APPENDIX 7-6

COLLISION RISK ASSESSMENT

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1. INTRODUCTION

This document outlines the methodology used to conduct a collision risk assessment of Lemanaghan Wind Farm, Co. Offaly. 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 predicted for each species that can be used in the impact assessment

2.2 Turbine Specifications

The turbine specifications used in the model are provided in Table 7 - 6 - 1.The expected operational time of the turbines is 85% according to report by the British Wind Energy Association (BWEA; 2007) which identifies the standard operational period of the wind turbines in the UK.

Table 7 - 6 - 1 Turbine specifications

Component	Scenario Modelled
Latitude (˚N)	53.3
Turbine model	Vestas 150
Number of turbines	15
Hub height (m)	145

Component	Scenario Modelled
Rotor diameter (m)	150
Blade pitch (°)	6
Maximum blade width (m)	4.2
Rotational speed (rpm)	8.45
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 2020 and March 2025. This represents a 54-month period, consisting of 4 breeding seasons and 5 winter seasons, which is in full compliance with and exceeds the recommended 24 month survey 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 five 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 70m from ground 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.

Table 7 - 6 - 3 Vantage points

Vantage Point	Area Watched (ha)
VP1	644
VP2	641
VP3	627
VP5	628
VP6	642

Survey methodology followed SNH (2017; revised in NatureScot, 2025). 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	30	108000
VP2	Jan	27	97200
VP3	Jan	24	86400
VP4	Jan	18	64800
VP4a	Jan	6	21600
VP5	Jan	24	86400
VP6	Jan	29	104400
VP1	Feb	24	86400
VP2	Feb	24	86400
VP3	Feb	24	86400
VP4	Feb	18	64800
VP4a	Feb	6	21600
VP5	Feb	24	86400
VP6	Feb	18	64800
VP1	Mar	24	86400
VP2	Mar	24	86400
VP3	Mar	24	86400
VP4	Mar	18	64800
VP4a	Mar	6	21600
VP5	Mar	24	86400
VP6	Mar	30	108000
VP1	Apr	12	43200
VP2	Apr	12	43200
VP3	Apr	15	54000
VP4	Apr	9	32400
VP4a	Apr	6	21600

Vantage Point	Month	Hours Survey	Seconds Survey
VP5	Apr	15	54000
VP6	Apr	15	54000
VP1	May	15	54000
VP2	May	15	54000
VP3	May	12	43200
VP4	May	3	10800
VP4a	May	6	21600
VP5	May	12	43200
VP6	May	12	43200
VP1	Jun	18	64800
VP2	Jun	18	64800
VP3	Jun	18	64800
VP4	Jun	15	54000
VP4a	Jun	6	21600
VP5	Jun	18	64800
VP6	Jun	18	64800
VP1	Jul	24	86400
VP2	Jul	24	86400
VP3	Jul	24	86400
VP4	Jul	12	43200
VP4a	Jul	6	21600
VP5	Jul	18	64800
VP6	Jul	18	64800
VP1	Aug	21	75600
VP2	Aug	21	75600
VP3	Aug	21	75600
VP4	Aug	21	75600
VP4a	Aug	6	21600
VP5	Aug	27	97200
VP6	Aug	31	111600
VP1	Sep	18	64800
VP2	Sep	18	64800
VP3	Sep	18	64800
VP4	Sep	12	43200
VP4a	Sep	6	21600
VP5	Sep	18	64800
VP6	Sep	15	54000
VP1	Oct	18	64800
VP2	Oct	24	86400
VP3	Oct	24	86400
VP4	Oct	18	64800
VP4a	Oct	6	21600
VP5	Oct	24	86400
VP6	Oct	24	86400
VP1	Nov	36	129600
VP2	Nov	30	108000

Vantage Point	Month	Hours Survey	Seconds Survey
VP3	Nov	30	108000
VP4	Nov	18	64800
VP4a	Nov	12	43200
VP5	Nov	24	86400
VP6	Nov	24	86400
VP1	Dec	12	43200
VP2	Dec	15	54000
VP3	Dec	18	64800
VP4	Dec	18	64800
VP5	Dec	24	86400
VP6	Dec	18	64800

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 70-220m, all flight activity in Band 3 and Band 4 are 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.

Table 7 - 6 - 5 Species assessed

Species	Months
Black-headed Gull	Oct-Mar
Black-headed Gull	Apr-Sep
Buzzard	Oct-Sep
Golden Plover	Sep-Apr
Hen Harrier	Sep-Mar
Kestrel	Oct-Sep
Lapwing	Oct-Mar
Lapwing	Apr-Sep
Merlin	Oct-Sep
Peregrine Falcon	Oct-Sep
Snipe	Oct-Sep
Sparrowhawk	Oct-Sep
Woodcock	Oct-Sep
Whooper Swan	Oct-Apr

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)	Flight Type	Nocturnal Activity Factor
Black-headed Gull	35.5	105.0	11.9	flapping	25
Buzzard	54.0	120.5	11.6	gliding	0
Golden Plover	27.5	71.5	17.9	flapping	25
Hen Harrier	48.0	110.0	8.0	flapping	0
Kestrel	33.5	75.5	10.1	flapping	0
Lapwing	29.5	84.5	12.8	flapping	50
Merlin	27.5	56.0	10.9	flapping	0
Peregrine Falcon	44.5	105.0	12.1	flapping	0
Snipe	25.5	42.0	17.1	flapping	100
Sparrowhawk	33.0	62.5	10.0	flapping	0
Woodcock	34.0	60.0	17.1	flapping	100
Whooper Swan	150.0	220.0	17.3	flapping	25

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). This included time spent in all recorded height bands, not just those bands within potential collision height. 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	Bird-seconds
Black-headed Gull	May	VP1	25
	Jun	VP1	11
	Jun	VP4	108
	Jan	VP5	75
	Jun	VP5	18
	Jul	VP6	54
Buzzard	Feb	VP1	413
	Mar	VP1	3401
	May	VP1	986
	Jun	VP1	3851
	Jul	VP1	823
	Aug	VP1	735
	Sep	VP1	1849

Species	Month	Vantage Point	Bird-seconds
	Oct	VP1	84
	Nov	VP1	342
	Dec	VP1	52
	Jan	VP2	115
	Feb	VP2	520
	Mar	VP2	415
	Apr	VP2	2574
	May	VP2	197
	Jun	VP2	3197
	Jul	VP2	2183
	Aug	VP2	430
	Sep	VP2	455
	Nov	VP2	1096
	Jan	VP3	876
	Feb	VP3	58
	Mar	VP3	1092
	Apr	VP3	608
	Jun	VP3	373
	Jul	VP3	764
	Aug	VP3	1295
	Sep	VP3	19
	Oct	VP3	206
	Nov	VP3	29
	Dec	VP3	66
	Jan	VP4	68
	Feb	VP4	1892
	Mar	VP4	346
	Apr	VP4	3513
	Jun	VP4	2086
	Jul	VP4	96
	Aug	VP4	569
	Sep	VP4	7795
	Oct	VP4	653
	Nov	VP4	1980
	Apr	VP4a	352
	Jun	VP4a	1888
	Jul	VP4a	113
	Jan	VP5	264
	Feb	VP5	4214
	Mar	VP5	570
	Apr	VP5	882
	Jun	VP5	4527
	Jul	VP5	1996

Species	Month	Vantage Point	Bird-seconds
	Aug	VP5	1331
	Sep	VP5	1023
	Oct	VP5	274
	Nov	VP5	9
	Dec	VP5	426
	Jan	VP6	16
	Feb	VP6	1438
	Mar	VP6	2974
	Apr	VP6	47
	May	VP6	154
	Jun	VP6	2697
	Jul	VP6	367
	Aug	VP6	1573
	Sep	VP6	89
	Oct	VP6	115
	Nov	VP6	327
	Dec	VP6	87
Cormorant	Jan	VP1	143
	Jan	VP2	223
	Jan	VP5	27
	Sep	VP5	181
	Dec	VP5	724
Curlew	Sep	VP5	5
Golden Plover	Jan	VP1	517
	Mar	VP1	876380
	Oct	VP1	11154
	Mar	VP2	36000
	Apr	VP2	86
	Sep	VP2	156
	Oct	VP2	1775
	Nov	VP2	4250
	Dec	VP2	282
	Feb	VP3	2950
	Apr	VP3	6380
	Oct	VP3	1769
	Nov	VP3	2240
	Feb	VP4	625
	Apr	VP4	22770
	Oct	VP4	179
	Feb	VP5	10750
	Mar	VP5	204
	Apr	VP5	29760
	Oct	VP5	291060

Species	Month	Vantage Point	Bird-seconds
	Nov	VP5	10045
	Feb	VP6	8924
	Mar	VP6	4784
	Apr	VP6	475
	Sep	VP6	5365
	Oct	VP6	824
Green Sandpiper	Jun	VP3	394
Greenshank	Sep	VP2	51
Grey Heron	Feb	VP1	767
	Apr	VP1	26
	May	VP1	188
	Aug	VP1	15
	Sep	VP1	84
	Nov	VP1	120
	Feb	VP2	17
	Mar	VP2	254
	Apr	VP2	302
	May	VP2	88
	Jun	VP2	95
	Jul	VP2	110
	Aug	VP2	315
	Sep	VP2	51
	Oct	VP2	133
	Mar	VP3	133
	Apr	VP3	40
	Aug	VP3	35
	Sep	VP3	30
	Oct	VP3	116
	Feb	VP4	90
	Mar	VP4	13
	Apr	VP4	64
	Jun	VP4	98
	Jul	VP4	81
	Sep	VP4	12
	Jun	VP5	22
	Jul	VP5	235
	Aug	VP5	33
	Nov	VP5	47
	Dec	VP5	47
	Apr	VP6	36
	Nov	VP6	125
Greylag Goose	May	VP1	40
	Jan	VP2	90

Species	Month	Vantage Point	Bird-seconds
	Feb	VP2	160
	Oct	VP2	2100
	Nov	VP2	40
	Dec	VP2	1125
	Nov	VP3	2720
	Dec	VP3	62
	Mar	VP4	340
	Mar	VP5	1120
Hen Harrier	Jan	VP1	129
	Feb	VP1	189
	Mar	VP1	150
	Sep	VP1	88
	Nov	VP1	204
	Feb	VP2	140
	Oct	VP2	125
	Feb	VP3	260
	Sep	VP4	270
	Sep	VP5	38
Kestrel	Jan	VP1	830
	Feb	VP1	217
	Mar	VP1	538
	Apr	VP1	47
	May	VP1	714
	Jun	VP1	2704
	Jul	VP1	5708
	Aug	VP1	698
	Sep	VP1	143
	Oct	VP1	306
	Nov	VP1	401
	Dec	VP1	873
	Jan	VP2	419
	Feb	VP2	1220
	Mar	VP2	2214
	Apr	VP2	1218
	May	VP2	243
	Jun	VP2	2335
	Jul	VP2	3619
	Aug	VP2	1840
	Sep	VP2	2109
	Oct	VP2	1514
	Nov	VP2	2369
	Dec	VP2	252
	Jan	VP3	1469

Species	Month	Vantage Point	Bird-seconds
	Feb	VP3	143
	Mar	VP3	361
	Apr	VP3	1244
	May	VP3	110
	Jun	VP3	162
	Jul	VP3	1231
	Aug	VP3	1780
	Sep	VP3	1882
	Oct	VP3	908
	Nov	VP3	1182
	Dec	VP3	186
	Jan	VP4	103
	Feb	VP4	68
	Mar	VP4	673
	Apr	VP4	107
	Jun	VP4	64
	Jul	VP4	37
	Aug	VP4	646
	Sep	VP4	482
	Oct	VP4	3405
	Nov	VP4	163
	Dec	VP4	653
	Apr	VP4a	95
	Jul	VP4a	536
	Jan	VP5	1298
	Feb	VP5	1823
	Mar	VP5	2525
	Apr	VP5	42
	Jun	VP5	321
	Jul	VP5	1139
	Aug	VP5	556
	Sep	VP5	2376
	Oct	VP5	1897
	Nov	VP5	2354
	Dec	VP5	321
	Jan	VP6	1452
	Feb	VP6	65
	Mar	VP6	391
	Apr	VP6	187
	May	VP6	60
	Jun	VP6	735
	Jul	VP6	200
	Aug	VP6	449

Species	Month	Vantage Point	Bird-seconds
	Sep	VP6	116
	Oct	VP6	442
	Nov	VP6	2364
	Dec	VP6	125
Kingfisher	May	VP2	13
	Jun	VP2	7
	Jul	VP2	33
Lapwing	Apr	VP1	12
	Dec	VP1	2500
	Apr	VP2	80
	May	VP2	1132
	Jun	VP2	1761
	Jul	VP2	3338
	Aug	VP2	41
	Apr	VP3	316
	Nov	VP3	5796
	Mar	VP4	42
	Mar	VP5	56
	Jul	VP5	110
	Jan	VP6	46
	Dec	VP6	2050
Lesser Black-backed Gull	May	VP1	330
	Jun	VP1	180
	Jul	VP1	297
	Apr	VP2	269
	Jun	VP2	42
	May	VP3	768
	Jul	VP3	296
	Jul	VP4	132
	Aug	VP4	144
	Jul	VP5	305
	Jun	VP6	537
Little Grebe	Sep	VP6	121
Long-eared Owl	May	VP1	24
Mallard	Mar	VP1	276
	Apr	VP1	129
	Aug	VP1	34
	Sep	VP1	167
	Feb	VP2	342
	Mar	VP2	537
	Apr	VP2	323
	May	VP2	278
	Jun	VP2	274

Species	Month	Vantage Point	Bird-seconds
	Jul	VP2	40
	Sep	VP2	413
	Oct	VP2	10156
	Nov	VP2	1024
	Jan	VP3	255
	Feb	VP3	60
	Mar	VP3	189
	Apr	VP3	296
	Jul	VP3	68
	Jan	VP4	24
	Feb	VP4	166
	Mar	VP4	237
	Apr	VP4a	26
	May	VP4a	5
	Feb	VP5	198
	Mar	VP5	156
	Apr	VP5	353
	May	VP5	576
	Jun	VP5	43
	Mar	VP6	124
	Jun	VP6	30
Meadow Pipit	Mar	VP1	22
	Jan	VP2	20
	Mar	VP2	69
	Jan	VP3	30
	Mar	VP3	184
	Jan	VP6	8
Merlin	Mar	VP1	5
	Nov	VP1	43
	Feb	VP2	43
	Feb	VP4	108
	Apr	VP4	42
	Jan	VP6	146
	Nov	VP6	24
	Dec	VP6	130
Mute Swan	Apr	VP2	89
	Sep	VP2	216
Peregrine Falcon	Mar	VP1	48
	Aug	VP1	634
	Nov	VP1	29
	Feb	VP2	15
	May	VP2	97
	Oct	VP2	666

Species	Month	Vantage Point	Bird-seconds
	Mar	VP3	453
	Nov	VP3	124
	Dec	VP4	259
	Feb	VP5	416
	Feb	VP6	126
	May	VP6	225
Redwing	Feb	VP1	600
	Nov	VP6	135
Ringed Plover	Mar	VP2	12
	May	VP2	818
	Jun	VP2	10
Snipe	Feb	VP1	200
	Jun	VP1	51
	Sep	VP1	8
	Nov	VP1	81
	May	VP2	96
	Jun	VP2	35
	Jul	VP2	525
	Oct	VP2	778
	Oct	VP3	8
	Nov	VP3	10
	Dec	VP3	10
	Jan	VP4	14
	Feb	VP4	140
	Mar	VP4	33
	Oct	VP4	25
	Dec	VP4	119
	Jan	VP5	37
	Feb	VP5	445
	Apr	VP5	16
	Jul	VP5	5
	Nov	VP5	93
	Jan	VP6	61
	Mar	VP6	8
	Oct	VP6	162
	Nov	VP6	30
Sparrowhawk	Jan	VP1	202
	Feb	VP1	48
	Mar	VP1	198
	Jun	VP1	65
	Aug	VP1	51
	Nov	VP1	14
	Dec	VP1	51

Species	Month	Vantage Point	Bird-seconds
	Jun	VP2	150
	Jul	VP2	59
	Sep	VP2	220
	Oct	VP2	83
	Feb	VP3	450
	Mar	VP3	30
	Jun	VP3	70
	Jul	VP3	65
	Aug	VP3	104
	Nov	VP3	36
	Dec	VP3	12
	Jan	VP4	1427
	Feb	VP4	35
	Mar	VP4	108
	Jul	VP4	18
	Aug	VP4	175
	Sep	VP4	503
	Jan	VP5	27
	Mar	VP5	147
	Apr	VP5	169
	Jun	VP5	60
	Jul	VP5	25
	Aug	VP5	23
	Sep	VP5	155
	Jan	VP6	169
	Jul	VP6	64
	Aug	VP6	22
	Nov	VP6	46
Swift	Jun	VP1	182
	Jul	VP2	75
	Jun	VP5	35
	Jul	VP5	25
Whooper Swan	Jan	VP1	861
	Feb	VP1	360
	Mar	VP1	4421
	Dec	VP1	186
	Jan	VP2	18551
	Feb	VP2	240
	Mar	VP2	160
	Apr	VP2	534
	Oct	VP2	2787
	Nov	VP2	2704
	Dec	VP2	86

Species	Month	Vantage Point	Bird-seconds
	Feb	VP3	399
	Oct	VP3	850
	Nov	VP3	4940
	Dec	VP3	533
	Jan	VP4	1198
	Feb	VP4	374
	Jan	VP5	276
	Feb	VP5	519
	Oct	VP5	14976
	Nov	VP5	12060
	Dec	VP5	4965
	Feb	VP6	205
	Oct	VP6	3790
	Dec	VP6	609
Woodcock	Mar	VP1	40
	May	VP1	876
	May	VP2	796
	Feb	VP3	46
	Apr	VP3	10
	May	VP3	189
	Dec	VP3	0
	May	VP4	20
	Jun	VP4	44
	Mar	VP5	16
	May	VP5	114
	Jan	VP6	5
	May	VP6	71

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 4486.731 and night-time hours was 4273.269.

Table 7 - 6 - 8 Photoperiod

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daylight Hours	252.0	273.9	366.4	418.4	491.0	506.7	509.7	458.7	382.5	329.8	261.4	236.2
Nighttime Hours	492.0	398.1	377.6	301.6	253.0	213.3	234.3	285.3	337.5	414.2	458.6	507.8

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.

Table 7 - 6 - 9 Aerial density and proportion flying at risk height

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Proportion
Black-headed Gull	0.00003	0.00000	0.00000	NA	NA	NA	NA	NA	NA	0.00000	0.00000	0.00000	0.74
Black-headed Gull	NA	NA	NA	0.00000	0.00001	0.00001	0.00003	0.00000	0.00000	NA	NA	NA	0.15
Buzzard	0.00046	0.00260	0.00284	0.00277	0.00079	0.00709	0.00252	0.00190	0.00167	0.00026	0.00053	0.00027	0.44
Golden Plover	0.00015	0.00934	0.32946	0.02166	NA	NA	NA	NA	0.00317	0.11422	0.00559	0.00016	0.46
Hen Harrier	0.00004	0.00021	0.00005	NA	NA	NA	NA	NA	0.00006	0.00005	0.00005	0.00000	0.25
Kestrel	0.00183	0.00127	0.00217	0.00178	0.00068	0.00301	0.00447	0.00210	0.00325	0.00189	0.00285	0.00104	0.39
Lapwing	0.00001	0.00000	0.00002	NA	NA	NA	NA	NA	NA	0.00000	0.00171	0.00278	0.47
Lapwing	NA	NA	NA	0.00025	0.00065	0.00085	0.00126	0.00002	0.00000	NA	NA	NA	0.32
Merlin	0.00004	0.00002	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00002	0.00006	0.11
Peregrine Falcon	0.00000	0.00022	0.00018	0.00000	0.00022	0.00000	0.00000	0.00026	0.00000	0.00024	0.00004	0.00000	0.47
Snipe	0.00003	0.00024	0.00000	0.00001	0.00006	0.00004	0.00019	0.00000	0.00000	0.00034	0.00007	0.00000	0.24
Sparrowhawk	0.00012	0.00018	0.00014	0.00010	0.00000	0.00017	0.00009	0.00008	0.00018	0.00003	0.00003	0.00004	0.22
Woodcock	0.00000	0.00002	0.00002	0.00001	0.00124	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.09
Whooper Swan	0.00630	0.00065	0.00165	0.00039	NA	NA	NA	NA	NA	0.00821	0.00669	0.00257	0.27

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 - 10 shows the projected number of transits per month for each species.

Table 7 - 6 - 10 Projected number of transits

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Black-headed Gull	0.584	0	0	-	-	-	-	-	-	0	0	0	0.58
Black-headed Gull	-	-	-	0	0.09	0.089	0.166	0	0	-	-	-	0.34
Buzzard	3.76	23	33.6	37.3	12.5	116	41.1	28.1	20.6	3.74	4.45	2.05	325.95
Golden Plover	2.9	182	7906	557	-	-	-	-	77.1	3457	11	3.08	12294.80
Hen Harrier	0.118	0.742	0.249	-	-	-	-	-	0.294	0.251	0.161	0	1.81
Kestrel	11.4	8.68	19.8	18.5	8.25	37.9	56.6	24	30.9	20.8	18.5	6.13	261.62
Lapwing	0.259	0	0.434	-	-	-	-	-	-	0	31.8	51.7	84.17
Lapwing	-	-	-	3.79	10.6	13.7	20.8	0.268	0	-	-	-	49.13
Merlin	0.087	0.034	0.005	0	0	0	0	0	0	0	0.039	0.117	0.28
Peregrine Falcon	0	2.16	2.43	0	3.86	0	0	4.3	0	3.81	0.41	0	16.96
Snipe	0.613	4.11	0.044	0.176	1.07	0.77	3.7	0	0.071	8.79	1.26	0.095	20.70
Sparrowhawk	0.427	0.718	0.714	0.596	0	1.21	0.644	0.515	0.996	0.188	0.114	0.144	6.27
Woodcock	0.01	0.106	0.14	0.039	8.53	0	0	0	0	0	0	0	8.82
Whooper Swan	70.4	7.26	22.6	5.67	-	-	-	-	-	141	74.9	27.8	349.86

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 - 11.

Table 7 - 6 - 11 Probability of collision

Species	Upwind	Downwind	Average
Black-headed Gull	0.058	0.042	0.05
Buzzard	0.064	0.047	0.055
Golden Plover	0.049	0.038	0.044
Hen Harrier	0.074	0.049	0.061
Kestrel	0.06	0.04	0.05
Lapwing	0.055	0.039	0.047
Merlin	0.055	0.037	0.046
Peregrine Falcon	0.061	0.044	0.052
Snipe	0.047	0.036	0.042
Sparrowhawk	0.059	0.039	0.049
Woodcock	0.05	0.038	0.044
Whooper Swan	0.081	0.07	0.076

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 Table 7 - 6 - 12.

Table 7 - 6 - 12 Expected collisions without avoidance

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Black-headed Gull	0.0249	0	0	-	-	-	-	-	-	0	0	0	0.0249
Black-headed Gull	-	-	-	0	0.00383	0.00379	0.00707	0	0	-	-	-	0.0147
Buzzard	0.176	1.08	1.58	1.75	0.588	5.43	1.93	1.32	0.965	0.175	0.209	0.096	15.3
Golden Plover	0.108	6.75	294	20.7	-	-	-	-	2.87	129	4.07	0.115	457
Hen Harrier	0.00614	0.0386	0.013	-	-	-	-	-	0.0153	0.0131	0.00838	0	0.0945
Kestrel	0.484	0.367	0.835	0.783	0.348	1.6	2.39	1.01	1.3	0.88	0.783	0.259	11.1
Lapwing	0.0103	0	0.0172	-	-	-	-	-	-	0	1.26	2.05	3.34
Lapwing	-	-	-	0.15	0.422	0.543	0.825	0.0106	0	-	-	-	1.95
Merlin	0.0034	0.00133	0.000195	0	0	0	0	0	0	0	0.00152	0.00457	0.011
Peregrine Falcon	0	0.0962	0.108	0	0.172	0	0	0.191	0	0.169	0.0182	0	0.755
Snipe	0.0217	0.145	0.00156	0.00622	0.0378	0.0272	0.131	0	0.00251	0.311	0.0445	0.00336	0.731
Sparrowhawk	0.0178	0.03	0.0298	0.0249	0	0.0506	0.0269	0.0215	0.0416	0.00786	0.00476	0.00602	0.262
Woodcock	0.000376	0.00398	0.00526	0.00147	0.321	0	0	0	0	0	0	0	0.332
Whooper Swan	4.52	0.467	1.45	0.364	-	-	-	-	-	9.07	4.81	1.78	22.5

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%. These are presented in Table 7 - 6 - 12Table 7 - 6 - 13.

Table 7 - 6 - 13 Expected collisions with avoidance

Species	Avoidance %	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Black-headed Gull	0.95	0.00124	0	0	-	-	-	-	-	-	0	0	0	0.00124
	0.98	0.0005	0	0	-	-	-	-	-	-	0	0	0	0.0005
	0.99	0.00025	0	0	-	-	-	-	-	-	0	0	0	0.00025
	0.995	0.00012	0	0	-	-	-	-	-	-	0	0	0	0.00012
	0.95	-	-	-	0	0.00019	0.00019	0.00035	0	0	-	-	-	0.00073
	0.98	-	-	-	0	0.00008	0.00008	0.00014	0	0	-	-	-	0.00029
	0.99	-	-	-	0	0.00004	0.00004	0.00007	0	0	-	-	-	0.00015
	0.995	-	-	-	0	0.00002	0.00002	0.00004	0	0	-	-	-	0.00007
Buzzard	0.95	0.00881	0.0539	0.0788	0.0875	0.0294	0.272	0.0964	0.0659	0.0483	0.00877	0.0104	0.0048	0.765
	0.98	0.00352	0.0216	0.0315	0.035	0.0118	0.109	0.0386	0.0264	0.0193	0.00351	0.00418	0.00192	0.306
	0.99	0.00176	0.0108	0.0158	0.0175	0.00588	0.0543	0.0193	0.0132	0.00965	0.00175	0.00209	0.00096	0.153
	0.995	0.00088	0.00539	0.00788	0.00875	0.00294	0.0272	0.00964	0.00659	0.00483	0.00088	0.00104	0.00048	0.0765
Golden Plover	0.95	0.0054	0.338	14.7	1.04	-	-	-	-	0.143	6.43	0.204	0.00573	22.9
	0.98	0.00216	0.135	5.88	0.414	-	-	-	-	0.0573	2.57	0.0814	0.00229	9.14
	0.99	0.00108	0.0675	2.94	0.207	-	-	-	-	0.0287	1.29	0.0407	0.00115	4.57
	0.995	0.00054	0.0338	1.47	0.104	-	-	-	-	0.0143	0.643	0.0204	0.00057	2.29
	0.996	0.00043	0.027	1.18	0.0828	-	-	-	-	0.0115	0.514	0.0163	0.00046	1.83
Hen Harrier	0.95	0.00031	0.00193	0.00065	-	-	-	-	-	0.00077	0.00065	0.00042	0	0.00472
	0.98	0.00012	0.00077	0.00026	-	-	-	-	-	0.00031	0.00026	0.00017	0	0.00189
	0.99	0.00006	0.00039	0.00013	-	-	-	-	-	0.00015	0.00013	0.00008	0	0.00094

Species	Avoidance %	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
	0.995	0.00003	0.00019	0.00006	-	-	-	-	-	0.00008	0.00007	0.00004	0	0.00047
Kestrel	0.95	0.0242	0.0183	0.0418	0.0391	0.0174	0.0802	0.12	0.0507	0.0652	0.044	0.0391	0.0129	0.553
	0.98	0.00967	0.00733	0.0167	0.0157	0.00697	0.0321	0.0479	0.0203	0.0261	0.0176	0.0157	0.00518	0.221
	0.99	0.00484	0.00367	0.00835	0.00783	0.00348	0.016	0.0239	0.0101	0.013	0.0088	0.00783	0.00259	0.111
	0.995	0.00242	0.00183	0.00418	0.00391	0.00174	0.00801	0.012	0.00507	0.00652	0.0044	0.00391	0.00129	0.0553
Lapwing	0.95	0.00051	0	0.00086	-	-	-	-	-	-	0	0.0632	0.103	0.167
	0.98	0.00021	0	0.00034	-	-	-	-	-	-	0	0.0253	0.041	0.0669
	0.99	0.0001	0	0.00017	-	-	-	-	-	-	0	0.0126	0.0205	0.0334
	0.995	0.00005	0	0.00009	-	-	-	-	-	-	0	0.00632	0.0103	0.0167
	0.95	-	-	-	0.00752	0.0211	0.0272	0.0412	0.00053	0	-	-	-	0.0975
	0.98	-	-	-	0.00301	0.00844	0.0109	0.0165	0.00021	0	-	-	-	0.039
	0.99	-	-	-	0.0015	0.00422	0.00543	0.00825	0.00011	0	-	-	-	0.0195
	0.995	-	-	-	0.00075	0.00211	0.00272	0.00412	0.00005	0	-	-	-	0.00975
Merlin	0.95	0.00017	0.00007	0.00001	0	0	0	0	0	0	0	0.00008	0.00023	0.00055
	0.98	0.00007	0.00003	0	0	0	0	0	0	0	0	0.00003	0.00009	0.00022
	0.99	0.00003	0.00001	0	0	0	0	0	0	0	0	0.00002	0.00005	0.00011
	0.995	0.00002	0.00001	0	0	0	0	0	0	0	0	0.00001	0.00002	0.00006
Peregrine Falcon	0.95	0	0.00481	0.00541	0	0.00858	0	0	0.00957	0	0.00847	0.00091	0	0.0378
	0.98	0	0.00192	0.00216	0	0.00343	0	0	0.00383	0	0.00339	0.00036	0	0.0151
	0.99	0	0.00096	0.00108	0	0.00172	0	0	0.00191	0	0.00169	0.00018	0	0.00755
	0.995	0	0.00048	0.00054	0	0.00086	0	0	0.00096	0	0.00085	0.00009	0	0.00377
Snipe	0.95	0.00108	0.00725	0.00008	0.00031	0.00189	0.00136	0.00654	0	0.00013	0.0155	0.00222	0.00017	0.0366
	0.98	0.00043	0.0029	0.00003	0.00012	0.00076	0.00054	0.00262	0	0.00005	0.00622	0.00089	0.00007	0.0146
	0.99	0.00022	0.00145	0.00002	0.00006	0.00038	0.00027	0.00131	0	0.00003	0.00311	0.00044	0.00003	0.00731
	0.995	0.00011	0.00073	0.00001	0.00003	0.00019	0.00014	0.00065	0	0.00001	0.00155	0.00022	0.00002	0.00366
Sparrowhawk	0.95	0.00089	0.0015	0.00149	0.00125	0	0.00253	0.00135	0.00108	0.00208	0.00039	0.00024	0.0003	0.0131
	0.98	0.00036	0.0006	0.0006	0.0005	0	0.00101	0.00054	0.00043	0.00083	0.00016	0.0001	0.00012	0.00524

Species	Avoidance %	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
	0.99	0.00018	0.0003	0.0003	0.00025	0	0.00051	0.00027	0.00022	0.00042	0.00008	0.00005	0.00006	0.00262
	0.995	0.00009	0.00015	0.00015	0.00012	0	0.00025	0.00013	0.00011	0.00021	0.00004	0.00002	0.00003	0.00131
Woodcock	0.95	0.00002	0.0002	0.00026	0.00007	0.016	0	0	0	0	0	0	0	0.0166
	0.98	0.00001	0.00008	0.00011	0.00003	0.00641	0	0	0	0	0	0	0	0.00663
	0.99	0	0.00004	0.00005	0.00001	0.00321	0	0	0	0	0	0	0	0.00332
	0.995	0	0.00002	0.00003	0.00001	0.0016	0	0	0	0	0	0	0	0.00166
Whooper Swan	0.95	0.226	0.0233	0.0726	0.0182	-	-	-	-	-	0.454	0.241	0.0892	1.12
	0.98	0.0905	0.00934	0.029	0.00729	-	-	-	-	-	0.181	0.0962	0.0357	0.45
	0.99	0.0452	0.00467	0.0145	0.00364	-	-	-	-	-	0.0907	0.0481	0.0179	0.225
	0.995	0.0226	0.00233	0.00726	0.00182	-	-	-	-	-	0.0454	0.024	0.00892	0.112

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.

To provide a measure of uncertainty in aerial density, the mean, standard deviation and relative standard error of the mean 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 is presented in Table 7 - 6 - 14.

3.7 Table 7 - 6 - 14 Range of uncertainty

Species	Months	Model	Mean	Standard Deviation	Standard Error of the Mean	Relative Standard Error	Uncertainty
Black-headed Gull	Oct-Mar	non-directional	0	0.00001	0	0.91287	0.98
Black-headed Gull	Apr-Sep	non-directional	0.00001	0.00001	0	0.44443	0.56
Buzzard	Oct-Sep	non-directional	0.00198	0.00182	0.00052	0.26481	0.43
Golden Plover	Sep-Apr	non-directional	0.06534	0.11094	0.03922	0.60027	0.69
Hen Harrier	Sep-Mar	non-directional	0.00007	0.00006	0.00002	0.35015	0.49
Kestrel	Oct-Sep	non-directional	0.00225	0.00101	0.00029	0.12967	0.37
Lapwing	Oct-Mar	non-directional	0.00075	0.0011	0.00045	0.59478	0.69

Lapwing	Apr-Sep	non-directional	0.00051	0.00046	0.00019	0.37113	0.51
Merlin	Oct-Sep	non-directional	0.00001	0.00002	0.00001	0.4826	0.59
Peregrine Falcon	Oct-Sep	non-directional	0.0001	0.00012	0.00003	0.33342	0.48
Snipe	Oct-Sep	non-directional	0.00009	0.00013	0.00004	0.41657	0.54
Sparrowhawk	Oct-Sep	non-directional	0.0001	0.00006	0.00002	0.17582	0.39
Woodcock	Oct-Sep	non-directional	0.00011	0.00034	0.0001	0.92126	0.98
Whooper Swan	Oct-Apr	non-directional	0.00417	0.00363	0.00137	0.32929	0.48

3.8 Collision Rates

To provide a best estimate of the collision rate for each species, the guidance on avoidance rates provided by NatureScot in 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 - 13. For each species, the predicted number of collisions corresponding to the recommended avoidance rate was identified. These are presented in Table 7 - 6 - 15, 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').

Table 7 - 6 - 15 presents the final predicted annual collision rate used for the assessment. The results should be considered as a best estimate of collision risk, rather than a precise figure.

Table 7 - 6 - 15 Predicted annual collision rate

Species	Months	Avoidance Factor	Annual Collision Rate	Range of Uncertainty	Years to One Collision
Black-headed Gull	Oct-Mar	0.98	0.0005	0.000-0.001	>35

Black-headed Gull	Apr-Sep	0.98	0.0002	0.000-0.000	>35
Buzzard	Oct-Sep	0.98	0.306	0.174-0.437	3
Golden Plover	Sep-Apr	0.996	1.828	0.567-3.090	<1
Hen Harrier	Sep-Mar	0.99	0.001	0.000-0.001	>35
Kestrel	Oct-Sep	0.95	0.553	0.348-0.757	2
Lapwing	Oct-Mar	0.98	0.067	0.021-0.113	15
Lapwing	Apr-Sep	0.98	0.039	0.019-0.059	26
Merlin	Oct-Sep	0.98	0.0002	0.000-0.000	>35
Peregrine Falcon	Oct-Sep	0.98	0.015	0.008-0.022	>35
Snipe	Oct-Sep	0.98	0.015	0.007-0.023	>35
Sparrowhawk	Oct-Sep	0.98	0.005	0.003-0.007	>35
Woodcock	Oct-Sep	0.98	0.007	0.000-0.013	>35
Whooper Swan	Oct-Apr	0.995	0.112	0.058-0.166	9

4. WORKED EXAMPLE

4.1 Proposed Project Scenario

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. 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 - 16. 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 - 16 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.

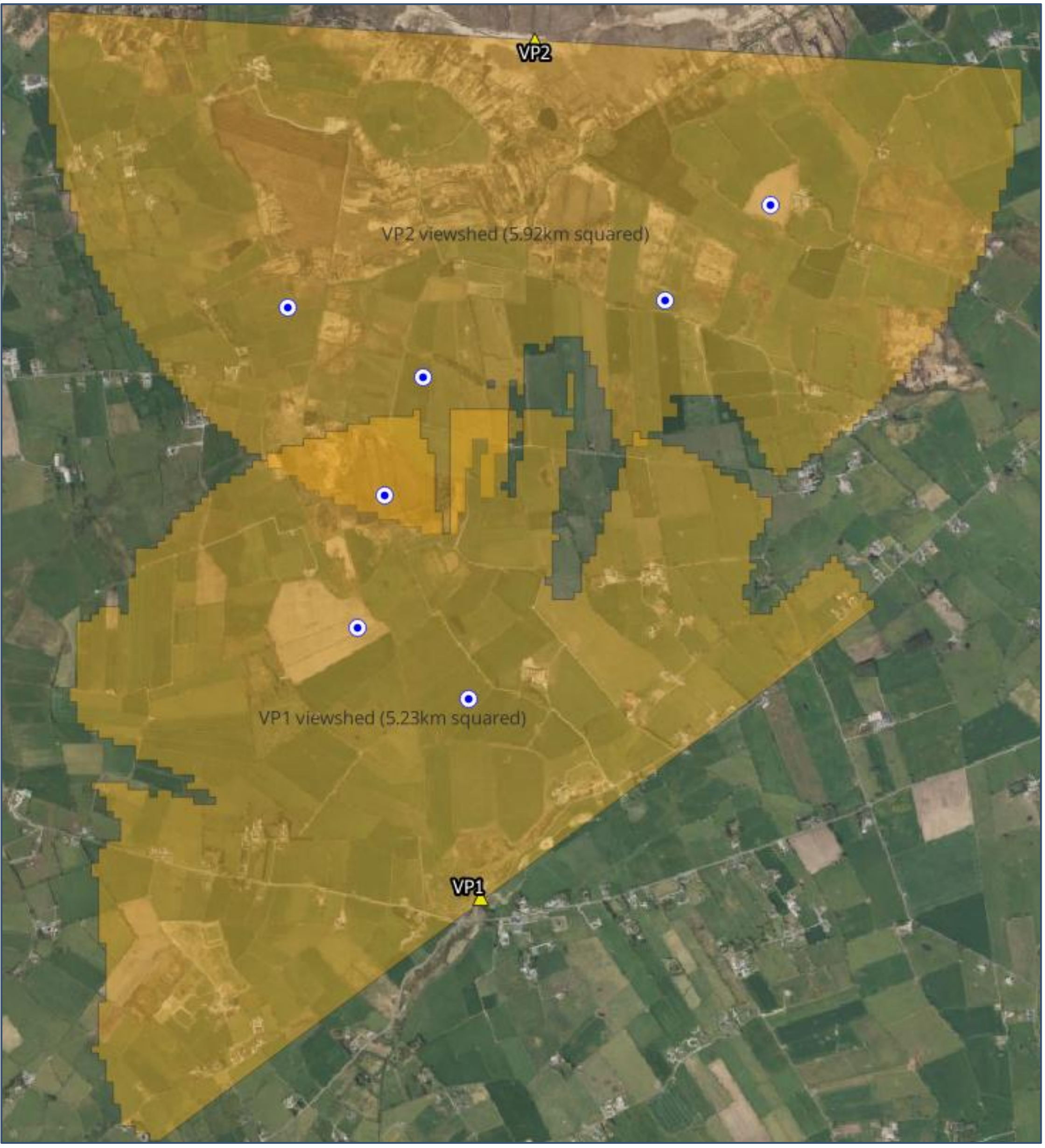

Figure 7 - 6 - 1 Vantage point survey locations and viewshed areas

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 - 17. Records denoted '-' represent non-flight activity, for example when a bird is perched.

The data in Table 7 - 6 - 17 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 - 17 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	17	0	0	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	35	0	0	0

VP	Date	Time	Species	Number	Band 1	Band 2	Band 3	Band 4
VP1	14/03/2024	11:48	Sparrowhawk	1	50	12	0	0
VP1	03/05/2024	11:25	Sparrowhawk	2	19	0	0	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	17	0	0	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	0	0
VP2	13/03/2025	08:46	Sparrowhawk	1	0	83	0	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). This included time spent in all recorded height bands, not just those bands within potential collision height. These values are presented in Table 7 - 6 - 18. Note that sparrowhawk was not recorded in every month, therefore some months are not present in the table.

Table 7 - 6 - 18 Bird-seconds per vantage point per month

Month	Vantage Point	Bird-Seconds
Jan	VP1	58
Mar	VP1	62
May	VP1	38
Jun	VP1	157
Jul	VP1	21
Oct	VP1	41
Nov	VP1	133
Jan	VP2	155
Feb	VP2	35
Mar	VP2	83
May	VP2	6
Jul	VP2	17
Nov	VP2	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 - 19.

Table 7 - 6 - 19 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 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 - 20. Zero is input for months in which sparrowhawk was not recorded.

Table 7 - 6 - 20 Aerial bird density

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

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 - 17. 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%.

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 - 21. The total daylight hours was 4,487.093 and night-time hours was 4,272.907.

Table 7 - 6 - 21 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:

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

ehere T is the number of turbines. In this example, that is $7 \text{ X } \pi \text{ X } 75^2 = 123700.2\text{m}^2$

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:

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

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

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

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 - 22 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 - 22 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

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 - 23.

Table 7 - 6 - 23 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), $\Delta r = 0.05$ (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:

$$0.487 \text{ X } 0.0537 \text{ X } 0.85 = 0.02224467$$

The predicted number of collisions for each month is presented in Table 7 - 6 - 24. Note that these rates assume no avoidance of turbines or wind farms by sparrowhawk.

Table 7 - 6 - 24 Expected collisions per month (without avoidance)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.022	0.004	0.023	0.000	0.010	0.036	0.008	0.000	0.000	0.006	0.018	0.000

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% and 99.5%. 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 - 25.

Table 7 - 6 - 25 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

4.8 Stage F: Uncertainty

To provide a measure of uncertainty in aerial density ($u1$), the relative standard error 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 standard error of the mean (SEM) was calculated as:

$$\text{SEM} = s/\sqrt{n}$$

where s is the standard deviation of the monthly values and n is the number of months being considered. In this example:

$$0.00015/\sqrt{12} = 0.000044$$

Finally, to express this as a proportion uncertainty, the relative standard error (RSE) was calculated as:

$$\text{RSE} = \text{SEM}/\bar{D}_A$$

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. If a large proportion of zero values were to occur (i.e., the species was recorded infrequently during vantage point surveys), this will increase the RSE. In this example the proportion uncertainty (RSE) was:

$$0.000044/0.0001445 = 0.3039$$

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:

$$\sqrt{(0.3^2 + 0.2^2 + 0.28^2)} = 0.46$$

Expressed as a percentage, the overall uncertainty was 46%.

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 - 26, along with the range of uncertainty and an estimation of the number of years for one collision to occur.

The column 'Annual Collision Rate' in Table 7 - 6 - 26 presents the final predicted annual collision rate for sparrowhawk that would be used in the impact assessment for this proposed development scenario: 0.0025 sparrowhawk per year. Due to the uncertainties discussed in stage F, this may range from 0.0011 to 0.0039 sparrowhawk per year. Dividing 1 by 0.0025 provides the number of years it would be expected for a collision to occur based on the model predictions.

Table 7 - 6 - 26 Predicted annual collision rate

Species	Annual Collision Rate	Range of Uncertainty	Years to one collision
Sparrowhawk	0.0025	0.0011-0.0039	395

5. REFERENCES

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APPENDIX 1: GOLDEN PLOVER AVOIDANCE RATE

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).

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[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	0	100%	> 99%	38%
	2007/08	0	100%		
Goole Fields I	2015/16	1	60%	82%	14%
	2016/17	0	81%		
	2018/19	0	79%		
Goole Fields II	2017/18	1	81%	91%	17%
	2018/19	0	88%		
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

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[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.

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