

PEN MARCH WIND FARM

Avian Collision Risk Assessment

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1.0 Introduction

This report presents the results of Collision Risk Modelling (CRM) undertaken for four bird species to inform the Environmental Impact Assessment (EIA) for the proposed Pen March Wind Farm, which comprises six turbines.

The exact make, type and model of turbine to be used as part of the proposed wind farm development will be the result of a future tendering process and therefore an indicative 'candidate' turbine model has been assumed for this assessment. Modelling was therefore based on the use of Nordex N149 turbines, each with a rotor diameter of 149.1m, tip height of 180m and hub height of 105.45m.

Where there was sufficient bird flight activity within the Collision Risk Zone (CRZ) (i.e., within the Wind Farm Polygon (WP¹)) at Potential Collision Height (PCH), CRM was used to predict the number of individuals per primary target species (see Section 1.1) that might collide with the wind turbine rotors.

Sufficient flight activity was defined as a minimum total of two flights or minimum ten individuals of each primary target species recorded in each CRZ during each season of analysis².

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 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 modelling results are presented in Section 3 and copies of the modelling calculations for each species modelled are included in Appendices 01-02.

The results of the CRM, as presented in this report, will be used to inform the EIA for the proposed wind farm. The assessment of significance of potential impacts is beyond the scope of this report and is covered within the Environmental Statement (ES).

1.1 Primary Target Species

Target species for the surveys were defined by legal and/ or conservation status and potential vulnerability to impacts caused by wind turbines, as defined in current NatureScot Guidance (SNH 2017³) (also applicable to Wales) and were also informed by the results of the bird surveys as they progressed.

Primary target species were therefore as follows:

- All Annex I and/ or Schedule 1 raptor and owl species, including:
 - Hen harrier *Circus cyaneus*
 - Marsh harrier *Circus aeruginosus*
 - Red kite *Milvus milvus*
 - Merlin *Falco columbarius*
 - Peregrine *Falco peregrinus*
 - Kestrel *Falco tinnunculus*⁴
 - Short-eared owl *Asio flammeus*

¹ The Wind Farm Polygon includes the area within 500m of the outermost turbine blades in the proposed layout.

² Numbers below these thresholds are likely to result in negligible predicted mortality.

³ Scottish Natural Heritage (SNH) (2017). *Recommended Bird Survey Methods to Inform Impact Assessment of Onshore Wind Farms. Version 2.*

⁴ Not Annex I or Schedule 1 but selected as a species of conservation concern with behaviour which results in potential vulnerability to collision impacts.

- All wildfowl species, excluding feral geese, and all wader species, including:
 - Mallard *Anas platyrhynchos*
 - Goosander *Mergus merganser*
 - Curlew *Numenius arquata*
 - Snipe *Gallinago gallinago*
 - Golden plover *Pluvialis apricaria*
 - Lapwing *Vanellus vanellus*

Secondary Target Species, as follows, were not subject to CRM;

- Non-Annex I and/ or Schedule 1 raptor species, including:
 - Buzzard *Buteo buteo*
 - Large gull species (herring gull *Larus argentatus*, lesser black-backed gull *Larus fuscus*)
 - Raven *Corvus corax*

2.0 Methods

The standard Band CRM (Band *et. al.* 2007⁵) 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 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.

2.1 Prediction of Rotor Transits from Vantage Point Survey Data

2.1.1 Survey Data April 2019 to March 2021

The number of birds that fly through the rotor swept area was estimated using flight data gathered during baseline studies carried out during two breeding seasons and two non-breeding seasons. These surveys gathered data from two vantage points (VPs), as summarised in **Table 2-1**.

Table 2-1
VP Surveys undertaken at Pen March, April 2019 – March 2021

VP Number	OS Grid Reference	Hours of Survey Completed				
		Apr-Aug 2019	Sep 2019-Feb 2020	Apr-Aug 2020	Sep 2020-Mar 2021	Total
1	SO 09017 11354	36	36	36	36	144
2	SO 07915 09699	36	36	36	36	144

2.1.2 Viewshed Data

Viewshed data are summarised in **Table 2-2**. A plan showing the VP locations and the viewsheds from each VP is provided in ES Figure 8.2. The combined viewshed area (minus overlap) from VP1 & VP2 (3,564,807m²) represents 94.97% of the WP (3,753,506m²). It is therefore considered that the vantage point data are representative of the site as a whole and sufficient to inform a robust assessment of the proposed development.

Table 2-2
Pen March VP Viewshed Data

VP/ Viewshed Number	Area of visibility (m ²)*
VP 1 viewshed	1,583,012
VP 2 viewshed	2,840,119
VP 1&2 viewshed combined (including overlap)	4,423,131

⁵ 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.

VP/ Viewshed Number	Area of visibility (m ²)*
VP 1&2 viewshed overlap	669,625
VP 1&2 viewshed combined (minus overlap)	3,564,807
	* area calculated in GIS using offset of 30m above ground level

2.1.3 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 the WP – defined by a 500 m 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 2 km distance truncation was used in the viewshed (i.e., the area visible) from each VP (as per NS guidance).

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

2.1.4 Correcting Survey PCH to Actual PCH

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

- 1 = <15m
- 2 = 15-30m
- 3 = 30-150m
- 4 = 150-200m
- 5 = >200m

As such, the height bands used to record flight activity do not correspond precisely to PCH for the proposed development (30-180m⁶), specifically height band 4 exceeds the upper limit of the actual PCH.

Because of this it was necessary to make assumptions about the distribution of some of the flight heights recorded. Assuming an equal distribution of heights within height band 4, it is clear that a proportion of flights will be below risk height. Therefore, as theoretically only a proportion of flights from 150-200m are at risk, the proportion of flights included within the CRM in height band 4 was assumed to be 30/50.

2.1.5 Seasonal Definitions

CRMs were constructed using data from the relevant breeding and non-breeding season periods, defined as April – August (breeding season) and September – March (non-breeding season, as per SNH (2017)).

⁶ Using the turbine data in Table 2-4, with the rotor radius rounded up to 75m.

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 period⁷.

2.1.6 Undertaking CRM

Collision risk modelling employs an estimated three-dimensional risk volume, in keeping with the assumption that flight directions are random in space. For species with non-directional (e.g., random, circling and foraging) flights, as at Pen March, the occupancy data are derived by multiplying the numbers of a particular species flying through the survey risk area by the total time spent within the survey risk area.

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

- The total observation effort within the risk volume (V_w) visible from each VP;
- The occupancy total: the total time spent by a particular species flying within the risk volume (V_w) visible from each VP;
- An estimation of average daylight hours within the season of analysis;
- Species-specific bird parameters (Table 2-3); and
- Wind farm parameters (Table 2-4).

The NS CRM spreadsheet⁸ 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 (hours per hectare) 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.

2.1.7 Bird Biometrics and Avoidance Rates

Measurements and flight speeds of the species for which CRM was undertaken were derived from Provan & Whitfield (2007⁹), Bruderer & Boldt (2001¹⁰) and Alerstram *et al.* (2007¹¹). The avoidance rates for these species are taken from NS (2018¹²) and are shown in **Table 2-3**.

Table 2-3
Bird biometrics and avoidance rates used in CRM

Species name	Bird length (m)	Wingspan (m)	Flight speed (m/s)	Avoidance rate (%)
Red kite	0.63	1.85	10.5	99
Kestrel	0.34	0.8	12.7	95
Peregrine	0.45	1.1	14	98

⁷ <https://www.timeanddate.com>.

⁸ <https://www.nature.scot/wind-farm-impacts-birds-calculating-probability-collision> [Accessed in August 2021].

⁹ Provan, S. and Whitfield, D.P. (2007) Avian flight speeds and biometrics for use in collision risk modelling. Report to Scottish Natural Heritage.

¹⁰ Bruderer, B. and Bolt, A. (2001) Flight characteristics of birds: 1. Radar measurements of speeds, *Ibis*, **143**. 178 – 204.

¹¹ Alerstram T, Rosén M, Bäckman J, Ericson PG, Hellgren O. (2007). Flight speeds among bird species: allometric and phylogenetic effects. *PLoS Biol*.

¹² 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>.

Species name	Bird length (m)	Wingspan (m)	Flight speed (m/s)	Avoidance rate (%)
Golden plover	0.28	0.7	18	98

2.1.8 Wind Farm and Turbine Parameters

The wind turbine parameters used in the CRM are detailed in **Table 2-4** and are based on the use of Nordex N149 turbines, which are considered a reasonable representation of various turbines under consideration.

Table 2-4
Wind farm & turbine parameters

Parameter	Value
Size of wind farm polygon (WP) ¹³	375.4ha
Number of turbines	6
Rotor radius/ diameter	74.55m/ 149.1m
Hub height	105.45m
Max. chord	4.15m
Pitch	6°
Rotation period	4.88s (max 12.3rpm)
Turbine operation time	90%

2.2 Pen March Flightline Data

Table 2-5 summarises the primary target species flight data from VPs from the 2019, 2019/2020, 2020 and 2020/2021 survey periods. Flight line data are shown on drawings within the relevant baseline survey reports (ES Technical Appendix 8.1-8.4). Species/ seasons with sufficient flight data and taken forward to CRM are shown in **bold**.

Table 2-5
Number of target species flights and individuals observed passing through the Pen March CRZ during VP surveys (2019-2021)

Species name	Period of analysis	Total number of birds recorded in flight	Flights through CRZ		Flights through CRZ at PCH	
			Flights	Individuals	Flights	Individuals
Mallard	Breeding season 2019 (1 Apr-31 Aug)	3	0	0	0	0

¹³ The Wind Farm Polygon includes the area within 500m of the outermost turbine blades.

Species name	Period of analysis	Total number of birds recorded in flight	Flights through CRZ		Flights through CRZ at PCH	
			Flights	Individuals	Flights	Individuals
	Non-breeding season 2019/20 (1 Sep-31 Mar)	10	1	4	0	0
	Breeding season 2020 (1 Apr-31 Aug)	8	2	2	0	0
Tufted duck	Non-breeding season 2019/20 (1 Sep-31 Mar)	3	0	0	0	0
	Non-breeding season 2020/21 (1 Sep-31 Mar)	16	0	0	0	0
Goosander	Non-breeding season 2019/20 (1 Sep-31 Mar)	19	0	0	0	0
	Breeding season 2020 (1 Apr-31 Aug)	18	0	0	0	0
	Non-breeding season 2020/21 (1 Sep-31 Mar)	7	0	0	0	0
Red kite	Breeding season 2019 (1 Apr-31 Aug)	60	42	47	23	27
	Non-breeding season 2019/20 (1 Sep-31 Mar)	19	17	17	0	0
	Breeding season 2020 (1 Apr-31 Aug)	81	53	68	20	30
	Non-breeding season 2020/21 (1 Sep-31 Mar)	44	33	34	8	9
Marsh harrier	Breeding season 2019 (1 Apr-31 Aug)	9	9	9	0	0
Hen Harrier	Breeding season 2019 (1 Apr-31 Aug)	2	2	2	0	0
	Non-breeding season 2019/20 (1 Sep-31 Mar)	2	2	2	0	0

Species name	Period of analysis	Total number of birds recorded in flight	Flights through CRZ		Flights through CRZ at PCH	
			Flights	Individuals	Flights	Individuals
	Breeding season 2020 (1 Apr-31 Aug)	9	8	9	0	0
	Non-breeding season 2020/21 (1 Sep-31 Mar)	8	6	6	0	0
Kestrel * incomplete data in July/August 2020 when mistakenly recorded as secondary species only ¹⁴	Breeding season 2019 (1 Apr-31 Aug)	3	3	3	2	2
	Non-breeding season 2019/20 (1 Sep-31 Mar)	2	1	1	0	0
	Breeding season 2020 (1 Apr-31 Aug)*	1	0	0	0	0
	Non-breeding season 2020/21 (1 Sep-31 Mar)	15	14	15	0	0
Merlin	Breeding season 2020 (1 Apr-31 Aug)	3	3	3	0	0
	Non-breeding season 2020/21 (1 Sep-31 Mar)	1	1	1	0	0
Peregrine	Breeding season 2019 (1 Apr-31 Aug)	4	2	2	2	2
	Non-breeding season 2019/20 (1 Sep-31 Mar)	3	2	2	2	2
	Breeding season 2020 (1 Apr-31 Aug)	2	2	2	2	2
	Non-breeding season 2020/21 (1 Sep-31 Mar)	1	1	1	0	0
Golden plover	Non-breeding season 2019/20 (1 Sep-31 Mar)	289	3	289	2	282
	Breeding season 2020 (1 Apr-31 Aug)	13.	3	13	0	0

¹⁴ As a secondary species, kestrel was only recorded on two occasions during this period.

Species name	Period of analysis	Total number of birds recorded in flight	Flights through CRZ		Flights through CRZ at PCH	
			Flights	Individuals	Flights	Individuals
	Non-breeding season 2020/21 (1 Sep-31 Mar)	13	3	13	2	5
Lapwing	Non-breeding season 2020/21 (1 Sep-31 Mar)	36	1	6	0	0
Snipe	Breeding season 2019 (1 Apr-31 Aug)	2	0	0	0	0
	Non-breeding season 2020/21 (1 Sep-31 Mar)	1	1	1	0	0
Curlew	Breeding season 2019 (1 Apr-31 Aug)	4	1	1	0	0
	Breeding season 2020 (1 Apr-31 Aug)	28	13	18	0	0
Short-eared owl	Non-breeding season 2020/21 (1 Sep-31 Mar)	2	2	2	0	0

2.3 Summary Flightline Data

Species input data are detailed in **Table 2-6** to **Table 2-13** inclusive. Note that all flights in height band 4 are presented here and the model then adjusts flight at survey risk height to flight at actual rotor heights in Step 1.3 (see CRM calculations in Appendix 02).

Table 2-6
Details of red kite flights recorded from VPs within CRZ, April 2019 to March 2020

Period	VP No.	No. of flights	No. of birds	Total flying time (s)	Time in height category (s)					
					<15m	15-30m	30-150m	150-200m	>200m	Risk height (30-200m)
Apr-19 to Aug-19	VP1	23	26	2672	882	625	667	132	366	799
	VP2	19	21	3042	308	1246	1396	92	0	1488
Sep-19 to Mar-20	VP1	8	8	296	168	128	0	0	0	0
	VP2	9	9	386	308	78	0	0	0	0
Total		59	64	6396	1666	2077	2063	224	366	2737

Table 2-7
Details of red kite flights recorded from VPs within CRZ, April 2020 to March 2021

Period	VP No.	No. of flights	No. of birds	Total flying time (s)	Time in height category (s)					
					<15m	15-30m	30-150m	150-200m	>200m	Risk height (30-200m)
Apr-20 to Aug-20	VP1	14	22	3858	1152	1601	1105	0	0	1105
	VP2	39	46	5465	1965	2181	1095	154	70	1249
Sep-20 to Mar-21	VP1	13	14	1926	923	693	310	0	0	310
	VP2	20	20	2158	784	576	798	0	0	798
Total		86	102	13407	4824	5051	3308	154	70	5749

Table 2-8
Details of kestrel flights recorded from VPs within CRZ, April 2019 to March 2020

Period	VP No.	No. of flights	No. of birds	Total flying time (s)	Time in height category (s)					
					<15m	15-30m	30-150m	150-200m	>200m	Risk height (30-200m)
Apr-19 to Aug-19	VP1	1	1	96	15	81	0	0	0	0
	VP2	2	2	409	0	260	149	0	0	149
Sep-19 to Mar-20	VP1	0	0	0	0	0	0	0	0	0
	VP2	1	1	63	33	30	0	0	0	0
Total		4	4	568	48	371	149	0	0	149

Table 2-9
Details of kestrel flights recorded from VPs within CRZ, April 2020 to March 2021

Period	VP No.	No. of flights	No. of birds	Total flying time (s)	Time in height category (s)					
					<15m	15-30m	30-150m	150-200m	>200m	Risk height (30-200m)
Apr-19 to Aug-19	VP1	0	0	0	0	0	0	0	0	0
	VP2	0	0	0	0	0	0	0	0	0
	VP1	5	5	703	703	0	0	0	0	0

Period	VP No.	No. of flights	No. of birds	Total flying time (s)	Time in height category (s)					
					<15m	15-30m	30-150m	150-200m	>200m	Risk height (30-200m)
Sep-19 to Mar-20	VP2	9	10	1598	1538	60	0	0	0	0
Total		14	15	2301	2241	60	0	0	0	0

Table 2-10
Details of peregrine flights recorded from VPs within CRZ, April 2019 to March 2020

Period	VP No.	No. of flights	No. of birds	Total flying time (s)	Time in height category (s)					
					<15m	15-30m	30-150m	150-200m	>200m	Risk height (30-200m)
Apr-19 to Aug-19	VP1	1	1	19	0	0	19	0	0	19
	VP2	1	1	40	0	0	15	25	0	40
Sep-19 to Mar-20	VP1	0	0	0	0	0	0	0	0	0
	VP2	2	2	174	9	30	135	0	0	135
Total		4	4	233	9	30	169	25	0	194

Table 2-11
Details of peregrine flights recorded from VPs within CRZ, April 2020 to March 2021

Period	VP No.	No. of flights	No. of birds	Total flying time (s)	Time in height category (s)					
					<15m	15-30m	30-150m	150-200m	>200m	Risk height (30-200m)
Apr-19 to Aug-19	VP1	0	0	0	0	0	0	0	0	0
	VP2	0	0	0	0	0	0	0	0	0
Sep-19 to Mar-20	VP1	1	1	210	0	210	0	0	0	0
	VP2	0	0	0	0	0	0	0	0	0
Total		1	1	210	0	210	0	0	0	0

Table 2-12
Details of golden plover flights recorded from VPs within CRZ, April 2019 to March 2020

Period	VP No.	No. of flights	No. of birds	Total flying time (s)	Time in height category (s)					
					<15m	15-30m	30-150m	150-200m	>200m	Risk height (30-200m)
Apr-19 to Aug-19	VP1	0	0	0	0	0	0	0	0	0
	VP2	0	0	0	0	0	0	0	0	0
Sep-19 to Mar-20	VP1	0	0	0	0	0	0	0	0	0
	VP2	3	289	11682	28	0	6600	3734	1320	10334
Total		3	289	11682	28	0	6600	3734	1320	10334

Table 2-13
Details of golden plover flights recorded from VPs CRZ, April 2020 to March 2021

Period	VP No.	No. of flights	No. of birds	Total flying time (s)	Time in height category (s)					
					<15m	15-30m	30-150m	150-200m	>200m	Risk height (30-200m)
Apr-19 to Aug-19	VP1	2	2	230	105	125	0	0	0	0
	VP2	1	11	110	110	0	0	0	0	0
Sep-19 to Mar-20	VP1	1	10	210	0	10	0	0	0	0
	VP2	2	12	800	0	480	320	0	0	320
Total		6	35	1350	215	615	320	0	0	320

3.0 Collision Risk Modelling Results

Table 3-1 summarises the predicted collision rates for each target species with sufficient data to undertake modelling.

Table 3-1
Summary of CRM Output

Species name	Area and period of analysis	Modelled collisions per Season/ Year	Years per collision
Red kite	Breeding season (01 Apr-31 Aug)	0.1456	6.87
	Non-breeding season (01 Sep-31 Mar)	0.0315	31.79
	Annual	0.1718	5.82
Kestrel	Breeding season (01 Apr-31 Aug)	0.0197	50.86
	Annual	0.0187	53.39
Peregrine	Breeding season (01 Apr-31 Aug)	0.0037	269.40
	Non-breeding season (01 Sep-31 Mar)	0.0077	130.08
	Annual	0.0116	86.01
Golden plover	Non-breeding season (01 Sep-31 Mar)	0.6310	1.58
	Annual	0.6641	1.51

APPENDIX 01

CRM Probability Calculations

Peregrine

K: [1D or 3D] (0 or 1)	1	Calculation of alpha and p(collision) as a function of radius									
NoBlades	3					Upwind:			Downwind:		
MaxChord	4.1	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	0.45	m	0.025	0.575	5.83	20.34	0.89	0.00112	19.85	0.87	0.00109
Wingspan	1.1	m	0.075	0.575	1.94	6.95	0.30	0.00229	6.45	0.28	0.00212
F: Flapping (0) or gliding (-)	0		0.125	0.702	1.17	4.92	0.22	0.00270	4.32	0.19	0.00237
			0.175	0.860	0.83	4.21	0.18	0.00323	3.47	0.15	0.00267
Bird speed	14	m/sec	0.225	0.994	0.65	3.77	0.17	0.00372	2.92	0.13	0.00288
RotorDiam	149.1	m	0.275	0.947	0.53	3.04	0.13	0.00367	2.22	0.10	0.00269
RotationPeriod	4.88	sec	0.325	0.899	0.45	2.52	0.11	0.00360	1.75	0.08	0.00250
			0.375	0.851	0.39	2.16	0.10	0.00356	1.44	0.06	0.00236
			0.425	0.804	0.34	1.92	0.08	0.00358	1.23	0.05	0.00230
			0.475	0.756	0.31	1.72	0.08	0.00359	1.07	0.05	0.00224
Bird aspect ratioo: β	0.41		0.525	0.708	0.28	1.56	0.07	0.00359	0.95	0.04	0.00219
			0.575	0.660	0.25	1.42	0.06	0.00358	0.85	0.04	0.00215
			0.625	0.613	0.23	1.30	0.06	0.00356	0.77	0.03	0.00211
			0.675	0.565	0.22	1.19	0.05	0.00353	0.71	0.03	0.00209
			0.725	0.517	0.20	1.10	0.05	0.00349	0.65	0.03	0.00208
			0.775	0.470	0.19	1.01	0.04	0.00344	0.61	0.03	0.00207
			0.825	0.422	0.18	0.94	0.04	0.00339	0.57	0.03	0.00208
			0.875	0.374	0.17	0.86	0.04	0.00332	0.54	0.02	0.00209
			0.925	0.327	0.16	0.80	0.04	0.00325	0.52	0.02	0.00211
			0.975	0.279	0.15	0.74	0.03	0.00317	0.50	0.02	0.00214
			Overall p(collision) =				Upwind	6.5%		Downwind	4.4%
								Average	5.5%		

Golden Plover

K: [1D or 3D] (0 or 1)	1	Calculation of alpha and p(collision) as a function of radius									
NoBlades	3				Upwind:			Downwind:			
MaxChord	4.1	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	0.28	m	0.025	0.575	7.50	23.08	0.79	0.00099	22.59	0.77	0.00096
Wingspan	0.7	m	0.075	0.575	2.50	7.86	0.27	0.00201	7.37	0.25	0.00189
F: Flapping (0) or gliding (-)	0		0.125	0.702	1.50	5.64	0.19	0.00241	5.04	0.17	0.00215
			0.175	0.860	1.07	4.88	0.17	0.00291	4.14	0.14	0.00247
Bird speed	18	m/sec	0.225	0.994	0.83	4.39	0.15	0.00337	3.54	0.12	0.00272
RotorDiam	149.1	m	0.275	0.947	0.68	3.52	0.12	0.00330	2.70	0.09	0.00254
RotationPeriod	4.88	sec	0.325	0.899	0.58	2.90	0.10	0.00322	2.13	0.07	0.00237
			0.375	0.851	0.50	2.45	0.08	0.00314	1.72	0.06	0.00220
			0.425	0.804	0.44	2.10	0.07	0.00305	1.41	0.05	0.00205
			0.475	0.756	0.39	1.82	0.06	0.00295	1.17	0.04	0.00190
Bird aspect ratio α : β	0.40		0.525	0.708	0.36	1.61	0.06	0.00290	1.01	0.03	0.00181
			0.575	0.660	0.33	1.44	0.05	0.00283	0.88	0.03	0.00172
			0.625	0.613	0.30	1.29	0.04	0.00276	0.77	0.03	0.00164
			0.675	0.565	0.28	1.16	0.04	0.00268	0.68	0.02	0.00156
			0.725	0.517	0.26	1.05	0.04	0.00259	0.60	0.02	0.00150
			0.775	0.470	0.24	0.94	0.03	0.00250	0.54	0.02	0.00143
			0.825	0.422	0.23	0.85	0.03	0.00240	0.49	0.02	0.00138
			0.875	0.374	0.21	0.77	0.03	0.00229	0.45	0.02	0.00133
			0.925	0.327	0.20	0.69	0.02	0.00218	0.41	0.01	0.00130
			0.975	0.279	0.19	0.62	0.02	0.00206	0.38	0.01	0.00126
			Overall p(collision) =			Upwind		5.3%	Downwind		3.6%
							Average		4.4%		

APPENDIX 02

CRM Calculations

Red Kite Breeding Season

	Viewsheds								
	1	2							
STAGE 1: Estimation of rotor transits									
Step 1.1: Seconds occupancy of the survey risk volume (T_w)¹ recorded within each viewshed (T_wV)	1904	2,737							
Step 1.2: Unweighted occupancy rate each viewshed (T_wVrate)									
Hours of survey effort (e)	72	72							
Windfarm area (ha) visible within viewshed (v)	158.30	284.00							
Observation effort (HaHr)	11397.60	20448.00							
T_wV rate = $T_wV/HaHr$	4.64E-05	3.72E-05							
Step 1.3: Weighted occupancy rate (weighted T_wV rate)¹									
Weight: proportion of total effort made at the VP	0.358	0.642							
Weighted T_wV rate (T_wV rate * weight)	1.66E-05	2.39E-05							
Total weighted occupancy rate	0.000040 birds seconds per ha/hour								
Mean activity hr ⁻¹ in wind farm at risk height	1.519%								
Mean activity hr ⁻¹ in wind farm at rotor height (z)	1.333%								

Step 1.4: Total occupancy of risk volume during surveys (T_w)		
Hours potentially active: breeding season (a) ²	2,352	hours
$T_w = z * a$	31.35	hours
Step 1.6: Flight risk volume (V_w)		
Risk volume: $V_w = A * h$ where A is actual wind farm area and h is height of rotors	559,647,745	m ³
Step 1.7: Volume swept by windfarm rotors (V_r)		
Bird length (L)	0.63	m
Rotor-swept volume: $V_r = N * \pi * r^2 * (d + L)$ where N is number of turbines, r is rotor radius and d is depth of blade (max chord used)	326,223.34	m ³
Step 1.8: Bird occupancy of rotor-swept volume (T_r)		
$T_r = T_w * (V_r / V_w)$	65.7834	seconds
Step 1.9: Time taken to transit rotor (t)		
Flight speed (s)	10.5	m/sec
$t = (d + L) / s$	0.30	seconds
Step 1.10: Number of rotor transits (N)		
$N = T_r / t$	222	rotor transits
STAGE 2: Probability of Collision for a bird flying through rotors ($p(\text{collision})$) from SNH spreadsheet⁴	0.073	
STAGE 3: Predicted mortality (birds per year)		

Step 3.1: With no avoidance, turbines operational 90% of the time N*p(collision)*0.90	14.557	collisions
Step 3.2: Adjusted using a range of avoidance rates:		
99%	0.1456	approx one collision every 6.87 years

¹ The survey risk volume was derived from the windfarm polygon including a precautionary 500m buffer around the turbine rotors.

² The total number of daylight hours during the period

⁴Assumes bird length=0.63m, wingspan 1.85m, flight speed= 10.5m/sec

Red Kite Non-Breeding Season

	Viewsheds								
	1	2							
STAGE 1: Estimation of rotor transits									
Step 1.1: Seconds occupancy of the survey risk volume (T_w)¹ recorded within each viewshed (T_wV)	310	798							
Step 1.2: Unweighted occupancy rate each viewshed (T_wVrate)									
Hours of survey effort (e)	72	72							
Windfarm area (ha) visible within viewshed (v)	158.30	284.00							
Observation effort (HaHr)	11397.60	20448.00							
$T_wV rate = T_wV / HaHr$	7.56E-06	1.08E-05							
Step 1.3: Weighted occupancy rate (weighted $T_wV rate$)¹									
Weight: proportion of total effort made at the VP	0.358	0.642							
Weighted $T_wV rate$ ($T_wV rate * weight$)	2.70E-06	6.96E-06							
Total weighted occupancy rate	0.000010 birds seconds per ha/hour								
Mean activity hr ⁻¹ in wind farm at risk height	0.363%								
Mean activity hr ⁻¹ in wind farm at rotor height (z)	0.318%								

Step 1.4: Total occupancy of risk volume during surveys (T_w)		
Hours potentially active: non-breeding season (a) ²	2,129	hours
$T_w = z \cdot a$	6.77	hours
Step 1.6: Flight risk volume (V_w)		
Risk volume: $V_w = A \cdot h$ where A is actual wind farm area and h is height of rotors	559,647,745	m ³
Step 1.7: Volume swept by windfarm rotors (V_r)		
Bird length (L)	0.63	m
Rotor-swept volume: $V_r = N \cdot \pi \cdot r^2 \cdot (d + L)$ where N is number of turbines, r is rotor radius and d is depth of blade (max chord used)	326,223.34	m ³
Step 1.8: Bird occupancy of rotor-swept volume (T_r)		
$T_r = T_w \cdot (V_r / V_w)$	14.22	seconds
Step 1.9: Time taken to transit rotor (t)		
Flight speed (s)	10.5	m/sec
$t = (d + L) / s$	0.30	seconds
Step 1.10: Number of rotor transits (N)		
$N = T_r / t$	48	rotor transits
STAGE 2: Probability of Collision for a bird flying through rotors ($p(\text{collision})$) from SNH spreadsheet⁴	0.073	
STAGE 3: Predicted mortality (birds per year)		

Step 3.1: With no avoidance, turbines operational 90% of the time N*p(collision)*0.90	3.146	collisions
Step 3.2: Adjusted using a range of avoidance rates:		
99%	0.0315	approx one collision every 31.79 years

¹ The survey risk volume was derived from the windfarm polygon including a precautionary 500m buffer around the turbine rotors.

² The total number of daylight hours during the period

⁴Assumes bird length=0.63m, wingspan 1.85m, flight speed= 10.5m/sec

Red Kite Annual

	Viewsheds							
	1	2						
STAGE 1: Estimation of rotor transits								
Step 1.1: Seconds occupancy of the survey risk volume (T_w)¹ recorded within each viewshed (T_wV)	2214	3,535						
Step 1.2: Unweighted occupancy rate each viewshed (T_wVrate)								
Hours of survey effort (e)	144	144						
Windfarm area (ha) visible within viewshed (v)	158.30	284.00						
Observation effort (HaHr)	22795.20	40896.00						
$T_wV rate = T_wV / HaHr$	2.70E-05	2.40E-05						
Step 1.3: Weighted occupancy rate (weighted $T_wV rate$)¹								
Weight: proportion of total effort made at the VP	0.358	0.642						
Weighted T_wV rate ($T_wV rate * weight$)	9.66E-06	1.54E-05						
Total weighted occupancy rate	0.000025 birds seconds per ha/hour							
Mean activity hr^{-1} in wind farm at risk height	0.941%							
Mean activity hr^{-1} in wind farm at rotor height (z)	0.825%							

Step 1.4: Total occupancy of risk volume during surveys (T_w)		
Hours potentially active: annual (a) ²	4,481	hours
$T_w = z * a$	36.99	hours
Step 1.6: Flight risk volume (V_w)		
Risk volume: $V_w = A * h$ where A is actual wind farm area and h is height of rotors	559,647,745	m ³
Step 1.7: Volume swept by windfarm rotors (V_r)		
Bird length (L)	0.63	m
Rotor-swept volume: $V_r = N * \pi * r^2 * (d + L)$ where N is number of turbines, r is rotor radius and d is depth of blade (max chord used)	326,223.34	m ³
Step 1.8: Bird occupancy of rotor-swept volume (T_r)		
$T_r = T_w * (V_r / V_w)$	77.6230	seconds
Step 1.9: Time taken to transit rotor (t)		
Flight speed (s)	10.5	m/sec
$t = (d + L) / s$	0.30	seconds
Step 1.10: Number of rotor transits (N)		
$N = T_r / t$	262	rotor transits
STAGE 2: Probability of Collision for a bird flying through rotors ($p(\text{collision})$) from SNH spreadsheet⁴	0.073	
STAGE 3: Predicted mortality (birds per year)		

Step 3.1: With no avoidance, turbines operational 90% of the time $N \cdot p(\text{collision}) \cdot 0.90$	17.177 collisions
Step 3.2: Adjusted using a range of avoidance rates:	
99%	0.1718 approx one collision every 5.82 years

¹ The survey risk volume was derived from the windfarm polygon including a precautionary 500m buffer around the turbine rotors.

² The total number of daytime hours during the period.

⁴ Assumes bird length=0.63m, wingspan 1.85m, flight speed= 10.5m/sec

Kestrel Breeding Season

	Viewsheds							
	1	2						
STAGE 1: Estimation of rotor transits								
Step 1.1: Seconds occupancy of the survey risk volume (T_w)¹ recorded within each viewshed (T_wV)	0	149						
Step 1.2: Unweighted occupancy rate each viewshed (T_wVrate)								
Hours of survey effort (e)	72	72						
Windfarm area (ha) visible within viewshed (v)	158.30	284.00						
Observation effort (HaHr)	11397.60	20448.00						
$T_wV rate = T_wV / HaHr$	0.00E+00	2.02E-06						
Step 1.3: Weighted occupancy rate (weighted $T_wV rate$)¹								
Weight: proportion of total effort made at the VP	0.358	0.642						
Weighted T_wV rate ($T_wV rate * weight$)	0.00E+00	1.30E-06						
Total weighted occupancy rate	0.000001 birds seconds per ha/hour							
Mean activity hr^{-1} in wind farm at risk height	0.049%							
Mean activity hr^{-1} in wind farm at rotor height (z)	0.043%							

Step 1.4: Total occupancy of risk volume during surveys (T_w)		
Hours potentially active: breeding season (a) ²	2,352	hours
$T_w = z * a$	1.01	hours
Step 1.6: Flight risk volume (V_w)		
Risk volume: $V_w = A * h$ where A is actual wind farm area and h is height of rotors	559,647,745	m ³
Step 1.7: Volume swept by windfarm rotors (V_r)		
Bird length (L)	0.34	m
Rotor-swept volume: $V_r = N * \pi * r^2 * (d + L)$ where N is number of turbines, r is rotor radius and d is depth of blade (max chord used)	295,842.87	m ³
Step 1.8: Bird occupancy of rotor-swept volume (T_r)		
$T_r = T_w * (V_r / V_w)$	1.9153	seconds
Step 1.9: Time taken to transit rotor (t)		
Flight speed (s)	12.7	m/sec
$t = (d + L) / s$	0.22	seconds
Step 1.10: Number of rotor transits (N)		
$N = T_r / t$	9	rotor transits
STAGE 2: Probability of Collision for a bird flying through rotors ($p(\text{collision})$) from SNH spreadsheet⁴	0.051	
STAGE 3: Predicted mortality (birds per year)		

Step 3.1: With no avoidance, turbines operational 90% of the time $N \cdot p(\text{collision}) \cdot 0.90$	0.393	collisions
Step 3.2: Adjusted using a range of avoidance rates:		
95%	0.0197	approx one collision every 50.86 years

¹ The survey risk volume was derived from the windfarm polygon including a precautionary 500m buffer around the turbine rotors.

² The total number of daylight hours during the period

⁴ Assumes bird length=0.34m, wingspan 0.8m, flight speed= 12.7m/sec

Kestrel Annual

	Viewsheds								
	1	2							
STAGE 1: Estimation of rotor transits									
Step 1.1: Seconds occupancy of the survey risk volume (T_w)¹ recorded within each viewshed (T_wV)	0	149							
Step 1.2: Unweighted occupancy rate each viewshed (T_wVrate)									
Hours of survey effort (e)	144	144							
Windfarm area (ha) visible within viewshed (v)	158.30	284.00							
Observation effort (HaHr)	22795.20	40896.00							
$T_wV \text{ rate} = T_wV / HaHr$	0.00E+00	1.01E-06							
Step 1.3: Weighted occupancy rate (weighted $T_wV \text{ rate}$)¹									
Weight: proportion of total effort made at the VP	0.358	0.642							
Weighted $T_wV \text{ rate}$ ($T_wV \text{ rate} * \text{weight}$)	0.00E+00	6.50E-07							
Total weighted occupancy rate	0.000001 birds seconds per ha/hour								
Mean activity hr ⁻¹ in wind farm at risk height	0.024%								
Mean activity hr ⁻¹ in wind farm at rotor height (z)	0.021%								

Step 1.4: Total occupancy of risk volume during surveys (T_w)		
Hours potentially active: annual (a) ²	4,481	hours
$T_w = z \cdot a$	0.96	hours
Step 1.6: Flight risk volume (V_w)		
Risk volume: $V_w = A \cdot h$ where A is actual wind farm area and h is height of rotors	559,647,745	m ³
Step 1.7: Volume swept by windfarm rotors (V_r)		
Bird length (L)	0.34	m
Rotor-swept volume: $V_r = N \cdot \pi \cdot r^2 \cdot (d + L)$ where N is number of turbines, r is rotor radius and d is depth of blade (max chord used)	295,842.87	m ³
Step 1.8: Bird occupancy of rotor-swept volume (T_r)		
$T_r = T_w \cdot (V_r / V_w)$	1.8244	seconds
Step 1.9: Time taken to transit rotor (t)		
Flight speed (s)	12.7	m/sec
$t = (d + L) / s$	0.22	seconds
Step 1.10: Number of rotor transits (N)		
$N = T_r / t$	8	rotor transits
STAGE 2: Probability of Collision for a bird flying through rotors ($p(\text{collision})$) from SNH spreadsheet⁴	0.051	
STAGE 3: Predicted mortality (birds per year)		

Step 3.1: With no avoidance, turbines operational 90% of the time N*p(collision)*0.90	0.375	collisions
Step 3.2: Adjusted using a range of avoidance rates:		
95%	0.0187	approx one collision every 53.39 years

¹ The survey risk volume was derived from the windfarm polygon including a precautionary 500m buffer around the turbine rotors.

² The total number of daytime hours during the period.

⁴Assumes bird length=0.34m, wingspan 0.8m, flight speed= 12.7m/sec

Peregrine Breeding Season

	Viewsheds								
	1	2							
STAGE 1: Estimation of rotor transits									
Step 1.1: Seconds occupancy of the survey risk volume (T_w)¹ recorded within each viewshed (T_wV)	19	40							
Step 1.2: Unweighted occupancy rate each viewshed (T_wVrate)									
Hours of survey effort (e)	72	72							
Windfarm area (ha) visible within viewshed (v)	158.30	284.00							
Observation effort (HaHr)	11397.60	20448.00							
$T_wV \text{ rate} = T_wV / HaHr$	4.63E-07	5.43E-07							
Step 1.3: Weighted occupancy rate (weighted $T_wV \text{ rate}$)¹									
Weight: proportion of total effort made at the VP	0.358	0.642							
Weighted $T_wV \text{ rate}$ ($T_wV \text{ rate} * \text{weight}$)	1.66E-07	3.49E-07							
Total weighted occupancy rate	0.000001 birds seconds per ha/hour								
Mean activity hr ⁻¹ in wind farm at risk height	0.019%								
Mean activity hr ⁻¹ in wind farm at rotor height (z)	0.017%								

Step 1.4: Total occupancy of risk volume during surveys (T_w)		
Hours potentially active: breeding season (a) ²	2,352	hours
$T_w = z \cdot a$	0.40	hours
Step 1.6: Flight risk volume (V_w)		
Risk volume: $V_w = A \cdot h$ where A is actual wind farm area and h is height of rotors	559,647,745	m ³
Step 1.7: Volume swept by windfarm rotors (V_r)		
Bird length (L)	0.45	m
Rotor-swept volume: $V_r = N \cdot \pi \cdot r^2 \cdot (d + L)$ where N is number of turbines, r is rotor radius and d is depth of blade (max chord used)	307,366.50	m ³
Step 1.8: Bird occupancy of rotor-swept volume (T_r)		
$T_r = T_w \cdot (V_r / V_w)$	0.7879	seconds
Step 1.9: Time taken to transit rotor (t)		
Flight speed (s)	14	m/sec
$t = (d + L) / s$	0.21	seconds
Step 1.10: Number of rotor transits (N)		
$N = T_r / t$	4	rotor transits
STAGE 2: Probability of Collision for a bird flying through rotors ($p(\text{collision})$) from SNH spreadsheet⁴	0.055	
STAGE 3: Predicted mortality (birds per year)		

Step 3.1: With no avoidance, turbines operational 90% of the time N*p(collision)*0.90	0.186	collisions
Step 3.2: Adjusted using a range of avoidance rates:		
98%	0.0037	approx one collision every 269.40 years

¹ The survey risk volume was derived from the windfarm polygon including a precautionary 500m buffer around the turbine rotors.

² The total number of daylight hours during the period

⁴Assumes bird length=0.45m, wingspan 1.1m, flight speed= 14m/sec

Peregrine Non-Breeding Season

	Viewsheds								
	1	2							
STAGE 1: Estimation of rotor transits									
Step 1.1: Seconds occupancy of the survey risk volume (T_w)¹ recorded within each viewshed (T_wV)	0	135							
Step 1.2: Unweighted occupancy rate each viewshed (T_wVrate)									
Hours of survey effort (e)	72	72							
Windfarm area (ha) visible within viewshed (v)	158.30	284.00							
Observation effort (HaHr)	11397.60	20448.00							
$T_wV \text{ rate} = T_wV / HaHr$	0.00E+00	1.83E-06							
Step 1.3: Weighted occupancy rate (weighted $T_wV \text{ rate}$)¹									
Weight: proportion of total effort made at the VP	0.358	0.642							
Weighted $T_wV \text{ rate}$ ($T_wV \text{ rate} * \text{weight}$)	0.00E+00	1.18E-06							
Total weighted occupancy rate	0.000001 birds seconds per ha/hour								
Mean activity hr ⁻¹ in wind farm at risk height	0.044%								
Mean activity hr ⁻¹ in wind farm at rotor height (z)	0.039%								

Step 1.4: Total occupancy of risk volume during surveys (T_w)		
Hours potentially active: non-breeding season (a) ²	2,129	hours
$T_w = z \cdot a$	0.83	hours
Step 1.6: Flight risk volume (V_w)		
Risk volume: $V_w = A \cdot h$ where A is actual wind farm area and h is height of rotors	559,647,745	m ³
Step 1.7: Volume swept by windfarm rotors (V_r)		
Bird length (L)	0.45	m
Rotor-swept volume: $V_r = N \cdot \pi \cdot r^2 \cdot (d + L)$ where N is number of turbines, r is rotor radius and d is depth of blade (max chord used)	307,366.50	m ³
Step 1.8: Bird occupancy of rotor-swept volume (T_r)		
$T_r = T_w \cdot (V_r / V_w)$	1.63	seconds
Step 1.9: Time taken to transit rotor (t)		
Flight speed (s)	14	m/sec
$t = (d + L) / s$	0.21	seconds
Step 1.10: Number of rotor transits (N)		
$N = T_r / t$	8	rotor transits
STAGE 2: Probability of Collision for a bird flying through rotors ($p(\text{collision})$) from SNH spreadsheet⁴	0.055	
STAGE 3: Predicted mortality (birds per year)		

Step 3.1: With no avoidance, turbines operational 90% of the time N*p(collision)*0.90	0.384	collisions
Step 3.2: Adjusted using a range of avoidance rates:		
98%	0.0077	approx one collision every 130.08 years

¹ The survey risk volume was derived from the windfarm polygon including a precautionary 500m buffer around the turbine rotors.

² The total number of daylight hours during the period

⁴Assumes bird length=0.45m, wingspan 1.1m, flight speed= 14m/sec

Peregrine Annual

	Viewsheds								
	1	2							
STAGE 1: Estimation of rotor transits									
Step 1.1: Seconds occupancy of the survey risk volume (T_w)¹ recorded within each viewshed (T_wV)	19	175							
Step 1.2: Unweighted occupancy rate each viewshed (T_wVrate)									
Hours of survey effort (e)	144	144							
Windfarm area (ha) visible within viewshed (v)	158.30	284.00							
Observation effort (HaHr)	22795.20	40896.00							
$T_wV \text{ rate} = T_wV / HaHr$	2.32E-07	1.19E-06							
Step 1.3: Weighted occupancy rate (weighted $T_wV \text{ rate}$)¹									
Weight: proportion of total effort made at the VP	0.358	0.642							
Weighted $T_wV \text{ rate}$ ($T_wV \text{ rate} * \text{weight}$)	8.29E-08	7.63E-07							
Total weighted occupancy rate	0.000001 birds seconds per ha/hour								
Mean activity hr ⁻¹ in wind farm at risk height	0.032%								
Mean activity hr ⁻¹ in wind farm at rotor height (z)	0.028%								

Step 1.4: Total occupancy of risk volume during surveys (T_w)		
Hours potentially active: annual (a) ²	4,481	hours
$T_w = z * a$	1.25	hours
Step 1.6: Flight risk volume (V_w)		
Risk volume: $V_w = A * h$ where A is actual wind farm area and h is height of rotors	559,647,745	m ³
Step 1.7: Volume swept by windfarm rotors (V_r)		
Bird length (L)	0.45	m
Rotor-swept volume: $V_r = N * \pi * r^2 * (d + L)$ where N is number of turbines, r is rotor radius and d is depth of blade (max chord used)	307,366.50	m ³
Step 1.8: Bird occupancy of rotor-swept volume (T_r)		
$T_r = T_w * (V_r / V_w)$	2.4680	seconds
Step 1.9: Time taken to transit rotor (t)		
Flight speed (s)	14	m/sec
$t = (d + L) / s$	0.21	seconds
Step 1.10: Number of rotor transits (N)		
$N = T_r / t$	12	rotor transits
STAGE 2: Probability of Collision for a bird flying through rotors ($p(\text{collision})$) from SNH spreadsheet⁴	0.055	
STAGE 3: Predicted mortality (birds per year)		

Step 3.1: With no avoidance, turbines operational 90% of the time N*p(collision)*0.90	0.581	collisions
Step 3.2: Adjusted using a range of avoidance rates:		
98%	0.0116	approx one collision every 86.01 years

¹ The survey risk volume was derived from the windfarm polygon including a precautionary 500m buffer around the turbine rotors.

² The total number of daytime hours during the period.

⁴Assumes bird length=0.45m, wingspan 1.1m, flight speed= 14m/sec

Golden Plover Non-Breeding Season

	Viewsheds								
	1	2							
STAGE 1: Estimation of rotor transits									
Step 1.1: Seconds occupancy of the survey risk volume (T_w)¹ recorded within each viewshed (T_wV)	0	10,654							
Step 1.2: Unweighted occupancy rate each viewshed (T_wVrate)									
Hours of survey effort (e)	72	72							
Windfarm area (ha) visible within viewshed (v)	158.30	284.00							
Observation effort (HaHr)	11397.60	20448.00							
$T_wV \text{ rate} = T_wV / HaHr$	0.00E+00	1.45E-04							
Step 1.3: Weighted occupancy rate (weighted $T_wV \text{ rate}$)¹									
Weight: proportion of total effort made at the VP	0.358	0.642							
Weighted $T_wV \text{ rate}$ ($T_wV \text{ rate} * \text{weight}$)	0.00E+00	9.29E-05							
Total weighted occupancy rate	0.000093 birds seconds per ha/hour								
Mean activity hr ⁻¹ in wind farm at risk height	3.488%								
Mean activity hr ⁻¹ in wind farm at rotor height (z)	3.059%								

Step 1.4: Total occupancy of risk volume during surveys (T_w)		
Hours potentially active: non-breeding season (a) ²	2,129	hours
$T_w = z \cdot a$	65.14	hours
Step 1.6: Flight risk volume (V_w)		
Risk volume: $V_w = A \cdot h$ where A is actual wind farm area and h is height of rotors	559,647,745	m ³
Step 1.7: Volume swept by windfarm rotors (V_r)		
Bird length (L)	0.28	m
Rotor-swept volume: $V_r = N \cdot \pi \cdot r^2 \cdot (d + L)$ where N is number of turbines, r is rotor radius and d is depth of blade (max chord used)	289,557.26	m ³
Step 1.8: Bird occupancy of rotor-swept volume (T_r)		
$T_r = T_w \cdot (V_r / V_w)$	121.32	seconds
Step 1.9: Time taken to transit rotor (t)		
Flight speed (s)	18	m/sec
$t = (d + L) / s$	0.15	seconds
Step 1.10: Number of rotor transits (N)		
$N = T_r / t$	790	rotor transits
STAGE 2: Probability of Collision for a bird flying through rotors ($p(\text{collision})$) from SNH spreadsheet⁴	0.044	
STAGE 3: Predicted mortality (birds per year)		

Step 3.1: With no avoidance, turbines operational 90% of the time N*p(collision)*0.90	31.549	collisions
Step 3.2: Adjusted using a range of avoidance rates:		
98%	0.6310	approx one collision every 1.58 years

¹ The survey risk volume was derived from the windfarm polygon including a precautionary 500m buffer around the turbine rotors.

² The total number of daylight hours during the period

⁴Assumes bird length=0.28m, wingspan 0.7m, flight speed= 18m/sec

Golden Plover Annual

	Viewsheds								
	1	2							
STAGE 1: Estimation of rotor transits									
Step 1.1: Seconds occupancy of the survey risk volume (T_w)¹ recorded within each viewshed (T_wV)	0	10,654							
Step 1.2: Unweighted occupancy rate each viewshed (T_wVrate)									
Hours of survey effort (e)	144	144							
Windfarm area (ha) visible within viewshed (v)	158.30	284.00							
Observation effort (HaHr)	22795.20	40896.00							
$T_wV \text{ rate} = T_wV / HaHr$	0.00E+00	7.24E-05							
Step 1.3: Weighted occupancy rate (weighted $T_wV \text{ rate}$)¹									
Weight: proportion of total effort made at the VP	0.358	0.642							
Weighted $T_wV \text{ rate}$ ($T_wV \text{ rate} * \text{weight}$)	0.00E+00	4.65E-05							
Total weighted occupancy rate	0.000046 birds seconds per ha/hour								
Mean activity hr ⁻¹ in wind farm at risk height	1.744%								
Mean activity hr ⁻¹ in wind farm at rotor height (z)	1.530%								

Step 1.4: Total occupancy of risk volume during surveys (T_w)		
Hours potentially active: annual (a) ²	4,481	hours
$T_w = z * a$	68.55	hours
Step 1.6: Flight risk volume (V_w)		
Risk volume: $V_w = A * h$ where A is actual wind farm area and h is height of rotors	559,647,745	m ³
Step 1.7: Volume swept by windfarm rotors (V_r)		
Bird length (L)	0.28	m
Rotor-swept volume: $V_r = N * \pi * r^2 * (d + L)$ where N is number of turbines, r is rotor radius and d is depth of blade (max chord used)	289,557.26	m ³
Step 1.8: Bird occupancy of rotor-swept volume (T_r)		
$T_r = T_w * (V_r / V_w)$	127.6822	seconds
Step 1.9: Time taken to transit rotor (t)		
Flight speed (s)	18	m/sec
$t = (d + L) / s$	0.26	seconds
Step 1.10: Number of rotor transits (N)		
$N = T_r / t$	832	rotor transits
STAGE 2: Probability of Collision for a bird flying through rotors ($p(\text{collision})$) from SNH spreadsheet⁴	0.044	
STAGE 3: Predicted mortality (birds per year)		

Step 3.1: With no avoidance, turbines operational 90% of the time N*p(collision)*0.90	33.203	collisions
Step 3.2: Adjusted using a range of avoidance rates:		
98%	0.6641	approx one collision every 1.51 years

¹ The survey risk volume was derived from the windfarm polygon including a precautionary 500m buffer around the turbine rotors.

² The total number of daytime hours during the period.

⁴Assumes bird length=0.28m, wingspan 0.7m, flight speed= 18m/sec

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