Collision Risk Modelling

Firlough Wind Farm Development

Carrowleagh (Kilbride), Ballina, Co. Mayo

Compiled by: Veon Ecology,
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Prepared for: BioSphere Environmental Services.

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Veon Ltd. Veon Ecology							
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Executive Summary

This report presents the outcome of a Collision Risk Assessment for target species at the proposed Firlough Wind Farm Development (Winter 2019/2020 to Summer 2021) located in Carrowleagh (Kilbride), Ballina, Co. Mayo. The results of the model are solely speculative and representative of worst-case scenario estimates, only drawing conclusions by assuming likely levels of active avoidance by specific species. As such, 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. The contents of this report, prepared by Veon Ecology are true and have been prepared with due regard to the Chartered Institute of Ecology and Environmental Management's (CIEEM) Code of Professional Conduct.

Section 1: INTRODUCTION

1.1 Background

Veon Ltd. (Veon Ecology) has been appointed by BioSphere Environmental Services, to carry out a Collision Risk Assessment for target bird species at the proposed Firlough Wind Farm Development in Carrowleagh (Kilbride), Ballina, Co. Mayo. This Assessment uses standardised Collision Risk Modelling (CRM) methods.

This document has been prepared by David M. McGillycuddy of (Veon Ecology) Veon Ltd. to assess the collision risk for birds (i.e. target species) at the proposed Firlough Wind Farm Site. The collision risk assessment, prepared by David M. McGillycuddy B.Sc. (Hons) in Wildlife Biology at MTU, QCIEEM, is based on vantage point surveys undertaken at the development site from the breeding and wintering seasons of 2019 - 2021 inclusive. The data represents a 24-month survey period, consisting of two breeding seasons and two non-breeding (wintering) seasons, in full compliance with the Scottish Natural Heritage guidelines SNH (2017).

Collision risk is calculated using a mathematical model to predict the numbers of individual birds, of a particular species (i.e. target species), that may be collide with moving wind turbine rotor blades. The modelling method and calculations used in this collision risk assessment follows Scottish Natural Heritage (SNH) guidance often referred to as the Band Model (Band et al. 2007). The calculations and results attained from the Band model must be interpreted with a degree of caution. The bird occupancy method (SNH, 2000) was used to calculate the number of bird transits through the rotors, and the spreadsheet accompanying the SNH report was used to calculate collision probabilities for birds transiting the rotors occupied space.

This collision risk modelling used data from vantage point (VP) surveys carried out in the summers of 2020 and 2021, and winters of 2019/2020 and 2020/2021. VP surveys were SNH (Scottish Natural Heritage) compliant (SNH, 2017). Surveys were undertaken from October 2019 to September 2021, from two fixed Vantage Point (VP) locations, (i.e. VP1 – VP2) (**See Appendix 1**). The locations of these VPs were strategically positioned to provide the maximum viewshed of the survey area from the minimum number of locations.
Five target species were recorded in flight within the study area during survey work. These include the following species Common Kestrel, Eurasian Sparrowhawk, European Golden Plover, Merlin and Peregrine Falcon.

One of the target species (i.e. European Golden Plover) recorded, were present during the winter surveys only and three (Eurasian Sparrowhawk, Peregrine Falcon and Merlin) were present during the summer surveys only, while the remaining species (Common Kestrel) were present throughout the year.

Two stages are involved in the model:

- **Stage 1:** This includes the estimation of the number of birds or flights passing through the wind turbines rotor blades swept air space. Two forms of collision risk modelling are considered when referencing the Band Model. These are referred to as the “Regular Flight Model” and the “Random Flight Model”. Transits are calculated in this assessment using the “Random Flight” model, due to the bird flight distribution and behaviour recorded.

- **Stage 2:** This includes the calculation of the probability of a bird strike occurring with rotor blades. The probability is calculated using a statistical spreadsheet which considers the turbine parameters and avian biometrics. This spreadsheet is publicly available on the SNH website (https://www.nature.scot/wind-farmimpacts-birds-calculating-probability-collision).

The results of Stage 1 and Stage 2 modelling gives a theoretical annual collision mortality rate and is based on the assumption that birds (i.e. target species) make no attempt to avoid colliding with the proposed turbines. Thus, an informal third stage is applied to the Stage 1 and Stage 2 results. The final stage of the assessment provides for a “real life” scenario, i.e. to account for the avoidance measures taken by each bird species, worked out as a percentage applied to the stage 1 and 2 results. Birds usually demonstrate high rates of avoidance (i.e. 95-99%) according to SNH (2018). This final stage as a result is typically the most important feature of collision risk modelling.

1.2 Proposed Development and Site Description

The proposed Firlough wind farm development is located at Carrowleagh (Kilbride), Ballina, Co. Mayo, approximately 11km north-east of Ballina. The proposed development site comprises of c. 446 hectares and lies adjacent to the Mayo-Sligo county border. The receiving environment for the proposed wind turbine locations is representative of peatland habitats and adjoining lands under active management for forestry and agriculture. The proposed development site is located in close proximity to other constructed windfarm developments (Carrowleagh Wind Farm and Black Lough Wind Farm).

The proposed wind farm design on which this CRM is based, is comprised of thirteen WTG turbines (Candidate Models: Siemens Gamesa SG 6.6 – 155, Nordex N149/5.X and Vestas V150). The Collision Risk Assessment (CRA) makes assumptions on the turbine specifications, such as rotor diameter and rotational speed. Because the final choice of turbine is not known at this stage, the worst-case scenario is assumed. The worst-case scenario is a combination of the maximum collision risk area (affected by hub height and rotor blade length), maximum number of turbines proposed and minimum turbine downtime (i.e. non-operational time) using the specifications of the candidate WTG turbines. Turbine specifications for the proposed Firlough Wind Farm development site used as per this CRM are shown below in **Table 1.1**.

Table 1.1: Wind turbine specification and Wind farm Parameters for Firlough Wind farm development.

Wind Farm Components/Turbine Parameters	
Technical Information and Wind Farm Component	**Data used/Scenario Modelled**
Turbine model	Siemens Gamesa SG 6.6 – 155
Number of turbines	13
Number of blades per turbine rotor	3
Rotor blade maximum chord (m) (i.e., depth of blade)	4.5m
Blade Length (m)	76m
Rotor Radius (m)	77.5m
Rotor Diameter (m)	155m
Circumference of blade tip (m) (Pi x Rotor Diameter)	486.7m
Swept area (m^2) (Pi x Rotor Radius^2)	18,859.6
Turbine height (m)	180m
Hub height (m)	102.5m
Swept height (m)	25-180m
Maximum height to blade tip (m)	180m
Minimum height to blade tip (m)	25m
Max Tip Speed (m/s)	0.724256m/s
Rotation speed (rpm)	11.2rpm
Rotation period (s) (i.e., seconds per rotation)	5.3571s
Turbine operation time*	85%
Mean pitch angle of the blade during normal operation (degrees)**	13°

* The European Wind Energy Association (2016) provides an average operation time of a turbine of between 70% and 85%. In following the precautionary principal approach this CRM uses the 85% figure.

** The pitch angle of the turbine blade is determined by wind speed, which is variable depending on several factors including, location, local topographic, landscape etc. To maintain a constant operating speed the pitch angle of the blade is altered. The pitch angle of the turbine blade is greater in higher wind speeds to “feather” the wind in order to control rotation speed. The figure of 13° used in this assessment is derived from specifications provided by the client which advocates an average pitch of between 6 – 13 degrees along the length of the turbine blade. In following the precautionary principal approach, the greater 13° figure has been adopted as part of this model.

1.3 Statement of Authority

David M. McGillycuddy holds a B.Sc. (Hons) in Wildlife Biology from MTU and is a qualified ecologist with over 6 years of experience in ecological research, teaching, and assessment. He is a member of the Chartered Institute of Ecology and Environmental Management (CIEEM) and has a strong background in experimental design and data analysis. David has managed a range of large-scale, multi-disciplinary ecological projects, including research and targeted management work for species of conservation concern. He is skilled in designing and delivering practical conservation actions with stakeholders and has a passion for educating and interpreting the interface between people and the environment.

David has extensive experience in developing co-ordinated, strategic plans for biodiversity, ensuring that ecological considerations are integrated into all aspects of planning and development. He has excellent communication and interpersonal skills, and is committed to providing high-quality, evidence-based advice and solutions to ecological challenges.

David is an ecologist with Veon Ltd. and Veon Ecology and is experienced in several key environmental projects and the production of ecological reports regarding Biodiversity Action Plans (BAP), Climate Action Plans (CAP), Invasive Species Management Plans (ISMP), Natura Impact Statement (NIS), Ecological Impact Assessment (EcIA), etc.

1.4 Data Sources

The following data and information were provided for this collision risk assessment:

- Data outlining all observations of flight activity recorded during the VP surveys.
- Mapping of the proposed turbine locations.
- Technical specifications for the proposed candidate WTG turbines.
- GIS mapping of flight lines recorded during the summers of 2020 and 2021 and winters of 2019/2020 and 2020/2021 VP surveys.
- Clarification regarding survey methodology.
- Mapping of the VP locations.

All of the survey data used in this assessment was provided externally by the client. Additional information, including technical details (e.g. turbine specifications) were also provided by the client.

1.5 Target Species

The key target species were selected in line with SNH (2017) guidance, thereby enabling VP surveys to focus on the species of greatest importance. In general target species are those species that are afforded a higher level of legislation protection and also includes species which are more likely to be subject to impact from wind farms, e.g., breeding and non-breeding species forming qualifying features for nearby SPAs or species listed on Annex I of the Birds Directive.

The following species recorded flights within the rotor swept height and inside the 2km arc of the selected vantage points during the VP surveys across 2019, 2020 and 2021:

- Common Kestrel (*Falco tinnunculus*)
- European Golden Plover (*Pluvialis apricaria*)
- Peregrine Falcon (*Falco peregrinus*)

Other species of conservation concern were recorded during the vantage point surveys but were excluded from consideration in the collision risk analysis due to the following reasons:

Eurasian Sparrowhawk (*Accipiter nisus*) were not recorded flying within the collision risk height band (20-180m). Thus, for this species, the collision risk can be assumed to be effectively zero excluding them from further consideration in the analysis.

Merlin (*Falco columbarius*) were also not recorded flying within the collision risk height band (20-180m). Thus, the collision risk for merlin can be assumed to be effectively zero excluding them from further consideration in the analysis.

1.6 Seasonal Definitions

For the species modelled (i.e. Common Kestrel, European Golden Plover and Peregrine Falcon), the CRM was constructed using data from the relevant breeding and non-breeding season periods, as defined by NatureScot in relation to Scotland and British Trust of Ornithology (BTO) which is also broadly applicable to Ireland.

The data used in this CRM was collected over a period of 24 months from October 2019 to September 2021 inclusive, thereby providing data for two breeding season cycles and two winter cycles for the target species. 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 1.2** 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 ensure that any potential underestimation or overestimation for a species risk of collision was minimised as much as possible.

Table 1.2: Seasonal divisions of relevant target species.

Species Name	Breeding season start	Breeding season end	Non-breeding season start	Non-breeding season end
Common Kestrel	April	August	September	March
Golden Plover	April	August	September	March
Peregrine Falcon	March	August	September	February

The number of hours that birds are potentially active during the day for the breeding and non-breeding season forms part of the CRM model. This is calculated as 15 hours per day for the summer survey period (i.e. the breeding season) and 10 hours per day for the winter survey period (i.e. the non-breeding season). These figures of activity are based on the average calculation of daylight minutes within the season of analysis and are likely to be over-estimated. These figures would be difficult to quantify in simple terms otherwise, although, the use of an over-estimation of species activity time increases the likelihood of a collision as birds are considered to be more active (i.e. increased flights) than if activity hours were reduced. This approach therefore offers an additional precaution in determining collision risk, and therefore a more robust estimation for collision risk assessment.

The hours that a species may potentially be active was calculated to include daylight, one hour before sunrise, and one hour after sunset (dusk) for all species with the exception of golden plover. For this 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.

1.7 Limitations and Constraints

There are a number of limitations and constraints associated with pre-planning ecological assessments for potential development sites, as well as constraints and limitations inherent to the collection and analysis of field-based ecological data. The field survey data evaluated as part of this Collision Risk Assessment was received from the client. The data comprised of the following:

- Bird flight data from timed Vantage Point surveys. This data consisted of flights within the rotor-swept height bands. The vantage point surveys recorded flight heights in five bands: 0-20 m; 20-50 m; 50-100 m; 100-180 m and > 180 m. The 20-50 m; 50-100 m; 100-180 m and > 180 m height bands have been taken to represent the flight activity within the potential collision risk height zone. Flight duration (in seconds) for all bird observations along with data relevant to each flight record (date, weather conditions, timing, VP number (location), etc.) were provided.
- Vantage Point survey effort data (i.e. hours of observations) on a monthly basis during the summer and winter seasons of 2019 - 2021 (October 2019 to September 2021 inclusive) for all VP survey work undertaken.
- Description and metrics for the wind farm as a whole as well as for individual turbine parameters.
- Area viewed from each vantage point.

This CRM relates specifically to the provided vantage point survey data which has not been independently validated by the author of this report. Any variation in the coverage of the vantage points surveyed during fieldwork, flight data, layout of the wind farm/turbine locations as well as the individual turbine specifications would require the outputs from this CRM to be amended.

For field-based surveys, the availability of suitable weather conditions is important with good visibility and little wind or rain. The flight data used as part of this CRM was collected during optimal weather conditions, as determined by Best Practice guidance. As a result, this required the re-arrangement of monthly schedules in some circumstances, with certain VPs being additionally surveyed in one month to compensate for months when no survey work took place. These alterations in survey schedules are indicated within the data provided. It should be noted that these scheduling re-arrangements are still in line with Best Practice guidelines which requires a minimum coverage or two years of data. The requirement in the SNH (2017) guidance is for 36 hours of VP survey effort per season. For a single species, this is equivalent to 72 hours of VP survey effort per year.

There were a small number of flights for which the number of birds, or duration of flight, were not recorded. Where the number of birds was not recorded, it is assumed that the flight referred to a single bird. Where the duration was not recorded, the mean flight duration for that species was used (in the relevant season, if there was sufficient data, or across the entire dataset).

Section 2: ASSESSMENT AND METHODOLOGY

In regard to the Band Model, two forms of collision risk modelling are typically considered. These are generally referred to as the "Regular Flight Model" and the "Random Flight Model". The "Regular Flight Model" is generally applied to flightlines which comprise of a more regular pattern such as a commuting corridor between feeding grounds, migratory routes and roosting sites. As a result, the "Regular Flight Model" is typically more relevant for aquatic bird species, particularly swans and geese. The alternative "Random Flight Model" is more relevant for species and scenarios whereby no apparent flight routes or patterns can be associated with a species within the survey area. Thus, Random flights is most prevalent when investigating hunting or foraging flight behaviour.

Collision Risk Modelling (CRM) adopts a mathematical approach to determining the probability of a bird species colliding with wind turbine rotors at a pre-defined site and is described in detail by Band *et al*. (2007) and Scottish Natural Heritage (SNH, 2000), with additional supporting information provided by Scottish Natural Heritage (SNH, 2018).

This report is based upon field data collected at the Firlough wind farm development, located at Carrowleagh (Kilbride), Ballina, Co. Mayo, approximately 11km north-east of Ballina. The proposed development site comprises of c. 446 hectares and lies adjacent to the Mayo-Sligo county border. The receiving environment for the proposed wind turbine locations is representative of peatland habitats and adjoining lands under active management for forestry and agriculture.

The resulting output from the model indicates the number of birds likely to collide with rotors of all 13 turbines within the proposed wind farm development per year of operation of the overall wind farm as a whole. The inverse of this (i.e. the number of years over which a single fatality would be likely) is additionally calculated.

The "**Random Flight Model**" examines the predicted number of transits through the windfarm site with regard to all flights recorded within the viewshed (i.e. a 2km arc of the vantage point) as randomly occurring. The random flight model therefore assumes that any observed flight could occur both within and outside of the wind farm site with equal likelihood. The viewshed of a given VP should extend to a distance no greater than 2km and include an arc of no greater than 180 degrees, as per the SNH (2017) guidelines. Any flights recorded within the rotor swept height and inside the 2km arc of the vantage point are included in the model.

The Random Flight Model has a number of limitations and assumptions.

- Both habitat and bird activity will remain the same over time and be unchanged during the operational stage of the proposed windfarm development.

- Bird activity is not spatially explicit, i.e. bird activity is equal throughout the viewshed area and this is equal to activity in the proposed windfarm development area.

- All flight activity used in the model occurred within the viewshed area calculated at the lowest swept rotor height. (e.g. if the lowest swept height of the turbine blade is 20m, the viewshed coverage displaying the visibility of the area within the 2km arc at a height of 20m above ground level is used). All flights are assumed to have occurred within this visible area, although many are likely to have been above this. The calculation for survey area visible (AVP) from each VP in the model is therefore highly precautionary as it is likely to have been a larger area of coverage for much of the flight activity.

The “**Regular Flight Model**” examines the predicted number of transits through a cross-sectional area of the windfarm which represents the width of the commuting corridor. A “risk window” comprises of a 2-dimesional line which represents the width of the windfarm in addition to a 500m buffer for each of the turbines, multiplied by the rotor diameter. All flights which pass through the identified risk window, within the swept height of the turbines, are included in the collision risk modelling. Any regular flights more than 500m from the turbine layout can be excluded from analysis.

The Regular Flight Model has a number of limitations and assumptions.

- Firstly, that the turbine rotor swept area is 2-dimensional, i.e. there is a single row of turbines in the windfarm. This represents all turbines within the commuting corridor accounted for by a single straight-line.
- It is assumed that bird activity is spatially explicit.
- Birds in an observed flight only cross the turbine area once and do not pass through the cross-section a second time (or multiple times).

Further details regarding both the Random and Regular Flight Model calculations are available on the SNH website. https://www.nature.scot/wind-farm-impacts-birds-calculating-theoreticalcollision-risk-assuming-no-avoiding-action.

The data used as part of the model, such as the number, size, dimensions and likely functioning of the proposed turbines for the Firlough Wind Farm Development Site (See **Table 1.1**) forms part of the calculations, along with the available bird biometric data (See **Table 3.2**). These values are modelled with the standardised field data collected using Best Practice methods on surveying birds flight activity within the proposed Firlough Wind Farm Development Site.

The data is collectively modelled to predict the number of bird flights through the rotors of all turbines within the site on an annual basis (CRM Stage 1) as well as the probability that a bird flying through the turbine will collide with the rotors (CRM Stage 2). The product of the numerical output from these two stages of assessment then predicts the number of birds likely to collide with the rotors of the turbines if no avoiding action is taken. This value is then corrected using the available avoidance rates (CRM Stage 3), to give a final indication of collision risk (number of bird colliding with the turbine rotors per annum).

The steps used to derive the collision risk for birds observed at the proposed development according to the Band Model are summarised below:

- Stage 1 (Band model): this model uses observations of birds flying through the study area during vantage point surveys to calculate the number of birds estimated to fly through the proposed turbines blade swept areas.
- Stage 2 (Band model): this model calculates the collision risk for an individual bird flying through a rotating turbine blade. The collision risk depends on the flight behaviour and biometrics.
- The result of the number of birds calculated to fly through the turbines annually is then multiplied by the collision risk probability. This calculation gives the worst-case scenario and assumes that birds flying through the site make no attempt to avoid turbines.
- Stage 3: An avoidance factor is applied to the result of the collision risk model to account for avoidance of the turbine rotors by bird species. Avoidance rates are available from SNH online bird collision risk guidance (SNH 2018). This avoidance rate corrects for the ability of the birds to detect and move around the turbines. This final output after all steps of modelling is a real-world estimation of the number of collisions that may occur at the proposed wind farm based on observed bird activity during the survey periods.

Several assumptions were made in the calculation of collision risk for the proposed Firlough Wind Farm Development. These assumptions are tailored specifically to Firlough Wind Farm Development and are as follows:

- Birds in flight within the study area at heights greater than 20m above ground level are assumed to be in danger of collision with the rotating turbine blades.

- No preference was taken for birds using gliding or flapping flight through the study area for target species as they exhibit both behaviours. In the calculation of the percentage risk of collision for a bird flying through a rotating turbine, the mean of the worst-case scenario (i.e. a bird flying upwind through a turbine using flapping flight whilst the turbine is at its fastest rotation speed) and the best-case scenario (i.e. a bird flying downwind through a rotating turbine using a gliding flight whilst the turbine at its slowest rotation speed) has been used for birds which exhibit both flapping and gliding flight. However, for Golden Plover (*Pluvialis apricaria*) only the mean calculations for flapping flights were used.

The Collision Risk Assessment (CRA) also makes assumptions on the turbine specifications, such as rotor diameter and rotational speed. Because the final choice of turbine will not be known until a later stage in the planning process, the worst-case scenario is assumed. The worst-case scenario is a combination of the maximum collision risk area (i.e. swept area determined by hub height and rotor blade length), maximum number of turbines proposed and turbine operational time. The turbine and wind farm characteristics for the purposes of this assessment at the proposed Firlough Wind Farm Development Site are presented in **Table 1.1**.

2.1 Determination of Bird Flights Through the Rotor Swept Area

Stage 1 of the CRM determines the number of transits through the rotors for a given period or season. For the calculations below, this is expressed as the number of birds flying through the rotors per season (Breeding and Non-breeding).

Flight data was recorded at fixed vantage point locations from October 2019 to September 2021 inclusive and the data was provided to Veon Ecology to undertake the Collision Risk modelling for the relevant target species. A potential collision risk height (PCH) of between 20m and 180m above ground was established based on the proposed turbines having a maximum blade tip height of 180m, and a rotor diameter of 155m. This ensured that the PCH was within the rotor sweep of the turbine but also, slightly overestimates the risk of collision as it greater than the actual turbine swept area. The flight height of species was classified into height bands (HB) as follows: HB1 = 0-20m, HB2 = 20-50m, HB3 = 50-100m, HB4 = 100-180m, HB5 = 180m+. Behavioural observations were also recorded with the minimum requirement of 36 hours per VP per season (breeding and non-breeding) and 72 hours of VP survey effort per year achieved.

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 area. 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 this CRM.

In the case of birds observed during surveys for the proposed Firlough Wind Farm Development, flights recorded from surveys were classified for the purpose of the analysis as “randomly” distributed flights which could occur anywhere within the given viewsheds. 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. Therefore the “Random Flight Model” was applied for each target species to calculate the predicted number of transits through the proposed wind farm site.

The proportion of flight time between 20 and 180+m 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 Golden Plover. For this 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.

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 wind farm. The Stage 1 calculation was carried out for each season (i.e. breeding and wintering) for each species.

2.2 Probability of Collision of Birds Passing Through the Rotor Swept Area

The probability of a birds flying through the rotors and colliding with the turbine blades is determined in Stage 2 of the CRM. The probability of a collision depends on the species biometrics including size (both length and wingspan) and average flight speed. In order to simplify the calculations for this CRM, all birds are assumed to be of simple cruciform shape, with the wings half-way down the length of the body. Characteristics of the turbine and rotor blades are also required as part of the calculations, including the pitch and width of the turbine rotor blades and the rotation speed of the proposed turbines. For Stage 2 of the CRM, the turbine rotor blades are assumed to have no thickness, although the blade depth is considered in Stage 1 of the model.

The risk of a bird colliding with the turbine rotor blades changes depending upon whether the bird passes through the rotor swept area towards the tip of the blade (where the blades are only present for a small proportion of the time, having a short chord width and a faster rotational time) or next to the turbine hub (where the blades have a wider chord width, occupy a larger volume of airspace and are travelling at slower speeds). Towards the blade tips, it is the length of the bird that offers greater contribution to the determination of the risk of collision. Closer to the turbine hub, the wingspan of the bird compared to the physical distance between the blades is the controlling factor. The bird is assumed to enter the rotor swept area at random anywhere along the disc.

The calculations determine the collision risk at several locations along the length of the rotor blade (in intervals of 0.05R, where R is the radius of the rotor swept area) using numerical integration of various elements in relation to the rotors (notably angular velocity of the blade and chord width) and the bird (such as the point at which the bird enters the rotor along the radius and the flight speed of the bird). These are calculated for both downwind and up-wind flights and averaged to give a probability of collision per season, assuming no avoiding action is taken.

The calculations are performed in the SNH collision risk model, where the relevant data on the turbines and bird biometrics are entered into the model, and the model estimates the probability of a collision when a bird flies through the rotor area. This calculation is based solely upon the behaviour and biometrics of the bird and the specifications of the turbines proposed at the Firlough site.

For the Firlough Wind Farm development site, the average probability of each species passing through the wind farm and colliding with the rotors if it takes no avoiding action is presented in **Table 3.4**.

Section 3: RESULTS

The Collison risks were calculated using flight data recorded during vantage point watches at two fixed vantage point locations (VP1-VP2) within the study area between October 2019 to September 2021. The target species recorded within the potential collision risk zone included Common Kestrel (*Falco tinnunculus*), European Golden Plover (*Pluvialis apricaria*), and Peregrine Falcon (*Falco peregrinus*).

The calculation parameters are outlined in **Tables 3.1, 3.2** and **Table 3.3**. A worked example of the calculation of collision risk for Kestrel is available in **Appendix 5**. **Table 3.1** below presents the details on the viewshed area for each VP.

Table 3.1: Summary of CRM parameters for VPS at Firlough Wind Farm.

Vantage Point	VP Arc (ha)	Viewshed area within VP Arc (ha)	Viewshed Coverage (%)	Turbine Buffer Area Within Viewshed (ha)	No. of Turbines Within Viewshed	Total Survey Effort (hrs)
VP 1	628	424.5	67.60	276.15	7	144
VP 2	628	556.5	88.61	424.10	11	144

Species-specific morphometric measurements, flight speeds and avoidance rates are shown in **Table 3.2.** The amount of time a species was observed flying at heights of between 20 - 180+ metres, i.e. within the Potential Collision Height (PCH), is presented in **Table 3.3** below. Birds in flight within the study area at heights between 20m and 180+m are assumed to be in danger of collision with the rotating turbine blades. This is a precautionary approach as the lower extent of the swept area of the turbine blades will be greater than 20m and the higher extent of the swept area will be less than 185m.

Table 3.2: Avian Biometric Data and Avoidance Rates.

Avian Biometric Data and Avoidance Rates				
Species Name	Length (m)	Wingspan (m)	Mean flight speed (m/s)	Avoidance rates (%)
Common Kestrel (*Falco tinnunculus*)	0.34	0.76	10.1	95
European Golden Plover (*Pluvialis apricaria*)	0.275	0.715	17.9	98
Peregrine Falcon (*Falco peregrinus*)	0.42	1.02	12.1	98

Table 3.3: Bird biometrics and bird-seconds spent by species at Potential Collision Height (20-180+m).

Seconds spent at PCH (2019-2021)							
Species Name (BTO Code)	Seconds in flight at PCH (20-180+m)						Total secs at PCH over 24 Months
	2019/2020			2020/2021			
	Winter	Summer	Total	Winter	Summer	Total	
Kestrel (K.)	210	180	390	180	210	390	780
Golden Plover (GP)	1,800	0	1,800	2,760	0	2,760	4,560
Peregrine (PE)	0	0	0	0	120	120	120

Table 3.4: Number of collisions predicted for target species without the application of avoidance rates.

Species	Year	Predicted collisions per season without avoidance rates applied		
		Non-Breeding	Breeding	Total
Common Kestrel	2019/20	0.94	1.00	1.94
	2020/21	1.01	1.00	2.01
European Golden Plover	2019/20	15.14	0.00	15.14
	2020/21	17.80	0.00	17.80
Peregrine	2019/20	0.00	0.00	0.00
	2020/21	0.66	0.00	0.66

Table 3.5: Number of collisions predicted for target species with the application of avoidance rates.

Species	Year	Predicted collisions per season with avoidance rates applied			Predicted collisions over 30-year lifetime of the windfarm		
		Non-Breeding	Breeding	Total	Non-Breeding	Breeding	Total
Common Kestrel	2019/20	0.009	0.010	0.019	0.283	0.300	0.583
	2020/21	0.010	0.010	0.020	0.303	0.300	0.603
European Golden Plover	2019/20	0.151	0.000	0.151	4.541	0.000	4.541
	2020/21	0.178	0.000	0.178	5.340	0.000	5.340
Peregrine	2019/20	0.000	0.000	0.000	0.000	0.000	0.000
	2020/21	0.007	0.000	0.007	0.199	0.000	0.199

Table 3.6: Mean number of collisions predicted for target species with avoidance rates.

Target Species number of collisions predicted			
Species Name	Mean no. of predicted collisions per year	Mean no. of predicted collisions per 30 years	Equivalent to 1 bird every x (years)
Kestrel (K.)	0.020	0.593	50.59
Golden Plover (GP)	0.165	4.941	6.07
Peregrine (PE)	0.004	0.010	3000

Section 4: CONCLUSION

This CRM has been completed for the proposed Firlough Wind Farm development. The VP survey data used for this CRM was collected over two summer surveys (breeding seasons) and two winter surveys (non-breeding seasons), which meets the requirements of current SNH guidelines.

There are a number of potential sources of uncertainty/error that apply to all CRM analyses. The main potential source of error is the accuracy of the surveys and flight activity data, which will affect the accuracy of the predicted transit rate, and the simplification involved in the calculations of collision probabilities. The Band method used for this collision risk model is developed using several assumptions, particularly regarding bird characteristics and behaviour, and relies on the accuracy of the available information regarding species avoidance rates, turbine specifications, and survey data. As a result of these limitations and assumptions in relation to the CRM, the predicted collision risk should be considered only an indication of the potential collision risk significance for each target species.

The output of the first two stages of the model presents the number of predicted bird collisions with the proposed wind turbines per annum. This is the result of the number of bird transits through the rotor occupied space per season and the probability of a bird passing through the rotor swept area colliding with the turbine blades.

In the present assessment, the predicted collision risks are very low for all the target species, with only Golden Plover, being predicted to have any collisions within the nominal 30 year. Thus, the only species that are likely to have significant levels of collisions are European Golden Plover (*Pluvialis apricaria*). It is clear from the VP surveys that there is a relatively low amount of bird activity in the area. During the non-breeding (wintering) seasons much of the Golden Plover flight activity is seemingly at the Potential Collision Height (i.e. 20-180m).

Kestrel, a year-round resident of the area, has a prediction of one collisions every 50+ years'. However, this value is also liable to be rather tenuous as a large percentage of recorded kestrel flight activity likely involved hovering birds which suggests that the mean kestrel flight speed used in this CRM (i.e. 10.1 m/s) will not be a true indication of the mean flight speed of the kestrels observed during the surveys. Kestrels fly relatively quickly between hovering spots which may lead to an underestimation of their speed resulting in a greater predicted risk of collision than would likely occur in "real-life" scenarios.

It is most notably the flocking species of Golden Plover which are at the greatest potential risk of impact. With 4.9 collisions predicted every 30 years, Golden Plover is by far the species with the highest predicted collision risk output (See **Table 3.6**). However, as the Golden Plover recorded are part of a wintering population, a single all-year CRM is likely to overestimate the collision risk of the species. The main activity area for Golden Plover lies within the viewsheds for VP 1 and 2, however, the entire turbine envelope does not occur within these viewsheds. The mean flock size recorded across the 2019/20 and 2020/21 winter seasons was of c. 10 individuals (a total of 4 observations comprising 41 individuals in total, with the peak flock size of 21 birds recorded in March 2021). It should be noted that the amount of time at collision risk height has been derived as a product of flight duration and the number of individuals in the flock. Furthermore, given the apparent random nature of golden plover flights, all of those observed within each viewshed (1 and 2) at collision risk height have been included in the CRM, including flights "out" of the collision-risk area. As such, the results of the CRM are likely to over-estimate the theoretical collision risk for Golden Plover.

In conclusion and with regard to the limitations and assumptions presented by collision risk modelling, the resulting predicted collisions should only be considered an indication and not a definitive result. Thus, the outputs of the collision risk modelling should be used solely as a comparative tool rather than an accurate indicator of bird mortality risk. Therefore, it is advised to interpret the results of CRM analyses as indicating only the order of magnitude of the predicted collision risk for given target species.

Section 5: REFERENCES

Alerstam, T., Rosén, M., Bäckman, J., Ericson, P.G. & Hellgren, O. (2007). Flight speeds among bird species: allometric and phylogenetic effects.

Band, W., Madders, M. and Whitfield, D.P. (2007). Developing field and analytical methods to assess avian collision risk at wind farms. In: Birds and wind power: risk assessment and mitigation. M. DeLucas, G.F.E. Janss and M. Ferrer, Eds.: 259-275.

Chamberlain, D.E., Rehfisch, M.R., Fox, A.D., Desholm, M., Anthony, S.J. 2006. The effect of avoidance rates on bird mortality predictions made by wind turbine collision risk models.

Cramp, S. (1993) Handbook of the Birds of the Western Palaearctic. Oxford University Press, Oxford.

Drewitt, A. & Langston, R. (2006). Assessing the impacts of wind farms on birds.

European Wind Energy Association. 2020. Wind energy's frequently asked questions (FAQ). EWEA, Brussels.

IWEA (Irish Wind Energy Association). 2012. Best Practice Guidelines for the Irish Wind Energy Industry. IWEA, Co. Kildare.

Madders, M. & Whitfield, P.D. (2006). Upland Raptors and the Assessment of Wind Farm Impacts.

Robinson, R.A. 2005. BirdFacts: profiles of birds occurring in Britain & Ireland. BTO, Thetford (Available at http://www.bto.org/birdfacts).

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 93. National Parks and Wildlife Service, Department of the Arts, Heritage and the Gaeltacht, Ireland.

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.

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-farmcollision-risk-model.

timeanddate.com Sunrise, Sunset, and Daylength. Available at: https://www.timeanddate.com

Wilson, M. W., Irwin, S., Norriss, D. W., Newton, S. F., Collins, K., Kelly, T. C. & O'Halloran, J. 2009. The importance of pre-thicket conifer plantations for nesting Hen Harriers Circus cyaneus in Ireland.

Wilson, M. W., Irwin, S., O'Donoghue, B., Kelly, T. C. & O'Halloran, J. 2010. The use of forested landscapes by Hen Harriers in Ireland. COFORD Connects. Environment No. 10.

Section 6: APPENDICES

Appendix 1. FIGURES AND MAPS

Figure 6.1: Site location and redline boundary indicating the area proposed for turbines.

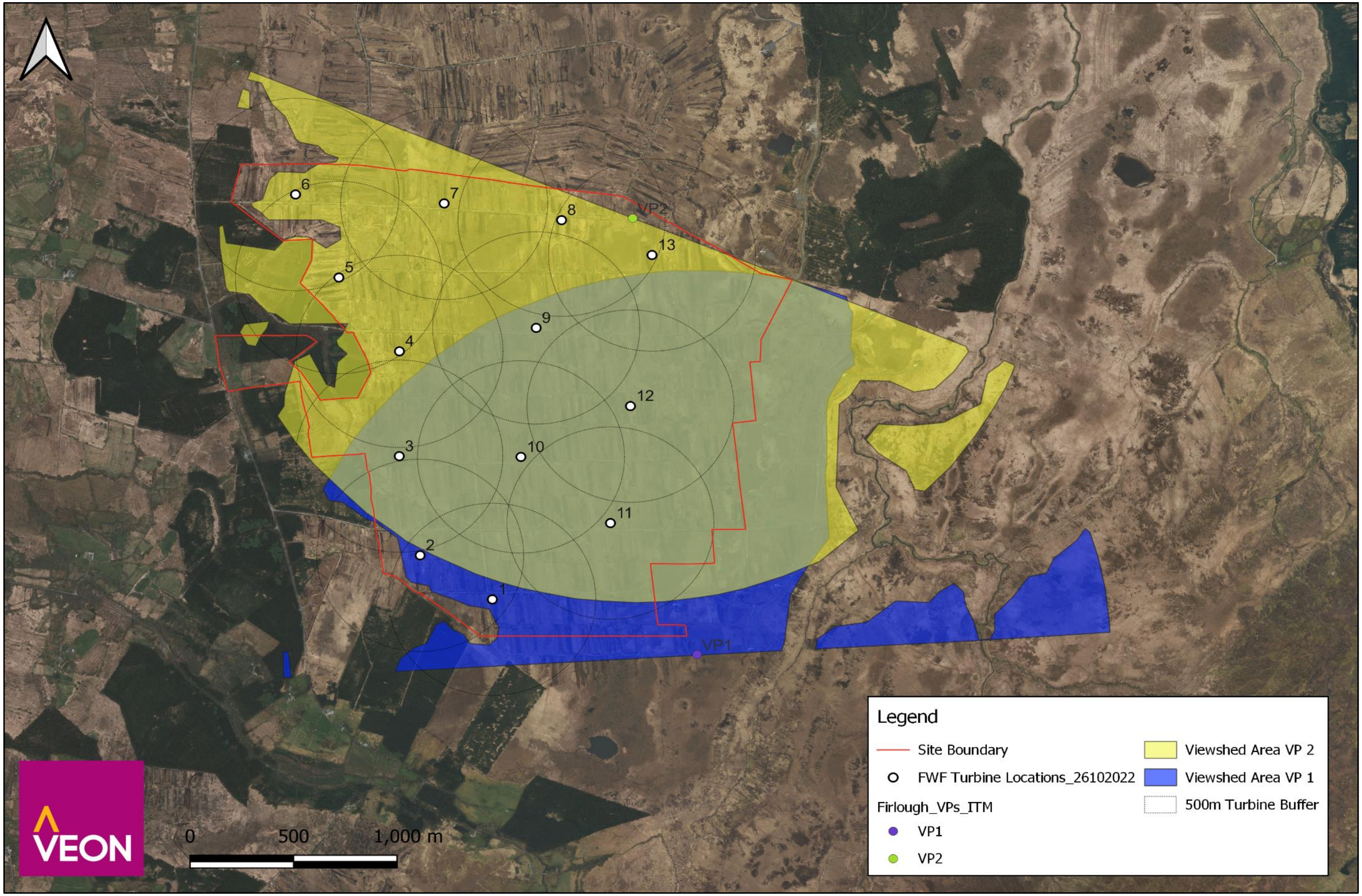

Figure 6.2: Vantage Point locations and viewshed map.

Appendix 2. VANTAGE POINT SURVEY EFFORT

VANTAGE POINT SURVEY EFFORT (HOURS) FOR WINTER 2019-2020

Table 6.1: Firlough VP data (VP1-2) survey effort Winter 2019-2020.

Survey Effort Data (Winter 2019-2020 October-March)							
Vantage Point	October	November	December	January	February	March	Total Hours
VP 1	6	6	6	6	6	6	36
VP 2	6	6	6	6	6	6	36
Total	12	12	12	12	12	12	72

VANTAGE POINT SURVEY EFFORT (HOURS) FOR SUMMER 2020

Table 6.2: Firlough VP data (VP1-2) survey effort Summer 2020.

Survey Effort Data (Summer 2020 April-September)							
Vantage Point	April	May	June	July	August	September	Total Hours
VP 1	6	6	6	6	6	6	36
VP 2	6	6	6	6	6	6	36
Total	12	12	12	12	12	12	72

VANTAGE POINT SURVEY EFFORT (HOURS) FOR WINTER 2020-2021

Table 6.3: Firlough VP data (VP1-2) survey effort Winter 2020-2021.

Survey Effort Data (Winter 2019-2020 October-March)							
Vantage Point	October	November	December	January	February	March	Total Hours
VP 1	6	6	6	6	6	6	36
VP 2	6	6	6	6	6	6	36
Total	12	12	12	12	12	12	72

VANTAGE POINT SURVEY EFFORT (HOURS) FOR SUMMER 2021

Table 6.4: Firlough VP data (VP1-2) survey effort Summer 2021.

Survey Effort Data (Summer 2020 April-September)							
Vantage Point	April	May	June	July	August	September	Total Hours
VP 1	6	6	6	6	6	6	36
VP 2	6	6	6	6	6	6	36
Total	12	12	12	12	12	12	72

Table 6.5: Firlough VP data (VP1-2) survey effort overview.

Vantage point survey effort (VP 1-2)			
Survey Dataset	**Months**	**Effort/Month**	**Total hours per VP**
Winter 2019 - 2020	October-March	6 hours	36
Summer 2020	April-September	6 hours	36
Winter 2020 - 2021	October-March	6 hours	36
Summer 2021	April-September	6 hours	36

Table 6.6: All species seconds spent at Potential Collision Height (20-180+m) (VP 1-2).

Seconds spent at PCH (2019-2021)							
Species Name (BTO Code)	**Seconds in flight at PCH (20-180+m)**						**Total secs at PCH over 24 Months**
	2019/2020			**2020/2021**			
	Winter	**Summer**	**Total**	**Winter**	**Summer**	**Total**	
Kestrel (K.)	210	180	390	180	210	390	780
Golden Plover (GP)	1,800	0	1,800	2,760	0	2,760	4,560
Peregrine (PE)	0	0	0	0	120	120	120
Merlin (ML)	0	0	0	0	0	0	0
Sparrowhawk (SH)	0	0	0	0	0	0	0

Table 6.7: VP data (VP1-2) Survey Effort and Viewshed Coverage.

Vantage Point	VP Arc (ha)	Viewshed area within VP Arc (ha)	Viewshed Coverage (%)	Turbine Buffer Area Within Viewshed (ha)	No. of Turbines Within Viewshed	Total Survey Effort (hrs)
VP 1	628	424.5	67.60	276.15	7	144
VP 2	628	556.5	88.61	424.10	11	144

Summary of vantage point (VP) watch variables, October 2019 to September 2021

Table 6.8: Summary of vantage point (VP) - Survey Details.

Date	Season	VP no.	Duration (hrs)	Start Time	Weather conditions
	Winter no. 1				
26/10/2019	Winter	2	3	11.00	Dry, Good visibility, NW F4
26/10/2019	Winter	1	3	15.00	Dry, Good visibility, NW F3
27/10/2019	Winter	2	3	08.30	Showers, Good visibility, W F2
27/10/2019	Winter	1	3	13.00	Showers, Good visibility, W F3
26/11/2019	Winter	1	3	09.30	Dry, Good visibility, NW wind, F2
26/11/2019	Winter	2	3	13.30	Dry, Good visibility, NW wind, F2
27/11/2019	Winter	1	3	08:00	Dry, Good visibility, W wind, F3
27/11/2019	Winter	2	3	12:30	Dry, Good visibility, W wind, F2
15/12/2019	Winter	2	3	09.15	Dry, Good visibility, W wind, F3
15/12/2019	Winter	1	3	13:30	Dry, Good visibility, W wind, F3
16/12/2019	Winter	1	3	08:30	Squalls, Good visibility, SW wind, F4
16/12/2019	Winter	2	3	12:30	Dry, Good visibility, SW wind, F3
20/01/2020	Winter	1	3	09:30	Dry, Good visibility, W wind, F3
20/01/2020	Winter	2	3	13:15	Dry, Good visibility, W wind, F3
21/01/2020	Winter	1	3	08:20	Squalls, Mod-Good visibility, NW wind, F3
21/01/2020	Winter	2	3	12:30	Squalls, Good visibility, NW wind, F3
16/02/2020	Winter	1	3	07:30	Dry, Good visibility, SW wind, F3
16/02/2020	Winter	2	3	12:00	Dry, Good visibility, SW wind, F2
18/02/2020	Winter	2	3	10:00	Dry, Good visibility, NW wind, F2
18/02/2020	Winter	1	3	14:00	Showers, Good visibility, NW wind, F3
14/03/2020	Winter	2	3	10:00	Dry, Good visibility, NW wind, F3
14/03/2020	Winter	1	3	13:00	Dry, Good visibility, NW wind, F3
15/03/2020	Winter	2	3	07:00	Dry, Good visibility, W wind, F2
15/03/2020	Winter	1	3	11:00	Dry, Good visibility, W wind, F2
	Summer no.1				
16/04/2020	Summer	1	3	09:45	Dry, Good visibility, S wind, F2
16/04/2020	Summer	2	3	13:00	Dry, Good visibility, S wind, F2
17/04/2020	Summer	1	3	07:15	Squalls, Good visibility, SW wind, F3
12/04/2020	Summer	2	3	12:00	Squalls, Good visibility, SW wind, F3
23/05/2020	Summer	1	3	15:30	Squall, Good visibility, SW wind, F4
24/05/2020	Summer	2	3	06.00	Dry, Good visibility, SW wind, F2
24/05/2020	Summer	1	3	09:45	Drizzle, Mod-good visibility, SW wind, F3
24/05/2020	Summer	2	3	13.00	Squalls, Good visibility, SW wind, F2-3
15/06/2020	Summer	1	3	12.15	Dry, Good visibility, S wind, F1
15/06/2020	Summer	2	3	16.00	Showers, Good visibility, SW-W wind, F2

Date	Season	VP no.	Duration (hrs)	Start Time	Weather conditions
16/06/2020	Summer	2	3	06:00	Dry, Good visibility, N wind, F3
16/06/2020	Summer	1	3	10:00	Dry, Good visibility, N wind, F3
24/07/2020	Summer	1	3	14:00	Showers, Good visibility, SE wind, F4
24/07/2020	Summer	2	3	17:30	Rain, Mod. visibility, SE wind, F3-4
25/07/2020	Summer	2	3	06:00	Mist clearing, Mod-good visibility, WSW wind, F2
25/07/2020	Summer	1	3	10:00	Showers, Good visibility, W wind, F2-3
19/08/2020	Summer	1	3	14:00	Dry, Good visibility, SE wind, F3
19/08/2020	Summer	2	3	17:30	Dry, Good visibility, ESE wind, F2
20/08/2020	Summer	2	3	06:50	Rain, Mod visibility, SW wind, F4+
20/08/2020	Summer	1	3	11:00	Showers, Good visibility, SW wind, F4
28/09/2020	Summer	1	3	11:40	Dry, Good visibility, SW wind, F2-3
28/09/2020	Summer	2	3	16:00	Dry, Good visibility, SW wind, F2
29/09/2020	Summer	1	3	05:40	Dry, Good visibility, SW wind, F3
29/09/2020	Summer	2	3	09:30	Dry, Good visibility, SW wind, F3-4
31/10/2020	Winter	1	3	11:20	Squalls, Mod.-good visibility, SW wind, F4+
31/10/2020	Winter	2	3	15:00	Dry, Good visibility, SW wind, F3-4
01/11/2020	Winter	1	3	07:10	Squalls, Good visibility, SW wind, F3-4
01/11/2020	Winter	2	3	11:00	Squalls, Good visibility, SW wind, F4
23/11/2020	Winter	2	3	10:00	Squalls, Mod-good visibility, SW wind, F4
23/11/2020	Winter	1	3	14:00	Squalls, Mod-good visibility, SW wind, F4
24/11/2020	Winter	2	3	07:30	Showers, Mod visibility, SW wind, F3
24/11/2020	Winter	1	3	11:30	Showers, Good visibility, SW wind, F3
	Winter no. 2				
30/12/2020	Winter	2	3	09:15	Dry, Good visibility, NW wind, F3
30/12/2020	Winter	1	3	13:00	Dry, Good visibility, NW wind, F3-4
31/12/2020	Winter	2	3	08:30	Dry, Good visibility, NW wind, F2
31/12/2020	Winter	1	3	12:15	Dry, Good visibility, NW wind, F2
29/01/2021	Winter	2	3	10:00	Drizzle, Mod visibility, SW wind, F2-3
29/01/2021	Winter	1	3	14:10	Drizzle, Mod visibility, SW wind, F2-3
30/01/2021	Winter	2	3	07:50	Drizzle, Mod visibility, NE wind, F4+
30/01/2021	Winter	1	3	12:00	Squalls, Mod visibility, NE wind, F4+
27/02/2021	Winter	1	3	13:00	Dry, Good visibility, WSW wind, F2
27/02/2021	Winter	2	3	16:00	Dry, Good visibility, SW wind, F1
28/02/2021	Winter	2	3	07:00	Dry, Good visibility, SW wind, F2
28/02/2021	Winter	1	3	12:00	Dry, Good visibility, SW wind, F2
22/03/2021	Winter	1	3	12:00	Occ shower, Good visibility, SW wind, F4
22/03/2021	Winter	2	3	15:45	Dry, Good visibility, SW wind, F4
23/03/2021	Winter	2	3	06:00	Showers, Good visibility, SW wind, F4

Date	Season	VP no.	Duration (hrs)	Start Time	Weather conditions
23/03/2021	Winter	1	3	10:00	Showers, Good visibility, SW wind, F4
	Summer no. 2				
27/04/2021	Summer	1	3	12:00	Showers, Good visibility, N wind, F
27/04/2021	Summer	2	3	16:00	Occ showers, Good visibility, N wind, F4
28/04/2021	Summer	2	3	05:30	Dry, Good visibility, NE wind, F3
28/04/2021	Summer	1	3	10:00	Dry, Good visibility, NE wind, F3
24/05/2021	Summer	1	3	12:30	Dry, Good visibility, NW wind, F3-4
24/05/2021	Summer	2	3	16:30	Dry, Good visibility, NW wind, F4
25/05/2021	Summer	2	3	06:00	Dry, Good visibility, W wind, F2
25/05/2021	Summer	1	3	10:00	Dry, Good visibility, W wind, F2
20/06/2021	Summer	1	3	12.00	Dry, Good visibility, NE F4
20/06/2021	Summer	2	3	15.45	Dry, Good visibility, NE F3-4
21/06/2021	Summer	1	3	06.00	Dry, Good visibility, NE F3
21/06/2021	Summer	2	3	10.0-	Dry, Good visibility, NE F4
26/07/2021	Summer	2	3	11.00	Mist clearing, dry, Good visibility, NE F2
26/07/2021	Summer	1	3	15.00	Dry, Good visibility, NE F2
27/07/2021	Summer	2	3	06.30	Dry, Good visibility, NE F2
27/07/2021	Summer	1	3	11.00	Dry, Good visibility, NE F3
28/08/2021	Summer	1	3	12.00	Dry, Good visibility, NW F3
28/08/2021	Summer	2	3	16.00	Dry, Good visibility, NW F2
29/08/2021	Summer	2	3	05.45	Dry, Good visibility, N F1
29/08/2021	Summer	1	3	10.00	Dry, Good visibility, N F1
22/09/2021	Summer	2	3	11.00	Dry, Good visibility, SW F2
22/09/2021	Summer	1	3	15.20	Dry, Good visibility, SW F1-2
23/09/2021	Summer	1	3	07.30	Dry, Good visibility, SW F3
23/09/2021	Summer	2	3	12.00	Dry, Good visibility, SW F3

Appendix 3. VANTAGE POINT BIRD FLIGHTLINE DATA

Table 6.9: Bird Flightline Data 2019-2021.

VP no.	Date	Map note / Flightline No.	Common Name	Species Quantity	Time of Obs.	Total Duration (s)	0-20 m (s)	20-50 m (s)	50-100 m (s)	100-180 m (s)	>180 m (s)	Comment
1	27/10/2019	1	Kestrel	1	13:56	180	30	60	90	-	-	Male hunting moving along close to forest edge
1	13/02/2020	2	Golden plover	12	16.04	150	0	0	0	40	110	Tight flock flying fast and high (towards adjoining wind farm)
2	14/03/2020	3	Kestrel	1	11.11	90	30	60	0	0	0	Hunting low and active – appear to drop to ground
2	24/05/2020	4	Kestrel	1	09.10	45	45	0	0	0	0	Male flying low & over forest
2	19/08/2020	5	Kestrel	1	18.19	180	0	140	40	0	0	Flew in and hunting – female
2	31/12/2020	6	Golden plover	6	09:19	60	0	0	0	0	60	Very high
1	29/01/2021	7	Golden plover	2	14.52	45	0	0	0	45	0	Over edge of site
1	28/02/2021	8	Kestrel	1	14.40	240	60	180	0	0	0	Hovering low - male
2	22/03/2021	9	Golden plover	21	18.20	120	10	20	90	0	0	Flock low and appeared to have landed on bog
2	27/04/2021	10	Kestrel	1	18.55	180	0	0	40	140	0	Female hovering quite high over bog
1	28/04/2021	11	Sparrowhawk	1	11.08	20	20	0	0	0	0	Male hunting edge of wood
2	20/06/2021	12	Merlin	1	17.32	20	20	0	0	0	0	Flying fast low over bog – prob male but not certain
1	22/09/2021	13	Kestrel	1	16.16	90	60	30	0	0	0	Hovering – female type
1	23/09/2021	14	Peregrine	1	14.23	120	0	0	0	120	0	Flew steadily thru site and over forest – large bird so prob female

Appendix 4. COLLISION RISK ASSESSMENT CALCULATIONS

Table 6.10: Bird-seconds spent by species at Potential Collision Height (20-180+m) for each VP.

Species (BTO Code)	Year	VP 1 Seconds spent at PCH		VP 2 Seconds spent at PCH	
		Winter Season	Summer Season	Winter Season	Summer Season
Kestrel (K.)	2019/20	150	0	60	180
	2020/21	180	30	0	210
Golden Plover (GP)	2019/20	1,800	0	0	0
	2020/21	90	0	2,670	0
Peregrine (PE)	2019/20	0	0	0	0
	2020/21	0	120	0	0

Table 6.11: Bird biometrics and bird-seconds spent by species at Potential Collision Height (20-180+m).

Seconds spent at PCH (2019-2021)										
Species Name (BTO Code)	Length (m)	Wingspan (m)	Mean flight speed (m/s)	Seconds in flight at PCH (25-180m)						Total secs at PCH over 24 Months
				2019/2020			2020/2021			
				Winter	Summer	Total	Winter	Summer	Total	
Kestrel (K.)	0.34	0.76	10.1	210	180	390	180	210	390	780
Golden Plover (GP)	0.275	0.715	17.9	1,800	0	1,800	2,760	0	2,760	4,560
Peregrine (PE)	0.42	1.02	12.1	0	0	0	0	120	120	120

Table 6.12: Probability of collision – Stage 2 Calculations.

Key Target Species Stage 2 Calculations							
Species Name (BTO Code)	Flapping bird			Gliding bird			Mean probability of Collision Risk (Flapping + Gliding)/2
	Upwind	Downwind	Average	Upwind	Downwind	Average	
Kestrel (K.)	8.5%	3.5%	6.0%	8.4%	3.4%	5.9%	5.95%
Golden Plover (GP)	6.2%	2.7%	4.5%	N/A	N/A	N/A	4.5%
Peregrine (PE)	8.1%	3.6%	5.8%	8.0%	3.4%	5.7%	5.75%

Table 6.13: Avian Biometric Data and Avoidance Rates.

Avian Biometric Data and Avoidance Rates				
Species Name	Length (m)	Wingspan (m)	Mean flight speed (m/s)	Avoidance rates (%)
Common Kestrel (*Falco tinnunculus*)	0.34	0.76	10.1	95
European Golden Plover (*Pluvialis apricaria*)	0.275	0.715	17.9	98
Peregrine Falcon (*Falco peregrinus*)	0.42	1.02	12.1	98

Table 6.14: Seasonal divisions of relevant target species.

Species Name	Breeding season start	Breeding season end	Non-breeding season start	Non-breeding season end
Common Kestrel	April	August	September	March
Golden Plover	April	August	September	March
Peregrine Falcon	March	August	September	February

Table 6.15: Bird-seconds spent by species at Potential Collision Height (20-180+m) within VP 1 Viewshed.

Species (BTO Code)	Year	Bird-seconds spent by species at Potential Collision Height (20-180+m) for each month within Vantage Point 1 viewshed											
		September	October	November	December	January	February	March	April	May	June	July	August
Kestrel (K.)	2019/20	0	150	0	0	0	0	0	0	0	0	0	0
	2020/21	30	0	0	0	0	180	0	0	0	0	0	0
Golden Plover (GP)	2019/20	0	0	0	0	0	1,800	0	0	0	0	0	0
	2020/21	0	0	0	0	90	0	0	0	0	0	0	0
Peregrine (PE)	2019/20	0	0	0	0	0	0	0	0	0	0	0	0
	2020/21	120	0	0	0	0	0	0	0	0	0	0	0

Table 6.16: Bird-seconds spent by species at Potential Collision Height (20-180+m) within VP 2 Viewshed.

Species (BTO Code)	Year	Bird-seconds spent by species at Potential Collision Height (20-180+m) for each month within Vantage Point 2 viewshed											
		September	October	November	December	January	February	March	April	May	June	July	August
Kestrel (K.)	2019/20	0	0	0	0	0	0	60	0	0	0	0	180
	2020/21	0	0	0	0	0	0	0	180	0	0	0	0
Golden Plover (GP)	2019/20	0	0	0	0	0	0	0	0	0	0	0	0
	2020/21	0	0	0	360	0	0	2,310	0	0	0	0	0
Peregrine (PE)	2019/20	0	0	0	0	0	0	0	0	0	0	0	0
	2020/21	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 5. WORKED CALCULATIONS

Table 6.17: Calculation of collision probability for Kestrel passing (Gliding) through rotor area.

K: [1D or [3D] (0 or 1)	1		Calculation of alpha and p(collision) as a function of radius								
NoBlades	3					Upwind:			Downwind:		
MaxChord	4.5	m	r/R	c/C	a	collide		contribution	collide		contribution
Pitch (degrees)	13		radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r
BirdLength	0.34	m	0.025	0.575	4.45	15.17	0.84	0.00105	14.01	0.78	0.00097
Wingspan	0.76	m	0.075	0.575	1.48	5.45	0.30	0.00226	4.28	0.24	0.00178
F: Flapping (0) or gliding (+1)	0		0.125	0.702	0.89	4.12	0.23	0.00286	2.70	0.15	0.00187
			0.175	0.860	0.64	3.75	0.21	0.00364	2.01	0.11	0.00195
Bird speed	10.1	m/sec	0.225	0.994	0.49	3.54	0.20	0.00441	1.52	0.08	0.00190
RotorDiam	155	m	0.275	0.947	0.40	2.98	0.16	0.00454	1.06	0.06	0.00161
RotationPeriod	5.36	sec	0.325	0.899	0.34	2.60	0.14	0.00468	0.78	0.04	0.00140
			0.375	0.851	0.30	2.31	0.13	0.00480	0.58	0.03	0.00122
			0.425	0.804	0.26	2.08	0.11	0.00489	0.45	0.02	0.00106
			0.475	0.756	0.23	1.88	0.10	0.00495	0.35	0.02	0.00092
Bird aspect ratioo: b	0.45		0.525	0.708	0.21	1.71	0.10	0.00499	0.40	0.02	0.00116
			0.575	0.660	0.19	1.57	0.09	0.00500	0.45	0.02	0.00143
			0.625	0.613	0.18	1.44	0.08	0.00498	0.48	0.03	0.00167
			0.675	0.565	0.16	1.32	0.07	0.00494	0.50	0.03	0.00188
			0.725	0.517	0.15	1.21	0.07	0.00487	0.52	0.03	0.00207
			0.775	0.470	0.14	1.11	0.06	0.00477	0.52	0.03	0.00223
			0.825	0.422	0.13	1.02	0.06	0.00465	0.52	0.03	0.00237
			0.875	0.374	0.13	0.93	0.05	0.00450	0.51	0.03	0.00247
			0.925	0.327	0.12	0.84	0.05	0.00432	0.50	0.03	0.00256
			0.975	0.279	0.11	0.76	0.04	0.00412	0.48	0.03	0.00261
				Overall p(collision) =			Upwind	8.5%		Downwind	3.5%
								Average	6.0%		

Table 6.18: Calculation of collision probability for Kestrel passing (Flapping) through rotor area.

K: [1D or [3D] (0 or 1)	1		**Calculation of alpha and p(collision) as a function of radius**								
NoBlades	3					Upwind:			Downwind:		
MaxChord	4.5	m	r/R	c/C	a	collide		contribution	collide		contribution
Pitch (degrees)	13		radius	chord	alpha	length	p(collision)	from radius r	length	p(collision)	from radius r
BirdLength	0.34	m	0.025	0.575	4.45	13.95	0.77	0.00097	12.78	0.71	0.00089
Wingspan	0.76	m	0.075	0.575	1.48	5.04	0.28	0.00209	3.87	0.21	0.00161
F: Flapping (0) or gliding (+1)	1		0.125	0.702	0.89	3.88	0.21	0.00268	2.46	0.14	0.00170
			0.175	0.860	0.64	3.57	0.20	0.00347	1.83	0.10	0.00178
Bird speed	10.1	m/sec	0.225	0.994	0.49	3.40	0.19	0.00424	1.39	0.08	0.00173
RotorDiam	155	m	0.275	0.947	0.40	2.98	0.16	0.00454	1.06	0.06	0.00161
RotationPeriod	5.36	sec	0.325	0.899	0.34	2.60	0.14	0.00468	0.78	0.04	0.00140
			0.375	0.851	0.30	2.31	0.13	0.00480	0.58	0.03	0.00122
			0.425	0.804	0.26	2.08	0.11	0.00489	0.45	0.02	0.00106
			0.475	0.756	0.23	1.88	0.10	0.00495	0.35	0.02	0.00092
Bird aspect ratioo: b	0.45		0.525	0.708	0.21	1.71	0.10	0.00499	0.40	0.02	0.00116
			0.575	0.660	0.19	1.57	0.09	0.00500	0.45	0.02	0.00143
			0.625	0.613	0.18	1.44	0.08	0.00498	0.48	0.03	0.00167
			0.675	0.565	0.16	1.32	0.07	0.00494	0.50	0.03	0.00188
			0.725	0.517	0.15	1.21	0.07	0.00487	0.52	0.03	0.00207
			0.775	0.470	0.14	1.11	0.06	0.00477	0.52	0.03	0.00223
			0.825	0.422	0.13	1.02	0.06	0.00465	0.52	0.03	0.00237
			0.875	0.374	0.13	0.93	0.05	0.00450	0.51	0.03	0.00247
			0.925	0.327	0.12	0.84	0.05	0.00432	0.50	0.03	0.00256
			0.975	0.279	0.11	0.76	0.04	0.00412	0.48	0.03	0.00261
				Overall p(collision) =			**Upwind**	**8.4%**		**Downwind**	**3.4%**
								Average	**5.9%**		

Table 6.19: Calculation of collision risk parameters for Kestrel Breeding Season 2020.

Kestrel, Breeding VP Surveys: 2020				
Measurements	Code	Value		
Rotor radius (metres)	R	77.5		
Rotor diameter (metres)	RD	155		
Max chord width of turbine blades (metres)	d	4.5		
Bird length (metres)	l	0.34		
Average flight speed (m/s)	s	10.1		
Daily Duration of Activity (hrs)	TDD	15		
Length of Season (days)	Tss	153		
Wingspan (m)		0.76		
Mean pitch of blade (degrees)		13		
Rotors per turbine		3		
Rotational period (seconds)		5.36		
Turbine operational time (%)		85		
			Vantage Point	
			VP 1	VP 2
Total Survey time over 5 months (secs)	T		108000	108000
Total flight at Rotor Height 25 – 180+m (bird-secs)	sPCH		0	180
No. of turbines in viewshed	x		7	11
Survey area visible from VP (hectares)	Avp		424.5	556.5
Flight Risk Area, i.e. 500m buffer of turbines within viewshed (hectares)	Afr		276.15	424.1
Availability of species activity during survey period (hrs)	Sa		2295	2295

Table 6.20: Stage 1 calculation of collision risk for Kestrel Breeding Season 2020.

Stage 1 Calculations				
Measurements	Code	Calculation	VP 1	VP 2
Proportion of Bird flight-time between 20 - 180m	t	sPCH/T	0	0.001666667
Flight activity in visible area per hectare	F	t/Avp	0	2.99491E-06
Proportion of Bird flight time in Risk Area	Trisk	F*Afr	0	0.001270141
Bird occupancy of Risk Area (hrs/season)	n	Trisk*Sa	0	2.914973046
Flight Risk volume (m3)	Vw	(Afr*RD)*10000	428032500	657355000
Actual volume of air swept by rotors (m3)	o	x*(πr2(d+l))	638964.095	1004086.435
Bird occupancy of rotor swept area (bird-secs)	b	3600*(n*(o/Vw))	0	16.02906438
Time taken for Bird to pass through rotors (secs)	v	(d+l)/s	0.479207921	0.479207921
Number of Bird passes through the rotor during survey period	N	b/v	0	33.44908063
Total transits adjusted for maximum operation of turbines (85%)	Tn	N*0.85	0	28.43171854
Number of transits per turbine within viewshed	TnT	Tn/x	0	2.584701685
Average TnT of all VP's (VP 1-2)	ATnT	(TnT1+TnT2+TnT3+.....)/2	1.292350843	
Number of transits across windfarm	NT	ATnT*(Total no. turbines)	16.80056095	

Table 6.21: Stage 2 calculation of collision risk for Kestrel Breeding Season 2020.

Stage 2 Calculation	Calculation	Result
Collision Probability (%)	(Model)	5.95%
Collisions during study period	NT*Collision Probability	1.00
Collisions during study period with 95% Avoidance Rate	*0.05	0.009996334
Over 30-year duration of windfarm	*30	0.299890013