APPENDIX 6

COLLISION RISK MODELLING TECHNICAL REPORT

SCEIRDE ROCKS OFFSHORE WIND FARM: COLLISION RISK MODELLING REPORT

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CONTENTS

SUMMARY

This report presents the collision risk model for the proposed Sceirde Rocks Offshore Wind Farm.

The collision risk modelling was based on the NatureScot guidance updated by advice from the UK Statutory Nature Conservation Bodies and was carried out using the stochLAB R package.

The highest annual predicted collision risks were for Black-legged Kittiwake and Great Black-backed Gull. The collision risk for Great Black-backed Gull was relatively high compared to the densities recorded in the Offshore Array Area due to the height distribution of Great Black-backed Gull flight activity in the dataset used in the collision risk model.

For Black-legged Kittiwake, slightly over half of the annual predicted collision risk occurred in the breeding season, but for Great Black-backed Gull, the predicted collision risk was higher in the non-breeding season.

Sensitivity analyses were carried out to examine the potential influence of variability in rotation speed, blade pitch and bird flight speed on the predicted collision risks.

1. INTRODUCTION

1.1. SCOPE

This report presents the collision risk model for the proposed Sceirde Rocks Offshore Wind Farm.

The approach to collision risk modelling in this report is based on NatureScot guidance (NatureScot, 2023), updated by advice from the UK Statutory Nature Conservation Bodies (JNCC *et al.*, 2024). The modelling used the bird survey data from the surveys described in the Ornithology Baseline Report (Technical Appendix 11-1). The stochLAB R package (Caneco *et al.*, 2022) was used to carry out the modelling.

1.2. STATEMENT OF COMPETENCE

Tom Gittings is an ecologist with 28 years' experience in professional consultancy work and research. Tom specialises in ecological surveying, monitoring and evaluation, ecological impact assessment, habitat management, and avian, invertebrate, wetland and woodland ecology. He is currently working as an independent ecological consultant. His previous experience includes working for the RPS Group (a multi-disciplinary environmental consultancy) and carrying out research into forest and wetland biodiversity in the Department of Zoology, Ecology and Plant Science at University College Cork. He has a BSc (Hons) and a PhD in Ecology and is a member of the Chartered Institute of Ecology and Environmental Management and has extensive professional experience in project management and ecological assessment. His recent consultancy work includes assessments for planning applications (including Appropriate Assessments, Environmental Impact Statements, and expert witness work at oral hearings), large-scale habitat surveys, preparation of management plans, contributions to multi-disciplinary conservation plans, and specialist ecological survey and research.

2. METHODS

2.1. COLLISION RISK MODELLING

2.1.1. General approach

The approach to collision risk modelling in this report was based on the NatureScot guidance (NatureScot, 2023a), updated by advice from the UK Statutory Nature Conservation Bodies (JNCC *et al.*, 2024). I also reviewed the method statement for the East Coast Phase 1 Projects (GoBe, 2022), the review of that method statement (ABPmer, 2023) and the collision risk model reports for those projects (GoBe, 2024; Macarthur Green, 2024a, b).

I used the stochLAB R package (Caneco *et al.*, 2022) in R version 4.4.1 (R Core Team, 2024) for the collision risk modelling. This is the package that the sCRM web-based tool (https://dmpstats.shinyapps.io/sCRM/) is based on.

I also carried out some sensitivity analyses to examine the influence of some key variables on the predicted collision risks.

2.1.2. Collision risk modelling principles

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

2.1.3. stochLAB / sCRM

The lineage of stochLAB / sCRM can be traced back to the original Scottish Natural Heritage collision risk model for onshore wind farms (SNH, 2000). Band (2012) developed versions of this collision risk model for use in offshore wind farm projects. As with the original model, Band's versions were also deterministic. Masden (2015) then developed stochastic versions of Band's models. The Avian Stochastic CRM (Donovan, 2017), a graphical user interface accessed via web-browsers, was then developed. This was based on Masden' models but included some corrections and modifications. Recently, the support for the Avian Stochastic CRM has been withdrawn and it has been replaced by stochLAB / sCRM. However, the latter are still based on the lineage described above.

The stochLAB / sCRM model includes four options that can be used to produce collision risk estimates:

- Option 1 uses site-specific data to derive the proportion of flight activity at collision risk height in the calculation of predicted transits.
- Option 2 uses generic flight height distributions to calculate the proportion of flight activity at collision risk height in the calculation of predicted transits.
- Option 3 uses generic flight height distributions to carry out an extended analysis which accounts for the fact that the most flight activity at potential collision height occurs in a segment of the rotor space close to the lowest edge of the rotor sweep. This means that the expected

number of transits will be reduced, compared to Options 1 and 2, because the width of the rotor space in this segment is smaller than in most of the remainder of the rotor space. The collision probability will also be reduced, compared to Options 1 and 2, because there is more air space between the rotor blades in this segment, compared to most of the remainder of the rotor space.

- Option 4 uses site-specific flight activity data to carry out an extended analysis as in Option 3.

Options 3 and 4 should produce more accurate predictions of transits through the turbines as they take account of height distribution of flight activity within the rotor space. This will usually result in lower numbers of predicted transits compared to Options 1 and 2. However, the over-estimation of predicted transits by Options 1 and 2 may be compensated for application of higher avoidance rates, compared to the avoidance rates for Options 3 and 4. In fact, for technical reasons about the way that avoidance rates have been calculated, suitable avoidance rates for Options 3 and 4 are not available (Ozsanlav-Harris *et al.*, 2023). Therefore, the Statutory Nature Conservation Bodies guidance (JNCC *et al.*, 2024) does not recommend use of Options 3 and 4.

No site-specific flight height distributions were available for this project. Therefore, Option 2 was used for the collision risk modelling.

2.1.4. Parameter values

Wind farm / turbine parameters

The wind farm and turbine parameters that I used for the collision risk modelling are shown in Table 2.1. Further details about some of these parameters are provided below.

Tidal offset / air gap

The air gap is the height of the lowest point of the sweep of the rotor blades above sea level and can be calculated from the hub height and the rotor radius. The actual height of the air gap will vary with the state of the tide, so it is necessary to consider how the air gap height calculated from the hub height relates to the data used for the height distribution of flight activity.

The hub height supplied by the Applicant was referenced to the lowest astronomical tide, while the height distribution of flight activity used in the collision risk modelling was referenced to the mean sea level. The lowest astronomical tide for the wind farm site is 0.53 m, while the mean sea level is 2.71 – 2.72 m (data supplied by the Applicant). Therefore, the air gap needed to be corrected by subtracting 2.185 m (2.715 - 0.53) to represent the difference between lowest astronomical tide and the mean sea level. This was achieved by applying a tidal offset value of -2.185 m.

Wind availability

Monthly wind availability data was supplied by the Applicant. This is shown in

Table 2.2.

Downtime

Project-specific downtime data was not available. Therefore, as advised by the Applicant, I used the default values from the Avian Stochastic CRM.

Rotation speed and blade pitch

I used the option in the stochLAB model to simulate rotation speed and blade pitch from relationships with wind speed. The data used to generate these relationships is shown in Table 2.3.

Species parameters

The species included in the collision risk model were Northern Gannet, Black-legged Kittiwake, Common Gull, Great Black-backed Gull, Herring Gull, Lesser Black-backed Gull, Common Tern and Arctic Tern. These were the species for which relevant density data was supplied in the Ornithology Baseline Report (Technical Appendix 11-1) and as bootstrapped samples.

The species parameters used in the collision risk model are shown in Table 2.4, Table 2.5 and Table 2.6. These were mainly the recommended values in the Statutory Nature Conservation Bodies guidance (JNCC *et al.*, 2024), except for species parameters for which no recommended values were provided in that guidance (see table footnotes).

The flight height distributions used in the modelling were the default data included in the stochLAB model, which are derived from Johnston *et al.* (2014). No site specific flight height data was available.

Northern Gannet macro-avoidance

Avoidance of turbines by birds can be divided into micro-, meso- and macro-avoidance, depending on the spatial scale at which it occurs. Micro- and meso-avoidance takes place within the wind farm. Macro-avoidance refers to avoidance of the wind farm site and represents the combined results of any displacement impacts or barrier effects that are generated by the wind farm.

The avoidance rates recommended by JNCC *et al.* (2024) reflect micro- and meso-avoidance behaviour, but do not take account of any macro-avoidance behaviour. However, there is strong evidence that Northern Gannets show significant macro-avoidance of offshore wind farms (Pavat *et al.*, 2023). Therefore, collision risk modelling that does not take account of macro-avoidance will significantly overestimate the collision risk for Northern Gannet.

The recent collision risk models for the two East Coast Phase 1 projects used a Northern Gannet macro-avoidance rate of 0.70. This was based on interim guidance (Natural England, 2023), which suggested "reducing the density of gannet in flight going into the CRM, either by a representative range of macro-avoidance rates of between 65% - 85% or by selecting a single rate of 70%". Since the publication of that interim guidance, the results of a review of Northern Gannet macro-avoidance have been published (Pavat *et al.*, 2023). This review reported a mean Northern Gannet macro-avoidance rate of 0.8564 (95% CI of 0.5349 – 0.97326). The Statutory Nature Conservation Bodies guidance (JNCC *et al.*, 2024) does not give any specific guidance on values to use for Northern Gannet macro-avoidance rates.

In this collision risk model, I have used a Northern Gannet macro-avoidance rate of 0.70 in line with the values used in the East Coast Phase 1 projects. This is precautionary compared to the mean Northern Gannet macro-avoidance rate from the Pavat *et al.* review.

The Northern Gannet macro-avoidance rate can be applied by either reducing the bird densities by the non-macro-avoidance rate, or by applying an overall avoidance rate that includes the macro-avoidance rate[1], or by reducing the final collision risk by the non-macro-avoidance rate. These methods are mathematically equivalent (Pavat *et al.*, 2023). However, in the stochastic collision risk model implemented by the stochLAB R package, the exact values of the predicted collision risk obtained by adjustment to the overall avoidance rate will differ from those obtained by the other methods, due to the way the model uses the beta distribution to simulate avoidance rates.

In this collision risk model, I used the first method and reduced the Northern Gannet densities inputted into the model by the non-macro-avoidance rate, which is the method recommended by Pavat *et al.* (2023) and SNCB (2024). This was broadly equivalent to applying an overall avoidance rate of 0.9979.

Species densities

The species densities used for the collision risk modelling were the bootstrap samples for the array area that were used to calculate the monthly means and standard deviations provided in Tables 15, 24, 30, 34, 38, 42, 45 and 50 of the Ornithology Baseline Report (Technical Appendix 11-1).

There was a total of 24 monthly surveys with 1000 bootstrap samples generated for each species for each survey in which they were recorded. To generate data for input into the model, I combined

[1] The overall avoidance rate is given by the sum of the micro/meso- and macro-avoidance rates minus their product. In this case it is (0.9929 + 0.7) – (0.9929 0.7) = 0.9979.

the samples for the two sets of surveys of each calendar month to create datasets of 2000 densities per month. For species that were not recorded in a particular survey, I used a dataset of 1000 zero values for that survey.

There were no surveys carried out in February 2022 and two surveys carried out in March 2022. I followed the protocol used in the Ornithology Baseline Report and used the March S01 survey to represent February 2022 and the March S02 survey to represent March 2022.

The bootstrap samples used for the modelling can be provided on request.

2.1.5. Implementation of the collision risk modelling

I carried out all the collision risk modelling using the stochLAB R package (Caneco *et al.*, 2022). I ran 1000 iterations of each simulation and used the large array correction.

The seed used for all the simulations was 1149. The value of this seed controls the sampling of the parameters in the stochastic collision risk model. Therefore, the results of the modelling reported here can be replicated by using this seed with the same input parameters.

I carried out separate runs of the model using the “months”, “seasons” and “annum” options for the output period. These produced predicted collision risks for each month, defined seasonal periods, and for the whole year. I used the same seed for these separate runs. The seasonal periods were as defined in Chapter 11 - Marine Ornithology chapter of the Environmental Impact Assessment Report. Note that the mean predicted collision risks for the seasonal periods and for the whole year are the sums of the mean predicted collision risks for the relevant months. However, the separate runs were required to produce confidence intervals for each output period.

2.1.6. Sensitivity analyses

I carried out sensitivity analyses to examine the potential influence of variability in rotation speed, blade pitch and bird flight speed on the predicted collision risks. Rotation speed and blade pitch are turbine parameters that vary with wind speed and for which there is often uncertainty about their exact values in collision risk modelling. Bird flight speed is a parameter that was highlighted in the review of the method statement for the East Coast Phase 1 Projects (ABPmer, 2023).

I carried out the sensitivity analyses by calculating collision probabilities for each species included in the collision risk model at 0.1 m/sec increments of the rotation speed and bird flight speed and 0.5° increments of blade pitch across the range of potential values for these parameters. For rotation speed and blade pitch, the ranges were defined by the maximum and minimum values in Table 2.3 (excluding the blade pitch values of 90°). For bird flight speed, I defined the ranges as the means plus and minus two standard deviations. However, for Northern Gannet, Black-legged Kittiwake and Lesser Black-backed Gull, I used the lowest instantaneous median speeds sampled at 300 seconds for commuting or foraging birds from Table 15 of Cook *et al.* (2023) as the minimum values of their ranges.

I carried the collision probability calculations in R 4.3.2 (R Core Team, 2023), using an adapted version of the R code provided by Masden (2015). I audited this R code against the Band (2012) spreadsheet to confirm that it produced matching collision probability calculations.

For rotation speed and blade pitch, I assessed the sensitivity of the predicted collision risk to variation in these parameters as the ratio between the maximum and minimum collision probabilities.

Bird flight speeds affect calculations of predicted transits as well as the collision probability. The predicted transits are directly proportional to the bird flight speed. I calculated the relative transit rate across the range of bird flight speed values by dividing each value by the minimum value. Then I calculated the relative collision risk by multiplying the relative transit rate by the collision probability. The ratio between the maximum and minimum relative collision risks provides an indication of the sensitivity of the predicted collision risk to variation in bird flight speed.

Table 2.1. Wind farm / turbine parameters.

Parameter	Value	Source
Number of turbines	30	1
Latitude	53.26	1
Wind farm width	8.7 km	1
Tidal offset	-2.185 m	see text
Number of blades	3	1
Hub height	178.9 m	1
Rotor radius	146 m	1
Air gap	32.9 m	see text
Maximum blade width	7.5 m	1
Wind availability	see Table 2.2	1
Downtime (mean)	6.30%	2
Downtime (SD)	2.00%	2
Rotation speed	see Table 2.3	1
Blade pitch	see Table 2.3	1
Wind speed (mean)	10.5 m/sec	1
Wind speed (SD)	4.916 m/sec	1

Sources: 1 = data supplied by Applicant; 2 = default value from Avian Stochastic CRM.

Table 2.2. Wind availability data.

Month	Wind availability
Jan	95.5%
Feb	96.0%
Mar	97.7%
Apr	98.3%
May	98.4%
Jun	97.5%
Jul	97.6%
Aug	97.5%
Sep	98.2%
Oct	97.9%
Nov	96.8%
Dec	92.0%

Source: Applicant.

Table 2.3. Relationships of rotation speed and blade pitch with wind speed.

Wind speed (m/sec)	Rotor speed (rpm)	Pitch (°)
0	0	90
1	0	90
2	0	90
3	0	90
4	4.51	5
5	4.53	5
6	4.76	5
7	5.45	5
8	6.22	5
9	6.96	5
10	7.53	5
11	7.74	5
12	7.78	7
13	7.8	7
14	7.79	10
15	7.78	12
16	7.8	14
17	7.8	14
18	7.81	15
19	7.81	17
20	7.81	17
21	7.81	18
22	7.81	20
23	7.81	22
24	7.81	24
25	7.81	25
26	7.81	28
27	7.81	29
28	7.81	32
29	7.81	33
30	7.81	35
31	7.81	37
32	7.81	39

Source: Applicant.

Table 2.4. Biometric parameters used in the collision risk model.

Species	Body length (m)	Wingspan (m)
Northern Gannet	0.94 (0.0325)	1.72 (0.0375)
Black-legged Kittiwake	0.39 (0.005)	1.08 (0.0625)
Common Gull	0.41 (0)	1.20 (0)
Great Black-backed Gull	0.71 (0.035)	1.58 (0.0375)
Herring Gull	0.60 (0.0225)	1.44 (0.03)
Lesser Black-backed Gull	0.58 (0.03)	1.42 (0.0375)
Common Tern	0.33 (0)	0.875 (0)
Arctic Tern	0.34 (0)	0.80 (0)

The values shown are means with standard deviations in parentheses. Sources: JNCC *et al.* (2023) for Northern Gannet, Black-legged Kittiwake, Great Black-backed Gull, Herring Gull and Lesser Black-backed Gull; Cramp and Simmons (2004) for Common Gull, Common Tern and Arctic Tern (mid-point of size ranges).

Table 2.5. Flight activity parameters used in the collision risk model.

Species	Flight type	% of flights upwind	Flight speed (m/sec)
Northern Gannet	flapping	50	14.9 (0)
Black-legged Kittiwake	flapping	50	13.1 (0.40)
Common Gull	flapping	50	13.4 (2.9)
Great Black-backed Gull	flapping	50	13.7 (1.20)
Herring Gull	flapping	50	12.8 (1.80)
Lesser Black-backed Gull	flapping	50	13.1 (1.90)
Common Tern	flapping	50	10.9 (0.9)
Arctic Tern	flapping	50	10.9 (0.9)

The values shown for flight speed are means with standard deviations in parentheses. Sources: JNCC *et al.* (2024), except Common Gull, Common Tern, and Arctic Tern flight speeds and Common Tern and Arctic Tern flight types and % of flights upwind. Common Gull and Arctic Tern flight speeds from Alerstam *et al.* (2007); Arctic Tern flight speed value used for Common Tern. Common Tern and Arctic Tern flight types and % of flights upwind set as flapping and 50, respectively, in line with values used for all the other species.

Table 2.6. Nocturnal activity and avoidance rate parameters used in the collision risk model.

Species	Nocturnal activity factors	Avoidance rate (micro/meso)	Avoidance rate (macro)
Northern Gannet	0.14 (0.10)	0.9929 (0.0003)	0.7
Black-legged Kittiwake	0.40 (0.12)	0.9929 (0.0003)	0
Common Gull	0.375 (0.0637)	0.9949 (0.0003)	0
Great Black-backed Gull	0.375 (0.0637)	0.9940 (0.0004)	0
Herring Gull	0.375 (0.0637)	0.9940 (0.0004)	0
Lesser Black-backed Gull	0.30 (0.18)	0.9940 (0.0004)	0
Common Tern	0	0.9908 (0.0004)	0
Arctic Tern	0	0.9908 (0.0004)	0

The values shown are means with standard deviations in parentheses. Sources: JNCC *et al.* (2024), except Common Gull, Common Tern, and Arctic Tern nocturnal activity factors, and Northern Gannet macro-avoidance rate. Nocturnal activity factor for Common Gull set at the same value as the Great Black-backed Gull and Herring Gull as it has the same nocturnal activity score (3) in Garthe and Hüppop (2004). Nocturnal activity factor for Arctic Tern and Common Tern set as zero as they have nocturnal activity scores of 1 in Garthe and Hüppop (2004). For Northern Gannet macro-avoidance rate, see text.

3. RESULTS

3.1. PREDICTED COLLISION RISKS

Annual and seasonal summaries of the predicted collision risks are shown in Table 3.1 and Table 3.2. These tables show the mean predicted collision risks and the upper and lower limits of the 95% confidence intervals around these means. Monthly summaries of the predicted collision risks are shown in Table A1.1 in Appendix 1.

Table 3.1. Summary of annual totals of predicted collision risks from the Option 2 stochastic model.

Species	Predicted collision risk (collisions / years)		
	Mean	2.5% CL	97.5% CL
Northern Gannet	0.8	0.1	1.9
Black-legged Kittiwake	8.2	4.1	14.0
Common Gull	0.3	0.0	1.6
Great Black-backed Gull	6.1	1.5	13.0
Herring Gull	4.5	0.0	13.6
Lesser Black-backed Gull	3.1	0.0	7.8
Common Tern	0.4	0.0	1.3
Arctic Tern	0.2	0.0	1.3

See Table A1.1 in Appendix 1 for monthly predicted collision risks.

Table 3.2. Summary of seasonal totals of predicted collision risks from the Option 2 stochastic model.

Species	Season	Months	Predicted collision risk (collisions / years)		
			Mean	2.5% CL	97.5% CL
Northern Gannet	spring	Dec-Feb	0.0	0.0	0.2
	breeding	Mar-Sep	0.7	0.1	1.9
	autumn	Oct-Nov	0.0	0.0	0.0
Black-legged Kittiwake	spring	Jan-Feb	1.0	0.2	2.3
	breeding	Mar-Aug	4.4	2.0	7.9
	autumn	Sep-Dec	2.8	0.8	6.1
Common Gull	breeding	Apr-Aug	0.0	0.0	0.0
	non-breeding	Sep-Mar	0.3	0.0	1.6
Great Black-backed Gull	breeding	Apr-Aug	2.4	0.0	7.7
	non-breeding	Sep-Mar	3.7	0.0	10.5
Herring Gull	breeding	Mar-Aug	3.1	0.0	10.5
	non-breeding	Sep-Feb	1.4	0.0	4.5
Lesser Black-backed Gull	spring	Mar	0.4	0.0	2.2
	breeding	Apr-Aug	2.8	0.0	6.7
	autumn	Sep-Oct	0.0	0.0	0.0
	winter	Nov-Feb	0.0	0.0	0.0
Common Tern	spring	Apr-May	0.0	0.0	0.0
	migration-free breeding	Jun-Jul	0.3	0.0	1.3
	autumn	Aug-Sep	0.1	0.0	0.5
	winter	Oct-Mar	0.0	0.0	0.0
Arctic Tern	spring	Apr	0.0	0.0	0.0
	breeding	May-Aug	0.2	0.0	1.3
	autumn	Sep	0.0	0.0	0.0
	winter	Oct-Mar	0.0	0.0	0.0

See Table A1.1 in Appendix 1 for monthly predicted collision risks.

The highest annual predicted collision risks were for Black-legged Kittiwake and Great Black-backed Gull. The high predicted collision risk for Great Black-backed Gull relative to the densities recorded in the Offshore Array Area reflects the height distribution of Great Black-backed Gull flight activity in the dataset used in the collision risk model.

For Black-legged Kittiwake, slightly over half of the annual predicted collision risk occurred in the breeding season, but for Great Black-backed Gull, the predicted collision risk was higher in the non-breeding season.

3.2. SENSITIVITY ANALYSES

3.2.1. Rotation speed

The collision probability increased by a factor of around 1.1 to 1.2 times across the operational speed range. Within this range, the relationships between collision probability and rotation speed were almost linear. These analyses indicate that any uncertainty in the rotation speed values used for the modelling will have little effect on the accuracy of the collision risk predictions.

Table 3.3. Variation in collision probabilities across the operational rotation speed range.

Species	Min	Max	Ratio
Northern Gannet	0.048	0.057	1.19
Black-legged Kittiwake	0.040	0.044	1.10
Common Gull	0.040	0.044	1.10
Great Black-backed Gull	0.045	0.053	1.18
Herring Gull	0.043	0.050	1.16
Lesser Black-backed Gull	0.044	0.051	1.16
Common Tern	0.039	0.044	1.13
Arctic Tern	0.039	0.044	1.13

Note that the collision probabilities represent the probability of a collision on a single transit of the rotor airspace. While they contribute to the calculation of the predicted collision risk, they should not be interpreted as providing any information about the likely magnitude of the predicted collision risk.

3.2.2. Blade pitch

In collision risk modelling, relationships between collision probability and blade pitch typically show little variation at low values of blade pitch with a sharp inflection point beyond which there is a steep increase in collision probability with increasing blade pitch. In the present analyses, the inflection point occurred at values of around 5-10° (Figure 3.1). Therefore, over most of the operational blade pitch range variation, collision probability will increase sharply with increases in blade pitch.

The blade pitch value at the mean windspeed of 10.5 m/sec is 5°, which is the minimum blade pitch value over the operational blade pitch range. The collision probabilities at the maximum blade pitch value were around 1.6 to 2.3 times higher (Table 3.4).

High values of blade pitch occur at high wind speeds, which are more likely to occur in winter. The stochLAB model uses a single mean and standard deviation to simulate wind speed distributions across the year. Therefore, the model is likely to overestimate the frequency of high values of blade pitch in summer and underestimate the frequency of these values in winter. This means that the breeding season predicted collision risks will be conservative with regard to variation in blade pitch, but the non-breeding season predicted collision risks may be underestimated. However, the values used for the relationship between wind speed and blade pitch were conservative as well. As the incidence of high wind speeds, even during winter, will be low, it is unlikely that any underestimation of the non-breeding season predicted collision risks was significant.

Table 3.4. Variation in collision probabilities across the operational blade pitch range.

Species	Min	Max	Ratio
Northern Gannet	0.056	0.091	1.62
Black-legged Kittiwake	0.044	0.087	1.98
Common Gull	0.044	0.086	1.95
Great Black-backed Gull	0.052	0.092	1.77
Herring Gull	0.049	0.093	1.90
Lesser Black-backed Gull	0.050	0.095	1.90
Common Tern	0.044	0.101	2.30
Arctic Tern	0.044	0.101	2.30

Note that the collision probabilities represent the probability of a collision on a single transit of the rotor airspace. While they contribute to the calculation of the predicted collision risk, they should not be interpreted as providing any information about the likely magnitude of the predicted collision risk.

3.2.3. Bird flight speed

The relative collision risk increased by a factor of around 1.2 to 1.9 times across the range of bird flight speeds assessed (

Table 3.5). The variation between species reflects both variation in the magnitude of the range of flight speeds assessed, as well as variation between species in how flight speed affects collision probability.

The maximum relative collision risk was around 1.1 to 1.3 times the relative collision risk obtained from using the bird flight speed value that corresponded to the mean bird flight speed used in the collision risk model. For Northern Gannet, the maximum bird flight speed assessed was the value used in the collision risk model as the standard deviation for Northern Gannet flight speed in JNCC (2024) is zero.

ABPmer (2023) cite the recent work of Cook *et al.* (2023), which reported significantly lower flight speeds for Northern Gannet, Black-legged Kittiwake and Lesser Black-backed Gull than the values recommended by JNCC (2024). Therefore, the collision risk estimates in this report will be conservative compared to estimates that would be produced using the flight speed data from Cook *et al.* (2023).

Table 3.5. Variation in relative collision risk across the range of bird flight speeds assessed.

	Relative collision risks			Ratios	
Species	Min	CRM value	Max	Max / Min	Max / CRM value
Northern Gannet	0.059	0.069	0.069	1.17	1.00
Black-legged Kittiwake	0.052	0.081	0.084	1.62	1.04
Common Gull	0.047	0.067	0.089	1.89	1.33
Great Black-backed Gull	0.050	0.056	0.062	1.24	1.11
Herring Gull	0.058	0.080	0.095	1.64	1.19
Lesser Black-backed Gull	0.051	0.061	0.072	1.41	1.18
Common Tern	0.040	0.045	0.050	1.25	1.11
Arctic Tern	0.040	0.045	0.050	1.25	1.11

The relative collision risk is the collision risk when the bird density has a value that would produce one transit at the minimum flight speed assessed. The CRM value is the relative collision risk for the bird flight speed value that was the mean value used in the collision risk model.

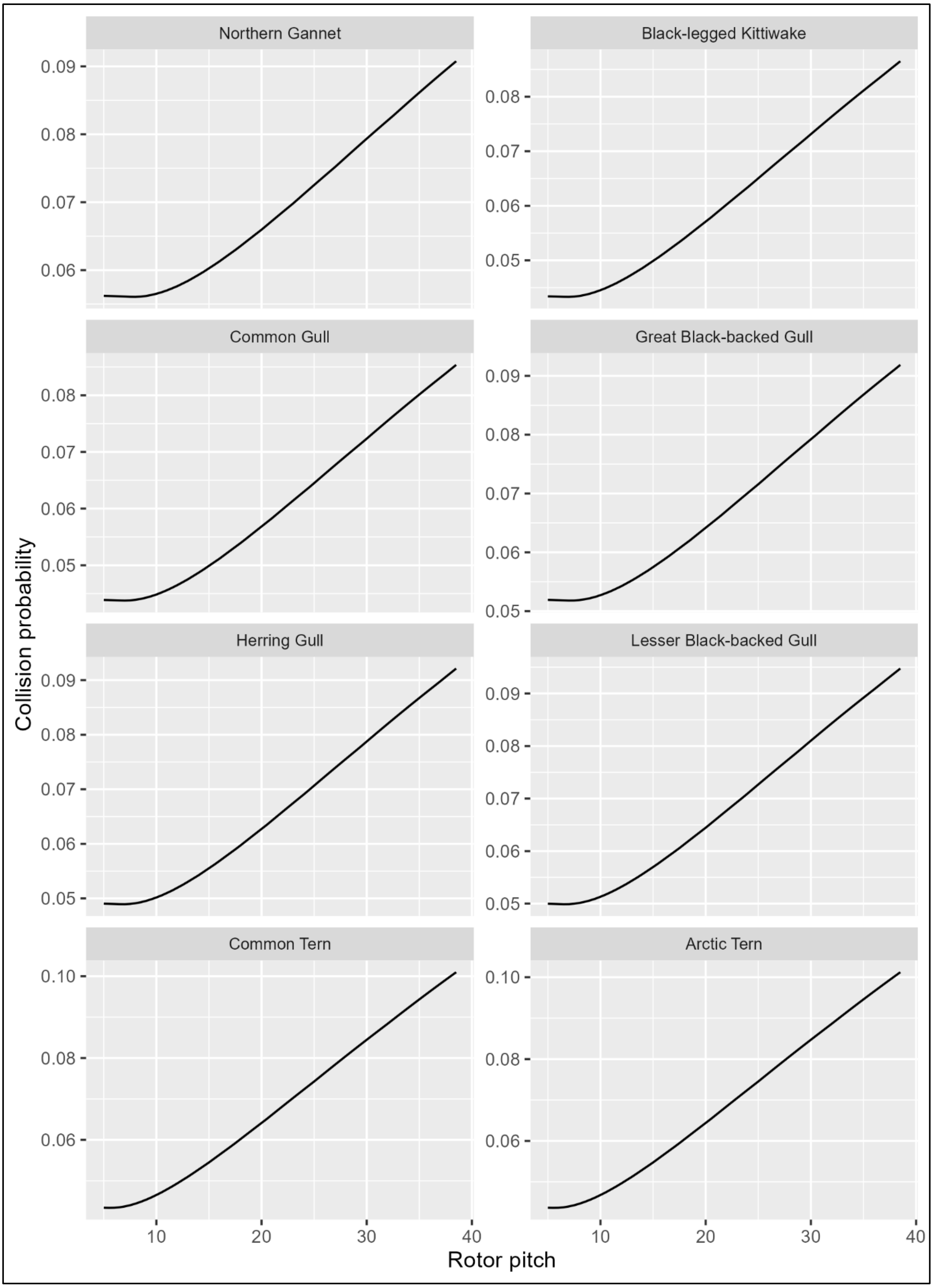

Figure 3.1. Relationship between collision probability and rotor pitch.

5. CONCLUSIONS

The highest annual predicted collision risks were for Black-legged Kittiwake and Great Black-backed Gull. The collision risk for Great Black-backed Gull was relatively high compared to the densities recorded in the Offshore Array Area due to the height distribution of Great Black-backed Gull flight activity in the dataset used in the collision risk model.

For Black-legged Kittiwake, slightly over half of the annual predicted collision risk occurred in the breeding season, but for Great Black-backed Gull, the predicted collision risk was higher in the non-breeding season.

Sensitivity analyses showed that variation in blade pitch across the operational blade pitch range may cause an up to twofold variation in the probability of a collision during turbine transits. However, this variation was not likely to have caused significant underestimation of the predicted collision risks.

Recent work (Cook *et al.*, 2023) has reported significantly lower flight speeds for Northern Gannet, Black-legged Kittiwake and Lesser Black-backed Gull than the values currently recommended for the stochLAB model. Therefore, the collision risk estimates in this report will be conservative compared to estimates that would be produced using these lower flight speeds.

The collision risk model included a macro-avoidance rate of 0.7 for Northern Gannet, following the rate used for the East Coast Phase 1 projects. Recent work (Pavat *et al.*, 2023) has indicated a higher mean macro-avoidance rate for Northern Gannet of around 0.8564. Application of the latter would halve the predicted collision risk for Northern Gannet. However, application of the lower limit of the 95% confidence interval (0.5349) from Pavat *et al.* would increase the predicted collision risk for Northern Gannet by a factor of around 1.5.

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Appendix 1 Monthly summaries of the predicted collision risks

Table A1.1. Summary of monthly totals of predicted collision risks from the Option 2 stochastic model.

Species	Month	Predicted collision risk (collisions / years)		
		Mean	2.5% CL	97.5% CL
Northern Gannet	Jan	0.0	0.0	0.0
Northern Gannet	Feb	0.0	0.0	0.0
Northern Gannet	Mar	0.0	0.0	0.0
Northern Gannet	Apr	0.1	0.0	0.3
Northern Gannet	May	0.3	0.0	1.0
Northern Gannet	Jun	0.2	0.0	0.5
Northern Gannet	Jul	0.0	0.0	0.0
Northern Gannet	Aug	0.1	0.0	0.6
Northern Gannet	Sep	0.1	0.0	0.7
Northern Gannet	Oct	0.0	0.0	0.0
Northern Gannet	Nov	0.0	0.0	0.0
Northern Gannet	Dec	0.0	0.0	0.2
Black-legged Kittiwake	Jan	0.0	0.0	0.0
Black-legged Kittiwake	Feb	1.0	0.2	2.3
Black-legged Kittiwake	Mar	0.5	0.0	1.8
Black-legged Kittiwake	Apr	0.7	0.0	2.7
Black-legged Kittiwake	May	1.4	0.0	3.2
Black-legged Kittiwake	Jun	0.9	0.0	2.2
Black-legged Kittiwake	Jul	0.8	0.0	2.2
Black-legged Kittiwake	Aug	0.2	0.0	0.8
Black-legged Kittiwake	Sep	0.1	0.0	0.8
Black-legged Kittiwake	Oct	0.3	0.0	1.4
Black-legged Kittiwake	Nov	1.2	0.2	2.8
Black-legged Kittiwake	Dec	1.2	0.0	3.9
Common Gull	Jan	0.0	0.0	0.0
Common Gull	Feb	0.0	0.0	0.0
Common Gull	Mar	0.2	0.0	1.1
Common Gull	Apr	0.0	0.0	0.0
Common Gull	May	0.0	0.0	0.0
Common Gull	Jun	0.0	0.0	0.0
Common Gull	Jul	0.0	0.0	0.0
Common Gull	Aug	0.0	0.0	0.0
Common Gull	Sep	0.0	0.0	0.0
Common Gull	Oct	0.0	0.0	0.0
Common Gull	Nov	0.0	0.0	0.0
Common Gull	Dec	0.1	0.0	0.8

Species	Month	Predicted collision risk (collisions / years)		
		Mean	2.5% CL	97.5% CL
Great Black-backed Gull	Jan	1.3	0.0	4.6
Great Black-backed Gull	Feb	0.0	0.0	0.0
Great Black-backed Gull	Mar	0.0	0.0	0.0
Great Black-backed Gull	Apr	0.0	0.0	0.0
Great Black-backed Gull	May	0.6	0.0	3.3
Great Black-backed Gull	Jun	0.6	0.0	3.2
Great Black-backed Gull	Jul	0.6	0.0	3.3
Great Black-backed Gull	Aug	0.6	0.0	3.2
Great Black-backed Gull	Sep	0.0	0.0	0.0
Great Black-backed Gull	Oct	1.5	0.0	6.5
Great Black-backed Gull	Nov	0.4	0.0	2.4
Great Black-backed Gull	Dec	0.4	0.0	2.4
Herring Gull	Jan	0.8	0.0	2.4
Herring Gull	Feb	0.0	0.0	0.0
Herring Gull	Mar	0.0	0.0	0.0
Herring Gull	Apr	2.1	0.0	9.0
Herring Gull	May	1.0	0.0	3.1
Herring Gull	Jun	0.0	0.0	0.0
Herring Gull	Jul	0.0	0.0	0.0
Herring Gull	Aug	0.0	0.0	0.0
Herring Gull	Sep	0.0	0.0	0.0
Herring Gull	Oct	0.4	0.0	2.1
Herring Gull	Nov	0.3	0.0	1.9
Herring Gull	Dec	0.0	0.0	0.0
Lesser Black-backed Gull	Jan	0.0	0.0	0.0
Lesser Black-backed Gull	Feb	0.0	0.0	0.0
Lesser Black-backed Gull	Mar	0.4	0.0	2.2
Lesser Black-backed Gull	Apr	0.3	0.0	1.8
Lesser Black-backed Gull	May	0.8	0.0	3.5
Lesser Black-backed Gull	Jun	0.0	0.0	0.0
Lesser Black-backed Gull	Jul	1.6	0.0	4.7
Lesser Black-backed Gull	Aug	0.0	0.0	0.0
Lesser Black-backed Gull	Sep	0.0	0.0	0.0
Lesser Black-backed Gull	Oct	0.0	0.0	0.0
Lesser Black-backed Gull	Nov	0.0	0.0	0.0
Lesser Black-backed Gull	Dec	0.0	0.0	0.0

Species	Month	Predicted collision risk (collisions / years)		
		Mean	2.5% CL	97.5% CL
Common Tern	Jan	0.0	0.0	0.0
Common Tern	Feb	0.0	0.0	0.0
Common Tern	Mar	0.0	0.0	0.0
Common Tern	Apr	0.0	0.0	0.0
Common Tern	May	0.0	0.0	0.0
Common Tern	Jun	0.1	0.0	0.3
Common Tern	Jul	0.3	0.0	1.3
Common Tern	Aug	0.1	0.0	0.5
Common Tern	Sep	0.0	0.0	0.0
Common Tern	Oct	0.0	0.0	0.0
Common Tern	Nov	0.0	0.0	0.0
Common Tern	Dec	0.0	0.0	0.0
Arctic Tern	Jan	0.0	0.0	0.0
Arctic Tern	Feb	0.0	0.0	0.0
Arctic Tern	Mar	0.0	0.0	0.0
Arctic Tern	Apr	0.0	0.0	0.0
Arctic Tern	May	0.0	0.0	0.0
Arctic Tern	Jun	0.2	0.0	0.9
Arctic Tern	Jul	0.1	0.0	0.6
Arctic Tern	Aug	0.0	0.0	0.0
Arctic Tern	Sep	0.0	0.0	0.0
Arctic Tern	Oct	0.0	0.0	0.0
Arctic Tern	Nov	0.0	0.0	0.0
Arctic Tern	Dec	0.0	0.0	0.0