APPENDIX 7-6

COLLISION RISK ASSESSMENT

Table of Contents

TABLE OF TABLES

1. INTRODUCTION

This document outlines the methodology used to assess the collision risk for birds at the proposed Ballivor Wind Farm, located at the Ballivor Bog Group in County Meath and Westmeath. The collision risk assessment is based on vantage point surveys undertaken at the wind farm site from April 2020 to September 2022 inclusive. This represents a 30-month survey period, consisting of three breeding seasons and two winter seasons, which is in full compliance with Scottish Natural Heritage guidance (SNH, 2017). Surveys were undertaken from sixteen fixed Vantage Point (VP) Locations, (i.e. VP1, VP2, VP3, VP4, VP5, VP6, VP7, VP8, VP9, VP10, VP11, VP12, VP13, VP14, VP15 & VP16) between April 2020 and September 2022.

Collision risk is calculated 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 in this collision risk calculation is known as the Band Model (Band *et al.,* 2007) and has been used in a number of studies on bird collision with wind turbines (e.g. Chamberlain *et al.,* 2006; Drewitt and Langston, 2006; Fernley *et al.,* 2006; Madders and Whitfield, 2006). Note that these are theoretical predictions, therefore results must be interpreted with a degree of caution.

Two stages are involved in the Band Model. First, the number of bird transits through the air space swept by the rotor blades of the wind turbines per year is estimated. Then the collision risk for a bird passing through the rotor blades is calculated using a mathematical formula. The product of these provides a theoretical annual collision mortality rate. Finally, a bird avoidance rate is applied to the collision mortality rate to account for birds attempting to avoid collision. This final collision mortality rate informs the assessment of impacts of the wind farm development on key ornithological receptors (KORs) in the EIAR.

2. METHODOLOGY

2.1 The Band Model

The Band Model is used to predict the number of bird collisions that might be caused by a wind farm development. It uses species-specific information on bird biometrics, flight characteristics and the expected amount of flight activity, along with turbine-specific information on hub height, rotor diameter, pitch and rotational speed. The 26 No. turbines will be 115m at hub height, with 3 blades with a diameter of 170m, giving a maximum rotor height of 200m and a minimum rotor height of 30m. The model makes a number of assumptions on the turbine design and on biometrics of birds:

1. Birds are assumed to be of a simple cruciform shape.
2. Turbine blades are assumed to have length, depth and pitch angle, but no thickness.
3. Birds fly through turbines in straight lines.
4. Bird flight is not affected by the slipstream of the turbine blade.

- Because the model assumes that no action is taken by a bird to avoid collision, it is recognised that the collision risk figures derived are purely theoretical (before an avoidance factor is applied)[1].

Two forms of collision risk modelling are outlined by Band *et al.* (2007): a **"Regular Flight Model"** and the **"Random Flight Model"**. A Regular Flight Model is generally applied to situations where flightlines form a regular pattern. This may occur, for example, when birds are using the wind farm site as a commuting corridor between roosting and feeding grounds or migratory routes, as is often observed in geese and swans. The Random Flight Model generally applied to situations where flightlines form no discernible patterns or routes. This is often observed, for example when raptors are in foraging or hunting flights.

The Regular Flight Model predicts the number of transits through a cross-sectional area of the wind farm which represents the width of the commuting corridor. A "risk window" is identified: a 2-dimensional line the width of the wind farm to a 500m buffer of the turbines, multiplied by the rotor diameter. All commuting flights which pass through this risk window within the rotor swept height (potential collision height; PCH) are included in collision risk modelling. Any regular flights more than 500m from the turbine layout can be excluded from the analysis. There are a number of key assumptions and limitations:

- 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.
- 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).
- Habitat and bird activity will remain the same over time and be unchanged during the operational stage of the windfarm.

[1] *As previously outlined, a bird avoidance rate is applied to the collision mortality rate predicted by the model to account for birds attempting to avoid collision*

- All flight activity used in the model occurred within the viewshed area calculated at the lowest swept rotor height.

The Random Flight Model predicts the number of transits through the wind farm while assuming that all flights within the vantage point viewshed are randomly occurring, i.e., any observed flight could just as easily occur within the wind farm site as outside it. All flights within PCH inside the viewshed are included in the model. There are a number of key assumptions and limitations:

- Bird activity is not spatially explicit, i.e., activity is equal throughout the viewshed area and this is equal to activity in the windfarm area.
- Habitat and bird activity will remain the same over time and be unchanged during the operational stage of the windfarm.
- All flight activity used in the model occurred within the viewshed area calculated at the lowest swept rotor height.

More detail on both the Random and Regular Flight Model calculations are available from SNH: https://www.nature.scot/wind-farm-impacts-birds-calculating-theoretical-collision-risk-assuming-no-avoiding-action. In the case of Ballivor wind farm, for all species recorded in flight in the wind farm study area, flights were randomly distributed. Therefore, a Random Flight Model was conducted for these species.

2.2 Modelling Process

The steps used in the Band Model to derive the collision mortality rate for each species observed at the wind farm site are outlined below.

- Stage 1: Estimate the number of bird transits through the air space swept by the rotor blades of the wind turbines. Transits are calculated using either the “Regular” or “Random” flight model (Band *et al.,* 2007), depending on flight distribution and behaviour.
- Stage 2: Calculate the collision risk for an individual bird flying through a rotating turbine blade. Collision risk is calculated using a formula which incorporates the number of bird transits (Stage 1), individual species’ biometrics, individual species’ flight speed and style, and the proposed turbine parameters. This formula is publicly available on the SNH website: https://www.nature.scot/wind-farm-impacts-birds-calculating-probability-collision. Biometrics are available from the British Trust of Ornithology (BTO, 2021) and flight speeds are available from Alerstam *et al.* (2007). For species that can both flap and glide, the mean of the collision risk for flapping and for gliding flight is taken.
- The product of the number of bird transits per year multiplied by the collision risk provides an annual collision mortality rate. Note that this is the worst-case scenario for collision mortality, as it assumes that birds flying towards the turbines make no attempt to avoid them.
- To account for birds attempting to avoid a collision, an avoidance factor is applied to the annual collision mortality rate. This corrects for the ability of the birds to detect and manoeuvre around the turbines. Avoidance rates are available from SNH (2018). Bird avoidance rates are generally 98-99% or higher for most species, based on empirical evidence, targeted studies and literature reviews, and continue to be updated following further studies of bird behaviour and mortality rates at wind farm sites.

The final annual collision risk corrected for avoidance is a “real-world” estimation of the number of collisions that may occur at the wind farm, based on observed bird activity during the vantage point survey period.

2.3 Turbine specifications

Birds in flight within the viewshed at heights between 30-200m above ground level have been included in the collision risk model. The turbine specifications are available in Table 1.

Table 1 Turbine specifications at Ballivor wind farm

Wind Farm Component	Scenario Modelled
Number of turbines	26
Blades per turbine rotor	3
Rotor diameter (m)	170
Rotor radius (m)	85
Hub height (m)	115
Swept height (m)	30-200
Pitch of blade (degrees)	6
Maximum chord (m) (i.e. depth of blade)	4.5
Rotational period (s)[2]	6.75
*Turbine operational time	85%

***This operational period of 85% is referenced from a report by the British Wind Energy Association (BWEA) (2007) which identifies the standard operational period of the wind turbines in the UK to be roughly 85%.**

Using the above turbine parameters ensures the 26 No. turbines with a blade diameter of 170m, giving a maximum rotor height of 200 and a minimum rotor height of between 30m are assessed in the analysis.

2.4 Key Ornithological Receptors

The key ornithological receptors (KORs) recorded within PCH during surveys at Ballivor were:

- Golden Plover
- Hen Harrier
- Merlin
- Peregrine
- Whooper Swan
- Kestrel
- Lapwing
- Snipe
- Buzzard
- Sparrowhawk

A CRM was conducted for each of these species. It is acknowledged that the predicted number of transits, and hence predicted rate of collision, for snipe may be largely underestimated, as flight activity for this species is largely crepuscular in nature (during twilight) while the VP survey sample predominantly consists of hours during daylight period when visibility is not an issue. It is assumed that waterbirds (including snipe) are active for 25% of the night along with daylight hours (as per SNH guidance) and this is accounted for in the model.

2.5 Calculation Parameters

The calculation parameters for the vantage point are outlined in Table 2. Bird biometrics are presented in Table 3. Table 4 presents the model input values: bird seconds in flight at PCH (random model)

[2] *The assumed turbine model was Nordex 163 Turbine for the following parameters: maximum chord and rotational period.*

observed from the vantage point during the relevant survey period. Bird seconds in flight at PCH is calculated by multiplying the number of birds observed per flight by the duration of the flight spent within PCH.

*Table 2 Ballivor wind farm survey effort and viewshed coverage**

Vantage Point	Visible Area at 30m	Risk Area	Turbines visible	Total Survey Effort
VP2	622.029	163.034	3	180.5
VP4	636.478	339.228	6	177
VP5	362.189	131.952	2	177
VP6	626.218	102.659	2	177
VP7	612.517	329.938	6	177
VP8	637.284	95.422	1	174
VP9	491.369	86.698	1	177
VP13	625.431	201.842	3	180.75
VP14	610.735	403.728	7	180
VP15	623.104	422.18	8	180
VP16	507.702	80.091	1	180

**VP1, VP3, VP10, VP11 and VP12 are omitted from this analysis as the visible area of the vantage point does not cover any of the proposed turbines.*

Table 3 Bird biometrics

Species	Body Length(m)	Wingspan(m)	Flight Speed(m/s)
Golden Plover	0.28	0.72	17.9
Hen Harrier	0.48	1.1	9.1
Merlin	0.28	0.56	12.6
Peregrine Falcon	0.42	1.02	20.7
Whooper Swan	1.52	2.3	17.3
Kestrel	0.34	0.76	10.1
Lapwing	0.3	0.84	11.9
Snipe	0.26	0.46	17.1
Buzzard	0.54	1.2	13.3
Sparrowhawk	0.33	0.62	10

Table 4 Model input values

Species	Model	Period	PCH sec. (Total)
Golden Plover	random	September to April	2,874,860
Hen Harrier	random	September to March	185
Merlin	random	All	356
Peregrine	random	All	3,724
Whooper Swan	random	Winter	63,242
Kestrel	random	All	26,494
Lapwing	random	Breeding	3,200
Lapwing	random	Winter	79,069
Snipe	random	All	3,930
Buzzard	random	All	53,314
Sparrowhawk	random	All	2,877

The avoidance rates applied to the collision risk were: 99.8% for golden plover[3], 99.5% for whooper swan, 99% for hen harrier, 95% for kestrel and 98% for the remaining species.

[3] *See Appendix 1 for further details.*

3. RESULTS

The predicted number of transits per year and the collision risk is presented in Table 5, along with the final predicted number of collisions per year. Note that for birds that both flap and glide, the average collision risk percentage between flapping and gliding is taken.

Table 5 Results of CRM

Species	Survey Period	Model	Transits	Collision Risk			Collision Rate			Estimated Collisions Over Lifetime of Wind Farm	One Bird Collision
				flapping	gliding	overall	without avoidance	avoidance factor	with avoidance		
Golden Plover	September to April	random	190281.2	4.08%	no gliding flight	4.08%	7763.49	99.8%	15.527	465.81 birds	<1 year
Hen Harrier	September to March	random	5.3	5.65%	5.54%	5.6%	0.29	99%	0.003	0.09 birds	339 years
Merlin	All	random	16.7	4.24%	4.18%	4.21%	0.7	98%	0.014	0.42 birds	71 years
Peregrine Falcon	All	random	262.3	4.41%	4.15%	4.28%	11.22	98%	0.224	6.73 birds	4 years
Whooper Swan	Winter	random	3615.9	7.42%	no gliding flight	7.42%	268.46	99.5%	1.342	40.27 birds	1 year
Kestrel	All	random	934.2	4.77%	4.68%	4.72%	44.13	95%	2.206	66.19 birds	<1 year
Lapwing	Breeding	random	162.6	4.47%	no gliding flight	4.47%	7.26	98%	0.145	4.36 birds	7 years
Lapwing	Winter	random	2952.2	4.47%	no gliding flight	4.47%	131.82	98%	2.636	79.09 birds	<1 year
Snipe	All	random	301.1	3.93%	no gliding flight	3.93%	11.84	98%	0.237	7.1 birds	4 years
Buzzard	All	random	2426.4	5.19%	5.03%	5.11%	124.04	98%	2.481	74.42 birds	<1 year
Sparrowhawk	All	random	103.9	4.7%	4.64%	4.67%	4.86	98%	0.097	2.91 birds	10 years

BIBLIOGRAPHY

Alerstam, T., Rosen M., Backman J., G P., Ericson P & Hellgren O. 2007. *Flight Speeds among Bird Species: Allometric and Phylogenetic Effects.* PLoS Biol, 5, 1656-1662. DOI:10.1371/journal.pbio.0050197

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. De Lucas, G.F.E. Janss and M. Ferrer, Eds.: 259-275. Quercus, Madrid.

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.* Ibis 148: 198–202.

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.* Ibis 148 p.29-42

Fernley, J., Lowther, S. & Whitfield P. 2006. *A Review of Goose Collisions at Operating Wind Farms and Estimation of the Goose Avoidance Rate.* Unpublished Report by West Coast Energy, Hyder Consulting and Natural Research.

Madders, M. & Whitfield, P.D. (2006). *Upland Raptors and the Assessment of Wind Farm Impacts.* Ibis (2006), 148, 43-56.

Whitfield, D.P. & Urquhart, B. (2015). *Deriving an avoidance rate for swans suitable for onshore wind farm collision risk modelling.* Natural Research Information Note 6. Natural Research Ltd, Banchory, UK.

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

British Trust of Ornithology (BTO) online BirdFacts. Available at https://www.bto.org/about-birds/birdfacts

https://www.timeanddate.com/sun/

APPENDIX 1

GOLDEN PLOVER AVOIDANCE RATES

`

BALLIVOR WIND FARM: GOLDEN PLOVER AVOIDANCE RATES

Tom Gittings BSc, PhD, MCIEEM
Ecological Consultant
3 Coastguard Cottages
Roches Point
Whitegate
CO. CORK
www.gittings.ie

REPORT NUMBER: 2211-F1
STATUS OF REPORT: Revision 2
DATE OF REPORT: 18 July 2022

CONTENTS

SUMMARY

This report assesses the evidence for developing a species-specific avoidance rate for wintering Golden Plover populations, and makes recommendations for specifying this rate.

Collision risk modelling for onshore wind farms in Ireland generally follows the latest Scottish Natural Heritage / Natural Scotland avoidance rate guidance. This guidance includes two types of avoidance rates: species-specific avoidance rates; and a default avoidance rate that should be applied to all other species. Based on the latest version of the guidance, the default avoidance rate of 98% applies to wintering Golden Plover populations. However, review of the development of the SNH avoidance rate guidance shows that the default avoidance rate of 98% is not based on any published empirical evidence, the trend is for avoidance rates to increase as more data becomes available, and the guidance does not always reflect the latest evidence on species-specific avoidance rates. Therefore, the lack of a species-specific avoidance rate for Golden Plover in the SNH avoidance rate guidance does not necessarily mean that there is not any robust data available that could be used to develop a species-specific avoidance rate for Golden Plover.

There are reports for four UK wind farms that provide data that can be used to estimate avoidance rates, or which provide their own estimates of avoidance rates, for wintering Golden Plover populations. For three of these wind farms, the collision monitoring methodologies are robust and generally comply with best practice guidance, so the collision fatality estimates can be regarded as reliable. The avoidance rates calculated for the wintering Golden Plover populations at these wind farms range from 99.87-99.98%. For the fourth wind farm, the available information on the collision monitoring methodology was limited, but there may have been some issues with the methodology and results. The avoidance rate for the wintering Golden Plover population given in the relevant reports for this wind farm was 99.6%.

The highest avoidance rate currently recommended by Scottish Natural Heritage / Natural Scotland is 99.8% for geese. The narrow range of the avoidance rate values for wintering Golden Plover populations at the three wind farms with reliable collision fatality estimates would suggest that 99.8% is a suitable avoidance rate for wintering Golden Plover populations. The 99.6% avoidance rate at the other wind farm is lower than this value, although there may be some issues with this avoidance rate. Therefore, I recommend that collision risk modelling for wintering Golden Plover populations use two avoidance rate values: 99.6% and 99.8%. In practice, this will mean two predicted collision rates, with the one calculated with the 99.6% avoidance rate being twice the value of the other calculated with the 99.8% avoidance rate. These predicted collisions will be five times, and ten times, respectively, lower than predicted collisions calculated with the default 98% avoidance rate.

1. INTRODUCTION

This report was commissioned by MKO.

The objective of the report was to assess the evidence for developing a species-specific avoidance rate for wintering Golden Plover populations, and, if appropriate, make recommendations for specifying this rate.

Collision risk modelling for onshore wind farms in Ireland generally follows the latest Scottish Natural Heritage / Natural Scotland avoidance rate guidance (referred to hereafter as the SNH avoidance rate guidance). The latest version of this guidance (SNH, 2018) does not include a species-specific avoidance rate for wintering Golden Plover populations. Therefore, following the SNH avoidance rate guidance would mean that the default 98% avoidance rate should be applied to wintering Golden Plover populations. However, there is apparently robust data available from post-construction monitoring that indicates that a much higher avoidance rate should be applied to wintering Golden Plover populations.

In this report, I first review the development of the SNH avoidance rate guidance and consider whether the history of its development affects the interpretation of the fact that it does not include a species-specific avoidance rate for wintering Golden Plover populations. I then review the methods and results of four post-construction monitoring studies, and use the data from these studies to derive empirical avoidance rates for the wintering Golden Plover population in each study. I then assess the overall weight of evidence for applying a species-specific avoidance rate to wintering Golden Plover populations and make recommendations for avoidance rate values that should be used in collision risk modelling for such populations.

2. THE SNH AVOIDANCE RATE GUIDANCE

2.1. TYPES OF AVOIDANCE RATES

The SNH avoidance rate guidance includes two types of avoidance rates: specific avoidance rates for individual species, or groups of closely-related species (e.g., swans or geese); and a default avoidance rate that should be applied to all other species.

2.2. THE EVOLUTION OF THE SNH AVOIDANCE RATES

The latest version of the SNH avoidance rate guidance (SNH, 2018) includes a default 98% avoidance rate for species not listed in their guidance. However, this default avoidance rate does not appear to have any empirical basis.

In 2000, the first guidance from Scottish Natural Heritage on avoidance rates recommended a precautionary avoidance rate of 95%, which was "based solely on expert opinion and has little or no empirical basis, as no sound, relevant data were available at the time" (SNH, 2010). In 2010, Scottish Natural Heritage updated their guidance on avoidance rates to included species-specific avoidance rates where relevant data was available (SNH, 2010). They also updated the default avoidance rate for other species to 98% because "in the majority of cases where avoidance rates have been derived from empirical data, the avoidance rates are higher than 95%" (SNH, 2010). Further revisions of the SNH avoidance rate guidance were published in 2016 and 2018 (SNH, 2016; 2018). Comparison of the first species-specific avoidance rates published by Scottish Natural Heritage with the latest species-specific avoidance rates (Table 2.1) shows that as the knowledge base has developed there has been an increase in the recommended avoidance rates. Most species-specific avoidance rates are 99% or higher. The only species with species-specific avoidance rates of less than 99% are White-tailed Eagle and Kestrel.

Table 2.1. Species-specific avoidance rates defined in SNH guidance

Species	SNH Guidance	
	2010	2018
Divers	98%	99.5%
Swans	98%	99.5%
Geese	99%	99.8%
Red Kite	98%	99%
Hen Harrier	99%	99%
Golden Eagle	99%	99%
White-tailed Eagle	95%	95%
Kestrel	95%	95%
Skuas	98%	99.5%

Sources: SNH (2010, 2018). Divers: the 2010 guidance gives a species-specific avoidance rate for Red-throated Diver and a default avoidance rate for Black-throated Diver. Swans: the 2010 guidance gives a species-specific avoidance rate for Whooper Swan, and does not provide avoidance rates for other swan species, while the 2018 guidance gives a species-specific avoidance rate for all swan species. Geese: the 2010 guidance gives separate (but identical) species-specific avoidance rates for Greylag, Pink-footed, Greenland White-fronted and Barnacle Geese, while the 2018 guidance gives a single species-specific avoidance rate for all geese species. Skuas: the 2010 guidance gives a single default avoidance rate for all skua species, while the 2018 guidance gives separate (but identical) species-specific avoidance rates for Great Skua and Arctic Skua.

2.3. EXAMPLES OF SPECIES-SPECIFIC AVOIDANCE RATES IN THE SNH AVOIDANCE RATE GUIDANCE

The 95% avoidance rate for White-tailed Eagle is described as being based on: "sufficient evidence from flight behaviour and collision monitoring studies in Norway for vulnerability to collisions; see May *at al.* (2011)" (SNH, 2018). However, this appears to include a citation error as May *at al.* (2011) provides an estimate for a year-round avoidance rate of 98%, with a confidence interval of 95-99%, based on satellite telemetry data. Presumably, the intended citation was May *at al.* (2010), which included an estimated avoidance rate of 95.8%, based on VP survey data, corrected for the observed wind speed distribution at the study site. This latter reference also included avoidance rates of 97.8% and 97.9% for fixed rotation speeds, and an avoidance rate of 92.5% when the collision risk was modelled using uncertainty levels. The SNH avoidance rate guidance on avoidance rates does not discuss these differing estimates of White-tailed Eagle avoidance rates, and the recommended 95% avoidance rate has remained unchanged since 2010 without any caveats added to reflect the various avoidance rates indicated by the May *at al.* (2010 and 2011) studies.

The 95% avoidance rate for Kestrel is described as being based on: *"*sufficient evidence from flight behaviour (including hovering) and collision monitoring studies for vulnerability to collisions*"* (SNH, 2018). The cited source (Whitfield and Madders, 2006) is, in fact, a review of avoidance rates for Red Kite. The information on Kestrel is derived from an analysis which finds a significant correlation between the *"*numbers of individuals seen*"* against numbers of carcasses found for 16 raptor species at a single wind farm in Spain. Kestrel is a large outlier above the regression line, and this appears to be the only empirical evidence that has been used by SNH to support the 95% avoidance rate for Kestrel. However, even taken at face value, all this analysis does is indicate that Kestrel has a lower avoidance rate than other raptor species, but it does not provide any quantitative data that can be used to estimate the avoidance rate. More seriously, this analysis does not account for behavioural and ecological differences between species that may affect the relationship between recorded bird activity and collisions. It is also subject to the perennial problem with analyses of collision rates: the small absolute numbers of collisions which means that random sampling error may have significant effects.

These two examples show that the species-specific avoidance rates in the SNH avoidance rate guidance do not necessarily reflect all the available evidence (White-tailed Eagle) and can be based on rather sketchy evidence (Kestrel).

2.4. UPDATING THE SNH AVOIDANCE RATE GUIDANCE

The SNH avoidance rate guidance states that *"*it is updated when robust new information becomes available*"* (SNH, 2018). However, while this may be an aspiration, it may not necessarily happen quickly. For example, the SNH avoidance rate guidance currently does not give species-specific avoidance rates for gulls, so the default avoidance rate of 98% applies to all gull species. This guidance refers specifically to onshore wind farms, while separate guidance has been developed for offshore wind farms (JNCC *at al.*, 2014). The latter guidance recommends an avoidance rate of 99.5% for large gulls, based on a review by Cook *at al.* (2014). The discrepancy between the recommended avoidance rates for large gulls between offshore and onshore wind farms, was not addressed until a review by Furness (2019), which was commissioned by SNH. This review recommended that the 99.5% avoidance rate for large gulls at offshore wind farms should also be adopted for onshore wind farms. The review also recommended an avoidance rate of 99.2% for small gulls, which was also based on the data in Cook *at al.* (2014). However, as of June 2022, Scottish Natural Heritage / NatureScot have not updated their guidance on avoidance rates for onshore wind farms to reflect the robust evidence that has been available about species-specific avoidance rates for gulls since at least 2014.

2.5. CONCLUSIONS

The above analysis of the development of the SNH avoidance rate guidance and its treatment of avoidance rates for White-tailed Eagle, Kestrel and gulls, shows that the default avoidance rate of 98% is not based on any published empirical evidence, the trend is for avoidance rates to increase as more data becomes available, and the guidance does not always reflect the latest evidence on species-specific avoidance rates. Therefore, the lack of a species-specific avoidance rate for Golden Plover in the SNH avoidance rate guidance does not necessarily mean that there is not any robust data available that could be used to develop a species-specific avoidance rate for Golden Plover.

3. REVIEW OF GOLDEN PLOVER AVOIDANCE RATES

3.1. SOURCES

I found post-construction monitoring reports for three UK wind farms that provide robust data on Golden Plover collision fatality rates, and, for which, there was appropriate data available that could be used to estimate avoidance rates. These reports were for the Blood Hill Wind Farm (Percival *at al.*, 2008), the Goole Fields I Wind Farm (Percival *at al.*, 2018a) and the Goole Fields II Wind Farm (Percival *at al.*, 2018b, 2019). In addition, information on Golden Plover collision fatality rates and avoidance rates is included in the Habitats Regulations Assessment reports for another UK wind farm site (Haverigg II and III[1]; Percival, 2020a, 2020b), although the reports do not contain sufficient detail to allow full review of the collision monitoring methods and results. Unless otherwise stated, all information and data used in this report for each wind farm was taken from the relevant references cited above.

The characteristics of these wind farms are summarised in Table 3.1.

Table 3.1. Characteristics of the wind farms.

Wind farm	Location	Commissioned	Number of turbines	Hub height (m)	Turbine dimeter (m)
Blood Hill Wind Farm	Norfolk	1992	10	30	27
Goole Fields I	Yorkshire	2014	16	80	92
Goole Fields II	Yorkshire	2016	17	80	92
Haverigg II	Cumbria	1998	4	62.5	42
Haverigg III	Cumbria	2005	4	76	52

Sources: Percival (2020a, 2020 b); Percival *at al.* (2008, 2018a, 2018b, 2019).

3.2. COLLISION MONITORING

3.2.1. Methods

The post-construction monitoring for the Blood Hill and Goole Fields I and II wind farms were carried out by the same consultancy and used the similar methodology for collision monitoring. These included weekly searches for carcasses, and searcher efficiency trials and carcass removal trials (Table 3.2). The weekly carcass searches included detailed searches of radii of 100 m (Blood Hill and Goole Fields I), or 130 m (Goole Fields II) around each turbine, with an additional 250 m scanned for large carcasses (Goole Fields I and Goole Fields II). The carcasses found were left in situ to provide data on searcher efficiency and removal rates. In addition, dedicated searcher efficiency, and carcass removal, trials were carried out at all three wind farms. These involved putting out a number of carcasses. A separate observer then tried to locate these carcasses the same day, while the carcasses were also monitored by trail cameras to investigate removal rates.

Table 3.2. Collision monitoring methods.

Wind farm	Seasons	Search frequency	Search radius	Searcher efficiency / carcass removal trials
Blood Hill	2006/07-2007/08	weekly	100 m	67 carcasses
Goole Fields I	2015/16-2018/19	weekly	100 m detailed search 250 m large carcass search	18 carcasses
Goole Fields II	2017/18-2018/19	weekly	130 m detailed search 250 m large carcass search	48 carcasses

Sources: Percival *at al.* (2008, 2018a, 2018b, 2019).

[1] Haverigg I and II are separate, but adjacent, wind farms. However, the reports combine the data for the two wind farms to calculate a single avoidance rate.

The post-construction monitoring for the Haverigg II and III wind farms was carried out between September 2018 and February 2019, with approximately monthly visits. Detailed information about the methodology of this monitoring was not available to me for this review. However, it included searcher efficiency and carcass removal trials.

3.2.2. Results

No Golden Plover fatalities were recorded at the Blood Hill Wind Farm, single fatalities were recorded at the Goole Fields I and Goole Fields II Wind Farms, and one probable Golden Plover fatality and another probable wader fatality were recorded at the Haverigg II and III Wind Farms (Table 3.3). At Blood Hill, searcher efficiency was very high, and the report notes that conditions were good for searching with winter cereals or bare ploughed ground under the turbines. At Goole Fields I and Goole Fields II, crop growth prevented full coverage of the search area on each visit, with overall coverage levels of 60-88% across the five winters covered at these two wind farms. Searcher efficiency was lower than at Blood Hill but still relatively high.

Table 3.3. Collision monitoring results.

Wind farm	Seasons	Golden Plover / wader fatalities recorded	Coverage	Searcher efficiency	% of carcasses missed due to scavengers
Blood Hill	2006/07 2007/08	0 0	100% 100%	> 99%	38%
Goole Fields I	2015/16 2016/17 2018/19	1 0 0	60% 81% 79%	82%	14%
Goole Fields II	2017/18 2018/19	1 0	81% 88%	91%	17%
Haverigg II and III	2018/19	2	no data	93%	33%

All data taken from the relevant reports cited in Section 3.1. The fatalities at Goole Fields I and Goole Fields II were confirmed Golden Plover fatalities. The fatalities at Haverigg II and III were one probable Golden Plover and one probable wader.

3.3. DERIVATION OF AVOIDANCE RATES

3.3.1. Avoidance rate calculations

Table 3.4 shows the predicted number of collisions using the SNH default 98% avoidance rate, the estimated number of collision fatalities, and the empirical avoidance rates for each site. The estimated number of collision fatalities are the actual number of collision fatalities recorded adjusted for coverage, searcher efficiency and carcass removal. Note that the data for Haverigg II and III is a combined estimate for Golden Plover and Curlew. At Blood Hill, Goole Fields I and Goole Fields II, the estimated numbers of collision fatalities were 30-90 times lower than the predicted collisions. The difference was lower at Haverigg II and III, but the estimated numbers of collision fatalities number of collision fatalities was still around six times lower than the predicted collisions. The empirical avoidance rates vary from 99.6% to 99.98%.

For the Blood Hill Wind Farm, there does not appear to be any pre-construction collision risk estimates available. Instead, collision risk estimates were obtained from post-construction vantage point surveys. The reports for the Haverigg II and III Wind Farms were for lifetime extension applications, so the collision risk estimates were also obtained from post-construction vantage point surveys. As noted in the reports, comparison of these estimates with the collision monitoring results may underestimate the avoidance rate, as birds avoiding the wind farm (macro-avoidance) will not be included in the collision risk predictions. However, the monitoring data does not indicate any significant displacement impacts to Golden Plover, so macro-avoidance may not be a significant factor for this species. For the Goole Fields I and Goole Fields II Wind Farms, the post-construction monitoring reports include the pre-construction collision risk predictions from the Environmental Statements for the projects.

No Golden Plover fatalities were recorded in the post-construction monitoring at Blood Hill. However, it would be incorrect to assume a 100% avoidance rate as, where collision rates are low, zero fatalities will be expected in some years ("false negatives"; SNH, 2009). The study by Fijn et al. (2012), which was used by Whitfield and Urquhart (2015) to derive an avoidance rate for Whooper Swan, also did not record any fatalities. To derive an avoidance rate, they assumed that one swan had been killed, and Whitfield and Urquhart (2015) followed that assumption. Therefore, to obtain an avoidance rate estimate for Blood Hill, I used a nominal value of 0.7 Golden Plover fatalities at Blood Hill (equal to one Golden Plover carcass found over two years, corrected for the expected percentage of carcasses missed due to scavenger removal).

Table 3.4. Comparison of collision risk predictions with collision monitoring results.

Wind farm	Predicted collisions (98% avoidance rate) per year	Golden Plover / wader fatalities per year	Avoidance rate
Blood Hill	62	0.7	99.98%
Goole Fields I	56	0.6	99.98%
Goole Fields II	53	1.7	99.94%
Haverigg II and III	28	5.0	99.6%

The data in this table for Haverigg II and III are combined calculations for Golden Plover and Curlew.

The predicted collisions were obtained from the data reported in the post-construction monitoring reports (see Section 3.1). In those reports, the predicted collisions were calculated from post-construction vantage point survey data for Blood Hill and Haverigg II and III, and from pre-construction vantage point survey data for Goole Fields I and Goole Fields II. For Blood Hill, the post-construction monitoring report includes the predicted collisions with an avoidance rate of 0% and the predicted collisions with a 98% avoidance rate were calculated from this figure. For Goole Fields I and Goole Fields II, the post-construction monitoring reports include the predicted collisions with a 99% avoidance rate, and the predicted collisions with a 98% avoidance rate were calculated from these figures.

The Golden Plover / wader fatalities (excluding Blood Hill) were obtained from the data reported in the post-construction monitoring reports (see Section 3.1). In those reports, the Golden Plover / wader fatalities are estimated figures that were calculated from the recorded collisions, adjusted for coverage, searcher efficiency and carcass removal. For Blood Hill, as no Golden Plover fatalities were recorded, a nominal value of 0.7 Golden Plover fatalities is used here to calculate the avoidance rate (see text). For Haverigg II and III, the recorded collisions used for the calculations comprised one probable Golden Plover and one probable wader.

The avoidance rates for Blood Hill, Goole Fields I and Goole Fields II were calculated from the predicted collisions and Golden Plover fatality data provided in the relevant post-construction monitoring reports (see Section 3.1). The avoidance rate for Haverigg II and III is the avoidance rate figure provided in the relevant reports (see Section 3.1).

3.3.2. Correction factors

There are some complicating factors that need to be taken into account in assessing the reliability of the avoidance rate estimates in Table 3.4.

The maps of Golden Plover flightlines in the Blood Hill post-construction monitoring report show a concentration of flightlines in the western section of the 500 m buffer used for the collision risk model, with relatively few flightlines actually crossing the central part of the buffer where the turbines are located. This pattern suggests that the assuming random distribution of flight activity within the 500 m buffer will overestimate the actual collision risk.

For the Goole Fields I and Goole Fields II Wind Farms, the use of pre-construction vantage point survey data for the collision risk predictions means that the accuracy of the avoidance rate estimates is dependent on the pre-construction Golden Plover flight activity being representative of the post-construction Golden Plover flight activity (allowing for any macro-avoidance effects). At Goole Fields II, the mean Golden Plover bird-days/km^2 were around 2.1 times higher in the pre-construction surveys, compared to the post-construction surveys (Figure 15 in Percival *at al.*, 2019), while the mean Golden Plover count within the 600 m buffer zone was around 2.2 times higher during the pre-construction surveys, compared to the post-construction surveys (Table 22 in Percival *at al.*, 2019). These differences seem unlikely to be due to macro-avoidance effects as any displacement impacts to wintering Golden Plover would be likely to be contained within the 600 m buffer zone (and the mean Golden Plover bird-days/km^2 included counts outside the 600 m buffer zone).

The collision risk predictions used for the avoidance rate calculation for the Haverigg II and III Wind Farms used post-construction vantage point survey data. However, this was from a different winter (2014/15) than the winter used for the collision monitoring (2018/19). Therefore, the accuracy of the avoidance rate estimates is dependent on the Golden Plover flight activity patterns being similar in the two winters.

To allow for the above issues, I have used correction factors of 2.0 for the Blood Hill non-avoidance rate estimate, and 2.15 for the Goole Fields II non-avoidance rate estimate. The correction factor of 2.0 for the Blood Hill non-avoidance rate estimate is based on a visual estimate of differences in flightline densities in the western section of the buffer, compared to the central and eastern sections. The correction factor of 2.15 for the Goole Fields II non-avoidance rate estimate is the mean of the pre-construction / post-construction ratio of Golden Plover bird-days/km^2 and the pre-construction / post-construction ratio of Golden Plover counts within the 600 m buffer zone.

Applying correction factors of 2.0 to the Blood Hill non-avoidance rate estimate, and 2.15 to the Goole Fields II non-avoidance rate estimate, gives corrected avoidance rate estimates of 99.87-99.98%, while sufficient information is not available to assess whether a correction factor should be applied to the 99.6% avoidance rate for Haverigg II and III (Table 3.5).

Table 3.5. Corrected avoidance rate estimates.

Wind farm	**Avoidance rate**		**Correction factor**	**Reason**
	original	**corrected**		
Blood Hill	99.98%	99.96%	2.0	Uneven distribution of flight activity relative to turbine locations
Goole Fields I	99.98%	99.98%	1.0	-
Goole Fields II	99.94%	99.87%	2.15	Reduction in Golden Plover numbers
Haverigg II and III	99.6%	-	-	No data available to assess whether correction factor is needed (see text)

Note that the correction factor is applied to the non-avoidance rate. See text for further details of the reasons for the avoidance rate correction factors.

4. CONCLUSIONS

The collision monitoring methodologies used in the Blood Hill, Goole Fields I and Goole Fields II post-construction monitoring studies are robust and generally comply with best practice guidance (SNH, 2009). Therefore, I consider that the Golden Plover collision fatality estimates for the Goole Fields I and Goole Fields II Wind Farms from these studies are reliable. The reported zero collision fatality estimate for the Blood Hill Wind Farm does not include any correction for “false negatives” (cf., SNH, 2009), but I have allowed for this by using a nominal estimate in my calculations of avoidance rates.

The avoidance rates derived from these studies are very high, and even when I corrected two of them by doubling the non-avoidance rate to reflect uneven distribution of flight activity (Blood Hill) and apparent reductions in Golden Plover numbers (Goole Fields II), they remain around, or higher than, 99.9%. However, a degree of caution is necessary in applying these figures. Due to the low collision rate, very few collision fatalities are found. This means that random variation in the number of collision fatalities found will can cause significant changes in the avoidance rate estimate. For example, if a second fatality had been found at Goole Fields II, then the corrected avoidance rate estimate would decrease from 99.87%-99.74%. While this change may seem small, it would cause a doubling in the predicted collision risk.

Detailed information about the collision monitoring methodology used for the Haverigg II and III Wind Farms post-construction monitoring study was not available to me for this review. However, I note that there was a lower frequency of monitoring (approximately monthly) compared to the other studies (weekly). This will have made the collision fatality estimate less reliable. The avoidance rate calculation for this wind farm used combined data for Golden Plover and Curlew, while the two collision fatalities were a probable Golden Plover and a probable wader. Also, the avoidance rate calculations used flight activity and collision fatality data from different winters, and, unlike with Goole Fields I and Goole Fields II it was not possible for me to assess whether differences in Golden Plover flight activity patterns between the winters could have affected the calculations[2]. Therefore, it is possible that the significantly lower avoidance rate calculated for this wind farm, compared to the avoidance rates for Blood Hill, Goole Fields I and Goole Fields II, reflects methodological issues.

These avoidance rates are only derived from four studies, with two of these studies carried out at adjoining wind farms. However, these still represent a much stronger evidence base for a species-specific avoidance rate than the evidence used for Kestrel in the SHN avoidance rate guidance (see Section 2.3). Also, other species-specific avoidance rates in the SHN avoidance rate guidance are based on data from limited numbers of sites: e.g., both the White-tailed Eagle avoidance rate (see Section 2.3) and the Whooper Swan avoidance rate (Whitfield and Urquhart, 2015) are based on data from single sites. Therefore, the evidence base for a species-specific avoidance rate is relatively strong for Golden Plover compared to some of the species for which the SNH avoidance rate guidance does include species-specific avoidance rates. The lack of a species-specific avoidance rate for Golden Plover in the SNH avoidance rate guidance may reflect the fact that the conservation concern about Golden Plover and wind farms in Scotland is focussed on breeding populations. Data from wintering populations (such as in the studies reviewed here) may not be applicable to breeding populations due to the differences in their behaviour and ecology.

The highest avoidance rate currently recommended by SNH (2018) is 99.8% for geese. The narrow range of the corrected avoidance rates for Blood Hill, Goole Fields I and Goole Fields II (99.87-99.98%) would suggest that 99.8% is a suitable avoidance rate for wintering Golden Plover populations. The 99.6% avoidance rate at Haverigg II and III is lower than this value, although

[2] Note that, while my assessment of this issue for the Goole Fields II Wind Farm resulted in an increase in the corrected avoidance rate, compared to the original value, it is equally plausible that differences in flight activity between winters could cause a decrease in the corrected avoidance rate, compared to the original value.

there may be some issues with this avoidance rate. Therefore, I recommend that collision risk modelling for wintering Golden Plover populations use two avoidance rate values: 99.6% and 99.8%. In practice, this will mean two predicted collision rates, with the one calculated with the 99.6% avoidance rate being twice the value of the other calculated with the 99.8% avoidance rate. These predicted collisions will be five times, and ten times, respectively, lower than predicted collisions calculated with the default 98% avoidance rate.

REFERENCES

Cook, A.S.C.P., Humphreys, E.M., Masden, E.A. & Burton, N.H.K. (2014). The avoidance rates of collision between birds and offshore turbines. BTO Research Report, 656.

Fijn, R., Krijgsveld, K., Tijsen, W., Prinsen, H. & Dirksen, S. (2012). Habitat use, disturbance and collision risks for Bewick's Swans *Cygnus columbianus bewickii* wintering near a wind farm in the Netherlands. Wildfowl 52, 97-116.

Furness, R.W. (2019) Avoidance Rates of Herring Gull, Great Black-Backed Gull and Common Gull for Use in the Assessment of Terrestrial Wind Farms in Scotland. Scottish Natural Heritage Research Report No. 1019. Scottish Natural Heritage.

JNCC, NE, NRW, NIEA & SNH. (2014). Joint response from the Statutory Nature Conservation Bodies to the Marine Scotland Science avoidance rate review. Peterborough: Joint Nature Conservation Committee.

May, R.F., Lund, P.A., Langston, R., Dahl, E.L., Bevanger, K.M., Reitan, O., Nygård, T., Pedersen, H.-C., Stokke, B.G. & Røskaft, E. (2010). Collision risk in white-tailed eagles. Modelling collision risk using vantage point observations in Smøla wind-power plant. NINA rapport.

May, R.F., Nygård, T., Dahl, E.L., Reitan, O. & Bevanger, K.M. (2011). Collision risk in white-tailed eagles. Modelling kernel-based collision risk using satellite telemetry data in Smøla wind power plant.

Percival, S. (2020a). Haverigg II Wind Farm Lifetime Extension: Report to Inform a Habitats Regulations Assessment. Unpublished report, Ecology Consulting, Durham. https://bit.ly/3jQ7Bkf, accessed 19/04/2022.

Percival, S. (2020b). Haverigg III Wind Farm Lifetime Extension: Report to Inform a Habitats Regulations Assessment. Unpublished report, Ecology Consulting, Durham. https://bit.ly/37pNhUe, accessed 19/04/2022.

Percival, S., Percival, T. & Lowe, T. (2018a). Goole Fields Wind Farm, East Yorkshire: post-construction Bird Surveys Autumn/Winter 2015-16 to 2017-18. Unpublished report, Ecology Consulting, Durham. https://bit.ly/3ka2OKF, accessed 16/08/2020.

Percival, S., Percival, T. & Lowe, T. (2018b). Goole Fields II Wind Farm, East Yorkshire: post-construction Year 1 Bird Surveys 2017-18. Unpublished report, Ecology Consulting, Durham. https://bit.ly/3ka2OKF, accessed 07/05/2020.

Percival, S., Percival, T. & Lowe, T. (2019). Goole Fields 2 Wind Farm, East Yorkshire: post-construction Year 2 Bird Surveys 2018-19. Unpublished report, Ecology Consulting, Durham. https://bit.ly/3ka2OK, accessed 16/08/2020.

Percival, S., Percival, T., Hoit, M., Langdon, K. & Lowe, T. (2008). Blood Hill Wind Farm, Norfolk: post-construction wintering bird surveys 2006-07 and 2007-08. Unpublished report, Ecology Consulting, Durham. https://bit.ly/3ka2OKF, accessed 07/05/2020.

SNH (2009). Guidance on Methods for Monitoring Bird Populations at Onshore Wind Farms. Guidance Note, January 2009. Scottish Natural Heritage.

SNH (2010). Use of Avoidance Rates in the SNH Wind Farm Collision Risk Model. Scottish Natural Heritage.

SNH (2016). Avoidance Rates for the Onshore SNH Wind Farm Collision Risk Model. Scottish Natural Heritage.

SNH (2018). Avoidance Rates for the Onshore SNH Wind Farm Collision Risk Model. Scottish Natural Heritage.

Whitfield, D.P. & Madders, M. (2006). Deriving collision avoidance rates for Red Kites *Milvus milvus*. Natural Research Information Note 3.

Whitfield, D.P. & Urquhart, B. (2015). Deriving an Avoidance Rate for Swans Suitable for Onshore Wind Farm Collision Risk Modelling.