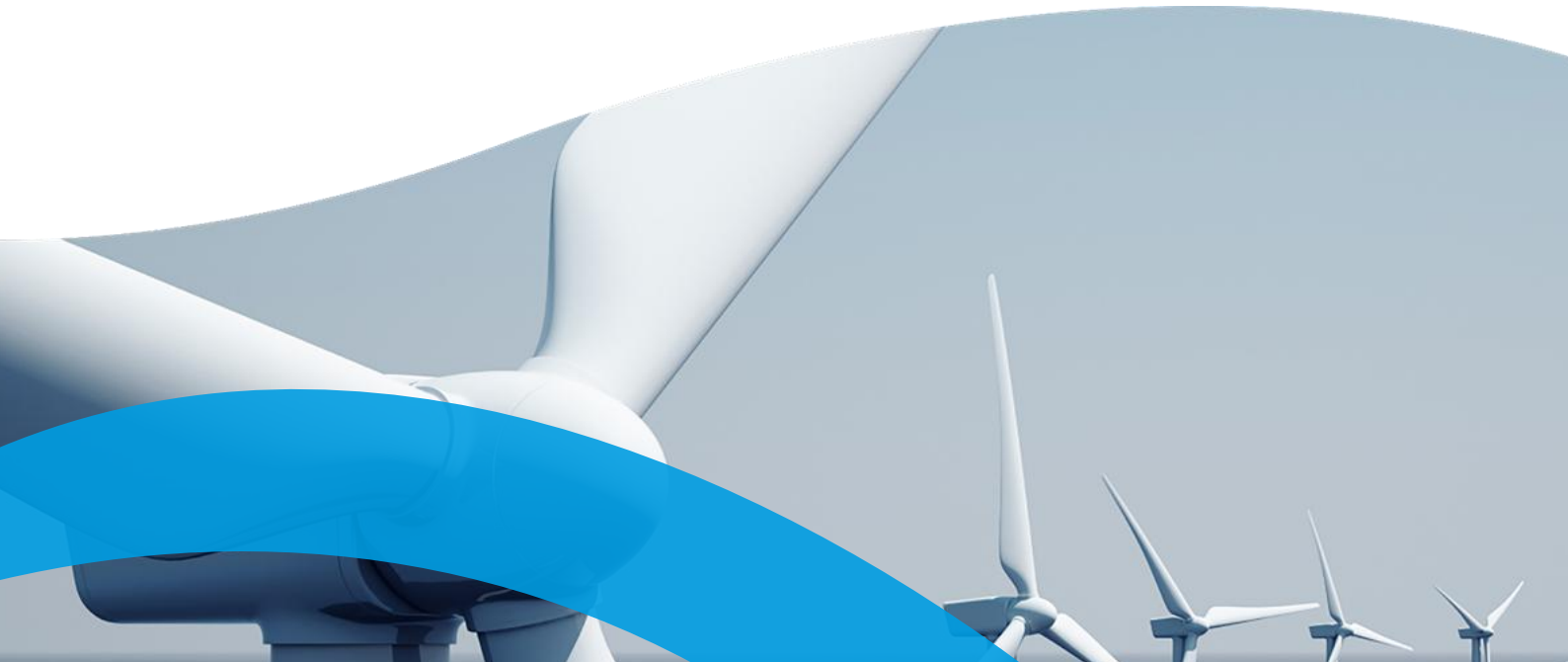
Muir Mhòr Offshore Wind Farm

Environmental Impact Assessment Report

Volume 3, Appendix 11.2: Offshore Ornithology Collision Risk Modelling Technical Report



Revision No.	Date	Reason for Issue	Author	Reviewer	Approver
01	22/11/2024	Final	Natural Power Ltd	GoBe Consultants Ltd	MMOWF Ltd

Document Information	
Document ID	**MMH-GBE-A004-ENV-0006-311**
Revision	01
Date	22/11/2024

Muir Mhòr Wind Farm

Offshore Ornithology Collision Risk Modelling Report (Volume 3, Appendix 11.2)

5 November 2024 1349036

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Document history

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Issue	Date	Revision Details
A	22 April 2024	First version submitted to client.
B	6 September 2024	Second version submitted to client.
C	2 October 2024	Third version submitted to client.
D	5 November 2024	Draft final version submitted to the client.

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Glossary

Term	Definition
Array Area	The area in which the generation infrastructure (including Wind Turbine Generators and associated foundations and inter-array cables), Offshore Electrical Platform(s), and an interconnector cable will be located.
Design-based	Relating to a density estimate calculated using the design-based methodology discussed in Volume 3, Appendix 11.6 (Offshore and Intertidal Density and Abundance Report).
Deterministic	Relating to collision risk modelling: assessing impact without any incorporation of uncertainty or variation in input parameters or estimated impacts.
Inter-array cables	Cables which link the wind turbine generators to each other and the Offshore Electrical Platform(s).
Interconnector cable	Cable which links the Offshore Electrical Platform(s) to one another, allowing for power to be transferred between the platforms.
Model-based	Relating to a density estimate calculated using the model-based methodology discussed in in Volume 3, Appendix 11.6 (Offshore and Intertidal Density and Abundance Report).
Offshore Electrical Platform(s)	Offshore platform consisting of High Voltage Alternating Current (HVAC) equipment, details depending on the final electrical set up of the Project.
Project	Muir Mhòr Offshore Wind Farm – comprises the wind farm and all associated offshore and onshore components.
Proposed Development	The offshore Muir Mhòr Offshore Wind Farm project elements to which this Offshore EIA Report relates.
Stochastic	Relating to collision risk modelling: allowing the incorporation of uncertainty and variation around parameter estimates.
Wind Turbine Generator	The wind turbines that generate electricity consisting of tubular towers and blades attached to a nacelle housing mechanical and electrical generating equipment.

Acronyms

Acronym	Definition
AA	Array Area
BDMPS	Biologically Defined Minimum Population Scales
BTO	British Trust for Ornithology
CRH	Collision Risk Height
CRM	Collision Risk Model/Modelling
CRMs	Collision Risk Models
CIs	Confidence Intervals (here relating to 95% confidence intervals)
DAS	Digital Aerial Survey
EIA	Environmental Impact Assessment

Acronym	Definition
HVAC	High Voltage Alternating Current
mCRM	Migratory Collision Risk Modelling
MLS	Most Likely Scenario (relating to wind turbine generator parameters)
PVA	Population Viability Analysis
RSPB	Royal Society for the Protection of Birds
SD	Standard Deviation
SPA	Special Protected Area
WCS	Worst Case Scenario (relating to wind turbine generator parameters and their collision impact)
WTG	Wind Turbine Generator
WWT	Wildfowl & Wetlands Trust

Species names

Common name	Scientific name	BTO Code
Kittiwake	*Rissa tridactyla*	KI
Common gull	*Larus canus*	CM
Great black-backed gull	*Larus marinus*	GB
Herring gull	*Larus argentatus*	HG
Common tern	*Sterna hirundo*	CN
Arctic tern	*Sterna paradisaea*	AE
Fulmar	*Fulmarus glacialis*	F.
Gannet	*Morus bassanus*	GX

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1. Introduction

Seabird collision risk modelling was carried out for the offshore infrastructure associated with the Muir Mhòr Offshore wind farm (hereafter referred to as the 'Proposed Development') using the collision risk model (CRM) tool recommended by NatureScot (2023a), implemented by Caneco (2022). The approach used follows the NatureScot (2023a) guidance on CRM as well as advice provided by NatureScot as part of their Scoping Opinion.

In addition to these seabird collision risk models, migratory collision risk was qualitatively assessed based on work published by Wildfowl & Wetlands Trust (WWT) (2014), while accounting for updates published in Woodward *et al.*, (2023). In the absence of the upcoming quantitative migratory Collision Risk Modelling (mCRM) tool which forms part of Scotland's National Marine Plan (Scottish Government, 2015), this qualitive approach was advised by NatureScot during scoping consultation as detailed in the Offshore and Intertidal Ornithology EIA Report (Volume 2, Chapter 12, Table 12-2).

2. Methodology

2.1. Seabird Collision Risk Modelling

Collision Risk Modelling is a process used to assess and predict the likelihood of birds colliding with wind turbine blades. The CRM tool (version 0.1.1) (Caneco, 2022) used for seabird CRM is a development of the Band (2012) offshore avian collision risk model, based on work by Masden (2015) and McGregor *et al*. (2018) to incorporate stochasticity. The original Band (2012) model predicts collision rates for a proposed development as a function of: Wind Turbine Generator (WTG) specifications, the density of seabirds at the site, their flight heights and species specific biometric and behavioural data. The stochastic model builds on this by allowing the incorporation of uncertainty in the input parameters to randomly sample from parameter distributions in iterative collision risk models. The collision risk estimates from each iteration construct a distribution which allows confidence intervals around predictions to be calculated.

Collision Risk Models (CRMs) were run for the Proposed Development using “option 2” only, as advised by NatureScot during Scoping Opinion (Offshore and Intertidal Ornithology EIA Report (Volume 2, Chapter 12, Table 12-2)). Option 2 assumes that the distribution of bird flight height is uniform within the entire rotor-swept area and estimates the number of birds at collision risk height based on a distribution of their flight heights. Here, generic flight height distributions published by Johnston *et al.* (2014) were used, as recommended by NatureScot (2023a). These generic flight height data were used to implement option 2 for all CRMs conducted for the Proposed Development. As per NatureScot guidance (NatureScot, 2023a) the collision risk models were run both stochastically (incorporating uncertainty) and deterministically (without uncertainty).

As detailed in Volume 3, Appendix 11.6 (Offshore and Intertidal Density and Abundance Report), densities of seabirds at the Proposed Development were estimated using both design-based and model-based approaches. Densities from both methods are used separately to parameterise CRMs presented here. Thus, four combinations of results are presented in this technical appendix: 1) Stochastic models using design-based densities and 2) Stochastic models using model-based densities. 3) Deterministic models using design-based densities and 4) Deterministic models using model-based densities. Where possible, the results of stochastic CRMs using model-based densities are carried forward to impact apportioning (Volume 3, Appendix 11.4 (Offshore and Intertidal Apportioning Report) as per guidance (NatureScot, 2023a). However, for some species reliable density estimates could not be modelled, as detailed in Volume 3, Appendix 11.6 (Offshore and Intertidal Density and Abundance Report), in which case results from stochastic CRMs using design-based density estimates are carried forward to impact apportioning Report Volume 3, Appendix 11.4 (Offshore and Intertidal Apportioning). Whether derived from design -based or model-based densities, only the stochastic results are carried forward to impact apportioning as per guidance (NatureScot, 2023a), but deterministic results were also obtained and are presented for comparison and backward compatibility. Similarly, design-based CRM estimates are also presented here even if the model-based estimate is being carried forward.

2.1.1. Modelled Species

All species observed in flight during the Digital Aerial Survey (DAS) campaign at the Array Area (AA), detailed in the Volume 3, Appendix 11.1 (Offshore and Intertidal Ornithology Baseline Report), have their total count and their maximum estimated monthly design-based densities (as described in Volume 3, Appendix 11.6 (Offshore and Intertidal Density and Abundance Report) shown in Table 2.1. Of these species, those potentially of concern regarding collision risk were screened into CRM based on their estimated density and each species’ sensitivity to collision. The sensitivity to collision classifications which helped inform this screening were obtained from Bradbury *et al.* (2014). Whether each species in Table 2.1 was screened in or out of CRM is also detailed in Table 2.1.

Table 2.1: All species observed in-flight in the AA during the DAS campaign, their total count, maximum estimated monthly design-based density, thier sensitivity to collision as per Bradbury *et al.* (2023) and whether they were screened in or out of CRM.

Common name	In-flight count	Maximum monthly density (animals/ km2)	Sensitivity to collision	Screening decision
Great black-backed gull	12	0.52	Very high	In
Herring gull	4	0.11	Very high	In
Common gull	2	0.10	High	In
Gannet	112	0.30	High	In
Kittiwake	401	4.14	High	In
Common tern	1	0.11	Moderate	In
Arctic tern	8	0.39	Low	In
Fulmar	289	1.72	Very low	In
Arctic skua	1	0.05	Moderate	Out
Black-headed gull	1	0.05	Moderate	Out
European storm petrel	7	0.20	Low	Out
Guillemot	58	1.45	Very low	Out
Razorbill	10	0.30	Very low	Out

2.1.2. Input Parameters

The CRMs were each run for 1000 iterations. The large array correction was not used as it is generally used for large wind farm sites (>100 turbines). Not using this correction is also a more precautionary approach as it does not reduce densities of birds for later rows of turbines, and instead risk is estimated per turbine and assessed across the windfarm additively. Simulations were undertaken using both the stochastic and deterministic approaches. The proportion of upwind flights for all species was assumed to be 0.5 and the random seed for all runs was 52.

2.1.3. Turbine Parameters

Three different design scenarios from the Proposed Development's design envelope were assessed, the turbine parameters for each are presented in Table 2.2. The design represented by scenario 1 is the Most Likely Scenario (MLS) based on the project design envelope and is the most likely to be constructed. As per the results presented below (Section 3), scenario 1 is also the Worst-Case Scenario (WCS) in terms of estimated impact for all species assessed. Scenario 2 and 3 represent other possible windfarm specifications which were modelled for comparison and to identify the worst-case scenario.

Table 2.2: Turbine parameters to be used for collision risk modelling for the Proposed Development with standard deviations presented in brackets. Standard deviations were not used in the deterministic models as they do not incorporate variability.

Parameter	Scenario 1	Scenario 2	Scenario 3
Number of turbines	67	48	40
Latitude (degrees)	57.41	57.41	57.41
Number of blades	3	3	3
Rotor radius (m)	118	138	150
Air gap (m)*	30	30	30
Tidal offset	0	0	0
Blade width (m)	8	10	12
Rotation speed (rpm)	8.4 (+/- 1.5)	8.4 (+/- 1.5)	8.4 (+/- 1.5)
Pitch (degrees)	8 (+/- 4)	8 (+/- 4)	8 (+/- 4)

Blade pitch and rotation speed were modelled using their estimated truncated normal distributions, constructed from a mean and standard deviation as opposed to a wind-speed relationship. The operational times of the wind farm assumed for all three modelled scenarios are presented in Table 2.3. In the absence of site-specific wind availability data, the default wind availability provided by Caneco (2022) was used. The mean downtime and Standard Deviation (SD) values are based on operational time availability predictions for the Proposed Development.

Table 2.3: Operational times of the Proposed Development used for all three scenarios of the CRMs.

(%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind availability	96.28	96.53	95.83	92.78	90.86	92.22	89.11	89.92	93.71	96.14	97.14	96.41
Mean downtime	3	3	3	3	3	3	3	3	3	3	3	3
SD downtime	2	2	2	2	2	2	2	2	2	2	2	2

2.1.4. Species Biometric Parameters

The species-specific biometric parameters used in all models are presented in Table 2.4. Where species' parameters are presented in NatureScot (2023a), these were used. Where species' body length and wingspan parameters were not provided in NatureScot guidance (2023a), these were taken from Snow & Perrins (1987). In the case of common gull and common tern, the values obtained from Snow & Perrins (1987) are the same as those pre-loaded in the stochastic CRM tool. For fulmar, the body length and wingspan values pre-loaded in the sCRM tool of 0.45m (0.025) and 1.07m (0.025) respectively, differ from those calculated from the Snow & Perrins (1987) range of 0.475m (0.0125) and 1.11m (0.005); in this case the values calculated from Snow & Perrins (1987) were used as these larger estimates will result in more precautionary collision estimates. Where a species' flight speed was not given in NatureScot (2023a), the values were taken from Alerstam *et al*. (2007). Each parameter and its source are detailed in

Table 2.4. All species were modelled with a "flapping" flight type apart from northern gannet which was modelled as "gliding". Fulmar was modelled as 'flapping' rather than 'gliding' due to this being the precautionary option which

leads to marginally higher collision rates. The same inputs were used for the stochastic and deterministic modelling, though naturally standard deviations were not used in the latter.

Table 2.4: Bird biometric data used for CRM (numbers in brackets are standard deviations).

Species	Body length (m)	Wingspan (m)	Flight speed (m/s)	Nocturnal activity (0-1)	Avoidance rate
Arctic tern	0.340 (0.005)[2]	0.80 (0.025)[2]	10.9 (0.9)[3]	0.000 (0.0000)[1]	0.991 (0.0004)[1]
Kittiwake	0.390 (0.0050)[1]	1.080 (0.0625)[1]	13.1 (0.40)[1]	0.375 (0.0637)[1]	0.993 (0.0003)[1]
Common gull	0.410 (0.0050)[2]	1.200 (0.0500)[2]	13.4 (2.90)[3]	0.250 (0.0637)[1]	0.995 (0.0002)[1]
Common tern	0.330 (0.0100)[2]	0.875 (0.0525)[2]	10.9 (0.9)[5]	0.000 (0.0000)[1]	0.991 (0.0004)[1]
Great black-backed gull	0.710 (0.0350)[1]	1.580 (0.0375)[1]	13.7 (1.20)[1]	0.375 (0.0637)[1]	0.994 (0.0004)[1]
Herring gull	0.6 (0.0225)[1]	1.440 (0.0300)[1]	12.8 (1.80)[1]	0.375 (0.0637)[1]	0.994 (0.0004)[1]
Fulmar	0.475 (0.0125)[2]	1.11 (0.005)[2]	13.00 (0.00)[5]	0.75 (0.00)[4]	0.991 (0.0004)[1]
Gannet	0.94 (0.0325)[1]	1.720 (0.0375)[1]	14.9 (0.00)[1]	0.080 (0.10)[1]	0.993 (0.0003)[1]

[1]NatureScot (2023a), [2] Mean and SD from range in Snow & Perrins (1987), [3]Alerstam et al., (2007), [4]Garthe & Hüppop (2004), [5]Pennycuick (1997)

[5]In the absence of common tern flight speed data in Alerstam et al., (2007) the value for Arctic tern was assumed to be representative.

For gannet, in addition to the avoidance rate from NatureScot (2023a), presented in

Table 2.4, the Royal Society for the Protection of Birds (RSPB) requested that this species was assessed with an avoidance rate of 98% during the breeding season (no standard deviation was provided with this). Therefore, gannet CRMs were also run using the parameters above but with an avoidance rate of 0.98 during the breeding season. This was done stochastically using both design-based and model-based density inputs for scenario one as this is both the MLS and WCS. Two annual gannet estimates are therefore presented in the results, one derived from the avoidance rate in

Table 2.4 used in both breeding and non-breeding season CRMs, and one from the combination of the breeding season CRM estimate using the RSPB avoidance rate and the non-breeding season estimate using the avoidance rate in

Table 2.4.

2.1.5. In-flight Densities

As detailed in Volume 3, Appendix 11.6 (Offshore and Intertidal Density and Abundance Report), density estimates of birds in the AA were derived from DAS data collected on site. This was achieved in two different ways; through design-based and model-based (using MRSea) estimation. MRSea was used to generate spatially explicit predictions of density and abundance across the AA and surrounding waters (Scott-Hayward *et al.*, 2014). The

number of observations of Artic tern, common gull and common tern present in the DAS data were insufficient to generate reliable models from MRSea; as such, no model-based density estimations were calculated for these species. However, for all other CRM relevant species, model-based densities were predicted, and all eight CRM relevant seabird species possessed estimated design-based densities. Regardless of density estimation method, collision risk models were parameterised with a monthly distribution of 2000 density estimates of birds in flight within the AA, for each species, when using stochastic models; discussed in the Volume 3, Appendix 11.6 (Offshore and Intertidal and Abundance Report). This approach follows NatureScot (2023a) guidance, and these bootstrapped data are available upon request for reproducibility as per guidance. As the deterministic models do not account for variability, only the point estimates (design-based) and mean predicted (model-based) values of the density estimations were used in those CRMs. These deterministic density inputs are presented in Annex A.

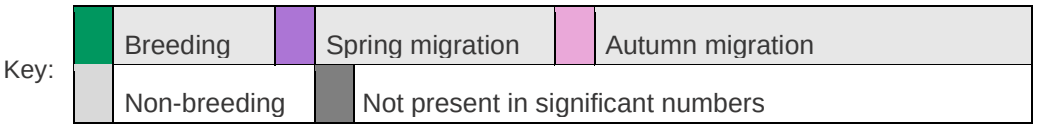
2.1.6. Seasonal definitions

In accordance with current guidance (NatureScot, 2023a), CRM results were calculated for both the breeding and non-breeding seasons. Each species' breeding season is that detailed in NatureScot (2020) as "Breeding period (strongly associated with nest site)". As per the scoping consultation (Offshore and Intertidal Ornithology EIA Report (Volume 2, Chapter 12, Table 12-2)) NatureScot confirmed that the period of 'breeding site attendance' constitutes part of the non-breeding season and should be excluded from the breeding season. Apportioning of non-breeding season impacts to Special Protection Areas (SPAs) requires the use of regional population estimates published by Furness (2015) (further detailed in the Offshore and Intertidal Apportioning Report (Volume 3, Appendix 11.4)). These regional population estimates relate to species-specific periods within the non-breeding season. As a result, non-breeding season impacts must be estimated within the levels of non-breeding periods presented in Furness (2015) to facilitate their accurate apportioning. Thus, while each species' non-breeding season can be defined as the inverse of their breeding season, this non-breeding season itself may contain further classification(s). These classifications are presented in Table 2.5.

For certain species, one or more of the non-breeding seasons in Furness (2015) extend into the breeding season detailed in NatureScot (2020). For example, the spring migration period of kittiwake is reported as spanning January-April by Furness (2015), however, the breeding season begins in mid-April in NatureScot (2020). In these circumstances, the non-breeding season(s) were foreshortened according to the breeding season as advised by NatureScot in their scoping response (Offshore and Intertidal Ornithology EIA Report (Volume 2, Chapter 12, Table 12-2)).

Table 2.5: Seasonal definitions of each modelled species used to estimate impacts per season. The Breeding season represents the breeding season as defined by NatureScot (2020). All other seasons are from Furness (2015) and have been foreshortened where they overlap with the breeding season.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kittiwake												
Common gull												
Great black-backed gull												
Herring gull												
Common tern*												
Arctic tern												
Fulmar												
Gannet												



*For common tern, the NatureScot definition of breeding season (strong association with nesting sites) completely overlaps the autumn migration period defined in Furness (2015). As priority is given to the NatureScot definition of breeding season, no autumn migration period is shown for common tern.

Some seasonal definitions include 'half months' i.e. the break between the seasons occurs in the middle of a month rather than at the end. Following scoping consultation (Offshore and Intertidal Ornithology EIA Report (Volume 2, Chapter 12, Table 12-2)), NatureScot advised that these 'half-months' be treated following the approach adopted in the Berwick Bank Wind Farm Environmental Impact Assessment (EIA) (Berwick Bank, 2022). Therefore, estimates for months which were split between seasons were allocated equally to each season with a proportion of 0.5. For example, the kittiwake spring migration ends mid-April and the breeding season starts then. Thus, if ten kittiwake collisions were predicted in April, five would be attributed to the spring migration season and five to the breeding season. How densities are calculated during these "half-months" is detailed in the Volume 3, Appendix 11.6 (Offshore and Intertidal Density and Abundance Report).

For the stochastic models, within each month of the year, 1000 iterations of each CRM were run. From this distribution of estimated collisions, monthly, seasonal and annual median collision estimates, and their 95% confidence intervals (CIs) were separately calculated for each combination of species, scenario and density estimation (design/model-based) method.

2.2. Migratory Collision Risk Modelling

In addition to foraging seabirds, offshore wind farms may also present a collision risk to migrating non-seabirds. Volume 3, Appendix 11.1 (Offshore and Intertidal Ornithology Baseline Report) identified a total of 57 non-seabird bird species with overlap between their migration corridor and the AA, putting them at potential collision risk. This risk can be quantitively assessed by estimating the number of birds (per species) expected to pass through a development and then undertaking CRM using migration specific bird biometrics. Such a quantitative assessment for nine Scottish offshore windfarms was commissioned by Marine Scotland and conducted by WWT consulting, (WWT, 2014).

As part of Scotland's National Marine Plan (Scottish Government, 2015) a strategic study of collision risk for birds on migration was commissioned and aims to update the process of assessing migrant collision risk such that it is comparable with that of seabirds and can incorporate uncertainty. Currently, only the first work package of this study has been published which is a review of birds migrating in Scottish waters by Woodward *et al*. (2023), this updates:

- Population estimates;
- Migratory routes;
- Timing of migration;
- Migratory flight heights;
- Migratory flight speeds; and
- Avoidance behaviour and rates.

The second work package of this study is the development of a stochastic CRM tool for migratory bird species; whilst this model now exists in its Beta version, it has not yet been approved by NatureScot or incorporated into guidance at the time of the present assessment. As such, during scoping consultation (Offshore and Intertidal Ornithology EIA Report (Volume 2, Chapter 12, Table 12-2)), NatureScot supported a qualitive approach to assessing which migratory species may need further consideration. This qualitive approach was undertaken relative to WWT (2014) while considering the updates presented in Woodward *et al*. (2023). WWT (2014) concludes that no non-seabird species had a collision mortality estimate of concern cumulatively across all nine windfarms assessed. On review of the updated parameters in Woodward *et al.* (2023), it is apparent that regardless of the size of each species'

migrating population, such a small proportion of that migrating population would be at risk of collision with the Proposed Development that none of the species require further consideration. This forms the basis of the method of qualitive assessment used here and is outlined below. This qualitative approach to assess whether species need further mCRM assessment is based on WWT (2014) in which an indicative threshold of 1% of the passage population being impacted is used to inform which species were of concern. As such, the same indicative threshold is used here. The proportion of each species migratory population at risk of collision with the Proposed Development was assessed as was done in WWT but with updated parameters from Woodward *et al*. (2023). The methods used by WWT (2014) to estimate the proportion of the population at risk are summarised in Equation 1.

$$Population\ proportion\ susceptible\ to\ collision = \left(1 - (\mathrm{pCRH} \times \mathrm{AR})\right) \times \frac{\text{average WFw}}{\mathrm{MFw}} \times P$$

Where:
pCRH = proportion at collision risk height
AR= avoidance rate
WFw = windfarm width
MFw = migration front width
P = proportion of population on windfarm coast

Equation 1: Equational summary of the methods used by WWT (2014) to estimate the proportion of a species' migrating population at risk of collision with a windfarm.

To determine whether 1% of the passage population of each species was at potential collision risk, first, the updated proportion at collision risk height and avoidance rates presented in Woodward *et al.* (2023) were combined, identifying any species for which less than 1% of the population was at risk even if the whole population was expected to pass through the AA. Following this, the amount of each remaining species' (those with >1% still at risk) population expected to pass through the AA was assessed based on the width of the AA as a proportion of the width of each species' migration front. If the final number of birds at potential collision risk exceeded 1% of the total passage population, then further assessment would be warranted. However, following this approach, no species exceeded 1%, and therefore no further quantitative assessment was conducted for migratory non-seabird species. These results are presented in Section 3.2.

3. Results

3.1. Seabird Collision Risk Modelling

For each modelled species, the seasonal collision estimate for all three design scenarios, using the type of density estimation (design/model-based) being carried forward to impact apportioning (Volume 3, Appendix 11.4 (Offshore and Intertidal Apportioning Report) is presented in Table 3.1. As outlined in Section 2.1, these are from stochastic CRMs using model-based densities where reliable models could be obtained (Volume 3, Appendix 11.6 (Offshore and Intertidal Density and Abundance Report) and design-based if not. The type of density estimation used for each species is detailed in Table 3.1. In the case of great black backed gull and gannet, reliable model-based densities could not be obtained for all seasonal periods. As such, a combination of collision estimates from model-based densities, where reliable, and design-based densities was used across the year. As a result, the annual estimate of these species is taken from a distribution created from the monthly values of the relevant CRM estimate (design/model-based) summed across each CRM iteration.

Table 3.1: **Stochastic, seasonal and annual collision estimates (number of birds) at the Proposed Development parameterised with model-based densities where possible and deisgn-based where not. Values are rounded to 3 decimal places for display purposes only and those greater than 1000 are shown in scientific notation. "-" denotes that non-breeding period as not applicable to that species. Values are the median estimates from 1000 iterations with 95% CIs in brackets.**

Species	Density type	Scenario	Breeding	Autumn migration	Spring migration	Over winter	Annual
Arctic tern	Design-based	One	0.233 (0 - 2.411)	-	-	-	0.233 (0-2.411)
	Design-based	Two	0.214 (0 - 2.285)	-	-	-	0.214 (0-2.285)
	Design-based	Three	0.22 (0 - 2.265)	-	-	-	0.22 (0-2.265)
Kittiwake	Model-based	One	61.733 (12.095 - 1.2e+02)	0.945 (0.346 - 2.054)	8.346 (4.889 - 13.526)	-	69.398 (17.661-133.125)
	Model-based	Two	55.299 (10.802 - 1.1e+02)	0.85 (0.308 - 1.907)	7.5 (4.394 - 12.279)	-	62.269 (15.633-123.109)
	Model-based	Three	55.12 (10.703 - 1.1e+02)	0.844 (0.303 - 1.927)	7.457 (4.363 - 12.37)	-	61.59 (15.46-125.426)
Common gull	Design-based	One	0 (0 - 2.165)	-	-	-	0 (0-2.165)
	Design-based	Two	0 (0 - 1.92)	-	-	-	0 (0-1.92)
	Design-based	Three	0 (0 - 1.929)	-	-	-	0 (0-1.929)
Common tern	Design-based	One	0 (0 - 0.691)	-	-	-	0 (0-0.691)
	Design-based	Two	0 (0 - 0.638)	-	-	-	0 (0-0.638)
	Design-based	Three	0 (0 - 0.649)	-	-	-	0 (0-0.649)
Great black-backed gull	Model-based & Design-based	One	0 (0 - 0)*	-	-	17.422 (2.018 – 5.0e+284)	17.4 (2.02-5.04e+284)
	Model-based & Design-based	Two	0 (0 – 0)*	-	-	15.685 (1.793 - 4.5e+284)	15.7 (1.79-4.47e+284)
	Model-based & Design-based	Three	0 (0 - 0)*	-	-	15.369 (1.761 - 4.4e+284)	15.4 (1.76-4.41e+284)
Herring gull	Model-based	One	0.854 (0.022 - 3.8e+272)	-	-	1.727 (0.017 - 1.2e+287)	4.519 (0.081-2.0e+297)
	Model-based	Two	0.756 (0.02 - 3.3e+272)	-	-	1.553 (0.015 - 1.1e+287)	4.1 (0.071-1.7e+297)
	Model-based	Three	0.744 (0.02 - 3.2e+272)	-	-	1.521 (0.015 - 1.0e+287)	4.064 (0.07-1.7e+297)
Fulmar	Model-based	One	0.345 (0 - 15.472)	0.169 (0 - 5.802	0.098 (0 - 7.443)	0.07 (0 - 9.067)	1.009 (0-28.618)
	Model-based	Two	0.318 (0 - 13.851)	0.157 (0 - 5.216)	0.09 (0 - 6.729)	0.065 (0 - 8.193)	0.933 (0-26.262)
	Model-based	Three	0.324 (0 - 13.633)	0.159 (0 - 5.182)	0.091 (0 - 6.751)	0.067 (0 - 8.183)	0.953 (0-26.403)
Gannet	Model-based & Design-based	One	9.589 (2.09 - 38.578)	2.305 (0.304 - 14.712)	0.46 (0 - 1.745)*	-	12.6 (2.51-54.3)
	Model-based & Design-based	Two	8.517 (1.888 - 34.472)	2.051 (0.27 - 13.437)	0.41 (0 - 1.595)*	-	11.2 (2.26-49.0)
	Model-based & Design-based	Three	8.366 (1.852 - 33.883)	2.014 (0.266 - 13.255)	0.402 (0 - 1.549)*	-	11.0 (2.26-48.1)

** Indicates these collision estimates were derived from design-based densities as reliable model-based values could not be obtained.*

Collision risk estimates were obtained stochastically and deterministically using both design-based and model-based (where possible) in-flight density estimations. In some instances, model-based density predictions included incredibly high estimates within the distributions. NatureScot guidance (2023b) recommends using model-based densities, and therefore these were used in collision risk models. Where these impossibly high-density estimates were sampled by the collision risk model, the resultant collision estimates and/or their upper confidence intervals were, in some cases, extremely large (this is further discussed Volume 3, Appendix 11.6 (Offshore and Intertidal Density and Abundance Report). All collision estimates using model-based densities are presented in Annex: C, Table 4.5. As the CIs are not carried forward into Population Viability Analysis (PVA) (Volume 3, Appendix 11.5 (Offshore and Intertidal Population Viability Analysis Report) this only creates unrealistic collision estimates for great black-backed gull during the breeding season and gannet during spring migration. As a result, these estimates were replaced with those derived from the design-based densities.

As requested by RSPB, seasonal results of gannet stochastic CRMs using an avoidance rate of 98% during the breeding season under design scenario 1 (MLS and WCS) are presented in Table 3.2. This estimate was obtained using the model-based density estimation. The same result using the NatureScot (2023a) avoidance rate is also presented for comparison. The non-breeding estimates using the NatureScot (2023a) avoidance rate are presented here again as these were combined with the breeding season estimate using the RSPB avoidance rate to calculate a different annual estimate.

Table 3.2: Stochastic seasonal and annual gannet (number of birds) collision estimates at the Proposed Development modelled using the avoidence rate (AR) recommended by NatureScot (2023a) and that requested by RSPB during the breeding season. Values are rounded to 3 decimal places for display purposes only. Values are the median estimates from 1000 iterations with 95% CIs in brackets. The annual estimate under the RSPB avoidance rate is obtained from the sum of the RSPB avoidance rate breeding estimate and the NatureScot avoidance rate non-breeding season estimates. Both annual estimates and their confidence intervals are the sum of the breeding and non-breeding estimates and were not calculated from the distribution of results.

Time period	RSPB (AR = 0.98 for breeding season)	NatureScot (AR = 0.993 (0.0003))
Breeding	26.964 (5.537 - 110.00)	9.589 (2.09 - 38.578)
Autumn migration	-	2.305 (0.304 - 14.712)
Spring migration	-	0.46 (0 - 1.745)
Annual	29.729 (5.841 – 126.457)	12.354 (2.394 - 55.035)

Monthly collision estimates of all eight species from stochastic CRMs are visualised in Figure 1. These are the collision estimates modelled with design-based densities only as some of the extreme confidence intervals around collision estimates from models parameterized with model-based densities made their visualisation uninformative. Seasonal, annual and monthly, stochastic and deterministic results, under each design scenario, of all modelled species, using design-based density estimates are presented in Annex B. The same results for CRMs parameterised with model-based densities (where possible) are also presented in Annex C.

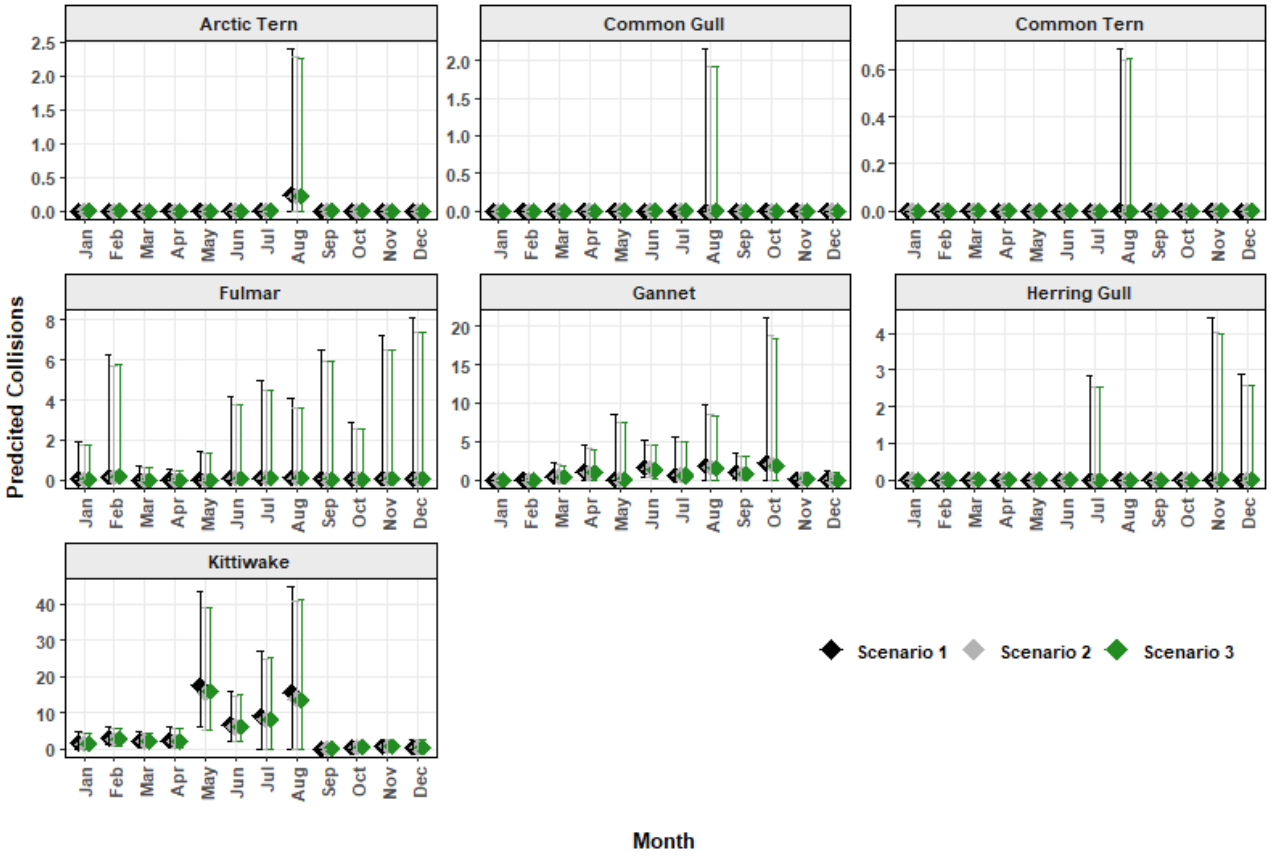


Figure 1: Monthly predicted median collision estimates and their 95% confidence intervals for all modelled species using design-based density estimates and stochastic collision models.

3.2. Migratory Collision Risk Modelling

3.2.1. Collision Risk Height and Avoidance Rate

Of the parameters in equation 1 (Section 2.2), recommendations for the proportion at CRH and avoidance rate are updated in Woodward *et al*. (2023) in a way that is comparable to those used by WWT (2014). These rates are compared in Table 3.3. Several species were screened out of mCRM by WWT (2014) owing to a lack of data, for these species a dash ("-") is used to represent no CRH data in Table 3.3.

WWT (2014) use a blanket avoidance rate of 0.98 for all species. The percentage of the population potentially at risk of collision using the updated metrics was calculated by multiplying the updated proportion at CRH by the updated avoidance rate and expressing this as a percentage. This is the percentage at risk of collision if all of the migrating population passed through a given development prior to undertaking CRM so does not account for variables generally included in quantitative CRM including flight speed, bird dimensions, or wind farm specifications.

Table 3.3: **All 57 species screened into migratory collision risk assessment their WWT (WWT, 2014) proportion at collision risk height (prop. CRH) and avoidance rate (AR), their updated (Woodward *et al.*, 2023) prop. CRH and AR and the percentage of a given population at risk of collision under the updated parameters.**

Species	WWT prop. CRH	Updated prop. CRH	WWT AR	Updated AR	Population at collision risk (%)
Common Scoter*	0.01	1	0.98	0.985	1.50
Gadwall*	-	1	0.98	0.985	1.50
Goldeneye*	-	1	0.98	0.985	1.50
Goosander*	-	1	0.98	0.985	1.50
Long-tailed Duck*	0.15	1	0.98	0.985	1.50
Mallard*	-	1	0.98	0.985	1.50
Pintail*	0.15	1	0.98	0.985	1.50
Pochard*	0.15	1	0.98	0.985	1.50
Red-breasted Merganser*	-	1	0.98	0.985	1.50
Scaup*	0.15	1	0.98	0.985	1.50
Shoveler*	-	1	0.98	0.985	1.50
Teal*	0.15	1	0.98	0.985	1.50
Tufted duck*	0.15	1	0.98	0.985	1.50
Velvet Scoter*	0.15	1	0.98	0.985	1.50
Wigeon*	0.15	1	0.98	0.985	1.50
Merlin*	-	1	0.98	0.989	1.10
Shelduck	-	0.5	0.98	0.985	0.75
Whooper Swan	0.5	0.5	0.98	0.988	0.60
Bittern	-	1	0.98	0.995	0.50
Corncrake	0.5	1	0.98	0.995	0.50
Great crested Grebe	-	1	0.98	0.995	0.50
Hen Harrier	0.5	1	0.98	0.995	0.50
Nightjar	-	1	0.98	0.995	0.50
Short-eared Owl	-	1	0.98	0.995	0.50
Slavonian Grebe	-	1	0.98	0.995	0.50
Spotted Crake	-	1	0.98	0.995	0.50
Eider	-	0.25	0.98	0.985	0.38
Marsh Harrier	-	0.5	0.98	0.995	0.25
Osprey	0.5	0.5	0.98	0.995	0.25
Black-throated Diver	0.001	0.25	0.98	0.995	0.13
Great Northern Diver	0.02	0.25	0.98	0.995	0.13
Red-throated Diver	0.02	0.25	0.98	0.995	0.13

Species	WWT prop. CRH	Updated prop. CRH	WWT AR	Updated AR	Population at collision risk (%)
Bar-tailed Godwit	0.25	1	0.98	0.999	0.10
Black-tailed Godwit	0.25	1	0.98	0.999	0.10
Curlew	0.25	1	0.98	0.999	0.10
Dotterel	0.25	1	0.98	0.999	0.10
Dunlin	0.25	1	0.98	0.999	0.10
Golden Plover	0.25	1	0.98	0.999	0.10
Greenshank	0.25	1	0.98	0.999	0.10
Grey Plover	0.25	1	0.98	0.999	0.10
Knot	-	1	0.98	0.999	0.10
Lapwing	-	1	0.98	0.999	0.10
Oystercatcher	0.25	1	0.98	0.999	0.10
Purple Sandpiper	-	1	0.98	0.999	0.10
Redshank	0.25	1	0.98	0.999	0.10
Ringed Plover	-	1	0.98	0.999	0.10
Ruff	0.25	1	0.98	0.999	0.10
Sanderling	0.25	1	0.98	0.999	0.10
Snipe	0.25	1	0.98	0.999	0.10
Svalbard Barnacle Goose (Svalbard/South-west Scotland)	0.3	1	0.98	0.999	0.10
Taiga Bean Goose	0.3	1	0.98	0.999	0.10
Turnstone	0.25	1	0.98	0.999	0.10
Whimbrel	0.25	1	0.98	0.999	0.10
Wood Sandpiper	0.25	1	0.98	0.999	0.10
East Atlantic Light-bellied Brent Goose (North Greenland/Svalbard)	0.3	0.5	0.98	0.999	0.05
Icelandic Greylag Goose (Iceland/UK & Ireland)	0.3	0.5	0.98	0.999	0.05
Pink-footed Goose (East Greenland and Iceland/UK)	0.3	0.5	0.98	0.999	0.05

** Indicates 1% or more of that species' total migrating population is at risk of collision accounting for the updated proportion at CRH and avoidance rate.*

Source: WWT (2014), Woodward et al. (2023).

For all 57 species, the proportion at CRH stayed the same or increased in the updated values from Woodward *et al.* (2023) compared to those in WWT (2014). However, the updated avoidance rates recommended by Woodward *et al.* (2023) are higher than the blanket rate of 0.98 applied to all species in WWT (2014). This increase in avoidance rate, which for some species becomes 99.9%, results in many species being screened out at this stage as less than 1% of the total migrating population would be at risk of collision, even if the entire passage population passed through the AA.

For example, snipe have an updated proportion at CRH of 1 and avoidance rate of 0.999. Under these parameters, even if 100% of the migrating population would pass through a development, and 100% are estimated to fly at CRH, an avoidance rate of 99.9% (0.999) would still result in only 0.10% of the population being at risk of collision and progressing to mCRM.

Under this screening process, only 16 out of the 57 species have 1% or more of the population at risk of collision and remained screened in as shown in Table 3.3.

Of these 16 species, all have 1.50% of the population at risk apart from merlin which has 1.10% at risk. These estimates assume all of each of these species' migrating population pass through the AA which is not the case.

3.2.1.1. **Population and Proposed Development Proportional Overlap**

As seen in equation 1, part of the method used by WWT (2014) to estimate the number of birds passing through a development is described as the proportion of the species' migration front overlapping said development. For example, if 0.05% of a species' migration front overlaps a development, 0.05% of that species total migrating population is expected to encounter that development. The proportional overlap between a migration front and development is calculated in WWT (2014) as the average width of the wind farm AA divided by the width of the migration front.

Migration corridors are updated in Woodward *et al.* (2023) however, migration fronts are not. While this qualitative method of screening aims to use updated parameters from Woodward *et al.* (2023), WWT (2014) migration fronts are narrower than the updated corridors of Woodward *et al.* (2023) and are not necessarily directly comparable. As such, WWT (2014) migration fronts were used here as their smaller width would result in a greater proportional overlap and more precautionary estimate of the number of birds at potential collision risk. An example of a migration front presented by WWT (2014) for wigeon is given in Figure 2, alongside the migration corridor for the same species from Woodward *et al.* (2023).

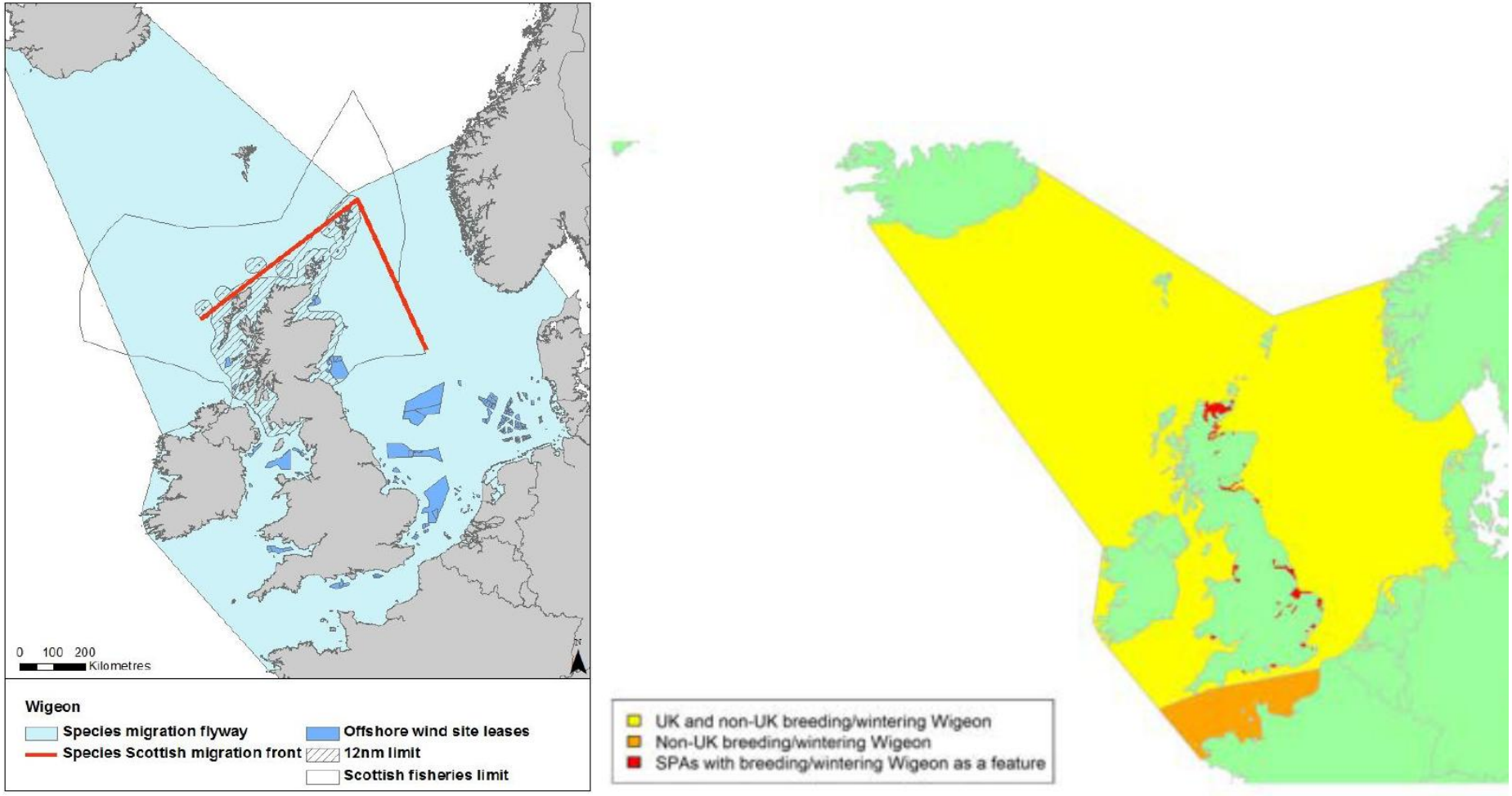


Figure 2: Left: Migration corridor and associated front passing through Scottish waters for wigeon, as presented in WWT (2014). Right: From Woodward *et al.* (2023); the migration corridor of wigeon

Comparing the migration corridors of Woodward *et al.* (2023) with the migration fronts of WWT (2014) is difficult for three reasons:

1. There appear to be two migration fronts, one for the individuals migrating to/from Iceland and one for Scandinavia, yet it is not discussed in WWT (2014) how the proportion of birds travelling to/from each destination is accounted for as the assessment was carried out over the whole migrating population passing through Scottish waters. The report by WWT (2014) would suggest the total width of both these fronts is used in calculations. However, this implies the whole migrating population is equally split between the two directions which is unlikely. It could be that correcting for the proportion of birds on each coast accounts for this, but this is not the same as the proportion of birds from each direction.

2. What a migration front represents or how it is estimated is not discussed in WWT (2014). These migration fronts are presumed to represent the area all birds passing though Scottish waters are expected to pass through. If this is the case then a migration front is presumably equal to the widest part of the migration corridor which overlaps Scottish waters, though these appear to be the widest part of the migration corridor which overlap Scottish land.

3. The migration fronts in WWT (2014) are trimmed by the amount falling in Scottish waters, where the front passing along the east coast of Scotland stops at the Scottish border. However, migration corridors are given for the UK as a whole in Woodward *et al.* (2023).

As a result of these differences, updating the migration fronts used by WWT (2014) to incorporate the migration corridors given by Woodward *et al.*, (2023) to estimate the proportion of each species' population that will pass through the AA is not a case of a simple update. As a result, the shortest width required for 1% of each species' passage population to be at potential collision risk was calculated and its feasibility assessed.

The widest part of the AA is approximately 23.15 km which is used here as a precautionary estimate because how the average width of a development was calculated by WWT (2014) is unclear. For the remaining 16 species not yet screened out by the proportion at CRH and avoidance rates alone, the highest percentage of the population passing through a development at potential risk of collision is 1.50%. Thus, unless any of these species have a migration front only three times as wide as the Proposed Development, more than 1% of the total migrating population cannot be at risk of overall collision risk. This would represent a migration front of only 69.45 km, which overlaps the whole AA width. Regardless of how a migration front is defined, no such migration front or corridor of that extent exists for any species assessed by Woodward *et al.* (2023) or WWT (2014), including the remaining 16 species. As such, all these species can also be screened out of further migratory collision risk assessment as less than 1% of the total migrating population is at risk of collision with the Proposed Development.

Due to no species reaching the indicative 1% of the passage population at collision risk threshold, as used by WWT (2014), no migratory species were assessed quantitatively with mCRM. This conclusion is reached before accounting for the proportion of the passage population expected to transit along the same coast as the Proposed Development, which would further reduce risk.

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Annexes

A. Deterministic Density Inputs

Table 4.1: **Design-based density point estimates (number of birds) used as the density input for the deterministic CRMs. Values rounded to 3 decimal places for display purposes only. Values are the mean of that months peak abundances of birds in flight in the AA for each species as presented in the Offshore and Intertidal Density and Abundance Report (Volume 3, Appendix 11.6, Section 4)**

Species	January	February	March	April	May	June	July	August	September	October	November	December
Arctic tern	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.362	0.000	0.000	0.000	0.000
Kittiwake	0.374	0.649	0.374	0.424	2.929	1.110	1.348	2.431	0.000	0.100	0.160	0.168
Common gull	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.050	0.000	0.000	0.000	0.000
Common tern	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.055	0.000	0.000	0.000	0.000
Great black-backed gull	0.075	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.028	0.260
Herring gull	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.000	0.000	0.000	0.057	0.033
Fulmar	0.300	1.148	0.100	0.075	0.175	0.649	0.799	0.699	0.849	0.449	1.053	0.959
Gannet	0.000	0.025	0.100	0.225	0.225	0.250	0.175	0.424	0.200	1.074	0.050	0.050

Table 4.2: **Model-based density predictions (number of birds) used as the density input for the model-based deterministic CRMs. Values rounded to 3 decimal places for display purposes only. Values greater than 1000 are shown in scientific notation. Values are the mean of that months peak abundances of birds in flight in the AA for each species as presented in the Offshore and Intertidal Density and Abundance Report (Volume 3, Appendix 11.6, Section 4)**

Species	January	February	March	April	May	June	July	August	September	October	November	December
Kittiwake	0.105	0.385	0.747	0.436	2.182	0.863	1.282	3.302	0.011	0.049	0.057	0.044
Great black-backed gull	0.048	0.019	7.03e+10	7.73e+10	7.03e+10	7.03e+10	7.03e+10	0.004	7.03e+10	7.03e+10	0.056	0.193

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Species	January	February	March	April	May	June	July	August	September	October	November	December
Herring gull	0.004	2.40e+10	0.004	2.64e+10	0.002	0.002	0.012	0.002	2.40e+10	2.40e+10	0.025	0.006
Fulmar	0.128	0.252	0.036	0.061	0.047	0.969	0.365	0.488	1.076	0.506	1.178	0.665
Gannet	1.58e+08	0.011	0.066	0.186	0.154	0.557	0.140	0.389	0.307	0.763	0.037	0.041

B. Seasonal, Annual and Monthly design-based Collision Estimates

Table 4.3: Stochastic and deterministic, seasonal and annual collision estimates (number of birds) at the Proposed Development modelled with design-based density estimates. Values are rounded to 3 decimal places for display purposes only. "-" denotes that non-breeding season as irrelevant for that species. Stochastic values are the median estimates from 1000 iterations with 95% CIs in brackets.

Species	Model type	Scenario	Breeding	Autumn migration	Spring migration	Over winter/non-breeding	Annual
Arctic tern	Deterministic	One	0.28	-	-	-	0.28
	Stochastic		0.233 (0 - 2.411)	-	-	-	0.233 (0-2.411)
	Deterministic	Two	0.259	-	-	-	0.259
	Stochastic		0.214 (0 - 2.285)	-	-	-	0.214 (0-2.285)
	Deterministic	Three	0.262	-	-	-	0.262
	Stochastic		0.22 (0 - 2.265)	-	-	-	0.22 (0-2.265)
Kittiwake	Deterministic	One	53.1865	2.196	8.6535	-	64.036
	Stochastic		47.771 (14.595 - 117.889)	2.015 (0.492 - 4.825)	8.437 (4.698 - 14.15)	-	56.969 (22.631-131.574)
	Deterministic	Two	47.4115	1.958	7.7125	-	57.082
	Stochastic		42.568 (13.011 - 107.745)	1.819 (0.437 - 4.463)	7.596 (4.182 - 12.837)	-	52.39 (20.495-121.608)
	Deterministic	Three	47.0035	1.94	7.6475	-	56.591
	Stochastic		42.397 (12.99 - 109.054)	1.815 (0.433 - 4.534)	7.577 (4.128 - 13.02)	-	52.189 (20.411-124.404)
Common gull	Deterministic	One	0.397	-	-	-	0.397
	Stochastic		0 (0 - 2.165)	-	-	-	0 (0-2.165)
	Deterministic	Two	0.351	-	-	-	0.351
	Stochastic		0 (0 - 1.92)	-	-	-	0 (0-1.92)
	Deterministic	Three	0.347	-	-	-	0.347
	Stochastic		0 (0 - 1.929)	-	-	-	0 (0-1.929)
Common tern	Deterministic	One	0.109	-	-	-	0.109
	Stochastic		0 (0 - 0.691)	-	-	-	0 (0-0.691)
	Deterministic	Two	0.1	-	-	-	0.1
	Stochastic		0 (0 - 0.638)	-	-	-	0 (0-0.638)
	Deterministic	Three	0.101	-	-	-	0.101
	Stochastic		0 (0 - 0.649)	-	-	-	0 (0-0.649)
Great black-backed gull	Deterministic	One	0	-	-	6.097	6.097
	Stochastic		0 (0 - 0)	-	-	4.74 (0 - 21.227)	4.74 (0-21.227)
	Deterministic	Two	0	-	-	5.34	5.34
	Stochastic		0 (0 - 0)	-	-	4.161 (0 - 18.997)	4.161 (0-18.997)
	Deterministic	Three	0	-	-	5.203	5.203
	Stochastic		0 (0 - 0)	-	-	4.047 (0 - 18.639)	4.047 (0-18.639)
Herring gull	Deterministic	One	0.501	-	-	1.324	1.825
	Stochastic		0 (0 - 2.843)	-	-	0 (0 - 5.959)	0 (0-7.423)

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Species	Model type	Scenario	Breeding	Autumn migration	Spring migration	Over winter/non-breeding	Annual
	Deterministic	Two	0.441	-	-	1.167	1.608
Herring gull	Stochastic		0 (0 - 2.521)	-	-	0 (0 - 5.312)	0 (0-6.727)
	Deterministic	Three	0.432	-	-	1.143	1.575
	Stochastic		0 (0 - 2.545)	-	-	0 (0 - 5.363)	0 (0-6.683)
Fulmar	Deterministic	One	0.5365	0.1645	0.4450	0.191	1.337
	Stochastic		0.475 (0 - 14.479)	0.137 (0 - 4.527)	0.345 (0 - 14.712)	0.101 (0 - 7.231)	1.135 (0-39.274)
	Deterministic	Two	0.4945	0.1515	0.4120	0.176	1.234
	Stochastic		0.443 (0 - 12.977)	0.126 (0 - 4.138)	0.319 (0 - 13.046)	0.095 (0 - 6.477)	1.065 (0-35.627)
	Deterministic	Three	0.5015	0.1535	0.4160	0.178	1.249
	Stochastic		0.454 (0 - 12.928)	0.131 (0 - 4.116)	0.328 (0 - 12.843)	0.095 (0 - 6.459)	1.084 (0-35.57)
Gannet	Deterministic	One	9.3455	5.092	0.5095	-	14.947
	Stochastic		8.007 (1.938 - 29.416)	2.579 (0.198 - 21.365)	0.46 (0 - 1.745)	-	11.648 (2.511-49.655)
	Deterministic	Two	8.255	4.498	0.45	-	13.203
	Stochastic		7.103 (1.743 - 26.156)	2.325 (0.175 - 19.003)	0.41 (0 - 1.595)	-	10.373 (2.258-45.007)
	Deterministic	Three	8.0375	4.38	0.4385	-	12.856
	Stochastic		6.966 (1.716 - 25.808)	2.293 (0.171 - 18.672)	0.402 (0 - 1.549)	-	10.172 (2.271-44.302)
Gannet (RSPB avoidance rate approach)	Stochastic	One	22.928 (5.126 - 85.674)	-	-	-	-

Table 4.4: Stochastic and deterministic, monthly collision estimates (number of birds) at the Proposed Development modelled with design-based density estimates. Values are rounded to 3 decimal places for display purposes only. Stochastic values are the median estimates from 1000 iterations with 95% CIs in brackets.

Species	Model type	Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Arctic tern	Deterministic	**One**	0	0	0	0	0	0	0	0.28	0	0	0	0
	Stochastic		0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0.233 (0-2.411)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)
	Deterministic	**Two**	0	0	0	0	0	0	0	0.259	0	0	0	0
	Stochastic		0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0.214 (0-2.285)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)
	Deterministic	**Three**	0	0	0	0	0	0	0	0.262	0	0	0	0
	Stochastic		0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0.22 (0-2.265)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)
Kittiwake	Deterministic	**One**	1.88	3.221	2.247	2.611	19.667	7.637	9.087	15.49	0	0.57	0.808	0.818
	Stochastic		1.621 (0-4.988)	3.003 (1.093-6.156)	2.19 (0.747-4.666)	2.32 (0.646-5.994)	17.534 (6.209-43.427)	6.798 (2.285-15.964)	9.135 (0-27.233)	15.608 (0-44.984)	0 (0-0)	0.488 (0-1.474)	0.761 (0-2.131)	0.601 (0-2.662)
	Deterministic	**Two**	1.675	2.871	2.003	2.327	17.531	6.808	8.101	13.808	0	0.508	0.721	0.729
	Stochastic		1.464 (0-4.49)	2.698 (0.983-5.669)	1.976 (0.67-4.227)	2.094 (0.575-5.54)	15.736 (5.495-39.076)	6.169 (2.071-14.583)	8.185 (0-24.937)	13.806 (0-40.856)	0 (0-0)	0.442 (0-1.356)	0.685 (0-1.937)	0.541 (0-2.445)
	Deterministic	**Three**	1.661	2.847	1.986	2.307	17.381	6.749	8.031	13.689	0	0.503	0.714	0.723

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Species	Model type	Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Stochastic		1.458 (0-4.599)	2.69 (0.981-5.597)	1.977 (0.681-4.23)	2.09 (0.571-5.574)	15.882 (5.485-39.272)	6.191 (2.054-14.865)	8.161 (0-25.36)	13.572 (0-41.256)	0 (0-0)	0.444 (0-1.35)	0.688 (0-1.947)	0.539 (0-2.443)
Common gull	Deterministic	**One**	0	0	0	0	0	0	0	0.397	0	0	0	0
	Stochastic		0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-2.165)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)
	Deterministic	**Two**	0	0	0	0	0	0	0	0.351	0	0	0	0
	Stochastic		0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-1.92)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)
	Deterministic	**Three**	0	0	0	0	0	0	0	0.347	0	0	0	0
	Stochastic		0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-1.929)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)
Common tern	Deterministic	**One**	0	0	0	0	0	0	0	0.109	0	0	0	0
	Stochastic		0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0.691)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)
	Deterministic	**Two**	0	0	0	0	0	0	0	0.1	0	0	0	0
	Stochastic		0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0.638)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)
	Deterministic	**Three**	0	0	0	0	0	0	0	0.101	0	0	0	0
	Stochastic		0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0.649)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)
Great black-backed gull	Deterministic	**One**	1.281	0	0	0	0	0	0	0	0	0	0.488	4.328
	Stochastic		1.176 (0-4.365)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-3.4)	1.095 (0-18.145)
	Deterministic	**Two**	1.122	0	0	0	0	0	0	0	0	0	0.427	3.791
	Stochastic		1.054 (0-3.87)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-3.009)	0.958 (0-16.572)
	Deterministic	**Three**	1.093	0	0	0	0	0	0	0	0	0	0.416	3.694
	Stochastic		1.027 (0-3.798)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-2.997)	0.93 (0-16.464)
Herring gull	Deterministic	**One**	0	0	0	0	0	0	0.501	0	0	0	0.852	0.472
	Stochastic		0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-2.843)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-4.434)	0 (0-2.892)
	Deterministic	**Two**	0	0	0	0	0	0	0.441	0	0	0	0.751	0.416
	Stochastic		0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-2.521)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-4.007)	0 (0-2.599)
	Deterministic	**Three**	0	0	0	0	0	0	0.432	0	0	0	0.735	0.408
	Stochastic		0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-2.545)	0 (0-0)	0 (0-0)	0 (0-0)	0 (0-3.988)	0 (0-2.581)
Fulmar	Deterministic	**One**	0.055	0.196	0.019	0.014	0.034	0.125	0.153	0.132	0.157	0.086	0.191	0.175
	Stochastic		0.044 (0-1.921)	0.154 (0-6.284)	0.004 (0-0.704)	0.001 (0-0.54)	0.004 (0-1.443)	0.084 (0-4.168)	0.102 (0-4.989)	0.104 (0-4.041)	0.054 (0-6.461)	0.057 (0-2.846)	0.101 (0-7.231)	0.048 (0-8.125)

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Species	Model type	Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Deterministic	**Two**	0.051	0.181	0.018	0.013	0.031	0.115	0.141	0.122	0.145	0.079	0.176	0.162
	Stochastic		0.042 (0-1.747)	0.143 (0-5.72)	0.004 (0-0.625)	0.001 (0-0.493)	0.003 (0-1.322)	0.079 (0-3.772)	0.097 (0-4.519)	0.098 (0-3.601)	0.05 (0-5.96)	0.053 (0-2.573)	0.095 (0-6.477)	0.045 (0-7.41)
	Deterministic	**Three**	0.051	0.183	0.018	0.013	0.032	0.117	0.143	0.123	0.147	0.08	0.178	0.164
	Stochastic		0.043 (0-1.721)	0.145 (0-5.74)	0.004 (0-0.631)	0.001 (0-0.498)	0.004 (0-1.326)	0.081 (0-3.759)	0.099 (0-4.46)	0.1 (0-3.567)	0.051 (0-5.969)	0.054 (0-2.587)	0.095 (0-6.459)	0.046 (0-7.37)
Gannet	Deterministic	**One**	0	0.095	0.505	1.256	1.447	1.692	1.147	2.52	1.031	4.91	0.182	0.162
	Stochastic		0 (0-0)	0 (0-0.67)	0.439 (0-2.233)	1.028 (0-4.557)	0 (0-8.512)	1.594 (0.306-5.142)	0.663 (0-5.571)	1.805 (0-9.732)	0.979 (0.098-3.59)	2.24 (0-21.156)	0.148 (0-0.815)	0 (0-1.249)
	Deterministic	**Two**	0	0.084	0.446	1.109	1.278	1.495	1.013	2.226	0.911	4.337	0.161	0.143
	Stochastic		0 (0-0)	0 (0-0.594)	0.39 (0-1.988)	0.917 (0-4.099)	0 (0-7.58)	1.424 (0.269-4.634)	0.592 (0-5.023)	1.612 (0-8.611)	0.866 (0.087-3.161)	1.973 (0-18.797)	0.131 (0-0.725)	0 (0-1.097)
	Deterministic	**Three**	0	0.082	0.435	1.08	1.244	1.455	0.987	2.167	0.887	4.223	0.157	0.139
	Stochastic		0 (0-0)	0 (0-0.583)	0.387 (0-1.926)	0.898 (0-4.009)	0 (0-7.388)	1.391 (0.265-4.541)	0.581 (0-4.889)	1.59 (0-8.378)	0.848 (0.086-3.108)	1.91 (0-18.29)	0.128 (0-0.711)	0 (0-1.06)
Gannet (RSPB avoidance rate)	Stochastic	**One**	0 (0-0)	0 (0-1.871)	1.235 (0-6.495)	2.851 (0-13.147)	0 (0-23.778)	4.492 (0.932-13.936)	1.82 (0-15.963)	5.116 (0-27.956)	2.649 (0.284-10.033)	6.414 (0-62.194)	0.385 (0-2.464)	0 (0-3.863)

C. Seasonal, Annual and Monthly model-based Collision Estimates

Table 4.5: Stochastic and deterministic, seasonal and annual collision estimates (number of birds) at the Proposed Development modelled with model-based density predictions. Values are rounded to 3 decimal places and those greater than 1000 are shown in scientific notation for display purposes only. "-" denotes that non-breeding season as irrelevant for that species. Stochastic values are the median estimates from 1000 iterations with 95% CIs in brackets.

Species	Model type	Scenario	Breeding	Autumn migration	Spring migration	Over winter/non-breeding	Annual
Kittiwake	Deterministic	One	51.6195	0.849	8.2635	-	60.732
	Stochastic		61.733 (12.095 - 1.2e+02)	0.945 (0.346 - 2.054)	8.346 (4.889 - 13.526)	-	69.398 (17.661-133.125)
	Deterministic	Two	46.014	0.757	7.366	-	54.137
	Stochastic		55.299 (10.802 - 1.1e+02)	0.85 (0.308 - 1.907)	7.5 (4.394 - 12.279)	-	62.269 (15.633-123.109)
	Deterministic	Three	45.6185	0.75	7.3025	-	53.671
	Stochastic		55.12 (10.703 - 1.1e+02)	0.844 (0.303 - 1.927)	7.457 (4.363 - 12.37)	-	61.59 (15.46-125.426)
Great black-backed gull	Deterministic	One	0.081	-	-	5.318	5.399
	Stochastic		1.9e+98 (0 - 1.7e+296)	-	-	17.422 (2.018 - 5.0e+284)	7.6e+179 (3.038-9.2e+298)
	Deterministic	Two	0.071	-	-	4.659	4.73
	Stochastic		1.6e+98 (0 - 1.5e+296)	-	-	15.685 (1.793 - 4.5e+284)	6.8e+179 (2.659-8.0e+298)
	Deterministic	Three	0.069	-	-	4.539	4.608
	Stochastic		1.6e+98 (0 - 1.5e+296)	-	-	15.369 (1.761 - 4.4e+284)	6.7e+179 (2.631-7.8e+298)
Herring gull	Deterministic	One	0.374	-	-	0.603	0.977
	Stochastic		0.854 (0.022 - 3.8e+272)	-	-	1.727 (0.017 - 1.2e+287)	4.519 (0.081-2.0e+297)
	Deterministic	Two	0.33	-	-	0.531	0.861
	Stochastic		0.756 (0.02 - 3.3e+272)	-	-	1.553 (0.015 - 1.1e+287)	4.1 (0.071-1.7e+297)
	Deterministic	Three	0.323	-	-	0.52	0.843
	Stochastic		0.744 (0.02 - 3.2e+272)	-	-	1.521 (0.015 - 1.0e+287)	4.064 (0.07-1.7e+297)
Fulmar	Deterministic	One	0.4685	0.1965	0.1960	0.214	1.075
	Stochastic		0.345 (0 - 15.472)	0.169 (0 - 5.802)	0.098 (0 - 7.443)	0.07 (0 - 9.067)	1.009 (0-28.618)
	Deterministic	Two	0.431	0.1810	0.1800	0.197	0.989
	Stochastic		0.318 (0 - 13.851)	0.157 (0 - 5.216)	0.09 (0 - 6.729)	0.065 (0 - 8.193)	0.933 (0-26.262)
	Deterministic	Three	0.438	0.1830	0.1820	0.199	1.002
	Stochastic		0.324 (0 - 13.633)	0.159 (0 - 5.182)	0.091 (0 - 6.751)	0.067 (0 - 8.183)	0.953 (0-26.403)
Gannet	Deterministic	One	10.788	3.627	0.345	-	14.76
	Stochastic		9.589 (2.09 - 38.578)	2.305 (0.304 - 14.712)	3.7e+25 (0.083 - 1.8e+280)	-	3.7e+25 (2.877-1.8e+280)
	Deterministic	Two	9.5295	3.204	0.3045	-	13.038
	Stochastic		8.517 (1.888 - 34.472)	2.051 (0.27 - 13.437)	3.3e+25 (0.075 - 1.6e+280)	-	3.3e+25 (2.591-1.6e+280)
	Deterministic	Three	9.278	3.12	0.297	-	12.695
	Stochastic		8.366 (1.852 - 33.883)	2.014 (0.266 - 13.255)	3.2e+25 (0.074 - 1.6e+280)	-	3.2e+25 (2.555-1.6e+280)
Gannet (RSPB Avoidance rate)	Stochastic	One	26.964 (5.537 - 1.1e+02)	6.503 (0.717 - 45.751)	1.2e+26 (0.269 - 5.2e+280)	-	1.2e+26 (7.967-5.2e+280)

Table 4.6: Stochastic and deterministic, monthly collision estimates (number of birds) at the proposed development modelled with model-based density predictions. Values are rounded to 3 decimal places and those greater than 1000 are shown in scientific notation for display purposes only. Stochastic values are the median estimates from 1000 iterations with 95% CIs in brackets.

Species	Model type	Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kittiwake	Deterministic	**One**	0.529	1.91	4.482	2.685	14.652	5.941	8.645	21.039	0.066	0.28	0.287	0.216
	Stochastic		0.524 (0.162-1.156)	1.902 (1.142-3.073)	4.483 (1.956-8.557)	2.578 (1.359-4.695)	15.96 (4.677-30.942)	5.261 (2.663-11.286)	12.377 (0.024-23.832)	29.848 (0.223-57.919)	0.063 (0.008-0.356)	0.284 (0.086-0.685)	0.304 (0.094-0.84)	0.234 (0.041-0.63)
	Deterministic	**Two**	0.471	1.703	3.995	2.394	13.061	5.296	7.706	18.754	0.059	0.25	0.256	0.192
	Stochastic		0.473 (0.143-1.029)	1.723 (1.018-2.865)	4.034 (1.744-7.971)	2.329 (1.208-4.283)	14.272 (4.208-28.536)	4.76 (2.372-10.334)	11.058 (0.022-21.896)	26.5 (0.198-53.455)	0.057 (0.007-0.321)	0.254 (0.077-0.63)	0.275 (0.084-0.77)	0.209 (0.037-0.573)
	Deterministic	**Three**	0.467	1.688	3.961	2.373	12.949	5.25	7.64	18.593	0.058	0.247	0.254	0.191
	Stochastic		0.467 (0.141-1.026)	1.717 (1.008-2.91)	4.039 (1.736-8.061)	2.321 (1.203-4.374)	14.087 (4.166-28.731)	4.754 (2.341-10.543)	10.934 (0.022-22.319)	26.165 (0.198-54.205)	0.057 (0.007-0.33)	0.251 (0.077-0.64)	0.274 (0.084-0.771)	0.208 (0.036-0.579)
Great black-backed gull	Deterministic	**One**	0.827	0.314	0	0	0	0	0	0.081	0	0	0.962	3.215
	Stochastic		0.976 (0.449-2.092)	0.378 (0.119-1.004)	0 (0-1.2e+270)	0 (0-1.5e+270)	0 (0-3.5e+256)	0 (0-5.5e+274)	0 (0-4.7e+270)	0.117 (0-5.5e+214)	0 (0-1.1e+259)	0 (0-6.2e+250)	1.219 (0.481-2.917)	5.703 (0.383-14.8)
	Deterministic	**Two**	0.724	0.275	0	0	0	0	0	0.071	0	0	0.843	2.817
	Stochastic		0.865 (0.399-1.862)	0.336 (0.105-0.883)	0 (0-1.1e+270)	0 (0-1.3e+270)	0 (0-3.0e+256)	0 (0-4.9e+274)	0 (0-4.1e+270)	0.103 (0-4.8e+214)	0 (0-9.9e+258)	0 (0-5.5e+250)	1.083 (0.425-2.565)	4.984 (0.339-13.177)
	Deterministic	**Three**	0.706	0.268	0	0	0	0	0	0.069	0	0	0.821	2.744
	Stochastic		0.849 (0.389-1.835)	0.328 (0.103-0.881)	0 (0-1.0e+270)	0 (0-1.3e+270)	0 (0-3.0e+256)	0 (0-4.8e+274)	0 (0-3.9e+270)	0.1 (0-4.6e+214)	0 (0-9.5e+258)	0 (0-5.4e+250)	1.063 (0.415-2.515)	4.866 (0.33-13.059)
Herring gull	Deterministic	**One**	0.062	0	0.074	0	0.042	0.043	0.25	0.039	0	0	0.376	0.091
	Stochastic		0.048 (0-7.0e+114)	0 (0-2.5e+230)	0.069 (0-1.9e+153)	0 (0-5.7e+242)	0.026 (0-5.5e+110)	0.031 (0-7.2e+151)	0.299 (0.017-1.81)	0.031 (0-1.2e+132)	0 (0-9.6e+211)	0 (0-5.2e+232)	0.453 (0.011-2.814)	0.121 (0-1.5e+94)
	Deterministic	**Two**	0.055	0	0.065	0	0.037	0.038	0.22	0.035	0	0	0.331	0.08
	Stochastic		0.042 (0-6.3e+114)	0 (0-2.2e+230)	0.062 (0-1.7e+153)	0 (0-5.1e+242)	0.023 (0-4.8e+110)	0.028 (0-6.6e+151)	0.266 (0.015-1.587)	0.028 (0-1.0e+132)	0 (0-8.4e+211)	0 (0-4.5e+232)	0.403 (0.01-2.465)	0.107 (0-1.3e+94)
	Deterministic	**Three**	0.054	0	0.064	0	0.036	0.037	0.216	0.034	0	0	0.324	0.078
	Stochastic		0.041 (0-6.3e+114)	0 (0-2.2e+230)	0.061 (0-1.6e+153)	0 (0-5.1e+242)	0.022 (0-4.7e+110)	0.027 (0-6.7e+151)	0.26 (0.015-1.572)	0.027 (0-9.8e+131)	0 (0-8.2e+211)	0 (0-4.4e+232)	0.402 (0.01-2.415)	0.105 (0-1.3e+94)
Fulmar	Deterministic	**One**	0.024	0.043	0.007	0.011	0.009	0.187	0.07	0.092	0.199	0.097	0.214	0.122
	Stochastic		0.021 (0-0.698)	0.037 (0-1.262)	0.004 (0-0.296)	0.009 (0-0.404)	0.002 (0-0.424)	0.052 (0-8.093)	0.06 (0-1.973)	0.069 (0-2.962)	0.151 (0-6.734)	0.026 (0-4.318)	0.07 (0-9.067)	0.032 (0-5.387)
	Deterministic	**Two**	0.022	0.04	0.006	0.01	0.008	0.172	0.064	0.085	0.184	0.089	0.197	0.112
	Stochastic		0.02 (0-0.635)	0.035 (0-1.123)	0.004 (0-0.27)	0.008 (0-0.366)	0.002 (0-0.386)	0.05 (0-7.327)	0.056 (0-1.8)	0.064 (0-2.695)	0.14 (0-6.019)	0.025 (0-3.878)	0.065 (0-8.193)	0.031 (0-4.93)
	Deterministic	**Three**	0.022	0.04	0.006	0.011	0.009	0.174	0.065	0.086	0.186	0.09	0.199	0.114
	Stochastic		0.02 (0-0.638)	0.036 (0-1.151)	0.004 (0-0.265)	0.008 (0-0.361)	0.002 (0-0.386)	0.051 (0-7.297)	0.058 (0-1.815)	0.065 (0-2.655)	0.141 (0-5.92)	0.026 (0-3.882)	0.067 (0-8.183)	0.031 (0-4.878)

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Species	Model type	Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gannet	Deterministic	**One**	0	0.044	0.334	1.041	0.991	3.777	0.918	2.311	1.583	3.491	0.136	0.134
	Stochastic		0 (0-5.6e+271)	0.085 (0-6.6e+218)	0.24 (0.003-1.82)	0.968 (0.181-3.855)	0.91 (0.116-4.139)	3.509 (0.701-13.291)	0.959 (0.255-3)	1.168 (0.07-9.887)	1.52 (0.308-5.632)	2.015 (0.227-14.483)	0.149 (0.029-0.743)	0.133 (0.025-0.647)
	Deterministic	**Two**	0	0.039	0.295	0.92	0.875	3.336	0.811	2.042	1.398	3.084	0.12	0.118
	Stochastic		0 (0-5.1e+271)	0.075 (0-6.0e+218)	0.217 (0.003-1.647)	0.856 (0.162-3.439)	0.815 (0.105-3.671)	3.145 (0.626-12.125)	0.857 (0.23-2.726)	1.044 (0.063-8.843)	1.354 (0.276-4.947)	1.795 (0.203-13.045)	0.133 (0.026-0.672)	0.118 (0.023-0.567)
	Deterministic	**Three**	0	0.038	0.288	0.895	0.852	3.248	0.79	1.988	1.361	3.003	0.117	0.115
	Stochastic		0 (0-5.0e+271)	0.073 (0-6.0e+218)	0.215 (0.003-1.609)	0.837 (0.161-3.369)	0.807 (0.104-3.612)	3.068 (0.619-11.905)	0.843 (0.225-2.669)	1.025 (0.062-8.722)	1.324 (0.276-4.874)	1.751 (0.199-12.853)	0.13 (0.026-0.652)	0.116 (0.022-0.562)
Gannet (RSPB avoidance rate approach)	Stochastic	**One**	0 (0-2.3e+272)	0.24 (0-1.5e+219)	0.674 (0.011-5.201)	2.592 (0.442-10.79)	2.653 (0.362-11.875)	10.029 (1.93-38.279)	2.74 (0.651-7.988)	3.021 (0.179-30.272)	4.214 (0.866-15.821)	5.366 (0.541-44.714)	0.419 (0.077-2.086)	0.382 (0.065-1.876)

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