BALLYKETT WIND FARM: COLLISION RISK MODELLING REPORT

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SUMMARY

This report presents the results of collision risk modelling for the proposed Ballykett Wind Farm, Co. Clare. The proposed wind farm will comprise four turbines. The turbines will have a hub height of 82 m and a rotor diameter of 136 m, which creates a potential collision height airspace of 14-150 m.

The collision risk model was based on two years of vantage point survey data from two vantage points with a survey effort of six hours / month / vantage point. The SNH/Band model was used, with the VP averaging method used for the stage 1 model.

There were 13 raptor and waterbird species included in the collision risk model. The predicted collision risk would result in 1-2 Buzzard and Kestrel collisions over the 30-year lifespan of the wind farm but would not result in collisions of any other species included in the collision risk model over this period.

Sensitivity analyses indicated that variation in rotor speed within the rotor speed range, and variation in pitch values within the typical operational range for Irish onshore wind farms, would not significantly affect the collision risk predictions.

To allow for uncertainty, the predicted collision risks should be multiplied by factors of 4 (large species) or 6 (small species) times to represent a worst-case scenario of high levels of under-detection of distant flightlines, and actual flight activity levels being at the upper limit of the theoretical confidence interval around the sampled flight activity. However, for Kestrel, the potential overestimation of the collision risk due to inclusion of hovering flight activity in the standard stage 1 model should also be considered.

1. INTRODUCTION

1.1. SCOPE

This report presents the results of collision risk modelling for the proposed Ballykett Wind Farm, Co. Clare. The proposed wind farm will comprise four turbines. The site location and proposed site layout is shown in Map 1.1. The turbines will have a hub height of 82 m and a rotor diameter of 136 m, which creates a potential collision height airspace of 14-150 m.

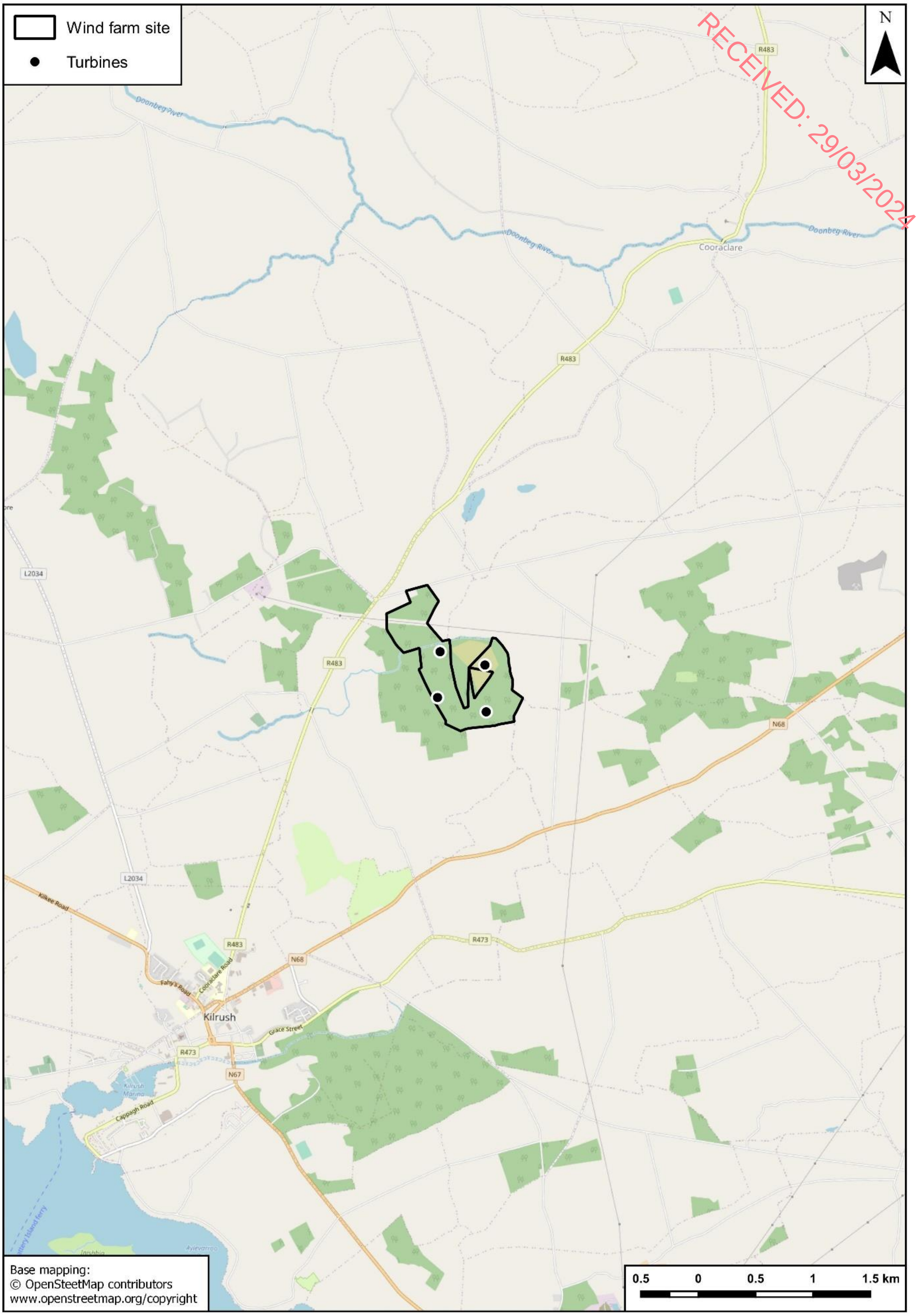
This work was commissioned by Greensource. The collision risk modelling and reporting was carried out by Tom Gittings.

1.2. COLLISION RISK MODELLING

Collision risk modelling uses statistical modelling techniques to predict the likely collision risk. It uses flight activity data from before the construction of a wind farm to calculate the likely risk of birds colliding with turbines in the operational wind farm. There are three stages to the collision risk model. In stage 1, the flight activity data that was recorded is scaled up to represent the overall level of flight activity in the wind farm site across the relevant period (e.g., a full year for a resident species, or a summer or winter for a migrant species). The number of predicted transits of the rotor swept volume in the wind farm is then calculated based on the proportion of the total air space that is occupied by the rotor swept volume. However, most transits of the rotor swept volume will not result in a collision, because for the duration of a transit, most of the rotor swept volume is not occupied by the turbine blades. Therefore, stage 2 of the collision risk model involves calculating the probability that a bird will collide with a turbine blade when it transits the rotor swept volume. Most birds try to avoid the turbine blades, either by avoiding the wind farm area altogether, or by taking evasive action if they are likely to collide with a blade while transiting the wind farm, so it is also necessary to factor in an avoidance rate. This is done in the final stage, where the predicted number of transits are converted to predicted number of collisions by multiplying by the collision probability (assuming no avoidance behaviour) and then correcting for the avoidance rate and other relevant factors.

1.3. STATEMENT OF COMPETENCE

Tom Gittings has a BSc in Ecology, a PhD in Zoology and is a member of the Chartered Institute of Ecology and Environmental Management. He has 27 years' experience in professional ecological consultancy work and research. He has specific expertise in ornithological assessments for wind energy projects and has been involved in numerous wind energy projects. His input to these projects has variously included field surveys (including vantage point surveys, breeding wader and raptor surveys and wintering waterbird surveys), collision risk modelling, writing the ornithological sections of EIS/EIAR and NIS reports, expert witness services at oral hearings, and provision of scoping advice and peer review services.



Map 1.1. Site location and proposed site layout.

2. METHODS

2.1. GENERAL APPROACH

The collision risk modelling methodology was based on the SNH guidance on collision risk modelling (SNH, 2000), and current practice in collision risk modelling.

2.2. DATA SOURCES

The flight activity data used for the collision risk model comprised a two-year vantage point survey. The survey was carried out between October 2020 and September 2022 and used two vantage points. The vantage point locations and their viewsheds are shown in Map 3.1. The viewsheds were mapped to show visibility from the vantage points at a minimum elevation of 25 m above ground level. Six hours of vantage point watches were completed at each vantage point in each month, amounting to a total of 144 hours at each vantage point across the survey period. The survey recorded timed flight activity of raptors and waterbirds in five height bands: 0-20 m, 20-50 m, 50-100 m, 100-180 m, and above 180 m. The full vantage point survey data is included in Appendix 6.4 Bird Survey Appendices under subsection 6.4.4 Target Species Observations.

The turbine specifications used for the collision risk model (apart from mean pitch angle; see Section 5.1) were supplied by Greensource and are shown in Table 2.1. The bird biometric parameters used for the collision risk model are shown in Table 2.2.

Table 2.1. Turbine parameters used for the collision risk model.

Parameter	Value
Hub height	82 m
Rotor diameter	136 m
Max_chord	4.1 m
Rotor speed range	5.6-14.0 m/sec
Midpoint of rotor speed range	9.8 m/sec
Mean pitch angle	6°

Sources: data supplied by Greensource, except for mean pitch for which see Section 5.1.

Table 2.2. Bird biometric parameters used for the collision risk model.

Species	Length (m)	Wingspan (m)	Flight speed (m/sec)
Mallard	0.58	0.9	18.5
Cormorant	0.9	1.45	15.2
Grey Heron	0.94	1.85	11.2
Hen Harrier	0.48	1.1	9.1
Sparrowhawk	0.33	0.62	11.3
Buzzard	0.54	1.2	11.6
Golden Plover	0.28	0.72	17.9
Whimbrel	0.41	0.82	16.3
Lesser Black-backed Gull	0.58	1.42	13.1
Herring Gull	0.6	1.44	12.8
Great Black-backed Gull	0.71	1.58	13.7
Kestrel	0.34	0.76	10.1
Merlin	0.28	0.56	10.1

Sources: length and wingspan from BirdFacts (www.bto.org/understanding-birds/birdfacts); flight speed from Alerstam *et al.* (2007) with the Grey Plover value used for Golden Plover.

2.3. DATA MANAGEMENT

Before beginning the analyses, I audited the flight activity data for data entry errors and missing data.

2.4. REVIEW OF THE VANTAGE POINT SURVEY COVERAGE AND RESULTS

Before beginning the development of the collision risk model, I carried out a review of the vantage point survey coverage and results. This helped to assess the degree of spatial and temporal variability in the recorded flight activity, which needed to be taken into account in the development of the collision risk model.

2.5. COLLISION RISK MODELLING METHODOLOGY

The collision risk modelling methodology is described in Sections 4-6 of this report as part of a step-by-step account of the development of the collision risk model.

3. REVIEW OF THE VANTAGE POINT SURVEY COVERAGE AND RESULTS

3.1. SPATIAL COVERAGE AND VIEWSHEDS

The mapped viewsheds of both vantage points each cover the entire wind farm site and cover around 90% of the 180° arcs from the vantage point locations. However, the mapped flightlines only occupy the central section of each viewshed (Map 3.1). This probably reflects the surveyors focusing on the sections of the viewshed that covered the wind farm site.

The viewshed area is included as the denominator in the calculation of flight density as part of stage 1 of the collision risk model. This means that, if not all of the viewshed areas were covered by the vantage point surveys, the inclusion of the full viewshed areas will underestimate the collision risk. Therefore, I clipped the mapped viewsheds, so that the viewsheds used for the collision risk model only included areas where mapped flightlines were recorded (Map 3.1). This reduced the overall viewshed area from around 1142 ha to 751 ha. The individual clipped viewshed areas were 355 ha for the VP1 viewshed and 396 ha for the VP2 viewshed.

3.2. SPATIAL PATTERNS OF FLIGHT ACTIVITY

3.2.1. Distance effects

The distribution of the mapped flightlines in relation to the clipped viewsheds (Map 3.1) shows that, while the viewsheds extended to a distance of 2 km from the vantage point locations, most of the recorded flight activity was concentrated within around 500-750 m of the vantage point locations.

The concentration of mapped flightlines close to the vantage point locations is a common feature of vantage point surveys and reflects the effects of distance from vantage point locations on the detection of flight activity. A meta-analysis of vantage point survey data from eight Irish wind farm projects found that detection rates of flight activity showed strong decreases at distances of over 1 km from the vantage point locations, and that this under-detection effect causes underestimation of collision risk by factors of around 1.5 to 5 times (Gittings, 2023).

Spatial patterns in flight activity within viewsheds can also be caused by habitat and/or topographical variation: e.g., due to species showing differences in flight activity between forestry and open habitats, or species avoiding high ground when commuting across a site. In large wind farm projects, the distance effects can be averaged across multiple viewsheds, and any such habitat or topographical factors are likely to balance out, allowing calculation of correction factors for detectability effects.

There were only two vantage points used for this project and both vantage point locations were in open ground looking towards more distant forestry. This means that potential distance and habitat effects will be confounded in the distribution of the mapped flightlines. Therefore, it is not possible to calculate correction factors for detectability effects for this project. However, the potential under-detection of distant flightlines should be considered in the interpretation of the predicted collision risks (see Section 6.3).

3.2.2. Flightlines outside the viewsheds

The distribution of the mapped flightlines in relation to the clipped viewsheds (Map 3.1) shows that several mapped flightlines extended outside the mapped viewsheds. This means that some of the recorded flight activity occurred outside the mapped viewshed. Inclusion of flight activity outside the mapped viewsheds will overestimate the collision risk. Therefore, for flightlines that extended outside the mapped viewsheds, it is necessary to correct for the portion of the flightlines that were outside the viewsheds (see Section 4.1.3).

3.2.3. Species-specific spatial structure

The stage 1 model assumes random distribution of flight activity across the wind farm site, or across portions of it. Therefore, in addition to considering the distance effects on detectability, it is also necessary to consider whether deviations from this assumption are likely to significantly bias the model. In large wind farm sites, species are likely to show significant deviations from this assumption.

The Ballykett Wind Farm site is a small site and the two viewsheds show a high degree of overlap. The most likely spatial structure (differences between the forestry and open areas) is confounded with the distance effects discussed above. This means that it was not feasible to analyse species-specific spatial structure. However, the highest density of flight activity was recorded in the open areas (as the vantage points were in open areas), while the turbine locations are in forestry areas. Therefore, if there is spatial structure due to differences in flight activity between forestry and open areas, the assumption of random distribution of flight activity will be precautionary (it will tend to overestimate the collision risk).

3.3. TEMPORAL PATTERNS OF FLIGHT ACTIVITY

The monthly numbers of vantage point survey records recorded during the vantage point survey are shown in Table 3.1. As there was equal survey effort per month, this table indicates the monthly pattern of flight activity.

Table 3.1. Monthly numbers of vantage point survey records recorded during the vantage point survey.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mallard	0	1	0	0	0	0	0	0	0	0	0	0
Cormorant	0	0	0	0	0	0	0	0	0	1	0	0
Grey Heron	1	0	1	0	0	0	0	0	3	1	0	0
Hen Harrier	0	0	0	1	0	0	0	0	0	1	0	0
Sparrowhawk	1	0	0	1	0	0	2	0	1	0	2	1
Buzzard	0	1	1	3	3	1	1	3	2	2	1	2
Golden Plover	1	0	0	0	0	0	0	0	0	0	0	0
Whimbrel	0	0	0	0	1	0	0	0	0	0	0	0
Snipe	0	0	0	0	0	0	0	0	0	1	1	0
Lesser Black-backed Gull	0	0	0	1	4	2	3	0	1	0	0	0
Herring Gull	1	2	0	0	3	1	2	1	1	0	0	0
Great Black-backed Gull	1	0	0	0	0	0	0	0	0	1	0	1
Kestrel	2	1	1	2	2	2	2	2	5	3	2	1
Merlin	0	1	0	0	0	0	0	0	0	0	0	0

This table includes all vantage point survey records.

3.4. HEIGHT BAND DISTRIBUTION OF FLIGHT ACTIVITY

The height band distribution of flightline records is shown in Table 3.2 and the height band distribution of total flight activity (bird-secs) is shown in Table 3.3. The flight activity was concentrated in the 25-50 m and 50-100 m height bands. There were no flightline records from the > 180 m height band.

Table 3.2. Numbers of flightline records recorded in each height band.

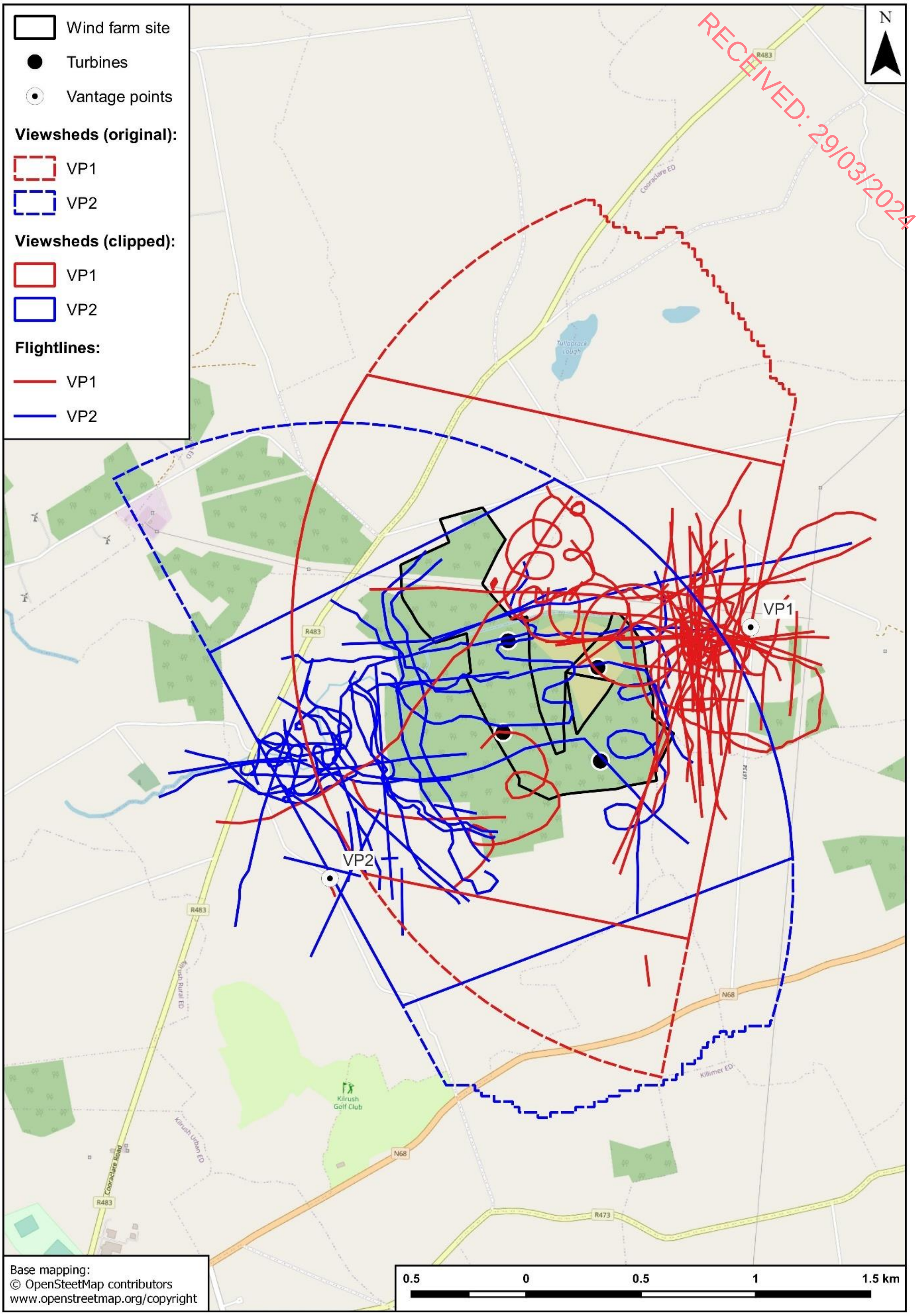
Species	0-20 m	20-50 m	50-100 m	100-180 m
Mallard	1	0	0	0
Cormorant	0	0	1	0
Grey Heron	2	3	0	0
Hen Harrier	1	0	0	0
Sparrowhawk	2	4	1	0
Buzzard	1	9	5	1
Golden Plover	0	1	0	0
Whimbrel	0	1	0	0
Snipe	0	1	0	0
Lesser Black-backed Gull	0	5	3	1
Herring Gull	1	7	3	0
Great Black-backed Gull	0	2	1	0
Kestrel	5	7	7	2
Merlin	0	1	0	0
Total	**13**	**41**	**21**	**4**

There were no flightline records from the > 180 m height band.

Table 3.3. Total amount of flight activity (bird-secs) recorded in each height band.

Species	0-20 m	20-50 m	50-100 m	100-180 m
Mallard	80	0	0	0
Cormorant	0	0	60	0
Grey Heron	70	137	0	0
Hen Harrier	60	0	0	0
Sparrowhawk	33	175	120	0
Buzzard	30	400	1565	360
Golden Plover	0	300	0	0
Whimbrel	0	360	0	0
Snipe	0	480	0	0
Lesser Black-backed Gull	0	262	270	180
Herring Gull	60	475	325	0
Great Black-backed Gull	0	80	60	0
Kestrel	265	440	650	145
Merlin	0	120	0	0
Total	**598**	**3229**	**3050**	**685**

There were no flightline records from the > 180 m height band.



Map 3.1. Vantage points, viewsheds and flightlines.

4. COLLISION RISK MODEL STAGE 1: BIRD TRANSITS

4.1. METHODOLOGY

4.1.1. General approach

The stage 1 calculations use the vantage point survey data to calculate the predicted number of bird transits across the rotor swept volume. There are two methods described by SNH (2000) for carrying out stage 1 calculations: the "risk window" approach for when birds make regular flights through the flight risk area (e.g., geese commuting between roost sites and feeding areas); and the "bird occupancy" approach for when birds show variable patterns of flight activity within the flight risk area. I have used the "bird occupancy" approach, as this is generally the appropriate method for species that show variable patterns of flight activity, and the vantage point survey data and flightline mapping do not indicate regular flightlines through the wind farm site.

The sequential calculations that derive the predicted number of bird transits across the swept volume are shown in Table 4.1.

Table 4.1. Calculations of predicted number of bird transects across the rotor swept volume.

Step	Parameter	Calculation	Formula	Units	Details
1	t_1	bird-secs observed at potential collision height / total duration of VP watches	D_{bird}/VP_{eff}	birds	Mean number of birds observed flying at rotor height during the vantage point watches
2	n	t1 * total duration of season	$t_1 \times D_{season} \times 3600$	bird-secs	Predicted total number of birds observed flying at rotor height if the vantage point watches had covered the entire season
3	b	n × (volume swept by rotors / flight risk volume)	$n \times (A_{rotor} \times (L_{rotor}+L_{bird}))/(A_{vis} \times H_{rotor})$	bird-secs	Predicted bird occupancy of the swept volume across the entire season
4	$N_{transits}$	b / time taken for a bird to fly through rotors of one turbine	$b/((L_{rotor}+L_{bird})/v_{bird})$	bird transits	Predicted number of transits across the swept volume across the entire season

Note: The SNH (2000) calculation procedure include additional steps, which calculate flight activity within the "risk area", and then correct for the proportion of the risk area airspace occupied by the rotor swept volume of the turbines. However, these steps cancel out, so the calculation procedure shown in this table produces identical results.

The calculations in Table 4.1 simplify as Equation 1, which is shown below:

Equation 1: $N_{transits} = (D_{bird} \times D_{season} \times N_{turb} \times A_{rotor} \times v_{bird}) / (H_{rotor} \times VP_{eff} \times A_{vis})$

D_{bird} = bird-secs observed at potential collision height, D_{season} = total daylight hours across the season, N_{turb} = number of turbines, A_{rotor} = area of rotor discs, v_{bird} = bird flight speed, H_{rotor} = rotor diameter, VP_{eff} = total duration of vantage point watches, and A_{vis}= total area of viewshed.

Note that the rotor depth (L_{rotor}) and bird length (L_{bird}), which are included in the sequential calculations in Table 4.1, cancel out. While bird length is required for the collision probability calculations in stage 2, the rotor depth parameter (L_{rotor}) is not usually required for collision risk modelling.

4.1.2. Model types

The basic mathematical method for calculating predicted transits using the occupancy method (as described above) is explained by SNH (2000), and, in any case, can be easily derived from first principles. However, SNH (2000) does not provide guidance on how to incorporate data from multiple vantage points in calculations of predicted transits. The simplest method (the combined VPs method) combines the data from all the vantage points, using the sum of the flight activity across all the vantage points for the D_{bird} value, and the sum of the viewshed areas for the A_{vis} value. This method assumes that flight activity is randomly distributed throughout the combined viewsheds.

A slightly more sophisticated method is the VP averaging method. This involves calculating the flight activity density separately for each vantage point. The flight activity density is calculated using the same formula as Equation 1 but omitting N_{turb}. Then the mean flight activity density across all vantage points is used to calculate the overall number of transits predicted across the entire wind farm site. This is a variant of a method that is widely used (in Ireland) and has also been taught at courses on collision risk modelling run by the Chartered Institute of Ecology and Environmental Management[1]. This method also assumes that there is random distribution of flight activity across the wind farm site but treats each vantage point as a separate sample.

More sophisticated spatially-structured models can be developed by subdividing the overall wind farm site and modelling the transits separately for each section. However, as discussed above (Section 3.2.3), I did not consider that incorporating spatial structure was necessary for this collision risk model.

In this assessment I have modelled the predicted transits for all species using the VP averaging method.

[1] The method that is widely used calculates predicted transits per turbine separately for each vantage point and then uses the mean predicted transits/turbine across all vantage points to calculate the overall number of transits predicted across the entire wind farm site. This is equivalent to the method used in this report when all viewsheds contain turbines. However, the method used in this report can also include data from viewsheds that do not contain turbines.

4.1.3. Data preparation

Selection of species for the collision risk model

The vantage point survey dataset included flightline data for 14 raptor and waterbird species. All of these species were included in the collision risk model, apart from Snipe. The flight activity of Snipe is not effectively sampled by standard vantage point survey methods, due to its high level of crepuscular and nocturnal flight activity. Therefore, collision risk modelling based on the vantage point survey dataset would not produce meaningful results.

Definition of seasonal periods

The seasonal periods that I used for each species included in the stage 1 model are shown in Table 4.2. These were based on the analyses of the monthly occurrence patterns (see Table 3.1) and general knowledge of the species ecology in Ireland.

The September – April periods for Hen Harrier and Merlin, and October – April period for Golden Plover represent the typical occurrence periods of non-breeding / wintering populations. The April – May period for Whimbrel represents their spring migration period. The April – September period for Lesser Black-backed Gull represents their breeding season and migration periods.

I used the suncalc package (Thieurmel and Elmarhraoui, 2022) in R 4.2.2 (R Core Team, 2022) to calculate the total daylight hours for the seasonal occurrence period of each species.

Table 4.2. Seasonal periods used for each species included in the stage 1 model.

Species	Seasonal period	Total daylight hours	Total survey hours / VP
Mallard	All year	4484	144
Cormorant	All year	4484	144
Grey Heron	All year	4484	144
Hen Harrier	September - April	2532	96
Sparrowhawk	All year	4484	144
Buzzard	All year	4484	144
Golden Plover	October - March	1733	72
Whimbrel	April - May	909	24
Lesser Black-backed Gull	April – September	2751	72
Herring Gull	All year	4484	144
Great Black-backed Gull	All year	4484	144
Kestrel	All year	4484	144
Merlin	September - April	2532	96

The total daylight hours are the D_{season} values used for the stage 1 model. The total survey hours / VP are the VP_{eff} values used for the stage 1 model.

Selection of height bands

The potential collision height airspace was 14-150 m. The height bands used for the vantage point survey were 0-20 m, 20-50 m, 50-100 m, 100-180 m, and above 180 m. Therefore, I used the data from the first four height bands, which cover an airspace of 0-180 m, for the collision risk modelling.

The inclusion of all the flight activity in the 0-20 m and 100-180 m height bands will result in an overestimation of the collision risk. However, in the case of the 0-20 m height band, this will be balanced, to some extent, by the fact that the viewsheds were mapped at a height of 25 m above ground level, and the viewsheds at a height of 14 m above ground level will be smaller.

The separate calculation of transits for each height band means that the lowest height band has a small influence on the collision risk as the rotor area included in this height band is very small: in this case the rotor area in the 0-20 m height band is 1.5% of the total rotor area (see below). The influence of the highest height band is also limited due to the relatively small amount of flight activity recorded in this height band (Table 3.3).

Re-calculation of flight durations

As some mapped flightlines extended outside the viewshed boundaries, I clipped the mapped flightlines by the viewsheds, and recalculated the flight durations and bird-secs by multiplying their original values by (clipped flightline length) / (original flightline length).

Rotor area

I calculated bird transits separately for each height band included in the model. To carry out these separate calculations, it was necessary to subdivide the overall rotor area (A_{rotor}) into the portions that occurred in each height band. To calculate the rotor area in each height band, the angles subtended by segments representing the 0-20 m, 20-50 m, and 50-100 m height bands were calculated using the following equations:

Equation 2: $\theta_{0\text{-}20} = 2 \times \cos^{-1}((Hhub - 20) / R_{rotor})$

Equation 3: $\theta_{20\text{-}50} = 2 \times \cos^{-1}((H_{hub} - 50) / R_{rotor})$

Equation 4: $\theta_{50\text{-}100} = 2 \times \cos^{-1}((H_{hub} - 100) / R_{rotor})$

Hhub = hub height; Rrotor = rotor radius.

I then calculated the rotor areas using the following equations:

Equation 5: $A_{rotor(0\text{-}20)} = 0.5 \times (\theta_{0\text{-}20} - \sin(\theta_{0\text{-}20})) \times R_{rotor}^2$

Equation 6: $A_{rotor(20\text{-}50)} = 0.5 \times (\theta_{20\text{-}50} - \sin(\theta_{20\text{-}50})) \times R_{rotor}^2 - A_{rotor(0\text{-}20)}$

Equation 7: $A_{rotor(50\text{-}100)} = 0.5 \times (\theta_{50\text{-}100} - \sin(\theta_{50\text{-}100})) \times R_{rotor}^2 - A_{rotor(0\text{-}20)} - A_{rotor(20\text{-}50)}$

Equation 8: $A_{rotor(100\text{-}180)} = A_{rotor} - A_{rotor(0\text{-}20)} - A_{rotor(20\text{-}50)} - A_{rotor(50\text{-}100)}$

Similarly, the rotor height (H_{rotor}) values for each height band were adjusted to equal the height of the rotor segment in the height band.

These calculations produced rotor areas of 225 m^2 for the 0-20 m height band, 2,852 m^2 for the 20-50 m height band, 6,605 m^2 for the 50-100 m height band, and 4,844 m^2 for the 100-180 m height band. The rotor height values were 6 m for the 0-20 m height band, 30 m for the 20-50 m height band, 50 m for the 50-100 m height band, and 50 m for the 100-180 m height band.

4.1.4. Stage 1 model implementation

I carried out the stage 1 model calculations in R 4.2.2 (R Core Team, 2022). As discussed above, I used the VP averaging method, calculated the transits separately for each height band, and used the seasonal periods in Table 4.2 to calculate VP_{eff} and D_{season} values for each species.

I first calculated the flight activity density in each height band separately for each viewshed using the equation below, which is a modified version of Equation 1:

Equation 9: $(D_{bird} \times D_{season} \times A_{rotor} \times v_{bird}) / (H_{rotor} \times VP_{eff} \times A_{vis})$

D_{bird} = bird-secs observed at potential collision height, D_{season} = total daylight hours across the season, N_{turb} = number of turbines, A_{rotor} = area of rotor discs, v_{bird} = bird flight speed, H_{rotor} = rotor diameter, VP_{eff} = total duration of vantage point watches, and A_{vis}= total area of viewshed.

I then averaged the flight activity density in each height band across the two viewsheds, multiplied these averaged values by the number of turbines to obtain the predicted transits in each height band, and then summed the predicted transits across the height bands to obtain the overall number of predicted transits.

The flight activity (D_{bird}) values for each height band are shown in Table 3.3. The seasonal duration (D_{season}) values are shown in Table 4.2. The rotor area (A_{rotor}) values are presented in Section 4.1.3 (Rotor area). The bird flight speed (v_{bird}) values are included in Table 2.2. The H_{rotor} values are presented in Section 4.1.3 (Rotor area). The survey effort (VP_{eff}) values are shown in Table 4.2. The viewshed area (A_{vis}) values are presented in Section 3.1. The number of turbines used for the collision risk model was four.

4.1.5. Stage 1 model results

The results of the stage 1 calculations are shown in Table 4.3. The species with the highest predicted transits per year were Buzzard, Whimbrel, Lesser Black-backed Gull, Herring Gull and Kestrel with 11-49 transits / year. All the other species had predictions of less than ten transits / year.

Table 4.3. Predicted transits per year.

Species	Transits / year
Mallard	0.21
Cormorant	1.9
Grey Heron	2.8
Hen Harrier	0.30
Sparrowhawk	5.8
Buzzard	49
Golden Plover	4.7
Whimbrel	11
Lesser Black-backed Gull	19
Herring Gull	19
Great Black-backed Gull	3.0
Kestrel	24
Merlin	1.5

5. COLLISION RISK MODEL STAGE 2: COLLISION PROBABILITY

5.1. METHODOLOGY

Stage 2 of the collision risk model involves calculating the probability of a collision when a bird makes a transit of the rotor swept volume.

The Scottish Natural Heritage collision risk model (SNH, 2000; Band *et al.,* 2007; Band, 2012) calculates the probability, p (r, φ), of collision for a bird at radius r from the hub and at a position along the radius that is at angle φ from the vertical. This probability is then integrated over the entire rotor disc, assuming that the bird transit may be anywhere at random within the area of the disc. Separate calculations are made for flapping and gliding birds and for upwind and downwind transits. This method assumes that: birds are of a simple cruciform shape; they fly through turbines in straight lines with a perpendicular approach to the plane of the rotor; their flight is not affected by the slipstream of the turbine blade; and that the turbine blades have width and pitch angle, but no thickness.

The collision probability calculations for the original Scottish Natural Heritage collision risk model can be carried out using an Excel spreadsheet which is provided as an accompaniment to the SNH (2000) guidance. This spreadsheet was updated by Band (2012) by changing the details of the blade profile used in the model[2]. The updated model is included in R code provided by Masden (2015).

I carried out all the collision probability calculations in R 4.2.2 (R Core Team, 2022), using an adapted version of the R code provided by Masden (2015). I audited this R code against the Band (2012) spreadsheet to confirm that it produced matching collision probability calculations.

One of the turbine parameters used to calculate collision probability is the mean pitch angle of the turbine blade. This parameter specifies the angle of the blade from the horizontal, so the collision probability will increase as the mean pitch angle increases. Data on mean pitch angle can be difficult to obtain so generic values are often used in collision risk models. These are often based on the statement by Band (2012) that a mean pitch angle of “25-30 degrees is reasonable for a typical large turbine”. However, Band was referring to offshore wind farms where wind speeds are higher than at onshore wind farms, resulting in higher mean pitch angles. For this assessment, I applied a more realistic scenario from an onshore wind farm (Meenwaun, Co. Offaly). The pitch angle over a continuous 12-month period at this site was for approximately 90% of the time between -3° and 9° (MKOS, 2019). I used a pitch value of 6° for the collision probability calculations, as this was the pitch value within the -3° to 9° range that produced the highest collision probability values for most species in the sensitivity analyses (see Section 0).

The bird biometric and turbine parameter values used in the calculations of collision probability are shown in Table 2.1 and Table 2.2. The proportions of upwind and downwind flight was set as 0.5.

[2] Note that, strictly speaking, the model should be adapted for each turbine specification by changing the details of the blade profile in the model to match the blade profile of the turbine. However, in practice, this would make very little difference to the predicted collision risk, and the details of the blade profile are usually not available.

5.2. RESULTS

The collision probability predictions for flapping and gliding flight were very similar, so I present the means of these predictions in this report and have used these mean values for the collision risk predictions.

The collision probability predictions are shown in Table 5.1. They varied from around a 1 in 20 chance of a collision on a single transit for Merlin to around a 1 in 15 chance for Cormorant. Note that these probabilities do not take account of avoidance rates.

Table 5.1. Probability of a collision on a single transit of the rotor airspace.

Species	Collision probability
Mallard	0.054
Cormorant	0.068
Grey Heron	0.080
Hen Harrier	0.064
Sparrowhawk	0.052
Buzzard	0.061
Golden Plover	0.046
Whimbrel	0.051
Lesser Black-backed Gull	0.061
Herring Gull	0.062
Great Black-backed Gull	0.065
Kestrel	0.054
Merlin	0.051

The collision probability values are the means of the separate probabilities for flapping and gliding flight.

5.3. SENSITIVITY

5.3.1. Rotation speed

The rotation speed has a strong influence on the collision probability values. However, the rotation speed value used in the stage 2 model was simply the mid-point of the rotor speed range. In practice, rotation speeds will vary with wind speed. Therefore, I carried out sensitivity analyses to investigate how collision probabilities varied with rotation speeds across the range of operational rotation speeds.

The relationships between collision probabilities and rotation speeds are shown in Figure 5.1 for the species included in the collision risk model. The effects of variation in rotation speed generally increases with body size. For small species like Golden Plover, the variation in rotation speed, within the operational speed ranges, had negligible effects on the collision probabilities. However, for large species like Grey Heron and Cormorant, there was a 2-3% variation in collision probabilities across the operational speed ranges. For these two species, this variation would result in an increase in the predicted collision risk of up to 1.5 times between the minimum and maximum rotation speeds.

5.3.2. Pitch angle

Modern wind turbines have variable pitch angles, so I carried out sensitivity analyses to investigate how collision probabilities varied with pitch angle. Collision probability values were calculated for each 1° increment in pitch angle between -5° and 90°.

The relationships between collision probabilities and pitch angles are shown in Figure 5.2 for the species included in the collision risk model. The collision probability values showed little variation up to pitch values of around 10-15°. As discussed above, monitoring data indicates that pitch angles at onshore wind farms in Ireland rarely exceed 9°. Therefore, variation in pitch angle is unlikely to affect collision risk predictions.

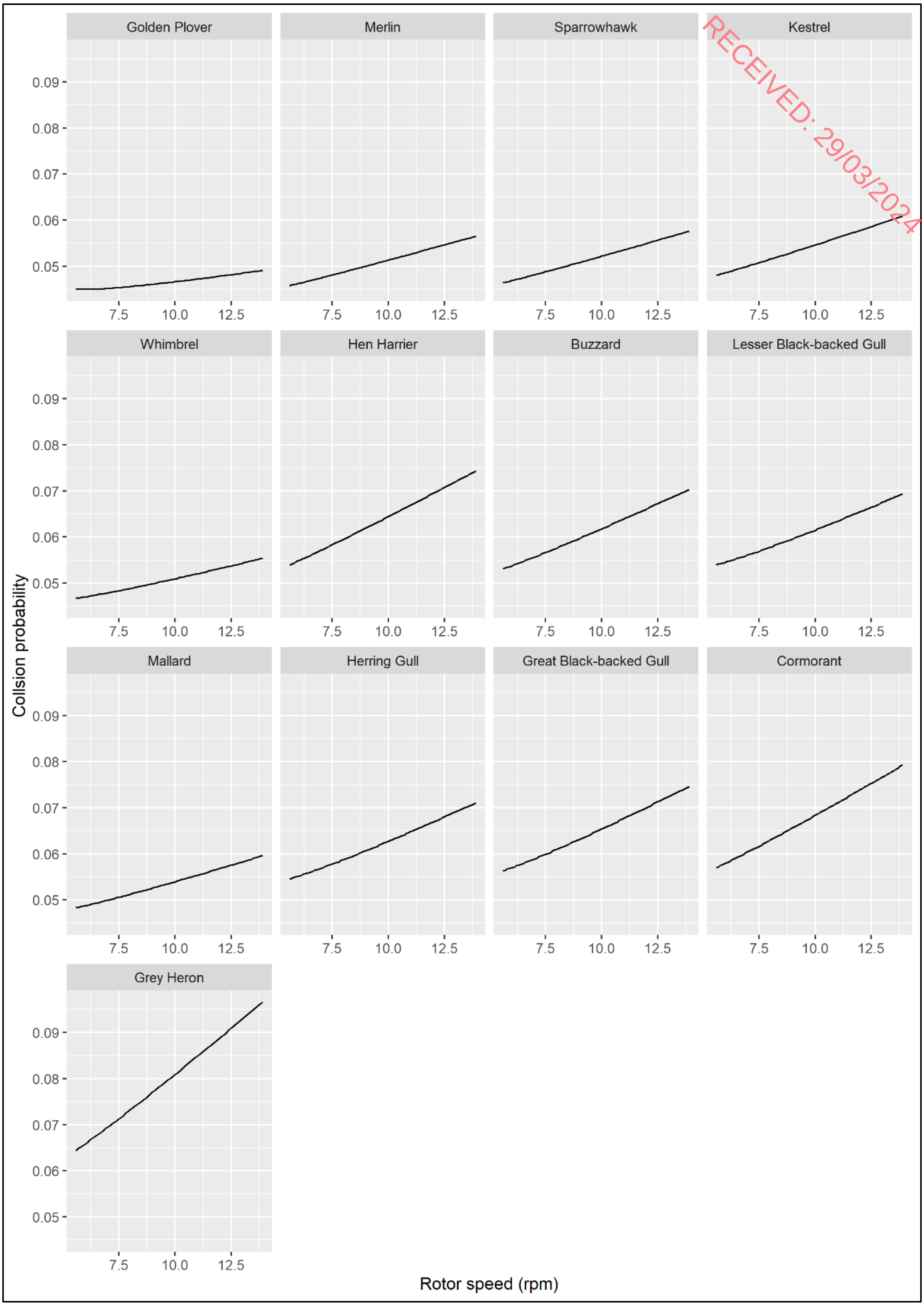


Figure 5.1. Relationship between rotor speed and collision probability, with species arranged in order of increasing body length.

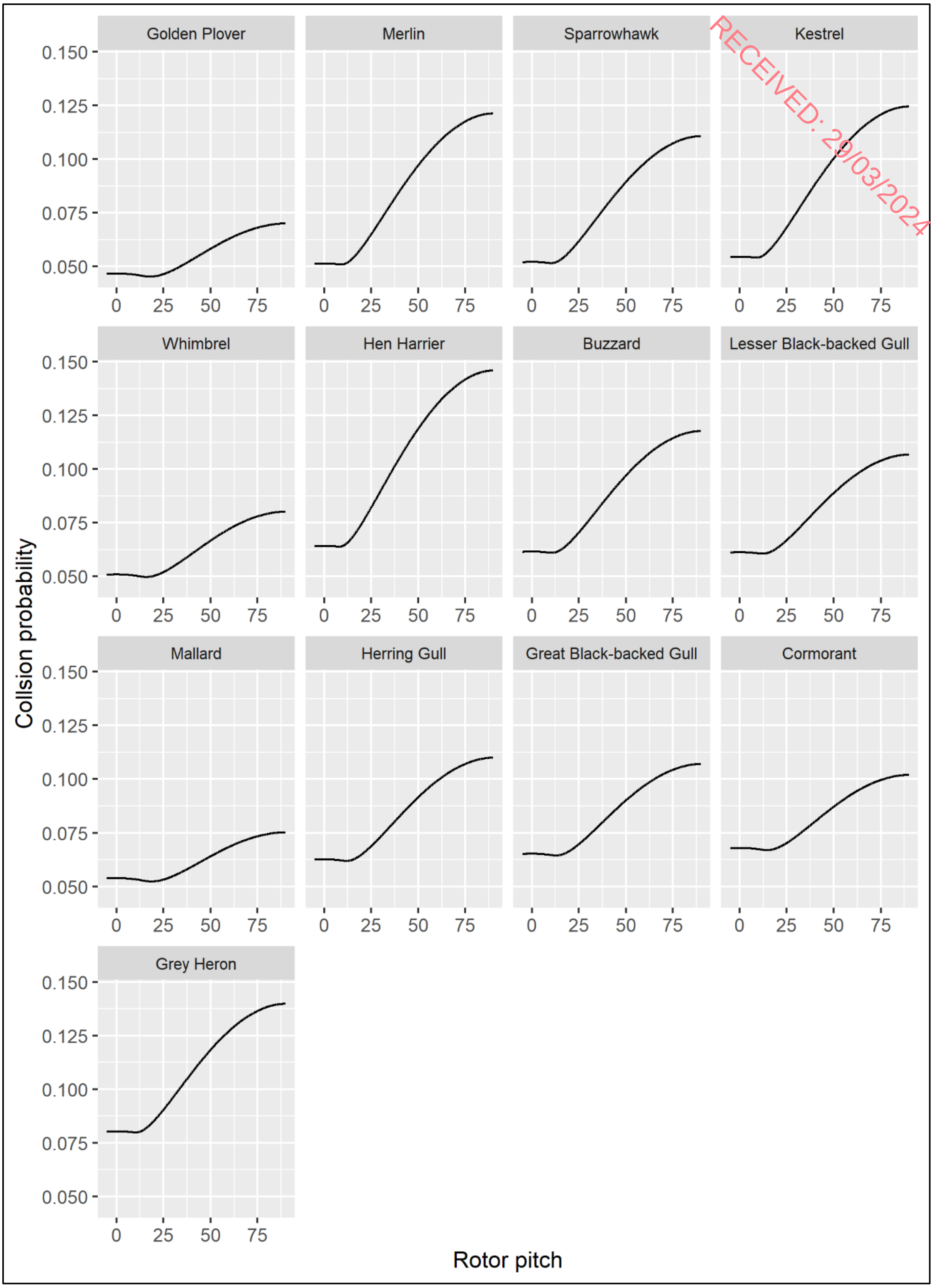


Figure 5.2. Relationship between rotor speed and pitch angle, with species arranged in order of increasing body length.

6. COLLISION RISK MODEL STAGE 3: COLLISION PREDICTION

6.1.1. General

Stage 3 of the collision risk model uses the predicted transits from Stage 1 and the collision probabilities from Stage 2 to calculate the predicted collisions. However, three correction factors need to be considered: the avoidance rate; the degree of any nocturnal flight activity; and the proportion of time the wind farm is operational.

6.1.2. Correction factors

Avoidance rates

The avoidance rate reflects the fact that most potential collisions are avoided due to birds taking evasive action (SNH, 2010). This avoidance rate includes both behavioural avoidance (micro-avoidance) and behavioural displacement (macro-avoidance).

Behavioural avoidance is “action taken by a bird, when close to an operational wind farm, which prevents a collision”. Behavioural displacement refers to the process by which a “bird may (possibly over time) change its home range, territory, or flight routes between roosting areas and feeding areas, so that its range use (or flight paths) no longer bring the bird into the vicinity of an operational wind farm”.

Scottish Natural Heritage provides guidance on avoidance rates to use in collision risk assessments (SNH, 2010, 2018). For some species, including Hen Harrier and Kestrel, there is some evidence available that has been used to specify species-specific avoidance rates (SNH, 2018). In addition, a recent review for Scottish Natural Heritage has recommended the use of an avoidance rate of 0.995 for large gulls (including Lesser Black-backed Gull) at onshore wind farms (Furness, 2019). For the other species included in this collision risk model, the SNH guidance specifies a default avoidance rate of 98%.

The avoidance rates used in the stage 3 model are shown in Table 6.1.

Nocturnal flight activity

Another factor that needs to be considered is the degree of nocturnal flight activity that is likely to occur. The calculations of predicted transits are based on flight activity during daylight hours only. Therefore, if a species is likely to have a significant amount of nocturnal flight activity, a correction should be made to account for this nocturnal flight activity.

Correction factors for nocturnal flight activity were included for Mallard, Grey Heron, Golden Plover and Whimbrel. These correction factors were calculated using the following equation.

Equation 10: $ncf = 1 + nfr \times h_{night^*} / h_{day^*}$

nfr = nocturnal flight activity rate as a proportion of the diurnal flight activity rate; h_{night^*} = mean night-time hours across seasonal period of occurrence; h_{day^*} = mean day-time hours across seasonal period of occurrence.

The Whimbrel overflying the wind farm are likely to be on direct migration, which is probably equally likely to occur by night as by day. So, the nocturnal flight activity rate for Whimbrel was set as 1.

For Mallard, visual inspection of Figure 2 in Korner *et al.* (2016) suggests that nocturnal activity is around half that of diurnal activity, so the nocturnal flight activity rate was set as 0.5. For Golden Plover, a figure of 25% of the day-time activity levels across the night-time hours is often used in collision risk modelling (e.g., MKOS, 2019), so the nocturnal flight activity rate was set as 0.25. Flight activity patterns for Grey Heron from Vessem and Draulans (1987) indicate low levels of nocturnal flight activity, so the nocturnal flight activity rate was set at the same rate as Golden Plover.

The nocturnal correction factors used in the stage 3 model are shown in Table 6.1.

Operational time

Wind turbines in operational wind farms will have periods when they are not turning due to maintenance or wind speeds. Therefore, the predicted collisions need to be corrected by the proportion of time the wind turbines will be operational. This value was set at 0.85 for all the species in the model, which is a widely value for this parameter in collision risk modelling for onshore wind farms in Ireland.

6.1.3. Calculations

The collision risk was calculated using the following equation:

Equation 11: $cr = N_{transits} \times cp \times (1\text{-}ar) \times ncf \times op$

$N_{transits}$ = predicted transits per year; cp = collision probability (probability of a collision on a single transit); ar = avoidance rate; ncf = nocturnal correction factor; op = proportion of operational time.

6.2. COLLISION PREDICTIONS

The results of the stage 3 calculations are summarised in Table 6.1. For Buzzard and Kestrel, the predicted collision risks would result in 1-2 collisions over the 30-year lifespan of the wind farm. For all the other species, the predicted collision risk would not cause any collisions over the lifespan of the wind farm.

Table 6.1. Collision risk predictions.

Species	Transits / year	Collision probability	Avoidance rate	Nocturnal correction factor	Collisions / year	Collisions / 30 years
Mallard	0.21	0.054	0.98	1.48	0.0085	0.0085
Cormorant	1.9	0.068	0.98	1	0.0022	0.065
Grey Heron	2.8	0.080	0.98	1.24	0.0039	0.14
Hen Harrier	0.30	0.064	0.99	1	0.00017	0.005
Sparrowhawk	5.8	0.052	0.98	1	0.0051	0.15
Buzzard	49	0.061	0.98	1	0.052	1.5
Golden Plover	4.7	0.046	0.98	1.38	0.0052	0.15
Whimbrel	11	0.051	0.98	1.61	0.015	0.44
Lesser Black-backed Gull	19	0.061	0.995	1	0.0049	0.15
Herring Gull	19	0.062	0.995	1	0.0049	0.15
Great Black-backed Gull	3.0	0.065	0.995	1	0.00084	0.025
Kestrel	24	0.054	0.95	1	0.056	1.7
Merlin	1.5	0.051	0.98	1	0.0013	0.04

The proportion of operational time was set as 0.85 for all species.

6.3. INTERPRETATION OF COLLISION RISK PREDICTIONS

6.3.1. General

A collision risk figure should be thought of as a probabilistic prediction rather than an absolute value and consideration should be given to the uncertainty around the prediction.

Some of the uncertainty relates to measurement error and imprecise specification of parameters, while sampling effects will also cause uncertainty.

6.3.2. Measurement error and imprecise specification of parameters

The effects of under-detection of distant flightlines on collision risk predictions have been discussed above (Section 3.2.1). This under-detection could cause under-estimation of the collision risk by factors of around 2-3 times. Other possible measurement errors in vantage point surveys include errors in allocation of flight activity to height bands, and errors in flightline mapping and/or determining when flightlines enter or leave viewsheds.

The use of the midpoint of the rotation speed range for the turbine rotation speed in the stage 2 model will affect the collision probability calculations, as the actual values of the turbine rotation speed during each potential collision event will vary. However, the sensitivity analyses (Section 5.3.1) suggest that this factor is not likely to have large effects on the predicted collision risk. For the species, showing the largest variation, the difference in the collision probability values between the midpoint and the minimum and maximum rotation speeds was around 25% of the midpoint value. In practice, extreme values of rotation speed are likely to be relatively infrequent.

The stage 2 model also uses a mean pitch value, while the actual pitch values during each potential collision event will vary. However, the sensitivity analyses suggest that the effect of this factor is on the predicted collision risk will be negligible, within the range of pitch values that are considered typical for onshore wind farms in Ireland (Section 5.3.2).

6.3.3. Sampling effects

The standard vantage point survey effort following the SNH guidelines (SNH, 2017) only samples around 1.5-2% of the available daylight hours. The hours are usually distributed in a clustered way: e.g., the six hours per month at a vantage point are often done as back-to-back three-hour surveys for logistical reasons. As flight activity patterns for many species will not be evenly distributed, the low proportion of daylight hours sampled and the clustered distribution of the sampling, mean that the flight activity sampled may not be representative of the overall pattern of flight activity. This is a particular issue for species where a small number of flights could generate a large collision risk: e.g., a large Golden Plover circling around for an extended period of time.

There will also be year-to-year variation in flight activity patterns, due to a variety of factors such as variation in local population sizes, habitat changes, etc. As the lifespan of a wind farm is measured in decades, a two-year survey period will only represent a snapshot of the potential variation in flight activity across the period when potential collision risk will occur.

In the collision risk model for the Ummeras Wind Farm, I used bootstrapping procedures to resample the flight activity data and generate confidence intervals for the predicted collision risk for four species that had high levels of flight activity (Gittings, 2020). These collision risk models produced upper limits of the confidence intervals that were around 1.4 (Buzzard) to 2.4 (Golden Plover) times higher than the mean predicted collision risk. Conversely, the actual collision risk could be lower than the predicted collision risk.

6.3.4. Behavioural effects

The equation for calculating predicted transits (Equation 1) includes the mean bird flight speed as part of the numerator. However, for Kestrel, a significant proportion of their flight activity will typically involve hovering birds. The flight speed of a hovering Kestrel is close to zero (a small amount of drift in position will often occur during long bouts of hovering). Therefore, using the mean flight speed for Kestrel (10.1 m/sec; Alerstam *et al.*, 2007) in Equation 1 to predict transits of hovering Kestrel is clearly inappropriate and will result in highly inflated estimates.

In the collision risk model for the Castlebanny Wind Farm (Gittings, 2021), I used data collected during the vantage point survey on the duration of hovering flight, and the mean number of hovering positions per second, to calculate separate predicted transits for hovering Kestrels, with the standard stage 1 model only used for direct Kestrel flight activity. This resulted in a predicted collision risk that was less than half the value of the collision risk that would have been generated by using the standard stage 1 model for all Kestrel flight activity.

6.3.5. Allowing for uncertainty

The two main potential sources of uncertainty in collision risk modelling are the effects of under-detection of distant flightlines and sampling effects. If appropriate corrections to allow for these sources of uncertainty are not possible, due to the nature of the data (as is the case with this project), the predicted collision risks should be multiplied by factors of around 4 (large species) or 6 (small species) times to represent a worst case scenario of high levels of under-detection of distant flightlines, and actual flight activity levels being at the upper limit of the theoretical confidence interval around the sampled flight activity. However, for Kestrel, the potential overestimation of the collision risk due to inclusion of hovering flight activity in the standard stage 1 model should also be considered.

7. CONCLUSIONS

The predicted collision risks for all the species included in the collision risk model are low. The predicted values would results in 1-2 collisions of Buzzard and Kestrel over the 30-year lifespan of the wind farm, and no collisions for any of the other species included in the collision risk model.

Sensitivity analyses indicated that variation in rotor speed within the rotor speed range, and variation in pitch values within the typical operational range for Irish onshore wind farms, would not significantly affect the collision risk predictions.

To allow for uncertainty, the predicted collision risks should be multiplied by factors of around 4 (large species) or 6 (small species) times to represent a worst-case scenario of high levels of under-detection of distant flightlines, and actual flight activity levels being at the upper limit of the theoretical confidence interval around the sampled flight activity. However, for Kestrel, the potential overestimation of the collision risk due to inclusion of hovering flight activity in the standard stage 1 model should also be considered.

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