Appendix 6.1 Collision Risk Analysis

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Appendix 6.1 Collision Risk Analysis

Introduction

Worked collision risk analysis for nine species (Greylag goose, red-throated diver, curlew, whimbrel, golden plover, great skua, arctic skua, arctic tern and fulmar) is contained in this Appendix. The collision risk analysis has been undertaken by BSG Ecology, and independently reviewed by McArthur Green.

The collision risk analysis follows the Scottish Natural Heritage (SNH) guidance note on calculating a theoretical collision risk (SNH, 2000). The calculations used in the guidance note are derived from Band *et al*., (2007). The calculations provide a collision risk based on birds undertaking no avoidance action. An avoidance factor is therefore applied to the output of the Band calculation, and this has been derived from recommended avoidance rates in SNH (2018). Each worked collision risk model in this Technical Appendix follows the calculations set out in SNH (2000).

The collision risk calculation determines the number of birds colliding per annum by multiplying the number of birds flying through the turbine rotors and the probability of a bird being hit. SNH (2000) identifies two approaches to determine the number of birds flying through the rotors; these are: the 'predictable flight' model, and the 'random flight' model.

Collision risk has been calculated using the 'random' flight model for all species as this is considered most appropriate given the distribution of flight activity over the site. For some species, a proportion of flights also fit the 'predictable' model; this is the case for greylag goose and breeding adult red-throated divers that consistently make direct flights between a nest and foraging area. However, the majority of such direct fights observed during survey work did not pass through the proposed turbine array, and tended to occur between lochans at the periphery of the Proposed Development footprint, away from the Site to the sea. It can be seen from Figures 6.2 (greylag goose) and 6.4 (red throated diver) that the majority of flights within the vicinity of the proposed turbine locations are typically wheeling flights. Direct flights made by red-throated diver typically occurred around Gloup Voe (in the centre-north of the Site), near Kussa Waters (beyond the north-eastern corner of the Site), near to the western coastline of Yell, and at Dalsetter (beyond the south-eastern corner of the Site).

In applying the random flight model, a "flight risk volume" has been calculated based on the area occupied by a 500 m perimeter of all turbines multiplied by the height of the turbines. The combined visible area is shown on Figure 6.1 (modelled visibility from vantage point locations), and 500 m perimeter of turbines shown on each subsequent bird flight figure. Flight data obtained from VPs 1, 4 and 5 (as presented in the 2019 EIA Report) were excluded from the model. VPs 1 and 5 did not overlook any of the proposed turbine locations in the 2021 Layout, and VP 4 only captured proposed turbine 16 (which is also overlooked by VP 3) at the edge of its viewshed. Inclusion of VPs 1, 4 and 5 into the model is likely to have skewed the collision risk outcome by enlarging the flight risk volume disproportionately.

The calculated flight risk volume is presented in each of the worked collision risk analyses. This was calculated using ArcGIS.

The total observation time entered into the analysis is 36 hours per season. This is based on 36 hours of observation being completed during each season for each of VPs 2, 3 and 6. Collision risk analysis has been undertaken separately for each of the 2016 and 2017/2018 survey periods. Only breeding season flight data and observation time has been analysed for those species that are not present, or do not use the airspace over the Site frequently during the winter period. This is true for species such as great skua which were recorded irregularly during autumn 2017, and likely to have involved dispersing or wandering individuals.

For those species that do not occur frequently outside of the breeding bird season, the period of the year over which the species are likely to be present within the airspace over the Proposed Development has been entered into the model as April to August inclusive. The mean daylight hours for Shetland in each month has been used to provide a total duration for which each species is active. As all of the species for which collision risk analysis has been conducted are diurnal, only 5 % of the total night time hours have been included in the analysis.

All flights recorded at collision risk height (> 40 m) during the survey work have been entered into the model. SNH (2000) guidance indicates that "*best results will be based on observational data about flight heights, such as will enable informed estimate of the proportion of flights at a level which may collide with windfarm rotors*." Whilst the flight height bands used in the field were well defined, and allowed exclusion of below collision risk (<40 m) flights from the model, the survey data did not allow exclusion of flights that occurred above the maximum tip height of the proposed turbines. This is because the maximum tip height of proposed turbines has reduced during the course of survey work, and the maximum height band used in the field captured both at and above collision risk heights. This has resulted in a slight overestimation of collision risk.

Estimates of bird size and flight speed for each species have been used for calculating the probability collision. There are numerous sources of information on flight speed in birds, but few of these present figures that correspond, and birds can vary their speed according to what they are doing (e.g. soaring, gliding or pursuing prey / trying to evade capture). Precautionary (low) flight speeds are presented for each species modelled (based on data presented in Bruderer & Boldt, 2001). Slower speed makes birds less likely to avoid turning blades by chance (i.e. through flying through the rotor swept area without taking avoiding action).

The size of birds (total length and length of the wing) is also precautionary in each case, and is based on the largest given measurement for the species concerned in Baker (2016). Larger size also makes avoiding rotating blades by chance less likely.

Summary of hours watched

Table 1 – VP 2 survey dates, times, and meteorological data.

Date	Start time	Stop Time	Time (Hrs)	Wind Direction	Wind speed	Cloud cover	Rain	Snow	Frost
05-Apr-16	13:30	16:30	3	NNW	3	8	0	0	0
05-Apr-16	17:00	20:00	3	NW	3	8	0	0	0
03-May-16	04:55	07:55	3	SSW	5	4	0	0	0
03-May-16	08:35	11:35	3	SSW	5	5	0	0	0
01-Jun-16	15:50	18:50	3	N	5	8	0	0	0
01-Jun-16	19:20	22:20	3	N	4	8	0	0	0
18-Jul-16	04:15	07:15	3	E	1	4	0	0	0
18-Jul-16	07:45	10:45	3	E	1	5	0	0	0
03-Aug-16	15:05	18:05	3	ENE	5	8	5	0	0
03-Aug-16	18:35	21:35	3	ENE	5	8	5	0	0
23-Aug-16	05:40	08:40	3	W	2	8	0	0	0
23-Aug-16	09:10	12:10	3	WNW	1	8	0	0	0
05-Apr-16	13:30	16:30	3	NNW	3	8	0	0	0
05-Apr-16	17:00	20:00	3	NW	3	8	0	0	0
03-May-16	04:55	07:55	3	SSW	5	4	0	0	0
03-May-16	08:35	11:35	3	SSW	5	5	0	0	0
01-Jun-16	15:50	18:50	3	N	5	8	0	0	0
01-Jun-16	19:20	22:20	3	N	4	8	0	0	0
18-Jul-16	04:15	07:15	3	E	1	4	0	0	0
18-Jul-16	07:45	10:45	3	E	1	5	0	0	0
03-Aug-16	15:05	18:05	3	ENE	5	8	5	0	0
03-Aug-16	18:35	21:35	3	ENE	5	8	5	0	0
23-Aug-16	05:40	08:40	3	W	2	8	0	0	0
23-Aug-16	09:10	12:10	3	WNW	1	8	0	0	0
21-Sep-17	16:07	19:07	3	W	1	8	2	0	0
26-Sep-17	08:30	11:30	3	SSE	6	8	0	0	0
04-Oct-17	07:19	10:19	3	W	6	7	4	0	0
04-Oct-17	10:49	13:49	3	W	5	5	0	0	0
05-Nov-17	09:26	12:26	3	NW	5	6	3	0	0
05-Nov-17	12:56	15:56	3	NW	6	5	3	0	0
15-Dec-17	09:45	12:45	3	NW	6	4	0	0	0
13-Jan-18	11:30	14:30	3	SSE	5	7	0	0	0
18-Feb-18	07:35	10:35	3	WSW	4	7	0	0	1
18-Feb-18	11:05	14:05	3	SW	3	7	0	0	0
09-Mar-18	07:25	10:25	3	SE	4	6	0	1	0
09-Mar-18	10:55	13:55	3	SE	4	5	0	1	0
04-Apr-18	13:10	16:10	3	W	2	5	0	0	0
04-Apr-18	16:50	19:50	3	W	2	1	0	0	0

Date	Start time	Stop Time	Time (Hrs)	Wind Direction	Wind speed	Cloud cover	Rain	Snow	Frost
02-May-18	14:10	17:10	3	SW	5	8	3	0	0
17-May-18	04:20	07:20	3	W	3	5	0	0	0
08-Jun-18	08:50	11:50	3	NE	3	8	0	0	0
08-Jun-18	12:20	15:20	3	NE	3	8	0	0	0
02-Jul-18	19:30	22:30	3	SW	4	8	0	0	0
02-Jul-18	16:00	19:00	3	SW	4	6	0	0	0
02-Aug-18	10:00	13:00	3	S	4	8	0	0	0
02-Aug-18	13:30	16:30	3	WSW	4	7	0	0	0
15-Aug-18	05:10	08:10	3	SW	3	8	2	0	0
15-Aug-18	08:40	11:40	3	S	4	8	0	0	0
Total duration (Hrs)	Breeding 2016		36						
	Winter 2017/18		36						
	Breeding 2018		36						

Table 2 – VP 3 survey dates, times, and meteorological data.

Date	Start time	Stop Time	Time (Hrs)	Wind Direction	Wind speed	Cloud cover	Rain	Snow	Frost
06-Apr-16	3	13:35	16:35	3	WSW	3	6	0	0
06-Apr-16	3	17:05	20:05	3	W	2	7	0	0
04-May-16	3	04:55	07:55	3	S	4	8	0	0
04-May-16	3	08:25	11:25	3	S	4	8	3	0
02-Jun-16	3	15:55	18:55	3	NE	6	8	0	0
02-Jun-16	3	19:25	22:25	3	NE	6	3	0	0
22-Jul-16	3	04:19	07:19	3	S	1	2	0	0
22-Jul-16	3	07:50	10:50	3	SE	2	2	0	0
10-Aug-16	3	14:45	17:45	3	W	3	2	0	0
10-Aug-16	3	18:15	21:15	3	WSW	2	2	0	0
31-Aug-16	3	05:35	08:35	3	SSW	5	2	0	0
31-Aug-16	3	09:25	12:25	3	SW	5	7	0	0
06-Apr-16	3	13:35	16:35	3	WSW	3	6	0	0
06-Apr-16	3	17:05	20:05	3	W	2	7	0	0
04-May-16	3	04:55	07:55	3	S	4	8	0	0
04-May-16	3	08:25	11:25	3	S	4	8	3	0
02-Jun-16	3	15:55	18:55	3	NE	6	8	0	0
02-Jun-16	3	19:25	22:25	3	NE	6	3	0	0
22-Jul-16	3	04:19	07:19	3	S	1	2	0	0
22-Jul-16	3	07:50	10:50	3	SE	2	2	0	0
10-Aug-16	3	14:45	17:45	3	W	3	2	0	0
10-Aug-16	3	18:15	21:15	3	WSW	2	2	0	0
31-Aug-16	3	05:35	08:35	3	SSW	5	2	0	0
31-Aug-16	3	09:25	12:25	3	SW	5	7	0	0

Date	Start time	Stop Time	Time (Hrs)	Wind Direction	Wind speed	Cloud cover	Rain	Snow	Frost
20-Sep-17	3	12:40	15:40	3	SE	3	7	0	0
20-Sep-17	3	16:10	19:10	3	SE	3	7	3	0
07-Oct-17	3	11:54	14:54	3	NE	3	8	0	0
07-Oct-17	3	15:24	18:24	3	N	3	7	0	0
06-Nov-17	3	07:40	10:40	3	S	4	8	0	0
06-Nov-17	3	11:10	14:10	3	S	5	8	0	0
11-Dec-17	3	11:50	14:50	3	WNW	4	7	1	0
11-Jan-18	3	12:15	15:15	3	NW	2	1	0	0
16-Feb-18	3	12:20	15:20	3	SW	5	5	0	0
19-Feb-18	3	07:30	10:30	3	ESE	6	5	0	0
06-Mar-18	3	09:10	12:10	3	NE	4	7	3	1
06-Mar-18	3	12:40	15:40	3	NE	3	7	3	1
03-Apr-18	3	13:00	16:00	3	E	4	8	3	0
03-Apr-18	3	16:45	19:45	3	NE	4	6	0	0
04-May-18	3	13:40	14:40	1	SW	5	8	3	0
18-May-18	3	04:10	07:10	3	SE	1	1	0	0
18-May-18	3	07:40	09:40	2	SE	2	1	0	0
07-Jun-18	3	10:00	13:00	3	NE	3	8	0	0
07-Jun-18	3	13:30	16:30	3	NE	3	8	0	0
09-Jul-18	3	19:30	22:30	3	SW	1	5	0	0
09-Jul-18	3	15:50	19:00	3	NW	3	4	0	0
31-Jul-18	3	12:15	15:15	3	S	5	5	0	0
31-Jul-18	3	15:45	18:45	3	ESE	4	1	0	0
20-Aug-18	3	05:15	08:15	3	W	2	7	0	0
Total duration (Hrs)	Breeding 2016		36						
	Winter 2017/18		36						
	Breeding 2018		36						

Table 3 – VP 6 survey dates, times, and meteorological data.

Date	Start time	Stop Time	Time (Hrs)	Wind Direction	Wind speed	Cloud cover	Rain	Snow	Frost
11-Apr-16	13:45	16:45	3	E	3	4	0	0	0
11-Apr-16	17:15	20:15	3	NE	3	4	0	0	0
27-May-16	05:00	08:00	3	ENE	5	8	0	0	0
27-May-16	09:00	12:00	3	ENE	4	8	4	0	0
07-Jun-16	16:00	19:00	3	N	4	8	0	0	0
07-Jun-16	19:30	22:30	3	N	3	8	0	0	0
02-Aug-16	04:50	07:50	3	NNW	3	8	0	0	0
02-Aug-16	08:20	11:20	3	NNW	3	8	0	0	0
12-Aug-16	14:40	17:40	3	WNW	3	8	0	0	0
12-Aug-16	18:10	21:10	3	W	4	8	0	0	0

Date	Start time	Stop Time	Time (Hrs)	Wind Direction	Wind speed	Cloud cover	Rain	Snow	Frost
24-Aug-16	13:15	16:15	3	NNW	3	8	0	0	0
24-Aug-16	16:45	19:45	3	W	2	7	0	0	0
11-Apr-16	13:45	16:45	3	E	3	4	0	0	0
11-Apr-16	17:15	20:15	3	NE	3	4	0	0	0
27-May-16	05:00	08:00	3	ENE	5	8	0	0	0
27-May-16	09:00	12:00	3	ENE	4	8	4	0	0
07-Jun-16	16:00	19:00	3	N	4	8	0	0	0
07-Jun-16	19:30	22:30	3	N	3	8	0	0	0
02-Aug-16	04:50	07:50	3	NNW	3	8	0	0	0
02-Aug-16	08:20	11:20	3	NNW	3	8	0	0	0
12-Aug-16	14:40	17:40	3	WNW	3	8	0	0	0
12-Aug-16	18:10	21:10	3	W	4	8	0	0	0
24-Aug-16	13:15	16:15	3	NNW	3	8	0	0	0
24-Aug-16	16:45	19:45	3	W	2	7	0	0	0
27-Sep-17	12:18	15:18	3	SE	6	8	0	0	0
27-Sep-17	15:48	18:48	3	SE	6	7	0	0	0
06-Oct-17	07:21	10:21	3	NW	5	8	3	0	0
06-Oct-17	10:51	13:51	3	NW	4	8	0	0	0
07-Nov-17	09:20	12:20	3	W	2	8	3	0	0
07-Nov-17	12:51	15:51	3	SW	3	8	0	0	0
14-Dec-17	10:45	13:45	3	E	3	7	1	0	1
18-Jan-18	11:00	14:00	3	W	4	5	0	0	0
21-Feb-18	07:25	10:25	3	NW	3	2	0	0	1
21-Feb-18	10:55	13:55	3	NW	2	3	0	0	1
31-Mar-18	11:30	14:30	3	NNW	5	4	0	0	1
31-Mar-18	15:00	18:00	3	WNW	4	3	0	0	1
10-Apr-18	13:10	16:10	3	S	2	8	0	0	0
10-Apr-18	16:50	19:50	3	S	2	7	0	0	0
15-May-18	04:20	07:20	3	SW	1	0	0	0	0
15-May-18	07:50	10:50	3	SE	4	0	0	0	0
12-Jun-18	10:00	13:00	3	W	3	6	0	0	0
12-Jun-18	13:30	16:30	3	NW	4	8	0	0	0
05-Jul-18	19:30	22:30	3	W	4	8	0	0	0
05-Jul-18	16:00	19:00	3	W	4	3	0	0	0
07-Aug-18	09:30	12:30	3	SW	3	8	1	0	0
07-Aug-18	13:00	16:00	3	S	3	8	1	0	0
24-Aug-18	05:15	08:15	3	NW	2	6	0	0	0
24-Aug-18	08:45	11:45	3	NW	4	7	2	0	0
Total duration (Hrs)	Breeding 2016		36						
	Winter 2017/18		36						
	Breeding 2018		36						

Summary of Flight Data

Table 4 – Flights recorded in 2016 within the collision risk zone.

Species	Count	Date	Time of Flight	Duration	At Risk Bird Seconds
RH	1	03-May-16	05:04	18	18
RH	1	03-May-16	05:06	3	3
RH	1	04-May-16	05:59	83	83
RH	2	07-Jun-16	21:36	50	101
RH	1	18-Jul-16	05:33	80	80
RH	5	18-Jul-16	06:16	13	63
RH	1	18-Jul-16	06:40	13	13
RH	1	18-Jul-16	07:08	50	50
RH	2	18-Jul-16	08:31	70	141
RH	2	22-Jul-16	05:08	30	59
RH	2	22-Jul-16	07:09	217	434
RH	1	02-Aug-16	06:00	20	20
RH	1	02-Aug-16	06:00	47	47
RH	2	02-Aug-16	06:31	54	108
RH	3	02-Aug-16	06:58	55	166
RH	2	02-Aug-16	07:09	40	81
RH	2	02-Aug-16	09:13	32	64
RH	1	10-Aug-16	18:36	107	107
RH	1	12-Aug-16	16:33	27	27
RH	4	12-Aug-16	20:20	15	62
RH	2	23-Aug-16	07:37	12	24
RH	1	23-Aug-16	10:30	21	21
RH	2	24-Aug-16	14:46	101	201
RH	1	24-Aug-16	17:00	43	43
RH	1	24-Aug-16	17:39	16	16
RH	2	24-Aug-16	18:23	51	103
NX	1	11-Apr-16	15:50	1	1
NX	1	11-Apr-16	16:43	19	19
NX	1	11-Apr-16	16:43	19	19
NX	1	03-May-16	10:53	119	119
NX	1	04-May-16	05:07	45	45
NX	1	04-May-16	07:27	20	20
NX	1	04-May-16	07:27	40	40
NX	1	04-May-16	09:19	21	21
NX	1	04-May-16	09:46	29	29
NX	1	04-May-16	09:50	21	21
NX	1	04-May-16	11:04	6	6
NX	1	27-May-16	07:22	11	11
NX	4	27-May-16	07:52	112	447

Species	Count	Date	Time of Flight	Duration	At Risk Bird Seconds
NX	1	27-May-16	10:16	14	14
NX	2	27-May-16	10:39	91	181
NX	6	27-May-16	11:21	169	1017
NX	4	27-May-16	11:42	384	1535
NX	4	27-May-16	11:59	38	152
NX	1	02-Jun-16	17:38	30	30
NX	2	02-Jun-16	18:13	61	122
NX	1	02-Jun-16	20:53	11	11
NX	1	02-Jun-16	21:14	25	25
NX	1	02-Jun-16	21:19	75	75
NX	1	07-Jun-16	18:09	11	11
NX	1	07-Jun-16	18:49	35	35
NX	1	07-Jun-16	20:11	30	30
NX	1	18-Jul-16	04:15	140	140
NX	1	18-Jul-16	04:28	33	33
NX	1	18-Jul-16	04:46	12	12
NX	1	18-Jul-16	05:30	59	59
NX	3	18-Jul-16	05:41	62	185
NX	1	18-Jul-16	06:24	29	29
NX	1	18-Jul-16	06:49	69	69
NX	1	18-Jul-16	06:57	68	68
NX	1	18-Jul-16	07:13	107	107
NX	1	18-Jul-16	08:09	407	407
NX	1	18-Jul-16	08:46	14	14
NX	1	18-Jul-16	08:54	37	37
NX	1	18-Jul-16	09:54	75	75
NX	1	18-Jul-16	10:11	44	44
NX	1	22-Jul-16	04:38	75	75
NX	1	22-Jul-16	04:49	77	77
NX	1	22-Jul-16	05:13	102	102
NX	1	22-Jul-16	06:32	159	159
NX	1	22-Jul-16	07:00	57	57
NX	1	22-Jul-16	09:51	45	45
NX	1	22-Jul-16	10:06	2	2
NX	2	22-Jul-16	10:14	150	300
NX	1	02-Aug-16	08:30	71	71
NX	1	02-Aug-16	09:01	21	21
NX	1	02-Aug-16	09:56	2	2
NX	2	03-Aug-16	17:02	116	232
NX	1	10-Aug-16	15:13	82	82
NX	1	10-Aug-16	15:42	83	83
NX	1	10-Aug-16	17:21	54	54

Species	Count	Date	Time of Flight	Duration	At Risk Bird Seconds
NX	1	10-Aug-16	19:38	40	40
NX	1	10-Aug-16	20:11	90	90
NX	1	10-Aug-16	20:11	85	85
NX	1	10-Aug-16	21:07	60	60
NX	1	12-Aug-16	20:19	36	36
NX	1	23-Aug-16	06:12	10	10
NX	2	23-Aug-16	06:31	8	16
NX	1	23-Aug-16	06:45	48	48
NX	1	24-Aug-16	19:42	120	120
NX	1	31-Aug-16	06:23	51	51
NX	1	31-Aug-16	06:55	5	5
NX	1	31-Aug-16	07:49	75	75
NX	1	31-Aug-16	08:34	1	1
NX	1	31-Aug-16	08:47	59	59
NX	1	31-Aug-16	10:34	60	60
NX	1	31-Aug-16	11:04	135	135
NX	1	31-Aug-16	11:30	90	90
NX	1	31-Aug-16	12:25	2	2
GP	1	02-Jun-16	18:13	3	3
GP	1	18-Jul-16	05:49	30	30
GP	1	22-Jul-16	05:07	9	9
GP	1	22-Jul-16	08:42	30	30
GJ	3	03-May-16	05:00	7	22
GJ	1	03-May-16	08:38	22	22
GJ	2	03-May-16	09:13	0	0
GJ	2	03-May-16	10:30	41	81
GJ	4	27-May-16	05:02	15	60
GJ	2	27-May-16	09:38	31	62
GJ	2	27-May-16	09:59	12	23
GJ	3	01-Jun-16	16:23	15	46
GJ	1	10-Aug-16	20:41	68	68
F.	1	05-Apr-16	17:45	3	3
F.	2	18-Jul-16	09:46	85	171
F.	1	10-Aug-16	16:14	217	217
F.	1	12-Aug-16	16:19	52	52
F.	1	24-Aug-16	15:32	1	1
F.	8	31-Aug-16	07:12	184	1468
F.	1	31-Aug-16	08:19	59	59
F.	2	31-Aug-16	10:18	100	200
F.	2	31-Aug-16	11:38	52	103
CU	1	11-Apr-16	18:00	50	50
CU	1	02-Jun-16	17:44	30	30

Species	Count	Date	Time of Flight	Duration	At Risk Bird Seconds
AE	2	01-Jun-16	17:50	19	37
AE	2	18-Jul-16	05:46	31	63
AE	1	22-Jul-16	04:59	171	171
AC	1	22-Jul-16	04:27	127	127

Table 5 – Flights recorded in 2017/2018 within the collision risk zone.

Species	Count	Date	Time of Flight	Duration	At Risk Bird Seconds
RK	1	26/09/2017	09:42	15	15
RK	1	18/02/2018	12:24	9	9
RK	2	03/04/2018	19:04	17	35
RH	1	17/05/2018	04:37	16	16
RH	2	17/05/2018	06:03	9	18
RH	1	17/05/2018	06:12	6	6
RH	1	18/05/2018	06:38	110	110
RH	2	15/05/2018	04:23	22	44
RH	1	15/05/2018	04:39	55	55
RH	1	15/05/2018	05:00	9	9
RH	1	15/05/2018	06:55	20	20
RH	1	07/06/2018	14:34	31	31
RH	1	07/06/2018	15:01	91	91
RH	3	08/06/2018	11:45	8	24
RH	1	08/06/2018	15:03	98	98
RH	2	12/06/2018	11:19	55	110
RH	3	05/07/2018	19:48	77	230
RH	1	05/07/2018	20:21	22	22
RH	2	02/07/2018	20:07	1	3
RH	2	02/08/2018	10:14	11	22
RH	2	02/08/2018	11:17	47	93
RH	3	02/08/2018	11:23	104	311
RH	1	02/08/2018	11:35	60	60
RH	1	02/08/2018	15:01	2	2
RH	1	15/08/2018	06:15	86	86
RH	1	15/08/2018	11:27	6	6
RH	2	20/08/2018	10:45	30	60
RH	2	24/08/2018	07:21	32	64
OC	2	18/05/2018	08:05	24	48
GP	5	05/11/2017	11:30	62	310
GP	1	08/06/2018	11:34	12	12
GJ	1	21/09/2017	18:12	35	35
GJ	16	21/09/2017	18:47	48	761
GJ	4	21/09/2017	18:48	85	338
GJ	4	26/09/2017	10:55	51	206
GJ	4	26/09/2017	11:10	23	91
GJ	9	04/10/2017	12:58	7	63
GJ	5	05/11/2017	15:04	18	89
GJ	1	06/11/2017	08:16	47	47
GJ	5	06/11/2017	08:33	19	97
GJ	2	06/11/2017	08:46	26	51

Species	Count	Date	Time of Flight	Duration	At Risk Bird Seconds
GJ	1	19/02/2018	08:20	19	19
GJ	1	19/02/2018	09:14	5	5
GJ	3	19/02/2018	10:25	15	45
GJ	2	09/03/2018	10:02	24	48
GJ	2	10/04/2018	13:25	0	1
GJ	2	07/06/2018	11:12	14	29
GJ	1	07/06/2018	14:01	124	124
GJ	1	08/06/2018	13:22	14	14
F.	1	18/05/2018	08:25	110	110
F.	3	24/08/2018	05:44	22	67
F.	1	24/08/2018	10:58	2	2
DN	1	07/06/2018	16:05	33	33
CU	1	10/04/2018	15:51	0	0
CU	4	15/08/2018	10:17	3	13
AE	2	18/05/2018	09:09	22	45
AE	1	08/06/2018	14:20	0	0
AE	2	09/07/2018	20:39	49	97
AC	6	05/07/2018	19:40	35	210
AC	4	05/07/2018	17:15	51	202
AC	1	09/07/2018	19:53	150	150
AC	1	07/08/2018	13:42	62	62

Collision Risk Model Calculations for Greylag goose (2016)

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species in 2016 is taken as April - August.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
2, 3, 6	830.338	36	29892.17	107611804.8	383.8170863	3.5667E-06
Total	830.338	36	29892.17	107611804.8	383.8170863	3.5667E-06

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall observed area

Mean bird activity =Total bird activity/combined VPs
Mean bird activity = 3.567E-6/1 = **3.567E-06**

Overall area covered by VPs (excluding overlap) = 830338 m2
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 830338 x 3.567E-6 = **2.9616E+00**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 103 m Observed height band max = 180 m
Rotor radius = 77 m Observed height band min = 40 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 180 m
Rotor min height = 26 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (180 - 26)/(180 - 40)
Proportion of actual height band = 1.1

Corrected bird activity = **3.258E+00**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for the whole year and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 4532.42

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 4532.42 x 3.258E+0
No. of hours of bird occupancy = 14765.296

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 830338 x 10000 x 77 x 2
Vw = 1278720520000 m3

Calculate the combined rotor swept volume

Number of turbines = 18
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.82 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 18 x Pi x 77 x 77 x (3.652 + 0.82)
Vr = 1499285.548 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)

Bird occupancy in rotor swept volume = 14765.296 x 3600 x 1499285.548/1278720520000
Bird occupancy in rotor swept volume = 62.324

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 13 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.82)/13
Bird transit time through the rotors = 0.344 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 62.324/0.344
No. of transits = 181.183

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1	
No. of blades	3	
Maximum chord	4	m
Pitch (degrees)	20	
Rotor radius	77	m
Rotation Period	3	s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.82	m
Wingspan	1.64	m
Bird speed	13	m/s
F:Flapping	1	

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.82/1.64
Bird aspect ratio (b) = 0.5

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	3.22443781	13.0436793	1	0.00125	11.4703866	0.882337433	0.001102922	0.00125
0.075	0.575	1.0748126	4.87232398	0.374794152	0.002810956	3.29903132	0.25377164	0.001903287	0.0075
0.125	0.7015	0.64488756	3.71774913	0.285980702	0.003574759	1.79833209	0.138333237	0.001729165	0.0125
0.175	0.8601	0.46063397	3.48587819	0.268144476	0.004692528	1.13250599	0.087115845	0.001524527	0.0175
0.225	0.99435	0.35827087	3.51940026	0.270723097	0.00609127	0.84130157	0.064715506	0.001456099	0.0225
0.275	0.94665	0.29313071	3.15812291	0.242932532	0.006680645	1.07206403	0.082466464	0.002267828	0.0275
0.325	0.89895	0.24803368	2.88792861	0.222148355	0.007219822	1.21174345	0.093211035	0.003029359	0.0325
0.375	0.85125	0.21496252	2.67238414	0.205568011	0.0077088	1.29677303	0.099751772	0.003740691	0.0375
0.425	0.80355	0.18967281	2.49220132	0.191707794	0.008147581	1.34644097	0.103572382	0.004401826	0.0425
0.475	0.75585	0.16970725	2.33621332	0.179708717	0.008536164	1.37191408	0.105531852	0.005012763	0.0475
0.525	0.70815	0.15354466	2.19750733	0.169039025	0.008874549	1.38010519	0.106161937	0.005573502	0.0525
0.575	0.66045	0.14019295	2.071575	0.159351923	0.009162736	1.37552263	0.105809433	0.006084042	0.0575
0.625	0.61275	0.12897751	1.95535065	0.150411589	0.009400724	1.36123209	0.104710161	0.006544385	0.0625
0.675	0.56505	0.11942362	1.84667696	0.142052073	0.009588515	1.3393909	0.103030069	0.00695453	0.0675
0.725	0.51735	0.11118751	1.74399171	0.134153208	0.009726108	1.31156126	0.100889328	0.007314476	0.0725
0.775	0.46965	0.10401412	1.64613585	0.126625835	0.009813502	1.27890223	0.098377094	0.007624225	0.0775
0.825	0.42195	0.09771024	1.55223132	0.119402409	0.009850699	1.24229187	0.095560913	0.007883775	0.0825
0.875	0.37425	0.09212679	1.46160075	0.112430827	0.009837697	1.20240756	0.09249289	0.008093128	0.0875
0.925	0.32655	0.08714697	1.37371321	0.105670247	0.009774498	1.15978021	0.089213863	0.008252282	0.0925
0.975	0.27885	0.08267789	1.28814671	0.099088208	0.0096611	1.11483183	0.085756294	0.008361239	0.0975
Overall p(collision)			**Upwind**		**0.152402653**	**Downwind**		**0.098854052**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.15240265 + 0.09885405)/2
Average probability of collision = 0.125628

Annual collision risk for Greylag goose assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 181.183 x 0.125628

Annual collision risk = 22.762 birds

Corrected annual collision risk assuming avoidance

Greylag goose avoidance rate = 0.998

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 22.762 x (1 - 0.998)
Annual collision risk, with avoidance = 0.046 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.039 birds

Calculate number of years per collision

Number of years per collision for Greylag goose = 1/corrected annual risk
Number of years per collision for Greylag goose = 1/0.039

Number of years per collision for Greylag goose = 25.8431

[1] Forsythe, W. C., Rykiel, E. J., Stahl, R. S., Wu, H. and Schoolfield, R. M.,1995. A model comparison for daylength as a function of latitude and day of year. Ecological Modelling Vol 80, Issue 1, 87-95

Collision Risk Model Calculations for Greylag goose 2017 / 2018

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as the whole year.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
2, 3, 6	830.338	72	59784.34	215223609.6	2062.195318	9.5816E-06
Total	830.338	72	59784.34	215223609.6	2062.195318	9.5816E-06

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall observed area

Mean bird activity =Total bird activity/combined VPs
Mean bird activity = 9.582E-6/1 = **9.582E-06**

Overall area covered by VPs (excluding overlap) = 830338 m2
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 830338 x 9.582E-6 = **7.9560E+00**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 103 m　　Observed height band max = 180 m
Rotor radius = 77 m　　Observed height band min = 40 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 180 m
Rotor min height = 26 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (180 - 26)/(180 - 40)
Proportion of actual height band = 1.1

Corrected bird activity = **8.752E+00**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for the whole year and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 4526.649

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 4526.649 x 8.752E+0
No. of hours of bird occupancy = 39615.422

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 830338 x 10000 x 77 x 2
Vw = 1278720520000 m3

Calculate the combined rotor swept volume

Number of turbines = 18
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.82 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 18 x Pi x 77 x 77 x (3.652 + 0.82)
Vr = 1499285.548 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)

Bird occupancy in rotor swept volume = 39615.422 x 3600 x 1499285.548/1278720520000
Bird occupancy in rotor swept volume = 167.215

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 13 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.82)/13
Bird transit time through the rotors = 0.344 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 167.215/0.344
No. of transits = 486.114

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1	
No. of blades	3	
Maximum chord	4	m
Pitch (degrees)	20	
Rotor radius	77	m
Rotation Period	3	s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.82	m
Wingspan	1.64	m
Bird speed	13	m/s
F:Flapping	1	

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.82/1.64
Bird aspect ratio (b) = 0.5

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	3.22443781	13.0436793	1	0.00125	11.4703866	0.882337433	0.001102922	0.00125
0.075	0.575	1.0748126	4.87232398	0.374794152	0.002810956	3.29903132	0.25377164	0.001903287	0.0075
0.125	0.7015	0.64488756	3.71774913	0.285980702	0.003574759	1.79833209	0.138333237	0.001729165	0.0125
0.175	0.8601	0.46063397	3.48587819	0.268144476	0.004692528	1.13250599	0.087115845	0.001524527	0.0175
0.225	0.99435	0.35827087	3.51940026	0.270723097	0.00609127	0.84130157	0.064715506	0.001456099	0.0225
0.275	0.94665	0.29313071	3.15812291	0.242932532	0.006680645	1.07206403	0.082466464	0.002267828	0.0275
0.325	0.89895	0.24803368	2.88792861	0.222148355	0.007219822	1.21174345	0.093211035	0.003029359	0.0325
0.375	0.85125	0.21496252	2.67238414	0.205568011	0.0077088	1.29677303	0.099751772	0.003740691	0.0375
0.425	0.80355	0.18967281	2.49220132	0.191707794	0.008147581	1.34644097	0.103572382	0.004401826	0.0425
0.475	0.75585	0.16970725	2.33621332	0.179708717	0.008536164	1.37191408	0.105531852	0.005012763	0.0475
0.525	0.70815	0.15354466	2.19750733	0.169039025	0.008874549	1.38010519	0.106161937	0.005573502	0.0525
0.575	0.66045	0.14019295	2.071575	0.159351923	0.009162736	1.37552263	0.105809433	0.006084042	0.0575
0.625	0.61275	0.12897751	1.95535065	0.150411589	0.009400724	1.36123209	0.104710161	0.006544385	0.0625
0.675	0.56505	0.11942362	1.84667696	0.142052073	0.009588515	1.3393909	0.103030069	0.00695453	0.0675
0.725	0.51735	0.11118751	1.74399171	0.134153208	0.009726108	1.31156126	0.100889328	0.007314476	0.0725
0.775	0.46965	0.10401412	1.64613585	0.126625835	0.009813502	1.27890223	0.098377094	0.007624225	0.0775
0.825	0.42195	0.09771024	1.55223132	0.119402409	0.009850699	1.24229187	0.095560913	0.007883775	0.0825
0.875	0.37425	0.09212679	1.46160075	0.112430827	0.009837697	1.20240756	0.09249289	0.008093128	0.0875
0.925	0.32655	0.08714697	1.37371321	0.105670247	0.009774498	1.15978021	0.089213863	0.008252282	0.0925
0.975	0.27885	0.08267789	1.28814671	0.099088208	0.0096611	1.11483183	0.085756294	0.008361239	0.0975
Overall p(collision)			**Upwind**		**0.152402653**	**Downwind**		**0.098854052**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.15240265 + 0.09885405)/2
Average probability of collision = 0.125628

Annual collision risk for Greylag goose assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 486.114 x 0.125628

Annual collision risk = 61.07 birds

<u>Corrected annual collision risk assuming avoidance</u>

Greylag goose avoidance rate = 0.998

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 61.07 x (1 - 0.998)
Annual collision risk, with avoidance = 0.122 birds

<u>Corrected for assumed operational downtime of the rotors</u>

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.104 birds

<u>Calculate number of years per collision</u>

Number of years per collision for Greylag goose = 1/corrected annual risk
Number of years per collision for Greylag goose = 1/0.104

Number of years per collision for Greylag goose = 9.6322

[1] Forsythe, W. C., Rykiel, E. J., Stahl, R. S., Wu, H. and Schoolfield, R. M.,1995. A model comparison for daylength as a function of latitude and day of year. Ecological Modelling Vol 80, Issue 1, 87-95

Collision Risk Model Calculations for Red-throated diver 2016

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as April - August.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
2, 3, 6	830.338	36	29892.17	107611804.8	2133.348085	1.9824E-05
Total	830.338	36	29892.17	107611804.8	2133.348085	1.9824E-05

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall observed area

Mean bird activity =Total bird activity/combined VPs
Mean bird activity = 1.982E-5/1 = **1.982E-05**

Overall area covered by VPs (excluding overlap) = 830338 m2
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 830338 x 1.982E-5 = **1.6461E+01**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 103 m Observed height band max = 180 m
Rotor radius = 77 m Observed height band min = 40 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 180 m
Rotor min height = 26 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (180 - 26)/(180 - 40)
Proportion of actual height band = 1.1

Corrected bird activity = **1.811E+01**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for April - August and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 2598.381

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 2598.381 x 1.811E+1
No. of hours of bird occupancy = 47049.208

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 830338 x 10000 x 77 x 2
Vw = 1278720520000 m3

Calculate the combined rotor swept volume

Number of turbines = 18
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = Reference Notes m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 18 x Pi x 77 x 77 x (3.652 + 0.61)
Vr = 1428877.367 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)

Bird occupancy in rotor swept volume = 47049.208 x 3600 x 1428877.367/1278720520000
Bird occupancy in rotor swept volume = 189.267

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 21.1 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.61)/21.1
Bird transit time through the rotors = 0.202 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 189.267/0.202
No. of transits = 937.057

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1	
No. of blades	3	
Maximum chord	4	m
Pitch (degrees)	20	
Rotor radius	77	m
Rotation Period	3	s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.61	m
Wingspan	1.11	m
Bird speed	21.1	m/s
F:Flapping	1	

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.61/1.11
Bird aspect ratio (b) = 0.55

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	5.2335106	17.9069931	0.848672657	0.001060841	16.3337004	0.774109023	0.000967636	0.00125
0.075	0.575	1.74450353	6.49342857	0.30774543	0.002308091	4.92013591	0.233181797	0.001748863	0.0075
0.125	0.7015	1.04670212	4.88146847	0.231349216	0.002891865	2.96205142	0.140381584	0.00175477	0.0125
0.175	0.8601	0.74764437	4.42364467	0.209651406	0.0036689	2.07027246	0.098117178	0.001717051	0.0175
0.225	0.99435	0.58150118	4.17919731	0.198066223	0.00445649	1.45849548	0.069123008	0.001555268	0.0225
0.275	0.94665	0.47577369	3.59801049	0.170521824	0.00468935	1.00782354	0.047764149	0.001313514	0.0275
0.325	0.89895	0.40257774	3.20012476	0.151664681	0.004929102	0.7404527	0.035092545	0.001140508	0.0325
0.375	0.85125	0.34890071	2.89093991	0.13701137	0.005137926	0.65821727	0.031195131	0.001169817	0.0375
0.425	0.80355	0.30785356	2.63914974	0.125078187	0.005315823	0.77949255	0.036942775	0.001570068	0.0425
0.475	0.75585	0.27544793	2.42662962	0.115006143	0.005462792	0.86149778	0.040829279	0.001939391	0.0475
0.525	0.70815	0.24921479	2.24215954	0.106263485	0.005578833	0.91545298	0.043386397	0.002277786	0.0525
0.575	0.66045	0.22754394	2.07842208	0.098503416	0.005663946	0.94867554	0.044960926	0.002585253	0.0575
0.625	0.61275	0.20934042	1.93044143	0.091490115	0.005718132	0.96614131	0.045788688	0.002861793	0.0625
0.675	0.56505	0.19383373	1.79471607	0.085057634	0.00574139	0.97135178	0.04603563	0.003107405	0.0675
0.725	0.51735	0.18046588	1.66871042	0.079085802	0.005733721	0.96684255	0.045821922	0.003322089	0.0725
0.775	0.46965	0.16882292	1.55054325	0.073485462	0.005695123	0.95449483	0.045236722	0.003505846	0.0775
0.825	0.42195	0.15859123	1.43878938	0.06818907	0.005625598	0.93573381	0.044347574	0.003658675	0.0825
0.875	0.37425	0.14952887	1.33234939	0.063144521	0.005525146	0.91165892	0.043206584	0.003780576	0.0875
0.925	0.32655	0.14144623	1.23036157	0.058310975	0.005393765	0.88313186	0.04185459	0.00387155	0.0925
0.975	0.27885	0.13419258	1.13214096	0.05365597	0.005231457	0.85083758	0.040324056	0.003931595	0.0975
Overall p(collision)			**Upwind**		**0.095828292**	**Downwind**		**0.047779454**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.09582829 + 0.04777945)/2
Average probability of collision = 0.071804

Annual collision risk for Red-throated diver assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 937.057 x 0.071804

Annual collision risk = 67.284 birds

Corrected annual collision risk assuming avoidance

Red-throated diver avoidance rate = 0.995

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 67.284 x (1 - 0.995)
Annual collision risk, with avoidance = 0.336 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.286 birds

Calculate number of years per collision

Number of years per collision for Red-throated diver = 1/corrected annual risk
Number of years per collision for Red-throated diver = 1/0.286

Number of years per collision for Red-throated diver = 3.497

[1] Forsythe, W. C., Rykiel, E. J., Stahl, R. S., Wu, H. and Schoolfield, R. M.,1995. A model comparison for daylength as a function of latitude and day of year. Ecological Modelling Vol 80, Issue 1, 87-95

Collision Risk Model Calculations for Red-throated diver 2017 / 2018

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as April - August.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
2, 3, 6	830.338	36	29892.17	107611804.8	1589.665468	1.4772E-05
Total	830.338	36	29892.17	107611804.8	1589.665468	1.4772E-05

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall observed area

Mean bird activity =Total bird activity/combined VPs
Mean bird activity = 1.477E-5/1 = **1.477E-05**

Overall area covered by VPs (excluding overlap) = 830338 m2
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 830338 x 1.477E-5 = **1.2266E+01**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 103 m Observed height band max = 180 m
Rotor radius = 77 m Observed height band min = 40 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 180 m
Rotor min height = 26 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (180 - 26)/(180 - 40)
Proportion of actual height band = 1.1

Corrected bird activity = **1.349E+01**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for April - August and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 2597.3

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 2597.3 x 1.349E+1
No. of hours of bird occupancy = 35044.15

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 830338 x 10000 x 77 x 2
Vw = 1278720520000 m3

Calculate the combined rotor swept volume

Number of turbines = 18
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = Reference Notes m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 18 x Pi x 77 x 77 x (3.652 + Reference Notes)
Vr = 1428877.367 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)

Bird occupancy in rotor swept volume = 35044.15 x 3600 x 1428877.367/1278720520000
Bird occupancy in rotor swept volume = 140.973

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 21.1 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.61)/21.1
Bird transit time through the rotors = 0.202 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 140.973/0.202
No. of transits = 697.955

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1	
No. of blades	3	
Maximum chord	4	m
Pitch (degrees)	20	
Rotor radius	77	m
Rotation Period	3	s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.61	m
Wingspan	1.11	m
Bird speed	21.1	m/s
F:Flapping	1	

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.61/1.11
Bird aspect ratio (b) = 0.55

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	5.2335106	17.9069931	0.848672657	0.001060841	16.3337004	0.774109023	0.000967636	0.00125
0.075	0.575	1.74450353	6.49342857	0.30774543	0.002308091	4.92013591	0.233181797	0.001748863	0.0075
0.125	0.7015	1.04670212	4.88146847	0.231349216	0.002891865	2.96205142	0.140381584	0.00175477	0.0125
0.175	0.8601	0.74764437	4.42364467	0.209651406	0.0036689	2.07027246	0.098117178	0.001717051	0.0175
0.225	0.99435	0.58150118	4.17919731	0.198066223	0.00445649	1.45849548	0.069123008	0.001555268	0.0225
0.275	0.94665	0.47577369	3.59801049	0.170521824	0.00468935	1.00782354	0.047764149	0.001313514	0.0275
0.325	0.89895	0.40257774	3.20012476	0.151664681	0.004929102	0.7404527	0.035092545	0.001140508	0.0325
0.375	0.85125	0.34890071	2.89093991	0.13701137	0.005137926	0.65821727	0.031195131	0.001169817	0.0375
0.425	0.80355	0.30785356	2.63914974	0.125078187	0.005315823	0.77949255	0.036942775	0.001570068	0.0425
0.475	0.75585	0.27544793	2.42662962	0.115006143	0.005462792	0.86149778	0.040829279	0.001939391	0.0475
0.525	0.70815	0.24921479	2.24215954	0.106263485	0.005578833	0.91545298	0.043386397	0.002277786	0.0525
0.575	0.66045	0.22754394	2.07842208	0.098503416	0.005663946	0.94867554	0.044960926	0.002585253	0.0575
0.625	0.61275	0.20934042	1.93044143	0.091490115	0.005718132	0.96614131	0.045788688	0.002861793	0.0625
0.675	0.56505	0.19383373	1.79471607	0.085057634	0.00574139	0.97135178	0.04603563	0.003107405	0.0675
0.725	0.51735	0.18046588	1.66871042	0.079085802	0.005733721	0.96684255	0.045821922	0.003322089	0.0725
0.775	0.46965	0.16882292	1.55054325	0.073485462	0.005695123	0.95449483	0.045236722	0.003505846	0.0775
0.825	0.42195	0.15859123	1.43878938	0.06818907	0.005625598	0.93573381	0.044347574	0.003658675	0.0825
0.875	0.37425	0.14952887	1.33234939	0.063144521	0.005525146	0.91165892	0.043206584	0.003780576	0.0875
0.925	0.32655	0.14144623	1.23036157	0.058310975	0.005393765	0.88313186	0.04185459	0.00387155	0.0925
0.975	0.27885	0.13419258	1.13214096	0.05365597	0.005231457	0.85083758	0.040324056	0.003931595	0.0975
Overall p(collision)			**Upwind**		**0.095828292**	**Downwind**		**0.047779454**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.09582829 + 0.04777945)/2
Average probability of collision = 0.071804

Annual collision risk for Red-throated diver assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 697.955 x 0.071804

Annual collision risk = 50.116 birds

Corrected annual collision risk assuming avoidance

Red-throated diver avoidance rate = 0.995

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 50.116 x (1 - 0.995)
Annual collision risk, with avoidance = 0.251 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.213 birds

Calculate number of years per collision

Number of years per collision for Red-throated diver = 1/corrected annual risk
Number of years per collision for Red-throated diver = 1/0.213

Number of years per collision for Red-throated diver = 4.695

[1] Forsythe, W. C., Rykiel, E. J., Stahl, R. S., Wu, H. and Schoolfield, R. M.,1995. A model comparison for daylength as a function of latitude and day of year. Ecological Modelling Vol 80, Issue 1, 87-95

Collision Risk Model Calculations for Great Skua 2016

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as April - August.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
2, 3, 6	830.338	36	29892.17	107611804.8	7660.06658	7.1182E-05
Total	830.338	36	29892.17	107611804.8	7660.06658	7.1182E-05

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall observed area

Mean bird activity =Total bird activity/combined VPs
Mean bird activity = 7.118E-5/1 = **7.118E-05**

Overall area covered by VPs (excluding overlap) = 830338 m2
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 830338 x 7.118E-5 = **5.9105E+01**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 103 m Observed height band max = 180 m
Rotor radius = 77 m Observed height band min = 40 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 180 m
Rotor min height = 26 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (180 - 26)/(180 - 40)
Proportion of actual height band = 1.1

Corrected bird activity = **6.502E+01**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for April - August and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 2598.381

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 2598.381 x 6.502E+1
No. of hours of bird occupancy = 168936.363

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 830338 x 10000 x 77 x 2
Vw = 1278720520000 m3

Calculate the combined rotor swept volume

Number of turbines = 18
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.56 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 18 x Pi x 77 x 77 x (3.652 + 0.56)
Vr = 1412113.515 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)

Bird occupancy in rotor swept volume = 168936.363 x 3600 x 1412113.515/1278720520000
Bird occupancy in rotor swept volume = 671.614

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 16 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.56)/16
Bird transit time through the rotors = 0.2632 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 671.614/0.2632
No. of transits = 2551.373

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1	
No. of blades	3	
Maximum chord	4	m
Pitch (degrees)	20	
Rotor radius	77	m
Rotation Period	3	s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.56	m
Wingspan	1.36	m
Bird speed	16	m/s
F:Flapping	1	

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.56/1.36
Bird aspect ratio (b) = 0.412

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	3.96853884	14.7610345	0.922564655	0.001153206	13.1877418	0.824233864	0.001030292	0.00125
0.075	0.575	1.32284628	5.44477571	0.340298482	0.002552239	3.87148305	0.241967691	0.001814758	0.0075
0.125	0.7015	0.79370777	4.13198187	0.258248867	0.003228111	2.21256482	0.138285301	0.001728566	0.0125
0.175	0.8601	0.56693412	3.78056831	0.236285519	0.004134997	1.4271961	0.089199756	0.001560996	0.0175
0.225	0.99435	0.44094876	3.60810196	0.225506373	0.005073893	0.88740013	0.055462508	0.001247906	0.0225
0.275	0.94665	0.36077626	3.13882202	0.196176376	0.00539485	0.57136493	0.035710308	0.000982033	0.0275
0.325	0.89895	0.30527222	2.82133459	0.176333412	0.005730836	0.75833747	0.047396092	0.001540373	0.0325
0.375	0.85125	0.26456926	2.5711085	0.160694281	0.006026036	0.87804868	0.054878042	0.002057927	0.0375
0.425	0.80355	0.23344346	2.36440444	0.147775278	0.006280449	0.95423785	0.059639865	0.002534694	0.0425
0.475	0.75585	0.20887047	2.18747862	0.136717414	0.006494077	1.00064878	0.062540549	0.002970676	0.0475
0.525	0.70815	0.18897804	2.03182296	0.126988935	0.006666919	1.02578955	0.064111847	0.003365872	0.0525
0.575	0.66045	0.17254517	1.89188873	0.118243046	0.006798975	1.03520889	0.064700556	0.003720282	0.0575
0.625	0.61275	0.15874155	1.76390279	0.110243925	0.006890245	1.03267995	0.064542497	0.004033906	0.0625
0.675	0.56505	0.14698292	1.64520996	0.102825623	0.00694073	1.02085789	0.063803618	0.004306744	0.0675
0.725	0.51735	0.13684617	1.53388753	0.095867971	0.006950428	1.00166544	0.06260409	0.004538797	0.0725
0.775	0.46965	0.12801738	1.42850897	0.08928181	0.00691934	0.97652912	0.06103307	0.004730063	0.0775
0.825	0.42195	0.12025875	1.32799357	0.082999598	0.006847467	0.94652963	0.059158102	0.004880543	0.0825
0.875	0.37425	0.11338682	1.23150765	0.076969228	0.006734807	0.91250066	0.057031291	0.004990238	0.0875
0.925	0.32655	0.10725781	1.13839779	0.071149862	0.006581362	0.87509564	0.054693477	0.005059147	0.0925
0.975	0.27885	0.10175741	1.04814458	0.065509036	0.006387131	0.83483396	0.052177122	0.005087269	0.0975
Overall p(collision)			**Upwind**		**0.113786098**	**Downwind**		**0.062181083**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.1137861 + 0.06218108)/2
Average probability of collision = 0.087984

Annual collision risk for Great Skua assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 2551.373 x 0.087984

Annual collision risk = 224.479 birds

Corrected annual collision risk assuming avoidance

Great Skua avoidance rate = 0.995

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 224.479 x (1 - 0.995)
Annual collision risk, with avoidance = 1.122 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.954 birds

Calculate number of years per collision

Number of years per collision for Great Skua = 1/corrected annual risk
Number of years per collision for Great Skua = 1/0.954

Number of years per collision for Great Skua = 1.0482

[1] Forsythe, W. C., Rykiel, E. J., Stahl, R. S., Wu, H. and Schoolfield, R. M.,1995. A model comparison for daylength as a function of latitude and day of year. Ecological Modelling Vol 80, Issue 1, 87-95

Collision Risk Model Calculations for Arctic skua 2016

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as April - August.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
2, 3, 6	830.338	36	29892.17	107611804.8	127.2673382	1.1827E-06
Total	830.338	36	29892.17	107611804.8	127.2673382	1.1827E-06

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall observed area

Mean bird activity =Total bird activity/combined VPs
Mean bird activity = 1.183E-6/1 = **1.183E-06**

Overall area covered by VPs (excluding overlap) = 830338 m2
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 830338 x 1.183E-6 = **9.8200E-01**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 103 m Observed height band max = 180 m
Rotor radius = 77 m Observed height band min = 40 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 180 m
Rotor min height = 26 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (180 - 26)/(180 - 40)
Proportion of actual height band = 1.1

Corrected bird activity = **1.080E+00**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for April - August and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 2598.381

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 2598.381 x 1.080E+0
No. of hours of bird occupancy = 2806.775

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 830338 x 10000 x 77 x 2
Vw = 1278720520000 m3

Calculate the combined rotor swept volume

Number of turbines = 18
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.44 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 18 x Pi x 77 x 77 x (3.652 + 0.44)
Vr = 1371880.269 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)

Bird occupancy in rotor swept volume = 2806.775 x 3600 x 1371880.269/1278720520000
Bird occupancy in rotor swept volume = 10.841

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 13.3 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.44)/13.3
Bird transit time through the rotors = 0.3077 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 10.841/0.3077
No. of transits = 35.238

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1	
No. of blades	3	
Maximum chord	4	m
Pitch (degrees)	20	
Rotor radius	77	m
Rotation Period	3	s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.44	m
Wingspan	1.18	m
Bird speed	13.3	m/s
F:Flapping	1	

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.44/1.18
Bird aspect ratio (b) = 0.373

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	3.29884791	11.8090639	0.887899538	0.001109874	10.2357712	0.769606857	0.000962009	0.00125
0.075	0.575	1.09961597	4.4607855	0.335397406	0.002515481	2.88749285	0.217104725	0.001628285	0.0075
0.125	0.7015	0.65976958	3.47790221	0.261496407	0.003268705	1.55848517	0.117179336	0.001464742	0.0125
0.175	0.8601	0.47126399	3.25633567	0.244837268	0.004284652	0.90296346	0.06789199	0.00118811	0.0175
0.225	0.99435	0.36653866	3.1703014	0.238368526	0.005363292	0.44959957	0.033804479	0.000760601	0.0225
0.275	0.94665	0.29989526	2.80219282	0.21069119	0.005794008	0.66799412	0.050225122	0.001381191	0.0275
0.325	0.89895	0.25375753	2.52726921	0.190020242	0.006175658	0.81240285	0.061082921	0.001985195	0.0325
0.375	0.85125	0.21992319	2.30825658	0.173553126	0.006508242	0.9009006	0.067736887	0.002540133	0.0375
0.425	0.80355	0.19404988	2.12542164	0.159806138	0.006791761	0.95322065	0.071670726	0.003046006	0.0425
0.475	0.75585	0.17362357	1.96733985	0.14792029	0.007026214	0.98078755	0.073743425	0.003502813	0.0475
0.525	0.70815	0.157088	1.82693889	0.137363827	0.007211601	0.99067362	0.074486739	0.003910554	0.0525
0.575	0.66045	0.14342817	1.69960637	0.127789953	0.007347922	0.98749126	0.074247463	0.004269229	0.0575
0.625	0.61275	0.13195392	1.58220587	0.118962847	0.007435178	0.97437688	0.073261419	0.004578839	0.0625
0.675	0.56505	0.12217955	1.47253026	0.110716561	0.007473368	0.9535376	0.071694556	0.004839383	0.0675
0.725	0.51735	0.11375338	1.36898129	0.102930924	0.007462492	0.92657168	0.069667044	0.005050861	0.0725
0.775	0.46965	0.10641445	1.27037317	0.095516779	0.00740255	0.89466492	0.067268039	0.005213273	0.0775
0.825	0.42195	0.09996509	1.17580755	0.088406583	0.007293543	0.85871565	0.064565086	0.00532662	0.0825
0.875	0.37425	0.0942528	1.08459144	0.081548228	0.00713547	0.81941687	0.061610291	0.0053909	0.0875
0.925	0.32655	0.08915805	0.99618167	0.074900877	0.006928331	0.77731176	0.058444493	0.005406116	0.0925
0.975	0.27885	0.08458584	0.91014649	0.068432067	0.006672127	0.73283204	0.055100153	0.005372265	0.0975
Overall p(collision)			**Upwind**		**0.121200469**	**Downwind**		**0.067817122**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.12120047 + 0.06781712)/2
Average probability of collision = 0.094509

Annual collision risk for Arctic skua assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 35.238 x 0.094509

Annual collision risk = 3.33 birds

Corrected annual collision risk assuming avoidance

Arctic skua avoidance rate = 0.995

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 3.33 x (1 - 0.995)
Annual collision risk, with avoidance = 0.017 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.014 birds

Calculate number of years per collision

Number of years per collision for Arctic skua = 1/corrected annual risk
Number of years per collision for Arctic skua = 1/0.014

Number of years per collision for Arctic skua = 70.6529

[1] Forsythe, W. C., Rykiel, E. J., Stahl, R. S., Wu, H. and Schoolfield, R. M.,1995. A model comparison for daylength as a function of latitude and day of year. Ecological Modelling Vol 80, Issue 1, 87-95

Collision Risk Model Calculations for Arctic skua 2017 / 2018

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as April - August.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
2, 3, 6	830.338	36	29892.17	107611804.8	624.4245433	5.8026E-06
Total	830.338	36	29892.17	107611804.8	624.4245433	5.8026E-06

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall observed area

Mean bird activity =Total bird activity/combined VPs
Mean bird activity = 5.803E-6/1 = **5.803E-06**

Overall area covered by VPs (excluding overlap) = 830338 m2
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 830338 x 5.803E-6 = **4.8181E+00**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 103 m Observed height band max = 180 m
Rotor radius = 77 m Observed height band min = 40 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 180 m
Rotor min height = 26 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (180 - 26)/(180 - 40)
Proportion of actual height band = 1.1

Corrected bird activity = **5.300E+00**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for April - August and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 2597.3

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 2597.3 x 5.300E+0
No. of hours of bird occupancy = 13765.429

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 830338 x 10000 x 77 x 2
Vw = 1278720520000 m3

Calculate the combined rotor swept volume

Number of turbines = 18
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.44 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 18 x Pi x 77 x 77 x (3.652 + 0.44)
Vr = 1371880.269 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)

Bird occupancy in rotor swept volume = 13765.429 x 3600 x 1371880.269/1278720520000
Bird occupancy in rotor swept volume = 53.166

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 13.3 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.44)/13.3
Bird transit time through the rotors = 0.3077 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 53.166/0.3077
No. of transits = 172.812

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1	
No. of blades	3	
Maximum chord	4	m
Pitch (degrees)	20	
Rotor radius	77	m
Rotation Period	3	s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.44	m
Wingspan	1.18	m
Bird speed	13.3	m/s
F:Flapping	1	

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.44/1.18
Bird aspect ratio (b) = 0.373

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	3.29884791	11.8090639	0.887899538	0.001109874	10.2357712	0.769606857	0.000962009	0.00125
0.075	0.575	1.09961597	4.4607855	0.335397406	0.002515481	2.88749285	0.217104725	0.001628285	0.0075
0.125	0.7015	0.65976958	3.47790221	0.261496407	0.003268705	1.55848517	0.117179336	0.001464742	0.0125
0.175	0.8601	0.47126399	3.25633567	0.244837268	0.004284652	0.90296346	0.06789199	0.00118811	0.0175
0.225	0.99435	0.36653866	3.1703014	0.238368526	0.005363292	0.44959957	0.033804479	0.000760601	0.0225
0.275	0.94665	0.29989526	2.80219282	0.21069119	0.005794008	0.66799412	0.050225122	0.001381191	0.0275
0.325	0.89895	0.25375753	2.52726921	0.190020242	0.006175658	0.81240285	0.061082921	0.001985195	0.0325
0.375	0.85125	0.21992319	2.30825658	0.173553126	0.006508242	0.9009006	0.067736887	0.002540133	0.0375
0.425	0.80355	0.19404988	2.12542164	0.159806138	0.006791761	0.95322065	0.071670726	0.003046006	0.0425
0.475	0.75585	0.17362357	1.96733985	0.14792029	0.007026214	0.98078755	0.073743425	0.003502813	0.0475
0.525	0.70815	0.157088	1.82693889	0.137363827	0.007211601	0.99067362	0.074486739	0.003910554	0.0525
0.575	0.66045	0.14342817	1.69960637	0.127789953	0.007347922	0.98749126	0.074247463	0.004269229	0.0575
0.625	0.61275	0.13195392	1.58220587	0.118962847	0.007435178	0.97437688	0.073261419	0.004578839	0.0625
0.675	0.56505	0.12217955	1.47253026	0.110716561	0.007473368	0.9535376	0.071694556	0.004839383	0.0675
0.725	0.51735	0.11375338	1.36898129	0.102930924	0.007462492	0.92657168	0.069667044	0.005050861	0.0725
0.775	0.46965	0.10641445	1.27037317	0.095516779	0.00740255	0.89466492	0.067268039	0.005213273	0.0775
0.825	0.42195	0.09996509	1.17580755	0.088406583	0.007293543	0.85871565	0.064565086	0.00532662	0.0825
0.875	0.37425	0.0942528	1.08459144	0.081548228	0.00713547	0.81941687	0.061610291	0.0053909	0.0875
0.925	0.32655	0.08915805	0.99618167	0.074900877	0.006928331	0.77731176	0.058444493	0.005406116	0.0925
0.975	0.27885	0.08458584	0.91014649	0.068432067	0.006672127	0.73283204	0.055100153	0.005372265	0.0975
Overall p(collision)			**Upwind**		**0.121200469**	**Downwind**		**0.067817122**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.12120047 + 0.06781712)/2
Average probability of collision = 0.094509

Annual collision risk for Arctic skua assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 172.812 x 0.094509

Annual collision risk = 16.332 birds

Corrected annual collision risk assuming avoidance

Arctic skua avoidance rate = 0.995

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 16.332 x (1 - 0.995)
Annual collision risk, with avoidance = 0.082 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.069 birds

Calculate number of years per collision

Number of years per collision for Arctic skua = 1/corrected annual risk
Number of years per collision for Arctic skua = 1/0.069

Number of years per collision for Arctic skua = 14.4067

[1] Forsythe, W. C., Rykiel, E. J., Stahl, R. S., Wu, H. and Schoolfield, R. M.,1995. A model comparison for daylength as a function of latitude and day of year. Ecological Modelling Vol 80, Issue 1, 87-95

Collision Risk Model Calculations for Arctic tern 2016

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as April - August.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
2, 3, 6	830.338	36	29892.17	107611804.8	271.0468212	2.5187E-06
Total	830.338	36	29892.17	107611804.8	271.0468212	2.5187E-06

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall observed area

Mean bird activity =Total bird activity/combined VPs
Mean bird activity = 2.519E-6/1 = **2.519E-06**

Overall area covered by VPs (excluding overlap) = 830338 m2
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 830338 x 2.519E-6 = **2.0914E+00**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 103 m Observed height band max = 180 m
Rotor radius = 77 m Observed height band min = 40 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 180 m
Rotor min height = 26 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (180 - 26)/(180 - 40)
Proportion of actual height band = 1.1

Corrected bird activity = **2.301E+00**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for April - August and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 2598.381

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 2598.381 x 2.301E+0
No. of hours of bird occupancy = 5977.711

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 830338 x 10000 x 77 x 2
Vw = 1278720520000 m3

Calculate the combined rotor swept volume

Number of turbines = 18
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.34 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 18 x Pi x 77 x 77 x (3.652 + 0.34)
Vr = 1338352.564 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)

Bird occupancy in rotor swept volume = 5977.711 x 3600 x 1338352.564/1278720520000
Bird occupancy in rotor swept volume = 22.523

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 10 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.34)/10
Bird transit time through the rotors = 0.3992 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 22.523/0.3992
No. of transits = 56.423

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1	
No. of blades	3	
Maximum chord	4	m
Pitch (degrees)	20	
Rotor radius	77	m
Rotation Period	3	s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.34	m
Wingspan	0.8	m
Bird speed	10	m/s
F:Flapping	1	

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.34/0.8
Bird aspect ratio (b) = 0.425

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	2.48033678	8.13165033	0.813165033	0.001016456	6.55835767	0.655835767	0.000819795	0.00125
0.075	0.575	0.82677893	3.234981	0.3234981	0.002426236	1.66168834	0.166168834	0.001246266	0.0075
0.125	0.7015	0.49606736	2.66458164	0.266458164	0.003330727	0.7451646	0.07451646	0.000931456	0.0125
0.175	0.8601	0.35433383	2.66221848	0.266221848	0.004658882	0.37115373	0.037115373	0.000649519	0.0175
0.225	0.99435	0.27559298	2.73038888	0.273038888	0.006143375	0.67031296	0.067031296	0.001508204	0.0225
0.275	0.94665	0.22548516	2.43742381	0.243742381	0.006702915	0.83276314	0.083276314	0.002290099	0.0275
0.325	0.89895	0.19079514	2.21452263	0.221452263	0.007197199	0.92514943	0.092514943	0.003006736	0.0325
0.375	0.85125	0.16535579	2.03365978	0.203365978	0.007626224	0.97549739	0.097549739	0.003658115	0.0375
0.425	0.80355	0.14590216	1.87999821	0.187999821	0.007989992	0.99864408	0.099864408	0.004244237	0.0425
0.475	0.75585	0.13054404	1.74494802	0.174494802	0.008288503	1.00317938	0.100317938	0.004765102	0.0475
0.525	0.70815	0.11811128	1.6231917	0.16231917	0.008521756	0.99442082	0.099442082	0.005220709	0.0525
0.575	0.66045	0.10784073	1.51126126	0.151126126	0.008689752	0.97583636	0.097583636	0.005611059	0.0575
0.625	0.61275	0.09921347	1.40679851	0.140679851	0.008792491	0.94978423	0.094978423	0.005936151	0.0625
0.675	0.56505	0.09186433	1.30814395	0.130814395	0.008829972	0.91792391	0.091792391	0.006195986	0.0675
0.725	0.51735	0.08552885	1.21409589	0.121409589	0.008802195	0.88145708	0.088145708	0.006390564	0.0725
0.775	0.46965	0.08001086	1.12376274	0.112376274	0.008709161	0.84127534	0.084127534	0.006519884	0.0775
0.825	0.42195	0.07516172	1.03646908	0.103646908	0.00855087	0.79805412	0.079805412	0.006583946	0.0825
0.875	0.37425	0.07086677	0.95169384	0.095169384	0.008327321	0.75231447	0.075231447	0.006582752	0.0875
0.925	0.32655	0.06703613	0.86902863	0.086902863	0.008038515	0.70446479	0.070446479	0.006516299	0.0925
0.975	0.27885	0.06359838	0.78814884	0.078814884	0.007684451	0.6548297	0.06548297	0.00638459	0.0975
Overall p(collision)			**Upwind**		**0.140326995**	**Downwind**		**0.08506147**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.14032699 + 0.08506147)/2
Average probability of collision = 0.112694

Annual collision risk for Arctic tern assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 56.423 x 0.112694

Annual collision risk = 6.359 birds

Corrected annual collision risk assuming avoidance

Arctic tern avoidance rate = 0.98

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 6.359 x (1 - 0.98)
Annual collision risk, with avoidance = 0.127 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.108 birds

Calculate number of years per collision

Number of years per collision for Arctic tern = 1/corrected annual risk
Number of years per collision for Arctic tern = 1/0.108

Number of years per collision for Arctic tern = 9.251

[1] Forsythe, W. C., Rykiel, E. J., Stahl, R. S., Wu, H. and Schoolfield, R. M.,1995. A model comparison for daylength as a function of latitude and day of year. Ecological Modelling Vol 80, Issue 1, 87-95

Collision Risk Model Calculations for Arctic tern 2017 / 2018

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as April - August.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
2, 3, 6	830.338	36	29892.17	107611804.8	142.0345363	1.3199E-06
Total	830.338	36	29892.17	107611804.8	142.0345363	1.3199E-06

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall observed area

Mean bird activity =Total bird activity/combined VPs
Mean bird activity = 1.320E-6/1 = **1.320E-06**

Overall area covered by VPs (excluding overlap) = 830338 m2
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 830338 x 1.320E-6 = **1.0959E+00**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 103 m Observed height band max = 180 m
Rotor radius = 77 m Observed height band min = 40 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 180 m
Rotor min height = 26 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (180 - 26)/(180 - 40)
Proportion of actual height band = 1.1

Corrected bird activity = **1.206E+00**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for April - August and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 2597.3

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 2597.3 x 1.206E+0
No. of hours of bird occupancy = 3131.149

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 830338 x 10000 x 77 x 2
Vw = 1278720520000 m3

Calculate the combined rotor swept volume

Number of turbines = 18
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.34 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 18 x Pi x 77 x 77 x (3.652 + 0.34)
Vr = 1338352.564 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)

Bird occupancy in rotor swept volume = 3131.149 x 3600 x 1338352.564/1278720520000
Bird occupancy in rotor swept volume = 11.798

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 10 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.34)/10
Bird transit time through the rotors = 0.3992 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 11.798/0.3992
No. of transits = 29.556

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1) 1
No. of blades 3
Maximum chord 4 m
Pitch (degrees) 20
Rotor radius 77 m
Rotation Period 3 s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length 0.34 m
Wingspan 0.8 m
Bird speed 10 m/s
F:Flapping 1

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.34/0.8
Bird aspect ratio (b) = 0.425

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	2.48033678	8.13165033	0.813165033	0.001016456	6.55835767	0.655835767	0.000819795	0.00125
0.075	0.575	0.82677893	3.234981	0.3234981	0.002426236	1.66168834	0.166168834	0.001246266	0.0075
0.125	0.7015	0.49606736	2.66458164	0.266458164	0.003330727	0.7451646	0.07451646	0.000931456	0.0125
0.175	0.8601	0.35433383	2.66221848	0.266221848	0.004658882	0.37115373	0.037115373	0.000649519	0.0175
0.225	0.99435	0.27559298	2.73038888	0.273038888	0.006143375	0.67031296	0.067031296	0.001508204	0.0225
0.275	0.94665	0.22548516	2.43742381	0.243742381	0.006702915	0.83276314	0.083276314	0.002290099	0.0275
0.325	0.89895	0.19079514	2.21452263	0.221452263	0.007197199	0.92514943	0.092514943	0.003006736	0.0325
0.375	0.85125	0.16535579	2.03365978	0.203365978	0.007626224	0.97549739	0.097549739	0.003658115	0.0375
0.425	0.80355	0.14590216	1.87999821	0.187999821	0.007989992	0.99864408	0.099864408	0.004244237	0.0425
0.475	0.75585	0.13054404	1.74494802	0.174494802	0.008288503	1.00317938	0.100317938	0.004765102	0.0475
0.525	0.70815	0.11811128	1.6231917	0.16231917	0.008521756	0.99442082	0.099442082	0.005220709	0.0525
0.575	0.66045	0.10784073	1.51126126	0.151126126	0.008689752	0.97583636	0.097583636	0.005611059	0.0575
0.625	0.61275	0.09921347	1.40679851	0.140679851	0.008792491	0.94978423	0.094978423	0.005936151	0.0625
0.675	0.56505	0.09186433	1.30814395	0.130814395	0.008829972	0.91792391	0.091792391	0.006195986	0.0675
0.725	0.51735	0.08552885	1.21409589	0.121409589	0.008802195	0.88145708	0.088145708	0.006390564	0.0725
0.775	0.46965	0.08001086	1.12376274	0.112376274	0.008709161	0.84127534	0.084127534	0.006519884	0.0775
0.825	0.42195	0.07516172	1.03646908	0.103646908	0.00855087	0.79805412	0.079805412	0.006583946	0.0825
0.875	0.37425	0.07086677	0.95169384	0.095169384	0.008327321	0.75231447	0.075231447	0.006582752	0.0875
0.925	0.32655	0.06703613	0.86902863	0.086902863	0.008038515	0.70446479	0.070446479	0.006516299	0.0925
0.975	0.27885	0.06359838	0.78814884	0.078814884	0.007684451	0.6548297	0.06548297	0.00638459	0.0975
Overall p(collision)			**Upwind**		**0.140326995**	**Downwind**		**0.08506147**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.14032699 + 0.08506147)/2
Average probability of collision = 0.112694

Annual collision risk for Arctic tern assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 29.556 x 0.112694

Annual collision risk = 3.331 birds

Corrected annual collision risk assuming avoidance

Arctic tern avoidance rate = 0.98

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 3.331 x (1 - 0.98)
Annual collision risk, with avoidance = 0.067 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.057 birds

Calculate number of years per collision

Number of years per collision for Arctic tern = 1/corrected annual risk
Number of years per collision for Arctic tern = 1/0.057

Number of years per collision for Arctic tern = 17.6607

[1] Forsythe, W. C., Rykiel, E. J., Stahl, R. S., Wu, H. and Schoolfield, R. M.,1995. A model comparison for daylength as a function of latitude and day of year. Ecological Modelling Vol 80, Issue 1, 87-95

Collision Risk Model Calculations for Fulmar 2016

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as April - August.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
2, 3, 6	830.338	36	29892.17	107611804.8	2273.507378	2.1127E-05
Total	830.338	36	29892.17	107611804.8	2273.507378	2.1127E-05

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall observed area

Mean bird activity =Total bird activity/combined VPs
Mean bird activity = 2.113E-5/1 = **2.113E-05**

Overall area covered by VPs (excluding overlap) = 830338 m2
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 830338 x 2.113E-5 = **1.7542E+01**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 103 m Observed height band max = 180 m
Rotor radius = 77 m Observed height band min = 40 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 180 m
Rotor min height = 26 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (180 - 26)/(180 - 40)
Proportion of actual height band = 1.1

Corrected bird activity = **1.930E+01**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for April - August and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 2598.381

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 2598.381 x 1.930E+1
No. of hours of bird occupancy = 50140.304

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 830338 x 10000 x 77 x 2
Vw = 1278720520000 m3

Calculate the combined rotor swept volume

Number of turbines = 18
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.48 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 18 x Pi x 77 x 77 x (3.652 + 0.48)
Vr = 1385291.351 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)

Bird occupancy in rotor swept volume = 50140.304 x 3600 x 1385291.351/1278720520000
Bird occupancy in rotor swept volume = 195.549

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 13 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.48)/13
Bird transit time through the rotors = 0.3178 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 195.549/0.3178
No. of transits = 615.264

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1	
No. of blades	3	
Maximum chord	4	m
Pitch (degrees)	20	
Rotor radius	77	m
Rotation Period	3	s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.48	m
Wingspan	1.07	m
Bird speed	13	m/s
F:Flapping	1	

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.48/1.07
Bird aspect ratio (b) = 0.449

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	check area total
0.025	0.575	3.22443781	11.2057497	0.861980749	0.001077476	9.63245708	0.740958237	0.000926198	0.00125
0.075	0.575	1.0748126	4.2596808	0.327667754	0.002457508	2.68638814	0.206645242	0.001549839	0.0075
0.125	0.7015	0.64488756	3.35016322	0.257704863	0.003221311	1.43074618	0.110057398	0.001375717	0.0125
0.175	0.8601	0.46063397	3.15875654	0.242981272	0.004252172	0.80538434	0.061952641	0.001084171	0.0175
0.225	0.99435	0.35827087	3.17940026	0.244569251	0.005502808	0.50130157	0.03856166	0.000867637	0.0225
0.275	0.94665	0.29313071	2.81812291	0.216778686	0.005961414	0.73206403	0.056312618	0.001548597	0.0275
0.325	0.89895	0.24803368	2.54792861	0.195994509	0.006369822	0.87174345	0.067057188	0.002179359	0.0325
0.375	0.85125	0.21496252	2.33238414	0.179414165	0.006728031	0.95677303	0.073597926	0.002759922	0.0375
0.425	0.80355	0.18967281	2.15220132	0.165553948	0.007036043	1.00644097	0.077418536	0.003290288	0.0425
0.475	0.75585	0.16970725	1.99621332	0.153554871	0.007293856	1.03191408	0.079378006	0.003770455	0.0475
0.525	0.70815	0.15354466	1.85750733	0.142885179	0.007501472	1.04010519	0.080008091	0.004200425	0.0525
0.575	0.66045	0.14019295	1.731575	0.133198077	0.007658889	1.03552263	0.079655587	0.004580196	0.0575
0.625	0.61275	0.12897751	1.61535065	0.124257742	0.007766109	1.02123209	0.078556315	0.00490977	0.0625
0.675	0.56505	0.11942362	1.50667696	0.115898227	0.00782313	0.9993909	0.076876223	0.005189145	0.0675
0.725	0.51735	0.11118751	1.40399171	0.107999362	0.007829954	0.97156126	0.074735482	0.005418322	0.0725
0.775	0.46965	0.10401412	1.30613585	0.100471989	0.007786579	0.93890223	0.072223248	0.005597302	0.0775
0.825	0.42195	0.09771024	1.21223132	0.093248563	0.007693006	0.90229187	0.069407067	0.005726083	0.0825
0.875	0.37425	0.09212679	1.12160075	0.08627698	0.007549236	0.86240756	0.066339043	0.005804666	0.0875
0.925	0.32655	0.08714697	1.03371321	0.079516401	0.007355267	0.81978021	0.063060016	0.005833052	0.0925
0.975	0.27885	0.08267789	0.94814671	0.072934362	0.0071111	0.77483183	0.059602448	0.005811239	0.0975
Overall p(collision)			**Upwind**		**0.125975184**	**Downwind**		**0.072422384**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.12597518 + 0.07242238)/2
Average probability of collision = 0.099199

Annual collision risk for Fulmar assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 615.264 x 0.099199

Annual collision risk = 61.033 birds

Corrected annual collision risk assuming avoidance

Fulmar avoidance rate = 0.98

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 61.033 x (1 - 0.98)
Annual collision risk, with avoidance = 1.221 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 1.038 birds

Calculate number of years per collision

Number of years per collision for Fulmar = 1/corrected annual risk
Number of years per collision for Fulmar = 1/1.038

Number of years per collision for Fulmar = 0.9638

[1] Forsythe, W. C., Rykiel, E. J., Stahl, R. S., Wu, H. and Schoolfield, R. M.,1995. A model comparison for daylength as a function of latitude and day of year. Ecological Modelling Vol 80, Issue 1, 87-95

Collision Risk Model Calculations for Fulmar 2017 / 2018

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as April - August.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
2, 3, 6	830.338	36	29892.17	107611804.8	179.4385471	1.6675E-06
Total	830.338	36	29892.17	107611804.8	179.4385471	1.6675E-06

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall observed area

Mean bird activity =Total bird activity/combined VPs
Mean bird activity = 1.667E-6/1 = **1.667E-06**

Overall area covered by VPs (excluding overlap) = 830338 m2
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 830338 x 1.667E-6 = **1.3846E+00**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 103 m Observed height band max = 180 m
Rotor radius = 77 m Observed height band min = 40 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 180 m
Rotor min height = 26 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (180 - 26)/(180 - 40)
Proportion of actual height band = 1.1

Corrected bird activity = **1.523E+00**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for April - August and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 2597.3

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 2597.3 x 1.523E+0
No. of hours of bird occupancy = 3955.72

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 830338 x 10000 x 77 x 2
Vw = 1278720520000 m3

Calculate the combined rotor swept volume

Number of turbines = 18
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.48 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 18 x Pi x 77 x 77 x (3.652 + 0.48)
Vr = 1385291.351 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)

Bird occupancy in rotor swept volume = 3955.72 x 3600 x 1385291.351/1278720520000
Bird occupancy in rotor swept volume = 15.427

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 13 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.48)/13
Bird transit time through the rotors = 0.3178 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 15.427/0.3178
No. of transits = 48.539

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1	
No. of blades	3	
Maximum chord	4	m
Pitch (degrees)	20	
Rotor radius	77	m
Rotation Period	3	s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.48	m
Wingspan	1.07	m
Bird speed	13	m/s
F:Flapping	1	

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.48/1.07
Bird aspect ratio (b) = 0.449

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	3.22443781	11.2057497	0.861980749	0.001077476	9.63245708	0.740958237	0.000926198	0.00125
0.075	0.575	1.0748126	4.2596808	0.327667754	0.002457508	2.68638814	0.206645242	0.001549839	0.0075
0.125	0.7015	0.64488756	3.35016322	0.257704863	0.003221311	1.43074618	0.110057398	0.001375717	0.0125
0.175	0.8601	0.46063397	3.15875654	0.242981272	0.004252172	0.80538434	0.061952641	0.001084171	0.0175
0.225	0.99435	0.35827087	3.17940026	0.244569251	0.005502808	0.50130157	0.03856166	0.000867637	0.0225
0.275	0.94665	0.29313071	2.81812291	0.216778686	0.005961414	0.73206403	0.056312618	0.001548597	0.0275
0.325	0.89895	0.24803368	2.54792861	0.195994509	0.006369822	0.87174345	0.067057188	0.002179359	0.0325
0.375	0.85125	0.21496252	2.33238414	0.179414165	0.006728031	0.95677303	0.073597926	0.002759922	0.0375
0.425	0.80355	0.18967281	2.15220132	0.165553948	0.007036043	1.00644097	0.077418536	0.003290288	0.0425
0.475	0.75585	0.16970725	1.99621332	0.153554871	0.007293856	1.03191408	0.079378006	0.003770455	0.0475
0.525	0.70815	0.15354466	1.85750733	0.142885179	0.007501472	1.04010519	0.080008091	0.004200425	0.0525
0.575	0.66045	0.14019295	1.731575	0.133198077	0.007658889	1.03552263	0.079655587	0.004580196	0.0575
0.625	0.61275	0.12897751	1.61535065	0.124257742	0.007766109	1.02123209	0.078556315	0.00490977	0.0625
0.675	0.56505	0.11942362	1.50667696	0.115898227	0.00782313	0.9993909	0.076876223	0.005189145	0.0675
0.725	0.51735	0.11118751	1.40399171	0.107999362	0.007829954	0.97156126	0.074735482	0.005418322	0.0725
0.775	0.46965	0.10401412	1.30613585	0.100471989	0.007786579	0.93890223	0.072223248	0.005597302	0.0775
0.825	0.42195	0.09771024	1.21223132	0.093248563	0.007693006	0.90229187	0.069407067	0.005726083	0.0825
0.875	0.37425	0.09212679	1.12160075	0.08627698	0.007549236	0.86240756	0.066339043	0.005804666	0.0875
0.925	0.32655	0.08714697	1.03371321	0.079516401	0.007355267	0.81978021	0.063060016	0.005833052	0.0925
0.975	0.27885	0.08267789	0.94814671	0.072934362	0.0071111	0.77483183	0.059602448	0.005811239	0.0975
Overall p(collision)			**Upwind**		**0.125975184**	**Downwind**		**0.072422384**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.12597518 + 0.07242238)/2
Average probability of collision = 0.099199

Annual collision risk for Fulmar assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 48.539 x 0.099199

Annual collision risk = 4.815 birds

<u>Corrected annual collision risk assuming avoidance</u>

Fulmar avoidance rate = 0.98

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 4.815 x (1 - 0.98)
Annual collision risk, with avoidance = 0.096 birds

<u>Corrected for assumed operational downtime of the rotors</u>

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.082 birds

<u>Calculate number of years per collision</u>

Number of years per collision for Fulmar = 1/corrected annual risk
Number of years per collision for Fulmar = 1/0.082

Number of years per collision for Fulmar = 12.2168

[1] Forsythe, W. C., Rykiel, E. J., Stahl, R. S., Wu, H. and Schoolfield, R. M.,1995. A model comparison for daylength as a function of latitude and day of year. Ecological Modelling Vol 80, Issue 1, 87-95

Collision Risk Model Calculations for Curlew 2016

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as April - August.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
2, 3, 6	830.338	36	29892.17	107611804.8	79.68050189	7.4044E-07
Total	830.338	36	29892.17	107611804.8	79.68050189	7.4044E-07

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall observed area

Mean bird activity =Total bird activity/combined VPs
Mean bird activity = 7.404E-7/1 = **7.404E-07**

Overall area covered by VPs (excluding overlap) = 830338 m2
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 830338 x 7.404E-7 = **6.1482E-01**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 103 m Observed height band max = 180 m
Rotor radius = 77 m Observed height band min = 40 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 180 m
Rotor min height = 26 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (180 - 26)/(180 - 40)
Proportion of actual height band = 1.1

Corrected bird activity = **6.763E-01**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for April - August and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 2598.381

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 2598.381 x 6.763E-1
No. of hours of bird occupancy = 1757.287

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 830338 x 10000 x 77 x 2
Vw = 1278720520000 m3

Calculate the combined rotor swept volume

Number of turbines = 18
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.55 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 18 x Pi x 77 x 77 x (3.652 + 0.55)
Vr = 1408760.744 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)

Bird occupancy in rotor swept volume = 1757.287 x 3600 x 1408760.744/1278720520000
Bird occupancy in rotor swept volume = 6.97

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 8 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.55)/8
Bird transit time through the rotors = 0.5252 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 6.97/0.5252
No. of transits = 13.271

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1	
No. of blades	3	
Maximum chord	4	m
Pitch (degrees)	20	
Rotor radius	77	m
Rotation Period	3	s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.55	m
Wingspan	0.9	m
Bird speed	8	m/s
F:Flapping	1	

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.55/0.9
Bird aspect ratio (b) = 0.611

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	1.98426942	6.86107647	0.857634559	0.001072043	5.28778381	0.660972977	0.000826216	0.00125
0.075	0.575	0.66142314	2.81145638	0.351432047	0.00263574	1.23816372	0.154770465	0.001160778	0.0075
0.125	0.7015	0.39685388	2.55612391	0.319515489	0.003993944	0.63670687	0.079588358	0.000994854	0.0125
0.175	0.8601	0.28346706	2.643112	0.330389	0.005781808	0.8102602	0.101282525	0.001772444	0.0175
0.225	0.99435	0.22047438	2.73438128	0.34179766	0.007690447	1.08632055	0.135790069	0.003055277	0.0225
0.275	0.94665	0.18038813	2.48695775	0.310869718	0.008548917	1.2032292	0.150403651	0.0041361	0.0275
0.325	0.89895	0.15263611	2.29558531	0.286948164	0.009325815	1.26408675	0.158010844	0.005135352	0.0325
0.375	0.85125	0.13228463	2.13784354	0.267230443	0.010021142	1.29131363	0.161414204	0.006053033	0.0375
0.425	0.80355	0.11672173	2.00186279	0.250232849	0.010634896	1.2967795	0.162097437	0.006889141	0.0425
0.475	0.75585	0.10443523	1.88077116	0.235096395	0.011167079	1.28735624	0.16091953	0.007643678	0.0475
0.525	0.70815	0.09448902	1.77031461	0.221289326	0.01161769	1.26729791	0.158412238	0.008316643	0.0525
0.575	0.66045	0.08627258	1.66771877	0.208464847	0.011986729	1.23937885	0.154922357	0.008908036	0.0575
0.625	0.61275	0.07937078	1.57109708	0.196387135	0.012274196	1.20548566	0.150685708	0.009417857	0.0625
0.675	0.56505	0.07349146	1.47912194	0.184890243	0.012480091	1.16694591	0.145868239	0.009846106	0.0675
0.725	0.51735	0.06842308	1.39083201	0.173854001	0.012604415	1.12472096	0.14059012	0.010192784	0.0725
0.775	0.46965	0.06400869	1.305514	0.16318925	0.012647167	1.07952408	0.13494051	0.01045789	0.0775
0.825	0.42195	0.06012938	1.22262758	0.152828448	0.012608347	1.03189561	0.128986952	0.010641424	0.0825
0.875	0.37425	0.05669341	1.1417559	0.142719488	0.012487955	0.98225241	0.122781551	0.010743386	0.0875
0.925	0.32655	0.0536289	1.06257225	0.132821531	0.012285992	0.93092117	0.116365147	0.010763776	0.0925
0.975	0.27885	0.0508787	0.98481692	0.123102115	0.012002456	0.87816161	0.109770202	0.010702595	0.0975
Overall p(collision)			**Upwind**		**0.193866869**	**Downwind**		**0.137657368**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.19386687 + 0.13765737)/2
Average probability of collision = 0.165762

Annual collision risk for Curlew assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 13.271 x 0.165762

Annual collision risk = 2.2 birds

Corrected annual collision risk assuming avoidance

Curlew avoidance rate = 0.98

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 2.2 x (1 - 0.98)
Annual collision risk, with avoidance = 0.044 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.037 birds

Calculate number of years per collision

Number of years per collision for Curlew = 1/corrected annual risk
Number of years per collision for Curlew = 1/0.037

Number of years per collision for Curlew = 26.7409

[1] Forsythe, W. C., Rykiel, E. J., Stahl, R. S., Wu, H. and Schoolfield, R. M.,1995. A model comparison for daylength as a function of latitude and day of year. Ecological Modelling Vol 80, Issue 1, 87-95

Collision Risk Model Calculations for Curlew 2017 / 2018

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as April - August.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
2, 3, 6	830.338	36	29892.17	107611804.8	13.80816474	1.2831E-07
Total	830.338	36	29892.17	107611804.8	13.80816474	1.2831E-07

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall observed area

Mean bird activity =Total bird activity/combined VPs
Mean bird activity = 1.283E-7/1 = **1.283E-07**

Overall area covered by VPs (excluding overlap) = 830338 m2
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 830338 x 1.283E-7 = **1.0654E-01**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 103 m   Observed height band max = 180 m
Rotor radius = 77 m   Observed height band min = 40 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 180 m
Rotor min height = 26 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (180 - 26)/(180 - 40)
Proportion of actual height band = 1.1

Corrected bird activity = **1.172E-01**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for April - August and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 2597.3

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 2597.3 x 1.172E-1
No. of hours of bird occupancy = 304.401

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 830338 x 10000 x 77 x 2
Vw = 1278720520000 m3

Calculate the combined rotor swept volume

Number of turbines = 18
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.55 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 18 x Pi x 77 x 77 x (3.652 + 0.55)
Vr = 1408760.744 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)

Bird occupancy in rotor swept volume = 304.401 x 3600 x 1408760.744/1278720520000
Bird occupancy in rotor swept volume = 1.207

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 8 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.55)/8
Bird transit time through the rotors = 0.5252 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 1.207/0.5252
No. of transits = 2.298

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1	
No. of blades	3	
Maximum chord	4	m
Pitch (degrees)	20	
Rotor radius	77	m
Rotation Period	3	s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.55	m
Wingspan	0.9	m
Bird speed	8	m/s
F:Flapping	1	

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.55/0.9
Bird aspect ratio (b) = 0.611

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	1.98426942	6.86107647	0.857634559	0.001072043	5.28778381	0.660972977	0.000826216	0.00125
0.075	0.575	0.66142314	2.81145638	0.351432047	0.00263574	1.23816372	0.154770465	0.001160778	0.0075
0.125	0.7015	0.39685388	2.55612391	0.319515489	0.003993944	0.63670687	0.079588358	0.000994854	0.0125
0.175	0.8601	0.28346706	2.643112	0.330389	0.005781808	0.8102602	0.101282525	0.001772444	0.0175
0.225	0.99435	0.22047438	2.73438128	0.34179766	0.007690447	1.08632055	0.135790069	0.003055277	0.0225
0.275	0.94665	0.18038813	2.48695775	0.310869718	0.008548917	1.2032292	0.150403651	0.0041361	0.0275
0.325	0.89895	0.15263611	2.29558531	0.286948164	0.009325815	1.26408675	0.158010844	0.005135352	0.0325
0.375	0.85125	0.13228463	2.13784354	0.267230443	0.010021142	1.29131363	0.161414204	0.006053033	0.0375
0.425	0.80355	0.11672173	2.00186279	0.250232849	0.010634896	1.2967795	0.162097437	0.006889141	0.0425
0.475	0.75585	0.10443523	1.88077116	0.235096395	0.011167079	1.28735624	0.16091953	0.007643678	0.0475
0.525	0.70815	0.09448902	1.77031461	0.221289326	0.01161769	1.26729791	0.158412238	0.008316643	0.0525
0.575	0.66045	0.08627258	1.66771877	0.208464847	0.011986729	1.23937885	0.154922357	0.008908036	0.0575
0.625	0.61275	0.07937078	1.57109708	0.196387135	0.012274196	1.20548566	0.150685708	0.009417857	0.0625
0.675	0.56505	0.07349146	1.47912194	0.184890243	0.012480091	1.16694591	0.145868239	0.009846106	0.0675
0.725	0.51735	0.06842308	1.39083201	0.173854001	0.012604415	1.12472096	0.14059012	0.010192784	0.0725
0.775	0.46965	0.06400869	1.305514	0.16318925	0.012647167	1.07952408	0.13494051	0.01045789	0.0775
0.825	0.42195	0.06012938	1.22262758	0.152828448	0.012608347	1.03189561	0.128986952	0.010641424	0.0825
0.875	0.37425	0.05669341	1.1417559	0.142719488	0.012487955	0.98225241	0.122781551	0.010743386	0.0875
0.925	0.32655	0.0536289	1.06257225	0.132821531	0.012285992	0.93092117	0.116365147	0.010763776	0.0925
0.975	0.27885	0.0508787	0.98481692	0.123102115	0.012002456	0.87816161	0.109770202	0.010702595	0.0975
Overall p(collision)			**Upwind**		**0.193866869**	**Downwind**		**0.137657368**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.19386687 + 0.13765737)/2
Average probability of collision = 0.165762

Annual collision risk for Curlew assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 2.298 x 0.165762

Annual collision risk = 0.381 birds

Corrected annual collision risk assuming avoidance

Curlew avoidance rate = 0.98

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 0.381 x (1 - 0.98)
Annual collision risk, with avoidance = 0.008 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.006 birds

Calculate number of years per collision

Number of years per collision for Curlew = 1/corrected annual risk
Number of years per collision for Curlew = 1/0.006

Number of years per collision for Curlew = 154.4194

[1] Forsythe, W. C., Rykiel, E. J., Stahl, R. S., Wu, H. and Schoolfield, R. M.,1995. A model comparison for daylength as a function of latitude and day of year. Ecological Modelling Vol 80, Issue 1, 87-95

Collision Risk Model Calculations for Golden plover 2016

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as April - August.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
2, 3, 6	830.338	36	29892.17	107611804.8	71.26911011	6.6228E-07
Total	830.338	36	29892.17	107611804.8	71.26911011	6.6228E-07

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall observed area

Mean bird activity =Total bird activity/combined VPs
Mean bird activity = 6.623E-7/1 = **6.623E-07**

Overall area covered by VPs (excluding overlap) = 830338 m2
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 830338 x 6.623E-7 = **5.4992E-01**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 103 m Observed height band max = 180 m
Rotor radius = 77 m Observed height band min = 40 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 180 m
Rotor min height = 26 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (180 - 26)/(180 - 40)
Proportion of actual height band = 1.1

Corrected bird activity = **6.049E-01**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for April - August and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 2598.381

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 2598.381 x 6.049E-1
No. of hours of bird occupancy = 1571.781

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 830338 x 10000 x 77 x 2
Vw = 1278720520000 m3

Calculate the combined rotor swept volume

Number of turbines = 18
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.28 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 18 x Pi x 77 x 77 x (3.652 + 0.28)
Vr = 1318235.941 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)

Bird occupancy in rotor swept volume = 1571.781 x 3600 x 1318235.941/1278720520000
Bird occupancy in rotor swept volume = 5.833

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 10 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.28)/10
Bird transit time through the rotors = 0.3932 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 5.833/0.3932
No. of transits = 14.836

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1	
No. of blades	3	
Maximum chord	4	m
Pitch (degrees)	20	
Rotor radius	77	m
Rotation Period	3	s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.28	m
Wingspan	0.72	m
Bird speed	10	m/s
F:Flapping	1	

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.28/0.72
Bird aspect ratio (b) = 0.389

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	2.48033678	7.93322339	0.793322339	0.000991653	6.35993073	0.635993073	0.000794991	0.00125
0.075	0.575	0.82677893	3.16883868	0.316883868	0.002376629	1.59554602	0.159554602	0.00119666	0.0075
0.125	0.7015	0.49606736	2.62489626	0.262489626	0.00328112	0.70547921	0.070547921	0.000881849	0.0125
0.175	0.8601	0.35433383	2.60221848	0.260221848	0.004553882	0.31115373	0.031115373	0.000544519	0.0175
0.225	0.99435	0.27559298	2.67038888	0.267038888	0.006008375	0.61031296	0.061031296	0.001373204	0.0225
0.275	0.94665	0.22548516	2.37742381	0.237742381	0.006537915	0.77276314	0.077276314	0.002125099	0.0275
0.325	0.89895	0.19079514	2.15452263	0.215452263	0.007002199	0.86514943	0.086514943	0.002811736	0.0325
0.375	0.85125	0.16535579	1.97365978	0.197365978	0.007401224	0.91549739	0.091549739	0.003433115	0.0375
0.425	0.80355	0.14590216	1.81999821	0.181999821	0.007734992	0.93864408	0.093864408	0.003989237	0.0425
0.475	0.75585	0.13054404	1.68494802	0.168494802	0.008003503	0.94317938	0.094317938	0.004480102	0.0475
0.525	0.70815	0.11811128	1.5631917	0.15631917	0.008206756	0.93442082	0.093442082	0.004905709	0.0525
0.575	0.66045	0.10784073	1.45126126	0.145126126	0.008344752	0.91583636	0.091583636	0.005266059	0.0575
0.625	0.61275	0.09921347	1.34679851	0.134679851	0.008417491	0.88978423	0.088978423	0.005561151	0.0625
0.675	0.56505	0.09186433	1.24814395	0.124814395	0.008424972	0.85792391	0.085792391	0.005790986	0.0675
0.725	0.51735	0.08552885	1.15409589	0.115409589	0.008367195	0.82145708	0.082145708	0.005955564	0.0725
0.775	0.46965	0.08001086	1.06376274	0.106376274	0.008244161	0.78127534	0.078127534	0.006054884	0.0775
0.825	0.42195	0.07516172	0.97646908	0.097646908	0.00805587	0.73805412	0.073805412	0.006088946	0.0825
0.875	0.37425	0.07086677	0.89169384	0.089169384	0.007802321	0.69231447	0.069231447	0.006057752	0.0875
0.925	0.32655	0.06703613	0.80902863	0.080902863	0.007483515	0.64446479	0.064446479	0.005961299	0.0925
0.975	0.27885	0.06359838	0.72814884	0.072814884	0.007099451	0.5948297	0.05948297	0.00579959	0.0975
Overall p(collision)			**Upwind**		**0.134337978**	**Downwind**		**0.079072453**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.13433798 + 0.07907245)/2
Average probability of collision = 0.106705

Annual collision risk for Golden plover assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 14.836 x 0.106705

Annual collision risk = 1.583 birds

Corrected annual collision risk assuming avoidance

Golden plover avoidance rate = 0.98

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 1.583 x (1 - 0.98)
Annual collision risk, with avoidance = 0.032 birds

Corrected for assumed operational downtime of the rotors

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.027 birds

Calculate number of years per collision

Number of years per collision for Golden plover = 1/corrected annual risk
Number of years per collision for Golden plover = 1/0.027

Number of years per collision for Golden plover = 37.1589

[1] Forsythe, W. C., Rykiel, E. J., Stahl, R. S., Wu, H. and Schoolfield, R. M.,1995. A model comparison for daylength as a function of latitude and day of year. Ecological Modelling Vol 80, Issue 1, 87-95

Collision Risk Model Calculations for Golden plover 2017 / 2018

Stage 1: Number of birds flying through the rotors per year

Calculate the time the site was observed for and how long birds (as a % area-time activity) were seen in the observation area during this time and bird activity for each vantage point

The survey period for this species is taken as the whole year.

VP	Area (Ha)	Time (hours)	Ha hours	Ha seconds (hours x 3600)	Flight time observed in risk window (s)	Bird Activity (flight time/ha-s)
2, 3, 6	830.338	72	59784.34	215223609.6	321.9718158	1.4960E-06
Total	830.338	72	59784.34	215223609.6	321.9718158	1.4960E-06

Calculate the average bird observation activity in all areas and the percentage of time birds active within the overall observed area

Mean bird activity =Total bird activity/combined VPs
Mean bird activity = 1.496E-6/1 = **1.496E-06**

Overall area covered by VPs (excluding overlap) = 830338 m2
Proportion of time birds active in the area = Overall area (excluding overlaps) in ha x mean bird activity
Proportion of time birds active in area = 830338 x 1.496E-6 = **1.2422E+00**

Correct for differences between the recording height band and the actual height swept by the rotors

Corrected bird activity=Proportion of actual height band x Proportion of time birds active in the area

Hub height = 103 m Observed height band max = 180 m
Rotor radius = 77 m Observed height band min = 40 m

Rotor max height= hub height + rotor radius
Rotor min height= hub height - rotor radius
Rotor max height = 180 m
Rotor min height = 26 m

Proportion of actual height band = (Rotor max height – rotor min height)/(observed height band max – observed height band min)
Proportion of actual height band = (180 - 26)/(180 - 40)
Proportion of actual height band = 1.1

Corrected bird activity = **1.366E+00**

Stage 2: Step 2: Transit through the rotor swept disk

Calculate the number of hours per day the birds are potentially active over a year and the number of hours of bird occupancy in the airspace per year

Hours potentially active are taken as daylight hours only for the whole year and then calculated where the day length is a function of latitude and day of the year[1]

Hours potentially active = 4526.649

No. of hours of bird occupancy in the airspace per year =hours potentially active x bird activity
No. of hours of bird occupancy in the airspace per year = 4526.649 x 1.366E+0
No. of hours of bird occupancy = 6185.18

Calculate the flight risk volume

Flight risk volume (Vw) = Overall area (ha) x 10000 x rotor radius (m) x 2
Vw = 830338 x 10000 x 77 x 2
Vw = 1278720520000 m3

Calculate the combined rotor swept volume

Number of turbines = 18
Maximum chord = 4 m
Pitch = 20 degrees
Bird length = 0.28 m

Apparent depth of the blade= Maximum chord x sin(pitch)
Apparent depth of blade = 3.652 m

Combined rotor swept volume (Vr) = number of turbines (N) x Pi x r2 x (depth of blade + bird length)
Vr = 18 x Pi x 77 x 77 x (3.652 + 0.28)
Vr = 1318235.941 m3

Calculate the bird occupancy in the rotor swept volume

No. of hours of bird occupancy (converted to seconds) x Combined rotor swept volume/Flight risk volume = n x (Vr/Vw)

Bird occupancy in rotor swept volume = 6185.18 x 3600 x 1318235.941/1278720520000
Bird occupancy in rotor swept volume = 22.955

Calculate the bird transit time through the rotors and the potential number of transits per year

Bird speed = 10 m/s

Bird transit time through the rotors = (depth of blade + bird length) /bird speed
Bird transit time through the rotors = (3.652 + 0.28)/10
Bird transit time through the rotors = 0.3932 s

No. of transits = bird occupancy in the rotor swept volume/bird transit time
No. of transits = 22.955/0.3932
No. of transits = 58.383

Stage 3: Collision risk for bird passing through rotor area (assuming no avoidance)

Convert pitch of chord into radians

K:1D or 3D (0 or 1)	1	
No. of blades	3	
Maximum chord	4	m
Pitch (degrees)	20	
Rotor radius	77	m
Rotation Period	3	s

Pitch in radians = pitch (degrees) x Pi/180
Pitch in radians = 20 x Pi/180
Pitch in radians = 0.3491

Calculate the bird aspect ratio

Bird length	0.28	m
Wingspan	0.72	m
Bird speed	10	m/s
F:Flapping	1	

Bird aspect ratio (b) = bird length/wingspan
Bird aspect ratio (b) = 0.28/0.72
Bird aspect ratio (b) = 0.389

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

r/R radius	c/C chord	a alpha	Upwind:			Downwind:			check area total
			collide length	p(collision)	contribution from radius r	collide length	p(collision)	contribution from radius r	
0.025	0.575	2.48033678	7.93322339	0.793322339	0.000991653	6.35993073	0.635993073	0.000794991	0.00125
0.075	0.575	0.82677893	3.16883868	0.316883868	0.002376629	1.59554602	0.159554602	0.00119666	0.0075
0.125	0.7015	0.49606736	2.62489626	0.262489626	0.00328112	0.70547921	0.070547921	0.000881849	0.0125
0.175	0.8601	0.35433383	2.60221848	0.260221848	0.004553882	0.31115373	0.031115373	0.000544519	0.0175
0.225	0.99435	0.27559298	2.67038888	0.267038888	0.006008375	0.61031296	0.061031296	0.001373204	0.0225
0.275	0.94665	0.22548516	2.37742381	0.237742381	0.006537915	0.77276314	0.077276314	0.002125099	0.0275
0.325	0.89895	0.19079514	2.15452263	0.215452263	0.007002199	0.86514943	0.086514943	0.002811736	0.0325
0.375	0.85125	0.16535579	1.97365978	0.197365978	0.007401224	0.91549739	0.091549739	0.003433115	0.0375
0.425	0.80355	0.14590216	1.81999821	0.181999821	0.007734992	0.93864408	0.093864408	0.003989237	0.0425
0.475	0.75585	0.13054404	1.68494802	0.168494802	0.008003503	0.94317938	0.094317938	0.004480102	0.0475
0.525	0.70815	0.11811128	1.5631917	0.15631917	0.008206756	0.93442082	0.093442082	0.004905709	0.0525
0.575	0.66045	0.10784073	1.45126126	0.145126126	0.008344752	0.91583636	0.091583636	0.005266059	0.0575
0.625	0.61275	0.09921347	1.34679851	0.134679851	0.008417491	0.88978423	0.088978423	0.005561151	0.0625
0.675	0.56505	0.09186433	1.24814395	0.124814395	0.008424972	0.85792391	0.085792391	0.005790986	0.0675
0.725	0.51735	0.08552885	1.15409589	0.115409589	0.008367195	0.82145708	0.082145708	0.005955564	0.0725
0.775	0.46965	0.08001086	1.06376274	0.106376274	0.008244161	0.78127534	0.078127534	0.006054884	0.0775
0.825	0.42195	0.07516172	0.97646908	0.097646908	0.00805587	0.73805412	0.073805412	0.006088946	0.0825
0.875	0.37425	0.07086677	0.89169384	0.089169384	0.007802321	0.69231447	0.069231447	0.006057752	0.0875
0.925	0.32655	0.06703613	0.80902863	0.080902863	0.007483515	0.64446479	0.064446479	0.005961299	0.0925
0.975	0.27885	0.06359838	0.72814884	0.072814884	0.007099451	0.5948297	0.05948297	0.00579959	0.0975
Overall p(collision)			**Upwind**		**0.134337978**	**Downwind**		**0.079072453**	**0.99875**

Average probability of collision = (upwind collision total + downwind collision total)/2
Average probability of collision = (0.13433798 + 0.07907245)/2
Average probability of collision = 0.106705

Annual collision risk for Golden plover assuming no avoidance

Annual collision risk = no. of transits per year through the rotors x the average probability of collision
Annual collision risk = 58.383 x 0.106705

Annual collision risk = 6.23 birds

<u>Corrected annual collision risk assuming avoidance</u>

Golden plover avoidance rate = 0.98

Annual collision risk, with avoidance = annual collision risk x (1 - avoidance rate)
Annual collision risk, with avoidance = 6.23 x (1 - 0.98)
Annual collision risk, with avoidance = 0.125 birds

<u>Corrected for assumed operational downtime of the rotors</u>

Proportion of time wind turbines operational = 0.85

Corrected annual risk = annual risk, with avoidance x proportion of time wind turbines operational
Corrected annual risk = 0.106 birds

<u>Calculate number of years per collision</u>

Number of years per collision for Golden plover = 1/corrected annual risk
Number of years per collision for Golden plover = 1/0.106

Number of years per collision for Golden plover = 9.4423

[1] Forsythe, W. C., Rykiel, E. J., Stahl, R. S., Wu, H. and Schoolfield, R. M.,1995. A model comparison for daylength as a function of latitude and day of year. Ecological Modelling Vol 80, Issue 1, 87-95

References

Band, W, Madders, M, & Whitfield, D.P. (2007) *Developing field and analytical methods to assess avian collision risk at wind farms.* In: Janss, G, de Lucas, M & Ferrer, M (eds.) Birds and Wind Farms. Quercus, Madrid. 259-275

Baker, J.K. (2016) *Identification of European Non-Passerines*. British Trust for Ornithology

Bruderer, B. & Boldt, A. (2001) *Flight characteristics of birds: I. radar measurements of speeds*. Ibis.143. Pp. 178-204

Scottish Natural Heritage (2000) Windfarms and Birds - Calculating a theoretical collision risk assuming no avoiding action. SNH Guidance Note.

Scottish Natural Heritage (2018) Avoidance Rates for the onshore SNH Wind Farm Collision Risk Model. SNH Guidance Note.