

TECHNICAL APPENDIX 7.6: COLLISION RISK MODELLING CALCULATIONS

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TECHNICAL APPENDIX 6.6: BALGRAY WIND FARM COLLISION RISK MODELLING CALCULATIONS

INTRODUCTION

This Technical Appendix sets out the collision risk modelling that has been undertaken to support the ornithological assessment of the Balgray Wind Farm (the proposed development). The collision risk modelling was carried out for all key target species recorded flying through the collision risk zone at rotor height (as per SNH guidance 2018). Rotor height would be 38-200m above ground level.

The modelling included five target raptor species (osprey, goshawk, red kite, peregrine and short-eared owl) and three breeding waders (curlew, lapwing and golden plover). The collision risk for each of these species was modelled using the non-direct flight model. In addition, whooper swans, greylag geese and pink-footed geese were observed flying through the collision risk zone and modelled to determine their collision risk. As their flights were largely direct ones through the site, the direct flight model was applied. 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 with the assumption that flight patterns are unaffected by the presence of the wind turbines, i.e. that 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 wind turbine blades) in order 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 wind turbines, will actually take a degree of avoiding action, as has been shown to occur in 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, Urquhart and Whitfield 2016) 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 below. 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 7.2% 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	p(collision)	contribution	collide	p(collision)	contribution	
Pitch (degrees)	15	radius	chord	alpha	length		from radius r	length		from radius r	
BirdLength	1.52 m	0.025	0.575	10.20	49.61	1.00	0.00125	48.27	1.00	0.00125	
Wingspan	2.3 m	0.075	0.575	3.40	16.98	0.39	0.00295	15.64	0.36	0.00271	
F: Flapping (0) or gliding (+1)	0	0.125	0.702	2.04	11.73	0.27	0.00339	10.09	0.23	0.00292	
		0.175	0.860	1.46	9.80	0.23	0.00396	7.80	0.18	0.00315	
Bird speed	17.3 m/sec	0.225	0.994	1.13	8.66	0.20	0.00451	6.35	0.15	0.00330	
RotorDiam	162 m	0.275	0.947	0.93	7.05	0.16	0.00448	4.84	0.11	0.00308	
RotationPeriod	7.50 sec	0.325	0.899	0.78	5.92	0.14	0.00445	3.82	0.09	0.00287	
		0.375	0.851	0.68	5.07	0.12	0.00440	3.09	0.07	0.00268	
		0.425	0.804	0.60	4.55	0.11	0.00447	2.68	0.06	0.00263	
		0.475	0.756	0.54	4.16	0.10	0.00457	2.40	0.06	0.00264	
Bird aspect ratio: b	0.66	0.525	0.708	0.49	3.84	0.09	0.00466	2.19	0.05	0.00266	
		0.575	0.660	0.44	3.56	0.08	0.00474	2.02	0.05	0.00269	
		0.625	0.613	0.41	3.32	0.08	0.00480	1.89	0.04	0.00274	
		0.675	0.565	0.38	3.11	0.07	0.00485	1.79	0.04	0.00279	
		0.725	0.517	0.35	2.91	0.07	0.00488	1.71	0.04	0.00286	
		0.775	0.470	0.33	2.74	0.06	0.00491	1.64	0.04	0.00295	
		0.825	0.422	0.31	2.58	0.06	0.00492	1.60	0.04	0.00304	
		0.875	0.374	0.29	2.43	0.06	0.00492	1.56	0.04	0.00315	
		0.925	0.327	0.28	2.29	0.05	0.00490	1.53	0.04	0.00327	
		0.975	0.279	0.26	2.16	0.05	0.00487	1.53	0.04	0.00344	
		Overall p(collision) =				Upwind	8.7%	Downwind	5.7%		
							Average	7.2%			

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	p(collision)	contribution	collide	p(collision)	contribution	
Pitch (degrees)	15	radius	chord	alpha	length		from radius r	length		from radius r	
BirdLength	0.82 m	0.025	0.575	10.08	42.39	0.99	0.00124	41.05	0.96	0.00120	
Wingspan	1.64 m	0.075	0.575	3.36	14.58	0.34	0.00256	13.24	0.31	0.00232	
F: Flapping (0) or gliding (+1)	0	0.125	0.702	2.02	10.27	0.24	0.00300	8.64	0.20	0.00253	
		0.175	0.860	1.44	8.75	0.20	0.00358	6.74	0.16	0.00276	
Bird speed	17.1 m/sec	0.225	0.994	1.12	7.84	0.18	0.00412	5.52	0.13	0.00290	
RotorDiam	162 m	0.275	0.947	0.92	6.38	0.15	0.00410	4.17	0.10	0.00268	
RotationPeriod	7.50 sec	0.325	0.899	0.78	5.35	0.13	0.00407	3.25	0.08	0.00247	
		0.375	0.851	0.67	4.58	0.11	0.00402	2.60	0.06	0.00228	
		0.425	0.804	0.59	3.98	0.09	0.00396	2.11	0.05	0.00210	
		0.475	0.756	0.53	3.49	0.08	0.00388	1.73	0.04	0.00193	
Bird aspect ratio: b	0.50	0.525	0.708	0.48	3.12	0.07	0.00383	1.47	0.03	0.00181	
		0.575	0.660	0.44	2.85	0.07	0.00383	1.31	0.03	0.00176	
		0.625	0.613	0.40	2.61	0.06	0.00381	1.18	0.03	0.00173	
		0.675	0.565	0.37	2.40	0.06	0.00378	1.08	0.03	0.00170	
		0.725	0.517	0.35	2.20	0.05	0.00374	1.00	0.02	0.00169	
		0.775	0.470	0.33	2.03	0.05	0.00368	0.94	0.02	0.00170	
		0.825	0.422	0.31	1.87	0.04	0.00361	0.89	0.02	0.00172	
		0.875	0.374	0.29	1.72	0.04	0.00353	0.85	0.02	0.00175	
		0.925	0.327	0.27	1.59	0.04	0.00343	0.83	0.02	0.00179	
		0.975	0.279	0.26	1.46	0.03	0.00333	0.83	0.02	0.00190	
		Overall p(collision) =				Upwind	7.1%	Downwind	4.1%		
							Average	5.6%			

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA											
Pink-footed 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	collide	contribution	
Pitch (degrees)	15	radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r	
BirdLength	0.68 m	0.025	0.575	10.20	41.66	0.96	0.00120	40.32	0.93	0.00117	
Wingspan	1.52 m	0.075	0.575	3.40	14.33	0.33	0.00249	12.99	0.30	0.00225	
F: Flapping (0) or gliding (+1)	0	0.125	0.702	2.04	10.14	0.23	0.00293	8.50	0.20	0.00246	
		0.175	0.860	1.46	8.66	0.20	0.00351	6.66	0.15	0.00269	
Bird speed	17.3 m/sec	0.225	0.994	1.13	7.78	0.18	0.00405	5.46	0.13	0.00284	
RotorDiam	162 m	0.275	0.947	0.93	6.33	0.15	0.00402	4.12	0.10	0.00262	
RotationPeriod	7.50 sec	0.325	0.899	0.78	5.30	0.12	0.00399	3.21	0.07	0.00241	
		0.375	0.851	0.68	4.54	0.10	0.00394	2.56	0.06	0.00222	
		0.425	0.804	0.60	3.94	0.09	0.00387	2.07	0.05	0.00204	
		0.475	0.756	0.54	3.46	0.08	0.00380	1.70	0.04	0.00187	
Bird aspect ratio: b	0.45	0.525	0.708	0.49	3.06	0.07	0.00371	1.41	0.03	0.00171	
		0.575	0.660	0.44	2.72	0.06	0.00362	1.18	0.03	0.00157	
		0.625	0.613	0.41	2.48	0.06	0.00358	1.05	0.02	0.00152	
		0.675	0.565	0.38	2.27	0.05	0.00354	0.95	0.02	0.00148	
		0.725	0.517	0.35	2.07	0.05	0.00348	0.87	0.02	0.00146	
		0.775	0.470	0.33	1.90	0.04	0.00340	0.80	0.02	0.00144	
		0.825	0.422	0.31	1.74	0.04	0.00332	0.76	0.02	0.00144	
		0.875	0.374	0.29	1.59	0.04	0.00322	0.72	0.02	0.00145	
		0.925	0.327	0.28	1.45	0.03	0.00310	0.69	0.02	0.00148	
		0.975	0.279	0.26	1.32	0.03	0.00298	0.69	0.02	0.00155	
Overall p(collision) =					Upwind			6.8%	Downwind		
								Average	5.3%		

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									
NoBlades	3	Upwind:						Downwind:			
MaxChord	4.5 m	r/R	c/C	a	collide	contribution	collide	contribution	collide	contribution	
Pitch (degrees)	15	radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r	
BirdLength	0.63 m	0.025	0.575	7.07	31.43	1.00	0.00125	30.10	1.00	0.00125	
Wingspan	1.85 m	0.075	0.575	2.36	10.92	0.36	0.00273	9.59	0.32	0.00240	
F: Flapping (0) or gliding (+1)	0	0.125	0.702	1.41	7.75	0.26	0.00323	6.11	0.20	0.00255	
		0.175	0.860	1.01	6.65	0.22	0.00388	4.65	0.15	0.00271	
Bird speed	12 m/sec	0.225	0.994	0.79	6.01	0.20	0.00451	3.69	0.12	0.00277	
RotorDiam	162 m	0.275	0.947	0.64	4.94	0.16	0.00453	2.73	0.09	0.00251	
RotationPeriod	7.50 sec	0.325	0.899	0.54	4.18	0.14	0.00453	2.09	0.07	0.00226	
		0.375	0.851	0.47	3.61	0.12	0.00451	1.63	0.05	0.00203	
		0.425	0.804	0.42	3.16	0.11	0.00448	1.29	0.04	0.00182	
		0.475	0.756	0.37	2.79	0.09	0.00442	1.03	0.03	0.00163	
Bird aspect ratio: b	0.34	0.525	0.708	0.34	2.49	0.08	0.00436	0.84	0.03	0.00147	
		0.575	0.660	0.31	2.28	0.08	0.00437	0.74	0.02	0.00143	
		0.625	0.613	0.28	2.10	0.07	0.00437	0.67	0.02	0.00140	
		0.675	0.565	0.26	1.93	0.06	0.00435	0.64	0.02	0.00145	
		0.725	0.517	0.24	1.78	0.06	0.00430	0.68	0.02	0.00165	
		0.775	0.470	0.23	1.64	0.05	0.00424	0.71	0.02	0.00184	
		0.825	0.422	0.21	1.51	0.05	0.00417	0.73	0.02	0.00200	
		0.875	0.374	0.20	1.39	0.05	0.00407	0.74	0.02	0.00215	
		0.925	0.327	0.19	1.28	0.04	0.00395	0.74	0.02	0.00228	
		0.975	0.279	0.18	1.17	0.04	0.00382	0.73	0.02	0.00239	
Overall p(collision) =					Upwind			8.0%	Downwind		
								Average	6.0%		

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA											
Goshawk											
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	collide	contribution	
Pitch (degrees)	15	radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r	
BirdLength	0.55 m	0.025	0.575	6.66	27.31	0.97	0.00121	25.97	0.92	0.00115	
Wingspan	1.5 m	0.075	0.575	2.22	9.55	0.34	0.00254	8.21	0.29	0.00218	
F: Flapping (0) or gliding (+1)	0	0.125	0.702	1.33	6.88	0.24	0.00304	5.24	0.19	0.00232	
		0.175	0.860	0.95	5.99	0.21	0.00371	3.98	0.14	0.00247	
Bird speed	11.3 m/sec	0.225	0.994	0.74	5.47	0.19	0.00435	3.15	0.11	0.00251	
RotorDiam	162 m	0.275	0.947	0.61	4.50	0.16	0.00438	2.30	0.08	0.00224	
RotationPeriod	7.50 sec	0.325	0.899	0.51	3.82	0.14	0.00439	1.72	0.06	0.00198	
		0.375	0.851	0.44	3.30	0.12	0.00438	1.32	0.05	0.00175	
		0.425	0.804	0.39	2.89	0.10	0.00435	1.02	0.04	0.00154	
		0.475	0.756	0.35	2.58	0.09	0.00434	0.82	0.03	0.00138	
Bird aspect ratio: b	0.37	0.525	0.708	0.32	2.35	0.08	0.00437	0.70	0.02	0.00130	
		0.575	0.660	0.29	2.15	0.08	0.00438	0.61	0.02	0.00125	
		0.625	0.613	0.27	1.97	0.07	0.00437	0.55	0.02	0.00123	
		0.675	0.565	0.25	1.81	0.06	0.00433	0.60	0.02	0.00144	
		0.725	0.517	0.23	1.67	0.06	0.00428	0.64	0.02	0.00163	
		0.775	0.470	0.21	1.54	0.05	0.00421	0.66	0.02	0.00181	
		0.825	0.422	0.20	1.41	0.05	0.00412	0.67	0.02	0.00196	
		0.875	0.374	0.19	1.30	0.05	0.00401	0.68	0.02	0.00209	
		0.925	0.327	0.18	1.19	0.04	0.00388	0.67	0.02	0.00221	
		0.975	0.279	0.17	1.08	0.04	0.00373	0.67	0.02	0.00230	
Overall p(collision) =					Upwind			7.8%	Downwind		
								Average	5.8%		

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA											
Osprey											
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	collide	contribution	
Pitch (degrees)	15	radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r	
BirdLength	0.56 m	0.025	0.575	7.84	32.81	0.99	0.00123	31.47	0.95	0.00118	
Wingspan	1.6 m	0.075	0.575	2.61	11.38	0.34	0.00257	10.04	0.30	0.00227	
F: Flapping (0) or gliding (+1)	0	0.125	0.702	1.57	8.11	0.24	0.00305	6.47	0.19	0.00243	
		0.175	0.860	1.12	6.98	0.21	0.00367	4.98	0.15	0.00262	
Bird speed	13.3 m/sec	0.225	0.994	0.87	6.32	0.19	0.00427	4.00	0.12	0.00271	
RotorDiam	162 m	0.275	0.947	0.71	5.18	0.16	0.00428	2.97	0.09	0.00246	
RotationPeriod	7.50 sec	0.325	0.899	0.60	4.37	0.13	0.00427	2.27	0.07	0.00222	
		0.375	0.851	0.52	3.76	0.11	0.00424	1.78	0.05	0.00201	
		0.425	0.804	0.46	3.28	0.10	0.00420	1.41	0.04	0.00181	
		0.475	0.756	0.41	2.90	0.09	0.00414	1.14	0.03	0.00162	
Bird aspect ratio: b	0.35	0.525	0.708	0.37	2.57	0.08	0.00406	0.92	0.03	0.00146	
		0.575	0.660	0.34	2.31	0.07	0.00399	0.77	0.02	0.00133	
		0.625	0.613	0.31	2.11	0.06	0.00396	0.68	0.02	0.00128	
		0.675	0.565	0.29	1.93	0.06	0.00392	0.62	0.02	0.00125	
		0.725	0.517	0.27	1.77	0.05	0.00386	0.57	0.02	0.00123	
		0.775	0.470	0.25	1.62	0.05	0.00378	0.59	0.02	0.00138	
		0.825	0.422	0.24	1.49	0.04	0.00369	0.62	0.02	0.00153	
		0.875	0.374	0.22	1.36	0.04	0.00358	0.63	0.02	0.00166	
		0.925	0.327	0.21	1.24	0.04	0.00345	0.64	0.02	0.00178	
		0.975	0.279	0.20	1.13	0.03	0.00331	0.64	0.02	0.00188	
Overall p(collision) =					Upwind			7.4%	Downwind		
								Average	5.5%		

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	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	7.13	25.77	0.85	0.00106	24.43	0.81	0.00101	
Wingspan	1.02 m	0.075	0.575	2.38	9.04	0.30	0.00224	7.70	0.25	0.00191	
F: Flapping (0) or gliding (+1)	0	0.125	0.702	1.43	6.62	0.22	0.00274	4.99	0.16	0.00206	
		0.175	0.860	1.02	5.85	0.19	0.00338	3.85	0.13	0.00223	
Bird speed	12.1 m/sec	0.225	0.994	0.79	5.39	0.18	0.00401	3.08	0.10	0.00229	
RotorDiam	162 m	0.275	0.947	0.65	4.43	0.15	0.00403	2.23	0.07	0.00202	
RotationPeriod	7.50 sec	0.325	0.899	0.55	3.75	0.12	0.00403	1.66	0.05	0.00178	
		0.375	0.851	0.48	3.24	0.11	0.00401	1.25	0.04	0.00155	
		0.425	0.804	0.42	2.83	0.09	0.00397	0.96	0.03	0.00135	
		0.475	0.756	0.38	2.53	0.08	0.00398	0.77	0.03	0.00121	
Bird aspect ratio: b	0.41	0.525	0.708	0.34	2.29	0.08	0.00397	0.64	0.02	0.00111	
		0.575	0.660	0.31	2.08	0.07	0.00395	0.54	0.02	0.00103	
		0.625	0.613	0.29	1.89	0.06	0.00391	0.47	0.02	0.00096	
		0.675	0.565	0.26	1.73	0.06	0.00385	0.43	0.01	0.00096	
		0.725	0.517	0.25	1.58	0.05	0.00378	0.47	0.02	0.00113	
		0.775	0.470	0.23	1.44	0.05	0.00368	0.50	0.02	0.00127	
		0.825	0.422	0.22	1.31	0.04	0.00357	0.52	0.02	0.00140	
		0.875	0.374	0.20	1.19	0.04	0.00343	0.52	0.02	0.00152	
		0.925	0.327	0.19	1.07	0.04	0.00328	0.53	0.02	0.00161	
		0.975	0.279	0.18	0.97	0.03	0.00311	0.52	0.02	0.00169	
Overall p(collision) =					Upwind			7.0%	Downwind		
								Average	5.0%		

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	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	8.08	26.67	0.78	0.00097	25.33	0.74	0.00092	
Wingspan	0.72 m	0.075	0.575	2.69	9.34	0.27	0.00204	8.00	0.23	0.00175	
F: Flapping (0) or gliding (+1)	0	0.125	0.702	1.62	6.90	0.20	0.00252	5.27	0.15	0.00192	
		0.175	0.860	1.15	6.15	0.18	0.00314	4.14	0.12	0.00212	
Bird speed	13.7 m/sec	0.225	0.994	0.90	5.68	0.17	0.00373	3.37	0.10	0.00221	
RotorDiam	162 m	0.275	0.947	0.73	4.65	0.14	0.00374	2.45	0.07	0.00196	
RotationPeriod	7.50 sec	0.325	0.899	0.62	3.92	0.11	0.00372	1.83	0.05	0.00173	
		0.375	0.851	0.54	3.37	0.10	0.00369	1.39	0.04	0.00152	
		0.425	0.804	0.48	2.94	0.09	0.00364	1.07	0.03	0.00132	
		0.475	0.756	0.43	2.58	0.08	0.00358	0.82	0.02	0.00114	
Bird aspect ratio: b	0.39	0.525	0.708	0.38	2.29	0.07	0.00351	0.64	0.02	0.00098	
		0.575	0.660	0.35	2.06	0.06	0.00345	0.52	0.02	0.00087	
		0.625	0.613	0.32	1.85	0.05	0.00338	0.43	0.01	0.00078	
		0.675	0.565	0.30	1.67	0.05	0.00330	0.36	0.01	0.00070	
		0.725	0.517	0.28	1.51	0.04	0.00319	0.30	0.01	0.00064	
		0.775	0.470	0.26	1.36	0.04	0.00307	0.30	0.01	0.00067	
		0.825	0.422	0.24	1.22	0.04	0.00294	0.32	0.01	0.00078	
		0.875	0.374	0.23	1.09	0.03	0.00279	0.34	0.01	0.00087	
		0.925	0.327	0.22	0.97	0.03	0.00262	0.35	0.01	0.00095	
		0.975	0.279	0.21	0.86	0.02	0.00244	0.35	0.01	0.00101	
Overall p(collision) =					Upwind			6.1%	Downwind		
								Average	4.3%		

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA											
Lapwing											
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	collide	contribution	
Pitch (degrees)	15	radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r	
BirdLength	0.3 m	0.025	0.575	7.01	24.09	0.81	0.00101	22.75	0.76	0.00096	
Wingspan	0.84 m	0.075	0.575	2.34	8.48	0.28	0.00214	7.14	0.24	0.00180	
F: Flapping (0) or gliding (+1)	0	0.125	0.702	1.40	6.27	0.21	0.00264	4.64	0.16	0.00195	
		0.175	0.860	1.00	5.59	0.19	0.00329	3.59	0.12	0.00211	
Bird speed	11.9 m/sec	0.225	0.994	0.78	5.18	0.17	0.00392	2.87	0.10	0.00217	
RotorDiam	162 m	0.275	0.947	0.64	4.26	0.14	0.00394	2.06	0.07	0.00190	
RotationPeriod	7.50 sec	0.325	0.899	0.54	3.61	0.12	0.00394	1.51	0.05	0.00165	
		0.375	0.851	0.47	3.11	0.10	0.00393	1.13	0.04	0.00143	
		0.425	0.804	0.41	2.72	0.09	0.00389	0.85	0.03	0.00122	
		0.475	0.756	0.37	2.40	0.08	0.00384	0.64	0.02	0.00103	
Bird aspect ratio: b	0.36	0.525	0.708	0.33	2.15	0.07	0.00380	0.50	0.02	0.00089	
		0.575	0.660	0.30	1.94	0.07	0.00376	0.41	0.01	0.00079	
		0.625	0.613	0.28	1.76	0.06	0.00370	0.33	0.01	0.00070	
		0.675	0.565	0.26	1.60	0.05	0.00362	0.32	0.01	0.00073	
		0.725	0.517	0.24	1.45	0.05	0.00353	0.36	0.01	0.00087	
		0.775	0.470	0.23	1.31	0.04	0.00341	0.39	0.01	0.00100	
		0.825	0.422	0.21	1.18	0.04	0.00328	0.40	0.01	0.00111	
		0.875	0.374	0.20	1.06	0.04	0.00312	0.41	0.01	0.00121	
		0.925	0.327	0.19	0.95	0.03	0.00295	0.41	0.01	0.00128	
		0.975	0.279	0.18	0.84	0.03	0.00276	0.41	0.01	0.00133	
Overall p(collision) =					Upwind			6.6%	Downwind		
								Average	4.6%		

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA											
Curlew											
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	collide	contribution	
Pitch (degrees)	15	radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r	
BirdLength	0.55 m	0.025	0.575	9.61	33.33	0.82	0.00102	31.99	0.79	0.00098	
Wingspan	0.9 m	0.075	0.575	3.20	11.56	0.28	0.00213	10.22	0.25	0.00188	
F: Flapping (0) or gliding (+1)	0	0.125	0.702	1.92	8.41	0.21	0.00258	6.77	0.17	0.00208	
		0.175	0.860	1.37	7.37	0.18	0.00316	5.37	0.13	0.00230	
Bird speed	16.3 m/sec	0.225	0.994	1.07	6.73	0.17	0.00372	4.42	0.11	0.00244	
RotorDiam	162 m	0.275	0.947	0.87	5.48	0.13	0.00370	3.28	0.08	0.00221	
RotationPeriod	7.50 sec	0.325	0.899	0.74	4.60	0.11	0.00367	2.51	0.06	0.00200	
		0.375	0.851	0.64	3.94	0.10	0.00362	1.96	0.05	0.00180	
		0.425	0.804	0.57	3.46	0.08	0.00361	1.59	0.04	0.00166	
		0.475	0.756	0.51	3.09	0.08	0.00360	1.33	0.03	0.00155	
Bird aspect ratio: b	0.61	0.525	0.708	0.46	2.78	0.07	0.00359	1.13	0.03	0.00146	
		0.575	0.660	0.42	2.52	0.06	0.00355	0.98	0.02	0.00138	
		0.625	0.613	0.38	2.29	0.06	0.00351	0.86	0.02	0.00132	
		0.675	0.565	0.36	2.08	0.05	0.00345	0.77	0.02	0.00127	
		0.725	0.517	0.33	1.90	0.05	0.00338	0.69	0.02	0.00123	
		0.775	0.470	0.31	1.73	0.04	0.00329	0.64	0.02	0.00121	
		0.825	0.422	0.29	1.58	0.04	0.00319	0.59	0.01	0.00120	
		0.875	0.374	0.27	1.43	0.04	0.00308	0.56	0.01	0.00120	
		0.925	0.327	0.26	1.30	0.03	0.00295	0.56	0.01	0.00128	
		0.975	0.279	0.25	1.17	0.03	0.00281	0.58	0.01	0.00138	
Overall p(collision) =					Upwind			6.4%	Downwind		
								Average	4.8%		

CALCULATION OF COLLISION RISK FOR BIRD PASSING THROUGH ROTOR AREA											
Short-eared Owl											
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	collide	contribution	
Pitch (degrees)	15	radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r	
BirdLength	0.56 m	0.025	0.575	7.84	28.10	0.85	0.00106	26.76	0.80	0.00101	
Wingspan	1 m	0.075	0.575	2.61	9.81	0.30	0.00221	8.48	0.25	0.00191	
F: Flapping (0) or gliding (+1)	0	0.125	0.702	1.57	7.17	0.22	0.00269	5.53	0.17	0.00208	
		0.175	0.860	1.12	6.31	0.19	0.00332	4.31	0.13	0.00227	
Bird speed	13.3 m/sec	0.225	0.994	0.87	5.79	0.17	0.00392	3.48	0.10	0.00235	
RotorDiam	162 m	0.275	0.947	0.71	4.75	0.14	0.00393	2.54	0.08	0.00210	
RotationPeriod	7.50 sec	0.325	0.899	0.60	4.01	0.12	0.00392	1.91	0.06	0.00187	
		0.375	0.851	0.52	3.49	0.10	0.00393	1.50	0.05	0.00169	
		0.425	0.804	0.46	3.11	0.09	0.00397	1.23	0.04	0.00158	
		0.475	0.756	0.41	2.80	0.08	0.00399	1.04	0.03	0.00148	
Bird aspect ratio: b	0.56	0.525	0.708	0.37	2.53	0.08	0.00400	0.88	0.03	0.00140	
		0.575	0.660	0.34	2.31	0.07	0.00399	0.77	0.02	0.00133	
		0.625	0.613	0.31	2.11	0.06	0.00396	0.68	0.02	0.00128	
		0.675	0.565	0.29	1.93	0.06	0.00392	0.62	0.02	0.00125	
		0.725	0.517	0.27	1.77	0.05	0.00386	0.57	0.02	0.00123	
		0.775	0.470	0.25	1.62	0.05	0.00378	0.59	0.02	0.00138	
		0.825	0.422	0.24	1.49	0.04	0.00369	0.62	0.02	0.00153	
		0.875	0.374	0.22	1.36	0.04	0.00358	0.63	0.02	0.00166	
		0.925	0.327	0.21	1.24	0.04	0.00345	0.64	0.02	0.00178	
		0.975	0.279	0.20	1.13	0.03	0.00331	0.64	0.02	0.00188	
Overall p(collision) =					Upwind			7.0%	Downwind		
								Average	5.2%		

KEY SPECIES FLIGHT ACTIVITY AND COLLISION 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.

The model was run separately for each of the three zones across the collision risk area visible from each of the two Vantage Points (VPs) (two areas were visible from only a single VP, and one where there was overlap between two VPs). Bird flight activity within each of these zones was calculated separately.

For the direct flight variant of the Band model (used for whooper swan, greylag goose and pink-footed goose), flight activity was calculated as the total number of flights through each of the five 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 6.6.1: Collision risk calculations for pink-footed goose for the 2021-22 and 2022-23 winters using the direct flight Band model**. 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 mean risk over the two winters.

Table 6.6.1: Collision risk calculations for pink-footed goose for the 2021-22 and 2022-23 winters using the direct flight Band model.

BALGRAY WIND FARM BAND ET AL 2007 COLLISION MODEL (DIRECT FLIGHTS)						
	Pink-footed Goose	Sep-Apr				
	2021-22			2022-23		
	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C
Collision risk height	170	170	170	170	170	170
Risk corridor Width	868	1,170	375	868	1,170	375
Risk corridor Area	147,475	198,900	63,750	147,475	198,900	63,750
Annual number of flights through collision zone at rotor ht	3,692	3,546	0	5,921	7,606	853
No turbines	1	4	1	1	4	1
Rotor diameter	162	162	162	162	162	162
Rotor swept area	20612	20612	20612	20612	20612	20612
Allowance for overlap	0%	0%	0%	0%	0%	0%
Proportion of risk window occupied by rotors	14%	41%	32%	14%	41%	32%
Annual no bird rotor passes	516	1470	0	828	3153	276
Band individual collision risk	5.3%	5.3%	5.3%	5.3%	5.3%	5.3%
Turbine downtime	15%	15%	15%	15%	15%	15%
Non-avoidance collisions	23	66	0	37	141	12
Avoidance rate	99.80%	99.80%	99.80%	99.80%	99.80%	99.80%
Predicted collisions per year	0.046	0.132	0.000	0.074	0.282	0.025
Total annual collision risk			0.178			0.381

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

As an example, for the variable non-direct flight modelling, the collision risk calculations for red kite for each of the winter and breeding baseline periods (breeding 2021 and 2022, winter 2021-22 and 2022-23) are shown in **Table 6.6.2: Collision risk calculations for red kite for using the non-direct random flight Band model**. 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 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 survey periods (breeding 2021 and 2022, winter 2021-22 and 2022-23). The survey results for these periods are given in Technical Appendices 6.1 – 6.5.

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.

Collision Risk Modelling Calculations

Table 6.6.2. Collision risk calculations for red kite using the non-direct random flight Band model.

BALGRAY WIND FARM BAND ET AL 2007 COLLISION MODEL (OCCUPANCY)	RED KITE			All year			2021-22			2022-23			2021			2022		
	2021-22			2022-23			2021			2022			2021			2022		
	Zone A	Zone B	Zone C	Zone A	Zone B	Zone C	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)	47	99	8	47	99	8	47	99	8	47	99	8	47	99	8	47	99	8
Hub Ht	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119	119
Rotor diameter	162	162	162	162	162	162	162	162	162	162	162	162	162	162	162	162	162	162
Lower rotor ht	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38	38
Upper rotor ht	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
Percentage of observation time seen flying in collision zone at rotor ht	0.19%	2.36%	0.63%	0.19%	0.92%	0.14%	0.00%	0.10%	0.03%	0.04%	0.30%	0.38%						
Season length	212	212	212	212	212	212	153	153	153	153	153	153						
Activity per day	9.8	9.8	9.8	9.8	9.8	9.8	15.9	15.9	15.9	15.9	15.9	15.9						
Total flight activity in collision zone at rotor ht	3.826	48.794	13.101	3.949	19.067	2.944	1.056	7.286	9.136	0.000	0.000	0.000						
Flight risk volume	7.614E+07	1.604E+08	1.296E+07	7.614E+07	1.604E+08	1.296E+07	7.614E+07	1.604E+08	1.296E+07	7.614E+07	1.604E+08	1.296E+07						
No Turbines	1	4	1	1	4	1	1	4	1	1	4	1						
Rotor radius	81	81	81	81	81	81	81	81	81	81	81	81						
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	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63						
Swept volume	105740	422958	105740	105740	422958	105740	105740	422958	105740	105740	422958	105740						
Bird occupancy of swept volume	19.13	463.25	384.81	19.74	181.02	86.47	5.28	69.18	268.35	0.00	0.00	0.00						
Bird speed	12	12	12	12	12	12	12	12	12	12	12	12						
Rotor transit time	0.428	0.428	0.428	0.428	0.428	0.428	0.428	0.428	0.428	0.428	0.428	0.428						
No of rotor transits	45	1084	900	46	423	202	12	162	628	0	0	0						
Turbine downtime	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%	15%						
Band collision rate	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%	6.0%						
Non-avoid collisions	2.3	55.3	45.9	2.4	21.6	10.3	0.6	8.3	32.0	0.0	0.0	0.0						
Avoidance rate	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%						
Collision prediction	0.023	0.553	0.459	0.024	0.216	0.103	0.006	0.083	0.320	0.000	0.000	0.000						
OVERALL TOTAL		BREEDING	WINTER	TOTAL														
	2021	0.409	1.035	1.444														
	2022	0.000	0.343	0.343														

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