Appendix 7C – Collision Risk Modelling report

Avian Collision Risk Modelling Report

Ballinlee Wind Farm, Co. Limerick

Report prepared by Woodrow Sustainable Solutions Ltd on behalf of Ballinlee Green Energy Ltd

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Overview

APEM Group Woodrow was commissioned by Ballinlee Green Energy Ltd. to undertake ornithological survey work for the proposed Ballinlee Wind Farm (hereafter referred to as the Development). The Development is located in a predominantly rural and agricultural landscape approximately 18 km southeast of Limerick City, spanning multiple townlands near Bruff, Co. Limerick. The development includes the installation of 17 wind turbines, internal access tracks (including watercourse crossings), underground cabling, and an on-site substation.

The intention of this report is to display modelled data, based on observed bird usage of the area, to provide an indication of the likely collision risk imposed by the Development on potentially sensitive avian populations. The report uses bird usage data derived from vantage point (VP) watches conducted by appropriately experienced ornithological surveyors. Furthermore, the new guidance published by NatureScot (Band, 2024) was used, which aims to promote a standardised approach to Collision Risk Modelling (CRM) for onshore wind farms, to increase the transparency of calculations and to promote greater confidence in the results.

Flightline data for selected target species were collected over a three-year period (October 2021 - September 2024). As per NatureScot guidance, the CRM analysis was undertaken for Years 2 and 3, the two most recent consecutive years. The survey periods were as follows:

- Year 2 - 2022-23 non-breeding season (October 2022 to March 2023) and the 2023 breeding season (April 2023 to September 2023)
- Year 3 - 2023-24 non-breeding season (October 2023 to March 2024) and the 2024 breeding season (April 2024 to September 2024)

This amounted to a total of 1,010 hours of VP data (506 hours during the non-breeding seasons and 504 hours during breeding seasons). Further information on VP locations, methods and results can be found in Appendix 7B Ballinlee Baseline Ornithology Report. VP watches fulfilled the minimum requirement of 36 hours per VP per season during the two-year survey period contained within this CRM report.

One turbine model has been selected for the Development; the Vestas 136 (V136), with CRM run using V136 turbine specifications. The Collision Risk Zone (CRZ) is defined as the height between the minimum and maximum swept height of the turbine rotor within a 500 m buffer of turbines. In this instance this is 24 – 160 m, as detailed in Table 1, except for Turbine Number 6 (X =559575, y= 634719) which the CRZ is between 14 – 150 m, as the hub height is 82 m height.

Based on professional judgement and best practice, CRM was run for target species with a total aggregate flight time (i.e., number of individuals x flight time) of > 300 seconds occurring within the CRZ during each survey year and with more than three observations over the survey period. Target species with an aggregate flight time of < 300 seconds during a year were excluded from CRM as the associated collision risk is considered negligible.

Based on the criteria outlined above, for Year 2, the CRM was run for 12 species, including:

- Black-headed gull (*Chroicocephalus ridibundus*)
- Buzzard (*Buteo buteo*)
- Cormorant (*Phalacrocorax carbo*)
- Golden plover (*Pluvialis apricaria*)

- Kestrel (*Falco tinnunculus*)
- Lapwing (*Vanellus vanellus*)
- Lesser black-backed gull (*Larus fuscus*)
- Mallard (*Anas platyrhychos*)
- Peregrine (*Falco peregrinus*)
- Snipe (*Gallinago gallinago*)
- Sparrowhawk (*Accipiter nisus*)
- Whooper swan (*Cygnus cygnus*)

For Year 3, the CRM was run for nine species, including:

- Buzzard
- Cormorant
- Golden plover
- Grey heron (*Ardea cinerea*)
- Kestrel
- Lapwing
- Mallard
- Sparrowhawk
- Whooper swan

Further information on the species recorded during surveys, and details of each survey observations can be found in the Ballinlee Baseline Ornithology Report (Appendix 7B) (see section 4.1).

Note:

A supplementary collision risk analysis for whooper swan, incorporating additional Year 3 behavioural observations, direct flight speed measurements, and bioacoustics data, is presented and discussed in Chapter 7 (Ornithology). The present appendix documents the baseline CRM only, based on standard vantage point survey data and parameters for all target species.

Methodology

Collision Risk Modelling was undertaken following the latest NatureScot guidance (Band, 2024). The NatureScot model provides two approaches depending on species' flight behaviour observed during surveys. The first approach applies to species that make regular, directional flights through a wind farm site (e.g. commuting flights) while the second is used for species whose flights activity lacks regular patterns and is more locally distributed. In this case, the second approach was adopted, as it is more appropriate for species exhibiting non-directional flight behaviour associated with local occupancy. This decision was informed by baseline surveys results, ecological knowledge of target species, and professional judgement.

CRM estimates the number of collisions through a process of six stages:

- Stage A utilises bird survey data that has been collected through the VP surveys (detailed in Appendix 7B Ballinlee Ornithology Baseline Report), to establish the density of flying birds within 500m of turbines, and the proportion of birds that are flying at a potential risk height between the lowest and highest points of the rotors (the CRZ).
- Stage B estimates the potential number of bird passages through rotors in the relevant time period, based on both the bird density, and the proportion of birds flying at risk height.

- Stage C determines the collision probability during a single bird rotor transit.
- Stage D estimates the rate of potential collision for a given bird species based on observed levels of site usage, whilst taking into consideration the proportion of time in which the turbines are not in operation.
- Stage E takes into consideration the likely proportion of birds avoiding either the wind farm or its turbines. This may either be due to displacement from the site, birds undertaking evasive action or birds being attracted to the wind farm, for example, as a response to habitat changes.
- Stage F considers potential uncertainties and an estimate of error in the number of predicted collisions.

Stage A- Flight activity

Stage A estimated the number of flights that may potentially be at risk of turbine collision in the absence of the displacement of birds, birds taking other avoidance actions, or birds being attracted towards the wind farm.

In the case of non-directional flights, there are two key parameters derived from survey observations that are needed in order describe the magnitude of flight activity:

- Areal bird density (DA); and
- Proportion of birds flying at risk height (Q_{2R})

Areal bird density (DA) is defined as the number of birds in flight, at any height, at a particular time, per unit area (typically per square kilometre, km^2). To calculate DA, bird occupancy was converted to areal bird density (per m^2) by dividing by the area watched from each VP viewshed (see Figure 1 and Figure 2). The flight activity during VP watches was recorded in bird seconds, a unit that captures both abundance and duration of flight and is particularly appropriate where bird numbers are low.

DA was calculated as shown in Equation 1.

$$D_A = b\,/\,(t\ x\ A)\ birds\ m^{-2} \qquad \text{(Equation 1)}$$

where:

(b) is the number of target species flight seconds recorded from a VP;
(t) is the duration (in seconds) of all VP watches during either a month, season or year;
(A) is the area of the VP viewshed (km^2)

D_A was calculated for each VP separately, with the figure subsequently averaged. However, where there exists a considerable difference in the time and/or area that is covered by relevant VP surveys the average figure should be weighted appropriately. Thus, the weighting factor used acknowledges that the quantity of data collected in a watch is proportional both to the size of the area observed and the duration of the VP watch.

The mean density DA is calculated using Equation 2:

$$Mean\ density\ DA\ =\ \Sigma\ bi\ \sqrt{(ti\ x\ Ai)}\ /\ (ti\ x\ Ai)\ /\ \Sigma\ \sqrt{(ti\ x\ Ai)} \qquad \text{(Equation 2)}$$

In the case of conditions where a VP viewshed results in a significant difference in mean density DA (for example, due to a difference in underlying habitat), the bird density should then either be calculated separately for each individual VP site and then applied to determine the likely collision risk within that area. Alternatively, a turbine-weighted average bird density should be employed instead, i.e. the bird density for each VP should be weighted by the number of turbines present within that viewshed.

In this case, the average areal bird density ($D_{average}$) was estimated using Equation 3. The formula for this is:

$$Daverage \; = \; \Sigma \; (Ni \; x \; Di) \; / \; \Sigma \; Ni \qquad \text{(Equation 3)}$$

where:

D_i is the areal bird density within the VP viewshed (i);
N_i is the number of turbines to be sited in that VP viewshed; and
$D_{average}$ is the average areal bird density.

The definition of **proportion of birds flying at risk height (Q_{2R})** is the proportion of birds present between the lowest and highest points of a rotor, measured relative to the rotor base. In cases where flights are only recorded in the rotor swept height band, Q_{2R} will be 100%.

Daylight hours and nocturnal activity

Bird surveys are generally undertaken diurnally, with recorded levels of flight activity assumed to be representative of flight activity across all daylight hours. Daylight hours depend on the wind farm site's latitude and the time of year. Daylight and night hours per month are provided within the NatureScot CRM spreadsheet when the latitude of a particular site is inputted. The latitude of the wind farm site is expressed as degrees and minutes in degrees with decimal places. This data is subsequently utilised to calculate the daylight hours for each given month. The latitude of the wind farm site in question is 52°27.59' North (entered in decimals as 52.483055°).

Calculations used in the collision model account for collision risk associated with diurnal and nocturnal flights. Diurnal activity is based on the flight activity recorded for each target species during field surveys. As nocturnal surveys were not possible, nocturnal flight activity is based on the diurnal flight activity, and professional judgement regarding the likely levels of nocturnal activity for each target species.

Levels of nocturnal activity by all target species were estimated, using a one to five scale to approximate nocturnal flight (with a score of one equal to 0% nocturnal activity, two equal to 25% of diurnal activity, three equal to 50% of diurnal activity, four equal to 75% of diurnal activity and five whereby nocturnal activity is equal to diurnal activity, see Table 2). It should be noted that for truly nocturnal species, this will underestimate nocturnal flight activity, which will be >100% of diurnal activity.

Stage B- Estimating number of bird flights through rotors

The total **amount of bird transit flights anticipated through rotors** is proportional to the number of turbines, as well as the cross-sectional area of the turbine rotors, and the density of birds in the airspace flying at risk height (calculated at Stage A). The total number of bird transits through rotors was calculated separately for each month. Therefore, a key output within the collision risk assessment is a statement of the potential number of bird transits per month and season or year through the wind farm turbines, assuming that birds exhibit no avoidance behaviour. As such, the risk of collision is considered to be directly proportional to the potential number of bird transit flights.

Stage B considers the available figures for bird density (D_A), the proportion of risk height flights (Q_{2R}), the nocturnal activity factor (f_{night}), and the figures for monthly daylight and night hours calculated at Stage A. In order to estimate the number of birds flying through rotors, the model takes into account the number of turbines, the turbine rotor radius and the flight speed of the target species. For flight speed, a typical mean flight speed is selected based on standard key literature, acknowledging that flight speed (and thus collision risk) will vary depending on bird behaviour (commuting, migration, foraging etc).

The number of bird transits expected through rotors was calculated using equation 4.

$$Number\ of\ transits = v * (D_{\text{average}}\ Q_{2R} / 2R) * (T\ \pi R2) * (tday + fnight\ tnight) \qquad \text{(Equation 4)}$$

where:

v is bird speed, relative to the ground (m sec^{-1});
$D_{average}$ is the average areal bird density (Birds m^{-2});

Q_{2r} is the proportion of birds flying at risk height (%);

R is the length of the rotor blades, from axis to tip (m);

T is the number of turbines;

f_{night} is the nocturnal activity factor; and

t_{day} and t_{night} the wind farm latitude is used to calculate daylight and night-time hours for each month, and the total for a year.

Stage C- Probability of collision for a single rotor transit

Stage C utilises information on turbine size and speed (Table 1), as well as physical details on bird size and speed in order to accurately calculate the collision risk for birds flying through an active turbine rotor (Table 2).

It is presumed that birds have the ability to avoid stationary infrastructure. This model therefore estimates the likely probability of collisions occurring if a bird passes at random at any point through the rotor disk on a flight path perpendicular to the rotor plane. The collision probability for birds approaching at an oblique angle is the same as the probability for those approaching at a perpendicular angle; there is no additional effect of turbulence in the wake of a rotor blade; and, no slipstream effect, i.e. air rushing over a blade may carry a bird clear of it.

Due to the geometry of the blades relational to the direction of flight, upwind flights carry a higher collision risk than downwind flights. This remains the case even when the flight speed of the bird relative to the ground is taken to be the same. In situations where there is an equal likelihood of both upwind and downwind flights, it is considered suitable to take an average of both collision probabilities. As such, the relative proportion of both upwind and downwind flights was utilised in this case to weigh the respective probabilities of collision. The default proportion was set to a probability of 50:50 upwind:downwind.

The NatureScot CRM spreadsheet includes a collision risk calculator that estimates the probability of a bird colliding with a turbine blade during a single passage through the rotor. This is done by assessing collision risk at various positions across the rotor disc, using increments of radial distance from $r/R=0.05$ out to $r/R=1$, and angular intervals (ϕ) of 10 degrees. The model calculates the collision probability at each combination of radius and angle, then averages these values across the entire area of the rotor disc to generate the average collision risk for a passage at any given point across the rotor.

By design, wind turbines operate at a range of various speeds. Typically, wind turbines do not operate below a cut-in speed, which is generally between three and four m/sec. The turbines then increase in speed in line with wind speed, up to a maximum operating wind speed of around 12 m/sec.

The model assessed the probability of collision risk using the **turbine rotational speed** for the proposed turbine model. In such cases where wind turbines operate at a range of different rotational speeds, the calculation should be carried out using a mean operational turbine speed. Preferably, the mean speed utilised in the calculation should be measured over time using an analysis of available wind data to determine the likely frequency distribution of turbine speeds. However, in cases where this is not available, the speed used should be based on the most likely value as anticipated by the wind farm developer. At Stage D of the model, an allowance is made to account for the proportion of time in which a wind turbine is not in operation. This may be due either because of low wind speeds or maintenance being carried out on the turbine. In this case, the mean turbine speed used in the calculation takes only the operational time of the turbine into account and excludes times when the turbine was idle or stationary.

Table 1: Turbine data

Symbol	Description	Units	Turbine model
			V136
B	Number of blades		3
	Hub height	m	92 **
R	Rotor radius	m	68
	Minimum swept height	m	24
	Maximum swept height	m	160
C	Maximum blade width	m	4.1
Γ	Average blade pitch*	°	13
Ω	Average rotation speed	rpm	8.3
	Average rotational period	s	7.23

*Note: Pitch angle varies along the length of the blade, from a high angle close to the hub, to a low pitch angle towards the blade tips, i.e. the blade is twisted. Pitch angle also varies as the pitch is controlled to alter the rotation speed of the turbine.

In the model, an average angle is used, representing an average pitch along the blade length. 6-15 degrees is reasonable for a typical large turbine.
**Except for Turbine Number 6 with a Hub height of 82 m

Table 2: Bird data and avoidance rates for target species

Target species	Bird length (m)	Wingspan (m)	Bird speed (m/s)	% of flight upwind/downwind	Nocturnal activity (From 1 to 5)	Avoidance rate*
Black-headed gull	0.4	1.05	11.9	50/50	2	0.992
Buzzard	0.54	1.21	11.6	50/50	1	0.980
Cormorant	0.90	1.45	15.2	50/50	2	0.980
Golden plover	0.275	0.72	17.9	50/50	2	0.980
Grey heron	0.94	1.85	12.5	50/50	2	0.980
Kestrel	0.34	0.76	10.1	50/50	1	0.950
Lapwing	0.30	0.84	12.8	50/50	2	0.980
Lesser black-backed gull	0.58	1.43	13.4	50/50	2	0.995
Mallard	0.58	0.90	18.5	50/50	2	0.980
Peregrine	0.42	1.03	12.1	50/50	1	0.980
Snipe	0.26	0.46	17.1	50/50	5	0.980
Sparrowhawk	0.33	0.62	11.3	50/50	1	0.980
Whooper swan	1.53	2.31	17.3	50/50	2	0.995
*Source SNH 2018, 2024 and Furness 2019						

Stage D- Multiplying to yield expected collisions per year

Single transit risk

Stage D multiplies the number of flights through rotors across the wind farm (Stage B) and the risk of collision for each single bird transit through a rotor (Stage C) to yield an estimate of total potential collision risk using equation 5.

*Single transit risk = (No. of bird transits through rotors * Weighted probability of collision single)/100* *(Equation 5)*

Non-operational time

The factor Q_{op} accounts for the time in which the turbine is not in operation, by representing the proportion of time in which the turbine is operational. Wind turbines are not in constant operation. Generally, a wind turbine is either idle or at rest for a certain proportion of time due either to wind speeds being too weak to generate power or, in exceptional cases, due to the turbines being intentionally closed down in order to avoid damage in the event of exceptionally high winds. Additionally, there is a requirement that wind turbines are occasionally shut down to allow for maintenance to be carried out.

Finally, the Single transit risk is multiplied by the factor Q_{op} to allow for the proportion of time that the wind turbines are operational. This is before considering avoidance behaviour, which is stage E.

Stage E- Applying the avoidance rate

Avoidance

The preceding stages of the model operate on the assumption that birds will not undertake any avoidance action in response to the presence of wind turbines. However, birds do generally undertake avoidance action in order to prevent wind turbine collisions. Data derived from collision monitoring, based on frequent carcass searches of the wind farm site and observations of habitat use in the vicinity, indicate avoidance rates of 98% or higher for many bird species. This data therefore indicates the collision risk to be less than 2% of that calculated from Stages A-D alone.

During this project, the potential collision mortality, for each month and for a year, after avoidance was calculated using a range of assumed avoidance rates of 95%, 98%, 99% and 99.5%.

Large turbine array correction factor

The large turbine array correction factor should be included only for large wind farms developments (more than 50 turbine wind farm). Therefore, this is not a requirement for the proposed development site and there is no need for further discussion.

Stage F- Expressing uncertainty

In the estimate of collision risk following the method detailed above, there exists numerous sources of variability or uncertainty in the output. Band (2024) sets out an accurate description of potential sources of uncertainty, as well as a procedure of evaluating and presenting these sources.

The aim of this stage is to reflect the range of uncertainty in the collision estimate that could impact target species populations and/or growth rates. Information to include should reflect:

- uncertainty or variability in flight activity data, such as imprecise flight height estimates and lack of knowledge about night-time behaviour;
- uncertainty surrounding the limitations of the collision model, such as the variability of bird dimensions and flight speed, the simplification in the shape of a bird and turbine blades; and
- uncertainty arising from turbine options such as the number, size and speed.

Results

Viewshed spatial coverage

The VP locations used were the same during the two years survey period. Viewshed analysis was undertaken to determine spatial coverage from each VP. In Year 2, viewsheds for each VP were arranged in the field, and VP watches were conducted simultaneously by five surveyors, each positioned at a separate VP with no overlapping viewsheds (Figure 1). In Year 3, viewshed spatial coverage for each VP were calculated using ArcGIS Pro and the accuracy of viewsheds was confirmed in the field by surveyors (Figure 2). The viewshed analysis was performed using a surface offset of 24 m (the minimum rotor swept height of the majority of the turbines in the final layout) which mapped visible airspace available to surveyors (of an assumed height of 1.75 m) at 24 m. This illustrates the visible area at collision risk height.

Spatial coverage of the viewsheds within the 2 km viewshed arc and the coverage as a proportion of the 500 m turbine buffer, is presented for both Year 2 and for Year 3. The locations of the VPs and their associated viewsheds are mapped in Figure 1 (Year 2) and Figure 2 (Year 3).

Table 3: Viewshed coverage of 500 m buffer of turbines and VP survey effort Year 2

Vantage Point (VP)	Area of CRZ visible within 500 m turbine buffer (Km^2)	% Coverage of the 500 m turbine buffer	VP effort (hrs)		
			Non-breeding season (Oct - Mar)	Breeding season (Apr-Sep)	Total
VP1	0.95	13.22	36.0	36.0	72.0
VP2	0.92	12.74	36.0	36.0	72.0
VP3	0.86	11.85	36.0	36.0	72.0
VP4	0.98	13.63	36.0	36.0	72.0
VP5	1.79	24.71	36.0	36.0	72.0
VP6	0.82	11.30	36.0	36.0	72.0
VP7	0.96	13.33	36.0	36.0	72.0
Total viewshed cover	**7.23**	**100.00**	**252**	**252**	**504**
*This is the total area within the 500 m turbine buffer that is covered by at least one viewshed					

Table 4*:* Viewshed coverage of 500 m buffer of turbines and VP survey effort Year 3

Vantage Point (VP)	Area of CRZ visible within 500 m turbine buffer (Km^2)	% Coverage of the 500 m turbine buffer	VP survey effort (hrs)		
			Non-breeding season (Oct - Mar)	Breeding season (Apr-Sep)	Total
VP1	2.71	37.49	36.0	36.0	72.0
VP2	2.83	39.19	36.0	36.0	72.0
VP3	2.46	34.03	36.0	36.0	72.0
VP4	3.62	50.05	36.0	36.0	72.0
VP5	4.14	57.36	36.0	36.0	72.0
VP6	2.12	29.34	37.5	36.0	73.5
VP7	3.58	49.61	36.0	36.0	72.0
Total viewshed cover	**7.23**	**100.00**	**253.5**	**252**	**506**
*This is the total area within the 500 m turbine buffer that is covered by at least one viewshed					

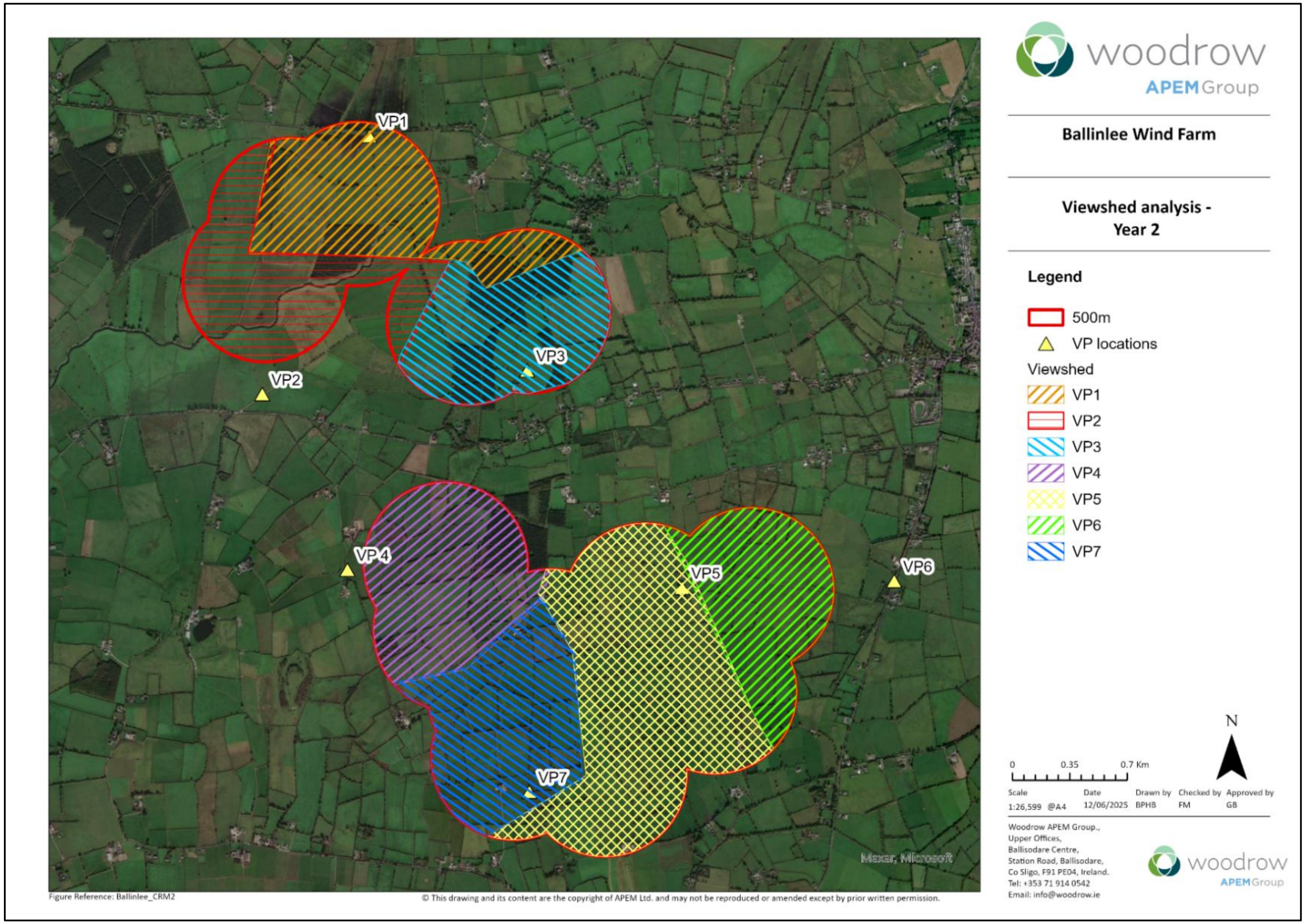

Figure 1: Viewshed Year 2.

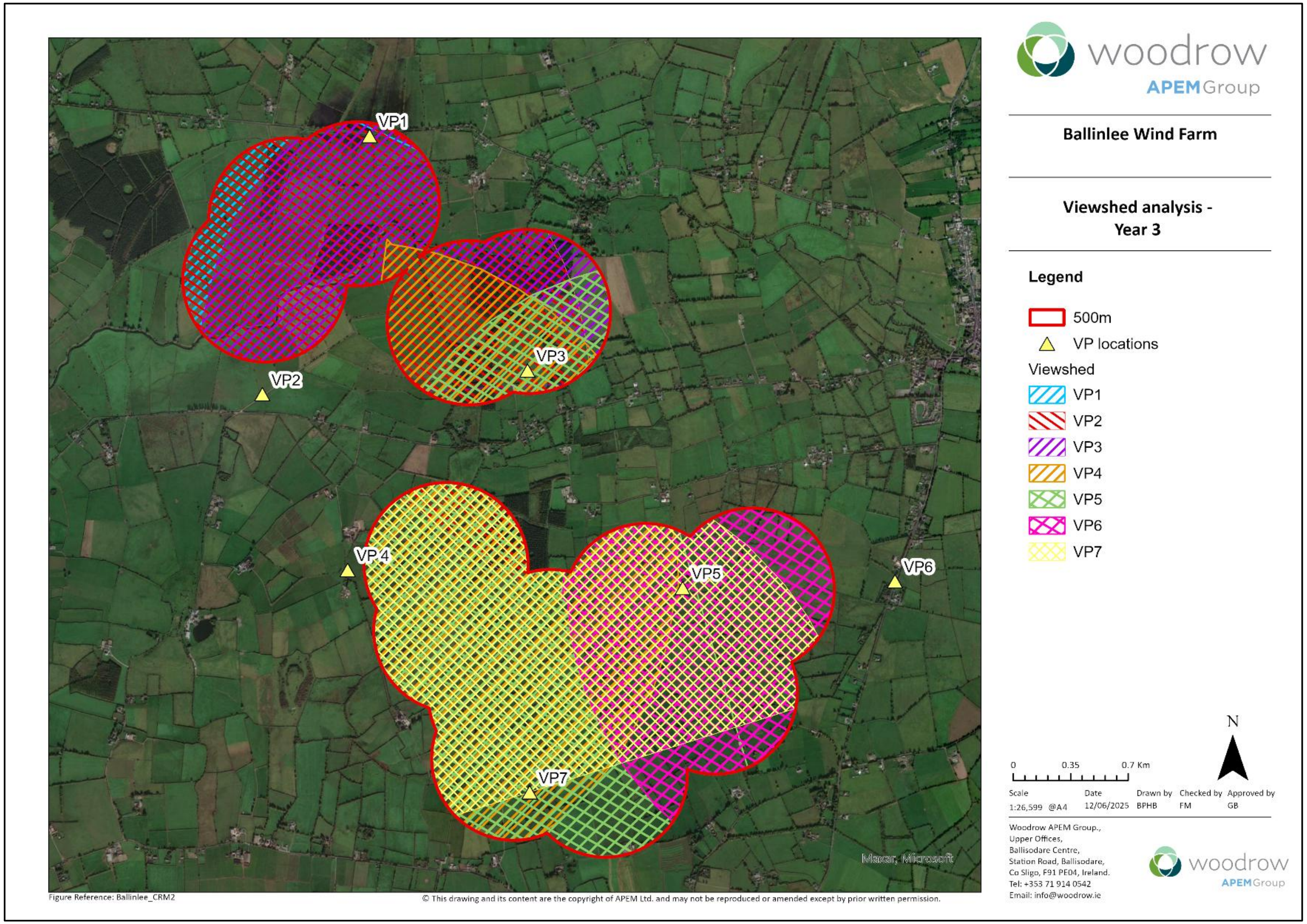

Figure 2: Viewshed Year 3

Stage A: Flight activity

Bird density

VP watches have been undertaken over three years. As per NatureScot guidance, the CRM analysis was undertaken for Years 2 and 3, the two most recent consecutive years. VP watches covered the entire site along with a 500 m buffer around the proposed turbine locations achieving 100% coverage (see Figure 1 and Figure 2). The Development was covered from seven VP locations.

VP watches were undertaken for a minimum of 72 hours per year; 36 hours during the breeding season (April – September) and 36 hours during the non-breeding season (October – March) in each of the two years, in line with NatureScot guidance (NatureScot, 2025). The watches were divided into sessions of less than three hours in duration with breaks between sessions to limit observer fatigue, and the sessions spread to include a representative sample of daylight hours. All flights of target species were recorded during each watch period, yielding total flying time in bird-seconds throughout the watch. Flying time was divided by the period of the watch (in seconds) and the area watched to give the average density of birds in flight per square kilometre.

The mean density (DA) is given in Table 5 for each target species and was calculated for each period (breeding and non-breeding) during each survey year. It should also be noted that golden plover is a winter visitor in Ireland, which also remains during the spring passage season (i.e., April). There are also localised breeding populations of golden plover in Ireland, however no breeding birds were recorded during baseline surveys. For this reason, golden plover flight activity recorded was included as part of the non-breeding season for this species.

Table 5*: Mean bird density for all target species during two years of surveys*

Target species	Analysis Period	Year 2		Year 3	
		Non-breeding: Mean density (birds/km^2)	Breeding: Mean density (birds/km^2)	Non-breeding: Mean density (birds/km^2)	Breeding: Mean density (birds/km^2)
Black-headed gull	Year-round	0.0133	0.0001	-	-
Buzzard	Year-round	0.0180	0.0046	0.0005	0.0070
Cormorant	Year-round	0.0007	0.0007	0.0001	0.0009
Golden plover	Non-breeding (+ April)	0.1019	-	0.0023	-
Grey heron	Year-round	-	-	0.0004	0.0005
Kestrel	Year-round	0.0084	0.0038	0.0004	0.0008
Lapwing	Non-breeding	0.0091	-	0.0026	-
Lesser black-backed gull	Year-round	0.0137	0.0534	-	-
Mallard	Year-round	0.0005	0.0011	-	0.0007
Peregrine	Year-round	0.0002	0.0009	-	-
Snipe	Year-round	0.0008	0.0007	-	-
Sparrowhawk	Year-round	0.0009	0.0007	0.0001	0.0004
Whooper swan	Non-breeding	0.0051	-	0.0002	-

Proportion flying at risk height

The assessment is based on a single turbine model option (Vestas V136), with a rotor swept height of 24 m to 160 m above ground level (see Table 1). During the surveys, bird flight heights were estimated visually. The proportion of observed birds at rotor risk height (or within the CRZ), was calculated separately for each year (see Table 6 and Table 7).

Table 6*: Proportion of observed birds flying at rotor risk height (%Q2R) during all VP watches in Year 2*

Target species	Number of birds observed	%Q2R for V136
Black-headed gull	169	0.97
Buzzard	112	0.59
Cormorant	37	0.41
Golden plover	782	0.44
Kestrel	115	0.30
Lapwing	202	1.00
Lesser black-backed gull	956	0.17
Mallard	62	0.42
Peregrine	7	0.43
Snipe	92	0.14
Sparrowhawk	19	0.58
Whooper swan	123	0.55

Table 7*: Proportion of observed birds flying at rotor risk height (%Q2R) during all VP watches in Year 3*

Target species	Number of birds observed	%Q2R for V136
Buzzard	133	0.96
Cormorant	29	1.00
Golden plover	232	1.00
Grey heron	23	1.00
Kestrel	28	0.93
Lapwing	497	0.77
Mallard	17	1.00
Sparrowhawk	24	1.00
Whooper swan	164	1.00

Stage B: Estimating number of flights through rotors

The output from Stage B is the potential number of bird transits through the rotor swept area, presented monthly and separately for each year (see Table 8 and Table 9). The total number of bird transits expected through rotors is proportional to the number and cross-sectional area of the rotors, and to the density of birds in the airspace at risk height or in the CRZ.

Table 8*: Potential number of bird transits through rotors during Year 2*

Target species	NUMBER OF TRANSITS												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Black-headed Gull	341	340	419	3	4	4	4	4	3	394	342	330	2187
Buzzard	183	199	267	78	92	95	95	86	71	240	190	171	1768
Cormorant	10	10	12	13	14	14	15	14	12	11	10	9	142
Golden plover	1203	1311	1757	-	-	-	-	-	-	1580	1250	1127	8229
Kestrel	57	57	71	34	38	39	39	37	32	66	57	55	584
Lapwing	258	258	318	-	-	-	-	-	-	299	259	250	1642

Target species	NUMBER OF TRANSITS												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Lesser black-backed gull	70	70	86	360	404	408	414	386	340	81	70	68	2755
Mallard	9	9	11	25	28	28	29	27	24	10	9	8	215
Peregrine	2	2	2	12	14	14	14	13	11	2	2	1	87
Snipe	7	7	7	6	7	-	-	-	-	-	-	7	82
Sparrowhawk	9	10	13	11	13	14	14	12	10	11	9	8	135
Whooper swan	108	108	133	-	-	-	-	-	-	125	109	105	688

Table 9*: Potential number of bird transits through rotors during Year 3*

Target species	NUMBER OF TRANSITS												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Buzzard	8	8	11	194	228	236	237	213	178	10	8	7	1337
Cormorant	2	2	2	40	44	45	46	42	37	2	2	2	265
Golden plover	63	68	91	-	-	-	-	-	-	82	65	59	427
Grey heron	1	1	1	17	19	19	20	18	16	1	1	1	116
Kestrel	7	7	9	21	24	24	24	23	20	9	7	7	182
Lapwing	57	57	70	-	-	-	-	-	-	66	57	55	363
Mallard	0	0	0	35	40	40	41	38	33	0	0	0	228
Sparrowhawk	1	1	2	12	14	14	14	13	11	1	1	1	85
Whooper swan	9	9	11	-	-	-	-	-	-	11	9	9	59

Stage C: Probability of collision for single rotor transit

Data relating to the likelihood of a bird being hit when flying through the rotor is derived from the NatureScot CRM spreadsheet. The outputs are provided for each target species in Table 10.

Table 10*: Probability of collision for a single rotor transit for target species*

Target species	Average single transit
Black-headed gull	5.02%
Buzzard	5.58%
Cormorant	6.08%
Golden plover	4.42%
Grey heron	6.90%
Kestrel	5.01%
Lapwing	4.52%
Lesser black-backed gull	5.52%
Mallard	4.79%
Peregrine	5.04%
Snipe	3.98%
Sparrowhawk	4.69%
Whooper swan	7.54%

Stage D: Multiplying to yield expected collisions per year

Following the above steps, the number of bird transits per year through the rotors can be combined with the probability of a bird being hit when flying through the rotor to give a likely collision rate per month and per year (assuming no avoidance). An avoidance figure is then applied to get a predicted likely collision rate, and thus a likely mortality rate. This stage considers the proportion of time that turbines are likely to be operational. The 85% default operational time is considered industry standard, originally stemming from guidance by the British Wind Energy Association (BWEA), now known as Renewable UK. It is a widely used assumption in CRM when site-specific turbine availability data is unavailable. In addition, the NatureScot guidance frequently cite 85% as a reasonable default. This figure is intended to account for downtime due to routine maintenance, weather-related curtailment, and other operational constraints, and is widely accepted in planning and environmental assessments.

The collision rate before this avoidance figure is applied is illustrated in Table 11.

Table 11*: Collision rate before avoidance for target species*

Model	Target species	Collision rate before avoidance												
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Year 2	Black-headed gull	14.5	14.5	17.9	0.1	0.2	0.2	0.2	0.2	0.1	16.8	14.6	14.1	93.3
	Buzzard	8.7	9.5	12.7	3.7	4.3	4.5	4.5	4.1	3.4	11.4	9.0	8.1	83.8
	Cormorant	0.5	0.5	0.6	0.7	0.7	0.7	0.8	0.7	0.6	0.6	0.5	0.5	7.3
	Golden plover	45.2	49.2	66.0	-	-	-	-	-	-	59.3	46.9	42.3	308.9
	Kestrel	2.4	2.4	3.0	1.5	1.6	1.7	1.7	1.6	1.4	2.8	2.4	2.4	24.9
	Lapwing	9.9	9.9	12.2	-	-	-	-	-	-	11.5	10.0	9.6	63.1
	Lesser black-backed gull	3.3	3.3	4.0	16.9	18.9	19.2	19.4	18.1	15.9	3.8	3.3	3.2	129.3
	Mallard	0.4	0.3	0.4	1.0	1.1	1.2	1.2	1.1	1.0	0.4	0.4	0.3	8.8
	Peregrine	0.1	0.1	0.1	0.5	0.6	0.6	0.6	0.5	0.5	0.1	0.1	0.1	3.7
	Snipe	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	2.8
	Sparrowhawk	0.3	0.4	0.5	0.5	0.5	0.5	0.6	0.5	0.4	0.5	0.4	0.3	5.4
	Whooper swan	6.9	6.9	8.5	-	-	-	-	-	-	8.0	7.0	6.7	44.1
Year 3	Buzzard	0.4	0.4	0.5	9.2	10.8	11.2	11.2	10.1	8.4	0.5	0.4	0.3	63.4
	Cormorant	0.1	0.1	0.1	2.0	2.3	2.3	2.4	2.2	1.9	0.1	0.1	0.1	13.7
	Golden plover	2.3	2.6	3.4	-	-	-	-	-	-	3.1	2.4	2.2	16.0
	Grey heron	0.1	0.1	0.1	1.0	1.1	1.1	1.2	1.1	0.9	0.1	0.1	0.1	6.8
	Kestrel	0.3	0.3	0.4	0.9	1.0	1.0	1.0	1.0	0.8	0.4	0.3	0.3	7.7
	Lapwing	2.2	2.2	2.7	-	-	-	-	-	-	2.5	2.2	2.1	14.0
	Mallard	0.0	0.0	0.0	1.4	1.6	1.6	1.7	1.5	1.4	0.0	0.0	0.0	9.3
	Sparrowhawk	0.0	0.0	0.1	0.5	0.5	0.6	0.6	0.5	0.4	0.1	0.0	0.0	3.4
	Whooper swan	0.6	0.6	0.7	-	-	-	-	-	-	0.7	0.6	0.6	3.8

Stage E: Applying the avoidance rate

NatureScot (2018) guides the use of avoidance rates in collision risk assessments. Collision risks have been calculated for avoidance rates of 95%, 98%, 99%, and 99.5% for each season (breeding and non-breeding) and for each year. The avoidance rates recommended by NatureScot (2018) and Furness (2019) (see Table 2) were applied to estimate the number of bird collisions per annum, per decade and over the 35-year operational lifespan of the Development (see Table 12).

Table 12 presents the estimated collision probabilities for the selected target species passing through the rotor swept area, taking into account different avoidance rate assumptions for the non-breeding and breeding seasons across both years. Species highlighted in bold denote those with an estimated collision rate exceeding one per decade, based on the avoidance rates recommended by NatureScot.

Based on the V136 model, the CRMs predicted low levels of theoretical collision risk, defined as less than one collision per decade using the avoidance rates recommended by SNH/NatureScot, over the 35-year life span of the proposed development for peregrine and snipe (Year 2) and sparrowhawk and whooper swan (Year 3) (see Table 12). This level of predicted collision mortality is considered negligible and is unlikely to have any significant effect at the population level; that is, collision-mediated mortality would not result in a greater than 1% increase in background mortality levels.

Higher levels of flight time in the CRZ (i.e. more than one collision per decade, with SNH/NatureScot recommended avoidance rate) over the 35-year life span of the proposed development was predicted for buzzard, cormorant, golden plover, kestrel, lapwing and mallard (all survey years), for black headed gull, lesser black backed gull, whooper swan and sparrowhawk (only Year 2), and for grey heron (only Year 3) (Table 12 and Table 13).

The predicted levels of collision risk warrant further consideration in relation to potential population-level effects. These can be assessed by comparing the additional (assumed non-additive) mortality resulting from collisions to background mortality rates. A 1% increase in annual mortality is commonly used as a threshold for determining significance (Percival, 2003). Estimated increases in annual mortality rates for target species are provided in the discussion section of the Chapter 7 Ornithology.

Table 12*:* Collision rate estimated by the non-breeding (NB) and the breeding seasons (B) and year-round, applying different avoidance rates.

Bold denotes annual collision rate using species-specific avoidance rates recommended by NatureScot (2024)

Turbine	Target species	Collision rate after 0.95 avoidance			Collision rate after 0.98 avoidance			Collision rate after 0.99 avoidance			Collision rate after 0.995 avoidance			Per decade	Per 35 years
		NB	B	Year	NB	B	Year	NB	B	Year	NB	B	Year		
Year 2	**Black-headed gull**	4.62	0.05	4.67	1.85	0.02	1.87	0.92	0.01	0.93	**0.47**	-	**0.47**	4.70	16.45
	Buzzard	2.97	1.23	4.2	**1.19**	**0.49**	**1.68**	0.59	0.25	0.84	0.3	0.12	0.42	16.80	58.80
	Cormorant	0.16	0.21	0.37	**0.06**	**0.08**	**0.14**	0.03	0.04	0.07	0.02	0.02	0.04	1.40	4.90
	Golden plover	15.44	-	15.44	**6.18**	**-**	**6.18**	3.09	-	3.09	1.54	-	1.54	61.80	216.21
	Kestrel	**0.78**	**0.47**	**1.25**	0.31	0.19	0.50	0.16	0.09	0.25	0.08	0.05	0.13	12.50	43.52
	Lapwing	3.15	-	3.15	**1.26**	**-**	**1.26**	0.63	-	0.63	0.32	-	0.32	12.60	44.16
	Lesser black-backed gull	1.04	5.42	6.46	0.42	2.17	2.59	0.21	1.08	1.29	**0.1**	**0.54**	**0.64**	6.40	22.63
	Mallard	0.11	0.33	0.44	**0.04**	**0.13**	**0.17**	0.02	0.07	0.09	0.01	0.03	0.04	1.70	6.14
	Peregrine	0.02	0.16	0.18	**0.01**	**0.07**	**0.08**	-	0.03	0.03	-	0.02	0.02	0.80	2.62
	Snipe	0.07	0.07	0.14	**0.03**	**0.03**	**0.06**	0.01	0.01	0.02	0.01	0.01	0.02	0.60	1.95
	Sparrowhawk	0.12	0.15	0.27	**0.05**	**0.06**	**0.11**	0.02	0.03	0.05	0.01	0.01	0.02	1.10	3.77
	Whooper swan	2.2	-	2.2	0.88	-	0.88	0.44	-	0.44	**0.22**	**-**	**0.22**	2.20	7.71
Year 3	**Buzzard**	0.12	3.05	3.17	**0.05**	**1.22**	**1.27**	0.02	0.61	0.63	0.01	0.3	0.31	12.70	44.40
	Cormorant	0.03	0.66	0.69	**0.01**	**0.26**	**0.27**	0.01	0.13	0.14	-	0.07	0.07	2.70	9.59
	Golden plover	0.8	-	0.8	**0.32**	**-**	**0.32**	0.16	-	0.16	0.08	-	0.08	3.20	11.23
	Grey heron	0.02	0.32	0.34	0.01	0.13	0.14	-	0.06	0.06	-	0.03	0.03	1.40	4.75
	Kestrel	**0.1**	**0.29**	**0.39**	0.04	0.11	0.15	0.02	0.06	0.08	0.01	0.03	0.04	3.90	13.54
	Lapwing	0.7	-	0.7	**0.28**	**-**	**0.28**	0.14	-	0.14	0.07	-	0.07	2.80	9.78
	Mallard	-	0.46	0.46	**-**	**0.19**	**0.19**	-	0.09	0.09	-	0.05	0.05	1.90	6.49
	Sparrowhawk	0.02	0.15	0.17	**0.01**	**0.06**	**0.07**	-	0.03	0.03	-	0.02	0.02	0.70	2.36
	Whooper swan	0.19	-	0.19	0.08	-	0.08	0.04	-	0.04	**0.02**	**-**	**0.02**	0.20	0.66

Table 13*: Mean collision rate estimated by year-round, applying different avoidance rates.*

Bold denotes annual collision rate using species-specific avoidance rates recommended by NatureScot (2024)

Target species	Collision rate after avoidance				Per decade	Per 35 years
	0.95	**0.98**	**0.99**	**0.995**		
Black-headed gull	4.67	1.87	0.93	**0.47**	4.70	16.45
Buzzard	3.68	**1.47**	0.74	0.37	14.70	51.45
Cormorant	0.53	**0.21**	0.11	0.055	2.10	7.35
Golden plover	8.12	**3.25**	1.63	0.81	32.50	113.75
Grey heron	0.34	**0.14**	0.07	0.03	1.40	4.90
Kestrel	**0.82**	0.33	0.16	0.08	8.20	28.70
Lapwing	1.93	**0.77**	0.39	0.20	7.70	26.95
Lesser black-backed gull	3.46	1.39	0.69	**0.35**	3.50	12.25
Mallard	0.31	**0.13**	0.06	0.03	1.30	4.55
Peregrine	0.19	**0.08**	0.04	0.02	0.80	2.80
Snipe	0.14	**0.06**	0.03	0.01	0.60	2.10
Sparrowhawk	0.27	**0.11**	0.05	0.03	1.10	3.85
Whooper swan	2.20	0.88	0.44	**0.22**	2.20	7.70

Stage F: Expressing uncertainty

As outlined in NatureScot guidance (Band, 2025), it is important to consider potential uncertainties when interpreting predicted collisions and quantifying this uncertainty as much as possible. There are many sources of uncertainty throughout the CRM process, however these generally fall into three main categories:

- Uncertainty or variability in the survey data collected;
- Uncertainty arising from limitations which are in built into the CRM due to the requirement for simplification; and
- Uncertainty arising from turbine specifications.

Uncertainty can arise during data collection, for example imprecision when mapping the location of flights or categorising flight heights. This has been limited as much as possible by using experienced surveyors. Data has been collected over multiple years to increase robustness; however, it should be acknowledged that data is recorded over a relatively short survey period and is extrapolated to predict activity across the year. The inability to collect nocturnal survey data means that there is uncertainty in predicted nocturnal flight activity throughout the operational phase, however significant nocturnal activity is only predicted for snipe. It is considered that data collection introduces uncertainty of ±20%.

The NatureScot CRM model contains simplifications, for example assuming uniform bird dimensions and flight speeds, and simplifications of turbine blade dimensions. This is inaccurate due to inherent natural variability within species populations and different flight speeds associated with different activities (commuting, hunting, display etc), however it is necessary to ensure that the model is not overly complex. It is considered that simplifications in the model introduce uncertainty of ±20%.

The turbine model dimensions used in the CRM have been provided by the client and are based on specifications for the proposed turbine model that will be used when the proposed development is constructed. It is considered that simplifications relating to the turbine model and layout introduce uncertainty of ±10%.

Overall uncertainty can be quantified by combining the three sources of uncertainty using the following equation.

$\sqrt{0.2^2+0.2^2+0.1^2}$

This gives an overall uncertainty of ±30%.

References

Band, W., Madders, M., and Whitfield, DP., (2007). Developing Field and Analytical Methods to Assess Avian Collision Risk at Wind Farm Sites. In: de Lucas, M., Janss, G. & Ferrer, M. (Eds) 2007. Birds and Wind Farms – Risk Assessment and Mitigation. Quercus Editions, Madrid, 259-279

Band, W. 2000. Windfarms and birds – calculating a theoretical collision risk assuming no avoiding action. Scottish Natural Heritage Guidance Note.

Band, W. 2024. Using a collision risk model to assess bird collision risks for onshore wind farms. NatureScot Research Report.

de Lucas, M.; Janss, G.; Ferrer, M. (2007). Birds and Wind Farms: Risk Assessment and Mitigation. Madrid: Quercus/Libreria Linneo.

Furness, R.W. (2019). Avoidance rates of herring gull, great black-backed gull and common gull for use in the assessment of terrestrial wind farms in Scotland. Scottish Natural Heritage Research Report No. 1019.

Percival, S. M. (2003). Birds and wind farms in Ireland: A review of potential issues and impact assessment. Ecology Consulting, Coxhoe, Durham

NatureScot (2025) Recommended bird survey methods to inform impact assessment of onshore wind farms.

Scottish Natural Heritage (2018). Avoidance rates for the onshore SNH wind farm collision risk model.

Scottish Natural Heritage (2024). Guidance on using an updated collision risk model to assess bird collision risk at onshore wind farms.