TECHNICAL APPENDIX 8.5: KILLEAN WIND FARM COLLISION RISK MODELLING CALCULATIONS

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INTRODUCTION

This Technical Appendix sets out the collision risk modelling undertaken to support the ornithological assessment of the proposed Killean Wind Farm (the 'Proposed Development'). The collision risk modelling was carried out for all the key target species recorded flying through the collision risk zone at rotor height (as per NatureScot guidance, SNH 2018). Rotor height will be 25-180 m above ground level.

The modelling included seven target raptor species (white-tailed eagle, golden eagle, osprey, red kite, hen harrier, peregrine and merlin), black grouse and golden plover. The collision risk for each species was modelled using the non-direct flight model. In addition, whooper swans, Greenland white-fronted geese, greylag geese, red-throated divers and herring gulls were observed flying through the collision risk zone and were also modelled to determine their collision risk. The direct flight model was applied as their flights were largely direct ones through the site. No other key species was recorded flying through the collision risk zone at rotor height.

The collision risk model used in this assessment (Band *et al.* 2007) was run as a two-stage process. Firstly, the risk is calculated assuming that flight patterns are unaffected by the wind turbines' presence, i.e., no avoidance action is taken. This is essentially a mechanistic calculation, with the collision risk calculated as the product of (i) the probability of a bird flying through the rotor swept area, and (ii) the probability of a bird colliding if it does so. This probability is then multiplied by the estimated numbers of bird movements through the wind farm rotors at the risk height (i.e. the height of the rotating rotor blades) to estimate the theoretical numbers at risk of collision if they take no avoiding action.

The second stage then incorporates the probability that the birds, rather than flying blindly into the turbines, will actually take a degree of avoiding action, as has been shown to occur in all studies of birds at existing wind farms. NatureScot has recommended a precautionary approach, using a value of 98% as a general default avoidance rate, 99% for some larger raptors (including red kite and hen harrier) and 99.8% for geese (SNH 2017). This precautionary approach is useful as an initial filter to identify sites where collision risk is clearly not an issue, but does not necessarily provide a realistic estimate of actual likely collision rates when compared with data from existing wind farms. The magnitude of the impact was determined as a percentage increase in the existing baseline mortality (to put the potential wind farm mortality into the ecological context of the birds' population dynamics), though professional judgement was also applied in the assessment of any non-negligible magnitude collision risks predicted.

Body sizes and baseline mortality rates were taken from Robinson (2005) and flight speeds from Alerstam *et al.* (2007).

BAND MODEL SPREADSHEETS (STAGE 1)

Firstly, the standard Band model spreadsheets (Band *et al*. 2007) are presented for each species modelled in turn. These provide the information used to calculate the risk that individuals of each species would face if they flew through the Proposed Development rotor swept area. For the first species, for example, whooper swan, this gives an overall average 7.4% chance of collision.

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA

Whooper Swan

Only enter input parameters in blue

K: [1D or [3D] (0 or 1)	1		Calculation of alpha and p(collision) as a function of radius						
NoBlades	3						Upwind:			Downwind:	
MaxChord	4.5	m	r/R	c/C	a	collide		contribution	collide		contribution
Pitch (degrees)	15		radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r
BirdLength	1.52	m	0.025	0.575	10.66	51.82	1.00	0.00125	50.48	1.00	0.00125
Wingspan	2.3	m	0.075	0.575	3.55	17.72	0.41	0.00307	16.38	0.38	0.00284
F: Flapping (0) or gliding (+1)	0		0.125	0.702	2.13	12.22	0.28	0.00353	10.59	0.24	0.00306
			0.175	0.860	1.52	10.20	0.24	0.00413	8.19	0.19	0.00331
Bird speed	17.3	m/sec	0.225	0.994	1.18	9.00	0.21	0.00468	6.68	0.15	0.00348
RotorDiam	155	m	0.275	0.947	0.97	7.32	0.17	0.00465	5.11	0.12	0.00325
RotationPeriod	7.50	sec	0.325	0.899	0.82	6.14	0.14	0.00461	4.04	0.09	0.00304
			0.375	0.851	0.71	5.25	0.12	0.00456	3.27	0.08	0.00284
			0.425	0.804	0.63	4.65	0.11	0.00457	2.77	0.06	0.00273
			0.475	0.756	0.56	4.24	0.10	0.00466	2.48	0.06	0.00273
Bird aspect ratio: b	0.66		0.525	0.708	0.51	3.91	0.09	0.00474	2.26	0.05	0.00274
			0.575	0.660	0.46	3.62	0.08	0.00481	2.08	0.05	0.00277
			0.625	0.613	0.43	3.37	0.08	0.00487	1.94	0.04	0.00281
			0.675	0.565	0.39	3.15	0.07	0.00491	1.83	0.04	0.00286
			0.725	0.517	0.37	2.95	0.07	0.00494	1.74	0.04	0.00292
			0.775	0.470	0.34	2.77	0.06	0.00496	1.67	0.04	0.00300
			0.825	0.422	0.32	2.60	0.06	0.00497	1.62	0.04	0.00309
			0.875	0.374	0.30	2.45	0.06	0.00496	1.58	0.04	0.00320
			0.925	0.327	0.29	2.31	0.05	0.00494	1.55	0.04	0.00331
			0.975	0.279	0.27	2.18	0.05	0.00491	1.53	0.04	0.00344
			\multicolumn{2}{l}{Overall p(collision) =}			Upwind	8.9%		Downwind	5.9%
									Average	7.4%	

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA

Greylag Goose

Only enter input parameters in blue

K: [1D or [3D] (0 or 1)	1		Calculation of alpha and p(collision) as a function of radius						
NoBlades	3						Upwind:			Downwind:	
MaxChord	4.5	m	r/R	c/C	a	collide		contribution	collide		contribution
Pitch (degrees)	15		radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r
BirdLength	0.82	m	0.025	0.575	10.54	44.28	1.00	0.00125	42.94	1.00	0.00125
Wingspan	1.64	m	0.075	0.575	3.51	15.21	0.36	0.00267	13.87	0.32	0.00243
F: Flapping (0) or gliding (+1)	0		0.125	0.702	2.11	10.70	0.25	0.00313	9.06	0.21	0.00265
			0.175	0.860	1.51	9.10	0.21	0.00372	7.09	0.17	0.00290
Bird speed	17.1	m/sec	0.225	0.994	1.17	8.14	0.19	0.00428	5.82	0.14	0.00306
RotorDiam	155	m	0.275	0.947	0.96	6.61	0.15	0.00425	4.41	0.10	0.00284
RotationPeriod	7.50	sec	0.325	0.899	0.81	5.54	0.13	0.00421	3.45	0.08	0.00262
			0.375	0.851	0.70	4.74	0.11	0.00416	2.76	0.06	0.00242
			0.425	0.804	0.62	4.12	0.10	0.00409	2.24	0.05	0.00223
			0.475	0.756	0.55	3.61	0.08	0.00401	1.85	0.04	0.00206
Bird aspect ratio: b	0.50		0.525	0.708	0.50	3.19	0.07	0.00392	1.54	0.04	0.00189
			0.575	0.660	0.46	2.90	0.07	0.00391	1.37	0.03	0.00184
			0.625	0.613	0.42	2.66	0.06	0.00388	1.23	0.03	0.00180
			0.675	0.565	0.39	2.44	0.06	0.00385	1.12	0.03	0.00177
			0.725	0.517	0.36	2.24	0.05	0.00380	1.03	0.02	0.00175
			0.775	0.470	0.34	2.06	0.05	0.00374	0.97	0.02	0.00175
			0.825	0.422	0.32	1.90	0.04	0.00366	0.91	0.02	0.00176
			0.875	0.374	0.30	1.75	0.04	0.00357	0.87	0.02	0.00179
			0.925	0.327	0.28	1.60	0.04	0.00347	0.84	0.02	0.00183
			0.975	0.279	0.27	1.47	0.03	0.00336	0.82	0.02	0.00188
			\multicolumn{2}{l}{Overall p(collision) =}			Upwind	7.3%		Downwind	4.3%
									Average	5.8%	

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA

White-fronted Goose

Only enter input parameters in blue

Parameter	Value	Unit
K: [1D or [3D] (0 or 1)	1	
NoBlades	3	
MaxChord	4.5	m
Pitch (degrees)	15	
BirdLength	0.71	m
Wingspan	1.45	m
F: Flapping (0) or gliding (+1)	0	
Bird speed	16.1	m/sec
RotorDiam	155	m
RotationPeriod	7.50	sec
Bird aspect ratio: b	0.49	

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

r/R radius	c/C chord	a alpha	Upwind: collide length	p(collision)	contribution from radius r	Downwind: collide length	p(collision)	contribution from radius r
0.025	0.575	9.92	39.84	0.99	0.00124	38.50	0.96	0.00120
0.075	0.575	3.31	13.73	0.34	0.00256	12.39	0.31	0.00231
0.125	0.702	1.98	9.74	0.24	0.00303	8.11	0.20	0.00252
0.175	0.860	1.42	8.35	0.21	0.00363	6.35	0.16	0.00276
0.225	0.994	1.10	7.52	0.19	0.00420	5.20	0.13	0.00291
0.275	0.947	0.90	6.12	0.15	0.00418	3.92	0.10	0.00268
0.325	0.899	0.76	5.13	0.13	0.00415	3.04	0.08	0.00246
0.375	0.851	0.66	4.40	0.11	0.00410	2.41	0.06	0.00225
0.425	0.804	0.58	3.82	0.09	0.00403	1.95	0.05	0.00206
0.475	0.756	0.52	3.35	0.08	0.00396	1.59	0.04	0.00188
0.525	0.708	0.47	2.99	0.07	0.00390	1.34	0.03	0.00175
0.575	0.660	0.43	2.72	0.07	0.00388	1.18	0.03	0.00168
0.625	0.613	0.40	2.48	0.06	0.00385	1.05	0.03	0.00164
0.675	0.565	0.37	2.27	0.06	0.00381	0.95	0.02	0.00160
0.725	0.517	0.34	2.08	0.05	0.00375	0.88	0.02	0.00158
0.775	0.470	0.32	1.91	0.05	0.00368	0.82	0.02	0.00157
0.825	0.422	0.30	1.75	0.04	0.00359	0.77	0.02	0.00158
0.875	0.374	0.28	1.61	0.04	0.00349	0.74	0.02	0.00160
0.925	0.327	0.27	1.47	0.04	0.00338	0.71	0.02	0.00163
0.975	0.279	0.25	1.34	0.03	0.00325	0.73	0.02	0.00176

Overall p(collision) =	Upwind	7.2%	Downwind	3.9%
	Average	5.6%		

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA

Red-throated Diver

Only enter input parameters in blue

Parameter	Value	Unit
K: [1D or [3D] (0 or 1)	1	
NoBlades	3	
MaxChord	4.5	m
Pitch (degrees)	15	
BirdLength	0.61	m
Wingspan	1.05	m
F: Flapping (0) or gliding (+1)	0	
Bird speed	18.6	m/sec
RotorDiam	155	m
RotationPeriod	7.50	sec
Bird aspect ratio: b	0.58	

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

r/R radius	c/C chord	a alpha	Upwind: collide length	p(collision)	contribution from radius r	Downwind: collide length	p(collision)	contribution from radius r
0.025	0.575	11.46	41.34	0.89	0.00111	40.00	0.86	0.00108
0.075	0.575	3.82	14.23	0.31	0.00229	12.89	0.28	0.00208
0.125	0.702	2.29	10.21	0.22	0.00275	8.58	0.18	0.00231
0.175	0.860	1.64	8.84	0.19	0.00333	6.84	0.15	0.00257
0.225	0.994	1.27	8.00	0.17	0.00387	5.68	0.12	0.00275
0.275	0.947	1.04	6.48	0.14	0.00383	4.28	0.09	0.00253
0.325	0.899	0.88	5.42	0.12	0.00379	3.32	0.07	0.00232
0.375	0.851	0.76	4.62	0.10	0.00373	2.64	0.06	0.00213
0.425	0.804	0.67	4.00	0.09	0.00365	2.13	0.05	0.00194
0.475	0.756	0.60	3.50	0.08	0.00357	1.73	0.04	0.00177
0.525	0.708	0.55	3.11	0.07	0.00352	1.46	0.03	0.00165
0.575	0.660	0.50	2.81	0.06	0.00347	1.27	0.03	0.00157
0.625	0.613	0.46	2.54	0.05	0.00342	1.12	0.02	0.00150
0.675	0.565	0.42	2.31	0.05	0.00335	0.99	0.02	0.00144
0.725	0.517	0.40	2.10	0.05	0.00328	0.90	0.02	0.00140
0.775	0.470	0.37	1.91	0.04	0.00319	0.82	0.02	0.00136
0.825	0.422	0.35	1.74	0.04	0.00308	0.76	0.02	0.00134
0.875	0.374	0.33	1.58	0.03	0.00297	0.71	0.02	0.00133
0.925	0.327	0.31	1.43	0.03	0.00284	0.67	0.01	0.00133
0.975	0.279	0.29	1.29	0.03	0.00271	0.64	0.01	0.00134

Overall p(collision) =	Upwind	6.4%	Downwind	3.6%
	Average	5.0%		

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA

Black Grouse

Only enter input parameters in blue

Parameter	Value	Unit		r/R	c/C	a	Upwind: collide	Upwind:	Upwind: contribution	Downwind: collide	Downwind:	Downwind: contribution
K: [1D or [3D] (0 or 1)	1		Calculation of alpha and p(collision) as a function of radius									
NoBlades	3			radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r
MaxChord	4.5	m										
Pitch (degrees)	15											
				0.025	0.575	8.01	26.45	0.81	0.00102	25.11	0.77	0.00097
BirdLength	0.48	m		0.075	0.575	2.67	9.26	0.29	0.00214	7.92	0.24	0.00183
Wingspan	0.72	m		0.125	0.702	1.60	6.85	0.21	0.00264	5.22	0.16	0.00201
F: Flapping (0) or gliding (+1)	0			0.175	0.860	1.14	6.10	0.19	0.00329	4.10	0.13	0.00221
Bird speed	13	m/sec		0.225	0.994	0.89	5.65	0.17	0.00391	3.33	0.10	0.00230
RotorDiam	155	m		0.275	0.947	0.73	4.62	0.14	0.00391	2.42	0.07	0.00205
RotationPeriod	7.50	sec		0.325	0.899	0.62	3.93	0.12	0.00393	1.84	0.06	0.00184
				0.375	0.851	0.53	3.45	0.11	0.00398	1.46	0.05	0.00169
				0.425	0.804	0.47	3.06	0.09	0.00400	1.19	0.04	0.00156
Bird aspect ratio: b	0.67			0.475	0.756	0.42	2.75	0.08	0.00401	0.98	0.03	0.00144
				0.525	0.708	0.38	2.48	0.08	0.00400	0.83	0.03	0.00134
				0.575	0.660	0.35	2.25	0.07	0.00398	0.71	0.02	0.00126
				0.625	0.613	0.32	2.05	0.06	0.00394	0.62	0.02	0.00119
				0.675	0.565	0.30	1.87	0.06	0.00388	0.55	0.02	0.00114
				0.725	0.517	0.28	1.70	0.05	0.00380	0.50	0.02	0.00111
				0.775	0.470	0.26	1.55	0.05	0.00371	0.50	0.02	0.00119
				0.825	0.422	0.24	1.42	0.04	0.00360	0.53	0.02	0.00134
				0.875	0.374	0.23	1.29	0.04	0.00347	0.54	0.02	0.00146
				0.925	0.327	0.22	1.17	0.04	0.00332	0.55	0.02	0.00157
				0.975	0.279	0.21	1.05	0.03	0.00316	0.56	0.02	0.00167
				Overall p(collision) =			Upwind	7.0%		Downwind	3.1%	
								Average	5.0%			

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA

Osprey

Only enter input parameters in blue

Parameter	Value	Unit		r/R	c/C	a	Upwind: collide	Upwind:	Upwind: contribution	Downwind: collide	Downwind:	Downwind: contribution
K: [1D or [3D] (0 or 1)	1		Calculation of alpha and p(collision) as a function of radius									
NoBlades	3			radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r
MaxChord	4.5	m										
Pitch (degrees)	15											
				0.025	0.575	8.19	34.26	1.00	0.00125	32.92	0.99	0.00124
BirdLength	0.56	m		0.075	0.575	2.73	11.87	0.36	0.00268	10.53	0.32	0.00237
Wingspan	1.6	m		0.125	0.702	1.64	8.44	0.25	0.00317	6.80	0.20	0.00256
F: Flapping (0) or gliding (+1)	0			0.175	0.860	1.17	7.25	0.22	0.00382	5.25	0.16	0.00276
Bird speed	13.3	m/sec		0.225	0.994	0.91	6.55	0.20	0.00443	4.23	0.13	0.00286
RotorDiam	155	m		0.275	0.947	0.74	5.36	0.16	0.00443	3.15	0.09	0.00261
RotationPeriod	7.50	sec		0.325	0.899	0.63	4.52	0.14	0.00442	2.42	0.07	0.00237
				0.375	0.851	0.55	3.89	0.12	0.00438	1.90	0.06	0.00215
				0.425	0.804	0.48	3.39	0.10	0.00433	1.52	0.05	0.00194
				0.475	0.756	0.43	2.99	0.09	0.00427	1.23	0.04	0.00175
Bird aspect ratio: b	0.35			0.525	0.708	0.39	2.65	0.08	0.00418	1.00	0.03	0.00158
				0.575	0.660	0.36	2.36	0.07	0.00408	0.82	0.02	0.00142
				0.625	0.613	0.33	2.15	0.06	0.00403	0.72	0.02	0.00135
				0.675	0.565	0.30	1.96	0.06	0.00399	0.65	0.02	0.00131
				0.725	0.517	0.28	1.80	0.05	0.00392	0.59	0.02	0.00129
				0.775	0.470	0.26	1.65	0.05	0.00384	0.57	0.02	0.00132
				0.825	0.422	0.25	1.51	0.05	0.00374	0.60	0.02	0.00148
				0.875	0.374	0.23	1.38	0.04	0.00362	0.62	0.02	0.00162
				0.925	0.327	0.22	1.25	0.04	0.00349	0.63	0.02	0.00174
				0.975	0.279	0.21	1.14	0.03	0.00334	0.63	0.02	0.00185
				Overall p(collision) =			Upwind	7.5%		Downwind	3.8%	
								Average	5.7%			

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA

Red Kite

Only enter input parameters in blue

K: [1D or [3D] (0 or 1)	1								

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

						Upwind:		Downwind:	
NoBlades	3								
MaxChord	4.5 m	r/R	c/C	a	collide		contribution	collide		contribution
Pitch (degrees)	15	radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r

		radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r
BirdLength	0.63 m	0.025	0.575	7.39	32.82	1.00	0.00125	31.48	1.00	0.00125
Wingspan	1.85 m	0.075	0.575	2.46	11.39	0.38	0.00285	10.05	0.33	0.00251
F: Flapping (0) or gliding (+1)	0	0.125	0.702	1.48	8.06	0.27	0.00336	6.43	0.21	0.00268
		0.175	0.860	1.06	6.90	0.23	0.00403	4.90	0.16	0.00286
Bird speed	12 m/sec	0.225	0.994	0.82	6.23	0.21	0.00467	3.91	0.13	0.00293
RotorDiam	155 m	0.275	0.947	0.67	5.11	0.17	0.00469	2.91	0.10	0.00266
RotationPeriod	7.50 sec	0.325	0.899	0.57	4.32	0.14	0.00468	2.23	0.07	0.00241
		0.375	0.851	0.49	3.73	0.12	0.00466	1.74	0.06	0.00218
		0.425	0.804	0.43	3.26	0.11	0.00462	1.39	0.05	0.00197
Bird aspect ratio: b	0.34	0.475	0.756	0.39	2.88	0.10	0.00456	1.12	0.04	0.00177
		0.525	0.708	0.35	2.56	0.09	0.00448	0.91	0.03	0.00159
		0.575	0.660	0.32	2.32	0.08	0.00445	0.78	0.03	0.00150
		0.625	0.613	0.30	2.13	0.07	0.00444	0.70	0.02	0.00147
		0.675	0.565	0.27	1.96	0.07	0.00441	0.64	0.02	0.00145
		0.725	0.517	0.25	1.81	0.06	0.00436	0.66	0.02	0.00159
		0.775	0.470	0.24	1.66	0.06	0.00430	0.69	0.02	0.00178
		0.825	0.422	0.22	1.53	0.05	0.00421	0.71	0.02	0.00195
		0.875	0.374	0.21	1.41	0.05	0.00411	0.72	0.02	0.00211
		0.925	0.327	0.20	1.29	0.04	0.00399	0.73	0.02	0.00224
		0.975	0.279	0.19	1.18	0.04	0.00385	0.73	0.02	0.00236
		Overall p(collision) =				Upwind	8.2%		Downwind	4.1%
								Average	6.2%	

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA

Golden Eagle

Only enter input parameters in blue

K: [1D or [3D] (0 or 1)	1								

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

		radius	chord	alpha	collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r
NoBlades	3					Upwind:		Downwind:		
MaxChord	4.5 m	r/R	c/C	a	collide		contribution	collide		contribution
Pitch (degrees)	15	radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r
BirdLength	0.87 m	0.025	0.575	6.14	28.80	0.97	0.00121	27.46	0.92	0.00115
Wingspan	2.08 m	0.075	0.575	2.05	10.05	0.34	0.00253	8.71	0.29	0.00219
F: Flapping (0) or gliding (+1)	0	0.125	0.702	1.23	7.12	0.24	0.00299	5.48	0.18	0.00230
		0.175	0.860	0.88	6.11	0.21	0.00359	4.10	0.14	0.00241
Bird speed	11.9 m/sec	0.225	0.994	0.68	5.53	0.19	0.00418	3.21	0.11	0.00243
RotorDiam	185 m	0.275	0.947	0.56	4.56	0.15	0.00422	2.36	0.08	0.00218
RotationPeriod	7.50 sec	0.325	0.899	0.47	3.88	0.13	0.00423	1.78	0.06	0.00195
		0.375	0.851	0.41	3.38	0.11	0.00426	1.39	0.05	0.00176
		0.425	0.804	0.36	3.07	0.10	0.00438	1.20	0.04	0.00171
		0.475	0.756	0.32	2.81	0.09	0.00449	1.05	0.04	0.00168
Bird aspect ratio: b	0.42	0.525	0.708	0.29	2.60	0.09	0.00458	0.95	0.03	0.00167
		0.575	0.660	0.27	2.41	0.08	0.00465	0.87	0.03	0.00169
		0.625	0.613	0.25	2.24	0.08	0.00470	0.93	0.03	0.00195
		0.675	0.565	0.23	2.09	0.07	0.00473	0.97	0.03	0.00220
		0.725	0.517	0.21	1.95	0.07	0.00475	1.00	0.03	0.00243
		0.775	0.470	0.20	1.82	0.06	0.00475	1.01	0.03	0.00264
		0.825	0.422	0.19	1.70	0.06	0.00472	1.02	0.03	0.00283
		0.875	0.374	0.18	1.59	0.05	0.00468	1.02	0.03	0.00300
		0.925	0.327	0.17	1.49	0.05	0.00462	1.01	0.03	0.00315
		0.975	0.279	0.16	1.39	0.05	0.00454	1.00	0.03	0.00329
		Overall p(collision) =				Upwind	8.3%		Downwind	4.5%
								Average	6.4%	

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA

White-tailed Eagle

Only enter input parameters in blue

			Calculation of alpha and p(collision) as a function of radius							
K: [1D or [3D] (0 or 1)	1									
NoBlades	3					Upwind:			Downwind:	
MaxChord	4.5 m	r/R	c/C	a	collide		contribution	collide		contribution
Pitch (degrees)	15	radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r
BirdLength	0.87 m	0.025	0.575	8.38	39.63	1.00	0.00125	38.29	1.00	0.00125
Wingspan	2.15 m	0.075	0.575	2.79	13.65	0.40	0.00301	12.32	0.36	0.00272
F: Flapping (0) or gliding (+1)	0	0.125	0.702	1.68	9.53	0.28	0.00350	7.90	0.23	0.00290
		0.175	0.860	1.20	8.05	0.24	0.00414	6.05	0.18	0.00311
Bird speed	13.6 m/sec	0.225	0.994	0.93	7.18	0.21	0.00475	4.87	0.14	0.00322
RotorDiam	155 m	0.275	0.947	0.76	5.87	0.17	0.00475	3.67	0.11	0.00297
RotationPeriod	7.50 sec	0.325	0.899	0.64	4.95	0.15	0.00473	2.86	0.08	0.00273
		0.375	0.851	0.56	4.26	0.13	0.00470	2.28	0.07	0.00251
		0.425	0.804	0.49	3.72	0.11	0.00465	1.85	0.05	0.00231
Bird aspect ratio: b	0.40	0.475	0.756	0.44	3.28	0.10	0.00458	1.52	0.04	0.00212
		0.525	0.708	0.40	2.92	0.09	0.00451	1.27	0.04	0.00197
		0.575	0.660	0.36	2.69	0.08	0.00454	1.15	0.03	0.00194
		0.625	0.613	0.34	2.48	0.07	0.00455	1.05	0.03	0.00193
		0.675	0.565	0.31	2.29	0.07	0.00455	0.97	0.03	0.00193
		0.725	0.517	0.29	2.12	0.06	0.00453	0.92	0.03	0.00196
		0.775	0.470	0.27	1.97	0.06	0.00449	0.87	0.03	0.00199
		0.825	0.422	0.25	1.83	0.05	0.00443	0.90	0.03	0.00217
		0.875	0.374	0.24	1.70	0.05	0.00436	0.92	0.03	0.00236
		0.925	0.327	0.23	1.57	0.05	0.00428	0.93	0.03	0.00253
		0.975	0.279	0.21	1.46	0.04	0.00417	0.93	0.03	0.00268
			Overall p(collision) =			Upwind	8.4%		Downwind	4.7%
								Average	6.6%	

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA

Hen Harrier

Only enter input parameters in blue

			Calculation of alpha and p(collision) as a function of radius							
K: [1D or [3D] (0 or 1)	1									
NoBlades	3					Upwind:			Downwind:	
MaxChord	4.5 m	r/R	c/C	a	collide		contribution	collide		contribution
Pitch (degrees)	15	radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r
BirdLength	0.46 m	0.025	0.575	5.61	20.96	0.92	0.00115	19.62	0.86	0.00108
Wingspan	1.12 m	0.075	0.575	1.87	7.43	0.33	0.00245	6.09	0.27	0.00201
F: Flapping (0) or gliding (+1)	0	0.125	0.702	1.12	5.49	0.24	0.00302	3.86	0.17	0.00212
		0.175	0.860	0.80	4.89	0.22	0.00376	2.89	0.13	0.00222
Bird speed	9.1 m/sec	0.225	0.994	0.62	4.55	0.20	0.00450	2.23	0.10	0.00221
RotorDiam	155 m	0.275	0.947	0.51	3.77	0.17	0.00456	1.57	0.07	0.00189
RotationPeriod	7.50 sec	0.325	0.899	0.43	3.22	0.14	0.00459	1.12	0.05	0.00160
		0.375	0.851	0.37	2.83	0.12	0.00467	0.85	0.04	0.00140
		0.425	0.804	0.33	2.55	0.11	0.00476	0.68	0.03	0.00126
		0.475	0.756	0.30	2.31	0.10	0.00482	0.55	0.02	0.00115
Bird aspect ratio: b	0.41	0.525	0.708	0.27	2.11	0.09	0.00486	0.46	0.02	0.00107
		0.575	0.660	0.24	1.93	0.08	0.00488	0.53	0.02	0.00134
		0.625	0.613	0.22	1.77	0.08	0.00487	0.58	0.03	0.00158
		0.675	0.565	0.21	1.63	0.07	0.00483	0.61	0.03	0.00180
		0.725	0.517	0.19	1.50	0.07	0.00477	0.63	0.03	0.00200
		0.775	0.470	0.18	1.38	0.06	0.00469	0.64	0.03	0.00217
		0.825	0.422	0.17	1.26	0.06	0.00458	0.64	0.03	0.00232
		0.875	0.374	0.16	1.16	0.05	0.00445	0.64	0.03	0.00244
		0.925	0.327	0.15	1.06	0.05	0.00429	0.63	0.03	0.00254
		0.975	0.279	0.14	0.96	0.04	0.00411	0.61	0.03	0.00262
			Overall p(collision) =			Upwind	8.5%		Downwind	3.7%
								Average	6.1%	

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA

Peregrine

Only enter input parameters in blue

K: [1D or [3D] (0 or 1)	1					Calculation of alpha and p(collision) as a function of radius					
NoBlades	3						Upwind:			Downwind:	
MaxChord	4.5	m	r/R	c/C	a	collide		contribution	collide		contribution
Pitch (degrees)	15		radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r
BirdLength	0.42	m	0.025	0.575	7.45	26.90	0.89	0.00111	25.57	0.85	0.00106
Wingspan	1.02	m	0.075	0.575	2.48	9.41	0.31	0.00233	8.08	0.27	0.00200
F: Flapping (0) or gliding (+1)	0		0.125	0.702	1.49	6.88	0.23	0.00284	5.25	0.17	0.00217
			0.175	0.860	1.06	6.07	0.20	0.00351	4.07	0.13	0.00235
Bird speed	12.1	m/sec	0.225	0.994	0.83	5.58	0.18	0.00415	3.27	0.11	0.00243
RotorDiam	155	m	0.275	0.947	0.68	4.58	0.15	0.00417	2.38	0.08	0.00216
RotationPeriod	7.50	sec	0.325	0.899	0.57	3.87	0.13	0.00416	1.78	0.06	0.00191
			0.375	0.851	0.50	3.34	0.11	0.00414	1.35	0.04	0.00168
			0.425	0.804	0.44	2.91	0.10	0.00410	1.04	0.03	0.00147
Bird aspect ratio: b	0.41		0.475	0.756	0.39	2.59	0.09	0.00407	0.83	0.03	0.00130
			0.525	0.708	0.35	2.34	0.08	0.00406	0.69	0.02	0.00119
			0.575	0.660	0.32	2.12	0.07	0.00403	0.58	0.02	0.00110
			0.625	0.613	0.30	1.93	0.06	0.00398	0.50	0.02	0.00103
			0.675	0.565	0.28	1.76	0.06	0.00392	0.44	0.01	0.00098
			0.725	0.517	0.26	1.60	0.05	0.00384	0.44	0.01	0.00107
			0.775	0.470	0.24	1.46	0.05	0.00374	0.48	0.02	0.00122
			0.825	0.422	0.23	1.33	0.04	0.00362	0.50	0.02	0.00136
			0.875	0.374	0.21	1.20	0.04	0.00348	0.51	0.02	0.00147
			0.925	0.327	0.20	1.09	0.04	0.00332	0.51	0.02	0.00157
			0.975	0.279	0.19	0.98	0.03	0.00315	0.51	0.02	0.00165
			Overall p(collision) =				Upwind	7.2%		Downwind	3.1%
									Average	5.1%	

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA

Merlin

Only enter input parameters in blue

K: [1D or [3D] (0 or 1)	1					Calculation of alpha and p(collision) as a function of radius					
NoBlades	3						Upwind:			Downwind:	
MaxChord	4.5	m	r/R	c/C	a	collide		contribution	collide		contribution
Pitch (degrees)	15		radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r
BirdLength	0.28	m	0.025	0.575	6.96	21.97	0.78	0.00097	20.63	0.73	0.00091
Wingspan	0.56	m	0.075	0.575	2.32	7.77	0.28	0.00206	6.43	0.23	0.00171
F: Flapping (0) or gliding (+1)	0		0.125	0.702	1.39	5.84	0.21	0.00259	4.21	0.15	0.00186
			0.175	0.860	0.99	5.28	0.19	0.00327	3.27	0.12	0.00203
Bird speed	11.3	m/sec	0.225	0.994	0.77	4.93	0.17	0.00393	2.62	0.09	0.00209
RotorDiam	155	m	0.275	0.947	0.63	4.06	0.14	0.00395	1.86	0.07	0.00181
RotationPeriod	7.50	sec	0.325	0.899	0.54	3.44	0.12	0.00396	1.35	0.05	0.00155
			0.375	0.851	0.46	2.99	0.11	0.00397	1.01	0.04	0.00134
			0.425	0.804	0.41	2.65	0.09	0.00398	0.77	0.03	0.00117
			0.475	0.756	0.37	2.36	0.08	0.00398	0.60	0.02	0.00101
Bird aspect ratio: b	0.50		0.525	0.708	0.33	2.13	0.08	0.00395	0.48	0.02	0.00088
			0.575	0.660	0.30	1.92	0.07	0.00390	0.38	0.01	0.00077
			0.625	0.613	0.28	1.74	0.06	0.00384	0.31	0.01	0.00068
			0.675	0.565	0.26	1.57	0.06	0.00375	0.30	0.01	0.00073
			0.725	0.517	0.24	1.42	0.05	0.00365	0.34	0.01	0.00088
			0.775	0.470	0.22	1.29	0.05	0.00353	0.37	0.01	0.00101
			0.825	0.422	0.21	1.16	0.04	0.00338	0.38	0.01	0.00112
			0.875	0.374	0.20	1.04	0.04	0.00322	0.39	0.01	0.00122
			0.925	0.327	0.19	0.93	0.03	0.00304	0.39	0.01	0.00129
			0.975	0.279	0.18	0.82	0.03	0.00283	0.39	0.01	0.00134
			Overall p(collision) =				Upwind	6.8%		Downwind	2.5%
									Average	4.7%	

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA

Golden Plover

Only enter input parameters in blue

| K: [1D or [3D] (0 or 1)	1			Calculation of alpha and p(collision) as a function of radius								
NoBlades	3						Upwind:			Downwind:		
MaxChord	4.5	m	r/R	c/C	a	collide		contribution	collide		contribution
Pitch (degrees)	15		radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r
BirdLength	0.28	m	0.025	0.575	8.44	27.84	0.81	0.00102	26.50	0.77	0.00097
Wingspan	0.72	m	0.075	0.575	2.81	9.73	0.28	0.00213	8.39	0.24	0.00184
F: Flapping (0) or gliding (+1)	0		0.125	0.702	1.69	7.18	0.21	0.00262	5.55	0.16	0.00202
			0.175	0.860	1.21	6.38	0.19	0.00326	4.37	0.13	0.00224
Bird speed	13.7	m/sec	0.225	0.994	0.94	5.89	0.17	0.00387	3.57	0.10	0.00235
RotorDiam	155	m	0.275	0.947	0.77	4.81	0.14	0.00386	2.61	0.08	0.00209
RotationPeriod	7.50	sec	0.325	0.899	0.65	4.05	0.12	0.00384	1.96	0.06	0.00186
			0.375	0.851	0.56	3.48	0.10	0.00381	1.50	0.04	0.00164
			0.425	0.804	0.50	3.03	0.09	0.00376	1.16	0.03	0.00143
Bird aspect ratio: b	0.39		0.475	0.756	0.44	2.66	0.08	0.00369	0.90	0.03	0.00125
			0.525	0.708	0.40	2.35	0.07	0.00360	0.70	0.02	0.00108
			0.575	0.660	0.37	2.10	0.06	0.00353	0.56	0.02	0.00095
			0.625	0.613	0.34	1.89	0.06	0.00345	0.47	0.01	0.00085
			0.675	0.565	0.31	1.71	0.05	0.00336	0.39	0.01	0.00077
			0.725	0.517	0.29	1.54	0.04	0.00325	0.33	0.01	0.00070
			0.775	0.470	0.27	1.38	0.04	0.00313	0.29	0.01	0.00065
			0.825	0.422	0.26	1.24	0.04	0.00299	0.30	0.01	0.00073
			0.875	0.374	0.24	1.11	0.03	0.00283	0.32	0.01	0.00083
			0.925	0.327	0.23	0.98	0.03	0.00266	0.34	0.01	0.00091
			0.975	0.279	0.22	0.87	0.03	0.00247	0.34	0.01	0.00097
			Overall p(collision) =				Upwind	6.3%		Downwind	2.6%
									Average	4.5%	

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA

Herring Gull

Only enter input parameters in blue

K: [1D or [3D] (0 or 1)	1			Calculation of alpha and p(collision) as a function of radius								
NoBlades	3						Upwind:			Downwind:		
MaxChord	4.5	m	r/R	c/C	a	collide		contribution	collide		contribution
Pitch (degrees)	15		radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r
BirdLength	0.6	m	0.025	0.575	7.89	31.73	0.99	0.00124	30.40	0.95	0.00119
Wingspan	1.44	m	0.075	0.575	2.63	11.02	0.34	0.00258	9.69	0.30	0.00227
F: Flapping (0) or gliding (+1)	0		0.125	0.702	1.58	7.90	0.25	0.00308	6.26	0.20	0.00245
			0.175	0.860	1.13	6.84	0.21	0.00374	4.83	0.15	0.00264
Bird speed	12.8	m/sec	0.225	0.994	0.88	6.21	0.19	0.00436	3.89	0.12	0.00274
RotorDiam	155	m	0.275	0.947	0.72	5.08	0.16	0.00437	2.88	0.09	0.00247
RotationPeriod	7.50	sec	0.325	0.899	0.61	4.29	0.13	0.00436	2.20	0.07	0.00223
			0.375	0.851	0.53	3.69	0.12	0.00433	1.71	0.05	0.00200
			0.425	0.804	0.46	3.22	0.10	0.00428	1.35	0.04	0.00180
			0.475	0.756	0.42	2.84	0.09	0.00422	1.08	0.03	0.00161
Bird aspect ratio: b	0.42		0.525	0.708	0.38	2.58	0.08	0.00423	0.93	0.03	0.00153
			0.575	0.660	0.34	2.35	0.07	0.00423	0.82	0.03	0.00146
			0.625	0.613	0.32	2.15	0.07	0.00421	0.73	0.02	0.00142
			0.675	0.565	0.29	1.98	0.06	0.00417	0.66	0.02	0.00139
			0.725	0.517	0.27	1.81	0.06	0.00411	0.61	0.02	0.00138
			0.775	0.470	0.25	1.67	0.05	0.00404	0.63	0.02	0.00152
			0.825	0.422	0.24	1.53	0.05	0.00394	0.65	0.02	0.00168
			0.875	0.374	0.23	1.40	0.04	0.00383	0.67	0.02	0.00183
			0.925	0.327	0.21	1.28	0.04	0.00371	0.68	0.02	0.00196
			0.975	0.279	0.20	1.17	0.04	0.00356	0.68	0.02	0.00207
			Overall p(collision) =				Upwind	7.7%		Downwind	3.8%
									Average	5.7%	

KEY SPECIES FLIGHT ACTIVITY AND COLLISON RISK: DIRECT FLIGHT MODEL (STAGE 2)

The second section of this Technical Appendix provides example calculations of the key species' flight activity within the collision risk zone and the resultant collision risk.

The model was run separately for each zone across the collision risk area that was visible from each of the two Vantage Points (VPs) and the overlap zone that was visible from both. Bird flight activity within each of these zones was calculated separately. These zones are shown in **Figure 8.5.1.** A 200 m buffer around the wind farm to define the risk zone, reduced from the standard 500 m as the locations of VPs and well-defined habitat edges (forest /moorland) meant that these direct flights could be more accurately mapped.

For the direct flight variant of the Band model (used for whooper swan, Greenland white-fronted goose, greylag goose, red-throated diver and herring gull), flight activity was calculated as the total number of flights through each of the three collision zones (delineated according to which VPs the zone was visible), estimated from the VP data (clipping mapped flights in QGIS to those zones and calculating the numbers of flights per hour at rotor height over each season). An example calculation is given below in **Table 8.5.1.** The total risk for the whole wind farm was calculated as the sum of the risks for each of the three zones (A-C), and the last row gives the total estimated risk for each winter.
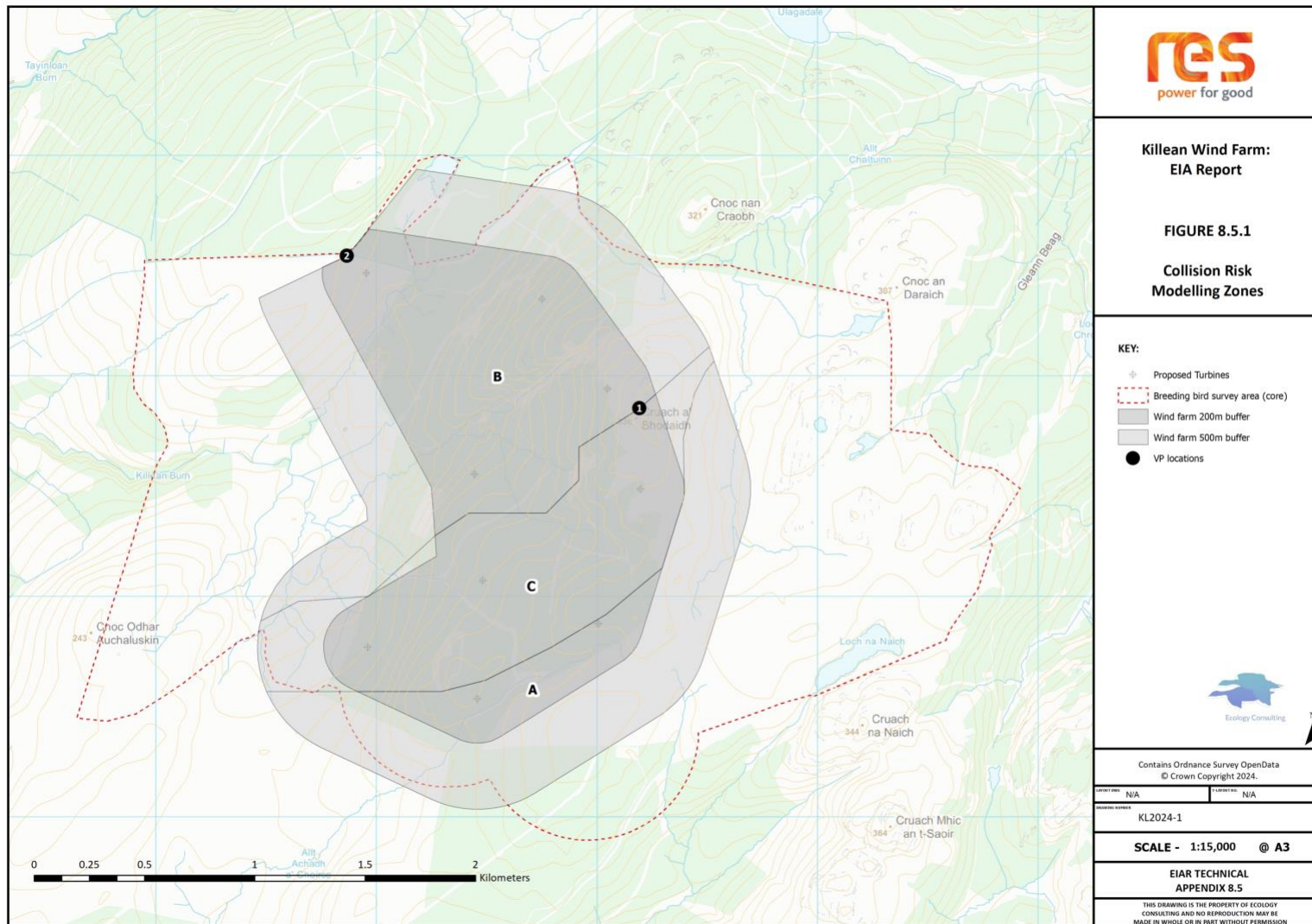
Table 8.5.1: Collision risk calculations for Greenland white-fronted goose for the 2021-22 and 2022-23 winters using the direct flight Band model.

KILLEAN WIND FARM BAND ET AL 2007 COLLISION MODEL (DIRECT FLIGHTS)	White-fronted Goose 2021-22 Zone A	Winter only Zone B	Zone C	2022-23 Zone A	Zone B	Zone C
Collision risk height	155	155	155	155	155	155
Risk corridor Width	675	1,270	1,265	675	1,270	1,265
Risk corridor Area	104,625	196,850	196,075	104,625	196,850	196,075
Annual number of flights through collision zone at rotor ht	0	7,220	113	0	4372	0
No turbines	2	4	3	2	4	3
Rotor diameter	155	155	155	155	155	155
Rotor swept area	18869	18869	18869	18869	18869	18869
Allowance for overlap	0%	0%	0%	0%	0%	0%
Proportion of risk window occupied by rotors	36%	38%	29%	36%	38%	29%
Annual no bird rotor passes	0	2768	33	0	1676	0
Band individual collision risk	5.6%	5.6%	5.6%	5.6%	5.6%	5.6%
Turbine downtime	15%	15%	15%	15%	15%	15%
Non-avoidance collisions	0	131	2	0	79	0
Avoidance rate	99.80%	99.80%	99.80%	99.80%	99.80%	99.80%
Predicted collisions per year	**0.000**	**0.261**	**0.003**	**0.000**	**0.158**	**0.000**
Total annual collision risk			*0.264*			*0.158*

KEY SPECIES FLIGHT ACTIVITY AND COLLISON RISK: NON-DIRECT FLIGHT MODEL (STAGE 2)

As for the direct flight modelling, this model was run separately for each of the zones across the collision risk area that was visible from each of the two Vantage Points (VPs) (all areas were visible from only a single VP, with no overlap). Bird flight activity within each of these zones was calculated separately. A 500 m buffer was used to define the collision risk zone for non-direct flights (**Figure 8.5.2**).

As an example, for the variable non-direct flight modelling, the collision risk calculations for golden eagle for each of the winter and breeding baseline periods (breeding 2022 and 2023, winter 2021-22 and 2022-23) is shown in **Table 8.5.2**. This requires an estimate of the amount of time that each species was present within the collision risk zone for its bird activity input, calculated from the amount of time observed in each zone during the VP surveys (as the percentage occupancy rate of each zone, i.e. the percentage of observation time that each species was observed flying at rotor height within the zone). This occupancy of the collision risk zone was determined from the flight tracks and divided by the observation time for each zone for each month to give the monthly occupancy rate (percentage of time present in the collision zone). The overall occupancy was then calculated for each of the four survey periods (breeding 2022 and 2023, winter 2021-22 and 2022-23). The survey results for these periods are given in **Technical Appendices 8.1, 8.2, 8.3 and 8.4** respectively.

As for the direct flight model, the total risk for the whole wind farm was calculated as the sum of the risks for each of the three zones.

Table 8.5.2. Collision risk calculations for golden eagle using the non-direct random flight Band model.

KILLEAN WIND FARM
BAND ET AL 2007 COLLISION MODEL (OCCUPANCY)

	Golden Eagle	All year		2022-23			2022			2023		
	2021-22											
	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C
Collision Zone Area (ha)	121	229	123	121	229	123	121	229	123	121	229	123
Hub Ht	102.5	102.5	102.5	102.5	102.5	102.5	102.5	102.5	102.5	102.5	102.5	102.5
Rotor diameter	155	155	155	155	155	155	155	155	155	155	155	155
Upper rotor ht	180	180	180	180	180	180	180	180	180	180	180	180
Lower rotor ht	25	25	25	25	25	25	25	25	25	25	25	25
Percentage of observation time seen flying in collision zone at rotor ht	0.04%	0.16%	0.14%	0.01%	1.20%	0.17%	0.13%	1.387%	0.447%	0.017%	0.000%	0.006%
Season length	212	212	212	212	212	212	153	153	153	153	153	153
Activity per day	9.7	9.7	9.7	9.7	9.7	9.7	15.9	15.9	15.9	15.9	15.9	15.9
Total flight activity in collision zone at rotor ht	0.790	3.295	2.973	0.267	24.788	3.406	3.191	33.842	10.901	0.411	0.000	0.137
Flight risk volume	1.876E+08	3.550E+08	1.907E+08	1.876E+08	3.550E+08	1.907E+08	1.876E+08	3.550E+08	1.907E+08	1.876E+08	3.550E+08	1.907E+08
No Turbines	2	4	3	2	4	3	2	4	3	2	4	3
Rotor radius	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
Rotor depth	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Bird length	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
Swept volume	202655	405310	303983	202655	405310	303983	202655	405310	303983	202655	405310	303983
Bird occupancy of swept volume	3.07	13.55	17.07	1.04	101.90	19.55	12.41	139.12	62.57	1.60	0.00	0.78
Bird speed	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9
Rotor transit time	0.451	0.451	0.451	0.451	0.451	0.451	0.451	0.451	0.451	0.451	0.451	0.451
No of rotor transits	7	30	38	2	226	43	28	308	139	4	0	2
Turbine downtime	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%
Band collision rate	6.4%	6.4%	6.4%	6.4%	6.4%	6.4%	6.4%	6.4%	6.4%	6.4%	6.4%	6.4%
Non-avoid collisions	0.4	1.6	2.0	0.1	12.2	2.3	1.5	16.7	7.5	0.2	0.0	0.1
Avoidance rate	99.0%	99.0%	99.0%	99.0%	99.0%	99.0%	99.0%	99.0%	99.0%	99.0%	99.0%	99.0%
Collision prediction	0.004	0.016	0.020	0.001	0.122	0.023	0.015	0.167	0.075	0.002	0.000	0.001
OVERALL TOTAL			0.040			0.147			0.257			0.003

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