



## **APPENDIX 7-6**

### ***COLLISION RISK ASSESSMENT***

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## 1. INTRODUCTION

This document outlines the methodology used to conduct a collision risk assessment of the Cunlaghfadda Green Energy Project. This assessment calculates an annual collision rate using a mathematical model to predict the number of birds that may be killed by collision with moving wind turbine rotor blades. The modelling method used is the Collision Risk Model provided by Band (2024). This method is recommended by NatureScot and provides a standardised approach to collision risk assessment for onshore wind farms. Note that these are theoretical predictions, therefore the results must be interpreted with a degree of caution.

## 2. METHODOLOGY

### 2.1 Modelling Process

The collision risk model estimates the number of collisions through the following stages:

- **Stage A Flight activity** - uses bird survey data to establish the density of flying birds in the vicinity of the turbines, and the proportion flying at a risk height (between the lowest and highest points of the rotors).
- **Stage B Number of flights through rotors** - makes an estimate, based on the bird density and proportion at risk height, of the potential number of bird passages through rotors. The initial assumption is that birds will continue to make flights within the area at the same intensity as before.
- **Stage C Probability of collision** - calculates the probability of collision during a single bird rotor transit.
- **Stage D Expected collisions** - multiplies the outputs of stage B and C to yield the potential collision rate for the bird species, assuming current levels of bird use of the site but allowing for the proportion of time that turbines are not operational.
- **Stage E Allowing for avoidance and attraction** - takes account of the proportion of birds likely to avoid the wind farm or its turbines, either because they have been displaced from the site or because they take evasive action or are attracted to the wind farm.
- **Stage F Uncertainty** - each of these five stages is followed by a further stage, stage F, which describes how to express the uncertainty surrounding a collision risk estimate.

The general features and assumptions of the collision risk model are discussed in further detail in Band (2024). Using the model, a final predicted annual collision rate can be predicted for each species that can be used in the impact assessment

### 2.2 Turbine Specifications

The turbine specifications used in the model are provided in Table 7 - 6 - 1. The expected operational time of the turbines is 85% according to report by the British Wind Energy Association (BWEA; 2007) which identifies the standard operational period of the wind turbines in the UK.

Table 7 - 6 - 1 Turbine specifications

| Component               | Scenario Modelled |
|-------------------------|-------------------|
| Latitude (°N)           | 53.74579          |
| Turbine model           | Vestas V136       |
| Number of turbines      | 7                 |
| Hub height (m)          | 92                |
| Rotor diameter (m)      | 136               |
| Blade pitch (°)         | 25                |
| Maximum blade width (m) | 4.2               |

| Component              | Scenario Modelled |
|------------------------|-------------------|
| Rotational speed (rpm) | 9.8               |
| Number of blades       | 3                 |

The turbine blade profile used in the model is presented in Table 7 - 6 - 2. In the absence of a specific blade profile for this turbine model, the blade profile provided in the collision risk model spreadsheet in Band (2024) has been used. This table provides the chord width values at 20 evenly spaced points along the blade, expressed relative to the maximum chord width. The ratio  $r/R$  represents the relative radial position along the blade, where 0 corresponds to the hub and 1 corresponds to the blade tip, while the ratio  $c/C$  represents the relative chord width. Further information on blade profiles is in Section 4 ‘Worked Example’.

Table 7 - 6 - 2 Turbine blade profile

| $r/R$ | $c/C$ |
|-------|-------|
| 0.00  | 0.690 |
| 0.05  | 0.730 |
| 0.10  | 0.790 |
| 0.15  | 0.880 |
| 0.20  | 0.960 |
| 0.25  | 1.000 |
| 0.30  | 0.980 |
| 0.35  | 0.920 |
| 0.40  | 0.850 |
| 0.45  | 0.800 |
| 0.50  | 0.750 |
| 0.55  | 0.700 |
| 0.60  | 0.640 |
| 0.65  | 0.580 |
| 0.70  | 0.520 |
| 0.75  | 0.470 |
| 0.80  | 0.410 |
| 0.85  | 0.370 |
| 0.90  | 0.300 |
| 0.95  | 0.240 |
| 1.00  | 0.000 |

## 2.3

## Vantage Point Surveys

The assessment is based on vantage point surveys to monitor flight activity undertaken between October 2021 and September 2025. This represents a 48-month period, consisting of four breeding seasons and four winter seasons, which is in full compliance with guidance from NatureScot (formerly Scottish Natural Heritage [SNH]) outlined in SNH (2017), which was revised in NatureScot (2025a). Surveys remain in accordance with the updated guidance. Due to the change in site layout in April 2023, one vantage point location was moved 290m south.

Surveys were undertaken at two vantage points. Viewsheds were calculated using the Visibility Analysis plugin (Version 1.8) over a raster digital terrain model (DTM) in QGIS (Version 3.28). A point 1.75m in height (to represent the height of the surveyor) was created on a map using 10m contours terrain data, accounting for the relative height of any surrounding landscape features (e.g., trees). The software produced a 360° viewshed 24m from ground level up to a 2km radius around the vantage point. The combined viewsheds from these vantage points provided coverage to a 500m radius of the potential

turbine positions. The vantage points and the area watched (i.e., the area of the viewsheds) are listed in Table 7 - 6 - 3.

Table 7 - 6 - 3 Vantage points

| Vantage Point | Area Watched (ha) |
|---------------|-------------------|
| 1             | 489               |
| 2             | 451               |
| 2a            | 408               |

Survey methodology followed SNH (2017; revised in NatureScot, 2025). The surveyor collected data on bird observations and flight activity from the scanning arc of 180° to a 2km radius at the fixed vantage point locations for two 3 hour watches separated by a minimum 30 minute break (i.e., 6 hours total) per month. The survey effort is presented in Table 7 - 6 - 4, expressed in terms of hours and seconds per month.

Table 7 - 6 - 4 Survey effort

| Vantage Point | Month | Hours Survey | Seconds Survey |
|---------------|-------|--------------|----------------|
| VP1           | Jan   | 30.00        | 108,000        |
| VP2           | Jan   | 18.00        | 64,800         |
| VP2a          | Jan   | 12.00        | 43,200         |
| VP1           | Feb   | 24.00        | 86,400         |
| VP2           | Feb   | 12.00        | 43,200         |
| VP2a          | Feb   | 12.00        | 43,200         |
| VP1           | Mar   | 24.50        | 88,200         |
| VP2           | Mar   | 12.00        | 43,200         |
| VP2a          | Mar   | 12.50        | 45,000         |
| VP1           | Apr   | 24.00        | 86,400         |
| VP2           | Apr   | 6.00         | 21,600         |
| VP2a          | Apr   | 18.00        | 64,800         |
| VP1           | May   | 24.00        | 86,400         |
| VP2           | May   | 6.00         | 21,600         |
| VP2a          | May   | 15.00        | 54,000         |
| VP1           | Jun   | 24.00        | 86,400         |
| VP2           | Jun   | 6.00         | 21,600         |
| VP2a          | Jun   | 18.00        | 64,800         |
| VP1           | Jul   | 24.00        | 86,400         |
| VP2           | Jul   | 6.00         | 21,600         |
| VP2a          | Jul   | 18.00        | 64,800         |
| VP1           | Aug   | 24.00        | 86,400         |
| VP2           | Aug   | 6.00         | 21,600         |
| VP2a          | Aug   | 18.00        | 64,800         |
| VP1           | Sep   | 24.00        | 86,400         |
| VP2           | Sep   | 6.00         | 21,600         |
| VP2a          | Sep   | 21.33        | 76,788         |
| VP1           | Oct   | 18.00        | 64,800         |
| VP2           | Oct   | 12.53        | 45,108         |
| VP2a          | Oct   | 12.00        | 43,200         |
| VP1           | Nov   | 30.00        | 108,000        |
| VP2           | Nov   | 6.00         | 21,600         |

| Vantage Point | Month | Hours Survey | Seconds Survey |
|---------------|-------|--------------|----------------|
| VP2a          | Nov   | 18.00        | 64,800         |
| VP1           | Dec   | 18.67        | 67,212         |
| VP2           | Dec   | 12.00        | 43,200         |
| VP2a          | Dec   | 6.50         | 23,400         |

Flight activity of target species was mapped and recorded as per defined flight bands which were chosen in relation to the dimensions of potential turbine models at the outset of surveys. These heights bands were:

- > Band 1 = 0-15m
- > Band 2 = 15-25m
- > Band 3 = 25-200m
- > Band 4 = 200m+

As the risk height range of the turbine is 24-160m, all flight activity in Band 2 and Band 3 are considered to be at potential collision height.

## 2.4

# Species Assessed

Collision rates were estimated for the species listed in Table 7 - 6 - 5. The months included for each species are also presented.

Table 7 - 6 - 5 Species assessed

| Species                  | Months  | Model          |
|--------------------------|---------|----------------|
| Golden Plover            | Sep-Apr | nondirectional |
| Whooper Swan             | Oct-Mar | nondirectional |
| Lesser Black-backed Gull | Oct-Sep | nondirectional |
| Curlew                   | Apr-Sep | nondirectional |
| Kestrel                  | Oct-Sep | nondirectional |
| Snipe                    | Oct-Sep | nondirectional |
| Buzzard                  | Oct-Sep | nondirectional |
| Sparrowhawk              | Oct-Sep | nondirectional |

Species biometrics, such as body length, body width (i.e., wingspan) and flight speed, as well as whether a bird typically flaps or glides in flight, are required to calculate collision risk. This information was sourced from the best available literature.

In addition, a ‘nocturnal activity factor is required’. There is considerable uncertainty about levels of bird flight activity by night (Band, 2024). There are no standard expert rankings available for terrestrial species and levels of activity may vary from season to season. Because of this, each species is ranked with a nocturnal activity factor of 0%, 25%, 50%, 75% and 100%. A ranking of 0% is given to represent hardly any flight activity at night and of 100% for much flight activity at night. As such, the figures used in the collision risk model take both day and night flights into account. The biometrics, flight type and nocturnal activity factor used in the model are presented in Table 7 - 6 - 6.

Table 7 - 6 - 6 Species biometrics, flight type and nocturnal activity factor

| Species       | Length(cm) | Width(cm) | Flight Speed (m/s) | Nocturnal Activity Factor | Flight Type |
|---------------|------------|-----------|--------------------|---------------------------|-------------|
| Buzzard       | 54         | 120.5     | 11.6               | 0%                        | gliding     |
| Curlew        | 55         | 90        | 16.3               | 50%                       | flapping    |
| Golden Plover | 27.5       | 71.5      | 17.9               | 25%                       | flapping    |
| Kestrel       | 33.5       | 75.5      | 10.1               | 0%                        | flapping    |

| Species                  | Length(cm) | Width(cm) | Flight Speed (m/s) | Nocturnal Activity Factor | Flight Type |
|--------------------------|------------|-----------|--------------------|---------------------------|-------------|
| Lesser Black-backed Gull | 58         | 142.5     | 11.9               | 25%                       | flapping    |
| Snipe                    | 25.5       | 42        | 17.1               | 100%                      | flapping    |
| Sparrowhawk              | 33         | 62.5      | 10                 | 0%                        | flapping    |
| Whooper Swan             | 150        | 220       | 17.3               | 25%                       | flapping    |

To prepare the field survey data for analysis, the number of ‘bird-seconds’ per month per vantage point was calculated for each observation by multiplying the number of birds aloft by the duration of the flight (in seconds). This included time spent in all recorded height bands, not just those bands within potential collision height. These values are presented per vantage point per month for each species in Table 7 - 6 - 7.

Table 7 - 6 - 7 Bird-seconds per vantage point per month

| Species       | Month | Vantage Point | Bird-Seconds |
|---------------|-------|---------------|--------------|
| Buzzard       | Mar   | VP1           | 1,192        |
|               | May   | VP1           | 186          |
|               | Aug   | VP1           | 194          |
|               | Sep   | VP1           | 857          |
|               | Oct   | VP1           | 1,110        |
|               | Nov   | VP1           | 120          |
|               | Feb   | VP2           | 3,773        |
|               | Mar   | VP2           | 166          |
|               | Apr   | VP2           | 191          |
|               | May   | VP2           | 192          |
|               | Jul   | VP2           | 429          |
|               | Aug   | VP2           | 361          |
|               | Sep   | VP2           | 760          |
|               | Oct   | VP2           | 87           |
|               | May   | VP2a          | 29           |
|               | Jun   | VP2a          | 124          |
|               | Jul   | VP2a          | 45           |
|               | Aug   | VP2a          | 232          |
|               | Nov   | VP2a          | 92           |
| Curlew        | May   | VP2           | 156          |
| Golden Plover | Apr   | VP1           | 297          |
|               | Mar   | VP2           | 910          |
|               | Apr   | VP2           | 585          |
|               | Sep   | VP2           | 9,056        |
|               | Oct   | VP2           | 13,447       |
|               | Nov   | VP2           | 22,652       |
|               | Dec   | VP2           | 1,400        |
| Kestrel       | Jan   | VP1           | 295          |
|               | Feb   | VP1           | 70           |
|               | Mar   | VP1           | 92           |
|               | May   | VP1           | 28           |
|               | Jun   | VP1           | 1,698        |
|               | Jul   | VP1           | 90           |

| Species                  | Month | Vantage Point | Bird-Seconds |
|--------------------------|-------|---------------|--------------|
|                          | Aug   | VP1           | 1,211        |
|                          | Sep   | VP1           | 311          |
|                          | Oct   | VP1           | 203          |
|                          | Nov   | VP1           | 372          |
|                          | Dec   | VP1           | 35           |
|                          | Jan   | VP2           | 2,975        |
|                          | Feb   | VP2           | 1,188        |
|                          | Mar   | VP2           | 268          |
|                          | Apr   | VP2           | 222          |
|                          | May   | VP2           | 1,389        |
|                          | Jun   | VP2           | 1,867        |
|                          | Jul   | VP2           | 1,200        |
|                          | Aug   | VP2           | 1,296        |
|                          | Sep   | VP2           | 2,360        |
|                          | Oct   | VP2           | 189          |
|                          | Nov   | VP2           | 141          |
|                          | Dec   | VP2           | 1,374        |
|                          | Apr   | VP2a          | 22           |
|                          | May   | VP2a          | 360          |
|                          | Jun   | VP2a          | 1,104        |
|                          | Aug   | VP2a          | 70           |
|                          | Sep   | VP2a          | 161          |
|                          | Oct   | VP2a          | 1,622        |
|                          | Nov   | VP2a          | 1,606        |
| Lesser Black-backed Gull | Feb   | VP1           | 70           |
|                          | Mar   | VP1           | 10,814       |
|                          | Apr   | VP1           | 1,126        |
|                          | May   | VP1           | 726          |
|                          | Jun   | VP1           | 4,293        |
|                          | Jul   | VP1           | 759          |
|                          | Aug   | VP1           | 1,871        |
|                          | Sep   | VP1           | 115          |
|                          | May   | VP2           | 621          |
|                          | Jun   | VP2           | 278          |
|                          | Jul   | VP2           | 238          |
|                          | Mar   | VP2a          | 33           |
|                          | Apr   | VP2a          | 177          |
|                          | May   | VP2a          | 115          |
|                          | Jun   | VP2a          | 1,305        |
|                          | Jul   | VP2a          | 20           |
|                          | Aug   | VP2a          | 34           |
| Snipe                    | Jan   | VP1           | 5            |
|                          | Feb   | VP1           | 15           |
|                          | Oct   | VP1           | 44           |
|                          | Dec   | VP1           | 18           |
|                          | Jan   | VP2           | 35           |

| Species      | Month | Vantage Point | Bird-Seconds |
|--------------|-------|---------------|--------------|
|              | Feb   | VP2           | 5            |
|              | Mar   | VP2           | 155          |
|              | Jun   | VP2           | 28           |
|              | Jul   | VP2           | 80           |
|              | Aug   | VP2           | 72           |
|              | Oct   | VP2           | 3,850        |
|              | Nov   | VP2           | 30           |
|              | Dec   | VP2           | 65           |
|              | Apr   | VP2a          | 2,225        |
|              | May   | VP2a          | 596          |
|              | Jun   | VP2a          | 2,828        |
| Sparrowhawk  | Jan   | VP1           | 35           |
|              | Feb   | VP1           | 57           |
|              | Aug   | VP1           | 29           |
|              | Sep   | VP1           | 63           |
|              | Oct   | VP1           | 23           |
|              | Dec   | VP1           | 35           |
|              | Jan   | VP2           | 575          |
|              | Feb   | VP2           | 48           |
|              | Mar   | VP2           | 48           |
|              | May   | VP2           | 59           |
|              | Jul   | VP2           | 115          |
|              | Aug   | VP2           | 38           |
|              | Sep   | VP2           | 29           |
|              | Oct   | VP2           | 199          |
|              | Nov   | VP2           | 103          |
|              | Dec   | VP2           | 17           |
|              | Sep   | VP2a          | 80           |
|              | Nov   | VP2a          | 64           |
| Whooper Swan | Jan   | VP1           | 280          |
|              | Feb   | VP1           | 35           |
|              | Nov   | VP1           | 6,979        |
|              | Dec   | VP1           | 70           |
|              | Feb   | VP2           | 1,183        |
|              | Mar   | VP2           | 264          |
|              | Nov   | VP2           | 1,036        |

## 2.5

## Photoperiod

The photoperiod at the latitude of the turbines was acquired for the survey period. The daylight and nighttime hours per month are shown in Table 7 - 6 - 8. The total daylight hours was 4,488 and night-time hours was 4,272.

Table 7 - 6 - 8 Photoperiod

|                | Jan   | Feb   | Mar   | Apr   | May   | Jun   | Jul   | Aug   | Sep   | Oct   | Nov   | Dec   |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Daylight Hours | 249.8 | 272.8 | 366.2 | 419.4 | 493.1 | 509.5 | 512.2 | 460.2 | 382.9 | 329.1 | 259.6 | 233.6 |

|                 | Jan   | Feb   | Mar   | Apr   | May   | Jun   | Jul   | Aug   | Sep   | Oct   | Nov   | Dec   |
|-----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Nighttime Hours | 494.2 | 399.2 | 377.8 | 300.6 | 250.9 | 210.5 | 231.8 | 283.8 | 337.1 | 414.9 | 460.4 | 510.4 |

3.

## RESULTS

3.1

### Stage A Flight Activity

Stage A of the modelling process uses the field survey data to establish the aerial density of flying birds in the vicinity of the turbines and the proportion flying at a risk height (between the lowest and highest points of the rotors). Aerial density was calculated following the formula provided by Band (2024; also see Section 4 ‘Worked Example’). Similarly, the proportion flying at risk height was calculated following the method in Band (2024; also see Section 4 ‘Worked Example’). The aerial density per month and the proportion flying at risk height for each species is shown in Table 7 - 6 - 9.

Table 7 - 6 - 9 Aerial density and proportion flying at risk height

| Species                  | Jan       | Feb       | Mar       | Apr      | May      | Jun      | Jul      | Aug      | Sep       | Oct     | Nov      | Dec       | Proportion |
|--------------------------|-----------|-----------|-----------|----------|----------|----------|----------|----------|-----------|---------|----------|-----------|------------|
| Golden Plover            | 0         | 0         | 0.00156   | 0.00224  | -        | -        | -        | -        | 0.031     | 0.022   | 0.0775   | 0.0024    | 0.41       |
| Whooper Swan             | 0.000177  | 0.00205   | 0.000452  | -        | -        | -        | -        | -        | -         | 0       | 0.00795  | 0.000071  | 0.27       |
| Lesser Black-backed Gull | 0         | 0.0000552 | 0.00842   | 0.00111  | 0.00287  | 0.00598  | 0.00144  | 0.00152  | 0.0000907 | 0       | 0        | 0         | 0.48       |
| Curlew                   | -         | -         | -         | 0        | 0.000534 | 0        | 0        | 0        | 0         | -       | -        | -         | 0.95       |
| Kestrel                  | 0.00358   | 0.00209   | 0.00053   | 0.000787 | 0.00532  | 0.00912  | 0.00418  | 0.00548  | 0.00849   | 0.00359 | 0.00274  | 0.00239   | 0.34       |
| Snipe                    | 0.0000431 | 0.0000204 | 0.000265  | 0.00281  | 0.000902 | 0.00366  | 0.000274 | 0.000246 | 0         | 0.00635 | 0.000103 | 0.000129  | 0.26       |
| Buzzard                  | 0         | 0.00646   | 0.00121   | 0.000654 | 0.000848 | 0.000156 | 0.00152  | 0.00168  | 0.00328   | 0.00131 | 0.000192 | 0         | 0.62       |
| Sparrowhawk              | 0.000678  | 0.000127  | 0.0000821 | 0        | 0.000202 | 0        | 0.000394 | 0.000153 | 0.000234  | 0.00035 | 0.000433 | 0.0000646 | 0.12       |

3.2

### Stage B Number of Flights Through Rotors

Stage B of the modelling process makes an estimate, based on the aerial density and proportion flying at risk height, of the potential number of bird passages through rotors. The projected number of transits through the rotor risk area was calculated following the formula provided by Band (2024; also see Section 4 ‘Worked Example’). Table 7 - 6 - 10 shows the projected number of transits per month for each species.

Table 7 - 6 - 10 Projected number of transits

| Species                  | Jan   | Feb   | Mar   | Apr  | May   | Jun  | Jul   | Aug   | Sep   | Oct   | Nov   | Dec   | Year    |
|--------------------------|-------|-------|-------|------|-------|------|-------|-------|-------|-------|-------|-------|---------|
| Golden Plover            | 0     | 0     | 14.1  | 21.8 | -     | -    | -     | -     | 285   | 188   | 572   | 17.1  | 1098.77 |
| Whooper Swan             | 0.831 | 9.63  | 2.62  | -    | -     | -    | -     | -     | -     | 0     | 37.5  | 0.323 | 50.94   |
| Lesser Black-backed Gull | 0     | 0.318 | 59.8  | 8.48 | 24.6  | 51.9 | 12.7  | 12.4  | 0.654 | 0     | 0     | 0     | 170.93  |
| Curlew                   | -     | -     | -     | 0    | 13.8  | 0    | 0     | 0     | 0     | -     | -     | -     | 13.83   |
| Kestrel                  | 8.15  | 5.2   | 1.77  | 3.01 | 23.9  | 42.4 | 19.5  | 23    | 29.7  | 10.8  | 6.49  | 5.08  | 178.96  |
| Snipe                    | 0.389 | 0.166 | 2.4   | 24.5 | 8.15  | 32   | 2.47  | 2.23  | 0     | 57.4  | 0.898 | 1.17  | 131.85  |
| Buzzard                  | 0     | 33.9  | 8.5   | 5.28 | 8.05  | 1.53 | 15    | 14.9  | 24.2  | 8.3   | 0.958 | 0     | 120.60  |
| Sparrowhawk              | 0.531 | 0.109 | 0.094 | 0    | 0.312 | 0    | 0.632 | 0.221 | 0.281 | 0.362 | 0.353 | 0.047 | 2.94    |

### 3.3

## Stage C Probability of Collision

Stage C of the modelling process calculates the probability of collision during a single bird rotor transit. The likelihood of a bird colliding with a turbine blade during a single pass through the rotor was calculated using the turbine specifications, species biometrics and flight characteristics outlined in the previous sections.

Collision risk was assessed across different parts of the rotor, as blade speed and width varies from the hub to the tip. Because of the geometry of the blades in relation to the flight direction, the collision risk for upwind flight is higher than for downwind (even if the bird's flight speed relative to the ground is taken to be the same), therefore collision risk probabilities were calculated separately for birds flying upwind and downwind. These were then averaged assuming a 50:50 weighting because both upwind and downwind flights are equally likely (further information in Section 4 'Worked Example'). This produced a probability of collision for a bird during a single transit of the rotor, which is presented for each species in Table 7 - 6 - 11.

Table 7 - 6 - 11 Probability of collision

| Species                  | Upwind | Downwind | Average |
|--------------------------|--------|----------|---------|
| Golden Plover            | 0.071  | 0.025    | 0.048   |
| Whooper Swan             | 0.109  | 0.062    | 0.086   |
| Lesser Black-backed Gull | 0.101  | 0.047    | 0.074   |
| Curlew                   | 0.082  | 0.034    | 0.058   |
| Kestrel                  | 0.099  | 0.041    | 0.07    |

| Species     | Upwind | Downwind | Average |
|-------------|--------|----------|---------|
| Snipe       | 0.07   | 0.023    | 0.047   |
| Buzzard     | 0.099  | 0.044    | 0.071   |
| Sparrowhawk | 0.098  | 0.041    | 0.07    |

3.4

## Stage D Expected Collisions

Stage D of the modelling process multiplies the outputs of stage B and C to yield the expected collision rate for each bird species, accounting for the proportion of time the wind farm is expected to be operational. This is before considering avoidance behaviour, which is stage E. The number of expected collisions per month and the year total for each species are presented in Table 7 - 6 - 12.

Table 7 - 6 - 12 Expected collisions without avoidance

| Species                  | Jan    | Feb     | Mar     | Apr   | May    | Jun    | Jul    | Aug    | Sep    | Oct    | Nov    | Dec     | Total |
|--------------------------|--------|---------|---------|-------|--------|--------|--------|--------|--------|--------|--------|---------|-------|
| Golden Plover            | 0      | 0       | 0.581   | 0.896 | -      | -      | -      | -      | 11.7   | 7.73   | 23.5   | 0.701   | 45.2  |
| Whooper Swan             | 0.0605 | 0.701   | 0.191   | -     | -      | -      | -      | -      | -      | 0      | 2.73   | 0.0235  | 3.71  |
| Lesser Black-backed Gull | 0      | 0.02    | 3.77    | 0.534 | 1.55   | 3.27   | 0.797  | 0.784  | 0.0412 | 0      | 0      | 0       | 10.8  |
| Curlew                   | -      | -       | -       | 0     | 0.68   | 0      | 0      | 0      | 0      | -      | -      | -       | 0.68  |
| Kestrel                  | 0.484  | 0.309   | 0.105   | 0.179 | 1.42   | 2.52   | 1.16   | 1.37   | 1.76   | 0.64   | 0.386  | 0.302   | 10.6  |
| Snipe                    | 0.0155 | 0.0066  | 0.0953  | 0.975 | 0.324  | 1.27   | 0.0984 | 0.0885 | 0      | 2.28   | 0.0357 | 0.0465  | 5.24  |
| Buzzard                  | 0      | 2.06    | 0.516   | 0.32  | 0.489  | 0.0931 | 0.913  | 0.904  | 1.47   | 0.504  | 0.0582 | 0       | 7.32  |
| Sparrowhawk              | 0.0315 | 0.00646 | 0.00557 | 0     | 0.0185 | 0      | 0.0374 | 0.0131 | 0.0166 | 0.0214 | 0.0209 | 0.00278 | 0.174 |

3.5

## Stage E Allowing for Avoidance and Attraction

Stage E of the modelling process takes account of the proportion of birds likely to avoid the wind farm or its turbines, either because they have been displaced from the site or because they take evasive action or are attracted to the wind farm. Band (2024) states that the collision rate estimate should show potential collision mortality using a range of assumed avoidance rates. In the absence of specific avoidance information for the species in question, it is recommended that collision risks be evaluated assuming avoidance factors of 95%, 98%, 99% and 99.5%. These are presented in Table 7 - 6 - 12Table 7 - 6 - 13.

Table 7 - 6 - 13 Expected collisions with avoidance

| Species                  | Avoidance Factor | Jan     | Feb     | Mar     | Apr     | May     | Jun    | Jul     | Aug     | Sep     | Oct    | Nov    | Dec     | Total  |
|--------------------------|------------------|---------|---------|---------|---------|---------|--------|---------|---------|---------|--------|--------|---------|--------|
| Golden Plover            | 0.95             | 0       | 0       | 0.0291  | 0.0448  | -       | -      | -       | -       | 0.587   | 0.386  | 1.18   | 0.0351  | 2.26   |
|                          | 0.98             | 0       | 0       | 0.0116  | 0.0179  | -       | -      | -       | -       | 0.235   | 0.155  | 0.471  | 0.014   | 0.903  |
|                          | 0.99             | 0       | 0       | 0.00581 | 0.00896 | -       | -      | -       | -       | 0.117   | 0.0773 | 0.235  | 0.00701 | 0.452  |
|                          | 0.995            | 0       | 0       | 0.00291 | 0.00448 | -       | -      | -       | -       | 0.0586  | 0.0386 | 0.118  | 0.00351 | 0.226  |
|                          | 0.996            | 0       | 0       | 0.00232 | 0.00358 | -       | -      | -       | -       | 0.0469  | 0.0309 | 0.0941 | 0.0028  | 0.181  |
| Whooper Swan             | 0.95             | 0.00302 | 0.035   | 0.00954 | -       | -       | -      | -       | -       | -       | 0      | 0.137  | 0.00117 | 0.185  |
|                          | 0.98             | 0.00121 | 0.014   | 0.00382 | -       | -       | -      | -       | -       | -       | 0      | 0.0546 | 0.00047 | 0.0741 |
|                          | 0.99             | 0.0006  | 0.00701 | 0.00191 | -       | -       | -      | -       | -       | -       | 0      | 0.0273 | 0.00023 | 0.0371 |
|                          | 0.995            | 0.0003  | 0.0035  | 0.00095 | -       | -       | -      | -       | -       | -       | 0      | 0.0137 | 0.00012 | 0.0185 |
|                          | 0.996            | 0.00024 | 0.0028  | 0.00076 | -       | -       | -      | -       | -       | -       | 0      | 0.0109 | 0.00009 | 0.0148 |
| Lesser Black-backed Gull | 0.95             | 0       | 0.001   | 0.188   | 0.0267  | 0.0776  | 0.164  | 0.0399  | 0.0392  | 0.00206 | 0      | 0      | 0       | 0.538  |
|                          | 0.98             | 0       | 0.0004  | 0.0754  | 0.0107  | 0.031   | 0.0654 | 0.0159  | 0.0157  | 0.00082 | 0      | 0      | 0       | 0.215  |
|                          | 0.99             | 0       | 0.0002  | 0.0377  | 0.00534 | 0.0155  | 0.0327 | 0.00797 | 0.00784 | 0.00041 | 0      | 0      | 0       | 0.108  |
|                          | 0.995            | 0       | 0.0001  | 0.0188  | 0.00267 | 0.00776 | 0.0164 | 0.00399 | 0.00392 | 0.00021 | 0      | 0      | 0       | 0.0538 |
|                          | 0.996            | 0       | 0.00008 | 0.0151  | 0.00214 | 0.00621 | 0.0131 | 0.00319 | 0.00314 | 0.00016 | 0      | 0      | 0       | 0.0431 |
| Curlew                   | 0.95             | -       | -       | -       | 0       | 0.034   | 0      | 0       | 0       | 0       | -      | -      | -       | 0.034  |
|                          | 0.98             | -       | -       | -       | 0       | 0.0136  | 0      | 0       | 0       | 0       | -      | -      | -       | 0.0136 |
|                          | 0.99             | -       | -       | -       | 0       | 0.0068  | 0      | 0       | 0       | 0       | -      | -      | -       | 0.0068 |

| Species | Avoidance Factor | Jan     | Feb     | Mar     | Apr     | May     | Jun     | Jul     | Aug     | Sep     | Oct     | Nov     | Dec     | Total   |
|---------|------------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
|         | 0.995            | -       | -       | -       | 0       | 0.0034  | 0       | 0       | 0       | 0       | -       | -       | -       | 0.0034  |
|         | 0.996            | -       | -       | -       | 0       | 0.00272 | 0       | 0       | 0       | 0       | -       | -       | -       | 0.00272 |
| Kestrel | 0.95             | 0.0242  | 0.0154  | 0.00525 | 0.00895 | 0.0711  | 0.126   | 0.058   | 0.0683  | 0.0881  | 0.032   | 0.0193  | 0.0151  | 0.532   |
|         | 0.98             | 0.00969 | 0.00617 | 0.0021  | 0.00358 | 0.0284  | 0.0504  | 0.0232  | 0.0273  | 0.0352  | 0.0128  | 0.00771 | 0.00604 | 0.213   |
|         | 0.99             | 0.00484 | 0.00309 | 0.00105 | 0.00179 | 0.0142  | 0.0252  | 0.0116  | 0.0137  | 0.0176  | 0.0064  | 0.00386 | 0.00302 | 0.106   |
|         | 0.995            | 0.00242 | 0.00154 | 0.00053 | 0.00089 | 0.00711 | 0.0126  | 0.0058  | 0.00683 | 0.00881 | 0.0032  | 0.00193 | 0.00151 | 0.0532  |
|         | 0.996            | 0.00194 | 0.00123 | 0.00042 | 0.00072 | 0.00569 | 0.0101  | 0.00464 | 0.00546 | 0.00705 | 0.00256 | 0.00154 | 0.00121 | 0.0425  |
| Snipe   | 0.95             | 0.00077 | 0.00033 | 0.00476 | 0.0488  | 0.0162  | 0.0636  | 0.00492 | 0.00442 | 0       | 0.114   | 0.00179 | 0.00233 | 0.262   |
|         | 0.98             | 0.00031 | 0.00013 | 0.00191 | 0.0195  | 0.00648 | 0.0255  | 0.00197 | 0.00177 | 0       | 0.0457  | 0.00071 | 0.00093 | 0.105   |
|         | 0.99             | 0.00015 | 0.00007 | 0.00095 | 0.00975 | 0.00324 | 0.0127  | 0.00098 | 0.00088 | 0       | 0.0228  | 0.00036 | 0.00047 | 0.0524  |
|         | 0.995            | 0.00008 | 0.00003 | 0.00048 | 0.00488 | 0.00162 | 0.00636 | 0.00049 | 0.00044 | 0       | 0.0114  | 0.00018 | 0.00023 | 0.0262  |
|         | 0.996            | 0.00006 | 0.00003 | 0.00038 | 0.0039  | 0.0013  | 0.00509 | 0.00039 | 0.00035 | 0       | 0.00913 | 0.00014 | 0.00019 | 0.021   |
| Buzzard | 0.95             | 0       | 0.103   | 0.0258  | 0.016   | 0.0244  | 0.00466 | 0.0457  | 0.0452  | 0.0733  | 0.0252  | 0.00291 | 0       | 0.366   |
|         | 0.98             | 0       | 0.0412  | 0.0103  | 0.00641 | 0.00977 | 0.00186 | 0.0183  | 0.0181  | 0.0293  | 0.0101  | 0.00116 | 0       | 0.146   |
|         | 0.99             | 0       | 0.0206  | 0.00516 | 0.0032  | 0.00489 | 0.00093 | 0.00913 | 0.00904 | 0.0147  | 0.00504 | 0.00058 | 0       | 0.0732  |
|         | 0.995            | 0       | 0.0103  | 0.00258 | 0.0016  | 0.00244 | 0.00047 | 0.00456 | 0.00452 | 0.00733 | 0.00252 | 0.00029 | 0       | 0.0366  |
|         | 0.996            | 0       | 0.00823 | 0.00206 | 0.00128 | 0.00195 | 0.00037 | 0.00365 | 0.00362 | 0.00587 | 0.00202 | 0.00023 | 0       | 0.0293  |

| Species     | Avoidance Factor | Jan     | Feb     | Mar     | Apr | May     | Jun | Jul     | Aug     | Sep     | Oct     | Nov     | Dec     | Total   |
|-------------|------------------|---------|---------|---------|-----|---------|-----|---------|---------|---------|---------|---------|---------|---------|
| Sparrowhawk | 0.95             | 0.00157 | 0.00032 | 0.00028 | 0   | 0.00092 | 0   | 0.00187 | 0.00065 | 0.00083 | 0.00107 | 0.00105 | 0.00014 | 0.00871 |
|             | 0.98             | 0.00063 | 0.00013 | 0.00011 | 0   | 0.00037 | 0   | 0.00075 | 0.00026 | 0.00033 | 0.00043 | 0.00042 | 0.00006 | 0.00349 |
|             | 0.99             | 0.00031 | 0.00006 | 0.00006 | 0   | 0.00018 | 0   | 0.00037 | 0.00013 | 0.00017 | 0.00021 | 0.00021 | 0.00003 | 0.00174 |
|             | 0.995            | 0.00016 | 0.00003 | 0.00003 | 0   | 0.00009 | 0   | 0.00019 | 0.00007 | 0.00008 | 0.00011 | 0.00011 | 0.00001 | 0.00087 |
|             | 0.996            | 0.00013 | 0.00003 | 0.00002 | 0   | 0.00007 | 0   | 0.00015 | 0.00005 | 0.00007 | 0.00009 | 0.00008 | 0.00001 | 0.00071 |

### 3.6

## Stage F Uncertainty

There are many sources of variability or uncertainty in the output of the Collision Risk Model. The main sources of uncertainty outlined in Band (2024) are:

- survey data is sampled, often both in time and space, and usually exhibits a high degree of variability. Mean estimates can only be representative of flight activity;
- survey data is unavailable for certain conditions, including nighttime and storm conditions;
- natural variability in bird populations, over time and space, for ecological reasons;
- flight height information may be subject to observer bias;
- the collision risk model uses a simplified geometry for turbine blades and bird shape;
- it does not include any risk of collision with turbine towers;
- details of blade dimension and pitch may be unavailable when making the estimate;
- turbines deployed may differ from those used in the collision risk analysis;
- bird parameters (length, wingspan, flight speed) are not fixed but have a distribution;
- bird speed is not a constant but is dependent on wind speed;
- insufficient knowledge about bird displacement and attraction effects;
- there is limited firm information on bird avoidance behaviour.

Because of this, a range of uncertainty is calculated for the predicted collision rates. The range of uncertainty should reflect:

- uncertainty or variability in flight activity data (including imprecision on flight height estimates and lack of knowledge about night-time behaviour);

- uncertainty due to the limitations of the collision model, including the variability of bird dimensions and flight speed, the simplification in shape of a bird and turbine blades;
- uncertainty arising from turbine options yet to be decided, in number, size and speed. These options should include a ‘worst case’ in terms of the option likely to present greatest bird collision risk.

To provide a measure of uncertainty in aerial density, the mean, standard deviation and relative standard error of the mean for the monthly values was calculated (see Section 4 ‘Worked Example’). Uncertainty due to simplifications in the collision risk model was assumed to be 0.20 (Band, 2024). Finally, uncertainty due to design options (including the blade profile, pitch, rotational speed and expected time operational) was considered to be 0.28. The overall range of uncertainty for each species is presented in Table 7 - 6 - 14.

Table 7 - 6 - 14 Range of uncertainty

| Species                  | Months  | Model           | Mean    | Standard Deviation | Standard Error of the Mean | Relative Standard Error | Uncertainty |
|--------------------------|---------|-----------------|---------|--------------------|----------------------------|-------------------------|-------------|
| Golden Plover            | Sep-Apr | non-directional | 0.01709 | 0.02532            | 0.00895                    | 0.52389                 | 0.63        |
| Whooper Swan             | Oct-Mar | non-directional | 0.00178 | 0.00285            | 0.00116                    | 0.65124                 | 0.74        |
| Lesser Black-backed Gull | Oct-Sep | non-directional | 0.00179 | 0.00261            | 0.00075                    | 0.42155                 | 0.54        |
| Curlew                   | Apr-Sep | non-directional | 0.00009 | 0.0002             | 0.00008                    | 0.91287                 | 0.98        |
| Kestrel                  | Oct-Sep | non-directional | 0.00402 | 0.0026             | 0.00075                    | 0.18625                 | 0.39        |
| Snipe                    | Oct-Sep | non-directional | 0.00123 | 0.00192            | 0.00056                    | 0.45032                 | 0.57        |
| Buzzard                  | Oct-Sep | non-directional | 0.00144 | 0.00176            | 0.00051                    | 0.35149                 | 0.49        |
| Sparrowhawk              | Oct-Sep | non-directional | 0.00023 | 0.00019            | 0.00006                    | 0.24831                 | 0.42        |

### 3.7

## Predicted Collision Rates

To provide a best estimate of the collision rate for each species, the guidance on avoidance rates provided in NatureScot (2025b) was consulted. This guidance suggests the most appropriate avoidance rate for each species; however it should be noted that the lack of research on most species’ avoidance rates means that the confidence interval of the prediction may extend from the lowest to the highest avoidance rate in Table 7 - 6 - 13. For each species, the predicted number of collisions corresponding to the recommended avoidance rate was identified. These are presented in

Table 7 - 6 - 15, along with the range of uncertainty, the predicted number of collisions over the operational lifetime of the facility and an estimation of the number of years for one collision to occur (details on these calculations are shown in Section 4 ‘Worked Example’).

Table 7 - 6 - 15 presents the final predicted annual collision rate used for the assessment. The results should be considered as a best estimate of collision risk, rather than a precise figure.

Table 7 - 6 - 15 Predicted collision rates

| Species                  | Months  | Model           | Avoidance Factor | Annual Collision Rate | Range of Uncertainty | Collisions Over Lifetime | Years to One Collision |
|--------------------------|---------|-----------------|------------------|-----------------------|----------------------|--------------------------|------------------------|
| Golden Plover            | Sep-Apr | non-directional | 0.996            | 0.181                 | 0.067-0.295          | 6.335                    | 6                      |
| Whooper Swan             | Oct-Mar | non-directional | 0.995            | 0.019                 | 0.005-0.032          | 0.665                    | >35                    |
| Lesser Black-backed Gull | Oct-Sep | non-directional | 0.98             | 0.215                 | 0.099-0.332          | 7.525                    | 5                      |
| Curlew                   | Apr-Sep | non-directional | 0.98             | 0.014                 | 0.000-0.027          | 0.49                     | >35                    |
| Kestrel                  | Oct-Sep | non-directional | 0.95             | 0.532                 | 0.324-0.739          | 18.62                    | 2                      |
| Snipe                    | Oct-Sep | non-directional | 0.98             | 0.105                 | 0.045-0.165          | 3.675                    | 10                     |
| Buzzard                  | Oct-Sep | non-directional | 0.98             | 0.146                 | 0.075-0.218          | 5.11                     | 7                      |
| Sparrowhawk              | Oct-Sep | non-directional | 0.98             | 0.003                 | 0.002-0.005          | 0.105                    | >35                    |

4.

## WORKED EXAMPLE

This section provides a worked example of the collision rate prediction for sparrowhawk at an imaginary facility. This example is deliberately simplified to assist readers with following the steps. The prediction is made using a short imaginary dataset presented in Section 4.2.

4.1

### Proposed Development Scenario

In this example, a wind farm is proposed in farmland at a latitude of 53.4°N. The development consists of seven turbines. Each turbine has a hub height of 105m and rotor diameter of 150m, giving a rotor-swept height range of 30-180m. The turbines have a blade radius ( $R$ ) of 75m, a blade pitch ( $\lambda$ ) of 6°, and a maximum blade chord width ( $C$ ) of 4.2m. Each turbine has 3 blades ( $b$ ) and operates at an average rotational speed ( $\Omega$ ) of 11.4rpm. The proposed operational lifetime of 35 years, with turbines expected to be operational approximately 85% of the time.

The blade profile of the turbines is presented in Table 7 - 6 - 16. This table provides the chord width values at 20 evenly spaced points along the blade, expressed relative to the maximum chord width. In this context,  $r$  denotes the distance from the hub, and  $R$  represents the total blade length (i.e., the rotor radius). The ratio  $r/R$  therefore represents the relative radial position along the blade, where 0 corresponds to the hub and 1 corresponds to the blade tip. Similarly,  $c$  represents the chord width at a given distance ( $r$ ) from the hub, and  $C$  is the maximum chord width of the blade. Therefore, the ratio  $c/C$  represents the relative chord width.

Table 7 - 6 - 16 Blade profile of the turbines

| $r/R$ | $c/C$ |
|-------|-------|
| 0.00  | 0.690 |
| 0.05  | 0.730 |
| 0.10  | 0.790 |
| 0.15  | 0.880 |
| 0.20  | 0.960 |
| 0.25  | 1.000 |
| 0.30  | 0.980 |
| 0.35  | 0.920 |
| 0.40  | 0.850 |
| 0.45  | 0.800 |
| 0.50  | 0.750 |
| 0.55  | 0.700 |
| 0.60  | 0.640 |
| 0.65  | 0.580 |
| 0.70  | 0.520 |
| 0.75  | 0.470 |
| 0.80  | 0.410 |
| 0.85  | 0.370 |
| 0.90  | 0.300 |
| 0.95  | 0.240 |
| 1.00  | 0.000 |

4.2

### Bird Survey Scenario

In this example, bird surveys were conducted at the proposed wind farm site for a two year period (April 2023 to March 2025). Vantage point surveys to monitor flight activity were undertaken at two vantage

points. The combined viewsheds from these vantage points provided at least 500m coverage around all turbines in addition to coverage of the site and surrounds (Figure 7 - 6 - 1). The total viewshed area was 5.23km<sup>2</sup> for VP1 and 5.92km<sup>2</sup> for VP2.

Both vantage points were surveyed for 6 hours per month throughout the survey period, totalling 144 hours of survey at each location. For each recorded flight, the duration (in seconds) that bird spent within pre-defined height bands was recorded. These heights bands were:

- > Band 1 = 0-15m
- > Band 2 = 15-25m
- > Band 3 = 25-200m
- > Band 4 = 200m+

As the risk height range of the turbine is 30-180m, all flight activity in Band 3 is considered to be at potential collision height.

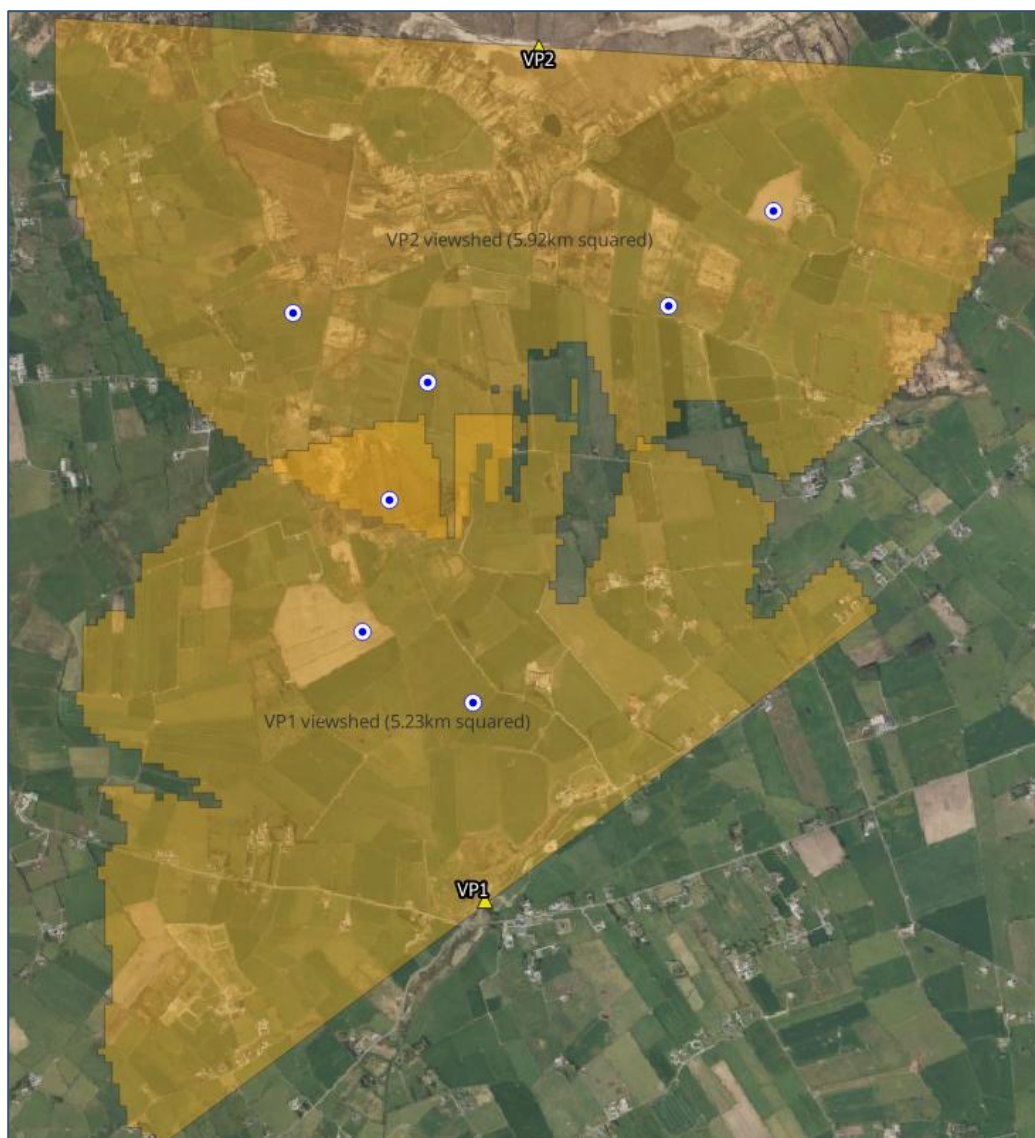


Figure 7 - 6 - 1 Vantage point survey locations and viewshed areas

In this example, a collision risk model will be conducted for the species sparrowhawk. All records for sparrowhawk collected during vantage point surveys are presented in Table 7 - 6 - 17. Records denoted ‘-’ represent non-flight activity, for example when a bird is perched.

The data in Table 7 - 6 - 17 shows that sparrowhawk was present at the site throughout the survey period, in both the breeding and winter season. Therefore, all months of the year will be modelled.

Table 7 - 6 - 17 Sparrowhawk records from vantage point surveys

| VP  | Date       | Time  | Species     | Number | Band 1 | Band 2 | Band 3 | Band 4 |
|-----|------------|-------|-------------|--------|--------|--------|--------|--------|
| VP2 | 17/11/2023 | 07:36 | Sparrowhawk | 1      | 17     | 0      | 0      | 0      |
| VP2 | 17/11/2023 | 07:43 | Sparrowhawk | 1      | -      | -      | -      | -      |
| VP1 | 12/12/2023 | 11:24 | Sparrowhawk | 1      | -      | -      | -      | -      |
| VP1 | 12/01/2024 | 12:14 | Sparrowhawk | 2      | 14     | 0      | 15     | 0      |
| VP2 | 30/01/2024 | 11:34 | Sparrowhawk | 1      | 87     | 0      | 0      | 0      |
| VP2 | 21/02/2024 | 16:19 | Sparrowhawk | 1      | 35     | 0      | 0      | 0      |
| VP1 | 14/03/2024 | 11:48 | Sparrowhawk | 1      | 50     | 12     | 0      | 0      |
| VP1 | 03/05/2024 | 11:25 | Sparrowhawk | 2      | 19     | 0      | 0      | 0      |
| VP2 | 09/05/2024 | 09:56 | Sparrowhawk | 1      | 6      | 0      | 0      | 0      |
| VP1 | 19/06/2024 | 10:14 | Sparrowhawk | 1      | 15     | 3      | 0      | 0      |
| VP1 | 19/06/2024 | 14:22 | Sparrowhawk | 1      | 0      | 0      | 139    | 0      |
| VP1 | 09/07/2024 | 16:56 | Sparrowhawk | 1      | 21     | 0      | 0      | 0      |
| VP2 | 26/07/2024 | 13:37 | Sparrowhawk | 1      | 17     | 0      | 0      | 0      |
| VP1 | 03/10/2024 | 14:02 | Sparrowhawk | 1      | 32     | 9      | 0      | 0      |
| VP1 | 06/11/2024 | 12:15 | Sparrowhawk | 1      | 14     | 4      | 0      | 0      |
| VP1 | 29/11/2024 | 13:09 | Sparrowhawk | 1      | 0      | 18     | 81     | 0      |
| VP1 | 29/11/2024 | 15:57 | Sparrowhawk | 1      | 16     | 0      | 0      | 0      |
| VP2 | 31/01/2025 | 13:07 | Sparrowhawk | 1      | 20     | 48     | 0      | 0      |
| VP2 | 13/03/2025 | 08:46 | Sparrowhawk | 1      | 0      | 83     | 0      | 0      |

#### 4.3

## Stage A: Flight Activity

### Aerial bird density

In order to calculate the aerial bird density ( $D_A$ ) for sparrowhawk, the following formula was used:

$$D_A = b / (t \times A) \text{ bird-seconds m}^2$$

To calculate parameter  $b$ , the number of 'bird-seconds' per month per vantage point was calculated by multiplying the number of birds aloft by the duration of the flight (in seconds). This included time spent in all recorded height bands, not just those bands within potential collision height. These values are presented in Table 7 - 6 - 18. Note that sparrowhawk was not recorded in every month, therefore some months are not present in the table.

Table 7 - 6 - 18 Bird-seconds per vantage point per month

| Month | Vantage Point | Bird-Seconds |
|-------|---------------|--------------|
| Jan   | VP1           | 58           |
| Mar   | VP1           | 62           |
| May   | VP1           | 38           |
| Jun   | VP1           | 157          |
| Jul   | VP1           | 21           |
| Oct   | VP1           | 41           |
| Nov   | VP1           | 133          |
| Jan   | VP2           | 155          |

| Month | Vantage Point | Bird-Seconds |
|-------|---------------|--------------|
| Feb   | VP2           | 35           |
| Mar   | VP2           | 83           |
| May   | VP2           | 6            |
| Jul   | VP2           | 17           |
| Nov   | VP2           | 17           |

Parameter  $t$ , the time that the vantage point was watched, was obtained from the survey effort. The breakdown of survey time at each vantage point is presented in Table 7 - 6 - 19.

Table 7 - 6 - 19 Survey time at each vantage point in hours and seconds according to month

| Vantage Point | Month | Time in hours | Time in seconds |
|---------------|-------|---------------|-----------------|
| VP1           | Jan   | 12            | 43200           |
| VP2           | Jan   | 12            | 43200           |
| VP1           | Feb   | 12            | 43200           |
| VP2           | Feb   | 12            | 43200           |
| VP1           | Mar   | 12            | 43200           |
| VP2           | Mar   | 12            | 43200           |
| VP1           | Apr   | 12            | 43200           |
| VP2           | Apr   | 12            | 43200           |
| VP1           | May   | 12            | 43200           |
| VP2           | May   | 12            | 43200           |
| VP1           | Jun   | 12            | 43200           |
| VP2           | Jun   | 12            | 43200           |
| VP1           | Jul   | 12            | 43200           |
| VP2           | Jul   | 12            | 43200           |
| VP1           | Aug   | 12            | 43200           |
| VP2           | Aug   | 12            | 43200           |
| VP1           | Sep   | 12            | 43200           |
| VP2           | Sep   | 12            | 43200           |
| VP1           | Oct   | 12            | 43200           |
| VP2           | Oct   | 12            | 43200           |
| VP1           | Nov   | 12            | 43200           |
| VP2           | Nov   | 12            | 43200           |
| VP1           | Dec   | 12            | 43200           |
| VP2           | Dec   | 12            | 43200           |

Parameter  $A$  is the entire area of the vantage point viewsheds. As described above, these were:

- > VP1 = 5.23km<sup>2</sup>
- > VP2 = 5.92km<sup>2</sup>

The aerial bird density ( $D_A$ ) was calculated for all vantage points, and then a mean value was obtained for each month. For example,  $D_A$  for January was calculated as:

$$\begin{aligned}
 &\mathbf{VP1} \\
 &b = 58 \\
 &t = 43200 \\
 &A = 5.23 \\
 &D_A = 0.0002563467
 \end{aligned}$$

### VP2

$b = 155$

$t = 43200$

$A = 5.92$

$D_A = 0.0006055715$

### Mean $D_A$ for the month of January

$$(0002563467 \times 0.0006055715)/2 = 0.0004309591$$

$D_A$  for all months is presented in Table 7 - 6 - 20. Zero is input for months in which sparrowhawk was not recorded.

Table 7 - 6 - 20 Aerial bird density

| Jan    | Feb    | Mar    | Apr | May    | Jun    | Jul    | Aug | Sep | Oct    | Nov    | Dec |
|--------|--------|--------|-----|--------|--------|--------|-----|-----|--------|--------|-----|
| 0.0004 | 0.0001 | 0.0003 | 0   | 0.0001 | 0.0003 | 0.0001 | 0   | 0   | 0.0001 | 0.0003 | 0   |

### Proportion of birds flying at risk height

The proportion of sparrowhawk flying at risk height ( $Q_R$ ) was calculated from the survey data in Table 7 - 6 - 17. Note that non-flight records are excluded from this calculation.

First, for each height band, the proportion of flights within that band relative to the total number of flights was calculated. Second, the proportion of each height band overlapping the rotor risk height (30-180m) was determined. Finally, these two proportions were multiplied. The workings for Band 3 (25-200m) are below.

#### Band 3

Total number of sparrowhawk flights = 17

Total number of sparrowhawk flights in band = 3

Proportion of flights in band = 0.176

Proportion of band overlapping rotor risk height = 0.858

$0.176 \times 0.858 = 0.151$

This calculation was made for all bands. Then, the result from each band was summed to provide a total proportion of birds flying at risk height. Note that the result for bands that do not overlap with rotor risk height will be 0. Because Band 3 was the only band that overlapped with rotor risk height in this example, the final proportion of birds flying at risk height ( $Q_R$ ) was 0.151 or 15.1%.

### Photoperiod

The photoperiod at the latitude of the site was acquired for the survey period. The daylight and nighttime hours per month (t<sub>day</sub> and t<sub>night</sub> respectively) are shown in Table 7 - 6 - 21. The total daylight hours was 4,487.093 and night-time hours was 4,272.907.

Table 7 - 6 - 21 Photoperiod

|                 | Jan   | Feb   | Mar   | Apr   | May   | Jun   | Jul   | Aug   | Sep   | Oct   | Nov   | Dec   |
|-----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Daylight Hours  | 251.5 | 273.7 | 366.3 | 418.6 | 491.5 | 507.3 | 510.3 | 459.0 | 382.6 | 329.7 | 261.0 | 235.6 |
| Nighttime Hours | 492.5 | 398.3 | 377.7 | 301.4 | 252.5 | 212.7 | 233.7 | 285.0 | 337.4 | 414.3 | 459.0 | 508.4 |

## 4.4

## Stage B: Number of Flights Through Rotors

To estimate the number of sparrowhawk flights through the rotors, firstly the total rotor frontal area for all turbines was calculated as:

$$\text{rotor frontal area} = T \pi R^2$$

where  $T$  is the number of turbines. In this example, that is  $7 \times \pi \times 75^2 = 123700.2\text{m}^2$

Sparrowhawk biometrics were taken from the best available literature:

- > Length ( $l$ ) = 0.33m
- > Wingspan ( $w$ ) = 0.625m
- > Flight speed ( $v$ ) = 10m/s
- > Flight type = flapping
- > Nocturnal activity ranking ( $f_{\text{night}}$ ) = 1 (0% nighttime activity)

Using the values from previous sections, the density ( $D_v$ ) for each month was calculated as:

$$D_v = (D_A \times Q_R) / (2 \times R)$$

Then the projected number of transits through the rotor risk area was calculated as:

$$\text{transits} = v \times D_v \times \text{rotor frontal area} \times ((t_{\text{day}} + (t_{\text{night}} \times (f_{\text{night}}/100))) \times 3600)$$

In this example, the density for the month of January was  $(0.0004 \times 0.151) / (2 \times 75) = 4.349921^{-13}$

The number of transits for the month of January was  $10 \times 4.349921^{-13} \times 123700.2 \times ((251.519 + (492.481 \times (0/100))) \times 3600) = 0.4872201$ . Table 7 - 6 - 22 shows the projected number of transits for all months. Note that a zero is input for months in which sparrowhawk was not recorded.

Table 7 - 6 - 22 Number of transits per month

| Jan   | Feb   | Mar   | Apr | May   | Jun   | Jul   | Aug | Sep | Oct   | Nov   | Dec |
|-------|-------|-------|-----|-------|-------|-------|-----|-----|-------|-------|-----|
| 0.487 | 0.084 | 0.493 | 0   | 0.211 | 0.791 | 0.183 | 0   | 0   | 0.134 | 0.384 | 0   |

## 4.5

# Stage C: Probability of Collision

The probability of a sparrowhawk collision during a single rotor transit was calculated. Sparrowhawk biometrics, flight behaviour and the turbine specifications outlined in the previous sections were used to define how the bird interacts with the moving blades and derive the geometric parameters described below. Collision probability was determined separately for upwind and downwind flight directions. It was calculated as a function of radial position across the rotor disc, at increments of 0.05 from 0.05 to 1.0 (excluding the rotor centre).

At each radial position, collision probability was calculated for flight angles at increments of 10° from 0° to 180°, which assumes a uniform distribution of bird approach angles. For each flight angle, the flight angle ( $\Phi$ ) was converted from degrees to radians and turbine rotation speed ( $\Omega$ ) was converted from rpm to radians per second. The dimensionless radial position ( $\text{radius}$ ) was converted to an absolute distance from the hub in metres. Then, the blade chord width at the radial position was estimated by interpolating the blade profile and scaling it by the maximum chord width, to reflect blade width changes from hub to tip. Flight direction ( $d$ ) was set as 1 for upwind flight directions and -1 for downwind.

A standard dimensionless blade encounter rate multiplier was defined as:

$$b \Omega / 2 \pi v$$

where  $b$  is number of blades,  $\Omega$  is rotation speed (now in  $\text{rad s}^{-1}$ ), and  $v$  is bird flight speed.

The ratio of bird speed to blade tangential speed ( $\alpha$ ) was calculated as:

$$\alpha = v / \text{radius} \Omega$$

The blade pitch ( $\lambda$ ) was converted from degrees to radians to obtain the blade tilt angle ( $\theta$ ) relative to the rotor plane:

$$\theta = \lambda\pi/180$$

Using these values, two collision lengths were calculated. The first was a blade-related component (accounting for blade chord width [ $c$ ], blade tilt [ $\theta$ ], bird flight direction [ $d$ ] and the ratio of bird speed to blade tangential speed [ $\alpha$ ]), which represents the effective ‘interaction length’ associated with blade motion and geometry:

$$|d c \sin(\theta) + \alpha c \cos(\theta)|$$

The second was a bird-size-related component (accounting for body length [ $l$ ], wingspan [ $w$ ] and flight type):

$$\max(l, w_{\text{eff}} \alpha)$$

Here,  $w_{\text{eff}}$  is the effective wingspan. For flapping flight, the full wingspan was used, but for gliding flight, the wingspan would be reduced by the absolute value of the cosine of the flight angle relative to the rotor plane ( $\Phi$ ) to represent the reduced projected cross-section when the bird’s wings are angled relative to the rotor plane.

Finally, the collision probability was calculated as the blade encounter rate multiplier multiplied by the sum of the two collision lengths. The result is capped at a maximum of 1 so that probabilities cannot exceed 100%. This collision probability was then averaged over the flight angles at the radial position. The upwind and downwind collision probabilities calculated for each radial position for sparrowhawk are presented in Table 7 - 6 - 23.

Table 7 - 6 - 23 Upwind and downwind collision probabilities

| Radial Position | Upwind   | Downwind |
|-----------------|----------|----------|
| 0.05            | 0.486082 | 0.449547 |
| 0.1             | 0.269631 | 0.230093 |
| 0.15            | 0.204551 | 0.160508 |
| 0.2             | 0.171557 | 0.123511 |
| 0.25            | 0.1502   | 0.100152 |
| 0.3             | 0.130199 | 0.081152 |
| 0.35            | 0.11173  | 0.065686 |
| 0.4             | 0.096588 | 0.054047 |
| 0.45            | 0.086103 | 0.046065 |
| 0.5             | 0.077465 | 0.039929 |
| 0.55            | 0.070171 | 0.035137 |
| 0.6             | 0.06319  | 0.031159 |
| 0.65            | 0.057052 | 0.028024 |
| 0.7             | 0.051576 | 0.025551 |
| 0.75            | 0.047235 | 0.023713 |
| 0.8             | 0.042698 | 0.022178 |
| 0.85            | 0.039644 | 0.021126 |
| 0.9             | 0.035181 | 0.020167 |
| 0.95            | 0.031534 | 0.019522 |
| 1               | 0.01881  | 0.01881  |

Next, the collision probabilities were averaged for flights through the rotor disk for upwind values and downwind values as follows:

$$P = 2[(i=1 \sum n - 1r_p) + 2p_n] \Delta r$$

Where  $P$  is the mean single-transit collision probability (upwind or downwind),  $r$  is the radial position,  $p_r$  is the collision probability at radial position  $r$ ,  $p_n$  is the collision probability at the outermost radial position (i.e., the blade tip),  $\Delta r = 0.05$  (i.e., the radial increments) and  $n$  is the number of evaluated radial positions

The average collision risk for flights through the rotor when moving upwind was calculated as 0.0672, and for downwind as 0.0402. A 50:50 weighting of upwind and downwind flight was assumed. Thus, the final probability of a sparrowhawk collision during a single rotor transit was calculated as the weighted average of these two estimates. The estimated probability of collision for a sparrowhawk during a single rotor transit was 0.0537.

## 4.6 Stage D Expected Collisions

The outputs of stage B and C were multiplied to yield the expected collision rate for sparrowhawk, and the product was multiplied by the proportion of time the wind farm is expected to be operational. In this example, the expected collisions for January was calculated as:

$$0.487 \times 0.0537 \times 0.85 = 0.02224467$$

The predicted number of collisions for each month is presented in Table 7 - 6 - 24. Note that these rates assume no avoidance of turbines or wind farms by sparrowhawk.

Table 7 - 6 - 24 Expected collisions per month (without avoidance)

| Jan   | Feb   | Mar   | Apr   | May   | Jun   | Jul   | Aug   | Sep   | Oct   | Nov   | Dec   |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 0.022 | 0.004 | 0.023 | 0.000 | 0.010 | 0.036 | 0.008 | 0.000 | 0.000 | 0.006 | 0.018 | 0.000 |

## 4.7 Stage E Allowing for Avoidance and Attraction

Stage E of the modelling process takes account of the proportion of sparrowhawk likely to avoid the wind farm or its turbines. This is calculated for a range of avoidance factors: 95%, 98%, 99% and 99.5%. The expected collisions per month calculated in stage D are multiplied by the avoidance rates to provide a collision rate with avoidance. These values are presented in Table 7 - 6 - 25.

Table 7 - 6 - 25 Expected collisions per month (with avoidance)

| Avoidance Factor | Jan        | Feb        | Mar        | Apr        | May        | Jun        | Jul        | Aug        | Sep        | Oct        | Nov        | Dec        |
|------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| 0.95             | 0.001<br>1 | 0.000<br>2 | 0.001<br>1 | 0.000<br>0 | 0.000<br>5 | 0.001<br>8 | 0.000<br>4 | 0.000<br>0 | 0.000<br>0 | 0.000<br>3 | 0.000<br>9 | 0.000<br>0 |
| 0.98             | 0.000<br>4 | 0.000<br>1 | 0.000<br>5 | 0.000<br>0 | 0.000<br>2 | 0.000<br>7 | 0.000<br>2 | 0.000<br>0 | 0.000<br>0 | 0.000<br>1 | 0.000<br>4 | 0.000<br>0 |
| 0.99             | 0.000<br>2 | 0.000<br>0 | 0.000<br>2 | 0.000<br>0 | 0.000<br>1 | 0.000<br>4 | 0.000<br>1 | 0.000<br>0 | 0.000<br>0 | 0.000<br>1 | 0.000<br>2 | 0.000<br>0 |
| 0.995            | 0.000<br>1 | 0.000<br>0 | 0.000<br>1 | 0.000<br>0 | 0.000<br>1 | 0.000<br>2 | 0.000<br>0 | 0.000<br>0 | 0.000<br>0 | 0.000<br>0 | 0.000<br>1 | 0.000<br>0 |

## 4.8 Stage F: Uncertainty

To provide a measure of uncertainty in aerial density ( $u_1$ ), the relative standard error for the monthly values was used. First, the mean aerial density ( $\bar{D}_x$ ) for all months was calculated to be 0.0001445. Then, the standard error of the mean (SEM) was calculated as:

$$SEM = s / \sqrt{n}$$

where *s* is the standard deviation of the monthly values and *n* is the number of months being considered. In this example:

$$0.00015 / \sqrt{12} = 0.000044$$

Finally, to express this as a proportion uncertainty, the relative standard error (**RSE**) was calculated as:

$$RSE = SEM / \bar{D}_x$$

Note that zero values (i.e., months in which the sparrowhawk was not recorded, such as April) were retained in this equation as they may represent true absence or intermittent use of the site. If a large proportion of zero values were to occur (i.e., the species was recorded infrequently during vantage point surveys), this will increase the RSE. In this example the proportion uncertainty (RSE) was:

$$0.000044 / 0.0001445 = 0.3039$$

Uncertainty due to simplifications in the collision risk model (*u2*) was assumed to be 20% (Band, 2024). Finally, uncertainty due to design options (*u3*) was considered to be 28%, as 4 of 14 turbine specifications were either not finalised or were approximate (blade profile, pitch, rotational speed and expected time operational). The overall range of uncertainty (*u*) was thus:

$$\sqrt{(u1^2 + u2^2 + u3^2)}$$

In this example, that is:

$$\sqrt{(0.3^2 + 0.2^2 + 0.28^2)} = 0.46$$

Expressed as a percentage, the overall uncertainty was 46%.

#### 4.9

## Worked Example Collision Rates

To provide a best estimate of the collision rate for sparrowhawk, the guidance on avoidance rates provided by NatureScot in NatureScot (2025b) was consulted. This guidance recommends a 98% avoidance rate for sparrowhawk. As such the predicted number of collisions corresponding to a 98% avoidance rate was identified and is presented in Table 7 - 6 - 26, along with the range of uncertainty and an estimation of the number of years for one collision to occur.

The column ‘Annual Collision Rate’ in Table 7 - 6 - 26 presents the final predicted annual collision rate for sparrowhawk that would be used in the impact assessment for this proposed development scenario: 0.0025 sparrowhawk per year. Due to the uncertainties discussed in stage F, this may range from 0.0011 to 0.0039 sparrowhawk per year. Dividing 1 by 0.0025 provides the number of years it would be expected for a collision to occur based on the model predictions.

Table 7 - 6 - 26 Predicted annual collision rate

| Species     | Annual Collision Rate | Range of Uncertainty | Years to one collision |
|-------------|-----------------------|----------------------|------------------------|
| Sparrowhawk | 0.0025                | 0.0011-0.0039        | 395                    |

#### 5.

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