2021

Hollandmey Renewable Energy Development

Technical Appendix 9.2: Ornithology Collision Risk Modelling

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November 2021

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Introduction

1.1. Birds that are not displaced would be potentially vulnerable to collision with the turbines. The level of collision with wind turbines is presumed to be dependent on the level of flight activity over the proposed Development and the ability of birds to detect and manoeuvre around rotating turbine blades. Birds that collide with a turbine are likely to be killed or fatally injured. This may in turn affect the maintenance of bird populations.

1.2. Further studies in the field of bird-windfarm research are required to establish with certainty the extent to which birds can avoid collision with wind turbines, although an increasing body of evidence suggests that avoidance capacity is very high (Whitfield & Madders 2006, Urquhart & Whitfield 2016, SNH 2018). The indications from studies are that collisions are rare events and occur mainly at sites where there are unusual concentrations of birds and turbines, or where the behaviour of the birds concerned leads to high-risk situations (e.g., Gill *et al*. 1996, Percival 1998, de Lucas *et al.* 2007). Examples include migration flyways, and where the food resource, and therefore level of bird activity, is exceptional.

Methods

1.3. Band *et al.* (2007) described a method by which field data on bird flight activity can be gathered and used to quantify crudely the likelihood of collisions with turbines: the 'Band' Collision Risk Model (CRM).

1.4. The Band CRM involves two methods to predict estimated collision fatalities, depending on the pattern of flight of the species involved: 'predictable' and 'unpredictable' flight methods. The predictable flight method (PFM) is appropriate when birds tend to move through an area in a relatively consistent direction, such as during migration or when moving between localised feeding and roosting sites. The unpredictable flight method (UFM) is more appropriate when flights are not in any particular direction and assumes that they are random. These two methods also differ in their field data requirements (see **Technical Appendix 9.1: Ornithology Technical Report**).

1.5. The two methods differ in the unit of exposure to collision risk. The PFM estimates a horizontal risk area which is the area of the turbine rotors facing a bird as it flies towards (with the 'intention' of flying through) the proposed Development. The extent of the Risk Area is given by the horizontal span of the proposed turbine array facing the bird on its typical flight direction multiplied by the vertical span of the proposed turbine rotors. The UFM employs an estimated risk volume, in keeping with the assumption that flight directions are random in space. Collision risk is estimated based on flight activity levels and behaviour, turbine numbers and dimensions, and bird biometrics and flight characteristics.

1.6. Dimensions and operational parameters of the candidate turbine model were used to populate the CRM, including an assumed hub height of 84 m and a rotor diameter of 132 m (see **Chapter 3: Proposed Development** of the EIA Report). The appropriate recorded flight height band was therefore 10 m – 150 m for data collected between March 2018 and March 2020 **(Technical Appendix 9.1)**. A turbine operation rate of 85% is assumed.

1.7. The PFM of the Band CRM was used to estimate the collision risk of greylag goose (*Anser anser*) in the non-breeding and migratory period, for golden plover (*Pluvialis apricaria*) all year and for curlew (*Numenius arquata*) in the breeding season.

1.8. The UFM of the Band CRM was used to estimate the collision risk of hen harrier (*Circus cyaneus*).

1.9. Following NatureScot guidance (SNH 2014) species length and wingspan have been derived using a mean of the figures presented within Snow & Perrins (1998) and flight speeds were derived using Alerstam *et al.* (2007) or Provan & Whitfield (2006) (**Table 9.2.1**), and the published avoidance rates were used (SNH 2018).

1.10. For each month, day length was calculated using the method of Forsythe *et al*. (1995).

1.11. Flight data were obtained from a total of two Generic Vantage Points (GVPs) and four Migration Watch Points (MWPs). Viewsheds were estimated using a Digital Elevation Model (DEM) and a 20 m vertical offset above the ground surface (lowest point of rotor sweep at 18 m). Details of at-risk flights are given in **Table 9.2.2**. An 'at–risk' flight is one which passes into the 500 m turbine buffer with at least part of its flight at an altitude between 10 m and 150 m.

1.12. Utilising all flight observations collected across the study area from all GVPs (PFM and UFM) and MWPs (for PFM) was likely to result in underestimates or overestimates of collision risk because data were collected for areas in which no turbines were (ultimately) proposed. Therefore, it was appropriate to employ only those observations in which flights were liable to incur a potential risk of collision, i.e., within the areas occupied by proposed turbines. Consequently, the CRM used only observations collected within a flight activity assessment area, comprising a 500 m buffer (centred on the turbine tower) around proposed turbine locations. This size of buffer encompasses rotor blade length, possible shifts in proposed turbine location due to micro-siting and, crucially, potential spatial errors in flight recording accuracy.

1.13. Turbine dimensions of hub height 84 m and blade length 66 m were utilised, giving a rotor diameter encompassing a bottom blade tip at 18 m and a top blade tip at 150 m. Thus, the flight height recording bands between 10 - 30 m and 100 - 150 m were defined as at collision risk height. The proposed Development is being applied for "in perpetuity" therefore there is currently no proposed lifetime duration for it.

1.14. For the UFM flight time within this buffer was calculated from the proportion of the length of each flight which fell within the 500 m buffer multiplied by the total duration of each flight (i.e., effectively assuming a constant speed for each flight). Time spent at different flight heights was estimated from time-interval data on height. To ensure that the CRM used robust measures of flight activity, a 2 km distance truncation was assumed in the area visible from each GVP.

1.15. For the PFM all flights which passed within the 500 m buffer of turbine locations were included, and the count of birds involved in those flights used. For goose flights a precautionary provision that 25% of flights were not observed because they occurred in the hours of darkness was included (estimates of daylight hours according to latitude followed the algorithm of Forsythe *et al*. (1995).

Table 9.2.1. Bird biometrics and flight speeds utilised in the CRM.

Species	**Length (m)**	**Wingspan (m)**	**Flight speed (m/s)**
Greylag goose	0.83	1.64	17.0
Golden plover	0.28	0.72	17.9
Curlew	0.55	0.90	16.3
Hen harrier	0.48	1.10	11.4

Table 9.2.2. Flights recorded within GVP viewsheds and clipped to 500 m survey buffer. Part, or all, of these flights at a height of 10 – 150 m agl places them at risk of a collision with the turbine blades (shaded columns).

Species	Season	VP No.	Bout ID	No. of birds	<10 m	10-30 m	30-50 m	50-100 m	100-150 m	>150 m
Hen harrier	Apr-Aug	GVP2	HOL_180404_002_B001	1	150	30				
	Sep-Mar	GVP1	HOL_191219_001_B001	1	76					
			HOL_191219_002_B003	1				47		
		GVP2	HOL_180905_002_B001	1		130				
			HOL_180905_002_B002	1		229				
			HOL_181017_001_B002	1		147				
			HOL_181216_002_B001	1	41					
			HOL_190128_002_B001	1		62				
			HOL_190128_003_B001	1			137			
			HOL_190206_002_B001	1		35				
			HOL_191219_003_B001	1	38					
			HOL_191219_003_B002	1	73					
			HOL_200129_002_B001	1	59					
			HOL_200129_002_B002	1	89					
			HOL_200129_002_B003	1	303					
			HOL_200306_002_B001	1	24					
			HOL_200312_002_B001	1		142				
Hen harrier Total				**17**	**853**	**775**	**137**	**47**		
Greylag goose	Sep-Mar	GVP1	HOL_181010_001_B003	2					*	
			HOL_181118_001_B001	11					*	
			HOL_181118_001_B002	13					*	
			HOL_181118_001_B003	25					*	
			HOL_181204_001_B001	15				*		
			HOL_181204_001_B002	15				*		
			HOL_181216_001_B002	20				*		
			HOL_190206_001_B001	80				*		
			HOL_190314_001_B002	5	*	*				
			HOL_191009_001_B005	220				*		
			HOL_191101_001_B001	30				*		
			HOL_191101_001_B002	11				*		
			HOL_191101_001_B007	4				*		
			HOL_191101_001_B008	30				*		
			HOL_191101_001_B009	50				*		
			HOL_191101_001_B012	30					*	
			HOL_191219_002_B002	6						*
			HOL_191220_001_B001	31					*	
			HOL_200129_001_B002	55			*	*		
			HOL_200223_001_B001	12				*		
			HOL_200223_001_B002	4						
			HOL_200225_001_B002	8			*	*		
			HOL_200225_001_B003	6				*		
			HOL_200225_001_B004	30				*		
			HOL_200225_001_B006	3				*		
		GVP2	HOL_180926_001_B001	15					*	
			HOL_181001_001_B001	50					*	
			HOL_181017_001_B001	1				*		
			HOL_181017_001_B003	80					*	
			HOL_181122_001_B001	5		*	*			
			HOL_181122_001_B002	40				*		
			HOL_181122_001_B003	6		*				
			HOL_181204_002_B001	8				*		
			HOL_190314_002_B002	5	*					

Table 9.2.2. Flights recorded within GVP viewsheds and clipped to 500 m survey buffer. Part, or all, of these flights at a height of 10 – 150 m agl places them at risk of a collision with the turbine blades (shaded columns).

Species	Season	VP No.	Bout ID	No. of birds	<10 m	10-30 m	30-50 m	50-100 m	100-150 m	>150 m
Greylag goose	Sep-Mar	GVP2	HOL_190327_001_B003	10			*			
			HOL_190327_001_B004	1			*			
			HOL_190906_002_B001	5					*	
			HOL_190906_002_B003	5					*	
			HOL_191003_001_B002	25				*		
			HOL_191011_001_B001	9				*		
			HOL_191011_001_B003	30				*		
			HOL_191118_001_B001	8				*		
			HOL_191118_001_B002	400					*	
			HOL_191118_001_B003	9			*			
			HOL_191126_001_B001	8				*		
			HOL_191220_003_B001	13					*	
			HOL_200223_002_B001	40		*	*	*		
			HOL_200223_002_B002	30			*			
			HOL_200225_002_B001	30				*		
			HOL_200225_002_B003	30					*	
		MWPA	HOL_180322_001_B001	34					*	
			HOL_180322_001_B003	9			*	*	*	*
			HOL_180322_001_B008	16					*	*
			HOL_180322_001_B009	85					*	
			HOL_180918_001_B002	2						*
			HOL_181010_002_B016	35				*	*	*
		MWPB	HOL_190919_002_B001	25			*			
			HOL_191009_002_B006	25				*		
			HOL_191011_002_B001	4			*			
	Sep-Mar Total			1814	*	*	*	*	*	*
	Apr-Aug	GVP1	HOL_180413_001_B002	70				*		
			HOL_180413_001_B005	60				*		
		GVP2	HOL_180411_001_B001	14			*			
		MWPC	HOL_180402_001_B004	250		*	*	*	*	*
			HOL_180406_001_B001	1				*		
		MWPB	HOL_190409_002_B001	7					*	
			HOL_190411_001_B001	40					*	
	Apr-Aug Total			442		*	*	*	*	*
Greylag goose Total				**2256**	*	*	*	*	*	*
Curlew	Apr-Aug	GVP1	HOL_180604_001_B004	2			*	*		
			HOL_180604_001_B005	2	*	*	*	*	*	
			HOL_180621_001_B002	2				*	*	
		GVP2	HOL_180424_002_B001	1	*	*				
			HOL_180501_002_B001	1		*				
			HOL_180501_002_B002	1		*				
			HOL_180501_002_B003	1		*				
			HOL_180501_002_B004	2		*				
			HOL_180501_002_B005	2			*			
			HOL_180501_002_B006	1			*			
			HOL_180501_002_B007	2		*	*	*		
			HOL_180501_002_B008	1		*				
			HOL_180511_001_B001	2		*				
			HOL_180511_001_B002	1		*				
			HOL_180511_001_B003	2		*				
			HOL_180607_001_B001	1		*	*	*	*	
			HOL_180621_002_B001	2			*			
			HOL_180625_001_B001	1			*			

Table 9.2.2. Flights recorded within GVP viewsheds and clipped to 500 m survey buffer. Part, or all, of these flights at a height of 10 – 150 m agl places them at risk of a collision with the turbine blades (shaded columns).

Species	Season	VP No.	Bout ID	No. of birds	<10 m	10-30 m	30-50 m	50-100 m	100-150 m	>150 m
Curlew	Apr-Aug	GVP2	HOL_180711_001_B001	1	*					
			HOL_180711_001_B002	1		*	*	*		
			HOL_180711_001_B003	1		*	*			
			HOL_190401_002_B001	1	*					
			HOL_190401_002_B002	1			*			
			HOL_190401_002_B003	1	*					
			HOL_190401_002_B004	2		*				
			HOL_190404_001_B001	1		*				
			HOL_190404_001_B002	1	*	*	*			
			HOL_190408_001_B001	1		*				
			HOL_190408_001_B002	1	*					
			HOL_190408_001_B004	2		*				
			HOL_190506_002_B001	1		*				
			HOL_190506_002_B002	1		*				
			HOL_190508_002_B001	1		*	*			
			HOL_190508_002_B002	1		*	*			
			HOL_190514_001_B001	1		*				
			HOL_190514_001_B002	1	*	*				
			HOL_190604_002_B001	1		*				
			HOL_190618_002_B001	1	*	*				
			HOL_190629_001_B001	1	*					
			HOL_190629_001_B002	1	*					
			HOL_190629_001_B003	1	*					
			HOL_190629_001_B005	1	*					
			HOL_190715_002_B001	1		*				
		MWPA	HOL_180504_001_B003	1			*			
		MWPB	HOL_190501_002_B007	1		*				
			HOL_190508_003_B003	1	*	*	*	*		
		MWPC	HOL_180428_001_B002	2		*				
Curlew Total				**59**	*	*	*	*	*	
Golden plover	Apr-Aug	GVP2	HOL_180511_001_B004	2	*					
			HOL_190408_001_B003	170			*			
		MWPA	HOL_180412_001_B001	150			*	*		
			HOL_180412_001_B002	110			*			
			HOL_180412_001_B004	200			*	*		
		MWPC	HOL_180403_001_B007	4		*	*			
			HOL_180403_001_B010	7	*	*	*	*		
	Apr-Aug Total			643	*	*	*	*		
	Sep-Mar	GVP2	HOL_190314_002_B001	80	*	*				
			HOL_190906_002_B002	1		*				
			HOL_191003_001_B001	6				*		
			HOL_191003_001_B003	7	*					
			HOL_200130_003_B001	3		*	*			
			HOL_200130_003_B002	6	*	*	*	*		
			HOL_200130_003_B003	6	*	*	*			
			HOL_200225_002_B002	1		*				
		MWPA	HOL_180321_001_B002	28				*	*	
			HOL_181010_002_B014	25				*	*	
Golden plover	Sep-Mar Total			163	*	*	*	*	*	
Golden plover Total				**806**	*	*	*	*	*	

Results

1.16. The PFM was used for greylag goose, golden plover and curlew. Results are presented in **Table 9.2.3**.

1.17. The annual collision risk for greylag goose is predicted to be 0.75 birds or one bird every 1.3 years.

1.18. The annual collision risk for golden plover is predicted to be 1.12 birds or one bird every 0.9 years.

1.19. The annual collision risk for curlew is predicted to be 0.18 birds or one bird every 5.7 years.

Table 9.2.3. Results of PFM

Species	Occupancy	Avoidance Rate (%)	Birds colliding per year
Greylag goose	Non-breeding / migration	99.8	0.75
Golden plover	All year	98.0	1.12
Curlew	Breeding	98.0	0.18

1.20. The UFM was used for hen harrier. Results are presented in **Table 9.2.4**.

1.21. The annual collision risk for hen harrier is predicted to be 0.025 birds, or one bird every 41 years.

Table 9.2.4. Results of UFM

Species	Occupancy	Avoidance Rate (%)	Birds colliding per year
Hen harrier	All year	99.0	0.025

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Input data and Model Results

Hen harrier

WIND FARM PARAMETERS		
Size of windfarm envelope	651.2	ha
Number of turbines	10	
Rotor diameter	132	m
Hub height	84.0	m
Max. rotor depth in metres	2.0	m
Max. chord	3.10	m
Pitch	15.0	degrees
Rotation period	4.70	s
Turbine operation time	85	%

BIRD PARAMETERS		
Length	0.48	m
Wingspan	1.10	m
Flapping (0) or gliding (+1)	1	
Assumed flight speed	11.4	ms^-1
Number of hours birds potentially present	4510	hrs
Assumed avoidance rate	99	%

BAND USED TO DEFINE 'RISK HEIGHT'		
Max height	150	m
Min height	10	m

VP	Watch Data		Bird Flight Data	
	Area (ha)	Time (hrs)	Total (s)	'Risk height' (s)
1	374.4	144.0	123	47
2	318.9	144.0	1689	912
Totals	693.3	288.0	1812	959

Flight Activity Per Unit Time & Area			Weighted By Observation Effort		
VP	Observation	Flying time	VP	Weighting	Adjusted time
1	53913.60	0.0000002	1	0.540	0.0000001
2	45921.60	0.0000055	2	0.460	0.0000025
Totals	99835.20	0.0000029	Totals	1.000	0.0000026682
			Mean activity hr^-1 in wind farm		
			Risk height		0.17375%
			Rotor height		0.16382%

MORTALITY ESTIMATE		
Flight risk volume (Vw)	859584000	m^3
Rotor radius^2	4356	m
Combined rotor swept area (Va)	136848	m^2
Vr = Va * (d + l)	339382	m^3
Bird occupancy (n)	7.39	hrs / yr
Bird occupancy of rotor swept vol (b)	10.50	bird-secs
Bird transit time (t)	0.22	secs
No. of transits through rotors	48.28	per year
Estimated no. of collisions	2.45	per year
After allowing for avoidance	0.025	per year
i.e. equivalent to one bird every	**40.8**	**years**

K: [1D or [3D] (0 o	1		**Calculation of alpha and p(collision) as a function of radius**								
NoBlades	3					Upwind:			Downwind:		
MaxChord	3.10	m	r/R	c/C	α	collide			collide		
Pitch (degrees)	15.0		radius	chord	alpha	length	p(collision)	y(x)	length	p(collision)	y(x)
			0				1.00	0.000		1.00	0.000
BirdLength	0.48	m	0.05	0.575	2.58	6.72	0.38	0.038	5.80	0.32	0.032
Wingspan	1.10	m	0.1	0.622	1.29	3.81	0.21	0.043	2.81	0.16	0.031
F: Flapping (0) or g	1		0.15	0.781	0.86	3.24	0.18	0.054	1.99	0.11	0.033
			0.2	0.939	0.65	3.02	0.17	0.068	1.52	0.08	0.034
Bird speed	11.4	m/sec	0.25	0.971	0.52	2.64	0.15	0.074	1.09	0.06	0.030
RotorDiam	132	m	0.3	0.923	0.43	2.41	0.13	0.081	0.93	0.05	0.031
RotationPeriod	4.70	sec	0.35	0.875	0.37	2.15	0.12	0.084	0.75	0.04	0.029
			0.4	0.827	0.32	1.94	0.11	0.087	0.62	0.03	0.028
integration interval	0.05		0.45	0.780	0.29	1.78	0.10	0.089	0.52	0.03	0.026
			0.5	0.732	0.26	1.63	0.09	0.091	0.50	0.03	0.028
Bird aspect ratioo:	0.44		0.55	0.684	0.23	1.51	0.08	0.093	0.55	0.03	0.034
			0.6	0.637	0.22	1.40	0.08	0.094	0.58	0.03	0.039
			0.65	0.589	0.20	1.30	0.07	0.095	0.60	0.03	0.044
			0.7	0.541	0.18	1.21	0.07	0.095	0.62	0.03	0.048
			0.75	0.494	0.17	1.13	0.06	0.095	0.62	0.03	0.052
			0.8	0.446	0.16	1.05	0.06	0.094	0.62	0.03	0.056
			0.85	0.398	0.15	0.98	0.05	0.093	0.62	0.03	0.059
			0.9	0.350	0.14	0.91	0.05	0.092	0.61	0.03	0.062
			0.95	0.303	0.14	0.85	0.05	0.090	0.60	0.03	0.064
			1	0.255	0.13	0.78	0.04	0.088	0.59	0.03	0.066
			Overall p(collision) =			**Upwind**		**8.0%**	**Downwind**		**4.0%**
						Average		**6.0%**			

Greylag goose

Greylag goose	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	Total
Observation effort (hours)	48.00	60.00	32.00	16.00	16.00	20.00	45.00	71.00	**308.00**
No. birds observed in risk window	52	481	680	102	55	273	160	442	**2245**
25% for nocturnal flights not observed	13	120	170	26	14	68	40	111	**561**
Total number of flights	65	601	850	128	69	341	200	553	**2806**
No. birds per hour of observation	1.35	10.02	26.56	7.97	4.30	17.06	4.44	7.78	-
Available hours for flight activity	387	320	238	202	223	260	365	431	**2426**
Potential no. birds in risk window during month	523.95	3210.59	6326.86	1608.94	957.30	4434.10	1621.17	3351.44	**22034.34**

Proposed scheme

Item	Quantity	Units
Collision risk window width	3077.5	m
Collision risk window height	140	m
X-sectional area of risk window	430850	m^2
Rotor diameter	132	m
No. of turbines	10	
Area of rotors	136848	m^2
Proportion of risk window taken up by rotors	31.8	%
No. of rotor blades	3	
Maximum chord width	3.1	m
Rotation period	4.7	seconds
Average pitch	15	degrees
Estimated operation time	85	%

Step	Description	Values
A	Bird flights through risk window	22034.34
B	Survey hours	308.00
D	Hours potentially active	2245
E	Predicted total flights per year	22034.34
F	Bird flights through rotors (E*proportion of risk window)	6998.61
G	Probability of collision (Stage 2 of CRM)	6.3%
H	Turbine operation rate	0.85
I	Collisions per year, no avoidance (F*G*H)	376.02
J	Collisions per year with 99.8% avoidance	0.75
i.e. equivalent to one bird every		**1.3 years**

K: [1D or [3D] (0 or 1)	1	
NoBlades	3	
MaxChord	3.1	m
Pitch (degrees)	15	
BirdLength	0.83	m
Wingspan	1.64	m
F: Flapping (0) or gliding (+1)	0	
Bird speed	17	m/sec
RotorDiam	132	m
RotationPeriod	4.7	sec
integration interval	0.05	
Bird aspect ratioo: b	0.51	

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

				Upwind:			Downwind:		
r/R	c/C	a	collide			collide		
radius	chord	alpha	length	p(collision)	y(x)	length	p(collision)	y(x)
0				1.00	0		1.00	0
0.05	0.575	3.85	13.42	0.50	0.05037	12.49	0.47	0.04691
0.1	0.622	1.93	7.25	0.27	0.05443	6.25	0.23	0.04694
0.15	0.781	1.28	5.74	0.22	0.06461	4.48	0.17	0.05050
0.2	0.939	0.96	5.04	0.19	0.07575	3.54	0.13	0.05311
0.25	0.971	0.77	4.28	0.16	0.08039	2.72	0.10	0.05116
0.3	0.923	0.64	3.57	0.13	0.08039	2.09	0.08	0.04703
0.35	0.875	0.55	3.05	0.11	0.08010	1.64	0.06	0.04319
0.4	0.827	0.48	2.69	0.10	0.08072	1.36	0.05	0.04084
0.45	0.780	0.43	2.46	0.09	0.08297	1.20	0.05	0.04069
0.5	0.732	0.39	2.26	0.08	0.08493	1.09	0.04	0.04083
0.55	0.684	0.35	2.10	0.08	0.08660	1.00	0.04	0.04125
0.6	0.637	0.32	1.95	0.07	0.08799	0.93	0.03	0.04196
0.65	0.589	0.30	1.83	0.07	0.08909	0.88	0.03	0.04296
0.7	0.541	0.28	1.71	0.06	0.08990	0.84	0.03	0.04425
0.75	0.494	0.26	1.61	0.06	0.09043	0.85	0.03	0.04767
0.8	0.446	0.24	1.51	0.06	0.09066	0.87	0.03	0.05204
0.85	0.398	0.23	1.42	0.05	0.09061	0.88	0.03	0.05612
0.9	0.350	0.21	1.34	0.05	0.09028	0.89	0.03	0.05991
0.95	0.303	0.20	1.26	0.05	0.08965	0.89	0.03	0.06342
1	0.255	0.19	1.18	0.04	0.08874	0.89	0.03	0.06664

Overall p(collision) = **Upwind** **7.9%** **Downwind** **4.7%**

Average **6.3%**

Golden plover

Golden plover	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
Observation effort (hours)	16.00	20.00	45.00	71.00	44.00	32.00	24.00	24.00	48.00	60.00	32.00	16.00	**432.00**
No. birds observed in risk window	15	1	108	641	0	0	0	0	1	31	0	0	**797**
No. birds per hour of observation	0.94	0.05	2.40	9.03	0.00	0.00	0.00	0.00	0.02	0.52	0.00	0.00	**-**
Available hours for flight activity	223	260	365	431	519	544	544	478	387	320	238	202	**4510**
Potential no. birds in risk window during month	208.86	12.99	875.43	3888.28	0.00	0.00	0.00	0.00	8.06	165.54	0.00	0.00	**5159.17**

Proposed scheme

Item	Quantity	Units
Collision risk window width	3077.5	m
Collision risk window height	140	m
X-sectional area of risk window	430850	m^2
Rotor diameter	132	m
No. of turbines	10	
Area of rotors	136848	m^2
Proportion of risk window taken up by rotors	31.8	%
No. of rotor blades	3	
Maximum chord width	3.1	m
Rotation period	4.7	seconds
Average pitch	15	degrees
Estimated operation time	85	%

Step	Description	Values
A	Bird flights through risk window	797
B	Survey hours	432
D	Hours potentially active	4510
E	Predicted total flights per year	5159.17
F	Bird flights through rotors (E*proportion of risk window)	1638.67
G	Probability of collision (Stage 2 of CRM)	4.0%
H	Turbine operation rate	0.85
I	Collisions per year, no avoidance (F*G*H)	56.12
J	Collisions per year with 98% avoidance	1.12
i.e. equivalent to one bird every		**0.9 years**

K: [1D or [3D] (0 or 1)	1	**Calculation of alpha and p(collision) as a function of radius**								
NoBlades	3				Upwind:			Downwind:		
MaxChord	3.1 m	r/R	c/C	a	collide			collide		
Pitch (degrees)	15	radius	chord	alpha	length	p(collision)	y(x)	length	p(collision)	y(x)
		0				1.00	0		1.00	0
BirdLength	0.28 m	0.05	0.575	4.06	10.37	0.37	0.03697	9.45	0.34	0.03368
Wingspan	0.72 m	0.1	0.622	2.03	5.74	0.20	0.04093	4.74	0.17	0.03381
F: Flapping (0) or gliding (+1)	0	0.15	0.781	1.35	4.76	0.17	0.05095	3.51	0.13	0.03754
		0.2	0.939	1.01	4.34	0.15	0.06187	2.83	0.10	0.04037
Bird speed	17.9 m/sec	0.25	0.971	0.81	3.72	0.13	0.06635	2.16	0.08	0.03858
RotorDiam	132 m	0.3	0.923	0.68	3.10	0.11	0.06624	1.62	0.06	0.03456
RotationPeriod	4.7 sec	0.35	0.875	0.58	2.64	0.09	0.06586	1.23	0.04	0.03080
		0.4	0.827	0.51	2.29	0.08	0.06520	0.96	0.03	0.02733
integration interval	0.05	0.45	0.780	0.45	2.00	0.07	0.06427	0.75	0.03	0.02412
		0.5	0.732	0.41	1.77	0.06	0.06307	0.59	0.02	0.02119
Bird aspect ratioo: b	0.39	0.55	0.684	0.37	1.58	0.06	0.06217	0.49	0.02	0.01909
		0.6	0.637	0.34	1.44	0.05	0.06142	0.41	0.01	0.01771
		0.65	0.589	0.31	1.30	0.05	0.06040	0.36	0.01	0.01659
		0.7	0.541	0.29	1.18	0.04	0.05910	0.32	0.01	0.01575
		0.75	0.494	0.27	1.08	0.04	0.05754	0.28	0.01	0.01518
		0.8	0.446	0.25	0.98	0.03	0.05570	0.30	0.01	0.01707
		0.85	0.398	0.24	0.88	0.03	0.05358	0.31	0.01	0.01909
		0.9	0.350	0.23	0.80	0.03	0.05120	0.32	0.01	0.02084
		0.95	0.303	0.21	0.72	0.03	0.04854	0.33	0.01	0.02231
		1	0.255	0.20	0.64	0.02	0.04561	0.33	0.01	0.02351
		Overall p(collision) =			**Upwind**		**5.6%**	**Downwind**		**2.5%**
						Average	**4.0%**			

Curlew

Curlew	APR	MAY	JUN	JUL	AUG	Total
Observation effort (hours)	71.00	44.00	32.00	24.00	24.00	**195.00**
No. birds observed in risk window	11	25	12	3	0	**51**
No. birds per hour of observation	0.15	0.57	0.38	0.13	0.00	**-**
Available hours for flight activity	431	519	544	544	478	**2515**
Potential no. birds in risk window during month	66.73	294.83	204.16	67.95	0.00	**633.67**

Proposed scheme

Item	Quantity	Units
Collision risk window width	3077.5	m
Collision risk window height	140	m
X-sectional area of risk window	430850	m^2
Rotor diameter	132	m
No. of turbines	10	
Area of rotors	136848	m^2
Proportion of risk window taken up by rotors	31.8	%
No. of rotor blades	3	
Maximum chord width	3.1	m
Rotation period	4.7	seconds
Average pitch	15	degrees
Estimated operation time	85	%

Step	Description	Values
A	Bird flights through risk window	51
B	Survey hours	195.00
D	Hours potentially active	2515
E	Predicted total flights per year	633.67
F	Bird flights through rotors (E*proportion of risk window)	201.27
G	Probability of collision (Stage 2 of CRM)	5.2%
H	Turbine operation rate	0.85
I	Collisions per year, no avoidance (F*G*H)	8.82
J	Collisions per year with 98% avoidance	0.18
i.e. equivalent to one bird every		**5.7 years**

K: [1D or [3D] (0 or 1)	1		**Calculation of alpha and p(collision) as a function of radius**								
NoBlades	3					Upwind:			Downwind:		
MaxChord	3.1	m	r/R	c/C	a	collide			collide		
Pitch (degrees)	15		radius	chord	alpha	length	p(collision)	y(x)	length	p(collision)	y(x)
			0				1.00	0		1.00	0
BirdLength	0.55	m	0.05	0.575	3.69	10.15	0.40	0.03974	9.23	0.36	0.03613
Wingspan	0.90	m	0.1	0.622	1.85	5.60	0.22	0.04389	4.61	0.18	0.03607
F: Flapping (0) or gliding (	0		0.15	0.781	1.23	4.61	0.18	0.05421	3.36	0.13	0.03949
			0.2	0.939	0.92	4.18	0.16	0.06553	2.68	0.10	0.04191
Bird speed	16.3	m/sec	0.25	0.971	0.74	3.59	0.14	0.07031	2.03	0.08	0.03982
RotorDiam	132	m	0.3	0.923	0.62	3.00	0.12	0.07040	1.52	0.06	0.03561
RotationPeriod	4.7	sec	0.35	0.875	0.53	2.64	0.10	0.07224	1.23	0.05	0.03374
			0.4	0.827	0.46	2.36	0.09	0.07387	1.03	0.04	0.03228
integration interval	0.05		0.45	0.780	0.41	2.13	0.08	0.07521	0.88	0.03	0.03112
			0.5	0.732	0.37	1.95	0.08	0.07625	0.77	0.03	0.03025
Bird aspect ratioo: b	0.61		0.55	0.684	0.34	1.79	0.07	0.07699	0.69	0.03	0.02969
			0.6	0.637	0.31	1.65	0.06	0.07743	0.63	0.02	0.02942
			0.65	0.589	0.28	1.52	0.06	0.07757	0.58	0.02	0.02946
			0.7	0.541	0.26	1.41	0.06	0.07741	0.56	0.02	0.03051
			0.75	0.494	0.25	1.31	0.05	0.07695	0.58	0.02	0.03418
			0.8	0.446	0.23	1.22	0.05	0.07618	0.60	0.02	0.03756
			0.85	0.398	0.22	1.13	0.04	0.07512	0.61	0.02	0.04063
			0.9	0.350	0.21	1.05	0.04	0.07377	0.62	0.02	0.04340
			0.95	0.303	0.19	0.97	0.04	0.07211	0.62	0.02	0.04588
			1	0.255	0.18	0.90	0.04	0.07015	0.61	0.02	0.04805
			Overall p(collision) =			**Upwind**		**6.8%**	**Downwind**		**3.5%**
							Average	**5.2%**			