/e/v$	1.76E-07	0						
Step 1.3: Weighted flux (weighted TwV rate)								
Metre-minutes at VP (Y*e)	5,678,261	4,717,351						
Weight: proportion of total effort made at the VP	0.55	0.45						
Weighted T_wV rate)	9.62E-08	0						
Step 1.4: Total flux through risk window during surveys (z)				9.62E-08	birds per metre per minute			
Step 1.5: Estimated total birds through survey risk window during the breeding season (T_w)								
Potentially active minutes: breeding season *(m)*[3]				167,271				
Total length of survey risk window (l)				3,368	m			
T_w =z**m**WP (seconds)				54				
Step 1.6: T_w adjusted from survey PCH band to actual PCH . adjT_w =T_w* (30-200m)/(25-200m)				53				
Step 1.7: Area of risk window *(W)*								
Length of risk window *(B)*				3,368	m			

Height of rotors *(h)*	170	m
Area of risk window: *W=B*h*	572,560	m^2
Step 1.8: Area swept by windfarm rotors *(A)*		
Number of turbines *(N)*	11	
π	3.1416	
Rotor radius *(R)*	85	m
Rotor-swept area: $A=N*\pi*R^2$	249,678	m^2
Step 1.9: Total birds through rotor-swept area outside breeding season (T_r)		
$T_r=T_w*(A/W)$	23.0	birds/transits
STAGE 2: Probability of Collision for a bird flying through rotors (*p*(collision))		
Step 2.1: *p*(collision) from SNH spreadsheet[4]	0.047	
STAGE 3: Predicted annual mortality during breeding season		
Step 3.1: With no avoidance, turbines operational 85% of the time		
*N*p*(collision)*0.85	0.92	
Step 3.2: Adjusted using a range of avoidance rates:		approx one collision every (years)
98%	0.02	54.51804425

Common Gull West Array; Breeding Season

	Viewsheds							
	1	2						
STAGE 1: Number of rotor transits								
Step 1.1: Number of birds flying through the survey risk window[1], recorded within each viewshed (T_wV)	0	8						
Minutes survey effort (*e*)	2,880	2,880						
Windfarm area (ha) within viewshed (*v*)	290.0	181.0						
X, proportion of windfarm area (WP is 326.9ha)[2]	0.89	0.55						
Y, length of survey risk window viewed (X * 2144)	1902	1187						
Step 1.2: Unweighted rate of birds (flux) through risk window (*$T_wV$rate*) T_wV rate=$T_wV/e/v$	0	2.34E-06						
Step 1.3: Weighted flux (weighted TwV rate)								
Metre-minutes at VP (Y*e)	5,477,538	3,419,235						
Weight: proportion of total effort made at the VP	0.62	0.38						
Weighted T_wV rate)	0	8.99E-07						
Step 1.4: Total flux through risk window during surveys (z)				8.99E-07	birds per metre per minute			
Step 1.5: Estimated total birds through survey risk window during the breeding season (*T_w*)								
Potentially active minutes: breeding season *(m)*[3]				167,271				
Total length of survey risk window (l)				2,144	m			
T_w =z**m**WP (seconds)				322				
Step 1.6: T_w adjusted from survey PCH band to actual PCH . adjT_w =T_w* (30-200m)/(25-200m)				313				
Step 1.7: Area of risk window *(W)*								
Length of risk window *(B)*				2,144	m			

Height of rotors *(h)*	170	m
Area of risk window: $W=B*h$	364,480	m^2
Step 1.8: Area swept by windfarm rotors *(A)*		
Number of turbines *(N)*	5	
π	3.1416	
Rotor radius *(R)*	85	m
Rotor-swept area: $A=N*\pi*R^2$	113,490	m^2
Step 1.9: Total birds through rotor-swept area during breeding season (T_r)		
$T_r=T_w*(A/W)$	97.5	birds/transits
STAGE 2: Probability of Collision for a bird flying through rotors (*p*(collision))		
Step 2.1: *p*(collision) from SNH spreadsheet[4]	0.047	
STAGE 3: Predicted annual mortality during breeding season		
Step 3.1: With no avoidance, turbines operational 85% of the time		
*N***p*(collision)*0.85	3.90	
Step 3.2: Adjusted using a range of avoidance rates:		approx one collision every (years)
98%	0.08	12.83084849

[1] The survey risk window is based on the windfarm polygon and so includes a precautionary 500m buffer to either side of the outermost rotors

[2] These proportions sum to more than 1.0 due to extensive overlapping.

[3] The total number of daytime minutes during the period .

[4]Assumes bird length=0.42m, wingspan 1.3m, flight speed=13.4m/sec

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