



Annex 11.3B: Deterministic CRM inputs and outputs.

MachairWind Offshore Ornithology

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1.0 Introduction

1. This **Annex 11.3B: Deterministic CRM inputs and outputs** provides deterministic (Band, 2012), collision risk model (CRM) inputs and outputs used to calculate collision risk for each collision risk species in flight within the Windfarm Development Area (WDA) listed in **Technical Appendix 11.3: Collision Risk Modelling**.
2. NatureScot advised at the Expert Topic Group meeting 4 (ETG 4, 2 December 2025) that deterministic CRM model inputs and outputs should be presented. Deterministic collision risk modelling is provided in this annex for additional information only; stochastic collision risk modelling (presented in **Technical Appendix 11.3: Collision Risk Modelling**) is used to assess collision risk in Chapter 11 Offshore Ornithology of the Environmental Impact Assessment (EIA) Report (EIAR) and the Report to Inform Appropriate Assessment (RIAA).



2.0 Methods

2.1 CRM model options

3. NatureScot Guidance Note 7¹ states that as a minimum, the following two scenarios should be modelled and results presented for each CRM species:
 - Most likely scenario (MLS) - Option 2 (using the generic flight height dataset); and
 - Worst-case scenario (WCS) - Option 2 (using the generic flight height dataset).
4. Both model options are presented in this annex. Breeding and non-breeding season totals for all CRM species (for a species list refer to **Technical Appendix 11.3: Collision Risk Modelling**) as well as the annual total, are calculated from the monthly outputs.

2.2 Collision risk modelling input parameters

5. CRMs require input information on densities of birds in flight, behavioural and physical characteristics of each bird species and offshore windfarm/turbine properties.
6. Density estimates of birds in flight were derived from digital aerial surveys (DAS) of the WDA (refer to **Technical Appendix 11.2: Baseline Site Characterisation** for further details). A total of 29 months of survey data collected between April 2021 to September 2023 were used for deterministic collision risk modelling. Refer to **Annex 11.3A: Bootstrapped density inputs to sCRM** for details of which survey months were used to estimate collision risk and for the full list of bootstrapped densities that were used to calculate the monthly means that inform deterministic CRM.
7. An estimated monthly mean density was derived for each of the 12 calendar months from the 29 surveys. Monthly mean densities were derived from the 29 individual survey estimates using bootstraps. Each individual design-based estimate for each of the 29 surveys has a set of 1,000 bootstrap resampled density estimates (see **Technical Appendix 11.2: Baseline Site Characterisation** for more details). The bootstrapped resampled density estimates from each survey carried out in that calendar month were collated and a mean was taken of all bootstrap estimates.
8. **Table 1** presents the mean density of birds in flight in each calendar month used in the deterministic CRM.

¹ NatureScot Guidance Note 7 (version 3 updated April 2025): [Guidance Note 7: Guidance to support Offshore Wind Applications: Marine Ornithology - Advice for assessing collision risk of marine birds](#) | NatureScot



Table 1: Monthly mean density estimates of birds in flight in the WDA by calendar month. Values are the mean of all bootstrap estimates from the digital aerial surveys carried out in that calendar month.

Mean density of birds in flight within the WDA (birds/km ²)												
Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kittiwake	1.283	1.340	0.772	0.546	1.445	1.141	1.195	0.094	0.209	1.638	3.498	3.904
Great black-backed gull	0.027	0.020	0.007	0	0	0	0.005	0	0.005	0.006	0.046	0.058
Herring gull	0.028	0.007	0	0	0	0	0.005	0.005	0	0.013	0.074	0.161
Arctic tern	0	0	0	0.002	0.087	0.007	0.061	0.119	0.009	0	0	0
Common tern	0	0	0	0.007	0	0	0.009	0.075	0.009	0	0	0
Gannet	0.007	0.013	0.086	0.093	0.275	0.194	0.084	0.165	0.221	0.072	0.014	0.014



2.2.1 Flight heights

9. For a bird to collide with a turbine, it needs to be flying at collision height, i.e. within the rotor swept area. NatureScot Guidance Note 7¹ recommends using generic flight heights (Johnston et al., 2014, with associated corrigendum). This approach was used in the deterministic collision risk modelling.

2.2.2 Avoidance rates

10. NatureScot Guidance Note 7 (**Appendix 1, Table 1**)¹ provides avoidance rates for deterministic CRM (presented in **Table 2**), these rates were used.

2.2.3 Gannet macro avoidance

11. There is evidence that gannets strongly avoid flying through offshore windfarms, i.e. that this species has high macro avoidance (Pavat et al., 2023). For gannets, NatureScot Guidance Note 7¹ advises applying macro avoidance of 70% in the non-breeding season, based on the outputs from Pavat et al., (2023). The collision mortality estimates produced for gannet in **Table 16** and **Table 17** takes account of a 70% macro avoidance applied to calendar months of January, February, October, November and December in the non-breeding season. The month of March is classified as part of the breeding season as well as the non-breeding season in NatureScot Guidance Note 9²; as both March DAS samples were recorded in the second half of March (March DAS samples include: 28 March 2022 and 19 + 23 March 2023), gannets recorded in March were considered to be breeding, and therefore the 70% macro avoidance was not applied to March.

2.2.4 Bird biometrics

12. The biometrics and avoidance rates used in collision risk modelling are presented in **Table 2**. Unless otherwise stated, values are provided in NatureScot Guidance Note 7¹ (**Appendix 1, Table 1**). For Arctic tern and common tern, flight speeds are taken from Alerstam et al., (2007), nocturnal activity factors are taken from Garthe and Hüppop, (2004) and body length and wingspan measurements are from Snow and Perrins, (1998).

² NatureScot Guidance Note 9: [Guidance Note 9 - Guidance to support Offshore Wind Applications: Seasonal periods for Birds in the Scottish Marine Environment | NatureScot](#)



Table 2: Species biometrics, including Nocturnal Activity Factor (NAF) and avoidance rates (AR) used in deterministic CRMs to generate collision estimates. All values are provided in NatureScot Guidance Note 7 (Appendix 1, Table 1)¹ unless otherwise stated.

Species	Deterministic CRM AR	Flight speed mean (m/s)	NAF mean	Body length (metres) (SD)	Wingspan mean (metres) (SD)	Flight type: Flapping or Gliding	% of flights upwind
Kittiwake	0.9923	13.1	0.40	0.39	1.08	Flapping	50
Great black-backed gull	0.9936	13.7	0.375	0.71	1.58	Flapping	50
Herring gull	0.9936	12.8	0.375	0.6	1.44	Flapping	50
Arctic tern	0.9902	10.9 ^a	0.125 ^b	0.34 ^c	0.8 ^c	Flapping	50
Common tern	0.9902	10.9 ^a	0.125 ^b	0.33 ^c	0.875 ^c	Flapping	50
Gannet	0.9923 ^d	14.9 ^e	0.14	0.94	1.72	Gliding	50

a Flight speed from Alerstam et al., (2007), consulted with NatureScot at Expert Topic Group meeting 3 (ETG 3, 2 October 2024), assuming flight speed of common tern is as measured for Arctic tern.

b Nocturnal Activity Factor from Garthe and Hüppop (2004), consulted with NatureScot at Expert Topic Group meeting 3 (ETG 3, 2 October 2024)

c Body length and wingspan from Snow and Perrins (1998), consulted with NatureScot at Expert Topic Group meeting 3 (ETG 3, 2 October 2024)

d Excluding macro-avoidance correction of 70% reduction required for nonbreeding season

e Gannet flight speed is incorrectly stated to have an SD of 0 in the JNCC and NatureScot guidance. The original data are from Pennycuik (1987) where the mean is given as 14.9 with an SD of 2, although the data advised by JNCC and NatureScot are for air speed and modelling should use ground speed.



2.2.5 Windfarm and turbine inputs

13. Collision risk models also need input information on the offshore windfarm, the number of turbines and properties of the individual turbines, as well as the proportion of time that the offshore windfarm is operational, i.e. removing collision risk for periods of downtime when turbines are not turning.
14. The Project will comprise up to 144 WTGs. NatureScot Guidance Note 7¹ recommends that estimated collision is presented for two scenarios for each CRM species including the Most Likely Scenario (MLS) and Worst Case Scenario (WCS). **Table 3** presents details of the WTG specifications for MLS and WCS.
15. The predicted monthly time that turbines will be operational (and therefore when collisions are possible) are presented in **Table 4**.

Table 3: Offshore windfarm and turbine specifications used in the collision risk modelling, for the Most Likely Scenario (MLS) and the Worst Case Scenario (WCS).

Input parameter	MLS	WCS
Rated rotor speed (RPM)	7.43	8.05
Rotor radius (m)	138	118
Maximum blade width (m)	7.5	6.5
Mean blade pitch (°)	3.50	3.50
Number of rotor blades	3	3
Hub height above Highest Astronomical Tide (HAT) (m)	166.40	146.40
Number of turbines	97	144
Windfarm Width (km)	29 km	29 km
Latitude (°)	56.03°	56.03°
Tidal offset (m) (difference between HAT and mean sea level at the site)	2.16 m	2.16 m



Table 4: Windfarm maintenance downtime and operational wind availability by month.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maintenance Downtime (%)	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%	3.0%
Maintenance Downtime (%) (SD)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Operational Wind Availability (%)	97.0%	96.1%	95.2%	92.4%	90.9%	90.3%	91.3%	92.1%	94.9%	96.5%	97.2%	96.6%



2.2.6 Seasons

16. NatureScot Guidance Note 7¹ advises to estimate the number of collisions for each season by compiling monthly collision estimates. Therefore, monthly estimates of collisions were summed to provide seasonal and annual collision estimates. For each species, the months allocated to each season were defined according to NatureScot Guidance Note 9² and the Biologically Defined Minimum Population Scale (BDMPS) seasons (Furness, 2015); refer to **Table 5** for details.
17. Seasonal collision estimates were derived by summing collision estimates for all calendar months in that season. Where a season was split between the NatureScot breeding and non-breeding season (e.g. April for kittiwake), the collision estimate for that calendar month was halved and assigned equally between the breeding and non-breeding seasons as advised in NatureScot Guidance Note 7¹.
18. For BDMPS spring and autumn seasons which overlap with NatureScot breeding seasons, collision estimates were allocated to the breeding season and not to the BDMPS period – this method follows the methodology used for recent offshore windfarm applications as advised by NatureScot, in their response to the Scoping Opinion (22 November 2024).
19. A summary of collision risk modelling parameters is provided in **Table 5**.

Table 5: Definitions of breeding and non-breeding seasons according to NatureScot Guidance Note 9² and BDMPS seasons according to Furness (2015).

Species	NatureScot seasons (Guidance Note 9)		BDMPS Seasons (Furness, 2015)		
	Breeding season	Non-breeding season	Spring migration	Autumn migration	Winter
Kittiwake	Mid-April to August	September to mid-April	January to April	August to December	n/a
Great black-backed gull	April to August	September to March	September to March (single non-breeding BDMPS season)		
Herring gull	April to August	September to March	September to February (single non-breeding BDMPS season)		
Arctic tern	May to August	September to April	Late April to May	July to early September	n/a
Common tern	May to mid-September	Mid-September to April	April to May	late July to early September	n/a
Gannet	Mid-March to September	October to mid-March	December to March	September to November	n/a



3.0 Results

20. Deterministic CRM outputs by species are presented in **Sections 3.1 to 3.6**. Results include estimated mean monthly collision mortalities and seasonal collision estimated totals.

3.1 Kittiwake

Table 6: Kittiwake estimated collisions from the deterministic CRM with Option 2 (generic flight height distribution) at 0.9923 avoidance rate for the MLS and WCS. Monthly values are the mean estimated collisions.

Scenario	Mean monthly collision mortality												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
MLS	9.95	10.03	6.90	4.96	14.29	11.26	12.13	0.91	1.87	14.14	27.04	29.40	142.89
WCS	12.98	13.08	8.99	6.47	18.64	14.68	15.82	1.18	2.44	18.44	35.26	38.33	186.31

Table 7: Kittiwake seasonal collision estimated totals, based on deterministic CRM WCS monthly mean estimates.

Season	Kittiwake Seasonal Collisions												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Seasonal Total
Annual	12.98	13.08	8.99	6.47	18.64	14.68	15.82	1.18	2.44	18.44	35.26	38.33	186.31
Breeding season (NatureScot)	12.98	13.08	8.99	*3.24	18.64	14.68	15.82	1.18	2.44	18.44	35.26	38.33	53.55
Non-breeding season (NatureScot)	12.98	13.08	8.99	*3.24	18.64	14.68	15.82	1.18	2.44	18.44	35.26	38.33	132.75
Spring migration (BDMPS)	12.98	13.08	8.99	*3.24	18.64	14.68	15.82	1.18	2.44	18.44	35.26	38.33	38.28
Autumn migration (BDMPS)	12.98	13.08	8.99	6.47	18.64	14.68	15.82	**1.18	2.44	18.44	35.26	38.33	94.47

* Where months are split between NatureScot breeding and non-breeding seasons, estimated collision mortality is split equally between the two seasons. The BDMPS spring migration period also overlaps with NatureScot breeding season in the month of April; as 50% of the collisions in April are part of the breeding season, the other 50% of collisions in April are allocated to the spring BDMPS.

** NatureScot breeding season overlaps with the autumn BDMPS season in August, the collisions in August are allocated to the breeding season and not the BDMPS autumn season.



3.2 Great black-backed gull

Table 8: Great black-backed gull estimated collisions from the deterministic CRM with Option 2 (generic flight height distribution) at 0.9936 avoidance rate for the MLS and WCS. Monthly values are the mean estimated collisions.

Scenario	Mean monthly collision mortality												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
MLS	0.68	0.50	0.21	0.00	0.00	0.00	0.16	0.00	0.14	0.17	1.16	1.45	4.48
WCS	0.90	0.66	0.28	0.00	0.00	0.00	0.21	0.00	0.19	0.23	1.54	1.91	5.92

Table 9: Great black-backed gull seasonal collision estimated totals, based on deterministic CRM WCS monthly mean estimates.

Season	Great black-backed gull Seasonal Collisions												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Seasonal Total
Annual	0.90	0.66	0.28	0.00	0.00	0.00	0.21	0.00	0.19	0.23	1.54	1.91	5.92
Breeding season (NatureScot)	0.90	0.66	0.28	0.00	0.00	0.00	0.21	0.00	0.19	0.23	1.54	1.91	0.21
Non-breeding season (NatureScot)	0.90	0.66	0.28	0.00	0.00	0.00	0.21	0.00	0.19	0.23	1.54	1.91	5.71
Non-breeding season (BDMPS)	0.90	0.66	0.28	0.00	0.00	0.00	0.21	0.00	0.19	0.23	1.54	1.91	5.71



3.3 Herring gull

Table 10: Herring gull estimated collisions from the deterministic CRM with Option 2 (generic flight height distribution) at 0.9936 avoidance rate for the MLS and WCS. Monthly values are the mean estimated collisions.

Scenario	Mean monthly collision mortality												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
MLS	0.62	0.15	0.00	0.00	0.00	0.00	0.14	0.14	0.00	0.31	1.63	3.47	6.47
WCS	0.82	0.20	0.00	0.00	0.00	0.00	0.18	0.18	0.00	0.42	2.16	4.58	8.53

Table 11: Herring gull seasonal collision estimated totals, based on deterministic CRM WCS monthly mean estimates.

Season	Herring gull Seasonal Collisions												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Seasonal Total
Annual	0.82	0.20	0.00	0.00	0.00	0.00	0.18	0.18	0.00	0.42	2.16	4.58	8.53
Breeding season (NatureScot)	0.82	0.20	0.00	0.00	0.00	0.00	0.18	0.18	0.00	0.42	2.16	4.58	0.36
Non-breeding season (NatureScot)	0.82	0.20	0.00	0.00	0.00	0.00	0.18	0.18	0.00	0.42	2.16	4.58	8.18
Non-breeding season (BDMPS)	0.82	0.20	0.00	0.00	0.00	0.00	0.18	0.18	0.00	0.42	2.16	4.58	8.18



3.4 Arctic tern

Table 12: Arctic tern estimated collisions from the deterministic CRM with Option 2 (generic flight height distribution) at 0.9902 avoidance rate for the MLS and WCS. Monthly values are the mean estimated collisions.

Scenario	Mean monthly collision mortality												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
MLS	0.00	0.00	0.00	0.00	0.11	0.01	0.08	0.14	0.01	0.00	0.00	0.00	0.35
WCS	0.00	0.00	0.00	0.00	0.14	0.01	0.10	0.18	0.01	0.00	0.00	0.00	0.45

Table 13: Arctic tern seasonal collision estimated totals, based on deterministic CRM WCS monthly mean estimates.

Season	Arctic tern Seasonal Collisions												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Seasonal Total
Annual	0.000	0.000	0.000	0.003	0.139	0.012	0.102	0.181	0.012	0.000	0.000	0.000	0.45
Breeding season (NatureScot)	0.000	0.000	0.000	0.003	0.139	0.012	0.102	0.181	0.012	0.000	0.000	0.000	0.43
Non-breeding season (NatureScot)	0.000	0.000	0.000	0.003	0.139	0.012	0.102	0.181	0.012	0.000	0.000	0.000	0.02
Spring migration (BDMPS)	0.000	0.000	0.000	0.003	*0.139	0.012	0.102	0.181	0.012	0.000	0.000	0.000	0.003
Autumn migration (BDMPS)	0.000	0.000	0.000	0.003	0.139	0.012	*0.102	*0.181	0.012	0.000	0.000	0.000	0.01

* Where NatureScot breeding season overlaps with the spring BDMPS season (May) and the autumn BDMPS season (July and August), the collisions in the BDMPS season are allocated to the breeding season and not the BDMPS season.



3.5 Common tern

Table 14: Common tern estimated collisions from the deterministic CRM with Option 2 (generic flight height distribution) at 0.9902 avoidance rate for the MLS and WCS. Monthly values are the mean estimated collisions.

Scenario	Mean monthly collision mortality												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
MLS	0.00	0.00	0.00	0.02	0.00	0.00	0.03	0.23	0.02	0.00	0.00	0.00	0.30
WCS	0.00	0.00	0.00	0.03	0.00	0.00	0.04	0.29	0.03	0.00	0.00	0.00	0.39

Table 15: Common tern seasonal collision estimated totals, based on deterministic CRM WCS monthly mean estimates.

Season	Common tern Seasonal Collisions												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Seasonal Total
Annual	0.000	0.000	0.000	0.026	0.000	0.000	0.038	0.295	0.030	0.000	0.000	0.000	0.39
Breeding season (NatureScot)	0.000	0.000	0.000	0.026	0.000	0.000	0.038	0.295	*0.015	0.000	0.000	0.000	0.35
Non-breeding season (NatureScot)	0.000	0.000	0.000	0.026	0.000	0.000	0.038	0.295	*0.015	0.000	0.000	0.000	0.04
Spring migration (BDMPS)	0.000	0.000	0.000	0.026	**0.000	0.000	0.038	0.295	0.030	0.000	0.000	0.000	0.03
Autumn migration (BDMPS)	0.000	0.000	0.000	0.026	0.000	0.000	**0.038	**0.295	*0.015	0.000	0.000	0.000	0.02
<p>* Where months are split between NatureScot breeding and non-breeding seasons (September), estimated collision mortality is split equally between the two seasons. The BDMPS autumn migration period also overlaps with NatureScot breeding season in the month of September; as 50% of the collisions in September are part of the breeding season, the other 50% of collisions in September are allocated to the autumn BDMPS.</p>													
<p>** NatureScot breeding season overlaps with the spring BDMPS season in May and the autumn BDMPS season in July, August and September, all collisions in May, July and August are allocated to the breeding season and not the BDMPS spring or autumn season.</p>													



3.6 Gannet

Table 16: Gannet estimated collisions from the deterministic CRM with Option 2 (generic flight height distribution) at 0.9923 avoidance rate for the MLS and WCS. Monthly values are the mean estimated collisions.

Scenario	Mean monthly collision mortality												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
MLS	0.01	0.02	0.68	0.80	2.67	1.92	0.84	1.53	1.80	0.16	0.03	0.02	10.48
WCS	0.02	0.03	0.89	1.05	3.51	2.51	1.11	2.01	2.36	0.21	0.03	0.03	13.76

* 70% Macro Avoidance applied to collision estimates in the gannet non-breeding season months including January, February, October, November and December

Table 17: Gannet seasonal collision estimated totals, based on deterministic CRM WCS monthly mean estimates.

Season	Gannet Seasonal Collisions												
	*Jan	*Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	*Oct	*Nov	*Dec	Seasonal Total
Annual	0.016	0.032	0.890	1.045	3.505	2.515	1.108	2.010	2.363	0.210	0.035	0.031	13.76
Breeding season (NatureScot)	0.016	0.032	**0.445	1.045	3.505	2.515	1.108	2.010	2.363	0.210	0.035	0.031	12.99
Non-breeding season (NatureScot)	0.016	0.032	**0.445	1.045	3.505	2.515	1.108	2.010	2.363	0.210	0.035	0.031	0.77
Spring migration (BDMPS)	0.016	0.032	**0.445	1.045	3.505	2.515	1.108	2.010	2.363	0.210	0.035	0.031	0.52
Autumn migration (BDMPS)	0.016	0.032	0.890	1.045	3.505	2.515	1.108	2.010	***2.363	0.210	0.035	0.031	0.24

* 70% Macro Avoidance applied to collision estimates in the gannet non-breeding season months including January, February, October, November and December

** Where months are split between NatureScot breeding and non-breeding seasons, estimated collision mortality is split equally between the two seasons. The BDMPS spring migration period also overlaps with NatureScot breeding season in the month of March; as 50% of the collisions in March are part of the breeding season, the other 50% of collisions in March are allocated to the spring BDMPS.

*** NatureScot breeding season overlaps with the autumn BDMPS season in September, the collisions in September are allocated to the breeding season and not the BDMPS autumn season.



4.0 References

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