Appendix 7-3

Avian Collision Risk Assessment

Avian Collision Risk Assessment

Carrownagowan Wind Farm, Co. Clare

Malachy Walsh and Partners
Engineering and Environmental Consultants

www.mwp.ie

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1   INTRODUCTION

1.1   BACKGROUND

Collision with the turbine rotors of onshore wind farms is a potential source of avian mortality. This document has been prepared to assess that risk by using a Collision Risk Model (CRM) for specific target bird species at the proposed Carrownagowan Wind Farm site in east County Clare.

In line with Scottish Natural Heritage (SNH, 2000) guidance, the Band Collision Risk Model (Band *et al*., 2007) was used in this assessment. The model estimates the risk of collision based on the activity levels and flight behaviour of target species, the number, layout and specifications of the proposed turbines, and the biometrics of relevant species. The data for this assessment was obtained from vantage point (VP) surveys carried out on site at the Carrownagowan wind farm site from August 2016 to September 2018 at eight fixed vantage point locations.

1.2   BAND MODELLING METHOD

The Band modelling method involves two stages:

- Stage 1: Establishing the number of birds or flights that pass through the air space swept by the turbine rotors. These transits are determined by using either the "Regular or Random flight" model depending on flight activity and behaviour.

- Stage 2: Calculating the probability of a bird being struck when making a transit through a rotor.

The figures obtained in both stages are then multiplied together to give a theoretical annual collision mortality rate based on the supposition that birds make no attempt to avoid collision. However in "real-life" circumstances, birds demonstrate high rates of avoidance - usually 98-99% according to SNH (2018). To account for these evasion measures, known avoidance rates are applied as a percentage to the theoretical collision value as a final step.

Band Model values are solely speculative and representative of worst-case estimates, only drawing conclusions by assuming likely levels of active avoidance by specific species. Accordingly, results obtained are dependent on the quality of field observation data and accuracy of the avoidance rates used, and must therefore be interpreted with a certain degree of caution.

2   METHODOLOGY

2.1   FLIGHT DATA

Flight data was recorded at eight vantage point (VP) locations from September 2016 to the end of August 2018 (inclusive) by MKOS and the data was provided to MWP to undertake the model. A potential collision risk height (PCH) of between 25m and 175m above ground was established based on the Carrownagowan Wind Farm turbines having a maximum blade tip height of 169m, and a rotor diameter of 136m (see **Table 5**). This ensured that the PCH was easily within the rotor sweep of the turbine but also, as it larger than the actual turbine diameter, slightly overestimates the risk of collision.

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VP watches were carried out at each VP location for 6 hours per month over a 2 year period between October 2016 and September 2018 based on recent SNH guidance (2017). The VP Arc for each VP is a 180° arc with a radius of 2km from the vantage point location, which represents the theoretical maximum coverage. The viewshed represents the actual area visible to the surveyor at a specified height above ground level from the vantage point location within each VP Arc. GIS computer software was used to generate the viewsheds for each VP. Flight data from the viewshed mapping for each VP was used to inform the CRM. During the bird survey in July 2017, the direction of view of the surveyor from a number of the VP locations was altered very slightly, namely VP1a, 2, 7a and 8a while the direction of view from VP9 was altered from the northwest to the north.

Flighpaths that were wholly outside of the viewshed were excluded from the CRM. Several flight paths were not located both inside and outside of their corresponding viewsheds. In some such cases, it was possible to exclude the flight paths outside of the viewshed by calculating the length of the section of flight path located within the viewshed and then find the proportion of the total duration of the flight this section represents. Six hen harrier (*Circus cyaneus*) flights as well as one flight each for buzzard (*Buteo buteo*) and kestrel (*Falco tinnunculus*) were suitable for such analysis. These flights are listed in **Table 1** below**.**

Table 1: Details and calculations of flight paths not entirely located within a viewshed

Species	Date	VP	No. of birds observed	Total length of flight (m)	Total duration of flight (secs)	Length of flight within viewshed (m)	Duration of flight within viewshed (secs)
Hen Harrier	16/09/16	7a	1	1891	180	508	48
Hen Harrier	21/04/17	9	1	2907	30	181	2
Hen Harrier	20/04/18	5a	1	990	30	921	28
Hen Harrier	11/06/18	2	1	794	45	189	11
Hen Harrier	24/07/18	3	1	558	74	527	70
Hen Harrier	25/07/18	4	2	1519	87	516	30
Buzzard	27/03/18	1a	1	1875	260	493	68
Kestrel	03/11/17	5a	1	1261	150	441	53

Table 2 below presents the details on the viewshed area for each VP while **Figures 1** to **3,** below illustrate the viewshed areas within each VP Arc.

Table 2: Viewshed and vantage point details

Vantage Point	VP Arc (ha)	Viewshed area within VP Arc (ha)	Viewshed coverage within VP Arc (%)	Turbine Buffer Area within Viewshed (ha)	No. of turbines within viewshed	Total survey effort (hrs)
VP1a	628	436	69.43	187.57	4	144
VP2	628	395	62.90	332.16	8	144
VP3	628	282	44.9	218.8	6	144
VP4a	628	303	48.2	171.3	5	144
VP5a	628	599	95.4	457.9	11	144
VP7a	628	422	67.20	268.27	6	144
VP8a	628	451	71.82	330.28	7	144
VP9	628	382	60.83	10.52	0	144

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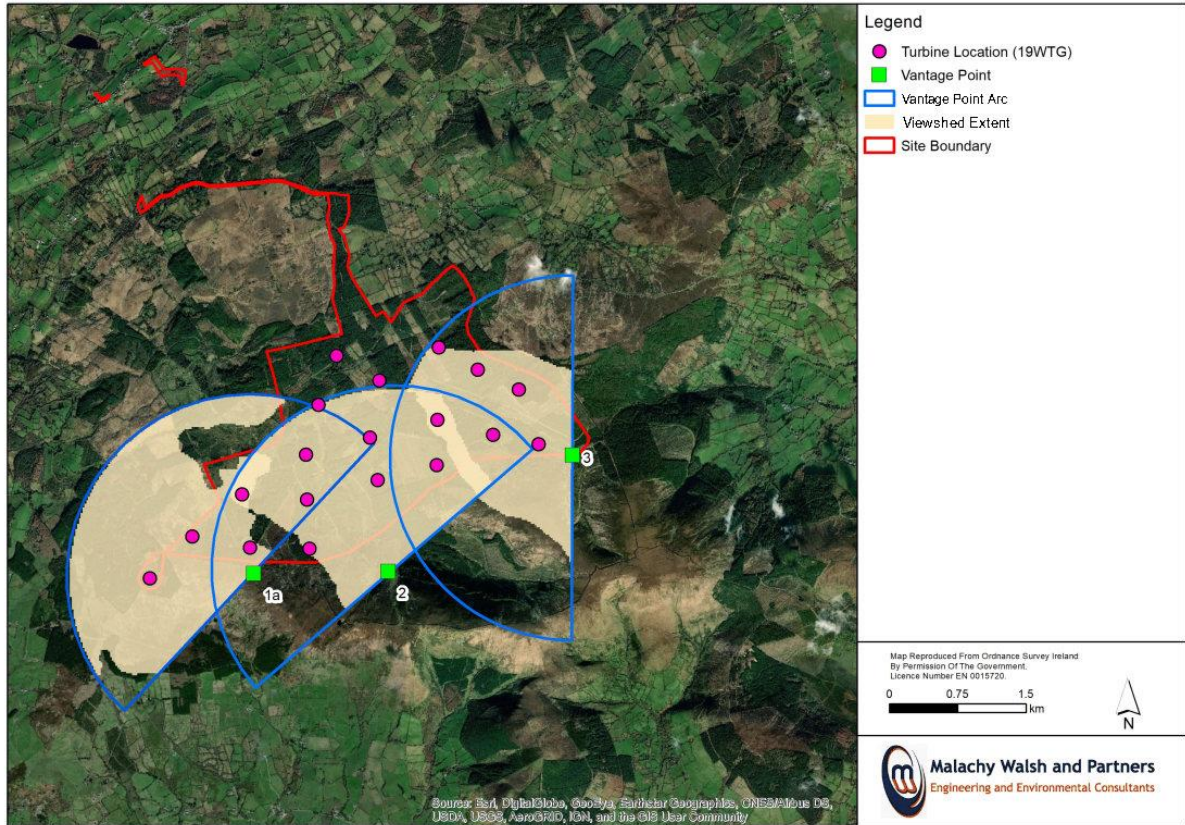
Figure 1: Viewshed maps for VP1a, VP2 and VP3.
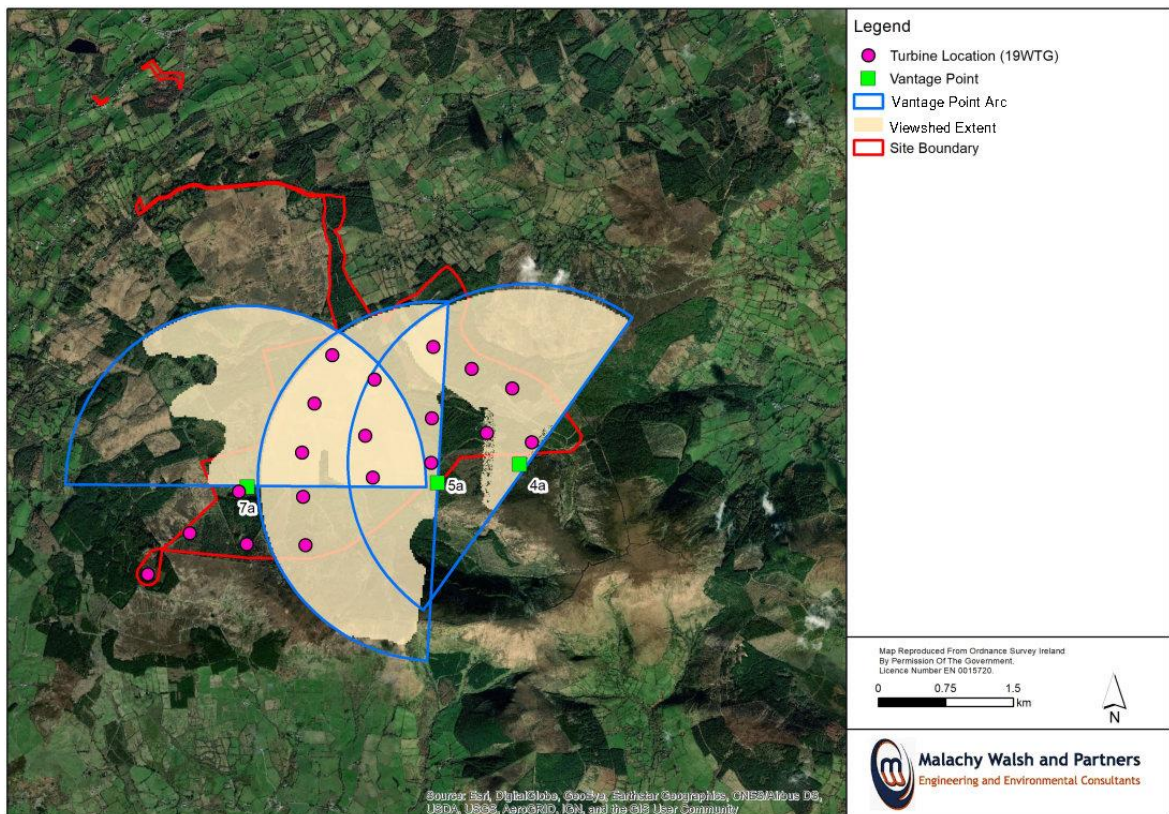
Figure 2: Viewshed maps for VP4a, VP5a and VP7a.

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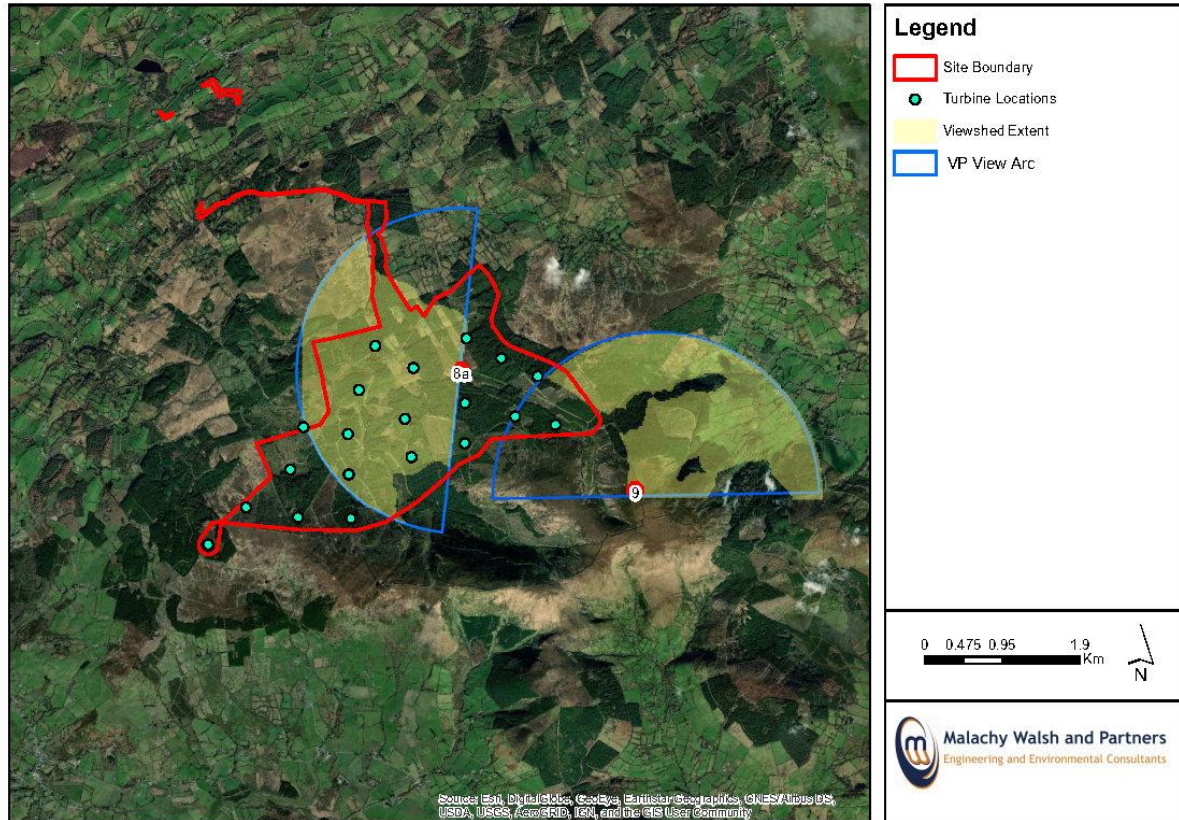
Figure 3: Viewshed maps for VP8a and VP9.

2.2   BIRD BIOMETRICS AND FLIGHT DURATION AT PCH

The amount of time a species was observed flying at heights of between 25 and 175 metres, i.e. within the PCH, is presented in **Table 3** below. Species-specific morphometric measurements and flight speeds are also shown in **Table 3** Total monthly values of bird-seconds at PCH within all viewsheds are set out in **Table 4.**

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Table 3: Bird biometrics and bird-seconds spent by species at Potential Collision Height (25-175m)

Species (BTO Code)	Length (m)	Wingspan (m)	Mean flight speed (m/s)	Bird-seconds in flight at PCH (25-175m)						Total bird-secs at PCH over 24 Months
				2016/2017			2017/2018			
				Winter	Breeding	Total over 12-months	Winter	Breeding	Total over 12-months	
Buzzard (BZ)	0.54	1.2	13.3	0	702	702	265	628	893	1595
Golden Plover (GP)	0.275	0.715	17.9	20250	0	20250	43950	0	43950	64200
Hen Harrier (HH)	0.48	1.1	12	78	1362	1440	0	2413	2413	3853
Kestrel (K.)	0.34	0.76	10.1	1700	1025	2725	5084	303	5387	8112
Mallard (MA)	0.58	0.9	18.5	0	115	115	0	163	163	278
Peregrine (PE)	0.42	1.02	12.1	0	0	0	60	110	170	170
Sparrowhawk (SH)	0.33	0.67	10	0	0	0	220	0	220	220

Table 4: Monthly values of bird-seconds spent at PCH (25-175m)

Species	Year	Monthly values of bird-seconds spent at PCH within viewsheds											
		September	October	November	December	January	February	March	April	May	June	July	August
Buzzard	2016/17	0	0	0	0	0	0	0	100	470	0	132	0
	2017/18	0	0	0	0	0	130	135	0	0	0	228	400
Golden Plover	2016/17	0	0	0	20250	0	0	0	0	0	0	0	0
	2017/18	0	0	43350	0	0	0	600	0	0	0	0	0
Hen Harrier	2016/17	48	30	0	0	0	0	53	729	460	80	0	40
	2017/18	0	0	0	0	0	0	0	1052	0	691	570	100
Kestrel	2016/17	450	158	95	0	849	0	148	0	0	30	685	310
	2017/18	3740	1116	73	0	0	0	155	23	0	0	240	40
Mallard	2016/17	0	0	0	0	0	0	0	115	0	0	0	0
	2017/18	0	0	0	0	0	0	0	10	153	0	0	0
Peregrine	2016/17	0	0	0	0	0	0	0	0	0	0	0	0
	2017/18	0	0	0	0	0	60	110	0	0	0	0	0
Sparrowhawk	2016/17	0	0	0	0	0	0	0	0	0	0	0	0
	2017/18	200	0	0	0	0	20	0	0	0	0	0	0

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2.3   BAND COLLISION RISK MODELLING

2.3.1   Regular and Random Flight Models – Stage 1

The Stage 1 calculations uses the VP survey data for each of the target species to calculate the number of predicted bird transits to fly through the turbine blade swept areas. Appendix 1 presents the Stage 1 calculations for each of the target species. Stage 1 calculations are carried out using one of two methods based on whether flight activity follows a regular pattern or is random – the "Regular Flight Model" or the "Random Flight Model", respectively.

For predictable flightlines, like those created by geese following a migratory route or those produced by the regular travel of divers to the coast from nest sites, the "Regular Flight Model" is used. This model involves calculating the number of birds flying through the rotor swept area each year.

The "Random Flight Model" is used in cases of irregular flight activity such as that displayed by raptors occupying a recognized territory, or by waders. This model requires calculation of the proportion of time birds were observed flying per unit of survey area.

More information on both Regular and Random Flight Model calculations have been made freely available by the SNH (2000) at: https://www.nature.scot/wind-farm-impacts-birds-calculating-theoretical-collision-risk-assuming-no-avoiding-action.

The recorded flights of target species from the eight vantage points (VP1a, VP2, VP3, VP4a, VP5a, VP7a, VP8a, and VP9) at the Carrownagowan Wind Farm site were deemed to be randomly distributed - that is, with a potential to occur anywhere within a viewshed. Consequently, the "Random Flight Model" was used for each target species to determine the predicted number of transits thorough the site.

The proportion of flight time between 25 and 175m for a bird species for each of the VPs was calculated. If multiple birds were observed in one flight, the seconds spent at PCH were calculated by multiplying the number of birds observed per flight by the duration of the flight at PCH (in line with SNH, 2000).

The hours that a species may potentially be active in either a breeding or non-breeding season was calculated to include daylight, one hour before sunrise, and one hour after sunset (dusk) for all species with the exception of mallard and golden plover. For these two species it was calculated as daylight, one hour before sunrise, one hour after sunset (dusk), and 25% of the night (SHN, 2017). These flight activity hours were calculated from timeanddate.com (2020), Band (2012), and Wilson *et al.* (2015).

This flight activity was used to calculate the number of bird passes through the rotor for each VP in turn and per turbine within each viewshed before being calculated for the entire 19-turbine wind farm. The Stage 1 calculation was carried out for each season - breeding and wintering - and for each species.

2.3.2   Probability of Collision – Stage 2

Stage 2 calculates the probability of a bird flying through the rotor being struck, and is determined using the same method for both regular and random flightlines using a publicly available SNH

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collision risk probability model spreadsheet available at: https://www.nature.scot/wind-farm-impacts-birds-calculating-probability-collision.

The spreadsheet provides for a scenario in which the bird is either flapping or gliding and where the transit is either upwind or downwind. For collision risk assessment, the mean probability of both flapping and gliding behaviour was used, with the exception of mallard (*Anas platyrhynchos*) where only flapping behaviour was considered, (see **Table 10** below). For a detailed explanation of Stage 2 calculations see Band *et al*. (2007). A completed spreadsheet of Stage 2 calculations for buzzard is included in **Appendix 1** as an example.

For Stage 2 the probability of collision depends on the size of the bird (length and wingspan), the breadth and pitch of the turbine blades, the rotation speed of the turbine, and the flight speed of the bird (Band *et al*., 2007). **Table 5** below lists the wind farm and turbine characteristics used in this analysis. Values for the mean pitch of a turbine blade (degrees), the maximum chord (metres), and the rotational speed (rotations per minute) were obtained from a senior wind farm engineer with Malachy Walsh and Partners based on knowledge and specifications of the proposed turbine dimensions.

Table 5: Turbine technical parameters

Parameter	Specification
Total number of proposed turbines	19
Number of blades per turbine rotor	3
Rotor diameter (metres)	136
Rotor radius (metres)	68
Hub height (metres)	101
Maximum height to blade tip (metres)	169
Minimum height to blade tip (metres)	33
Swept area (metres^2)	14527
Mean pitch of blade (degrees)	5
Maximum chord (metres)	4.1
Rotational speed (rotations per minute)	5.6 - 14.0
Mean rotational speed (rotations per minute)	9.8
Average rotational period (seconds)	6.12
Turbine operational time (%)	85

Bird biometric parameters (**Table 3**) were obtained from Wilson *et al*. (2015), Alerstam *et al*. (2007), and the British Trust for Ornithology (BTO) (2000).

2.3.3   Calculating Collision Risk

For each target species included in the CRM, collision risk predictions were calculated for both relevant seasonal periods within each 12-month cycle (see **Table 6** for the seasonal divisions for each species). The sum of these separate summer and winter CRM results was taken as the predicted annual collision risk rather than using results from a single all-year CRM. This method minimised any potential biases that may arise from seasonal variation in daylength and the number of hours of activity available to each species in each month. This was to increase precision of the CRM and to

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ensure that any potential underestimation or overestimation for a species risk of collision was minimised as much as possible. For example, all sightings of buzzard are likely to be of resident birds from the same population. However, during winter some birds may disperse from the area meaning that a single all-year CRM would likely underestimate the risk of collision. Conversely, local golden plover are part of wintering population so producing a single, all-year CRM would likely overestimate collision risk of this species.

Table 6: Seasonal divisions of species (British Trust for Ornithology (BTO) (2020), and Wilson *et al*. (2015))

Species	Breeding Season	Winter Season
Buzzard	April to August	September to March
Golden Plover	April to August	September to March
Hen Harrier	March to August	September to February
Kestrel	April to August	September to March
Mallard	April to August	September to March
Peregrine	March to August	September to February
Sparrowhawk	April to August	September to March

Collision data derived from Stage 1 and Stage 2 were multiplied together to calculate the risk of collision for the target bird species per season. Multiplying Stage 1 by Stage 2 produces a predicted collision mortality rate that assumes birds take no action to avoid collision. In practice however, birds probably show a very high degree of collision avoidance which dramatically lowers predicted mortality (Band *et al*., 2007). An avoidance rate was applied to the collision risk, which considerably reduces the predicted risk. The collision risk was then multiplied by 30 years to calculate the risk over the lifetime of the wind farm for each season. Following this, the winter and breeding results were added to estimate the risk per year.

3   RESULTS

The following target species were observed flying at the collision risk height at Carrownagowan over the two year survey period:

- Buzzard (*Buteo buteo*)
- Golden Plover (*Pluvialis apricaria*)
- Hen Harrier (*Circus cyaneus*)
- Kestrel (*Falco tinnunculus*)
- Peregrine (*Falco peregrinus*)
- Sparrowhawk (*Accipiter nisus*).

Mallard is a green-listed species in Ireland and is classed as least conservation concern but was also included in this collision risk assessment as it is considered to be a wind farm-sensitive species.

3.1   STAGE 1 CALCULATIONS RESULTS

Table 7, **Table 8** and **Table 9** below, show results of Stage 1 calculations – the number of birds estimated to fly through the blades of the proposed turbines at the Carrownagowan Wind Farm. Both **Table 7** and **Table 8** report the number of transits predicted per turbine within the viewshed of each VP during each breeding season and each winter season, while **Table 9** gives further details on

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the mean predicted transits through each turbine per season, and mean predicted transits per season through all turbines across the proposed 19-turbine site.

The viewshed for VP9 does not contain any of the proposed wind turbines and thus the flight activity recorded in this viewshed does not make any contribution to the CRM. Consequently, the survey data obtained from VP9 was omitted from the CRM and consequently, is excluded from the worked spreadsheets in **Appendix 1**.

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Table 7: Predicted transits per turbine within the viewsheds of VP's 1a, 2, 3 and 4a for the 2016/17 and 2017/18 breeding seasons and the 2016/17 and 2017/18 winter seasons.

Species	Year	VP1a			VP2			VP3			VP4a		
		Winter	Breeding	Total	Winter	Breeding	Total	Winter	Breeding	Total	Winter	Breeding	Total
Buzzard	2016/17	0	0	0	0	5.48	5.48	0	0	0	0	0	0
	2017/18	1.13	0	1.13	1.77	0	1.77	0	0	0	0	6.43	6.43
Golden Plover	2016/17	0	0	0	0	0	0	0	0	0	735.35	0	735.35
	2017/18	0	0	0	0	0	0	0	0	0	0	0	0
Hen Harrier	2016/17	0	0	0	0	6.90	6.90	0	10.16	10.16	0	5.89	5.89
	2017/18	0	0	0	0	10.96	10.96	0	2.33	2.33	0	3.41	3.41
Kestrel	2016/17	2.70	0	2.70	5.70	0	5.70	4.02	0	4.02	0.50	0	0.50
	2017/18	0.73	0	0.73	2.45	0	2.45	37.49	0	37.49	0.36	0	0.36
Mallard	2016/17	0	0	0	0	0	0	0	1.80	1.80	0	0	0
	2017/18	0	0	0	0	0	0	0	1.38	1.38	0	0	0
Peregrine	2016/17	0	0	0	0	0	0	0	0	0	0	0	0
	2017/18	0	0	0	0	0	0	0	0	0	0	0	0
Sparrowhawk	2016/17	0	0	0	0	0	0	0	0	0	0	0	0
	2017/18	0.25	0	0.25	0	0	0	1.93	0	1.93	0	0	0

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Table 8: Predicted transits per turbine within the viewsheds of VP's 5a, 7a, 8a and 9 for the 2016/17 and 2017/18 breeding seasons and the 2016/17 and 2017/18 winter seasons.

Species	Year	VP5a			VP7a			VP8a		
		Winter	Breeding	Total	Winter	Breeding	Total	Winter	Breeding	Total
Buzzard	2016/17	0	5.88	5.88	0	1.15	1.15	0	3.17	3.17
	2017/18	0.36	7.23	7.59	1.15	0	1.15	0	1.15	1.15
Golden Plover	2016/17	0	0	0	0	0	0	0	0	0
	2017/18	0	0	0	0	0	0	0	0	0
Hen Harrier	2016/17	0	0	0	1.17	5.90	7.07	0	0	0
	2017/18	0	11.73	11.73	0	20.79	20.79	0	1.87	1.87
Kestrel	2016/17	0	2.47	2.47	9.04	6.04	15.08	1.84	9.76	11.60
	2017/18	25.86	0.14	26.00	1.27	5.26	6.53	0	0	0
Mallard	2016/17	0	1.70	1.70	0	0	0	0	0	0
	2017/18	0	0	0	0	5.23	5.23	0	0.38	0.38
Peregrine	2016/17	0	0	0	0	0	0	0	0	0
	2017/18	0	0	0	0	0	0	0	0	0
Sparrowhawk	2016/17	0	0	0	0	0	0	0	0	0
	2017/18	0	0	0	0	0	0	0	0	0

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Table 9: Mean number of predicted transits per turbine per season, and mean number of predicted transits across the entire wind farm site per season.

Species	Year	Mean transits predicted per turbine per season			Mean transits predicted across entire proposed wind farm site per season		
		Winter	Breeding	Entire Year	Winter	Breeding	Entire Year
Buzzard	2016/2017	0	1.96	1.96	0	37.25	37.25
	2017/2018	0.56	1.85	2.41	10.64	35.19	45.83
Golden Plover	2016/2017	91.92	0	91.92	1746.46	0	1746.46
	2017/2018	0	0	0	0	0	0
Hen Harrier	2016/2017	0.15	3.61	3.76	2.78	68.50	71.28
	2017/2018	0	6.39	6.39	0	121.35	121.35
Kestrel	2016/2017	2.98	2.28	5.26	56.53	43.39	99.92
	2017/2018	8.52	0.67	9.19	161.87	12.82	174.69
Mallard	2016/2017	0	0.44	0.44	0	8.32	8.32
	2017/2018	0	0.87	0.87	0	16.59	16.59
Peregrine	2016/2017	0	0	0	0	0	0
	2017/2018	0	0	0	0	0	0
Sparrowhawk	2016/2017	0	0	0	0	0	0
	2017/2018	0.27	0	0.27	5.18	0	5.18

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3.2   STAGE 2 CALCULATIONS RESULTS

The second stage of calculations determines the percentage risk of collision of a bird flying through a rotating turbine, the results of which are presented in **Table 10** below.

The highest values or "worst-case scenario" collision percentages occur when the bird flies upwind using flapping behaviour whilst the turbine is rotating at its fastest speed. Conversely, "best-case scenario" or lowest percentage values occur when a bird flies downwind using a gliding flight whilst the turbine is rotating at its slowest speed. The collision risk assessment in this case used the mean of these two scenarios for each species, the values of which can be found in the final column of **Table 10** below.

Table 10: Probability of collision – Stage 2 calculation outputs

Species	Flapping bird, p		Gliding bird, p		Mean probability
	upwind	downwind	upwind	downwind	
Buzzard	6.7%	5.2%	6.4%	5.0%	5.80%
Golden Plover	5.2%	4.1%	5.0%	3.9%	4.60%
Hen Harrier	6.7%	5.0%	6.4%	4.8%	5.70%
Kestrel	6.4%	4.4%	6.3%	4.3%	5.35%
Mallard	5.9%	4.8%	\	\	5.35%
Peregrine	6.4%	4.8%	6.2%	4.6%	5.50%
Sparrowhawk	6.3%	4.4%	6.2%	4.3%	5.30%

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3.3   COLLISION RATES

The theoretical collision rates for each species per season, based on the assumption that the bird makes no attempt to avoid the moving rotors, is presented in **Table 11** below. Rates were calculated using the data collected from two consecutive years of bird surveying at the Carrownagowan Wind Farm from 2016 to 2018. In general, species show a noticeably higher rate of predicted collisions per season in 2017/18 when compared with rates from 2016/17.

Table 11: Predicted collision per season assuming no avoidance measures taken by bird.

Species	Collision Probability	Year	Predicted collisions per season with no avoidance measures applied		
			Winter	**Breeding**	**Total**
Buzzard	5.80%	**2016/2017**	0	2.16	2.16
		2017/2018	0.62	2.04	2.66
Golden Plover	4.55%	**2016/2017**	79.46	0	79.46
		2017/2018	0	0	0
Hen Harrier	5.70%	**2016/2017**	0.16	3.90	4.06
		2017/2018	0	6.92	6.92
Kestrel	5.35%	**2016/2017**	3.02	2.32	5.34
		2017/2018	8.66	0.69	9.35
Mallard	5.35%	**2016/2017**	0	0.46	0.46
		2017/2018	0	0.89	0.89
Peregrine	5.50%	**2016/2017**	0	0	0
		2017/2018	0	0	0
Sparrowhawk	5.30%	**2016/2017**	0	0	0
		2017/2018	0.27	0	0.27

3.3.1   Collision Rates with Application of Specific Avoidance Rates

The final phase of the collision risk assessment is to apply avoidance rates to the predicted collision rates from **Table 11** above, to correct for a bird's ability to identify and move around turbines. The avoidance rates used were those recommended by SNH (2018).

The seasonal values for each species for each year were added together to give the predicted number of annual collisions for both of the 12-month datasets. Finally, the number of collisions predicted to occur over the life-span of the wind farm (30 years) was calculated (refer to **Table 12** below).

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Table 12: Number of collisions predicted with the application of avoidance rates specified by SNH (2018).

Species	Avoidance Rate	Year	Predicted collisions per season with avoidance rates applied			Predicted collisions over 30-year lifetime of proposed wind farm		
			Winter	Breeding	Total	Winter	Breeding	Total
Buzzard	98%	2016/17	0	0.04	0.04	0	1.27	1.27
		2017/18	0.01	0.04	0.05	0.37	1.22	1.59
Golden Plover	98%	2016/17	1.59	0	1.59	47.68	0	47.68
		2017/18	0	0	0	0	0	0
Hen Harrier	99%	2016/17	0.001	0.04	0.041	0.05	1.17	1.22
		2017/18	0	0.07	0.07	0	2.08	2.08
Kestrel	95%	2016/17	0.15	0.12	0.27	4.54	3.48	8.02
		2017/18	0.43	0.03	0.46	12.99	1.03	14.02
Mallard	98%	2016/17	0	0.01	0.01	0	0.27	0.27
		2017/18	0	0.02	0.02	0	0.53	0.53
Peregrine	98%	2016/17	0	0	0	0	0	0
		2017/18	0	0	0	0	0	0
Sparrowhawk	98%	2016/17	0	0	0	0	0	0
		2017/18	0.005	0	0.005	0.16	0	0.16

Table 13 below presents the final collision risk modelling results for each species. The predicted number for all species is less than one bird – that is to say, it is predicted that less than one bird a year will collide with the turbine blades. The amount of predicted collisions per 30 years is also relatively low for most species. All peregrine flights used in the model were within VP9's viewshed, and since there are no turbines in this viewshed, the predicted number of peregrine collisions is zero. There are, however, two species with comparatively high rates of predicted collisions over 30 years, namely kestrel and golden plover.

Table 13: Mean number of collisions predicted using avoidance rates specified by SNH (2018).

Species	Mean no. of predicted collisions per year	Mean no. of predicted collisions per 30 years	Equivalent to 1 bird every x (years)
Buzzard	0.045	1.43	21
Golden Plover	0.795	23.84	1.26
Hen Harrier	0.056	1.65	18.18
Kestrel	0.365	11.02	2.72
Mallard	0.015	0.40	75
Peregrine	0	0	0
Sparrowhawk	0.003	0.08	375

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4   WIND FARM MORTALITY AND BACKGROUND MORTALITY

The population level consequences of predicted collision risks can be assessed by considering the additional mortality that would be caused, which is the absolute increase, relative to background mortality rates in the population, where a threshold level of a 1% increase in annual mortality is used to establish whether the predicted collision impact will be significant (Percival, 2003). A negligible magnitude impact would be predicted if the collision mortality was to represent an increase of less than 1% on the background mortality rate.

The estimates of the potential increase in annual mortality provided below are for the hen harrier, kestrel, buzzard, and golden plover. For the breeding hen harrier population of the Slieve Bernagh – Keeper Hill area, an increase of 2% in mortality rate was predicted.

Further assessment will be carried out in the ornithological impact assessment in Chapter 7 of the EIAR.

Table 14: Calculations of potential increases in annual mortality

Species	Local population data	National population data	Adult mortality Rate[1]	Percentage increase in annual mortality	
				Locally	Nationally
Hen harrier Breeding	14[2]	216	0.19	2.018	0.131
Kestrel Breeding and Winter	50[3]	12100	0.31	2.332	0.010
Buzzard Breeding	12[4]	1500	0.19	5.263	0.017
Golden plover (Wintering)	11221[5]	99870	0.27	0.003	0.026

5   CONCLUSION

A CRM has been completed for the proposed Carrownagowan Wind Farm development. The Band method for collision risk modelling operates using many assumptions, particularly regarding bird behaviour and characteristics, and relies on accurate information regarding species avoidance rates, turbine specifications, and the recording of data. As a result of the assumptions and the limitations collision risk modelling presents, the predicted collisions should only be considered indicative of the potential magnitude of the predicted collision risk.

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[1] https://app.bto.org/birdfacts/results/bob3200.htm

[2] Estimated breeding population of Slieve Bernagh – Keeper Hill Area (Rudduck *et al*., 2016)

[3] Estimated population per 1km² (Crowe, *et al*., 2014) X 4 hectads covering the entire proposed project

[4] Estimated population within 10km of proposed project (Pers. comm. John Murphy (Clare BWI) & Malachy Walsh and Partners)

[5] Estimated golden plover wintering population of Shannon-Fergus Estuary (Lewis *et al*., 2016)

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It is clear from the VP surveys that there is a considerable amount of hen harrier activity in the area with much of it seemingly at PCH. However, as discussed above, collision risk modelling is dependent on many assumptions and can be prone to biases.

Kestrel, a year-round resident of the area, has a prediction of 10 collisions every 30 years. This value, however, is also liable to be rather tenuous as a large percentage of recorded kestrel flight activity has involved hovering birds which suggests that the mean kestrel flight speed used in the CRM will not be indicative of the mean flight speed of the kestrels observed during the surveys.

With regards hen harrier at Carrownagowan, the predicted percentage increase in annual mortality for the Slieve Bernagh population is sufficiently above the 1% threshold to require further assessment.

It is probably safest to interpret the results of CRM analyses as only indicating the order of magnitude of the predicted collision risk.

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6   REFERENCES

Alerstam, T., Rosén, M., Bäckman, J., Ericson, P.G. & Hellgren, O.(2007). Flight speeds among bird species: allometric and phylogenetic effects. *PLoS biology*, *5*(8), p.e197.

Band, W., Madders, M. & Whitfield, D.P. (2007) "Developing field and analytical methods to assess avian collision risk at wind farms", In De Lucas, M. Et al. (eds.) *Birds and wind farms: Risk assessment and mitigation*. Madrid: Quercus/Libreria Linneo, pp.259-275.

Band, B. (2012). Using a collision risk model to assess bird collision risks for offshore windfarms. *Guidance document. SOSS Crown Estate*. Available at: https://tethys.pnnl.gov/sites/default/files/publications/Band%202012.pdf

British Trust for Ornithology (2020). *Welcome to BirdFacts*. Available at: https://www.bto.org/understanding-birds/birdfacts.

Crowe, O., Musgrove, A.J. & O'Halloran, J. (2014) Generating population estimates for common and widespread breeding birds in Ireland. *Bird Study, 61(1),* pp.82-90.

Masden, E. A., & Cook, A. S. C. P. (2016). Avian collision risk models for wind energy impact assessments. *Environmental Impact Assessment Review*, 56, 43-49.

Percival, S.M. (2003). Birds and Wind farms in Ireland: A Review of Potential Issues and Impact Assessment. *Sustainable Energy Ireland*. Available at: https://tethys.pnnl.gov/sites/default/files/publications/Percival_2003.pdf

Ruddock, M., Mee, A., Lusby, J., Nagle, A., O'Neill, S. & O'Toole, L. (2016). The 2015 National Survey of Breeding Hen Harrier in Ireland. *Irish Wildlife Manuals*, No. 93. National Parks and Wildlife Service, Department of the Arts, Heritage and the Gaeltacht, Ireland. Available at: https://www.npws.ie/sites/default/files/publications/pdf/IWM93.pdf

Scottish Natural Heritage (2000). *Windfarms and Birds - Calculating a theoretical collision risk assuming no avoiding action.* SNH Guidance Note. Available at http://www.snh.gov.uk/docs/C205425.pdf

Scottish Natural Heritage (2017). *Recommended Bird Survey Methods to Inform Impact Assessment on Onshore Wind Farms.* Version 2. Available at: https://www.nature.scot/sites/default/files/2018-06/Guidance%20Note%20-%20Recommended%20bird%20survey%20methods%20to%20inform%20impact%20assessment%20of%20onshore%20windfarms.pdf

Scottish Natural Heritage (2018). *Use of avoidance rates in the SNH wind farm Collision Risk Model*. Available at: https://www.nature.scot/wind-farm-impacts-birds-use-avoidance-rates-snh-wind-farm-collision-risk-model.

timeanddate.com (2020). *Ennis, Ireland – Sunrise, Sunset, and Daylength*. Available at: https://www.timeanddate.com/sun/ireland/ennis

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Wilson, M., Fernández-Bellon, D., Irwin, S. & O'Halloran, J. (2015). *The interactions between Hen Harriers and wind turbines: WINDHARRIER - Final Project Report*. School of Biological Earth & Environmental Sciences at University College Cork (BEES). Available at: https://www.ucc.ie/en/media/research/planforbio/forestecology/WINDHARRIERFinalProjectReport.pdf

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Appendix 1

Buzzard, Breeding VP Surveys: April 2017 - Aug 2017

Measurements	Code	Value
Rotor radius (metres)	r	68
Rotor diameter (metres)	D	136
Max chord width of turbine blades (metres)	d	4.1
Buzzard length (metres)	l	0.54
Average flight speed of Buzzard (m/s)	v	13.3
Wingspan (m)		1.2
Mean pitch of blade (degrees)		5
Rotors per turbine		3
Rotational period (seconds)		6.12
Turbine operational time (%)		85

			Vantage Point						
			1a	2	3	4a	5a	7a	8a
Survey time over 5 months (secs)	s		108000	108000	108000	108000	108000	108000	108000
Total flight-time between 25 - 175m (bird-secs)	PCH		0	200	0	0	325	45	132
No. of turbines in viewshed	x		4	8	6	5	11	6	7
Survey area visible from VP (hectares)	Avp		436	395	282	303	599	422	451
Area of risk, i.e. 500m buffer of turbines within viewshed (hectares)	Arisk		187.57	332.16	218.8	171.3	457.9	268.27	330.28
Availability of species activity during survey period (hours)	Ba		2692	2692	2692	2692	2692	2692	2692

Stage 1 Calculations

Measurements	Code	Calculation							
Proportion of flight-time between 25 - 175m	t1	PCH/s	0.0000	0.0019	0.0000	0.0000	0.0030	0.0004	0.0012
Flight activity per visible unit of area	F	t1/Avp	0	4.6882E-06	0	0	5.0238E-06	9.87362E-07	2.71E-06
Proportion of time in risk area	Trisk	F*Arisk	0	0.00155724	0	0	0.0023004	0.00026488	0.00089507
Bird occupancy of risk area	n	Trisk*Ba	0	4.19209902	0	0	6.19267777	0.713055727	2.40952238
Risk volume	Vw	(Arisk*D)*10000	255095200	451737600	297568000	232968000	622744000	364847200	449180800
Actual volume of air swept by rotors	o	$x*(Pi*r^2(d+l))$	269479.3216	538958.643	404218.982	336849.152	741068.134	404218.9824	471588.813
Bird occupancy of rotor swept area (bird-secs)	b	3600*(n*(o/Vw))	0	18.0054191	0	0	26.5295309	2.84401354	9.10700921
Time taken for bird to pass through rotors (secs)	t2	(d+l)/v	0.34887218	0.34887218	0.34887218	0.34887218	0.34887218	0.34887218	0.34887218
Number of bird passes through the rotor during survey period	N	b/t2	0	51.6103607	0	0	76.0436984	8.15202157	26.1041428
Total transits adjusted for maximum operation of turbines (85%)	Tn	N*0.85	0	43.8688066	0	0	64.6371436	6.929218334	22.1885214
Number of transits per turbine within viewshed	TnT	Tn/x	0	5.48360082	0	0	5.87610397	1.154869722	3.16978877
Average TnT of all VP's	ATnT	$(TnT_1+TnT_2+TnT_3+.....)/8$	1.960545409						
Number of transits across windfarm	T	ATnT*(Total no. turbines)	37.25036278						
		Collision Probability (Stage 2)	**5.80%**						
		Collisions during study period	T*Collision Probability	2.16052104					
		Collisions during study period with 98% Avoidance Rate	*0.02	0.04321042					
		Over 30-year duration of windfarm	*30	**1.29631262**					

Buzzard, Winter VP Surveys: Sep 2017 - March 2018

Measurements	Code	Value
Rotor radius (metres)	r	68
Rotor diameter (metres)	D	136
Max chord width of turbine blades (metres)	d	4.1
Buzzard length (metres)	l	0.54
Average flight speed of Buzzard (m/s)	v	13.3
Wingspan (m)		1.2
Mean pitch of blade (degrees)		5
Rotors per turbine		3
Rotational period (seconds)		6.12
Turbine operational time (%)		85

			Vantage Point						
			1a	2	3	4a	5a	7a	8a
Survey time over 7 months (secs)	s		151200	151200	151200	151200	151200	151200	151200
Total flight-time between 25 - 175m (bird-secs)	PCH		68	100	0	0	30	67	0
No. of turbines in viewshed	x		4	8	6	5	11	6	7
Survey area visible from VP (hectares)	Avp		436	395	282	303	599	422	451
Area of risk, i.e. 500m buffer of turbines within viewshed (hectares)	Arisk		187.57	332.16	218.8	171.3	457.9	268.27	330.28
Availability of species activity during survey period (hours)	Ba		2523	2523	2523	2523	2523	2523	2523

Stage 1 Calculations

Measurements	Code	Calculation							
Proportion of flight-time between 25 - 175m	t1	PCH/s	0.0004	0.0007	0.0000	0.0000	0.0002	0.0004	0.0000
Flight activity per visible unit of area	F	t1/Avp	1.0315E-06	1.674E-06	0	0	3.312E-07	1.05005E-06	0
Proportion of time in risk area	Trisk	F*Arisk	0.000193479	0.0005562	0	0	0.0001517	0.000281697	0
Bird occupancy of risk area	n	Trisk*Ba	0.488147716	1.4031875	0	0	0.3826754	0.710722264	0
Risk volume	Vw	(Arisk*D)*10000	255095200	451737600	297568000	232968000	622744000	364847200	449180800
Actual volume of air swept by rotors	o	$x*(Pi*r^2(d+l))$	269479.3216	538958.64	404218.98	336849.15	741068.13	404218.9824	471588.81
Bird occupancy of rotor swept area (bird-secs)	b	3600*(n*(o/Vw))	1.856422915	6.0268086	0	0	1.6393875	2.834706555	0
Time taken for bird to pass through rotors (secs)	t2	(d+l)/v	0.34887218	0.3488722	0.3488722	0.3488722	0.3488722	0.34887218	0.3488722
Number of bird passes through the rotor during survey period	N	b/t2	5.321212235	17.275119	0	0	4.6991065	8.125344219	0
Total transits adjusted for maximum operation of turbines (85%)	Tn	N*0.85	4.5230304	14.683851	0	0	3.9942405	6.906542586	0
Number of transits per turbine within viewshed	TnT	Tn/x	1.1307576	1.8354814	0	0	0.3631128	1.151090431	0
Average TnT of all VP's	ATnT	$(TnT_1+TnT_2+TnT_3+.....)/8$	0.56005528						
Number of transits across windfarm	T	ATnT*(Total no. turbines)	10.64105031						

		Collision Probability (Stage 2)	5.80%
		Collisions during study period	T*Collision Probabilty	0.6171809
		Collisions during study period with 98% Avoidance Rate	*0.02	0.0123436
		Over 30-year duration of windfarm	*30	**0.3703086**

Buzzard, Breeding VP Surveys: April 2018 - Aug 2018

Measurements	Code	Value
Rotor radius (metres)	r	68
Rotor diameter (metres)	D	136
Max chord width of turbine blades (metres)	d	4.1
Buzzard length (metres)	l	0.54
Average flight speed of Buzzard (m/s)	v	13.3
Wingspan (m)		1.2
Mean pitch of blade (degrees)		5
Rotors per turbine		3
Rotational period (seconds)		6.12
Turbine operational time (%)		85

			Vantage Point						
			1a	2	3	4a	5a	7a	8a
Survey time over 5 months (secs)	s		108000	108000	108000	108000	108000	108000	108000
Total flight-time between 25 - 175m (bird-secs)	PCH		0	0	0	180	400	0	48
No. of turbines in viewshed	x		4	8	6	5	11	6	7
Survey area visible from VP (hectares)	Avp		436	395	282	303	599	422	451
Area of risk, i.e. 500m buffer of turbines within viewshed (hectares)	Arisk		187.57	332.16	218.8	171.3	457.9	268.27	330.28
Availability of species activity during survey period (hours)	Ba		2692	2692	2692	2692	2692	2692	2692

Stage 1 Calculations

Measurements	Code	Calculation							
Proportion of flight-time between 25 - 175m	t1	PCH/s	0.0000	0.0000	0.0000	0.0017	0.0037	0.0000	0.0004
Flight activity per visible unit of area	F	t1/Avp	0	0	0	5.501E-06	6.183E-06	0	9.855E-07
Proportion of time in risk area	Trisk	F*Arisk	0	0	0	0.0009422	0.0028313	0	0.0003255
Bird occupancy of risk area	n	Trisk*Ba	0	0	0	2.5365215	7.6217572	0	0.87619
Risk volume	Vw	(Arisk*D)*10000	255095200	451737600	297568000	232968000	622744000	364847200	449180800(
Actual volume of air swept by rotors	o	x*(Pi*r^2(d+l))	269479.3216	538958.64	404218.98	336849.15	741068.13	404218.9824	471588.81
Bird occupancy of rotor swept area (bird-secs)	b	3600*(n*(o/Vw))	0	0	0	13.203231	32.65173	0	3.3116397
Time taken for bird to pass through rotors (secs)	t2	(d+l)/v	0.34887218	0.3488722	0.3488722	0.3488722	0.3488722	0.34887218	0.3488722
Number of bird passes through the rotor during survey period	N	b/t2	0	0	0	37.845469	93.592244	0	9.4924156
Total transits adjusted for maximum operation of turbines (85%)	Tn	N*0.85	0	0	0	32.168648	79.553408	0	8.0685532
Number of transits per turbine within viewshed	TnT	Tn/x	0	0	0	6.4337297	7.232128	0	1.1526505

Average TnT of all VP's	ATnT	(TnT$_1$+TnT$_2$+TnT$_3$+.....)/8	1.852313512	
Number of transits across windfarm	T	ATnT*(Total no. turbines)	35.19395672	
		Collision Probability (Stage 2)	**5.80%**	
		Collisions during study period	T*Collision Probability	2.0412495
		Collisions during study period with 98% Avoidance Rate	*0.02	0.040825
		Over 30-year duration of windfarm	*30	**1.2247497**

Golden Plover, Winter VP Surveys: Sep 2016 - March 2017

Measurements	Code	Value
Rotor radius (metres)	r	68
Rotor diameter (metres)	D	136
Max chord width of turbine blades (metres)	d	4.1
Golden Plover length (metres)	l	0.275
Average flight speed of Golden Plover (m/s)	v	17.9
Wingspan (m)		0.715
Mean pitch of blade (degrees)		5
Rotors per turbine		3
Average rotational period (seconds)		6.12
Turbine operational time (%)		85

			Vantage Point						
			1a	2	3	4a	5a	7a	8a
Survey time over 7 months (secs)	s		151200	151200	151200	151200	151200	151200	151200
Total flight-time between 25 - 175m (bird-secs)	PCH		0	0	0	20250	0	0	0
No. of turbines in viewshed	x		4	8	6	5	11	6	7
Survey area visible from VP (hectares)	Avp		436	395	282	303	599	422	451
Area of risk, i.e. 500m buffer of turbines within viewshed (hectares)	Arisk		187.57	332.16	218.8	171.3	457.9	268.27	330.28
Availability of species activity during survey period (hours)	Ba		2845	2845	2845	2845	2845	2845	2845

Stage 1 Calculations

Measurements	Code	Calculation	1a	2	3	4a	5a	7a	8a
Proportion of flight-time between 25 - 175m	t1	PCH/s	0.0000	0.0000	0.0000	0.1339	0.0000	0.0000	0.0000
Flight activity per visible unit of area	F	t1/Avp	0	0	0	0.000442	0	0	0
Proportion of time in risk area	Trisk	F*Arisk	0	0	0	0.0757161	0	0	0
Bird occupancy of risk area	n	Trisk*Ba	0	0	0	215.41217	0	0	0
Risk volume	Vw	(Arisk*D)*10000	255095200	451737600	297568000	232968000	622744000	364847200	449180800
Actual volume of air swept by rotors	o	x*(Pi*r^2(d+l))	254088.8	508177.6	381133.2	317611	698744.2	381133.2	444655.4
Bird occupancy of rotor swept area (bird-secs)	b	3600*(n*(o/Vw))	0	0	0	1057.2362	0	0	0
Time taken for bird to pass through rotors (secs)	t2	(d+l)/v	0.244413408	0.2444134	0.2444134	0.2444134	0.2444134	0.2444134	0.2444134
Number of bird passes through the rotor during survey period	N	b/t2	0	0	0	4325.6062	0	0	0
Total transits adjusted for maximum operation of turbines (85%)	Tn	N*0.85	0	0	0	3676.7653	0	0	0
Number of transits per turbine within viewshed	TnT	Tn/x	0	0	0	735.35306	0	0	0
Average TnT of all VP's	ATnT	(TnT$_1$+TnT$_2$+TnT$_3$+.....)/8	91.91913191						
Number of transits across windfarm	T	ATnT*(Total no. turbines)	1746.463506						
		Collision Probability (Stage 2)	**4.55%**						
		Collisions during study period	T*Collision Probabilty	79.46409					
		Collisions during study period with 98% Avoidance Rate	*0.02	1.5892818					
		Over 30-year duration of windfarm	*30	**47.678454**					

Golden Plover, Winter VP Surveys: Sep 2017 - March 2018

Measurements	Code	Value
Rotor radius (metres)	r	68
Rotor diameter (metres)	D	136
Max chord width of turbine blades (metres)	d	4.1
Golden Plover length (metres)	l	0.275
Average flight speed of Golden Plover (m/s)	v	17.9
Wingspan (m)		0.715
Mean pitch of blade (degrees)		5
Rotors per turbine		3
Average rotational period (seconds)		6.12
Turbine operational time (%)		85

			Vantage Point						
			1a	2	3	4a	5a	7a	8a
Survey time over 7 months (secs)	s		151200	151200	151200	151200	151200	151200	151200
Total flight-time between 25 - 175m (bird-secs)	PCH		0	0	0	0	0	0	0
No. of turbines in viewshed	x		4	8	6	5	11	6	7
Survey area visible from VP (hectares)	Avp		436	395	282	303	599	422	451
Area of risk, i.e. 500m buffer of turbines within viewshed (hectares)	Arisk		187.57	332.16	218.8	171.3	457.9	268.27	330.28
Availability of species activity during survey period (hours)	Ba		2845	2845	2845	2845	2845	2845	2845

Stage 1 Calculations

Measurements	Code	Calculation							
Proportion of flight-time between 25 - 175m	t1	PCH/s	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Flight activity per visible unit of area	F	t1/Avp	0	0	0	0	0	0	0
Proportion of time in risk area	Trisk	F*Arisk	0	0	0	0	0	0	0
Bird occupancy of risk area	n	Trisk*Ba	0	0	0	0	0	0	0
Risk volume	Vw	(Arisk*D)*10000	255095200	451737600	297568000	232968000	622744000	364847200	449180800
Actual volume of air swept by rotors	o	$x*(Pi*r^2(d+l))$	254088.8	508177.6	381133.2	317611	698744.2	381133.2	444655.4
Bird occupancy of rotor swept area (bird-secs)	b	3600*(n*(o/Vw))	0	0	0	0	0	0	0
Time taken for bird to pass through rotors (secs)	t2	(d+l)/v	0.244413408	0.244413408	0.244413408	0.244413408	0.244413408	0.244413408	0.244413408
Number of bird passes through the rotor during survey period	N	b/t2	0	0	0	0	0	0	0
Total transits adjusted for maximum operation of turbines (85%)	Tn	N*0.85	0	0	0	0	0	0	0
Number of transits per turbine within viewshed	TnT	Tn/x	0	0	0	0	0	0	0
Average TnT of all VP's	ATnT	$(TnT_1+TnT_2+TnT_3+.....)/8$	0						
Number of transits across windfarm	T	ATnT*(Total no. turbines)	0						
		Collision Probability (Stage 2)	**4.55%**						
		Collisions during study period	T*Collision Probability	0					
		Collisions during study period with 98% Avoidance Rate	*0.02	0					
		Over 30-year duration of windfarm	*30	**0**					

Hen Harrier, Winter VP Surveys: Sep 2016 - Feb 2017

Measurements	Code	Value
Rotor radius (metres)	r	68
Rotor diameter (metres)	D	136
Max chord width of turbine blades (metres)	d	4.1
Hen Harrier length (metres)	l	0.48
Average flight speed of Hen Harrier (m/s)	v	12
Wingspan (m)		1.1
Mean pitch of blade (degrees)		5
Rotors per turbine		3
Rotational period (seconds)		6.12
Turbine operational time (%)		85

			Vantage Point						
			1a	2	3	4a	5a	7a	8a
Survey time over 6 months (secs)	s		129600	129600	129600	129600	129600	129600	129600
Total flight-time between 25 - 175m (bird-secs)	PCH		0	0	0	0	0	78	0
No. of turbines in viewshed	x		4	8	6	5	11	6	7
Survey area visible from VP (hectares)	Avp		436	395	282	303	599	422	451
Area of risk, i.e. 500m buffer of turbines within viewshed (hectares)	Arisk		187.57	332.16	218.8	171.3	457.9	268.27	330.28
Availability of species activity during survey period (hours)	Ba		2090	2090	2090	2090	2090	2090	2090

Stage 1 Calculations

Measurements	Code	Calculation							
Proportion of flight-time between 25 - 175m	t1	PCH/s	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006	0.0000
Flight activity per visible unit of area	F	t1/Avp	0	0	0	0	0	1.42619E-06	0
Proportion of time in risk area	Trisk	F*Arisk	0	0	0	0	0	0.000382604	0
Bird occupancy of risk area	n	Trisk*Ba	0	0	0	0	0	0.799641906	0
Risk volume	Vw	(Arisk*D)*10000	255095200	451737600	297568000	232968000	622744000	364847200	449180800
Actual volume of air swept by rotors	o	$x*(Pi*r^2(d+l))$	265994.6752	531989.35	398992.013	332493.344	731485.357	398992.0128	465490.682
Bird occupancy of rotor swept area (bird-secs)	b	3600*(n*(o/Vw))	0	0	0	0	0	3.148119653	0
Time taken for bird to pass through rotors (secs)	t2	(d+l)/v	0.381666667	0.38166667	0.38166667	0.38166667	0.38166667	0.381666667	0.38166667
Number of bird passes through the rotor during survey period	N	b/t2	0	0	0	0	0	8.248348436	0
Total transits adjusted for maximum operation of turbines (85%)	Tn	N*0.85	0	0	0	0	0	7.011096171	0
Number of transits per turbine within viewshed	TnT	Tn/x	0	0	0	0	0	1.168516028	0

Average TnT of all VP's	ATnT	$(TnT_1+TnT_2+TnT_3+.....)/8$	0.146064504	
Number of transits across windfarm	T	ATnT*(Total no. turbines)	2.775225568	
		Collision Probability (Stage 2)	**5.70%**	
		Collisions during study period	T*Collision Probabilty	0.15818786
		Collisions during study period with 99% Avoidance Rate	*0.01	0.00158188
		Over 30-year duration of windfarm	*30	**0.04745636**

Hen Harrier, Breeding VP Surveys: March 2017 - Aug 2017

Measurements	Code	Value
Rotor radius (metres)	r	68
Rotor diameter (metres)	D	136
Max chord width of turbine blades (metres)	d	4.1
Hen Harrier length (metres)	l	0.48
Average flight speed of Hen Harrier (m/s)	v	12
Wingspan (m)		1.1
Mean pitch of blade (degrees)		5
Rotors per turbine		3
Rotational period (seconds)		6.12
Turbine operational time (%)		85

			Vantage Point						
			1a	2	3	4a	5a	7a	8a
Survey time over 6 months (secs)	s		129600	129600	129600	129600	129600	129600	129600
Total flight-time between 25 - 175m (bird-secs)	PCH		0	290	305	190	0	265	0
No. of turbines in viewshed	x		4	8	6	5	11	6	7
Survey area visible from VP (hectares)	Avp		436	395	282	303	599	422	451
Area of risk, i.e. 500m buffer of turbines within viewshed (hectares)	Arisk		187.57	332.16	218.8	171.3	457.9	268.27	330.28
Availability of species activity during survey period (hours)	Ba		3105	3105	3105	3105	3105	3105	3105

Stage 1 Calculations

Measurements	Code	Calculation	1a	2	3	4a	5a	7a	8a
Proportion of flight-time between 25 - 175m	t1	PCH/s	0.0000	0.0022	0.0024	0.0015	0.0000	0.0020	0.0000
Flight activity per visible unit of area	F	t1/Avp	0	5.6649E-06	8.3454E-06	4.8384E-06	0	4.84539E-06	0
Proportion of time in risk area	Trisk	F*Arisk	0	0.00188167	0.00182597	0.00082883	0	0.001299872	0
Bird occupancy of risk area	n	Trisk*Ba	0	5.84258228	5.66962914	2.57350454	0	4.036102019	0
Risk volume	Vw	(Arisk*D)*10000	255095200	451737600	297568000	232968000	622744000	364847200	449180800
Actual volume of air swept by rotors	o	x*(Pi*r^2(d+l))	265994.6752	531989.35	398992.013	332493.344	731485.357	398992.0128	465490.682
Bird occupancy of rotor swept area (bird-secs)	b	3600*(n*(o/Vw))	0	24.7698876	27.3675001	13.2225167	0	15.88977766	0
Time taken for bird to pass through rotors (secs)	t2	(d+l)/v	0.381666667	0.38166667	0.38166667	0.38166667	0.38166667	0.381666667	0.38166667
Number of bird passes through the rotor during survey period	N	b/t2	0	64.8992689	71.7052404	34.6441485	0	41.63260521	0
Total transits adjusted for maximum operation of turbines (85%)	Tn	N*0.85	0	55.1643785	60.9494544	29.4475262	0	35.38771443	0
Number of transits per turbine within viewshed	TnT	Tn/x	0	6.89554732	10.1582424	5.88950525	0	5.897952405	0
Average TnT of all VP's	ATnT	(TnT_1+TnT_2+TnT_3+.....)/8	3.60515592						
Number of transits across windfarm	T	ATnT*(Total no. turbines)	68.49796249						
		Collision Probability (Stage 2)	5.70%						
		Collisions during study period	T*Collision Probability	3.90438386					
		Collisions during study period with 99% Avoidance Rate	*0.01	0.03904384					
		Over 30-year duration of windfarm	*30	**1.17131516**					

Hen Harrier, Breeding VP Surveys: March 2018 - Aug 2018

Measurements	Code	Value
Rotor radius (metres)	r	68
Rotor diameter (metres)	D	136
Max chord width of turbine blades (metres)	d	4.1
Hen Harrier length (metres)	l	0.48
Average flight speed of Hen Harrier (m/s)	v	12
Wingspan (m)		1.1
Mean pitch of blade (degrees)		5
Rotors per turbine		3
Rotational period (seconds)		6.12
Turbine operational time (%)		85

			Vantage Point						
			1a	**2**	**3**	**4a**	**5a**	**7a**	**8a**
Survey time over 6 months (secs)	s		129600	129600	129600	129600	129600	129600	129600
Total flight-time between 25 - 175m (bird-secs)	PCH		0	461	70	110	748	934	90
No. of turbines in viewshed	x		4	8	6	5	11	6	7
Survey area visible from VP (hectares)	Avp		436	395	282	303	599	422	451
Area of risk, i.e. 500m buffer of turbines within viewshed (hectares)	Arisk		187.57	332.16	218.8	171.3	457.9	268.27	330.28
Availability of species activity during survey period (hours)	Ba		3105	3105	3105	3105	3105	3105	3105

Stage 1 Calculations

Measurements	Code	Calculation							
Proportion of flight-time between 25 - 175m	t1	PCH/s	0.0000	0.0036	0.0005	0.0008	0.0058	0.0072	0.0007
Flight activity per visible unit of area	F	t1/Avp	0	9.0053E-06	1.9153E-06	2.8012E-06	9.6354E-06	1.70777E-05	1.5398E-06
Proportion of time in risk area	Trisk	F*Arisk	0	0.0029912	0.00041907	0.00047985	0.00441205	0.004581435	0.00050856
Bird occupancy of risk area	n	Trisk*Ba	0	9.28769114	1.30122636	1.48992368	13.699415	14.2253558	1.57908259
Risk volume	Vw	(Arisk*D)*10000	255095200	451737600	297568000	232968000	622744000	364847200	449180800
Actual volume of air swept by rotors	o	$x*(Pi*r^2(d+l))$	265994.6752	531989.35	398992.013	332493.344	731485.357	398992.0128	465490.682
Bird occupancy of rotor swept area (bird-secs)	b	3600*(n*(o/Vw))	0	39.37558	6.2810656	7.65514124	57.9296104	56.00397106	5.8911103
Time taken for bird to pass through rotors (secs)	t2	(d+l)/v	0.381666667	0.38166667	0.38166667	0.38166667	0.38166667	0.381666667	0.38166667
Number of bird passes through the rotor during survey period	N	b/t2	0	103.167458	16.4569404	20.0571386	151.780639	146.7352954	15.4352235
Total transits adjusted for maximum operation of turbines (85%)	Tn	N*0.85	0	87.6923397	13.9883994	17.0485678	129.013543	124.7250011	13.11994
Number of transits per turbine within viewshed	TnT	Tn/x	0	10.9615425	2.33139989	3.40971356	11.7285039	20.78750018	1.87427714

Average TnT of all VP's	ATnT	$(TnT_1+TnT_2+TnT_3+.....)/8$	6.38661714	
Number of transits across windfarm	T	ATnT*(Total no. turbines)	121.3457257	
		Collision Probability (Stage 2)	**5.70%**	
		Collisions during study period	T*Collision Probability	6.91670636
		Collisions during study period with 99% Avoidance Rate	*0.01	0.06916706
		Over 30-year duration of windfarm	*30	**2.07501191**

Kestrel, Winter VP Surveys: Sep 2016 - March 2017

Measurements	Code	Value
Rotor radius (metres)	r	68
Rotor diameter (metres)	D	136
Max chord width of turbine blades (metres)	d	4.1
Kestrel length (metres)	l	0.34
Average flight speed of Kestrel (m/s)	v	10.1
Wingspan (m)		0.76
Mean pitch of blade (degrees)		5
Rotors per turbine		3
Rotational period (seconds)		6.12
Turbine operational time (%)		85

			Vantage Point						
			1a	**2**	**3**	**4a**	**5a**	**7a**	**8a**
Survey time over 7 months (secs)	s		151200	151200	151200	151200	151200	151200	151200
Total flight-time between 25 - 175m (bird-secs)	PCH		214	409	206	27	0	693	151
No. of turbines in viewshed	x		4	8	6	5	11	6	7
Survey area visible from VP (hectares)	Avp		436	395	282	303	599	422	451
Area of risk, i.e. 500m buffer of turbines within viewshed (hectares)	Arisk		187.57	332.16	218.8	171.3	457.9	268.27	330.28
Availability of species activity during survey period (hours)	Ba		2523	2523	2523	2523	2523	2523	2523

Stage 1 Calculations

Measurements	Code	Calculation							
Proportion of flight-time between 25 - 175m	t1	PCH/s	0.0014	0.0027	0.0014	0.0002	0.0000	0.0046	0.0010
Flight activity per visible unit of area	F	t1/Avp	3.2462E-06	6.8482E-06	4.8313E-06	5.8934E-07	0	1.0861E-05	2.2144E-06
Proportion of time in risk area	Trisk	F*Arisk	0.00060889	0.00227469	0.00105709	0.00010095	0	0.002913675	0.00073136
Bird occupancy of risk area	n	Trisk*Ba	1.536229575	5.73903672	2.66704835	0.2547088	0	7.351201925	1.84521995
Risk volume	Vw	(Arisk*D)*10000	255095200	451737600	297568000	232968000	622744000	364847200	449180800
Actual volume of air swept by rotors	o	x*(Pi*r^2(d+l))	257863.8336	515727.667	386795.75	322329.792	709125.542	386795.7504	451261.709
Bird occupancy of rotor swept area (bird-secs)	b	3600*(n*(o/Vw))	5.590450041	23.5871623	12.4804101	1.26867574	0	28.05637317	6.67356571
Time taken for bird to pass through rotors (secs)	t2	(d+l)/v	0.43960396	0.43960396	0.43960396	0.43960396	0.43960396	0.43960396	0.43960396
Number of bird passes through the rotor during survey period	N	b/t2	12.71701473	53.6554817	28.3901222	2.88595157	0	63.82192996	15.1808589
Total transits adjusted for maximum operation of turbines (85%)	Tn	N*0.85	10.80946252	45.6071595	24.1316038	2.45305884	0	54.24864047	12.9037301
Number of transits per turbine within viewshed	TnT	Tn/x	2.702365631	5.70089493	4.02193397	0.49061177	0	9.041440078	1.84339001
Average TnT of all VP's	ATnT	(TnT$_1$+TnT$_2$+TnT$_3$+.....)/8	2.97507955						
Number of transits across windfarm	T	ATnT*(Total no. turbines)	56.52651144						
		Collision Probability (Stage 2)	**5.35%**						
		Collisions during study period	T*Collision Probability	3.02416836					
		Collisions during study period with 95% Avoidance Rate	*0.05	0.15120842					
		Over 30-year duration of windfarm	*30	**4.53625254**					

Kestrel, Breeding VP Surveys: April 2017 - Aug 2017

Measurements	Code	Value
Rotor radius (metres)	r	68
Rotor diameter (metres)	D	136
Max chord width of turbine blades (metres)	d	4.1
Kestrel length (metres)	l	0.34
Average flight speed of Kestrel (m/s)	v	10.1
Wingspan (m)		0.76
Mean pitch of blade (degrees)		5
Rotors per turbine		3
Rotational period (seconds)		6.12
Turbine operational time (%)		85

			Vantage Point						
			1a	2	3	4a	5a	7a	8a
Survey time over 5 months (secs)	s		108000	108000	108000	108000	108000	108000	108000
Total flight-time between 25 - 175m (bird-secs)	PCH		0	0	0	0	180	310	535
No. of turbines in viewshed	x		4	8	6	5	11	6	7
Survey area visible from VP (hectares)	Avp		436	395	282	303	599	422	451
Area of risk, i.e. 500m buffer of turbines within viewshed (hectares)	Arisk		187.57	332.16	218.8	171.3	457.9	268.27	330.28
Availability of species activity during survey period (hours)	Ba		2692	2692	2692	2692	2692	2692	2692

Stage 1 Calculations

Measurements	Code	Calculation							
Proportion of flight-time between 25 - 175m	t1	PCH/s	0.0000	0.0000	0.0000	0.0000	0.0017	0.0029	0.0050
Flight activity per visible unit of area	F	t1/Avp	0	0	0	0	2.7824E-06	6.80183E-06	1.0984E-05
Proportion of time in risk area	Trisk	F*Arisk	0	0	0	0	0.00127407	0.001824726	0.00362774
Bird occupancy of risk area	n	Trisk*Ba	0	0	0	0	3.42979076	4.912161673	9.76586724
Risk volume	Vw	(Arisk*D)*10000	255095200	451737600	297568000	232968000	622744000	364847200	449180800
Actual volume of air swept by rotors	o	$x*(Pi*r^2(d+l))$	257863.8336	515727.667	386795.75	322329.792	709125.542	386795.7504	451261.709
Bird occupancy of rotor swept area (bird-secs)	b	3600*(n*(o/Vw))	0	0	0	0	14.0599477	18.7476065	35.3199936
Time taken for bird to pass through rotors (secs)	t2	(d+l)/v	0.43960396	0.43960396	0.43960396	0.43960396	0.43960396	0.43960396	0.43960396
Number of bird passes through the rotor during survey period	N	b/t2	0	0	0	0	31.9832143	42.64658235	80.3450305
Total transits adjusted for maximum operation of turbines (85%)	Tn	N*0.85	0	0	0	0	27.1857321	36.24959499	68.2932759
Number of transits per turbine within viewshed	TnT	Tn/x	0	0	0	0	2.47143019	6.041599166	9.75618227

Average TnT of all VP's	ATnT	$(TnT_1+TnT_2+TnT_3+.....)/8$	2.283651454						
Number of transits across windfarm	T	ATnT*(Total no. turbines)	43.38937763						

		Collision Probability (Stage 2)	**5.35%**	
		Collisions during study period	T*Collision Probability	2.3213317
		Collisions during study period with 95% Avoidance Rate	*0.05	0.11606659
		Over 30-year duration of windfarm	*30	**3.48199755**

Kestrel, Winter VP Surveys: Sep 2017 - March 2018

Measurements	Code	Value
Rotor radius (metres)	r	68
Rotor diameter (metres)	D	136
Max chord width of turbine blades (metres)	d	4.1
Kestrel length (metres)	l	0.34
Average flight speed of Kestrel (m/s)	v	10.1
Wingspan (m)		0.76
Mean pitch of blade (degrees)		5
Rotors per turbine		3
Rotational period (seconds)		6.12
Turbine operational time (%)		85

			Vantage Point						
			1a	2	3	4a	5a	7a	8a
Survey time over 7 months (secs)	s		151200	151200	151200	151200	151200	151200	151200
Total flight-time between 25 - 175m (bird-secs)	PCH		58	176	1920	20	2813	97	0
No. of turbines in viewshed	x		4	8	6	5	11	6	7
Survey area visible from VP (hectares)	Avp		436	395	282	303	599	422	451
Area of risk, i.e. 500m buffer of turbines within viewshed (hectares)	Arisk		187.57	332.16	218.8	171.3	457.9	268.27	330.28
Availability of species activity during survey period (hours)	Ba		2523	2523	2523	2523	2523	2523	2523

Stage 1 Calculations

Measurements	Code	Calculation							
Proportion of flight-time between 25 - 175m	t1	PCH/s	0.0004	0.0012	0.0127	0.0001	0.0186	0.0006	0.0000
Flight activity per visible unit of area	F	t1/Avp	8.79812E-07	2.94689E-06	4.50298E-05	4.36552E-07	3.10593E-05	1.52022E-06	0
Proportion of time in risk area	Trisk	F*Arisk	0.000165026	0.000978839	0.009852527	7.47813E-05	0.014222036	0.00040783	0
Bird occupancy of risk area	n	Trisk*Ba	0.416361287	2.469609934	24.85792638	0.188673189	35.88219588	1.028956114	0
Risk volume	Vw	(Arisk*D)*10000	255095200	451737600	297568000	232968000	622744000	364847200	449180800
Actual volume of air swept by rotors	o	x*(Pi*r^2(d+l))	257863.8336	515727.6672	386795.7504	322329.792	709125.5424	386795.7504	451261.7088
Bird occupancy of rotor swept area (bird-secs)	b	3600*(n*(o/Vw))	1.515168703	10.14997692	116.3222693	0.939759808	147.0940448	3.927082536	0
Time taken for bird to pass through rotors (secs)	t2	(d+l)/v	0.43960396	0.43960396	0.43960396	0.43960396	0.43960396	0.43960396	0.43960396
Number of bird passes through the rotor during survey period	N	b/t2	3.446667544	23.08891145	264.6069639	2.137741905	334.6058226	8.933228292	0
Total transits adjusted for maximum operation of turbines (85%)	Tn	N*0.85	2.929667413	19.62557473	224.9159193	1.817080619	284.4149492	7.593244048	0
Number of transits per turbine within viewshed	TnT	Tn/x	0.732416853	2.453196842	37.48598656	0.363416124	25.85590447	1.265540675	0
Average TnT of all VP's	ATnT	(TnT$_1$+TnT$_2$+TnT$_3$+.....)/8	8.51955769						
Number of transits across windfarm	T	ATnT*(Total no. turbines)	161.8715961						
		Collision Probability (Stage 2)	**5.35%**						
		Collisions during study period	T*Collision Probability	8.660130392					
		Collisions during study period with 95% Avoidance Rate	*0.05	0.43300652					
		Over 30-year duration of windfarm	*30	**12.99019559**					

Kestrel, Breeding VP Surveys: April 2018 - Aug 2018

Measurements	Code	Value
Rotor radius (metres)	r	68
Rotor diameter (metres)	D	136
Max chord width of turbine blades (metres)	d	4.1
Kestrel length (metres)	l	0.34
Average flight speed of Kestrel (m/s)	v	10.1
Wingspan (m)		0.76
Mean pitch of blade (degrees)		5
Rotors per turbine		3
Rotational period (seconds)		6.12
Turbine operational time (%)		85

			Vantage Point						
			1a	2	3	4a	5a	7a	8a
Survey time over 5 months (secs)	s		108000	108000	108000	108000	108000	108000	108000
Total flight-time between 25 - 175m (bird-secs)	PCH		0	0	0	0	10	270	0
No. of turbines in viewshed	x		4	8	6	5	11	6	7
Survey area visible from VP (hectares)	Avp		436	395	282	303	599	422	451
Area of risk, i.e. 500m buffer of turbines within viewshed (hectares)	Arisk		187.57	332.16	218.8	171.3	457.9	268.27	330.28
Availability of species activity during survey period (hours)	Ba		2692	2692	2692	2692	2692	2692	2692

Stage 1 Calculations

Measurements	Code	Calculation							
Proportion of flight-time between 25 - 175m	t1	PCH/s	0.0000	0.0000	0.0000	0.0000	0.0001	0.0025	0.0000
Flight activity per visible unit of area	F	t1/Avp	0	0	0	0	1.54579E-07	5.92417E-06	0
Proportion of time in risk area	Trisk	F*Arisk	0	0	0	0	7.07815E-05	0.001589277	0
Bird occupancy of risk area	n	Trisk*Ba	0	0	0	0	0.190543931	4.27833436	0
Risk volume	Vw	(Arisk*D)*10000	255095200	451737600	297568000	232968000	622744000	364847200	449180800
Actual volume of air swept by rotors	o	x*(Pi*r^2(d+l))	257863.8336	515727.6672	386795.7504	322329.792	709125.5424	386795.7504	451261.7088
Bird occupancy of rotor swept area (bird-secs)	b	3600*(n*(o/Vw))	0	0	0	0	0.781108203	16.3285605	0
Time taken for bird to pass through rotors (secs)	t2	(d+l)/v	0.43960396	0.43960396	0.43960396	0.43960396	0.43960396	0.43960396	0.43960396
Number of bird passes through the rotor during survey period	N	b/t2	0	0	0	0	1.776845237	37.14379753	0
Total transits adjusted for maximum operation of turbines (85%)	Tn	N*0.85	0	0	0	0	1.510318452	31.5722279	0
Number of transits per turbine within viewshed	TnT	Tn/x	0	0	0	0	0.137301677	5.262037983	0
Average TnT of all VP's	ATnT	(TnT$_1$+TnT$_2$+TnT$_3$+.....)/8	0.674917458						
Number of transits across windfarm	T	ATnT*(Total no. turbines)	12.82343169						
		Collision Probability (Stage 2)	**5.35%**						
		Collisions during study period	T*Collision Probability	0.686053596					
		Collisions during study period with 95% Avoidance Rate	*0.05	0.03430268					
		Over 30-year duration of windfarm	*30	**1.029080393**					

Mallard, Breeding VP Surveys: April 2017 - Aug 2017

Measurements	Code	Value
Rotor radius (metres)	r	68
Rotor diameter (metres)	D	136
Max chord width of turbine blades (metres)	d	4.1
Mallard length (metres)	l	0.58
Average flight speed of Mallard (m/s)	v	18.5
Wingspan (m)		0.88
Mean pitch of blade (degrees)		5
Rotors per turbine		3
Rotational period (seconds)		6.12
Turbine operational time (%)		85

			Vantage Point						
			1a	2	3	4a	5a	7a	8a
Survey time over 5 months (secs)	s		108000	108000	108000	108000	108000	108000	108000
Total flight-time between 25 - 175m (bird-secs)	PCH		0	0	30	0	60	0	0
No. of turbines in viewshed	x		4	8	6	5	11	6	7
Survey area visible from VP (hectares)	Avp		436	395	282	303	599	422	451
Area of risk, i.e. 500m buffer of turbines within viewshed (hectares)	Arisk		187.57	332.16	218.8	171.3	457.9	268.27	330.28
Availability of species activity during survey period (hours)	Ba		3031	3031	3031	3031	3031	3031	3031

Stage 1 Calculations

Measurements	Code	Calculation							
Proportion of flight-time between 25 - 175m	t1	PCH/s	0.0000	0.0000	0.0003	0.0000	0.0006	0.0000	0.0000
Flight activity per visible unit of area	F	t1/Avp	0	0	9.85E-07	0	9.275E-07	0	0
Proportion of time in risk area	Trisk	F*Arisk	0	0	0.0002155	0	0.0004247	0	0
Bird occupancy of risk area	n	Trisk*Ba	0	0	0.6532533	0	1.2872333	0	0
Risk volume	Vw	(Arisk*D)*10000	255095200	451737600	297568000	232968000	622744000	364847200	449180800
Actual volume of air swept by rotors	o	$x*(Pi*r^2(d+l))$	271802.4192	543604.84	407703.63	339753.02	747456.65	407703.6288	475654.23
Bird occupancy of rotor swept area (bird-secs)	b	3600*(n*(o/Vw))	0	0	3.2221258	0	5.562067	0	0
Time taken for bird to pass through rotors (secs)	t2	(d+l)/v	0.252972973	0.252973	0.252973	0.252973	0.252973	0.252972973	0.252973
Number of bird passes through the rotor during survey period	N	b/t2	0	0	12.737036	0	21.986803	0	0
Total transits adjusted for maximum operation of turbines (85%)	Tn	N*0.85	0	0	10.82648	0	18.688783	0	0
Number of transits per turbine within viewshed	TnT	Tn/x	0	0	1.8044134	0	1.6989802	0	0
Average TnT of all VP's	ATnT	(TnT₁+TnT₂+TnT₃+.....)/8	0.437924207						
Number of transits across windfarm	T	ATnT*(Total no. turbines)	8.320559941						
		Collision Probability (Stage 2)	**5.35%**						
		Collisions during study period	T*Collision Probability	0.44515					
		Collisions during study period with 98% Avoidance Rate	*0.02	0.008903					
		Over 30-year duration of windfarm	*30	**0.26709**					

Mallard, Breeding VP Surveys: April 2018 - Aug 2018

Measurements	Code	Value
Rotor radius (metres)	r	68
Rotor diameter (metres)	D	136
Max chord width of turbine blades (metres)	d	4.1
Mallard length (metres)	l	0.58
Average flight speed of Mallard (m/s)	v	18.5
Wingspan (m)		0.88
Mean pitch of blade (degrees)		5
Rotors per turbine		3
Rotational period (seconds)		6.12
Turbine operational time (%)		85

			Vantage Point						
			1a	2	3	4a	5a	7a	8a
Survey time over 5 months (secs)	s		108000	108000	108000	108000	108000	108000	108000
Total flight-time between 25 - 175m (bird-secs)	PCH		0	0	23	0	0	130	10
No. of turbines in viewshed	x		4	8	6	5	11	6	7
Survey area visible from VP (hectares)	Avp		436	395	282	303	599	422	451
Area of risk, i.e. 500m buffer of turbines within viewshed (hectares)	Arisk		187.57	332.16	218.8	171.3	457.9	268.27	330.28
Availability of species activity during survey period (hours)	Ba		3031	3031	3031	3031	3031	3031	3031

Stage 1 Calculations

Measurements	Code	Calculation							
Proportion of flight-time between 25 - 175m	t1	PCH/s	0.0000	0.0000	0.0002	0.0000	0.0000	0.0012	0.0001
Flight activity per visible unit of area	F	t1/Avp	0	0	7.552E-07	0	0	2.85238E-06	2.053E-07
Proportion of time in risk area	Trisk	F*Arisk	0	0	0.0001652	0	0	0.000765208	6.781E-05
Bird occupancy of risk area	n	Trisk*Ba	0	0	0.5008276	0	0	2.319344131	0.2055265
Risk volume	Vw	(Arisk*D)*10000	255095200	451737600	297568000	232968000	622744000	364847200	449180800
Actual volume of air swept by rotors	o	x*(Pi*r^2(d+l))	271802.4192	543604.84	407703.63	339753.02	747456.65	407703.6288	475654.23
Bird occupancy of rotor swept area (bird-secs)	b	3600*(n*(o/Vw))	0	0	2.4702965	0	0	9.330421247	0.7835029
Time taken for bird to pass through rotors (secs)	t2	(d+l)/v	0.252972973	0.252973	0.252973	0.252973	0.252973	0.252972973	0.252973
Number of bird passes through the rotor during survey period	N	b/t2	0	0	9.7650608	0	0	36.88307544	3.0971802
Total transits adjusted for maximum operation of turbines (85%)	Tn	N*0.85	0	0	8.3003017	0	0	31.35061412	2.6326032
Number of transits per turbine within viewshed	TnT	Tn/x	0	0	1.3833836	0	0	5.225102354	0.3760862
Average TnT of all VP's	ATnT	(TnT$_1$+TnT$_2$+TnT$_3$+.....)/8	0.873071517						
Number of transits across windfarm	T	ATnT*(Total no. turbines)	16.58835883						

		Collision Probability (Stage 2)	**5.35%**	
		Collisions during study period	T*Collision Probability	0.8874772
		Collisions during study period with 98% Avoidance Rate	*0.02	0.0177495
		Over 30-year duration of windfarm	*30	**0.5324863**

Peregrine, Winter VP Surveys: Sep 2017 - Feb 2018

Measurements	Code	Value
Rotor radius (metres)	r	68
Rotor diameter (metres)	D	136
Max chord width of turbine blades (metres)	d	4.1
Peregrine length (metres)	l	0.48
Average flight speed of Peregrine (m/s)	v	12
Wingspan (m)		1.02
Mean pitch of blade (degrees)		5
Rotors per turbine		3
Rotational period (seconds)		6.12
Turbine operational time (%)		85

			Vantage Point						
			1a	**2**	**3**	**4a**	**5a**	**7a**	**8a**
Survey time over 6 months (secs)	s		129600	129600	129600	129600	129600	129600	129600
Total flight-time between 25 - 175m (bird-secs)	PCH		0	0	0	0	0	0	0
No. of turbines in viewshed	x		4	8	6	5	11	6	7
Survey area visible from VP (hectares)	Avp		436	395	282	303	599	422	451
Area of risk, i.e. 500m buffer of turbines within viewshed (hectares)	Arisk		187.57	332.16	218.8	171.3	457.9	268.27	330.28
Availability of species activity during survey period (hours)	Ba		2090	2090	2090	2090	2090	2090	2090

Stage 1 Calculations

Measurements	Code	Calculation							
Proportion of flight-time between 25 - 175m	t1	PCH/s	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Flight activity per visible unit of area	F	t1/Avp	0	0	0	0	0	0	0
Proportion of time in risk area	Trisk	F*Arisk	0	0	0	0	0	0	0
Bird occupancy of risk area	n	Trisk*Ba	0	0	0	0	0	0	0
Risk volume	Vw	(Arisk*D)*10000	255095200	451737600	297568000	232968000	622744000	364847200	449180800
Actual volume of air swept by rotors	o	x*(Pi*r^2(d+l))	265994.6752	531989.35	398992.013	332493.344	731485.357	398992.0128	465490.682
Bird occupancy of rotor swept area (bird-secs)	b	3600*(n*(o/Vw))	0	0	0	0	0	0	0
Time taken for bird to pass through rotors (secs)	t2	(d+l)/v	0.381666667	0.38166667	0.38166667	0.38166667	0.38166667	0.381666667	0.38166667
Number of bird passes through the rotor during survey period	N	b/t2	0	0	0	0	0	0	0
Total transits adjusted for maximum operation of turbines (85%)	Tn	N*0.85	0	0	0	0	0	0	0
Total transits in a year	TnY	(Tn/No. months surveyed)*12	0	0	0	0	0	0	0
Number of transits per turbine within viewshed	TnT	Tn/x	0	0	0	0	0	0	0
Average TnT of all VP's	ATnT	(TnT$_1$+TnT$_2$+TnT$_3$+.....)/8	0						
Number of transits across windfarm	T	ATnT*(Total no. turbines)	0						

		Collision Probability (Stage 2)	**5.50%**	
		Collisions during study period	T*Collision Probability	0
		Collisions during study period with 98% Avoidance Rate	*0.02	0
		Over 30-year duration of windfarm	*30	**0**

Peregrine, Breeding VP Surveys: March 2018 - Aug 2018

Measurements	Code	Value
Rotor radius (metres)	r	68
Rotor diameter (metres)	D	136
Max chord width of turbine blades (metres)	d	4.1
Peregrine length (metres)	l	0.42
Average flight speed of Peregrine (m/s)	v	12.1
Wingspan (m)		1.02
Mean pitch of blade (degrees)		5
Rotors per turbine		3
Rotational period (seconds)		6.12
Turbine operational time (%)		85

			Vantage Point						
			1a	2	3	4a	5a	7a	8a
Survey time over 6 months (secs)	s		129600	129600	129600	129600	129600	129600	129600
Total flight-time between 25 - 175m (bird-secs)	PCH		0	0	0	0	0	0	0
No. of turbines in viewshed	x		4	8	6	5	11	6	7
Survey area visible from VP (hectares)	Avp		436	395	282	303	599	422	451
Area of risk, i.e. 500m buffer of turbines within viewshed (hectares)	Arisk		187.57	332.16	218.8	171.3	457.9	268.27	330.28
Availability of species activity during survey period (hours)	Ba		3105	3105	3105	3105	3105	3105	3105

Stage 1 Calculations

Measurements	Code	Calculation							
Proportion of flight-time between 25 - 175m	t1	PCH/s	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Flight activity per visible unit of area	F	t1/Avp	0	0	0	0	0	0	0
Proportion of time in risk area	Trisk	F*Arisk	0	0	0	0	0	0	0
Bird occupancy of risk area	n	Trisk*Ba	0	0	0	0	0	0	0
Risk volume	Vw	(Arisk*D)*10000	255095200	451737600	297568000	232968000	622744000	364847200	449180800
Actual volume of air swept by rotors	o	x*(Pi*r^2(d+l))	262510.0288	525020.058	393765.043	328137.536	721902.579	393765.0432	459392.55
Bird occupancy of rotor swept area (bird-secs)	b	3600*(n*(o/Vw))	0	0	0	0	0	0	0
Time taken for bird to pass through rotors (secs)	t2	(d+l)/v	0.373553719	0.37355372	0.37355372	0.37355372	0.37355372	0.373553719	0.37355372
Number of bird passes through the rotor during survey period	N	b/t2	0	0	0	0	0	0	0
Total transits adjusted for maximum operation of turbines (85%)	Tn	N*0.85	0	0	0	0	0	0	0
Total transits in a year	TnY	(Tn/No. months surveyed)*12	0	0	0	0	0	0	0
Number of transits per turbine within viewshed	TnT	Tn/x	0	0	0	0	0	0	0
Average TnT of all VP's	ATnT	(TnT$_1$+TnT$_2$+TnT$_3$+.....)/8	0						
Number of transits across windfarm	T	ATnT*(Total no. turbines)	0						

		Collision Probability (Stage 2)	**5.50%**						
		Collisions during study period	T*Collision Probability	0					
		Collisions during study period with 98% Avoidance Rate	*0.02	0					
		Over 30-year duration of windfarm	*30	**0**					

Sparrowhawk, Winter VP Surveys: Sep 2017 - March 2018

Measurements	Code	Value
Rotor radius (metres)	r	68
Rotor diameter (metres)	D	136
Max chord width of turbine blades (metres)	d	4.1
Sparrowhawk length (metres)	l	0.33
Average flight speed of Sparrowhawk (m/s)	v	10
Wingspan (m)		0.67
Mean pitch of blade (degrees)		5
Rotors per turbine		3
Rotational period (seconds)		6.12
Turbine operational time (%)		85

			Vantage Point						
			1a	2	3	4a	5a	7a	8a
Survey time over 7 months (secs)	s		151200	151200	151200	151200	151200	151200	151200
Total flight-time between 25 - 175m (bird-secs)	PCH		20	0	100	0	0	0	0
No. of turbines in viewshed	x		4	8	6	5	11	6	7
Survey area visible from VP (hectares)	Avp		436	395	282	303	599	422	451
Area of risk, i.e. 500m buffer of turbines within viewshed (hectares)	Arisk		187.57	332.16	218.8	171.3	457.9	268.27	330.28
Availability of species activity during survey period (hours)	Ba		2523	2523	2523	2523	2523	2523	2523

Stage 1 Calculations

Measurements	Code	Calculation							
Proportion of flight-time between 25 - 175m	t1	PCH/s	0.0001	0.0000	0.0007	0.0000	0.0000	0.0000	0.0000
Flight activity per visible unit of area	F	t1/Avp	3.03383E-07	0	2.3453E-06	0	0	0	0
Proportion of time in risk area	Trisk	F*Arisk	5.69056E-05	0	0.00051315	0	0	0	0
Bird occupancy of risk area	n	Trisk*Ba	0.143572858	0	1.29468367	0	0	0	0
Risk volume	Vw	(Arisk*D)*10000	255095200	451737600	297568000	232968000	622744000	364847200	449180800
Actual volume of air swept by rotors	o	$x*(Pi*r^2(d+l))$	257283.0592	514566.118	385924.589	321603.824	707528.413	385924.5888	450245.354
Bird occupancy of rotor swept area (bird-secs)	b	3600*(n*(o/Vw))	0.521295228	0	6.04480636	0	0	0	0
Time taken for bird to pass through rotors (secs)	t2	(d+l)/v	0.443	0.443	0.443	0.443	0.443	0.443	0.443
Number of bird passes through the rotor during survey period	N	b/t2	1.176738663	0	13.6451611	0	0	0	0
Total transits adjusted for maximum operation of turbines (85%)	Tn	N*0.85	1.000227864	0	11.5983869	0	0	0	0
Number of transits per turbine within viewshed	TnT	Tn/x	0.250056966	0	1.93306449	0	0	0	0
Average TnT of all VP's	ATnT	$(TnT_1+TnT_2+TnT_3+.....)/8$	0.272890182						
Number of transits across windfarm	T	ATnT*(Total no. turbines)	5.184913454						
		Collision Probability (Stage 2)	**5.30%**						
		Collisions during study period	T*Collision Probability	0.27480041					
		Collisions during study period with 98% Avoidance Rate	*0.02	0.00549601					
		Over 30-year duration of windfarm	*30	**0.16488025**					

CALCULATION OF COLLISION RISK FOR BUZZARD PASSING THROUGH ROTOR AREA

W Band   #########

							Upwind:			Downwind:		
K: [1D or [3D] (0 or 1)	1		span: Calculation of alpha and p(collision) as a function of radius									
NoBlades	3		r/R	c/C	α	collide		contribution	collide		contribution
MaxChord	4.1	m	r/R	c/C	α	collide		contribution	collide		contribution
Pitch (degrees)	5		radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r
BirdLength	0.54	m	0.025	0.575	7.62	27.25	1.00	0.00125	26.84	0.99	0.00124
Wingspan	1.2	m	0.075	0.575	2.54	9.22	0.34	0.00255	8.81	0.32	0.00243
F: Flapping (0) or gliding (+1)	0		0.125	0.702	1.52	6.45	0.24	0.00297	5.94	0.22	0.00274
			0.175	0.860	1.09	5.44	0.20	0.00351	4.82	0.18	0.00311
Bird speed	13.3	m/sec	0.225	0.994	0.85	4.81	0.18	0.00399	4.10	0.15	0.00340
RotorDiam	136	m	0.275	0.947	0.69	3.85	0.14	0.00390	3.17	0.12	0.00321
RotationPeriod	6.12	sec	0.325	0.899	0.59	3.18	0.12	0.00381	2.53	0.09	0.00304
			0.375	0.851	0.51	2.68	0.10	0.00370	2.07	0.08	0.00286
			0.425	0.804	0.45	2.30	0.08	0.00360	1.72	0.06	0.00270
			0.475	0.756	0.40	2.05	0.08	0.00359	1.51	0.06	0.00264
Bird aspect ratio: β	0.45		0.525	0.708	0.36	1.84	0.07	0.00357	1.34	0.05	0.00259
			0.575	0.660	0.33	1.67	0.06	0.00354	1.20	0.04	0.00254
			0.625	0.613	0.30	1.52	0.06	0.00351	1.08	0.04	0.00250
			0.675	0.565	0.28	1.39	0.05	0.00347	0.99	0.04	0.00246
			0.725	0.517	0.26	1.28	0.05	0.00342	0.91	0.03	0.00243
			0.775	0.470	0.25	1.18	0.04	0.00337	0.84	0.03	0.00241
			0.825	0.422	0.23	1.09	0.04	0.00331	0.79	0.03	0.00239
			0.875	0.374	0.22	1.01	0.04	0.00325	0.74	0.03	0.00238
			0.925	0.327	0.21	0.93	0.03	0.00318	0.70	0.03	0.00238
			0.975	0.279	0.20	0.86	0.03	0.00310	0.66	0.02	0.00238
				Overall p(collision) =			**Upwind**	**6.7%**		**Downwind**	**5.2%**
								Average	**5.9%**		