APPENDIX 7-6

COLLISION RISK ASSESSMENT

Collision Risk Assessment

Meenbog Wind Farm

DOCUMENT DETAILS

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1. INTRODUCTION

This document outlines the methodology used to conduct a collision risk assessment of Meenbog Wind Farm, Co. Donegal. This assessment calculates an annual collision rate using a mathematical model to predict the number of birds that may be killed by collision with moving wind turbine rotor blades. The modelling method used is the Collision Risk Model provided by Band (2024). This method is recommended by NatureScot and provides a standardised approach to collision risk assessment for onshore wind farms. Note that these are theoretical predictions, therefore the results must be interpreted with a degree of caution.

2. METHODOLOGY

2.1 Modelling Process

The collision risk model estimates the number of collisions through the following stages:

- **Stage A Flight activity** - uses bird survey data to establish the density of flying birds in the vicinity of the turbines, and the proportion flying at a risk height (between the lowest and highest points of the rotors).
- **Stage B Number of flights through rotors** – makes an estimate, based on the bird density and proportion at risk height, of the potential number of bird passages through rotors. The initial assumption is that birds will continue to make flights within the area at the same intensity as before.
- **Stage C Probability of collision** - calculates the probability of collision during a single bird rotor transit.
- **Stage D Expected collisions** - multiplies the outputs of stage B and C to yield the potential collision rate for the bird species, assuming current levels of bird use of the site but allowing for the proportion of time that turbines are not operational.
- **Stage E Allowing for avoidance and attraction** - takes account of the proportion of birds likely to avoid the wind farm or its turbines, either because they have been displaced from the site or because they take evasive action or are attracted to the wind farm.
- **Stage F Uncertainty** - each of these five stages is followed by a further stage, stage F, which describes how to express the uncertainty surrounding a collision risk estimate.

The general features and assumptions of the collision risk model are discussed in further detail in Band (2024). Using the model, a final predicted annual collision rate can be produced for each species that will be used in the impact assessment.

2.2 Turbine Specifications

The turbine specifications used in the model are provided in Table 7 - 6 - 1. Note that the pitch angle of the blade is variable and alters according to wind speed, with higher wind speeds requiring a higher pitch angle. Band (2024) suggests an average pitch of 15-30°, therefore the middle value (23°) is used here. The expected operational time of the turbines is 85% according to reports by the British Wind Energy Association (BWEA; 2016) which identifies the standard operational period of the wind turbines in the UK.

Table 7 - 6 - 1 Turbine specifications

Component	Scenario Modelled
Latitude (˚N)	54.7
Turbine model	N133 4.8MW
Number of turbines	19
Hub height (m)	90
Rotor diameter (m)	133
Blade pitch (˚)	23
Maximum blade width (m)	4
Rotational speed (rpm)	11.4
Number of blades	3

The turbine blade profile used in the model is presented in Table 7 - 6 - 2. In the absence of a specific blade profile for this turbine model, the blade profile provided in the collision risk model spreadsheet in Band (2024) has been used. This table provides the chord width values at 20 evenly spaced points along the blade, expressed relative to the maximum chord width. The ratio r/R represents the relative radial position along the blade, where 0 corresponds to the hub and 1 corresponds to the blade tip, while the ratio c/C represents the relative chord width. Further information on blade profiles is in Section 4 'Worked Example'.

Table 7 - 6 - 2 Turbine blade profile

r/R	c/C
0.00	0.690
0.05	0.730
0.10	0.790
0.15	0.880
0.20	0.960
0.25	1.000
0.30	0.980
0.35	0.920
0.40	0.850
0.45	0.800
0.50	0.750
0.55	0.700
0.60	0.640
0.65	0.580
0.70	0.520
0.75	0.470
0.80	0.410
0.85	0.370
0.90	0.300
0.95	0.240
1.00	0.000

2.3 Vantage Point Surveys

The assessment is based on vantage point surveys to monitor flight activity undertaken between October 2023 and September 2025. This represents a 24-month period, consisting of 2 breeding seasons and 2 winter seasons, which is in full compliance with guidance from NatureScot (formerly Scottish Natural Heritage [SNH]) outlined in SNH (2017), which was revised in NatureScot (2025a). Surveys remain in accordance with the updated guidance.

Surveys were undertaken at six vantage points. Viewsheds were calculated using the Visibility Analysis plugin (Version 1.8) over a raster digital terrain model (DTM) in QGIS (Version 3.28). A point 1.75m in height (to represent the height of the surveyor) was created on a map using 10m contours terrain data, accounting for the relative height of any surrounding landscape features (e.g., trees). The software produced a 360° viewshed 23m from ground/vegetation level up to a 2km radius around the vantage point. The combined viewsheds from these vantage points provided coverage to a 500m radius of the potential turbine positions. The vantage points and the area watched (i.e., the area of the viewsheds) are listed in Table 7 - 6 - 3.

Sampling effects can occur during vantage point surveys because of incomplete coverage, as the standard effort of 36 hours per season only covers 1.5-2% of daylight hours and may – by chance – miss or oversample certain types of flights. Due to the landscape topography and screening features, some viewsheds are smaller than others (for example VP5). In principle, larger viewsheds should generate more records, which in turn reduces the influence of sampling effects. However, VP5 covers a similar habitat and environmental conditions to the surrounding vantage points, and the species activity within this viewshed was similar to and representative of those surrounding it (see number of records per vantage point in Table 7 - 6 - 3). In addition, bird detectability decreases with distance from the surveyor, therefore flights during these surveys were more likely to be detected closer to the vantage points. Uncertainty around estimates is discussed further in Stage F: Uncertainty.

Table 7 - 6 - 3 Vantage points

Vantage Point	Area Watched (ha)	Number of Records
VP1	469.191	71
VP2	337.826	72
VP3	525.681	148
VP4	176.604	133
VP5	50.987	124
VP6	413.126	111

Vantage Point Survey methodology followed SNH (2017; revised in NatureScot, 2025a). The surveyor collected data on bird observations and flight activity from the scanning arc of 180° to a 2km radius at the fixed vantage point locations for two 3-hour watches separated by a minimum 30 minute break (i.e., 6 hours total) per month. The survey effort is presented in Table 7 - 6 - 4, expressed in terms of hours and seconds per month.

Table 7 - 6 - 4 Survey effort

Vantage Point	Month	Hours Survey	Seconds Survey
VP1	Jan	18.00	64,800
VP2	Jan	18.00	64,800
VP3	Jan	18.00	64,800
VP4	Jan	18.00	64,800
VP5	Jan	18.00	64,800

Vantage Point	Month	Hours Survey	Seconds Survey
VP6	Jan	18.00	64,800
VP1	Feb	12.00	43,200
VP2	Feb	12.00	43,200
VP3	Feb	12.00	43,200
VP4	Feb	12.00	43,200
VP5	Feb	12.00	43,200
VP6	Feb	12.00	43,200
VP1	Mar	12.00	43,200
VP2	Mar	12.00	43,200
VP3	Mar	12.00	43,200
VP4	Mar	12.00	43,200
VP5	Mar	12.00	43,200
VP6	Mar	12.00	43,200
VP1	Apr	12.00	43,200
VP2	Apr	15.00	54,000
VP3	Apr	12.00	43,200
VP4	Apr	12.00	43,200
VP5	Apr	12.00	43,200
VP6	Apr	12.00	43,200
VP1	May	12.00	43,200
VP2	May	12.00	43,200
VP3	May	9.00	32,400
VP4	May	12.00	43,200
VP5	May	12.00	43,200
VP6	May	12.00	43,200
VP1	Jun	12.00	43,200
VP2	Jun	12.00	43,200
VP3	Jun	12.00	43,200
VP4	Jun	12.00	43,200
VP5	Jun	12.00	43,200
VP6	Jun	12.00	43,200
VP1	Jul	12.00	43,200
VP2	Jul	12.00	43,200
VP3	Jul	15.00	54,000
VP4	Jul	12.04	43,344
VP5	Jul	12.00	43,200
VP6	Jul	12.00	43,200
VP1	Aug	12.00	43,200
VP2	Aug	12.00	43,200
VP3	Aug	12.00	43,200
VP4	Aug	12.00	43,200
VP5	Aug	12.00	43,200

Vantage Point	Month	Hours Survey	Seconds Survey
VP6	Aug	12.00	43,200
VP1	Sep	12.00	43,200
VP2	Sep	12.00	43,200
VP3	Sep	12.00	43,200
VP4	Sep	12.00	43,200
VP5	Sep	12.00	43,200
VP6	Sep	12.00	43,200
VP1	Oct	12.00	43,200
VP2	Oct	12.00	43,200
VP3	Oct	6.00	21,600
VP4	Oct	6.00	21,600
VP5	Oct	6.00	21,600
VP6	Oct	6.00	21,600
VP1	Nov	12.00	43,200
VP2	Nov	14.00	50,400
VP3	Nov	12.00	43,200
VP4	Nov	13.00	46,800
VP5	Nov	9.00	32,400
VP6	Nov	6.00	21,600
VP1	Dec	18.00	64,800
VP2	Dec	12.00	43,200
VP3	Dec	18.00	64,800
VP4	Dec	12.00	43,200
VP5	Dec	15.00	54,000
VP6	Dec	18.00	64,800

Flight activity of target species was mapped and recorded as per defined flight bands which were chosen in relation to the dimensions of potential turbine models at the outset of surveys. These heights bands were:

- Band 1 = 0-15m
- Band 2 = 15-25m
- Band 3 = 25-200m
- Band 4 = 200+

As the risk height range of the turbine is 23.5-156.5m, all flight activity in Band 2 and Band 3 is considered to be at potential collision height.

2.4 Species Assessed

Collision rates were estimated for the species listed in Table 7 - 6 - 5. The months included for each species are also presented (note breeding and winter populations were assessed separately for some species). The type of Band (2024) model used is also specified.

Table 7 - 6 - 5 Species assessed

Species	Months	Model
Golden Plover	Oct-Apr	nondirectional
Hen Harrier	Apr-Sep	nondirectional
Hen Harrier	Oct-Mar	nondirectional
Peregrine Falcon	Oct-Sep	nondirectional
Whooper Swan	Oct-Apr	nondirectional
Kestrel	Oct-Sep	nondirectional
Snipe	Oct-Sep	nondirectional
Buzzard	Oct-Sep	nondirectional
Sparrowhawk	Oct-Sep	nondirectional

Species biometrics, such as body length, body width (i.e., wingspan) and flight speed, as well as whether a bird typically flaps or glides in flight, are required to calculate collision risk. This information was sourced from the best available literature.

In addition, a 'nocturnal activity factor is required'. There is considerable uncertainty about levels of bird flight activity by night (Band, 2024). There are no standard expert rankings available for terrestrial species and levels of activity may vary from season to season. Because of this, each species is ranked with a nocturnal activity factor of 0%, 25%, 50%, 75% and 100%. A ranking of 0% is given to represent hardly any flight activity at night and of 100% for much flight activity at night. As such, the figures used in the collision risk model take both day and night flights into account. The biometrics, flight type and nocturnal activity factor used in the model are presented in Table 7 - 6 - 6.

Table 7 - 6 - 6 Species biometrics, flight type and nocturnal activity factor

Species	Length (cm)	Width (cm)	Flight Speed (m/s)	Nocturnal Activity Factor	Flight Type
Buzzard	54	120.5	11.6	0%	gliding
Golden Plover	27.5	71.5	17.9	25%	flapping
Hen Harrier	48	110	8	0%	flapping
Kestrel	33.5	75.5	10.1	0%	flapping
Peregrine Falcon	44.5	105	12.1	0%	flapping
Snipe	25.5	42	17.1	100%	flapping
Sparrowhawk	33	62.5	10	0%	flapping
Whooper Swan	150	220	17.3	25%	flapping

To prepare the field survey data for analysis, the number of 'bird-seconds' per month per vantage point was calculated for each observation by multiplying the number of birds aloft by the duration of the flight (in seconds). The time spent in all recorded height bands and the time spend only in bands within potential collision height was calculated separately. These values are presented per vantage point per month for each species in Table 7 - 6 - 7.

Table 7 - 6 - 7 Bird-seconds per vantage point per month

Species	Month	Vantage Point	Total Bird-Seconds	Bird-Seconds at Potential Collision Height
Buzzard	Jan	VP1	55	52
	Apr	VP1	166	162
	May	VP1	82	2
	Jun	VP1	1,548	1,381
	Jul	VP1	84	80
	Sep	VP1	130	124
	Oct	VP1	112	112
	Nov	VP1	15	3
	Dec	VP1	294	250
	Mar	VP2	711	36
	May	VP2	72	72
	Oct	VP2	65	65
	Nov	VP2	99	99
	Jan	VP3	1,037	1,037
	Feb	VP3	1,000	432
	Mar	VP3	341	341
	Jun	VP3	14	0
	Jul	VP3	684	600
	Aug	VP3	960	260
	Sep	VP3	143	135
	Nov	VP3	530	530
	Jan	VP4	417	377
	Feb	VP4	275	260
	Apr	VP4	720	365
	May	VP4	15	4
	Jun	VP4	118	111
	Jul	VP4	31	21
	Nov	VP4	89	89
	Jan	VP5	379	315
	Feb	VP5	134	92
	Feb	VP6	940	60
	Apr	VP6	1,380	780
	Aug	VP6	50	50
	Nov	VP6	165	165
	Dec	VP6	45	25
Golden Plover	Feb	VP1	164	164
	Oct	VP3	1,990	800
	Apr	VP4	15,640	2,550
Hen Harrier	Apr	VP1	25	25
	Jun	VP1	63	0

Species	Month	Vantage Point	Total Bird-Seconds	Bird-Seconds at Potential Collision Height
	Feb	VP2	255	0
	Mar	VP2	147	147
	Dec	VP2	132	132
	Jan	VP3	4	0
	Feb	VP3	356	27
	Apr	VP3	499	418
	May	VP3	799	380
	Jun	VP3	1,134	691
	Jul	VP3	223	43
	Mar	VP4	316	73
	Apr	VP4	86	76
Kestrel	Feb	VP1	27	27
	Nov	VP1	46	36
	Dec	VP1	450	297
	Jan	VP2	365	357
	Feb	VP2	220	0
	Apr	VP2	7	0
	Sep	VP2	8	0
	Jan	VP3	15	13
	Mar	VP3	15	0
	Aug	VP3	60	50
	Sep	VP3	483	100
	Oct	VP3	77	77
	Nov	VP3	1,155	985
	Dec	VP3	55	0
	Apr	VP4	160	110
	Aug	VP4	455	329
	Sep	VP4	100	100
	Oct	VP4	7	0
	Nov	VP4	931	825
	Dec	VP4	165	35
	Jan	VP5	231	231
	May	VP5	40	40
	Jan	VP6	1,565	1,515
	Oct	VP6	140	115
	Dec	VP6	55	0
Peregrine Falcon	Feb	VP3	22	22
Snipe	May	VP1	87	87
	Oct	VP1	8	6
	Feb	VP2	52	0
	Apr	VP2	300	0

Species	Month	Vantage Point	Total Bird-Seconds	Bird-Seconds at Potential Collision Height
	Feb	VP3	9	0
	Mar	VP3	4	0
	Apr	VP3	29	20
	Jul	VP3	54	50
	Nov	VP3	55	55
	Dec	VP3	60	60
	Jan	VP4	22	6
	Aug	VP4	95	95
	Nov	VP4	105	95
	Dec	VP4	33	28
	Jan	VP5	35	35
	Dec	VP5	68	68
	Jan	VP6	95	75
	Feb	VP6	70	70
	Dec	VP6	25	25
Sparrowhawk	Apr	VP1	3	0
	May	VP1	6	0
	Jun	VP1	27	27
	Dec	VP1	50	0
	Mar	VP2	9	0
	Apr	VP2	775	25
	Jul	VP2	10	0
	Jan	VP3	11	0
	May	VP3	28	0
	Aug	VP3	229	184
	Jan	VP4	22	18
	Mar	VP4	28	4
	Jun	VP4	7	0
	Nov	VP4	22	0
	Apr	VP5	200	0
	Jun	VP5	16	16
	Jan	VP6	41	26
Whooper Swan	Oct	VP1	7,744	3,339
	Oct	VP2	4,009	3,622
	Oct	VP3	423	0
	Mar	VP4	2,352	2,352
	Mar	VP5	528	0

2.5 Photoperiod

The photoperiod at the latitude of the turbines was acquired for the survey period. The daylight and nighttime hours per month are shown in Table 7 - 6 - 8. The total daylight hours was 4492.251 and night-time hours was 4267.749.

Table 7 - 6 - 8 Photoperiod

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daylight Hours	244.7	270.3	365.9	421.5	497.9	515.9	518.0	463.5	383.7	327.4	255.6	227.7
Nighttime Hours	499.3	401.7	378.1	298.5	246.1	204.1	226.0	280.5	336.3	416.6	464.4	516.3

3. RESULTS

3.1 Stage A Flight Activity

Stage A of the modelling process uses the field survey data to establish the aerial density of flying birds in the vicinity of the turbines and the proportion flying at a risk height (between the lowest and highest points of the rotors). Aerial density was calculated following the formula provided by Band (2024; also see Section 4 'Worked Example'). Similarly, the proportion flying at risk height was calculated following the method in Band (2024; also see Section 4 'Worked Example'). The aerial density per month and the proportion flying at risk height for each species is shown in Table 7 - 6 - 9.

This method assumes that the relative detectability of different height bands is consistent across vantage points. However, this assumption is unlikely to hold for the lower bands in landscapes where some low altitude flights may be obscured by topography or vegetation. This variation in detectability may bias the estimated proportion of activity at potential risk height according to the visibility conditions at each vantage point, rather than the true distribution of flight heights. In addition, the Band (2024) method assumes that flight activity is uniformly distributed within each height band. This assumption is also unlikely to hold, especially in the lower bands, where flight height is influenced by topography, vegetation and species-specific behaviours. Assuming a uniform distribution within each height band may over- or under-estimate the proportion of flight activity assigned to potential collision height. Furthermore, calculating the proportion of flight activity across bands based on the number of flights also risks biasing the estimated proportion of activity at potential collision height, particularly at low bands where flights may be fragmented as the bird moves between screening topography and vegetation and the resulting number of flights may be affected by the surveyor's judgement and visibility conditions at each vantage point.

To address the above, a second calculation was performed. This used only the flight activity in the bands within potential collision risk height in the calculation of aerial density, but with the proportion flying at risk height always considered to be 1. This represents a slight deviation from the methodology outlined in Band (2024) however it reduces the risk of biasing the estimated flight activity at potential collision height. The aerial density per month for each species when calculated in this way is shown in Table 7 - 6 - 10.

Table 7 - 6 - 9 Aerial density and proportion flying at risk height following Band (2024)

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Proportion
Golden Plover	0	0.000135	0	0.0342	-	-	-	-	-	0.00292	0	0	0.75
Hen Harrier	-	-	-	0.000575	0.000782	0.000884	0.000131	0	0	-	-	-	0.26
Hen Harrier	0.00000196	0.000552	0.000858	-	-	-	-	-	-	0	0	0.000151	0.29
Peregrine Falcon	0	0.0000161	0	0	0	0	0	0	0	0	0	0	0.18

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Proportion
Whooper Swan	0	0	0.00913	0	-	-	-	-	-	0.0116	0	0	0.44
Kestrel	0.00242	0.000273	0.000011	0.000356	0.000303	0	0	0.00104	0.000582	0.000405	0.00276	0.000668	0.43
Snipe	0.000268	0.000131	0.00000294	0.000295	0.0000715	0	0.0000317	0.000208	0	0.00000658	0.000252	0.000529	0.34
Buzzard	0.00306	0.00323	0.00106	0.003	0.000182	0.00154	0.000538	0.000751	0.000212	0.000166	0.000986	0.000189	0.55
Sparrowhawk	0.0000629	0	0.0000714	0.00222	0.0000323	0.000159	0.0000114	0.000168	0	0	0.0000444	0.0000274	0.10

Table 7 - 6 - 10 Aerial density using only the flight activity in the bands within potential collision risk height

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Golden Plover	0	0.000135	0	0.00557	-	-	-	-	-	0.00117	0	0
Hen Harrier	-	-	-	0.000493	0.000372	0.000507	0.0000252	0	0	-	-	-
Hen Harrier	0	0.0000198	0.000327	-	-	-	-	-	-	0	0	0.000151
Peregrine Falcon	0	0.0000161	0	0	0	0	0	0	0	0	0	0
Whooper Swan	0	0	0.00514	0	-	-	-	-	-	0.00688	0	0
Kestrel	0.00239	0.0000222	0	0.00024	0.000303	0	0	0.000755	0.000292	0.000328	0.00242	0.000239
Snipe	0.000232	0.0000654	0	0.0000147	0.0000715	0	0.0000294	0.000208	0	0.00000493	0.000232	0.000518
Buzzard	0.00267	0.00164	0.000291	0.00166	0.0000926	0.00138	0.000464	0.000238	0.000201	0.000166	0.000976	0.000153
Sparrowhawk	0.0000424	0	0.00000874	0.0000228	0	0.000143	0	0.000135	0	0	0	0

3.2 Stage B Number of Flights Through Rotors

Stage B of the modelling process makes an estimate, based on the aerial density and proportion flying at risk height, of the potential number of bird passages through rotors. The projected number of transits through the rotor risk area was calculated following the formula provided by Band (2024; also see Section 4 'Worked Example'). Table 7 - 6 - 11 shows the projected number of transits per month for each species based on aerial density and proportion flying at risk height calculated following Band (2024).

Table 7 - 6 - 12 shows the projected number of transits based on aerial density using only the flight activity in the bands within potential collision risk height and where the proportion flying at risk height was always considered to be 1.

Table 7 - 6 - 11 Projected number of transits following Band (2024)

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Golden Plover	0	4.77	0	1616	-	-	-	-	-	12	0	0	1741.08
Hen Harrier	-	-	-	3.63	5.84	6.84	1.02	0	0	-	-	-	17.32
Hen Harrier	0.008	2.45	5.16	-	-	-	-	-	-	0	0	0.564	8.18
Peregrine Falcon	0	0.069	0	0	0	0	0	0	0	0	0	0	0.07
Whooper Swan	0	0	227	0	-	-	-	-	-	27	0	0	497.38
Kestrel	18.4	2.29	0.125	4.65	4.67	0	0	14.9	6.92	4.11	21.9	4.71	82.62
Snipe	8.16	3.62	0.089	8.71	2.18	0	0.966	6.32	0	0.2	7.43	16.1	53.79
Buzzard	34.3	40	17.8	57.9	4.16	36.4	12.8	16	3.72	2.5	11.5	1.97	239.04
Sparrowhawk	0.106	0	0.179	6.42	0.11	0.56	0.041	0.533	0	0	0.078	0.043	8.07

Table 7 - 6 - 12 Projected number of transits based on aerial density using only the flight activity in the bands within potential collision risk height and always setting the proportion flying at risk height to 1

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Golden Plover	0	6.39	0	353	-	-	-	-	-	64.8	0	0	424.68
Hen Harrier	-	-	-	11.9	10.6	15	0.748	0	0	-	-	-	38.17
Hen Harrier	0	0.306	6.85	-	-	-	-	-	-	0	0	1.96	9.12
Peregrine Falcon	0	0.377	0	0	0	0	0	0	0	0	0	0	0.38
Whooper Swan	0	0	292	0	-	-	-	-	-	367	0	0	659.56
Kestrel	42.2	0.433	0	7.31	10.9	0	0	25.3	8.08	7.75	44.6	3.93	150.35
Snipe	21.1	5.37	0	1.29	6.5	0	2.67	18.9	0	0.448	20.4	47.1	123.69
Buzzard	54.2	36.7	8.84	58	3.82	58.9	19.9	9.12	6.39	4.51	20.7	2.88	283.96
Sparrowhawk	0.741	0	0.228	0.688	0	5.28	0	4.47	0	0	0	0	11.41

3.3 Stage C Probability of Collision

Stage C of the modelling process calculates the probability of collision during a single bird rotor transit. The likelihood of a bird colliding with a turbine blade during a single pass through the rotor was calculated using the turbine specifications, species biometrics and flight characteristics outlined in the previous sections.

Collision risk was assessed across different parts of the rotor, as blade speed and width varies from the hub to the tip. Because of the geometry of the blades in relation to the flight direction, the collision risk for upwind flight is higher than for downwind (even if the bird's flight speed relative to the ground is taken to be the same), therefore collision risk probabilities were calculated separately for birds flying upwind and downwind. These were then averaged assuming a 50:50 weighting because both upwind and downwind flights are equally likely (further information in Section 4 'Worked Example'). This produced a probability of collision for a bird during a single transit of the rotor, which is presented for each species in Table 7 - 6 - 13.

Table 7 - 6 - 13 Probability of collision

Species	Upwind	Downwind	Average
Golden Plover	0.072	0.026	0.049
Hen Harrier	0.13	0.069	0.100
Peregrine Falcon	0.097	0.043	0.070
Whooper Swan	0.116	0.069	0.092
Kestrel	0.102	0.044	0.073
Snipe	0.072	0.024	0.048
Buzzard	0.103	0.048	0.076
Sparrowhawk	0.102	0.044	0.073

3.4 Stage D Expected Collisions

Stage D of the modelling process multiplies the outputs of stage B and C to yield the expected collision rate for each bird species, accounting for the proportion of time the wind farm is expected to be operational. This is before considering avoidance behaviour, which is stage E. The number of expected collisions per month and the year total for each species are presented in two tables: Table 7 - 6 - 14 presents values based on the aerial density and number of transits calculated following Band (2024), while Table

7 - 6 - 15 presents values based on the aerial density and number of transits calculated using only the flight activity in the bands within potential collision risk height and always setting the proportion flying at risk height to 1.

Table 7 - 6 - 14 Expected collisions without avoidance following Band (2024)

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Golden Plover	0	0.2	0	67.8	-	-	-	-	-	5.04	0	0	73
Hen Harrier	-	-	-	0.307	0.494	0.579	0.0861	0	0	-	-	-	1.47
Hen Harrier	0.000677	0.208	0.436	-	-	-	-	-	-	0	0	0.0477	0.692
Peregrine Falcon	0	0.0041	0	0	0	0	0	0	0	0	0	0	0.0041
Whooper Swan	0	0	17.8	0	-	-	-	-	-	21.1	0	0	38.9
Kestrel	1.14	0.142	0.00777	0.289	0.29	0	0	0.926	0.43	0.255	1.36	0.293	5.14
Snipe	0.333	0.147	0.00363	0.355	0.0889	0	0.0394	0.258	0	0.00815	0.303	0.657	2.19
Buzzard	2.2	2.57	1.14	3.72	0.267	2.34	0.821	1.03	0.239	0.16	0.742	0.127	15.4
Sparrowhawk	0.00658	0	0.0111	0.398	0.00683	0.0348	0.00254	0.0331	0	0	0.00484	0.00267	0.501

Table 7 - 6 - 15 Expected collisions without avoidance using only the flight activity in the bands within potential collision risk height and always setting the proportion flying at risk height to 1

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Golden Plover	0	0.268	0	14.8	-	-	-	-	-	2.72	0	0	17.8
Hen Harrier	-	-	-	1.01	0.896	1.27	0.0633	0	0	-	-	-	3.23
Hen Harrier	0	0.0259	0.58	-	-	-	-	-	-	0	0	0.166	0.772
Peregrine Falcon	0	0.0224	0	0	0	0	0	0	0	0	0	0	0.0224
Whooper Swan	0	0	22.9	0	-	-	-	-	-	28.7	0	0	51.6
Kestrel	2.62	0.0269	0	0.454	0.676	0	0	1.57	0.502	0.481	2.77	0.244	9.35
Snipe	0.86	0.219	0	0.0526	0.265	0	0.109	0.769	0	0.0183	0.832	1.92	5.04
Buzzard	3.48	2.36	0.568	3.72	0.246	3.79	1.28	0.586	0.411	0.29	1.33	0.185	18.2
Sparrowhawk	0.046	0	0.0141	0.0427	0	0.328	0	0.278	0	0	0	0	0.708

3.5 Stage E Allowing for Avoidance and Attraction

Stage E of the modelling process takes account of the proportion of birds likely to avoid the wind farm or its turbines, either because they have been displaced from the site or because they take evasive action or are attracted to the wind farm. Band (2024) states that the collision rate estimate should show potential collision mortality using a range of assumed avoidance rates. In the absence of specific avoidance information for the species in question, it is recommended that collision risks be evaluated assuming avoidance factors of 95%, 98%, 99% and 99.5%. An avoidance factor of 99.6% was also evaluated for golden plover following an assessment of a specific avoidance rate for wintering populations of this species by Gittings (2011; see Appendix 7-6-1). These values are presented in two tables: Table 7 - 6 - 14Table 7 – 6 – 16 presents values based on the aerial density and number of transits calculated following Band (2024), while

Table 7 - 6 - 17 presents values based on the aerial density and number of transits calculated using only the flight activity in the bands within potential collision risk height and always setting the proportion flying at risk height to 1.

Table 7 - 6 - 16 Expected collisions without avoidance following Band (2024)

Species	Avoidance Factor	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Golden Plover	0.95	0	0.01	0	3.39	-	-	-	-	-	0.252	0	0	3.65
	0.98	0	0.004	0	1.36	-	-	-	-	-	0.101	0	0	1.46
	0.99	0	0.002	0	0.678	-	-	-	-	-	0.0504	0	0	0.73
	0.995	0	0.001	0	0.339	-	-	-	-	-	0.0252	0	0	0.365
	0.996	0	0.0008	0	0.271	-	-	-	-	-	0.0202	0	0	0.292
Hen Harrier	0.95	-	-	-	0.0154	0.0247	0.0289	0.0043	0	0	-	-	-	0.0733
	0.98	-	-	-	0.00615	0.00988	0.0116	0.00172	0	0	-	-	-	0.0293
	0.99	-	-	-	0.00307	0.00494	0.00579	0.00086	0	0	-	-	-	0.0147
	0.995	-	-	-	0.00154	0.00247	0.00289	0.00043	0	0	-	-	-	0.00733
	0.996	-	-	-	0.00123	0.00198	0.00232	0.00034	0	0	-	-	-	0.00587
	0.95	0.00003	0.0104	0.0218	-	-	-	-	-	-	0	0	0.00239	0.0346
	0.98	0.00001	0.00415	0.00873	-	-	-	-	-	-	0	0	0.00095	0.0138
	0.99	0.00001	0.00208	0.00436	-	-	-	-	-	-	0	0	0.00048	0.00692

Species	Avoidance Factor	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
	0.995	0	0.00104	0.00218	-	-	-	-	-	-	0	0	0.00024	0.00346
	0.996	0	0.00083	0.00175	-	-	-	-	-	-	0	0	0.00019	0.00277
Peregrine Falcon	0.95	0	0.0002	0	0	0	0	0	0	0	0	0	0	0.0002
	0.98	0	0.00008	0	0	0	0	0	0	0	0	0	0	0.00008
	0.99	0	0.00004	0	0	0	0	0	0	0	0	0	0	0.00004
	0.995	0	0.00002	0	0	0	0	0	0	0	0	0	0	0.00002
	0.996	0	0.00002	0	0	0	0	0	0	0	0	0	0	0.00002
Whooper Swan	0.95	0	0	0.89	0	-	-	-	-	-	1.06	0	0	1.95
	0.98	0	0	0.356	0	-	-	-	-	-	0.423	0	0	0.778
	0.99	0	0	0.178	0	-	-	-	-	-	0.211	0	0	0.389
	0.995	0	0	0.089	0	-	-	-	-	-	0.106	0	0	0.195
	0.996	0	0	0.0712	0	-	-	-	-	-	0.0845	0	0	0.156
Kestrel	0.95	0.0571	0.00712	0.00039	0.0144	0.0145	0	0	0.0463	0.0215	0.0128	0.068	0.0146	0.257
	0.98	0.0228	0.00285	0.00016	0.00578	0.0058	0	0	0.0185	0.0086	0.00511	0.0272	0.00586	0.103
	0.99	0.0114	0.00142	0.00008	0.00289	0.0029	0	0	0.00926	0.0043	0.00255	0.0136	0.00293	0.0514
	0.995	0.00571	0.00071	0.00004	0.00144	0.00145	0	0	0.00463	0.00215	0.00128	0.0068	0.00147	0.0257
	0.996	0.00457	0.00057	0.00003	0.00116	0.00116	0	0	0.0037	0.00172	0.00102	0.00544	0.00117	0.0205
Snipe	0.95	0.0166	0.00737	0.00018	0.0177	0.00444	0	0.00197	0.0129	0	0.00041	0.0152	0.0328	0.11
	0.98	0.00665	0.00295	0.00007	0.0071	0.00178	0	0.00079	0.00516	0	0.00016	0.00606	0.0131	0.0438
	0.99	0.00333	0.00147	0.00004	0.00355	0.00089	0	0.00039	0.00258	0	0.00008	0.00303	0.00657	0.0219
	0.995	0.00166	0.00074	0.00002	0.00178	0.00044	0	0.0002	0.00129	0	0.00004	0.00152	0.00328	0.011
	0.996	0.00133	0.00059	0.00001	0.00142	0.00036	0	0.00016	0.00103	0	0.00003	0.00121	0.00263	0.00877
Buzzard	0.95	0.11	0.128	0.0572	0.186	0.0134	0.117	0.041	0.0513	0.012	0.00802	0.0371	0.00634	0.768
	0.98	0.044	0.0514	0.0229	0.0744	0.00535	0.0468	0.0164	0.0205	0.00479	0.00321	0.0148	0.00254	0.307
	0.99	0.022	0.0257	0.0114	0.0372	0.00267	0.0234	0.00821	0.0102	0.00239	0.0016	0.00742	0.00127	0.154
	0.995	0.011	0.0128	0.00572	0.0186	0.00134	0.0117	0.0041	0.00513	0.0012	0.0008	0.00371	0.00063	0.0768

Species	Avoidance Factor	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
	0.996	0.00881	0.0103	0.00458	0.0149	0.00107	0.00936	0.00328	0.0041	0.00096	0.00064	0.00297	0.00051	0.0614
Sparrowhawk	0.95	0.00033	0	0.00056	0.0199	0.00034	0.00174	0.00013	0.00165	0	0	0.00024	0.00013	0.025
	0.98	0.00013	0	0.00022	0.00797	0.00014	0.0007	0.00005	0.00066	0	0	0.0001	0.00005	0.01
	0.99	0.00007	0	0.00011	0.00398	0.00007	0.00035	0.00003	0.00033	0	0	0.00005	0.00003	0.00501
	0.995	0.00003	0	0.00006	0.00199	0.00003	0.00017	0.00001	0.00017	0	0	0.00002	0.00001	0.0025
	0.996	0.00003	0	0.00004	0.00159	0.00003	0.00014	0.00001	0.00013	0	0	0.00002	0.00001	0.002

Table 7 - 6 - 17 Expected collisions with avoidance using only the flight activity in the bands within potential collision risk height and always setting the proportion flying at risk height to 1

Species	Avoidance Factor	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Golden Plover	0.95	0	0.0134	0	0.741	-	-	-	-	-	0.136	0	0	0.891
	0.98	0	0.00536	0	0.297	-	-	-	-	-	0.0544	0	0	0.356
	0.99	0	0.00268	0	0.148	-	-	-	-	-	0.0272	0	0	0.178
	0.995	0	0.00134	0	0.0741	-	-	-	-	-	0.0136	0	0	0.0891
	0.996	0	0.00107	0	0.0593	-	-	-	-	-	0.0109	0	0	0.0713
Hen Harrier	0.95	-	-	-	0.0503	0.0448	0.0633	0.00317	0	0	-	-	-	0.162
	0.98	-	-	-	0.0201	0.0179	0.0253	0.00127	0	0	-	-	-	0.0646
	0.99	-	-	-	0.0101	0.00896	0.0127	0.00063	0	0	-	-	-	0.0323
	0.995	-	-	-	0.00503	0.00448	0.00633	0.00032	0	0	-	-	-	0.0162
	0.996	-	-	-	0.00402	0.00358	0.00506	0.00025	0	0	-	-	-	0.0129
	0.95	0	0.0013	0.029	-	-	-	-	-	-	0	0	0.0083	0.0386
	0.98	0	0.00052	0.0116	-	-	-	-	-	-	0	0	0.00332	0.0154
	0.99	0	0.00026	0.0058	-	-	-	-	-	-	0	0	0.00166	0.00772
	0.995	0	0.00013	0.0029	-	-	-	-	-	-	0	0	0.00083	0.00386
	0.996	0	0.0001	0.00232	-	-	-	-	-	-	0	0	0.00066	0.00309
Peregrine Falcon	0.95	0	0.00112	0	0	0	0	0	0	0	0	0	0	0.00112
	0.98	0	0.00045	0	0	0	0	0	0	0	0	0	0	0.00045

Species	Avoidance Factor	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
	0.99	0	0.00022	0	0	0	0	0	0	0	0	0	0	0.00022
	0.995	0	0.00011	0	0	0	0	0	0	0	0	0	0	0.00011
	0.996	0	0.00009	0	0	0	0	0	0	0	0	0	0	0.00009
Whooper Swan	0.95	0	0	1.14	0	-	-	-	-	-	1.44	0	0	2.58
	0.98	0	0	0.458	0	-	-	-	-	-	0.575	0	0	1.03
	0.99	0	0	0.229	0	-	-	-	-	-	0.287	0	0	0.516
	0.995	0	0	0.114	0	-	-	-	-	-	0.144	0	0	0.258
	0.996	0	0	0.0915	0	-	-	-	-	-	0.115	0	0	0.206
Kestrel	0.95	0.131	0.00135	0	0.0227	0.0338	0	0	0.0785	0.0251	0.0241	0.138	0.0122	0.467
	0.98	0.0524	0.00054	0	0.00909	0.0135	0	0	0.0314	0.01	0.00963	0.0554	0.00489	0.187
	0.99	0.0262	0.00027	0	0.00454	0.00676	0	0	0.0157	0.00502	0.00481	0.0277	0.00244	0.0935
	0.995	0.0131	0.00013	0	0.00227	0.00338	0	0	0.00785	0.00251	0.00241	0.0138	0.00122	0.0467
	0.996	0.0105	0.00011	0	0.00182	0.0027	0	0	0.00628	0.00201	0.00193	0.0111	0.00098	0.0374
Snipe	0.95	0.043	0.0109	0	0.00263	0.0133	0	0.00544	0.0384	0	0.00091	0.0416	0.0959	0.252
	0.98	0.0172	0.00438	0	0.00105	0.0053	0	0.00218	0.0154	0	0.00037	0.0166	0.0384	0.101
	0.99	0.0086	0.00219	0	0.00053	0.00265	0	0.00109	0.00769	0	0.00018	0.00832	0.0192	0.0504
	0.995	0.0043	0.00109	0	0.00026	0.00133	0	0.00054	0.00385	0	0.00009	0.00416	0.00959	0.0252
	0.996	0.00344	0.00088	0	0.00021	0.00106	0	0.00044	0.00308	0	0.00007	0.00333	0.00767	0.0202
Buzzard	0.95	0.174	0.118	0.0284	0.186	0.0123	0.189	0.064	0.0293	0.0205	0.0145	0.0664	0.00926	0.912
	0.98	0.0697	0.0471	0.0114	0.0745	0.00491	0.0757	0.0256	0.0117	0.00822	0.0058	0.0266	0.0037	0.365
	0.99	0.0348	0.0236	0.00568	0.0372	0.00246	0.0379	0.0128	0.00586	0.00411	0.0029	0.0133	0.00185	0.182
	0.995	0.0174	0.0118	0.00284	0.0186	0.00123	0.0189	0.0064	0.00293	0.00205	0.00145	0.00664	0.00093	0.0912
	0.996	0.0139	0.00943	0.00227	0.0149	0.00098	0.0151	0.00512	0.00234	0.00164	0.00116	0.00531	0.00074	0.073
Sparrowhawk	0.95	0.0023	0	0.00071	0.00213	0	0.0164	0	0.0139	0	0	0	0	0.0354
	0.98	0.00092	0	0.00028	0.00085	0	0.00655	0	0.00555	0	0	0	0	0.0142
	0.99	0.00046	0	0.00014	0.00043	0	0.00328	0	0.00278	0	0	0	0	0.00708

Species	Avoidance Factor	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
	0.995	0.00023	0	0.00007	0.00021	0	0.00164	0	0.00139	0	0	0	0	0.00354
	0.996	0.00018	0	0.00006	0.00017	0	0.00131	0	0.00111	0	0	0	0	0.00283

3.6 Stage F Uncertainty

There are many sources of variability or uncertainty in the output of the Collision Risk Model. The main sources of uncertainty outlined in Band (2024) are:

- survey data is sampled, often both in time and space, and usually exhibits a high degree of variability. Mean estimates can only be representative of flight activity;
- survey data is unavailable for certain conditions, including nighttime and storm conditions;
- natural variability in bird populations, over time and space, for ecological reasons;
- flight height information may be subject to observer bias;
- the collision risk model uses a simplified geometry for turbine blades and bird shape;
- it does not include any risk of collision with turbine towers;
- details of blade dimension and pitch may be unavailable when making the estimate;
- turbines deployed may differ from those used in the collision risk analysis;
- bird parameters (length, wingspan, flight speed) are not fixed but have a distribution;
- bird speed is not a constant but is dependent on wind speed;
- insufficient knowledge about bird displacement and attraction effects;
- there is limited firm information on bird avoidance behaviour.

Because of this, a range of uncertainty is calculated for the predicted collision rates. The range of uncertainty should reflect:

- uncertainty or variability in flight activity data (including imprecision on flight height estimates and lack of knowledge about night-time behaviour);
- uncertainty due to the limitations of the collision model, including the variability of bird dimensions and flight speed, the simplification in shape of a bird and turbine blades;
- uncertainty arising from turbine options yet to be decided, in number, size and speed. These options should include a 'worst case' in terms of the option likely to present greatest bird collision risk.

It should be noted that other additional sources of uncertainty exist. These include potential under-detection of flights that are distant from the surveyor (Gittings, 2024), errors in allocation of flight activity to height bands (Largey *et al.,* 2026) and errors in the nocturnal activity factors (discussed in Section 2.4). Each of these may result in over-or underestimation of flight activity at potential collision height. It is not possible to quantify these uncertainties to provide a measure of uncertainty, but these effects should be considered during interpretation of the results.

To provide a measure of uncertainty in aerial density, the mean, standard deviation and relative standard deviation for the monthly values was calculated (see Section 4 'Worked Example'). Uncertainty due to simplifications in the collision risk model was assumed to be 0.20 (Band, 2024). Finally, uncertainty due to design options (including the blade profile, pitch, rotational speed and expected time operational) was considered to be 0.28. The overall range of uncertainty for each species was calculated as the root sum of squares of these values and is presented in Table 7 - 6 - 18.

The Band (2024) method assumes that the uncertainties combine additively. However, the components of the model are multiplied rather than summed, therefore the uncertainty values should also be multiplied to avoid underestimating overall uncertainty that could occur when using the root sum of squares method. To address the above, a second calculation was performed to calculate the overall range of uncertainty for each species using a multiplicative method and is presented in Table 7 - 6 - 19 for the expected collisions calculated using only the flight activity in the bands within potential collision risk height and always setting the proportion flying at risk height to 1 (see Section 4 'Worked Example' for further details).

Table 7 - 6 - 18 Range of uncertainty

Species	Months	Model	Mean	Standard Deviation	Relative Standard Deviation	Uncertainty
Golden Plover	Oct-Apr	non-directional	0.00532	0.01182	2.22284	2.25
Hen Harrier	Apr-Sep	non-directional	0.0004	0.00037	0.92551	0.99
Hen Harrier	Oct-Mar	non-directional	0.00026	0.00033	1.27007	1.32
Peregrine Falcon	Oct-Sep	non-directional	0.000001	0.000004	3.31662	3.33
Whooper Swan	Oct-Apr	non-directional	0.00296	0.00472	1.59636	1.63
Kestrel	Oct-Sep	non-directional	0.00074	0.00088	1.20004	1.25
Snipe	Oct-Sep	non-directional	0.00015	0.00016	1.05637	1.11
Buzzard	Oct-Sep	non-directional	0.00124	0.00114	0.92026	0.98
Sparrowhawk	Oct-Sep	non-directional	0.00023	0.0006	2.58245	2.61

Table 7 - 6 - 19 Range of uncertainty using a multiplicative method for the expected collisions calculated using only the flight activity in the bands within potential collision risk height and always setting the proportion flying at risk height to 1

Species	Months	Model	Mean	Standard Deviation	Relative Standard Deviation	Uncertainty
Golden Plover	Oct-Apr	non-directional	0.000983	0.001915	1.948356	4.53

Species	Months	Model	Mean	Standard Deviation	Relative Standard Deviation	Uncertainty
Hen Harrier	Apr-Sep	non-directional	0.000233	0.000229	0.982041	3.04
Hen Harrier	Oct-Mar	non-directional	0.000083	0.000122	1.46727	3.79
Peregrine Falcon	Oct-Sep	non-directional	0.000001	0.000004	3.316625	6.63
Whooper Swan	Oct-Apr	non-directional	0.001717	0.002755	1.604265	4.00
Kestrel	Oct-Sep	non-directional	0.000582	0.000839	1.441454	3.75
Snipe	Oct-Sep	non-directional	0.000115	0.00015	1.313019	3.55
Buzzard	Oct-Sep	non-directional	0.000827	0.0008	0.966474	3.02
Sparrowhawk	Oct-Sep	non-directional	0.000029	0.000051	1.726136	4.19

3.7 Predicted Collision Rates

To provide a best estimate of the collision rate for each species, the guidance on avoidance rates provided by NatureScot (2025b) was consulted. This guidance suggests the most appropriate avoidance rate for each species; however it should be noted that the lack of research on most species' avoidance rates means that the confidence interval of the prediction may extend from the lowest to the highest avoidance rate in Table 7 - 6 - 16 and

Table 7 - 6 - 17. For each species, the predicted number of collisions corresponding to the recommended avoidance rate was identified. These are presented in Table 7 - 6 - 20 and Table 7 - 6 - 21, along with the range of uncertainty and an estimation of the number of years for one collision to occur (details on these calculations are shown in Section 4 'Worked Example'). The lowest value given for the range of uncertainty is zero, as it is not possible for less than zero collisions to occur.

Table 7 - 6 - 20 presents the final predicted annual collision rates and uncertainty based on the Band (2024) method, and Table 7 – 6 – 21 presents the final predicted annual collision rates calculated using only the flight activity in the bands within potential collision risk height and always setting the proportion flying at risk height to 1 respectively and uncertainty calculated using the multiplicative method. The range of these two predictions was used for the impact assessment. The results should be considered as a best estimate of collision risk, rather than a precise figure.

Table 7 - 6 - 20 Predicted annual collision rate following Band (2024)

Species	Months	Model	Avoidance Factor	Annual Collision Rate	Range of Uncertainty	Collisions Over Lifetime	Years to One Collision
Golden Plover	Oct-Apr	non-directional	0.996	0.292	0-0.950	10.22	3
Hen Harrier	Apr-Sep	non-directional	0.99	0.015	0-0.029	0.525	>35

Species	Months	Model	Avoidance Factor	Annual Collision Rate	Range of Uncertainty	Collisions Over Lifetime	Years to One Collision
Hen Harrier	Oct-Mar	non-directional	0.99	0.007	0-0.016	0.245	>35
Peregrine Falcon	Oct-Sep	non-directional	0.98	0.00008	0-0.00035	0.003	>35
Whooper Swan	Oct-Apr	non-directional	0.995	0.195	0-0.512	6.825	5
Kestrel	Oct-Sep	non-directional	0.95	0.257	0-0.578	8.995	4
Snipe	Oct-Sep	non-directional	0.98	0.044	0-0.093	1.54	23
Buzzard	Oct-Sep	non-directional	0.98	0.307	0.006-0.608	10.745	3
Sparrowhawk	Oct-Sep	non-directional	0.98	0.01	0-0.036	0.35	>35

Table 7 - 6 - 21 Predicted annual collision rate calculated using only the flight activity in the bands within potential collision risk height and always setting the proportion flying at risk height to 1 and with a range of uncertainty using a multiplicative method

Species	Months	Model	Avoidance Factor	Annual Collision Rate	Range of Uncertainty	Collisions Over Lifetime	Years to One Collision
Golden Plover	Oct-Apr	non-directional	0.996	0.0713	0.016-0.323	2.4955	14
Hen Harrier	Apr-Sep	non-directional	0.99	0.0323	0.011-0.098	1.1305	31
Hen Harrier	Oct-Mar	non-directional	0.99	0.0077	0.002-0.029	0.2695	>35
Peregrine Falcon	Oct-Sep	non-directional	0.98	0.0004	0-0.003	0.014	>35
Whooper Swan	Oct-Apr	non-directional	0.995	0.2581	0.065-1.032	9.0335	4
Kestrel	Oct-Sep	non-directional	0.95	0.4673	0.125-1.752	16.3555	2
Snipe	Oct-Sep	non-directional	0.98	0.1008	0.028-0.358	3.528	10
Buzzard	Oct-Sep	non-directional	0.98	0.3649	0.121-1.102	12.7715	3
Sparrowhawk	Oct-Sep	non-directional	0.98	0.0142	0.003-0.059	0.497	>35

4. WORKED EXAMPLE

This section provides a worked example of the collision rate prediction for sparrowhawk at an imaginary facility. This example is deliberately simplified to assist readers with following the steps. The prediction is made using a short imaginary dataset presented in Section 4.2.

4.1 Proposed Development Scenario

In this example, a wind farm is proposed in farmland at a latitude of 53.4°N. The development consists of seven turbines. Each turbine has a hub height of 105m and rotor diameter of 150m, giving a rotor-swept height range of 30-180m. The turbines have a blade radius (R) of 75m, a blade pitch (λ) of 6°, and a maximum blade chord width (C) of 4.2m. Each turbine has 3 blades (b) and operates at an average rotational speed (Ω) of 11.4rpm. The proposed operational lifetime of 35 years, with turbines expected to be operational approximately 85% of the time.

The blade profile of the turbines is presented in Table 7 - 6 - 22. This table provides the chord width values at 20 evenly spaced points along the blade, expressed relative to the maximum chord width. In this context, r denotes the distance from the hub, and R represents the total blade length (i.e., the rotor radius). The ratio r/R therefore represents the relative radial position along the blade, where 0 corresponds to the hub and 1 corresponds to the blade tip. Similarly, c represents the chord width at a given distance (r) from the hub, and C is the maximum chord width of the blade. Therefore, the ratio c/C represents the relative chord width.

Table 7 - 6 - 22 Blade profile of the turbines

r/R	c/C
0.00	0.690
0.05	0.730
0.10	0.790
0.15	0.880
0.20	0.960
0.25	1.000
0.30	0.980
0.35	0.920
0.40	0.850
0.45	0.800
0.50	0.750
0.55	0.700
0.60	0.640
0.65	0.580
0.70	0.520
0.75	0.470
0.80	0.410
0.85	0.370
0.90	0.300
0.95	0.240
1.00	0.000

4.2 Bird Survey Scenario

In this example, bird surveys were conducted at the proposed wind farm site for a two year period (April 2023 to March 2025). Vantage point surveys to monitor flight activity were undertaken at two vantage points. The combined viewsheds from these vantage points provided at least 500m coverage around all turbines in addition to coverage of the site and surrounds (Figure 7 - 6 - 1). The total viewshed area was 5.23km^2 for VP1 and 5.92km^2 for VP2.

Both vantage points were surveyed for 6 hours per month throughout the survey period, totalling 144 hours of survey at each location. For each recorded flight, the duration (in seconds) that bird spent within pre-defined height bands was recorded. These heights bands were:

- Band 1 = 0-15m
- Band 2 = 15-25m
- Band 3 = 25-200m
- Band 4 = 200m+

As the risk height range of the turbine is 30-180m, all flight activity in Band 3 is considered to be at potential collision height.

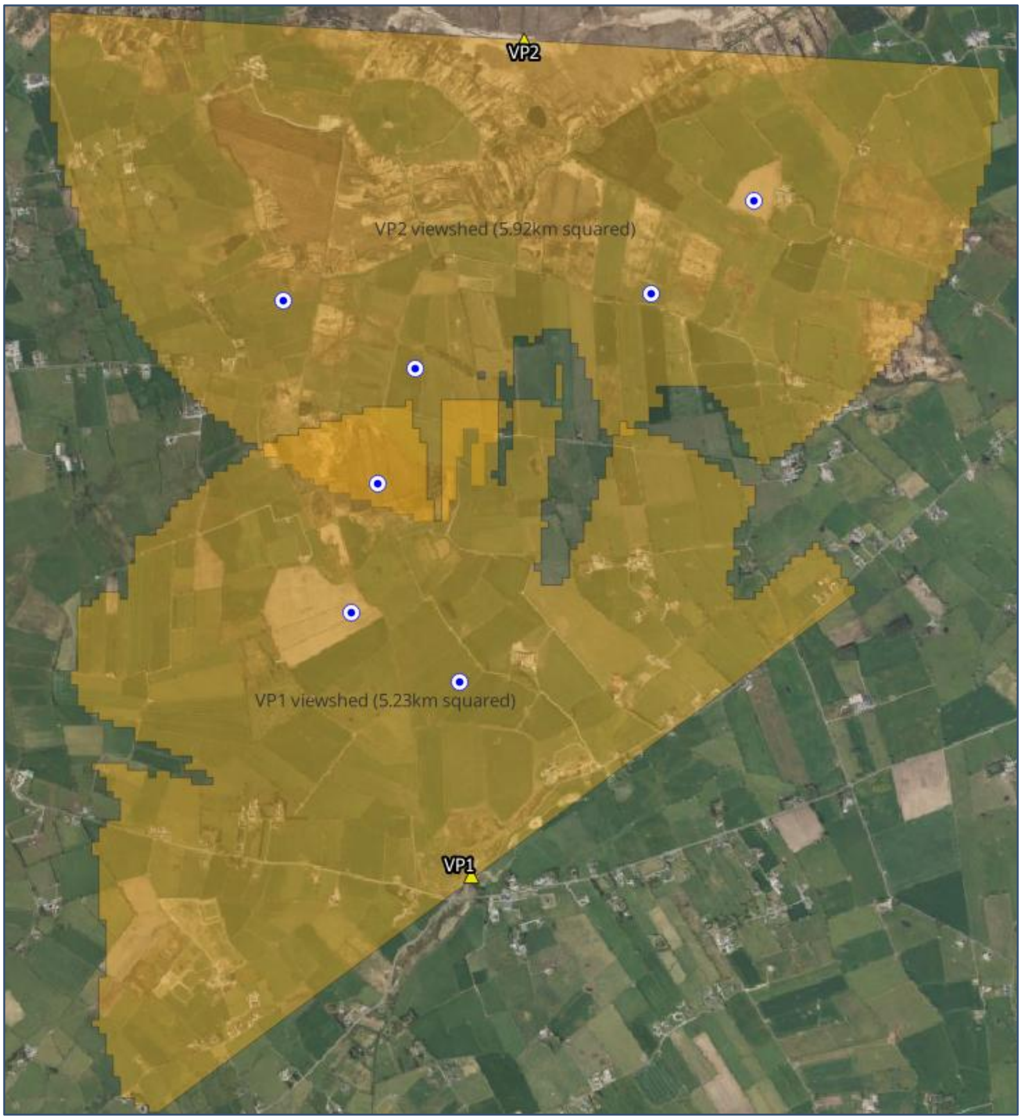

Figure 7 - 6 - 1 Vantage point survey locations and viewshed areas

In this example, a collision risk model will be conducted for the species sparrowhawk. All records for sparrowhawk collected during vantage point surveys are presented in Table 7 - 6 - 23. Records denoted '-' represent non-flight activity, for example when a bird is perched.

The data in Table 7 - 6 - 23 shows that sparrowhawk was present at the site throughout the survey period, in both the breeding and winter season. Therefore, all months of the year will be modelled.

Table 7 - 6 - 23 Sparrowhawk records from vantage point surveys

VP	Date	Time	Species	Number	Band 1	Band 2	Band 3	Band 4
VP2	17/11/2023	07:36	Sparrowhawk	1	0	0	17	0
VP2	17/11/2023	07:43	Sparrowhawk	1	-	-	-	-
VP1	12/12/2023	11:24	Sparrowhawk	1	-	-	-	-
VP1	12/01/2024	12:14	Sparrowhawk	2	14	0	15	0
VP2	30/01/2024	11:34	Sparrowhawk	1	87	0	0	0
VP2	21/02/2024	16:19	Sparrowhawk	1	0	5	30	0
VP1	14/03/2024	11:48	Sparrowhawk	1	50	12	0	0
VP1	03/05/2024	11:25	Sparrowhawk	2	0	0	19	0
VP2	09/05/2024	09:56	Sparrowhawk	1	6	0	0	0
VP1	19/06/2024	10:14	Sparrowhawk	1	15	3	0	0
VP1	19/06/2024	14:22	Sparrowhawk	1	0	0	139	0
VP1	09/07/2024	16:56	Sparrowhawk	1	21	0	0	0
VP2	26/07/2024	13:37	Sparrowhawk	1	0	0	17	0
VP1	03/10/2024	14:02	Sparrowhawk	1	32	9	0	0
VP1	06/11/2024	12:15	Sparrowhawk	1	14	4	0	0
VP1	29/11/2024	13:09	Sparrowhawk	1	0	18	81	0
VP1	29/11/2024	15:57	Sparrowhawk	1	16	0	0	0
VP2	31/01/2025	13:07	Sparrowhawk	1	20	48	10	0
VP2	13/03/2025	08:46	Sparrowhawk	1	0	80	3	0

4.3 Stage A: Flight Activity

Aerial bird density

In order to calculate the aerial bird density (D_A) for sparrowhawk, the following formula was used:

$$DA = b / (t \times A) \text{ bird-seconds m}^2$$

To calculate parameter b, the number of 'bird-seconds' per month per vantage point was calculated by multiplying the number of birds aloft by the duration of the flight (in seconds). The time spent in all bands and only the time spent in bands within potential collision height (i.e., Band 3) were calculated. These values are presented in Table 7 - 6 - 24. Note that sparrowhawk was not recorded in every month, therefore some months are not present in the table.

Table 7 - 6 - 24 Bird-seconds per vantage point per month

Month	Vantage Point	Bird-Seconds	Bird-Seconds at Potential Collision Height
Jan	VP1	58	30

Month	Vantage Point	Bird-Seconds	Bird-Seconds at Potential Collision Height
Mar	VP1	62	0
May	VP1	38	38
Jun	VP1	157	139
Jul	VP1	21	0
Oct	VP1	41	0
Nov	VP1	133	81
Jan	VP2	165	10
Feb	VP2	35	30
Mar	VP2	83	3
May	VP2	6	0
Jul	VP2	17	17
Nov	VP2	17	17

Parameter t, the time that the vantage point was watched, was obtained from the survey effort. The breakdown of survey time at each vantage point is presented in Table 7 - 6 - 25.

Table 7 - 6 - 25 Survey time at each vantage point in hours and seconds according to month

Vantage Point	Month	Time in hours	Time in seconds
VP1	Jan	12	43200
VP2	Jan	12	43200
VP1	Feb	12	43200
VP2	Feb	12	43200
VP1	Mar	12	43200
VP2	Mar	12	43200
VP1	Apr	12	43200
VP2	Apr	12	43200
VP1	May	12	43200
VP2	May	12	43200
VP1	Jun	12	43200
VP2	Jun	12	43200
VP1	Jul	12	43200
VP2	Jul	12	43200
VP1	Aug	12	43200
VP2	Aug	12	43200
VP1	Sep	12	43200
VP2	Sep	12	43200
VP1	Oct	12	43200
VP2	Oct	12	43200
VP1	Nov	12	43200
VP2	Nov	12	43200
VP1	Dec	12	43200
VP2	Dec	12	43200

Parameter A is the entire area of the vantage point viewsheds. As described above, these were:

- VP1 = 5.23km^2
- VP2 = 5.92km^2

The aerial bird density (D_A) was calculated for all vantage points, and then a mean value was obtained for each month. For example, D_A for January at all height bands was calculated as:

VP1
b = 58
t = 43200
A = 5.23
D_A = 0.0002563467

VP2
b = 155
t = 43200
A = 5.92
D_A = 0.0006055715

Mean D_A for the month of January

(0002563467 X 0.0006055715)/2 = 0.0004309591

D_A for all months is presented in Table 7 - 6 - 26 (calculated using flight activity in all bands) and Table 7 - 6 - 27 (calculated using only the flight activity in the bands within potential collision risk height). Zero is input for months in which sparrowhawk was not recorded.

Table 7 - 6 - 26 Aerial bird density calculated using flight activity in all bands

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.0004	0.0001	0.0003	0	0.0001	0.0003	0.0001	0	0	0.0001	0.0003	0

Table 7 - 6 - 27 Aerial bird density calculated using only the flight activity in the bands within potential collision risk height

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.00009	0.00006	0.00001	0	0.00008	0.00031	0.00003	0	0	0	0.00021	0

Proportion of birds flying at risk height

The proportion of sparrowhawk flying at risk height (Q_2R) was calculated from the survey data in Table 7 - 6 - 23. Note that non-flight records are excluded from this calculation.

First, for each height band, the proportion of flights within that band relative to the total number of flights was calculated. Second, the proportion of each height band overlapping the rotor risk height (30-180m) was determined. Finally, these two proportions were multiplied. The workings for Band 3 (25-200m) are below.

Band 3
Total number of sparrowhawk flights = 17
Total number of sparrowhawk flights in band = 3
Proportion of flights in band = 0.176
Proportion of band overlapping rotor risk height = 0.858
0.176 X 0.858 = 0.151

This calculation was made for all bands. Then, the result from each band was summed to provide a total proportion of birds flying at risk height. Note that the result for bands that do not overlap with rotor risk height will be 0. Because Band 3 was the only band that overlapped with rotor risk height in this example, the final proportion of birds flying at risk height (Q_2R) was 0.151 or 15.1%.

A second calculation will be performed in this example in which the proportion of sparrowhawk flying at risk height (Q_2R) is always set to 1 (or 100%).

Photoperiod

The photoperiod at the latitude of the site was acquired for the survey period. The daylight and nighttime hours per month (tday and tnight respectively) are shown in Table 7 - 6 - 28. The total daylight hours was 4,487.093 and night-time hours was 4,272.907.

Table 7 - 6 - 28 Photoperiod

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daylight Hours	251.5	273.7	366.3	418.6	491.5	507.3	510.3	459.0	382.6	329.7	261.0	235.6
Nighttime Hours	492.5	398.3	377.7	301.4	252.5	212.7	233.7	285.0	337.4	414.3	459.0	508.4

4.4 Stage B: Number of Flights Through Rotors

To estimate the number of sparrowhawk flights through the rotors, firstly the total rotor frontal area for all turbines was calculated as:

$$\text{rotor frontal area} = T\ \pi R^2$$

Where T is the number of turbines. In this example, that is 7 X π X 75^2 = 123700.2m^2

Sparrowhawk biometrics were taken from the best available literature:

- Length (l) = 0.33m
- Wingspan (w) = 0.625m
- Flight speed (v) = 10m/s
- Flight type = flapping
- Nocturnal activity ranking (fnight) = 1 (0% nighttime activity)

Using the values from previous sections, the density (D_V) for each month was calculated as:

$$D_v = (D_A * Q_2R)/(2*R)$$

Then the projected number of transits through the rotor risk area was calculated as:

$$\text{transits} = v * D_v * \text{rotor frontal area} * ((tday + (tnight * (fnight/100))) * 3600)$$

In this example, the density for the month of January was (0.0004 X 0.151)/(2 X 75) = 4.349921^{-13}

The number of transits for the month of January was 10 X 4.349921^{-13} X 123700.2 X ((251.519 + (492.481 X (0/100))) X 3600) = 0.4872201. Table 7 - 6 - 29 (calculated using flight activity from all height bands and an estimated Q_2R) and Table 7 - 6 - 30 (calculated using only the flight activity in the bands within potential collision risk height and always setting the proportion flying at risk height to 1) shows the projected number of transits for all months. Note that a zero is input for months in which sparrowhawk was not recorded.

Table 7 - 6 - 29 Number of transits per month

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.487	0.084	0.493	0	0.211	0.791	0.183	0	0	0.134	0.384	0

Table 7 - 6 - 30 Number of transits per month calculated using only the flight activity in the bands within potential collision risk height and always setting the proportion flying at risk height to 1

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.642	0.477	0.064	0	1.227	4.633	0.503	0	0	0	1.646	0

4.5 Stage C: Probability of Collision

The probability of a sparrowhawk collision during a single rotor transit was calculated. Sparrowhawk biometrics, flight behaviour and the turbine specifications outlined in the previous sections were used to define how the bird interacts with the moving blades and derive the geometric parameters described below. Collision probability was determined separately for upwind and downwind flight directions. It was calculated as a function of radial position across the rotor disc, at increments of 0.05 from 0.05 to 1.0 (excluding the rotor centre).

At each radial position, collision probability was calculated for flight angles at increments of 10° from 0° to 180°, which assumes a uniform distribution of bird approach angles. For each flight angle, the flight angle (Φ) was converted from degrees to radians and turbine rotation speed (Ω) was converted from rpm to radians per second. The dimensionless radial position (radius) was converted to an absolute distance from the hub in metres. Then, the blade chord width at the radial position was estimated by interpolating the blade profile and scaling it by the maximum chord width, to reflect blade width changes from hub to tip. Flight direction (d) was set as 1 for upwind flight directions and -1 for downwind.

A standard dimensionless blade encounter rate multiplier was defined as:

$$b\ \Omega/2\ \pi v$$

where b is number of blades, Ω is rotation speed (now in rad s^{-1}), and v is bird flight speed.

The ratio of bird speed to blade tangential speed (α) was calculated as:

$$\alpha = v/\text{radius}\ \Omega$$

The blade pitch (λ) was converted from degrees to radians to obtain the blade tilt angle (θ) relative to the rotor plane:

$$\theta = \lambda\pi/180$$

Using these values, two collision lengths were calculated. The first was a blade-related component (accounting for blade chord width [c], blade tilt [θ], bird flight direction [d] and the ratio of bird speed to blade tangential speed [α]), which represents the effective 'interaction length' associated with blade motion and geometry:

$$|\ d\ c\ \sin(\theta)+\alpha\ c\ \cos(\theta)|$$

The second was a bird-size-related component (accounting for body length [l], wingspan [w] and flight type):

$$\max(l, w_{eff}\ \alpha)$$

Here, w_{eff} is the effective wingspan. For flapping flight, the full wingspan was used, but for gliding flight, the wingspan would be reduced by the absolute value of the cosine of the flight angle relative to the rotor plane (Φ) to represent the reduced projected cross-section when the bird's wings are angled relative to the rotor plane.

Finally, the collision probability was calculated as the blade encounter rate multiplier multiplied by the sum of the two collision lengths. The result is capped at a maximum of 1 so that probabilities cannot exceed 100%. This collision probability was then averaged over the flight angles at the radial position. The upwind and downwind collision probabilities calculated for each radial position for sparrowhawk are presented in Table 7 - 6 - 31.

Table 7 - 6 - 31 Upwind and downwind collision probabilities

Radial Position	Upwind	Downwind
0.05	0.486082	0.449547
0.1	0.269631	0.230093
0.15	0.204551	0.160508
0.2	0.171557	0.123511
0.25	0.1502	0.100152
0.3	0.130199	0.081152
0.35	0.11173	0.065686
0.4	0.096588	0.054047
0.45	0.086103	0.046065
0.5	0.077465	0.039929
0.55	0.070171	0.035137
0.6	0.06319	0.031159
0.65	0.057052	0.028024
0.7	0.051576	0.025551
0.75	0.047235	0.023713
0.8	0.042698	0.022178
0.85	0.039644	0.021126
0.9	0.035181	0.020167
0.95	0.031534	0.019522
1	0.01881	0.01881

Next, the collision probabilities were averaged for flights through the rotor disk for upwind values and downwind values as follows:

$$P = 2[(i=1\sum n-1 r_i p_i)+2p_n]\Delta r$$

Where P is the mean single-transit collision probability (upwind or downwind), r_i is the radial position, p_i is the collision probability at radial position r_i, p_n is the collision probability at the outermost radial position (i.e., the blade tip), Δr = 0.05 (i.e., the radial increments) and n is the number of evaluated radial positions

The average collision risk for flights through the rotor when moving upwind was calculated as 0.0672, and for downwind as 0.0402. A 50:50 weighting of upwind and downwind flight was assumed. Thus, the final probability of a sparrowhawk collision during a single rotor transit was calculated as the weighted average of these two estimates. The estimated probability of collision for a sparrowhawk during a single rotor transit was 0.0537.

4.6 Stage D Expected Collisions

The outputs of stage B and C were multiplied to yield the expected collision rate for sparrowhawk, and the product was multiplied by the proportion of time the wind farm is expected to be operational. In this example, the expected collisions for January was calculated as:

0.487 X 0.0537 X 0.85 = 0.02224467

The predicted number of collisions for each month is presented in Table 7 - 6 - 32 (calculated using flight activity from all height bands and an estimated Q_2R) and Table 7 - 6 - 33 (calculated using only the flight activity in the bands within potential collision risk height and always setting the proportion flying at risk height to 1). Note that these rates assume no avoidance of turbines or wind farms by sparrowhawk.

Table 7 - 6 - 32 Expected collisions per month (without avoidance)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.022	0.004	0.023	0	0.010	0.036	0.008	0	0	0.006	0.018	0

Table 7 - 6 - 33 Expected collisions per month (without avoidance) calculated using only the flight activity in the bands within potential collision risk height and always setting the proportion flying at risk height to 1

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.029	0.022	0.003	0	0.056	0.212	0.023	0	0	0	0.075	0

4.7 Stage E Allowing for Avoidance and Attraction

Stage E of the modelling process takes account of the proportion of sparrowhawk likely to avoid the wind farm or its turbines. This is calculated for a range of avoidance factors: 95%, 98%, 99%, 99.5% (following guidance from Band [2004[) and 99.6% (following guidance from Gittings [2011; see Appendix 7-6-1]). The expected collisions per month calculated in stage D are multiplied by the avoidance rates to provide a collision rate with avoidance. These values are presented in Table 7 - 6 - 34 (calculated using flight activity from all height bands and an estimated Q_2R) and Table 7 - 6 - 35(calculated using only the flight activity in the bands within potential collision risk height potential collision risk height and always setting the proportion flying at risk height to 1).

Table 7 - 6 - 34 Expected collisions per month (with avoidance)

Avoidance Factor	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.95	0.0011	0.0002	0.0011	0.0000	0.0005	0.0018	0.0004	0.0000	0.0000	0.0003	0.0009	0.0000
0.98	0.0004	0.0001	0.0005	0.0000	0.0002	0.0007	0.0002	0.0000	0.0000	0.0001	0.0004	0.0000
0.99	0.0002	0.0000	0.0002	0.0000	0.0001	0.0004	0.0001	0.0000	0.0000	0.0001	0.0002	0.0000
0.995	0.0001	0.0000	0.0001	0.0000	0.0001	0.0002	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000

Table 7 - 6 - 35 Expected collisions per month (with avoidance) calculated using only the flight activity in the bands within potential collision risk height and always setting the proportion flying at risk height to 1

Avoidance Factor	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.95	0.0015	0.0011	0.0002	0.0000	0.0028	0.0106	0.0012	0.0000	0.0000	0.0000	0.0038	0.0000
0.98	0.0006	0.0004	0.0001	0.0000	0.0011	0.0042	0.0005	0.0000	0.0000	0.0000	0.0015	0.0000
0.99	0.0003	0.0002	0.0000	0.0000	0.0006	0.0021	0.0002	0.0000	0.0000	0.0000	0.0008	0.0000
0.995	0.0002	0.0001	0.0000	0.0000	0.0003	0.0011	0.0001	0.0000	0.0000	0.0000	0.0004	0.0000
0.996	0.0001	0.0001	0.0000	0.0000	0.0002	0.0009	0.0001	0.0000	0.0000	0.0000	0.0003	0.0000

4.8 Stage F: Uncertainty

To provide a measure of uncertainty in aerial density (u1), the relative standard deviation for the monthly values was used. First, the mean aerial density ($\bar{D}_A$) for all months was calculated to be 0.0001445. Then, the relative standard deviation (RSD) was calculated as:

$$RSD = s / \bar{D}_A$$

where s is the standard deviation of the monthly values. In this example:

$$0.00015/0.0001445 = 1.038062$$

Note that zero values (i.e., months in which the sparrowhawk was not recorded, such as April) were retained in this equation as they may represent true absence or intermittent use of the site.

Uncertainty due to simplifications in the collision risk model (u2) was assumed to be 20% (Band, 2024). Finally, uncertainty due to design options (u3) was considered to be 28%, as 4 of 14 turbine specifications were either not finalised or were approximate (blade profile, pitch, rotational speed and expected time operational). The overall range of uncertainty (u) was thus:

$$\sqrt{(u1^2 + u2^2 + u3^2)}$$

In this example, that is:

$$\sqrt{(1.038062^2 + 0.2^2 + 0.28^2)} = 1.093605$$

The Band (2024) method assumes that the uncertainties combine additively. However, the components of the model are multiplied rather than summed, therefore the uncertainty values should also be multiplied to avoid underestimating overall uncertainty. In this example, that is:

$$(1 + u1) * (1 + u2) * (1 + u3)$$

$$(1 + 1.038062) * (1 + 0.2) * (1 + 0.28) = 3.130463$$

4.9 Worked Example Collision Rates

To provide a best estimate of the collision rate for sparrowhawk, the guidance on avoidance rates provided by NatureScot in NatureScot (2025b) was consulted. This guidance recommends a 98% avoidance rate for sparrowhawk. As such the predicted number of collisions corresponding to a 98% avoidance rate was identified and is presented in Table 7 - 6 - 36 (calculated using flight activity from all height bands and an estimated Q_2R) and Table 7 - 6 - 37 (calculated using only the flight activity in the bands within potential collision risk height and always setting the proportion flying at risk height to 1), The range of uncertainty and an estimation of the number of years for one collision to occur is also presented; Table 7 - 6 - 36 presents uncertainty calculated using the root sum of squares and Table 7 - 6 - 37 presents uncertainty using the multiplicative method.

The columns 'Annual Collision Rate' in Table 7 - 6 - 36 and Table 7 - 6 - 37 present a range for the final predicted annual collision rate for sparrowhawk that would be used in the impact assessment for this proposed development scenario: 0.0025-0.0084 sparrowhawk per year. Due to the uncertainties discussed in stage F, this may range up to 0.0052-0.026 sparrowhawk per year. Dividing 1 by 0.0025 or 0.0084 provides the number of years it would be expected for a collision to occur based on the model predictions.

Table 7 - 6 - 36 Predicted annual collision rate

Species	Annual Collision Rate	Range of Uncertainty	Years to one collision
Sparrowhawk	0.0025	0-0.0052	395

Table 7 - 6 - 37 Predicted annual collision rate calculated using only the flight activity in the bands within potential collision risk height and always setting the proportion flying at risk height to 1 and with a range of uncertainty using a multiplicative method

Species	Annual Collision Rate	Range of Uncertainty	Years to one collision
Sparrowhawk	0.0084	0-0.026	119

5. BIBLIOGRAPHY

Band, W. (2024). Using a collision risk model to assess bird collision risks for onshore wind farms. NatureScot Research Report 909. NatureScot, Inverness, Scotland. Available at: https://www.nature.scot/doc/naturescot-research-report-909-using-collision-risk-model-assess-bird-collision-risks-onshore-wind

Gittings, T. (2024). Distance effects on detection rates in wind farm vantage point survyes: implications for avian collision risk modelling. *In Practice Bulletin of the Chartered Institute of Ecology and Environmental Management*, 126: 40-44.

Largey, N., Edwards, H., Fernández-Bellon, D. and Doyle, S. (2026). Implications of surveyor accuracy in bird flight height estimation for wind farm collision risk assessment. *Ecological Solutions and Evidence,* 7(2): e70238.

NatureScot (2025a). Recommended bird survey methods to inform impact assessment of onshore windfarms. NatureScot, Inverness, Scotland. Available at: https://www.nature.scot/doc/recommended-bird-survey-methods-inform-impact-assessment-onshore-windfarms

NatureScot (2025b). Wind farm impacts on birds - Use of Avoidance Rates in the NatureScot Wind Farm Collision Risk Model. NatureScot, Inverness, Scotland. Available at: https://www.nature.scot/doc/wind-farm-impacts-birds-use-avoidance-rates-naturescot-wind-farm-collision-risk-model

6. APPENDICES

APPENDIX 7-6-1

GOLDEN PLOVER AVOIDANCE RATES (GITTINGS, 2011)

GOLDEN PLOVER AVOIDANCE RATES

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CONTENTS

SUMMARY

This report assesses the evidence for developing a species-specific avoidance rate for wintering Golden Plover populations, and makes recommendations for specifying this rate.

Collision risk modelling for onshore wind farms in Ireland generally follows the latest Scottish Natural Heritage / Natural Scotland avoidance rate guidance. This guidance includes two types of avoidance rates: species-specific avoidance rates; and a default avoidance rate that should be applied to all other species. Based on the latest version of the guidance, the default avoidance rate of 98% applies to wintering Golden Plover populations. However, review of the development of the SNH avoidance rate guidance shows that the default avoidance rate of 98% is not based on any published empirical evidence, the trend is for avoidance rates to increase as more data becomes available, and the guidance does not always reflect the latest evidence on species-specific avoidance rates. Therefore, the lack of a species-specific avoidance rate for Golden Plover in the SNH avoidance rate guidance does not necessarily mean that there is not any robust data available that could be used to develop a species-specific avoidance rate for Golden Plover.

There are reports for four UK wind farms that provide data that can be used to estimate avoidance rates, or which provide their own estimates of avoidance rates, for wintering Golden Plover populations. For three of these wind farms, the collision monitoring methodologies are robust and generally comply with best practice guidance, so the collision fatality estimates can be regarded as reliable. The avoidance rates calculated for the wintering Golden Plover populations at these wind farms range from 99.87-99.98%. For the fourth wind farm, the available information on the collision monitoring methodology was limited, but there may have been some issues with the methodology and results. The avoidance rate for the wintering Golden Plover population given in the relevant reports for this wind farm was 99.6%.

The highest avoidance rate currently recommended by Scottish Natural Heritage / Natural Scotland is 99.8% for geese. The narrow range of the avoidance rate values for wintering Golden Plover populations at the three wind farms with reliable collision fatality estimates would suggest that 99.8% is a suitable avoidance rate for wintering Golden Plover populations. The 99.6% avoidance rate at the other wind farm is lower than this value, although there may be some issues with this avoidance rate. Therefore, I recommend that collision risk modelling for wintering Golden Plover populations use two avoidance rate values: 99.6% and 99.8%. In practice, this will mean two predicted collision rates, with the one calculated with the 99.6% avoidance rate being twice the value of the other calculated with the 99.8% avoidance rate. These predicted collisions will be five times, and ten times, respectively, lower than predicted collisions calculated with the default 98% avoidance rate.

1. INTRODUCTION

This report was commissioned by MKO.

The objective of the report was to assess the evidence for developing a species-specific avoidance rate for wintering Golden Plover populations, and, if appropriate, make recommendations for specifying this rate.

Collision risk modelling for onshore wind farms in Ireland generally follows the latest Scottish Natural Heritage / Natural Scotland avoidance rate guidance (referred to hereafter as the SNH avoidance rate guidance). The latest version of this guidance (SNH, 2018) does not include a species-specific avoidance rate for wintering Golden Plover populations. Therefore, following the SNH avoidance rate guidance would mean that the default 98% avoidance rate should be applied to wintering Golden Plover populations. However, there is apparently robust data available from post-construction monitoring that indicates that a much higher avoidance rate should be applied to wintering Golden Plover populations.

In this report, I first review the development of the SNH avoidance rate guidance and consider whether the history of its development affects the interpretation of the fact that it does not include a species-specific avoidance rate for wintering Golden Plover populations. I then review the methods and results of four post-construction monitoring studies, and use the data from these studies to derive empirical avoidance rates for the wintering Golden Plover population in each study. I then assess the overall weight of evidence for applying a species-specific avoidance rate to wintering Golden Plover populations and make recommendations for avoidance rate values that should be used in collision risk modelling for such populations.

2. THE SNH AVOIDANCE RATE GUIDANCE

2.1. TYPES OF AVOIDANCE RATES

The SNH avoidance rate guidance includes two types of avoidance rates: specific avoidance rates for individual species, or groups of closely-related species (e.g., swans or geese); and a default avoidance rate that should be applied to all other species.

2.2. THE EVOLUTION OF THE SNH AVOIDANCE RATES

The latest version of the SNH avoidance rate guidance (SNH, 2018) includes a default 98% avoidance rate for species not listed in their guidance. However, this default avoidance rate does not appear to have any empirical basis.

In 2000, the first guidance from Scottish Natural Heritage on avoidance rates recommended a precautionary avoidance rate of 95%, which was "based solely on expert opinion and has little or no empirical basis, as no sound, relevant data were available at the time" (SNH, 2010). In 2010, Scottish Natural Heritage updated their guidance on avoidance rates to included species-specific avoidance rates where relevant data was available (SNH, 2010). They also updated the default avoidance rate for other species to 98% because "in the majority of cases where avoidance rates have been derived from empirical data, the avoidance rates are higher than 95%" (SNH, 2010). Further revisions of the SNH avoidance rate guidance were published in 2016 and 2018 (SNH, 2016; 2018). Comparison of the first species-specific avoidance rates published by Scottish Natural Heritage with the latest species-specific avoidance rates (Table 2.1) shows that as the knowledge base has developed there has been an increase in the recommended avoidance rates. Most species-specific avoidance rates are 99% or higher. The only species with species-specific avoidance rates of less than 99% are White-tailed Eagle and Kestrel.

Table 2.1. Species-specific avoidance rates defined in SNH guidance

Species	SNH Guidance	
	2010	2018
Divers	98%	99.5%
Swans	98%	99.5%
Geese	99%	99.8%
Red Kite	98%	99%
Hen Harrier	99%	99%
Golden Eagle	99%	99%
White-tailed Eagle	95%	95%
Kestrel	95%	95%
Skuas	98%	99.5%

Sources: SNH (2010, 2018). Divers: the 2010 guidance gives a species-specific avoidance rate for Red-throated Diver and a default avoidance rate for Black-throated Diver. Swans: the 2010 guidance gives a species-specific avoidance rate for Whooper Swan, and does not provide avoidance rates for other swan species, while the 2018 guidance gives a species-specific avoidance rate for all swan species. Geese: the 2010 guidance gives separate (but identical) species-specific avoidance rates for Greylag, Pink-footed, Greenland White-fronted and Barnacle Geese, while the 2018 guidance gives a single species-specific avoidance rate for all geese species. Skuas: the 2010 guidance gives a single default avoidance rate for all skua species, while the 2018 guidance gives separate (but identical) species-specific avoidance rates for Great Skua and Arctic Skua.

2.3. EXAMPLES OF SPECIES-SPECIFIC AVOIDANCE RATES IN THE SNH AVOIDANCE RATE GUIDANCE

The 95% avoidance rate for White-tailed Eagle is described as being based on: "sufficient evidence from flight behaviour and collision monitoring studies in Norway for vulnerability to collisions; see May *at al.* (2011)" (SNH, 2018). However, this appears to include a citation error as May *at al.* (2011) provides an estimate for a year-round avoidance rate of 98%, with a confidence interval of 95-99%, based on satellite telemetry data. Presumably, the intended citation was May *at al.* (2010), which included an estimated avoidance rate of 95.8%, based on VP survey data, corrected for the observed wind speed distribution at the study site. This latter reference also included avoidance rates of 97.8% and 97.9% for fixed rotation speeds, and an avoidance rate of 92.5% when the collision risk was modelled using uncertainty levels. The SNH avoidance rate guidance on avoidance rates does not discuss these differing estimates of White-tailed Eagle avoidance rates, and the recommended 95% avoidance rate has remained unchanged since 2010 without any caveats added to reflect the various avoidance rates indicated by the May *at al.* (2010 and 2011) studies.

The 95% avoidance rate for Kestrel is described as being based on: *"*sufficient evidence from flight behaviour (including hovering) and collision monitoring studies for vulnerability to collisions*"* (SNH, 2018). The cited source (Whitfield and Madders, 2006) is, in fact, a review of avoidance rates for Red Kite. The information on Kestrel is derived from an analysis which finds a significant correlation between the *"*numbers of individuals seen*"* against numbers of carcasses found for 16 raptor species at a single wind farm in Spain. Kestrel is a large outlier above the regression line, and this appears to be the only empirical evidence that has been used by SNH to support the 95% avoidance rate for Kestrel. However, even taken at face value, all this analysis does is indicate that Kestrel has a lower avoidance rate than other raptor species, but it does not provide any quantitative data that can be used to estimate the avoidance rate. More seriously, this analysis does not account for behavioural and ecological differences between species that may affect the relationship between recorded bird activity and collisions. It is also subject to the perennial problem with analyses of collision rates: the small absolute numbers of collisions which means that random sampling error may have significant effects.

These two examples show that the species-specific avoidance rates in the SNH avoidance rate guidance do not necessarily reflect all the available evidence (White-tailed Eagle) and can be based on rather sketchy evidence (Kestrel).

2.4. UPDATING THE SNH AVOIDANCE RATE GUIDANCE

The SNH avoidance rate guidance states that *"*it is updated when robust new information becomes available*"* (SNH, 2018). However, while this may be an aspiration, it may not necessarily happen quickly. For example, the SNH avoidance rate guidance currently does not give species-specific avoidance rates for gulls, so the default avoidance rate of 98% applies to all gull species. This guidance refers specifically to onshore wind farms, while separate guidance has been developed for offshore wind farms (JNCC *at al.*, 2014). The latter guidance recommends an avoidance rate of 99.5% for large gulls, based on a review by Cook *at al.* (2014). The discrepancy between the recommended avoidance rates for large gulls between offshore and onshore wind farms, was not addressed until a review by Furness (2019), which was commissioned by SNH. This review recommended that the 99.5% avoidance rate for large gulls at offshore wind farms should also be adopted for onshore wind farms. The review also recommended an avoidance rate of 99.2% for small gulls, which was also based on the data in Cook *at al.* (2014). However, as of June 2022, Scottish Natural Heritage / NatureScot have not updated their guidance on avoidance rates for onshore wind farms to reflect the robust evidence that has been available about species-specific avoidance rates for gulls since at least 2014.

2.5. CONCLUSIONS

The above analysis of the development of the SNH avoidance rate guidance and its treatment of avoidance rates for White-tailed Eagle, Kestrel and gulls, shows that the default avoidance rate of 98% is not based on any published empirical evidence, the trend is for avoidance rates to increase as more data becomes available, and the guidance does not always reflect the latest evidence on species-specific avoidance rates. Therefore, the lack of a species-specific avoidance rate for Golden Plover in the SNH avoidance rate guidance does not necessarily mean that there is not any robust data available that could be used to develop a species-specific avoidance rate for Golden Plover.

3. REVIEW OF GOLDEN PLOVER AVOIDANCE RATES

3.1. SOURCES

I found post-construction monitoring reports for three UK wind farms that provide robust data on Golden Plover collision fatality rates, and, for which, there was appropriate data available that could be used to estimate avoidance rates. These reports were for the Blood Hill Wind Farm (Percival *at al.*, 2008), the Goole Fields I Wind Farm (Percival *at al.*, 2018a) and the Goole Fields II Wind Farm (Percival *at al.*, 2018b, 2019). In addition, information on Golden Plover collision fatality rates and avoidance rates is included in the Habitats Regulations Assessment reports for another UK wind farm site (Haverigg II and III[1]; Percival, 2020a, 2020b), although the reports do not contain sufficient detail to allow full review of the collision monitoring methods and results. Unless otherwise stated, all information and data used in this report for each wind farm was taken from the relevant references cited above.

The characteristics of these wind farms are summarised in Table 3.1.

Table 3.1. Characteristics of the wind farms.

Wind farm	Location	Commissioned	Number of turbines	Hub height (m)	Turbine dimeter (m)
Blood Hill Wind Farm	Norfolk	1992	10	30	27
Goole Fields I	Yorkshire	2014	16	80	92
Goole Fields II	Yorkshire	2016	17	80	92
Haverigg II	Cumbria	1998	4	62.5	42
Haverigg III	Cumbria	2005	4	76	52

Sources: Percival (2020a, 2020 b); Percival *at al.* (2008, 2018a, 2018b, 2019).

3.2. COLLISION MONITORING

3.2.1. Methods

The post-construction monitoring for the Blood Hill and Goole Fields I and II wind farms were carried out by the same consultancy and used the similar methodology for collision monitoring. These included weekly searches for carcasses, and searcher efficiency trials and carcass removal trials (Table 3.2). The weekly carcass searches included detailed searches of radii of 100 m (Blood Hill and Goole Fields I), or 130 m (Goole Fields II) around each turbine, with an additional 250 m scanned for large carcasses (Goole Fields I and Goole Fields II). The carcasses found were left in situ to provide data on searcher efficiency and removal rates. In addition, dedicated searcher efficiency, and carcass removal, trials were carried out at all three wind farms. These involved putting out a number of carcasses. A separate observer then tried to locate these carcasses the same day, while the carcasses were also monitored by trail cameras to investigate removal rates.

Table 3.2. Collision monitoring methods.

Wind farm	Seasons	Search frequency	Search radius	Searcher efficiency / carcass removal trials
Blood Hill	2006/07-2007/08	weekly	100 m	67 carcasses
Goole Fields I	2015/16-2018/19	weekly	100 m detailed search 250 m large carcass search	18 carcasses
Goole Fields II	2017/18-2018/19	weekly	130 m detailed search 250 m large carcass search	48 carcasses

Sources: Percival *at al.* (2008, 2018a, 2018b, 2019).

[1] Haverigg I and II are separate, but adjacent, wind farms. However, the reports combine the data for the two wind farms to calculate a single avoidance rate.

The post-construction monitoring for the Haverigg II and III wind farms was carried out between September 2018 and February 2019, with approximately monthly visits. Detailed information about the methodology of this monitoring was not available to me for this review. However, it included searcher efficiency and carcass removal trials.

3.2.2. Results

No Golden Plover fatalities were recorded at the Blood Hill Wind Farm, single fatalities were recorded at the Goole Fields I and Goole Fields II Wind Farms, and one probable Golden Plover fatality and another probable wader fatality were recorded at the Haverigg II and III Wind Farms (Table 3.3). At Blood Hill, searcher efficiency was very high, and the report notes that conditions were good for searching with winter cereals or bare ploughed ground under the turbines. At Goole Fields I and Goole Fields II, crop growth prevented full coverage of the search area on each visit, with overall coverage levels of 60-88% across the five winters covered at these two wind farms. Searcher efficiency was lower than at Blood Hill but still relatively high.

Table 3.3. Collision monitoring results.

Wind farm	Seasons	Golden Plover / wader fatalities recorded	Coverage	Searcher efficiency	% of carcasses missed due to scavengers
Blood Hill	2006/07 2007/08	0 0	100% 100%	> 99%	38%
Goole Fields I	2015/16 2016/17 2018/19	1 0 0	60% 81% 79%	82%	14%
Goole Fields II	2017/18 2018/19	1 0	81% 88%	91%	17%
Haverigg II and III	2018/19	2	no data	93%	33%

All data taken from the relevant reports cited in Section 3.1. The fatalities at Goole Fields I and Goole Fields II were confirmed Golden Plover fatalities. The fatalities at Haverigg II and III were one probable Golden Plover and one probable wader.

3.3. DERIVATION OF AVOIDANCE RATES

3.3.1. Avoidance rate calculations

Table 3.4 shows the predicted number of collisions using the SNH default 98% avoidance rate, the estimated number of collision fatalities, and the empirical avoidance rates for each site. The estimated number of collision fatalities are the actual number of collision fatalities recorded adjusted for coverage, searcher efficiency and carcass removal. Note that the data for Haverigg II and III is a combined estimate for Golden Plover and Curlew. At Blood Hill, Goole Fields I and Goole Fields II, the estimated numbers of collision fatalities were 30-90 times lower than the predicted collisions. The difference was lower at Haverigg II and III, but the estimated numbers of collision fatalities number of collision fatalities was still around six times lower than the predicted collisions. The empirical avoidance rates vary from 99.6% to 99.98%.

For the Blood Hill Wind Farm, there does not appear to be any pre-construction collision risk estimates available. Instead, collision risk estimates were obtained from post-construction vantage point surveys. The reports for the Haverigg II and III Wind Farms were for lifetime extension applications, so the collision risk estimates were also obtained from post-construction vantage point surveys. As noted in the reports, comparison of these estimates with the collision monitoring results may underestimate the avoidance rate, as birds avoiding the wind farm (macro-avoidance) will not be included in the collision risk predictions. However, the monitoring data does not indicate any significant displacement impacts to Golden Plover, so macro-avoidance may not be a significant factor for this species. For the Goole Fields I and Goole Fields II Wind Farms, the post-construction monitoring reports include the pre-construction collision risk predictions from the Environmental Statements for the projects.

No Golden Plover fatalities were recorded in the post-construction monitoring at Blood Hill. However, it would be incorrect to assume a 100% avoidance rate as, where collision rates are low, zero fatalities will be expected in some years ("false negatives"; SNH, 2009). The study by Fijn et al. (2012), which was used by Whitfield and Urquhart (2015) to derive an avoidance rate for Whooper Swan, also did not record any fatalities. To derive an avoidance rate, they assumed that one swan had been killed, and Whitfield and Urquhart (2015) followed that assumption. Therefore, to obtain an avoidance rate estimate for Blood Hill, I used a nominal value of 0.7 Golden Plover fatalities at Blood Hill (equal to one Golden Plover carcass found over two years, corrected for the expected percentage of carcasses missed due to scavenger removal).

Table 3.4. Comparison of collision risk predictions with collision monitoring results.

Wind farm	Predicted collisions (98% avoidance rate) per year	Golden Plover / wader fatalities per year	Avoidance rate
Blood Hill	62	0.7	99.98%
Goole Fields I	56	0.6	99.98%
Goole Fields II	53	1.7	99.94%
Haverigg II and III	28	5.0	99.6%

The data in this table for Haverigg II and III are combined calculations for Golden Plover and Curlew.

The predicted collisions were obtained from the data reported in the post-construction monitoring reports (see Section 3.1). In those reports, the predicted collisions were calculated from post-construction vantage point survey data for Blood Hill and Haverigg II and III, and from pre-construction vantage point survey data for Goole Fields I and Goole Fields II. For Blood Hill, the post-construction monitoring report includes the predicted collisions with an avoidance rate of 0% and the predicted collisions with a 98% avoidance rate were calculated from this figure. For Goole Fields I and Goole Fields II, the post-construction monitoring reports include the predicted collisions with a 99% avoidance rate, and the predicted collisions with a 98% avoidance rate were calculated from these figures.

The Golden Plover / wader fatalities (excluding Blood Hill) were obtained from the data reported in the post-construction monitoring reports (see Section 3.1). In those reports, the Golden Plover / wader fatalities are estimated figures that were calculated from the recorded collisions, adjusted for coverage, searcher efficiency and carcass removal. For Blood Hill, as no Golden Plover fatalities were recorded, a nominal value of 0.7 Golden Plover fatalities is used here to calculate the avoidance rate (see text). For Haverigg II and III, the recorded collisions used for the calculations comprised one probable Golden Plover and one probable wader.

The avoidance rates for Blood Hill, Goole Fields I and Goole Fields II were calculated from the predicted collisions and Golden Plover fatality data provided in the relevant post-construction monitoring reports (see Section 3.1). The avoidance rate for Haverigg II and III is the avoidance rate figure provided in the relevant reports (see Section 3.1).

3.3.2. Correction factors

There are some complicating factors that need to be taken into account in assessing the reliability of the avoidance rate estimates in Table 3.4.

The maps of Golden Plover flightlines in the Blood Hill post-construction monitoring report show a concentration of flightlines in the western section of the 500 m buffer used for the collision risk model, with relatively few flightlines actually crossing the central part of the buffer where the turbines are located. This pattern suggests that the assuming random distribution of flight activity within the 500 m buffer will overestimate the actual collision risk.

For the Goole Fields I and Goole Fields II Wind Farms, the use of pre-construction vantage point survey data for the collision risk predictions means that the accuracy of the avoidance rate estimates is dependent on the pre-construction Golden Plover flight activity being representative of the post-construction Golden Plover flight activity (allowing for any macro-avoidance effects). At Goole Fields II, the mean Golden Plover bird-days/km^2 were around 2.1 times higher in the pre-construction surveys, compared to the post-construction surveys (Figure 15 in Percival *at al.*, 2019), while the mean Golden Plover count within the 600 m buffer zone was around 2.2 times higher during the pre-construction surveys, compared to the post-construction surveys (Table 22 in Percival *at al.*, 2019). These differences seem unlikely to be due to macro-avoidance effects as any displacement impacts to wintering Golden Plover would be likely to be contained within the 600 m buffer zone (and the mean Golden Plover bird-days/km^2 included counts outside the 600 m buffer zone).

The collision risk predictions used for the avoidance rate calculation for the Haverigg II and III Wind Farms used post-construction vantage point survey data. However, this was from a different winter (2014/15) than the winter used for the collision monitoring (2018/19). Therefore, the accuracy of the avoidance rate estimates is dependent on the Golden Plover flight activity patterns being similar in the two winters.

To allow for the above issues, I have used correction factors of 2.0 for the Blood Hill non-avoidance rate estimate, and 2.15 for the Goole Fields II non-avoidance rate estimate. The correction factor of 2.0 for the Blood Hill non-avoidance rate estimate is based on a visual estimate of differences in flightline densities in the western section of the buffer, compared to the central and eastern sections. The correction factor of 2.15 for the Goole Fields II non-avoidance rate estimate is the mean of the pre-construction / post-construction ratio of Golden Plover bird-days/km^2 and the pre-construction / post-construction ratio of Golden Plover counts within the 600 m buffer zone.

Applying correction factors of 2.0 to the Blood Hill non-avoidance rate estimate, and 2.15 to the Goole Fields II non-avoidance rate estimate, gives corrected avoidance rate estimates of 99.87-99.98%, while sufficient information is not available to assess whether a correction factor should be applied to the 99.6% avoidance rate for Haverigg II and III (Table 3.5).

Table 3.5. Corrected avoidance rate estimates.

Wind farm	**Avoidance rate**		**Correction factor**	**Reason**
	original	**corrected**		
Blood Hill	99.98%	99.96%	2.0	Uneven distribution of flight activity relative to turbine locations
Goole Fields I	99.98%	99.98%	1.0	-
Goole Fields II	99.94%	99.87%	2.15	Reduction in Golden Plover numbers
Haverigg II and III	99.6%	-	-	No data available to assess whether correction factor is needed (see text)

Note that the correction factor is applied to the non-avoidance rate. See text for further details of the reasons for the avoidance rate correction factors.

4. CONCLUSIONS

The collision monitoring methodologies used in the Blood Hill, Goole Fields I and Goole Fields II post-construction monitoring studies are robust and generally comply with best practice guidance (SNH, 2009). Therefore, I consider that the Golden Plover collision fatality estimates for the Goole Fields I and Goole Fields II Wind Farms from these studies are reliable. The reported zero collision fatality estimate for the Blood Hill Wind Farm does not include any correction for "false negatives" (cf., SNH, 2009), but I have allowed for this by using a nominal estimate in my calculations of avoidance rates.

The avoidance rates derived from these studies are very high, and even when I corrected two of them by doubling the non-avoidance rate to reflect uneven distribution of flight activity (Blood Hill) and apparent reductions in Golden Plover numbers (Goole Fields II), they remain around, or higher than, 99.9%. However, a degree of caution is necessary in applying these figures. Due to the low collision rate, very few collision fatalities are found. This means that random variation in the number of collision fatalities found will can cause significant changes in the avoidance rate estimate. For example, if a second fatality had been found at Goole Fields II, then the corrected avoidance rate estimate would decrease from 99.87%-99.74%. While this change may seem small, it would cause a doubling in the predicted collision risk.

Detailed information about the collision monitoring methodology used for the Haverigg II and III Wind Farms post-construction monitoring study was not available to me for this review. However, I note that there was a lower frequency of monitoring (approximately monthly) compared to the other studies (weekly). This will have made the collision fatality estimate less reliable. The avoidance rate calculation for this wind farm used combined data for Golden Plover and Curlew, while the two collision fatalities were a probable Golden Plover and a probable wader. Also, the avoidance rate calculations used flight activity and collision fatality data from different winters, and, unlike with Goole Fields I and Goole Fields II it was not possible for me to assess whether differences in Golden Plover flight activity patterns between the winters could have affected the calculations[2]. Therefore, it is possible that the significantly lower avoidance rate calculated for this wind farm, compared to the avoidance rates for Blood Hill, Goole Fields I and Goole Fields II, reflects methodological issues.

These avoidance rates are only derived from four studies, with two of these studies carried out at adjoining wind farms. However, these still represent a much stronger evidence base for a species-specific avoidance rate than the evidence used for Kestrel in the SHN avoidance rate guidance (see Section 2.3). Also, other species-specific avoidance rates in the SHN avoidance rate guidance are based on data from limited numbers of sites: e.g., both the White-tailed Eagle avoidance rate (see Section 2.3) and the Whooper Swan avoidance rate (Whitfield and Urquhart, 2015) are based on data from single sites. Therefore, the evidence base for a species-specific avoidance rate is relatively strong for Golden Plover compared to some of the species for which the SNH avoidance rate guidance does include species-specific avoidance rates. The lack of a species-specific avoidance rate for Golden Plover in the SNH avoidance rate guidance may reflect the fact that the conservation concern about Golden Plover and wind farms in Scotland is focussed on breeding populations. Data from wintering populations (such as in the studies reviewed here) may not be applicable to breeding populations due to the differences in their behaviour and ecology.

The highest avoidance rate currently recommended by SNH (2018) is 99.8% for geese. The narrow range of the corrected avoidance rates for Blood Hill, Goole Fields I and Goole Fields II (99.87-99.98%) would suggest that 99.8% is a suitable avoidance rate for wintering Golden Plover populations. The 99.6% avoidance rate at Haverigg II and III is lower than this value, although

[2] Note that, while my assessment of this issue for the Goole Fields II Wind Farm resulted in an increase in the corrected avoidance rate, compared to the original value, it is equally plausible that differences in flight activity between winters could cause a decrease in the corrected avoidance rate, compared to the original value.

there may be some issues with this avoidance rate. Therefore, I recommend that collision risk modelling for wintering Golden Plover populations use two avoidance rate values: 99.6% and 99.8%. In practice, this will mean two predicted collision rates, with the one calculated with the 99.6% avoidance rate being twice the value of the other calculated with the 99.8% avoidance rate. These predicted collisions will be five times, and ten times, respectively, lower than predicted collisions calculated with the default 98% avoidance rate.

REFERENCES

Cook, A.S.C.P., Humphreys, E.M., Masden, E.A. & Burton, N.H.K. (2014). The avoidance rates of collision between birds and offshore turbines. BTO Research Report, 656.

Fijn, R., Krijgsveld, K., Tijsen, W., Prinsen, H. & Dirksen, S. (2012). Habitat use, disturbance and collision risks for Bewick's Swans *Cygnus columbianus bewickii* wintering near a wind farm in the Netherlands. Wildfowl 52, 97-116.

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. Scottish Natural Heritage.

JNCC, NE, NRW, NIEA & SNH. (2014). Joint response from the Statutory Nature Conservation Bodies to the Marine Scotland Science avoidance rate review. Peterborough: Joint Nature Conservation Committee.

May, R.F., Lund, P.A., Langston, R., Dahl, E.L., Bevanger, K.M., Reitan, O., Nygård, T., Pedersen, H.-C., Stokke, B.G. & Røskaft, E. (2010). Collision risk in white-tailed eagles. Modelling collision risk using vantage point observations in Smøla wind-power plant. NINA rapport.

May, R.F., Nygård, T., Dahl, E.L., Reitan, O. & Bevanger, K.M. (2011). Collision risk in white-tailed eagles. Modelling kernel-based collision risk using satellite telemetry data in Smøla wind power plant.

Percival, S. (2020a). Haverigg II Wind Farm Lifetime Extension: Report to Inform a Habitats Regulations Assessment. Unpublished report, Ecology Consulting, Durham. https://bit.ly/3jQ7Bkf, accessed 19/04/2022.

Percival, S. (2020b). Haverigg III Wind Farm Lifetime Extension: Report to Inform a Habitats Regulations Assessment. Unpublished report, Ecology Consulting, Durham. https://bit.ly/37pNhUe, accessed 19/04/2022.

Percival, S., Percival, T. & Lowe, T. (2018a). Goole Fields Wind Farm, East Yorkshire: post-construction Bird Surveys Autumn/Winter 2015-16 to 2017-18. Unpublished report, Ecology Consulting, Durham. https://bit.ly/3ka2OKF, accessed 16/08/2020.

Percival, S., Percival, T. & Lowe, T. (2018b). Goole Fields II Wind Farm, East Yorkshire: post-construction Year 1 Bird Surveys 2017-18. Unpublished report, Ecology Consulting, Durham. https://bit.ly/3ka2OKF, accessed 07/05/2020.

Percival, S., Percival, T. & Lowe, T. (2019). Goole Fields 2 Wind Farm, East Yorkshire: post-construction Year 2 Bird Surveys 2018-19. Unpublished report, Ecology Consulting, Durham. https://bit.ly/3ka2OK, accessed 16/08/2020.

Percival, S., Percival, T., Hoit, M., Langdon, K. & Lowe, T. (2008). Blood Hill Wind Farm, Norfolk: post-construction wintering bird surveys 2006-07 and 2007-08. Unpublished report, Ecology Consulting, Durham. https://bit.ly/3ka2OKF, accessed 07/05/2020.

SNH (2009). Guidance on Methods for Monitoring Bird Populations at Onshore Wind Farms. Guidance Note, January 2009. Scottish Natural Heritage.

SNH (2010). Use of Avoidance Rates in the SNH Wind Farm Collision Risk Model. Scottish Natural Heritage.

SNH (2016). Avoidance Rates for the Onshore SNH Wind Farm Collision Risk Model. Scottish Natural Heritage.

SNH (2018). Avoidance Rates for the Onshore SNH Wind Farm Collision Risk Model. Scottish Natural Heritage.

Whitfield, D.P. & Madders, M. (2006). Deriving collision avoidance rates for Red Kites *Milvus milvus*. Natural Research Information Note 3.

Whitfield, D.P. & Urquhart, B. (2015). Deriving an Avoidance Rate for Swans Suitable for Onshore Wind Farm Collision Risk Modelling.