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TECHNICAL APPENDIX A8.4: COLLISION RISK MODELLING

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1 INTRODUCTION

This Technical Appendix has been produced as a supporting document to the Ornithology Chapter of the Environmental Impact Assessment Report (EIAR). It includes details of the avian Collision Risk Modelling (CRM) calculations used to predict collision risk to target species recorded during the 2015/16 and 2018 Flight Activity Surveys. As recommended in Scottish Natural Heritage (SNH) guidance, the CRM methods were based on Band *et al.* (2007)[1].

For the 2015-16 Flight Activity Surveys, height bands 1-4 (0-150 m) fall either entirely or partly within the Rotor Swept Height (RSH) (13.9-149.9 m), while for the 2018 Flight Activity Surveys height bands 1 and 2 (0-150 m) fall either entirely or partly within the RSH. Therefore, a 'worst-case scenario' approach was adopted and all target species flights within these height bands that passed within the Collision Risk Zone (CRZ) at PCH were included in the CRM (where sufficient flight activity was recorded, defined as ≥ 3 flights or ≥ 10 individuals within the CRZ at PCH). Professional judgement was used to scope in or out additional flights, for example flights relating to a greylag goose territory were scoped out, where there was no risk of collision due to distance from the turbines and flights were associated with the territory, rather than random within the CRZ.

Exceptions to this were peregrine (2015-16), golden plover (2015), red-throated diver (2015 and 2018) and white-tailed eagle (2018). Flight activity of peregrine and red-throated diver was very low during one breeding season (below the specified threshold for CRM) but higher (above the threshold) during the other. To allow mean breeding season flight activity to be estimated across years, CRM was completed for both breeding seasons. Although levels of flight activity were below the specified threshold, CRM was also completed for golden plover as it is a qualifying feature of the Caithness and Sutherland Peatlands SPA, and for white-tailed eagle as this is considered a high-risk species due to the small size of the regional population, its status as a Schedule 1 species, and evidence that it may be relatively vulnerable to turbine collisions (e.g. Nygård *et al.*, 2010[2]).

Where the direct model was used, the Collision Risk Zone was defined as the area within 500 m of the proposed turbine locations (the Turbine Envelope). Where the random model was used, the CRZ was defined as the visible area within the Vantage Point (VP) Viewsheds used for the Flight Activity Surveys.

2 COLLISION RISK CALCULATIONS

CRM was completed separately for particular seasons (breeding and non-breeding), with the estimate based on the observed occupancy rate and the number of potentially active minutes in that period. Seasons were defined in accordance with SNH guidance on species-breeding seasons[3]. The only exception was the 2018 red-throated diver breeding season, which was defined as April to August inclusive (rather than April to mid-September inclusive as defined in SNH guidance[3]). This was because the 2018 surveys ended in August.

Species that met these criteria during 2015/16 were: greylag goose (breeding and non-breeding seasons), osprey (breeding season), hen harrier (breeding and non-breeding seasons), merlin (breeding season), peregrine (breeding season), golden plover (breeding season) lapwing (breeding season), snipe (breeding season), and curlew (breeding season).

[1] Band, W., Madders, M. & Whitfield, D.P. (2007) Develo*ping field and analytical methods to assess avian collision risk at wind farms*. In de Lucas, M., Janss, G. & Ferrer, M. (eds.) *Birds and Wind Power*. Quercus, Madrid.

[2] Nygård, T. Bevanger, K., Dahl, E.L., Flagstad, Ø., Follestad, Lund Hoel, P., May, R. & Reitan, O. (2010). *A study of White-tailed Eagle* Haliaeetus albicilla *movements*. BOU Proceedings – Climate Change and Birds.

[3] SNH (2009) Breeding season dates for key breeding species in Scotland [Online] Available at: https://www.nature.scot/bird-breeding-season-dates-scotland (Accessed 11/05/20)

Species that met these criteria during 2018 were: greylag goose (breeding season), red-throated diver (breeding season), osprey (breeding season), hen harrier (breeding season), white-tailed eagle (breeding season), merlin (breeding season), peregrine (breeding season), golden plover (breeding season) lapwing (breeding season), snipe (breeding season), and curlew (breeding season).

CRM was not completed using the 2014-15 Flight Activity Survey data because these records are more than five years old and therefore considered to be too out of date to allow a robust assessment. An exception was red-throated diver because flight activity recorded during the 2014 breeding season indicated the presence of a regular flight path across the Site that was not used in subsequent survey years, but could be used in future.

Details of each target species flight included in the CRM are presented in Tables A8.4.1-A8.4.3.

Table A8.4.1: Details of Flights used for Collision Risk Modelling: 2014

Species*	Observer**	VP no.	Date	Flight start time	Flight duration (s)	Flight duration at RSH (s)	Minimum no. of birds	Key no.***	Notes
Red-throated Diver	JB	3	27/06/14	16:20	135	135	2	95	Calling.
	TJS	3	28/06/14	05:00	45	0	1	69	Flew over in straight line. Calling.
	TGr	2	29/06/14	06:31	285	285	1	99	Took off from loch behind VP, flying east, then south before returning to loch.
	TGr	2	29/06/14	04:18	60	60	2	96	Calling; flying high, south.
	TGr	3	15/08/14	11:49	105	105	1	125	Calling, flying north from Caol-Loch. Pair disturbed from same loch on approach to VP.

* Species names and order follow the British List maintained by the British Ornithologists' Union (BOU)[4]

** Observer JB = John Bell, TJS = Tim Sykes, TGr = Torcuil Grant

*** Key numbers allow identification of individual flights, and correspond with the numbers shown on Figure 8-5.7, Appendix A8.5

[4] British Ornithologists' Union. (2017). The British List: A Checklist of Birds of Britain (9th edition). *Ibis* 160: 190-240.

Table A8.4.2: Details of Flights used for Collision Risk Modelling: 2015/16

Species*	Observer**	VP no.	Date	Flight start time	Flight duration (s)	Flight duration at RSH (s)	Minimum no. of birds	Key no.***	Notes
Greylag Goose	JHo	3	08/04/15	07:13	45	45	2	A171	
	JHo	3	08/04/15	08:53	120	120	1	A175	Flying together with flight A174.
	DM	2	06/05/15	11:08	90	90	2	A182	
	TJS	3	31/05/15	22:20	225	225	2	A239	Circling territory before landing.
	TJS	3	15/06/15	04:30	90	90	19	A241	Loose straggling flock flying north, low over water and immediately out of sight.
	DM	1	22/08/15	06:21	120	120	5	A269	
	DM	1	22/08/15	05:54	90	90	2	A268	
	DPB	3	11/11/15	12:43	75	75	8	A177	
Osprey	DM	1	27/05/15	10:11	45	45	1	A211	Hunting.
	DM	2	30/05/15	20:15	405	405	1	A231	
	TGr	3	25/06/15	14:09	90	90	1	A229	
Hen Harrier	DM	3	24/08/15	07:13	60	60	1	A274	Hunting female.
	DM	3	24/08/15	06:24	30	30	1	A272	Hunting female.
	DM	3	24/08/15	07:11	135	135	1	A273	Female. Hovering and mobbing raven.
	DPB	2	14/01/16	10:51	45	45	1	A279	Male flying very low.
	DPB	1	26/02/16	07:24	45	45	1	A282	Male.
	MSc	3	23/03/16	13:40	60	60	1	A285	Came up from ground.
Merlin	CMc	2	01/04/15	12:26	75	75	2	A155	Hunting.
	CMc	2	01/04/15	11:36	300	300	2	A154	Mobbing buzzard.
	JHo	2	21/08/15	06:48	15	15	2	A264	Female.
Peregrine	JHo	1	30/07/15	21:32	15	15	1	A259	
	JHo	1	30/07/15	21:53	15	15	1	A260	

Species*	Observer**	VP no.	Date	Flight start time	Flight duration (s)	Flight duration at RSH (s)	Minimum no. of birds	Key no.***	Notes
Golden Plover	JHo	3	13/05/15	20:19	30	30	1	A194	
	JB	1	26/06/15	05:37	30	30	1	A250	Calling in flight. Had been calling from ground at 05:11.
Lapwing	TJS	1	16/06/15	10:25	30	30	1	A246	
	TJS	1	16/06/15	09:30	150	150	2	A244	Pair milling about including weak attempt at display before apparently landing on in-bye land.
	JHo	2	29/06/15	05:33	105	105	2	A256	
Snipe	JHo	1	11/05/15	20:25	60	60	1	A192	
	JHo	1	28/05/15	19:23	45	45	1	A219	
	JHo	1	28/05/15	19:22	60	60	2	A218	
	JHo	1	28/05/15	19:21	60	60	4	A217	
	JHo	1	28/05/15	19:15	60	60	2	A216	
	JHo	1	28/05/15	19:14	150	150	1	A215	
	TJS	1	16/06/15	10:20	45	45	1	A245	Brief chipping display.
	JB	1	26/06/15	06:25	225	225	1	A253	One of two snipe flying together in display then splitting. A252 & A253.
	JB	1	26/06/15	06:39	135	135	1	A254	Display flight.
	JB	1	26/06/15	06:25	240	240	1	A252	One of two snipe flying together in display then splitting. A252 & A253.
	JB	1	26/06/15	05:44	120	120	1	A251	Display flight.
	JB	1	26/06/15	06:47	120	120	1	A255	Display flight.
Curlew	CMc	2	01/04/15	10:51	45	45	1	A153	Calling.
	CMc	1	02/04/15	14:02	30	30	2	A156	Breeding behaviour.

Species*	Observer**	VP no.	Date	Flight start time	Flight duration (s)	Flight duration at RSH (s)	Minimum no. of birds	Key no.***	Notes
	CMc	2	03/04/15	09:22	30	30	1	A162	Calling.
	TGr	3	13/04/15	13:36	60	60	2	A167	Calling.
	JHo	1	15/04/15	08:10	30	30	2	A179	
	DM	2	06/05/15	10:10	15	15	1	A180	
	DM	2	06/05/15	11:34	15	15	1	A184	Feeding.
	DM	2	06/05/15	12:10	75	75	1	A185	
	JHo	1	11/05/15	19:50	15	15	1	A188	
	JHo	1	11/05/15	20:17	45	45	1	A190	
	JHo	3	13/05/15	20:38	30	30	1	A196	
	JHo	3	13/05/15	20:20	15	15	1	A195	
	JHo	3	13/05/15	20:04	15	15	1	A193	
	DM	1	27/05/15	11:53	30	30	1	A214	Calling.
	DM	2	29/05/15	14:40	495	495	1	A227	Defending territory from buzzard, circling for 8.5 minutes.
	DM	2	29/05/15	14:18	45	45	1	A225	
	DM	2	29/05/15	13:49	45	45	1	A223	
	DM	2	29/05/15	13:25	75	75	1	A222	
	DM	2	29/05/15	13:09	120	120	2	A221	Defending territory against buzzard.
	DM	2	29/05/15	12:24	45	45	1	A220	
	DM	2	30/05/15	21:04	15	15	1	A232	
	DM	2	30/05/15	21:16	75	75	1	A233	
	JHo	1	10/06/15	15:25	30	30	2	A240	
	TGr	3	12/06/15	05:50	45	45	1	A206	Same bird as Key no A207. Calling, lands briefly, display flight to south.
	TGr	2	12/06/15	10:17	60	60	2	A210	Calling and displaying.
	TGr	3	12/06/15	05:43	15	15	1	A203	One of pair). Takes off, presumably a territory (same

Species*	Observer**	VP no.	Date	Flight start time	Flight duration (s)	Flight duration at RSH (s)	Minimum no. of birds	Key no.***	Notes
									as in 2014 surveys).
	TGr	3	12/06/15	05:44	75	75	1	A205	Display flight north, then south.
	TGr	3	12/06/15	05:51	60	60	1	A207	Same bird as Key no A206.
	TGr	3	12/06/15	05:37	30	30	2	A201	Pair, calling, flying low southwards.
	TGr	3	12/06/15	05:43	15	15	1	A202	One of pair. Lands on ground by flight A201.
	TJS	3	15/06/15	05:10	45	45	2	A242	Pair circling possible territory. Male singing.
	TJS	2	16/06/15	06:40	210	210	1	A249	Displaying and singing bird.
	TGr	2	25/06/15	04:47	15	15	1	A228	Displaying.

* Species names and order follow the British List maintained by the BOU4

** Observer CMc = Clare McInroy, DM = Daniel Menendez, DPB = David Butterfield, JB = John Bell, JHo = James Homer TJS = Tim Sykes, TGr = Torcuil Grant

*** Key numbers allow identification of individual flights, and correspond with the numbers shown on Figures 8-4.1-8 Appendix A8.4 and Figures 8-5.11 and 8-5.15, Appendix A8.5.

Table A8.4.3: Details of Flights used for Collision Risk Modelling: 2018

Species*	Observer**	VP no.	Date	Flight start time	Flight duration (s)	Flight duration at RSH (s)	Minimum no. of birds	Key no.***
Greylag Goose	PC	3	21/02/18	13:15	157	135	8	B2
	AJM	2	22/03/18	09:13	136	46	9	B7
	AJM	2	22/03/18	10:03	30	30	30	B9
	AJM	2	22/03/18	10:17	32	32	22	B10
	AJM	2	22/03/18	10:50	85	7	1	B11
	AJM	2	11/04/18	08:15	16	16	2	B25
	RTW	3	08/04/18	09:18	72	72	12	B31
	AJM	3	12/04/18	16:28	75	75	1	B32

Species*	Observer**	VP no.	Date	Flight start time	Flight duration (s)	Flight duration at RSH (s)	Minimum no. of birds	Key no.***
	KL	2	21/05/18	16:47	15	15	2	B59
	AL	2	22/05/18	11:33	15	15	2	B64
	AL	2	22/05/18	11:41	45	45	2	B65
	AL	2	22/05/18	12:17	15	15	2	B67
	AL	2	25/05/18	08:33	15	15	2	B74
	AL	2	25/05/18	08:45	30	30	2	B77
	AL	2	25/05/18	08:58	30	30	2	B79
	KL	1	25/06/18	14:20	120	30	4	B100
	PC	2	14/06/18	17:10	42	42	17	B111
	PC	2	14/06/18	18:20	157	157	7	B113
	KL	1	25/06/18	15:24	120	120	3	B151
Red-throated Diver	AL	1	29/06/18	10:44	90	90	1	B107
	PC	3	01/08/18	05:41	68	68	2	B195
Osprey	AL	3	28/06/18	11:17	45	45	1	B130
	AL	3	28/06/18	11:28	120	120	1	B132
	AL	3	28/06/18	11:37	180	45	1	B133
Hen Harrier	PC	2	11/04/18	07:19	118	118	1	B22
	KL	1	21/05/18	17:11	120	120	1	B40
	KL	1	22/05/18	11:52	180	180	1	B44
	KL	3	28/06/18	15:25	15	15	1	B147
	KL	3	28/06/18	15:31	60	60	1	B148
	KL	2	09/07/18	14:23	15	15	1	B165
	KL	2	09/07/18	15:01	240	135	2	B168
White-tailed Eagle	PC	3	01/05/18	09:23	135	135	1	B88
	KL	3	24/05/18	10:36	60	60	1	B89
Merlin	AJM	1	31/07/18	09:16	20	20	1	B162
	AL	2	09/07/18	14:32	15	15	2	B166
	KL	2	13/07/18	12:27	30	30	1	B172
	KL	2	13/07/18	12:54	90	90	1	B173
Peregrine	PC	2	22/03/18	09:41	749	105	2	B8
	PC	2	22/03/18	12:52	20	20	1	B13
	PC	2	11/04/18	07:18	25	25	1	B21
	AL	2	22/05/18	14:22	360	30	1	B93
	AL	2	09/07/18	14:05	420	180	2	B164

Species*	Observer**	VP no.	Date	Flight start time	Flight duration (s)	Flight duration at RSH (s)	Minimum no. of birds	Key no.***
Golden Plover	KL	3	11/07/18	13:46	60	60	23	B185
Lapwing	PC	1	22/03/18	09:19	35	35	2	B3
	PC	2	16/03/18	09:47	124	124	1	B5
	PC	2	22/03/18	08:44	194	194	1	B6
	AJM	1	11/04/18	16:22	15	15	1	B16
	AJM	1	11/04/18	07:18	15	15	1	B17
	AL	2	22/05/18	12:23	5	5	1	B68
	AL	2	22/05/18	13:01	5	5	2	B69
	AL	2	22/05/18	16:36	45	45	1	B72
	AL	2	25/05/18	08:31	5	5	1	B73
	AJM	1	14/06/18	18:29	15	15	1	B95
	AL	2	09/07/18	14:44	30	30	1	B167
Snipe	AL	1	21/05/18	17:23	15	15	1	B41
	KL	1	22/05/18	10:33	15	15	1	B42
	AL	2	22/05/18	11:30	5	5	1	B63
	KL	2	29/06/18	10:15	15	15	1	B117
	AJM	1	31/07/18	09:10	80	75	1	B161
Curlew	AJM	1	12/04/18	09:56	20	20	1	B36
	KL	1	22/05/18	11:15	120	30	1	B43
	KL	2	21/05/18	15:18	30	30	1	B56
	KL	2	22/05/18	10:35	135	135	1	B60
	KL	2	22/05/18	10:45	15	15	1	B61
	KL	2	22/05/18	10:57	15	15	1	B62
	KL	2	22/05/18	11:50	15	15	1	B66
	KL	2	22/05/18	13:11	15	15	1	B70
	AL	2	25/05/18	08:49	15	15	1	B78
	AL	2	25/05/18	09:15	30	30	2	B80
	AL	2	25/05/18	09:27	15	15	1	B81
	AL	2	25/05/18	10:11	30	30	1	B82
	AL	2	25/05/18	10:49	15	15	1	B83
	AL	2	25/05/18	10:52	15	15	1	B84
	AJM	1	14/06/18	17:11	30	30	1	B94
	AJM	1	14/06/18	19:02	35	35	1	B96
	KL	1	22/05/18	14:11	30	30	5	B48

Species*	Observer**	VP no.	Date	Flight start time	Flight duration (s)	Flight duration at RSH (s)	Minimum no. of birds	Key no.***
Arctic Tern	KL	1	22/05/18	15:24	120	120	1	B51
	KL	3	24/05/18	12:46	60	30	1	B91
	KL	3	24/05/18	14:03	60	30	2	B92
	KL	1	25/06/18	13:38	90	90	1	B97
	KL	1	25/06/18	14:13	105	105	2	B99
	KL	1	25/06/18	14:35	30	30	1	B102
	KL	1	25/06/18	15:13	120	120	1	B103
	KL	1	25/06/18	15:19	75	75	1	B104
	KL	1	25/06/18	15:24	120	120	3	B105
	AL	1	29/06/18	09:28	120	120	2	B106
	AL	1	29/06/18	10:53	105	105	1	B108
	AL	1	29/06/18	10:58	90	90	1	B109
	AL	1	29/06/18	11:21	90	90	1	B110
	KL	2	29/06/18	08:55	60	60	1	B116
	KL	2	29/06/18	11:18	60	60	1	B119
	AJM	3	14/06/18	13:24	135	135	1	B120
	AJM	3	14/06/18	15:03	150	150	1	B121
	AL	3	28/06/18	10:53	15	15	2	B129
	AL	3	28/06/18	11:17	30	30	3	B131
	AL	3	28/06/18	11:51	15	15	1	B134
	AL	3	28/06/18	12:01	60	30	1	B135
	AL	3	28/06/18	12:01	15	15	1	B136
	AL	3	28/06/18	12:10	15	15	1	B137
	AL	3	28/06/18	12:28	15	15	1	B138
	AL	3	28/06/18	12:37	15	15	2	B139
	AL	3	28/06/18	13:12	30	30	2	B140
	KL	3	28/06/18	14:02	120	45	1	B141
	KL	3	28/06/18	14:23	120	15	1	B142
	KL	3	28/06/18	14:28	120	30	1	B143
	KL	3	28/06/18	14:30	90	60	1	B144
	KL	3	28/06/18	15:06	15	15	1	B145
	KL	3	28/06/18	15:22	30	30	1	B146
	KL	3	28/06/18	15:44	60	30	2	B149
	KL	3	28/06/18	16:17	15	15	3	B150
	KL	1	09/07/18	14:26	120	30	1	B153

Species*	Observer**	VP no.	Date	Flight start time	Flight duration (s)	Flight duration at RSH (s)	Minimum no. of birds	Key no.***
	KL	1	09/07/18	14:44	60	30	1	B154
	KL	1	09/07/18	14:52	120	90	3	B155
	KL	1	09/07/18	15:23	120	90	1	B156
	KL	1	09/07/18	16:20	30	15	2	B157
	KL	1	09/07/18	16:26	60	60	1	B158
	AL	1	13/07/18	11:57	60	60	1	B159
	AL	3	10/07/18	13:10	75	60	2	B174
	AL	3	10/07/18	13:37	90	60	1	B175
	AL	3	10/07/18	13:39	45	15	1	B176
	AL	3	10/07/18	13:54	60	60	2	B177
	AL	3	10/07/18	14:18	60	60	2	B178
	AL	3	10/07/18	14:59	30	30	1	B179
	AL	3	10/07/18	15:05	120	120	1	B180
	AL	3	10/07/18	15:23	60	45	2	B181
	AL	3	10/07/18	16:00	60	45	1	B182
	KL	3	11/07/18	13:20	30	30	1	B183
	KL	3	11/07/18	13:26	30	30	2	B184
	KL	3	11/07/18	14:52	120	120	1	B187
	KL	3	11/07/18	15:28	90	90	2	B188
	KL	3	11/07/18	16:03	60	60	1	B189

* Species names and order follow the British List maintained by the BOU[4];

** Observer: AJM = Mr A. McNab; AL = Mr A. Little; KL = Mr K. Little; PC = Mr P. Carroll; RTW = Mr R. Whytock;

*** Key numbers allow identification of individual flights, and correspond with the numbers shown on Figures 8-4.9-17, Appendix A8.4 and Figures 8-5.13, 8-5.14 and 8-5.16 and CA1.16-17, Appendix A8.5.

For each species, the risk of collision for an individual was calculated by estimating the likelihood of collision based on the characteristics of the birds and of the turbines, using the Band *et al*. (2007) model[1]. The model runs as a two-stage process:

- Stage 1: calculate the number of birds flying through the rotors; and
- Stage 2: estimate the probability of a bird flying through rotor being hit.

2.1 Stage 1: Calculating Numbers of Birds Flying Through the Rotors

2.1.1 Available Hours for Flight Activity

The total amount of time that a species was potentially active was determined by calculating the hours of available daylight for each species during the months of interest. For waders and wildfowl, which could be active nocturnally, an additional 25% of night

hours were added to the daylight hours to give a more accurate representation of the available hours for these species. The total available hours for flight activity for each species are included in Tables A8.4.4-A8.4.8 below.

2.1.2 Input Variables for the 2014 CRM

The input variables for Stage 1 of the CRM for red-throated diver (for which a direct model was used) are presented in Table A8.4.4.

Table A8.4.4: Input Variables for Red-throated Diver Regular CRM Model

Species	Season	Observation effort (hours)	No. of birds observed in CRZ	No. of birds per hour of effort	Available hours for flight activity	Potential no. of birds at risk during season
Red-throated Diver	Breeding Season (April to mid-September)	156	8	0.051	2712.5	139.10

2.1.3 Input Variables for the 2015/16 CRM

2.1.3.1 Direct Models

The input variables for Stage 1 of the CRM for greylag goose and red-throated diver are presented in Table A8.4.5.

Table A8.4.5: Input Variables for Regular CRM Models

Species	Season	Observation effort (hours)	No. of birds observed in CRZ	No. of birds per hour of effort	Available hours for flight activity	Potential no. of birds at risk during season
Greylag Goose	Breeding Season (April to mid-August)	159	28	0.176	2536.5*	446.68
	Non-breeding Season (mid-August to March)	126	15	0.119	3024.75*	360.09
Red-throated Diver	Breeding Season (April to mid-September)	165	2	0.012	2712.5	32.88
*Includes additional 25% of night hours.						

2.1.3.2 Random Models

The random model was used all other species for which collision risk was estimated using 2015/16 data (osprey, hen harrier, merlin, peregrine, golden plover, lapwing, snipe and curlew). The CRZ (i.e. the area within the VP viewsheds) was 1057.26 ha. Species-specific input variables are presented in Table A8.4.6.

Table A8.4.6: Input Variables for Random CRM Models

Species (and season)	Season	Total observation time	Available hours for flight activity	Time at RSH (seconds)
Osprey	Breeding (April to August)	572400 seconds	2520	540
Hen Harrier	Breeding (April to mid-August)	518400 seconds	2282	225
	Non-breeding (mid-August to March)	507600 seconds	2205	150
Merlin	Breeding (April to mid-August)	518400 seconds	2282	690
Peregrine	Breeding (March to mid-August)	583200 seconds	2649	30
Golden Plover	Breeding (April to July)	507600 seconds	2265*	60
Lapwing	Breeding (March to July)	572400 seconds	2726.25*	540
Snipe	Breeding (April to mid-August)	518400 seconds	2536.5*	1620
Curlew	Breeding (April to July)	507600 seconds	2265*	2370
*Includes additional 25% of night hours.				

2.1.4 Input Variables for the 2018 CRM

2.1.4.1 Direct Models

The input variables for Stage 1 of the CRM for red-throated diver and Arctic tern (for which direct models were used) are presented in Table A8.4.7.

Table A.8.4.7: Input Variables for Regular CRM Models

Species	Season	Observation effort (hours)	No. of birds observed in CRZ	No. of birds per hour of effort	Available hours for flight activity	Potential no. of birds at risk during season
Red-throated Diver	Breeding Season (April to August)*	162	3	0.019	2712.5	50.23
Arctic Tern	Breeding Season (May to August)	132	95	0.773	2087	1502.01
*SNH defines the breeding season as April to mid-September3, however FAS surveys concluded in August.						

2.1.4.2 Random Models

The random model was used all other species for which collision risk was estimated using 2018 data (greylag goose, osprey, hen harrier, white-tailed eagle, merlin, peregrine, golden

plover, lapwing, snipe and curlew). The CRZ (i.e. the area within the VP viewsheds was 929.92 ha). Species-specific input variables are presented in Table A.8.

Table A.8: Input Variables for Random CRM Model: 2018

Species (and season)	Season	Total observation time	Available hours for flight activity	Time at RSH (seconds)
Greylag Goose	Breeding Season (April to mid-August)	162	2536.5*	3594
Osprey	Breeding (April to August)	583200 seconds	2520	210
Hen Harrier	Breeding (April to mid-August)	583200 seconds	2282	778
White-tailed Eagle	Breeding (mid-February to August)	777600 seconds	3017.5	195
Merlin	Breeding (April to mid-August)	583200 seconds	2282	170
Peregrine	Breeding (March to mid-August)	712800 seconds	2649	645
Golden Plover	Breeding (April to July)	518400 seconds	2265*	1380
Lapwing	Breeding (March to July)	648000 seconds	2726.25*	528
Snipe	Breeding (April to mid-August)	583200 seconds	2536.5*	125
Curlew	Breeding (April to July)	518400 seconds	2265*	490
*Includes additional 25% of night hours.				

2.2 Stage 2: Estimating the Probability of Collision

2.2.1 Bird Biometrics and Avoidance Rates

The relevant biometrics and species-specific avoidance rates for each species used in Stage 2 of the CRM are presented in Table A8.4.9. All target species were considered to use flapping (rather than gliding) flight.

Table A8.4.9: Target Species Biometrics and Avoidance Rates used in the CRM

Species	Body length* (m)	Wingspan* (m)	Assumed flight speed (m/s)*	Avoidance rate*** (%)
Greylag Goose	0.825	1.635	19.30	99.80
Red-throated Diver	0.610	1.110	20.80	99.50
Osprey	0.560	1.580	12.00	98.00
Hen Harrier	0.480	1.100	11.50	99.00
White-tailed Eagle	0.800	2.200	13.40	95.00

Species	Body length* (m)	Wingspan* (m)	Assumed flight speed (m/s)*	Avoidance rate*** (%)
Merlin	0.280	0.560	13.90	98.00
Peregrine	0.420	1.020	12.10	98.00
Golden Plover	0.275	0.715	13.70	98.00
Lapwing	0.295	0.845	12.80	98.00
Snipe	0.260	0.455	17.10	98.00
Curlew	0.550	0.900	16.30	98.00
Arctic Tern	0.340	0.800	11.30	98.00

* Values taken from Robinson, R.A. (2005) *BirdFacts: profiles of birds occurring in Britain & Ireland. BTO, Thetford* www.bto.org/about-birds/birdfacts (accessed 20/05/2020)

** Values taken from a range of literature which includes:

- Alerstam T., Rosén M., Bäckman J., Ericson P.G.P., Hellgren O. 2007. Flight speeds among bird species: allometric and phylogenetic effects. *PLoS Biol*, 5, 1656-1662;
- Provan, S. & Whitfield, D.P. 2006. *Avian Flight Speeds and Biometrics for Use in Collision Risk Modelling*. Unpublished Report to Scottish Natural Heritage; and
- Bruderer, B. & Bolt, A. 2001. Flight characteristics of birds: I. Radar measurements of speeds. *Ibis*, 143, 178-204.
- Gudmundsson, G.A., Alerstam, T. and Larsson, B., 1992. Radar observations of northbound migration of the Arctic tern, *Sterna paradisaea*, at the Antarctic Peninsula. *Antarctic Science*, 4(2), pp.163-170.
- Warkentin, I.G. and Oliphant, L.W., 1990. Habitat use and foraging behaviour of urban merlins (*Falco columbarius*) in winter. *Journal of Zoology*, 221(4), pp.539-563.
- Davis, R.A., 1971. Flight speed of arctic and red-throated loons. *The Auk*, 88(1), pp.169-169.

*** SNH (2018) *Avoidance Rates for the onshore SNH Wind Farm Collision Risk Model*.

2.2.2 Turbine Parameters

The candidate turbine model for the proposed Development is the Le Mans V136. Specifications of this turbine model used in the CRM are presented in Table A8.4.10.

Table A8.4.10: Turbine Dimensions used in the CRM

Parameter	Value
Hub height	81.90 m
Rotor radius	68.00 m
No. of turbines	12
No. of rotor blades	3
Risk window area	4,189,860.98 m^2
Risk volume	569,821,093.28 m^3
Maximum chord width	4.00 m
Rotation period	7.14 seconds
Average pitch	6.00 degrees
Estimated maximum operation*	85%

Parameter	Value
* Taken from British Wind Energy Association (BWEA). 2007. Factsheet: *Can We Rely on Wind?* BWEA, London	

2.3 Calculation of Collision Probability

Collision risk for birds passing through the rotors was calculated using the SNH example spreadsheet for calculating the probability of collision[5]. The results are presented in Table A8.4.11.

Table A8.4.11: Probability of Collision for Birds Passing through Rotors

Species	p(collision)* Upwind	p(collision)* Downwind	Mean
Greylag Goose (flapping)	6.5%	5.5%	6.0%
Red-throated Diver (flapping)	5.7%	4.7%	5.2%
Osprey (flapping)	6.9%	5.2%	6.0%
Hen Harrier (flapping)	6.4%	4.7%	5.6%
White-tailed Eagle (flapping)	7.6%	6.1%	6.9%
Merlin (flapping)	5.2%	3.8%	4.5%
Peregrine (flapping)	6.1%	4.5%	5.3%
Golden Plover (flapping)	5.4%	3.9%	4.6%
Lapwing (flapping)	5.6%	4.1%	4.8%
Snipe (flapping)	4.9%	3.7%	4.3%
Curlew (flapping)	5.8%	4.6%	5.2%
Arctic Tern (flapping)	5.9%	4.1%	5.0%
*Where p = probability; the probability is calculated for both upwind and downwind flights, with a higher collision risk in upwind conditions; the mean was then used to estimate collision risk			

[5] Available at: https://www.nature.scot/professional-advice/planning-and-development/advice-planners-and-developers/renewable-energy-development/onshore-wind-energy/wind-farm-impacts-birds (last accessed 16/07/2020).

Table A8.4.12: Estimated Seasonal Collision Risk and Number of years per Collision for Species for which CRM was completed

Species	PeriodError! Bookmark not defined.	Annual collision risk (no. of birds killed)		No. of years per collision	
		Assuming no avoidance	Using species-specific avoidance rates*	Assuming no avoidance	Using species-specific avoidance rates*
Greylag goose	2015 breeding season	10.784	0.022	0.093	46.364
	2015-16 Non-breeding season	8.694	0.017	0.115	57.513
	2015-16 whole year	19.478	0.039	0.051	25.641
	2018 breeding season	7.611	0.015	0.131	65.691
	Breeding season mean	9.198	0.019	0.109	52.632
Red-throated diver	2014 breeding season/whole year	2.966	0.015	0.337	67.420
	2015 breeding season/ whole year	0.820	0.004	1.219	243.796
	2018 breeding season	1.116	0.006	0.896	179.256
	Breeding season mean	1.634	0.008	0.612	125.000
Osprey	2015 breeding season/ whole year	0.640	0.013	1.563	78.167
	2018 breeding season	0.278	0.006	3.603	180.128
	Breeding season mean	0.459	0.009	2.180	109.023
Hen harrier	2015-16 Non-breeding season	0.155	0.002	2.559	255.943
	2015 breeding season	0.236	0.002	4.243	424.321
	2015-16 whole year	0.391	0.004	6.450	644.985

Species	PeriodError! Bookmark not defined.	Annual collision risk (no. of birds killed)		No. of years per collision	
		Assuming no avoidance	Using species-specific avoidance rates*	Assuming no avoidance	Using species-specific avoidance rates*
	2018 breeding season	0.824	0.008	1.214	121.427
	Breeding season mean	0.530	0.005	1.888	188.819
White-tailed eagle	2015 breeding season/ whole year	0	0	N/A	N/A
	2018 breeding season	0.294	0.015	3.403	68.055
	Breeding season mean	0.141	0.007	6.806	136.111
Lapwing	2015 breeding season/ whole year	0.589	0.012	1.697	84.864
	2018 breeding season	0.579	0.012	1.728	86.421
	Breeding season mean	0.584	0.012	1.713	85.635
Golden plover	2015 breeding season/ whole year	0.063	0.001	15.841	792.044
	2018 breeding season	1.616	0.032	0.619	30.933
	Breeding season mean	0.840	0.017	1.191	59.541
Curlew	2015 breeding season/ whole year	3.319	0.066	0.301	15.065
	2018 breeding season	0.764	0.015	1.309	65.453
	Breeding season mean	2.041	0.041	0.490	24.493
Snipe	2015 breeding season/ whole year	2.165	0.043	0.462	23.099

Species	PeriodError! Bookmark not defined.	Annual collision risk (no. of birds killed)		No. of years per collision	
		Assuming no avoidance	Using species-specific avoidance rates*	Assuming no avoidance	Using species-specific avoidance rates*
	2018 breeding season	0.169	0.003	5.924	296.214
	Breeding season mean	1.167	0.023	0.857	42.855
Arctic Tern	2015 breeding season/ whole year	0	0	N/A	N/A
	2018 breeding season	32.145	0.643	0.031	1.555
	Breeding season mean	16.073	0.322	0.062	3.106
Merlin	2015 breeding season/ whole year	0.710	0.014	1.409	70.449
	2018 breeding season	0.177	0.004	5.659	282.937
	Breeding season mean	0.443	0.009	2.256	112.809
Peregrine	2015 breeding season/ whole year	0.032	0.001	30.867	1,543.366
	2018 breeding season	0.648	0.013	1.543	77.169
	Breeding season mean	0.340	0.007	2.940	146.989

APPENDIX A8.4: FIGURES