Hornsea Three
Offshore Wind Farm

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Preliminary Environmental Information Report: Annex 5.3 - Collision Risk Modelling

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Hornsea 3
Offshore Wind Farm

DONG energy

Environmental Impact Assessment

Preliminary Environmental Information Report

Volume 4

Annex 5.3 Collision Risk Modelling Report

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Front cover picture: Kite surfer near one of DONG Energy's UK offshore wind farms © DONG Energy Hornsea Three (UK) Ltd., 2016.

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Table of Contents

List of Tables

List of Figures

1. Collision Risk Modelling

1.1 Introduction

1.1.1.1 This Annex presents the preliminary collision risk modelling processes undertaken for Hornsea Three to inform PEI Volume 2, Chapter 5: Offshore Ornithology incorporating, where relevant site-specific data up to February 2017. This includes collision risk modelling for the following groups of species

- Regularly occurring seabird species at Hornsea Three - e.g. gannet and kittiwake;
- Migratory seabird species – e.g. skuas, terns and little gull; and
- Migratory waterbirds – e.g. ducks and waders.

1.1.1.2 The main focus of this Annex is regularly occurring seabird species while Appendices B and C present the collision risk modelling process for migratory seabirds and for migratory waterbirds respectively.

1.1.1.3 The results presented in this report and associated appendices are preliminary and incorporate aerial data collected between April 2016 and February 2017. Aerial surveys at Hornsea Three are currently ongoing, with an update to collision risk modelling incorporating additional data to be presented as part of the final EIA for Hornsea Three, with relevant information subsequent to this communicated to key stakeholders through the Evidence Plan process.

1.2 Background

1.2.1 Overview

1.2.1.1 Birds can collide with the turbine rotor blades, which is likely to result in direct mortality. Most studies have found evidence of only low levels of bird mortality associated with operational onshore wind farms, as birds are able to take avoiding action (Drewitt and Langston, 2006). The actual risk of collision depends on a number of factors including the location of a wind farm, the bird species using the area, weather and visibility conditions, and the size and design of the wind farm, including the number and size of turbines and the use, or otherwise, of lighting (e.g., Kerlinger and Curry, 2002).

1.2.1.2 The effect of collision rates on a population is influenced by various characteristics, notably its size, density, recruitment rate (additions to the population through reproduction and immigration) and mortality rate (the natural rate of losses due to death and emigration). In general, the effect of an individual lost from the population will be greater for species that occur at low density, are relatively long-lived and reproduce at a low rate with most seabird species falling into this category. Conversely, the effect will often be reduced for shorter-lived species with higher reproductive rates found at high densities, including some smaller gull species. Species that habitually fly at night or during low light conditions at dawn and dusk may also be at increased risk from collisions, however, both eider and scoter have been shown to detect and avoid offshore turbines at night in both the Netherlands (Winkelman, 1995) and at offshore towers at Tuno Knob in Denmark (Tulp *et al*., 1999).

1.2.1.3 Wade *et al.* (2016), assigned cumulative vulnerability scores for a range of seabird species in relation to collision impacts although did not categorise these for use in impact assessment. Table 1.1 provides an interpretation of these vulnerability scores with these used alongside the size of the population occurring at Hornsea Three (see Annex 5.1 Baseline Characterisation Report and Section 1.3.1 below) to identify those species for which collision risk modelling was required.

Table 1.1: Vulnerability of selected seabird species to collision with offshore wind turbines (based on Wade *et al.* 2016).

Vulnerability	Species/species group
Very high	Lesser black-backed gull, herring gull, great black-backed gull, common gull
High	Sandwich tern, kittiwake, skuas, gannet
Moderate	Divers, common tern, Arctic tern
Low	Seaducks
Very low	Auks, fulmar, shearwaters

1.2.1.4 In general, the effects of increased mortality on populations due to collisions with turbines are considered to be long-term (i.e., throughout the operational wind farm's lifespan) and it is assumed that in the model, collision rate does not decrease in response to losses in the population. In reality, effects may change over time, as birds, particularly those resident near the wind farm, may become habituated to the presence of turbines, or external factors such as changes in fishing activities, may alter the attractiveness of the wind farm area to birds, thereby changing activity levels within it.

1.2.2 Collision risk modelling

1.2.2.1 The most frequently used collision risk model in the UK is commonly referred to as 'the Band model'. This model was originally devised in 1995 and has since been subject to a number of iterations, most recently to facilitate application in the offshore environment (Band, 2011) and to allow for the use of flight height distribution data and to include a methodology for considering birds on migration (Band, 2012).

1.2.2.2 Masden (2015) presents an update to Band (2012) which further develops the application of the Band model using a simulation modelling approach to incorporate variability and uncertainty. The update provides for an improved understanding of uncertainty by pseudo-randomly sampling parameter values from distributions for each parameter, deriving average collision risk estimates with associated measures of variability. However, it has recently come to light through advice from Natural England that further evaluation of the Masden (2015) update of the collision risk model is required. As a result, Masden (2015) has not been used to calculate collision risk estimates for the PEI stage of Hornsea Three. Pending this review and any subsequent modification, the use of Masden (2015) will be considered as part of the final EIA for Hornsea Three.

1.2.2.3 Figure 1.1 provides an overview of the information required for Band (2012) and the key outputs from the modelling process. The process to calculate the collision risk for a given species is a six stage process described as follows:

- Stage A: assemble data on the number of flights which, in the absence of birds being displaced or taking other avoiding action, or being attracted to the wind farm, are potentially at risk from wind farm turbines;
- Stage B: use that flight activity data to estimate the potential number of bird transits through rotors of the wind farm;
- Stage C: calculate the probability of collision during a single bird transit;
- Stage D: multiply these to yield the potential collision mortality rate for the bird species under consideration, allowing for the proportion of time the turbines are not operational, assuming current bird use of the site and that no avoiding action is taken;
- Stage E: allow for the proportion of birds likely to avoid the wind farm or its turbines, either because they have been displaced from the site or because they take evasive action; and allow for any attraction by birds to the wind farm; and
- Stage F: express the uncertainty surrounding such a collision risk estimate.

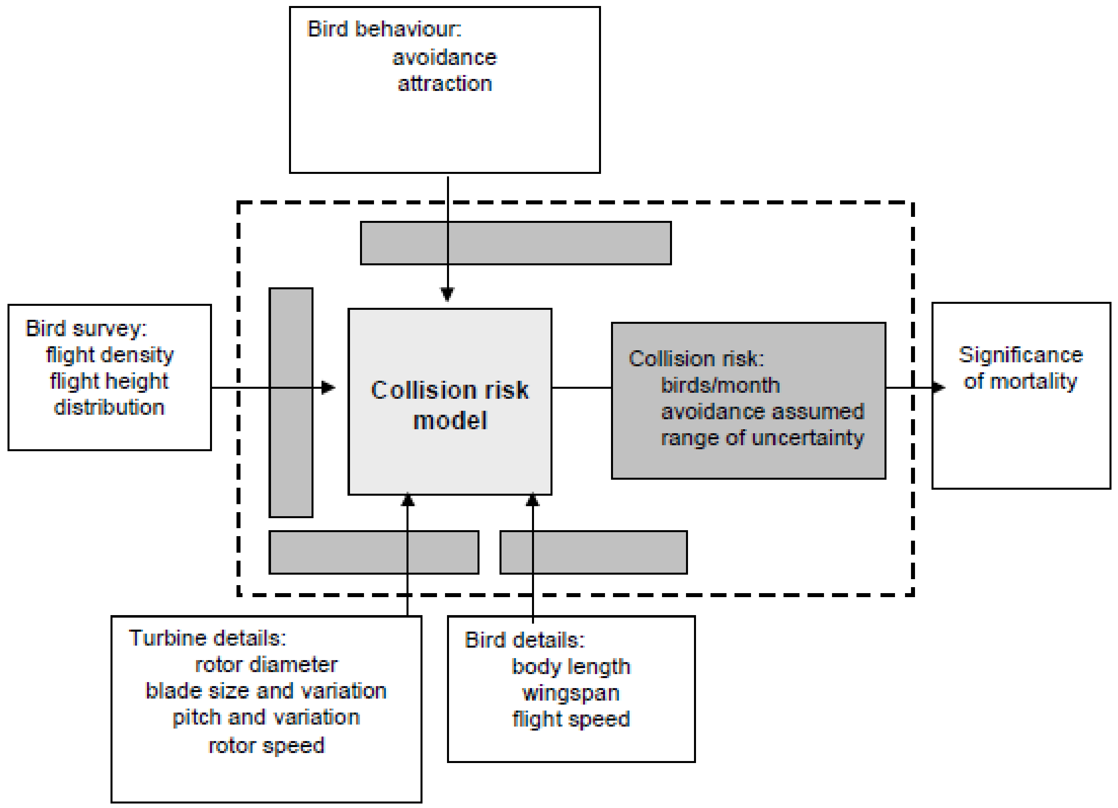

Figure 1.1: Band (2012) collision risk model overview.

1.2.2.4 The Band (2012) model incorporates two approaches to calculating the risk of collision referred to as the 'Basic' and 'Extended' versions of the model. A key difference between these versions is the extent to which they account for the flight height patterns of seabirds (Band 2012). The distribution of seabird flights across the sea is generally skewed towards lower altitudes. As stated by Band (2012) there are three consequences of a skewed flight height distribution:

- *"the proportion of birds flying at risk height decreases as the height of the rotor is increased;*
- *more birds miss the rotor, where flights lie close to the bottom of the circle presented by the rotor; and*
- *the collision risk, for birds passing through the lower parts of a rotor, is less than the average collision risk for the whole rotor."*

1.2.2.5 The Basic model assumes a uniform distribution of flights across the rotor with a consistent risk of collision across the whole rotor swept area. The Extended model of Band (2012) takes into account the distribution of birds in addition to the differential risk across the rotor swept area.

1.2.2.6 The Band (2012) guidance provides a method for which uncertainty associated with collision risk estimates can be expressed. The proposed method suggests expressing uncertainty at the 95% confidence level by attempting to incorporate the variability associated with input parameters into Band (2012). However, for the majority of parameters any consideration of uncertainty will be subjective.

1.3 Methodology

1.3.1 Species for consideration

1.3.1.1 The process to identify species that may be impacted by collision risk impacts is documented in the Baseline Characterisation Report (Annex 5.1: Offshore Ornithology Baseline Characterisation Report). In summary, the selection of species was informed using the following criteria which were considered in-combination and not individually (e.g. a species with a high vulnerability but small population may not be considered but a species with a large population but low vulnerability may be considered):

- The population of the species at the development site plus a 4 km buffer which was compared against a relevant population scale (regional, national or international);
- The vulnerability of a species to collision risk (Wade *et al.,* 2016; Bradbury *et al.,* 2014).

1.3.1.2 For example, a species occurring in low numbers at Hornsea Three or those species that have a low vulnerability to collision impacts are unlikely to be impacted to the extent whereby population level effects may occur.

1.3.1.3 The following species were selected for collision risk modelling:

- Gannet;
- Kittiwake;
- Lesser black-backed gull; and
- Great black-backed gull.

1.3.2 Species parameters

Bird biometric and behavioural data

1.3.2.1 Table 1.2 presents the species-specific parameters for those species identified for collision risk modelling.

1.3.2.2 The avoidance rates presented in Table 1.2 are taken from Cook *et al*. (2014) which presents avoidance rates for all four species incorporated into this Annex. The report recommended avoidance rates for use with the Basic model for all four species and with the Extended model for lesser black-backed gull and great black-backed gull. However, Cook *et al.* (2014) were unable to recommend an avoidance rate for use in the Extended model for gannet and kittiwake and as such a default 98% avoidance rate is applied in the modelling conducted in this Annex consistent with that recommended by the review of avoidance rates conducted in SMartWind and Forewind (2014). Ongoing research is currently investigating the avoidance behaviour of seabirds at offshore wind farms (the Offshore Renewables Joint Industry Programme), with any information that becomes available during the programme for Hornsea Three to be incorporated into the generic empirical evidence base for avoidance rates, if considered appropriate.

1.3.2.3 The aerial survey programme for Hornsea Three is not yet complete with only data from April 2016 to February 2017 currently incorporated into the analyses presented in this Annex. This has implications for the calculation of the proportion of birds at rotor height at Hornsea Three due to there currently being a limited flight height dataset. Therefore at this stage only generic flight height information (from Johnston *et al.,* 2014) have been used to calculate collision risk estimates.

1.3.2.4 In a joint response, UK SNCBs supported the recommended avoidance rates of Cook *et al*. (2014) with the exception of those calculated for use with the Basic model for kittiwake (JNCC *et al.,* 2014). The SNCBs did not agree with the application of avoidance rates calculated for the 'small gull' category to kittiwake and recommended that the avoidance rate calculated for the 'all gull' category should be applied instead. Modelling in this Annex is therefore conducted using the avoidance rates presented in Table 1.2 taking into account the recommendations in both Cook *et al*. (2014) and JNCC *et al*. (2014).

Table 1.2: Seabird parameters used for collision risk modelling (standard deviations, if necessary/available, are shown in parentheses).

Parameter	Source	Gannet	Kittiwake	Lesser black-backed gull	Great black-backed gull
Bird length (m)	Robinson (2017)	0.94	0.39	0.58	0.71
Wingspan (m)	Robinson (2017)	1.72	1.08	1.42	1.58
Flight speed (m/s)	Pennycuick (1987) or Alerstam (2007)	14.9	13.1 (0.4)	13.1 (1.9)	13.7 (1.2)
Nocturnal activity factor [1]	King *et al.* (2009)	2	3	3	3
Flight type	N/A[2]	Flapping	Flapping	Flapping	Flapping
Proportion of flights upwind	N/A[3]	50	50	50	50
Avoidance rate (Basic model) (%)[4]	Cook *et al.* (2014) JNCC *et al.* (2014)	98.9 (±0.2)	98.9 (±0.2) 99.2 (±0.2)	99.5 (±0.1)	99.5 (±0.1)
Avoidance rate (Extended model) (%)	Cook *et al.* (2014)	98.0	98.0	98.9 (±0.2)	98.9 (±0.2)

1.3.2.5 Table 1.3 presents monthly densities for each of the species selected for collision risk modelling at Hornsea Three. These densities have been derived from monthly aerial surveys undertaken across Hornsea Three and represent birds in flight only. These density values have not been adjusted for age structure or apportioning to SPAs with this element of anlysisconducted where relevant as part of assessments presented in Volume 2, Chapter 5: Offshore Ornithology and the Hornsea Three Draft Report to Inform Appropriate Assessment (RIAA).

1.3.2.6 Density values are available from from Hornsea Three (with no buffer) aerial surveys undertaken between April 2016 and February 2017. As such, a density value for March is not yet available and a density of 0 birds/km^2 has been used to inform the preliminary modelling presented here. This is an interim measure being used to inform the PEI and will be updated for the final ES chapter following the completion of aerial surveys at Hornsea Three. Further information on the aerial surveys undertaken for Hornsea Three is provided in the Baseline Characterisation Report (Annex 5.1: Offshore Ornithology Baseline Characterisation Report).

[1] A 1-5 scale is used for nocturnal activity with 1 representing limited nocturnal activity and 5 large amounts of nocturnal activity
[2] Based on expert opinion - the input parameters for flight type are either 'flapping' or 'gliding' with flapping representing the worst case scenario
[3] Assumed that there is a 50:50 split in flights upwind and downwind
[4] A range of avoidance rates are presented in the following sections, with those in Table 1.2 the rates reported in Cook *et al.* (2014)

Table 1.3: Densities from Hornsea Project Three with no buffer used for collision risk modelling (birds/km^2).

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gannet	0.02	0.00	0.00	0.17	0.00	0.09	0.17	0.03	0.10	0.08	0.07	0.59
Kittiwake	0.47	0.18	0.00	2.73	1.44	0.31	2.58	0.25	0.91	0.10	0.50	1.95
Lesser black-backed gull	0.00	0.00	0.00	0.02	0.00	0.34	0.12	0.00	0.00	0.00	0.00	0.00
Great black-backed gull	0.13	0.04	0.00	0.02	0.00	0.04	0.08	0.00	0.04	0.03	0.20	0.46

1.3.3 Hornsea Three design and turbine parameters

1.3.3.1 The worst case scenario for collision risk in this modelling process is taken to be the development scenario comprising 342 turbines with parameters as presented in Table 1.4 (see the maximum adverse scenario table in Volume 2, Chapter 5: Offshore Ornithology). The parameters for this turbine scenario required by Band (2012) are presented in Table 1.4. The large array correction feature of Band (2012) was not applied at this stage as this does not have a meaningful effect on collision risk estimates (although if applied would be expected to very slightly decrease collision estimates).

1.3.3.2 A wind turbine hub-height of 123.87 m (above HAT) will be used at Hornsea Three. This provides for a lower tip height clearance of 34.97 m LAT reducing the potential collision risk impacts on birds. The lower tip height is consistent with the consented value at Hornsea Project Two and equates to an "air gap" between MSL and lower tip height of 33.17m. This has been incorporated into the turbine design at Hornsea Three in order to mitigate collision risk impacts on seabirds. The flight height distribution of birds flying across the sea is known to be skewed to lower heights (Johnston *et al.*, 2014). As such, by increasing the lower rotor height at an offshore wind farm considerably fewer birds will occur within the rotor swept area and therefore collision risk will be lower.

Table 1.4: Wind farm and turbine parameters used for collision risk modelling.

Parameter	Value
Wind farm	
Latitude (degrees)	53.87
Number of turbines	342
Tidal offset (m)	1.8
Turbine	
Average rotation speed (rpm)	8.43
Rotor radius (m)	92.5
Hub height (m)	123.87 (HAT)
Max blade width (m)	6
Average pitch (°)	4.1

1.3.3.3 Band (2012) also requires information relating to the monthly proportion of time turbines will be operational taking into account maintenance activities and wind availability. Table 1.5 presents this information.

Table 1.5: Monthly proportion of time turbines at Hornsea Three will be operational.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Proportion of time operational (%)	93.18	92.90	92.17	90.90	90.65	89.28	89.10	89.79	91.25	92.80	92.85	93.05

1.3.4 Band model options

1.3.4.1 As mentioned in Section 1.3.2 the survey programme for Hornsea Three is not yet complete. As a result, at this stage, only generic flight height data from Johnston *et al.* (2014) will be used to calculate collision risk estimates. Therefore collision risk estimates are calculated using only Options 2 and 3 of Band (2012).

1.3.4.2 It is highlighted that the use of the basic model is precautionary as it does not take into account the variability in risk of collision that occurs across a rotor swept area, with the risk of collision decreasing as the distance from the hub of the turbine increases. If this were to be taken into account (as when using Option 3) it is likely that collision risk estimates would be of a lower magnitude as the vertical distribution of birds flying across water is skewed towards lower heights (i.e. those associated with a lower risk of collision within a rotor swept area).

1.4 Results

1.4.1 Collision risk estimates

Gannet

1.4.1.1 The preliminary annual collision risk estimates (Options 2-3) calculated for gannet using Band (2012) are shown in Table 1.6.

Table 1.6: Preliminary annual collision risk estimates for gannet calculated using Options 2 and 3 of the Band (2012) collision risk model.

Avoidance rate (%)	Collision risk estimates
Option 2	
98.7	39
98.9	33
99.1	27
Option 3	
98	14

Kittiwake

1.4.1.2 The preliminary annual collision risk estimates (Options 2-3) calculated for kittiwake using Band (2012) are shown in Table 1.7.

Table 1.7: Preliminary annual collision risk estimates for kittiwake calculated using Options 2 and 3 of the Band (2012) collision risk model.

Avoidance rate (%)	Collision risk estimates
Option 2	
98.7	403
98.9	341
99.1	279
99.2	248
99.5	155
Option 3	
98	124

Lesser black-backed gull

1.4.1.3 The preliminary annual collision risk estimates (Options 2-3) calculated for lesser black-backed gull using Band (2012) are shown in Table 1.8.

Table 1.8: Preliminary annual collision risk estimates for lesser black-backed gull calculated using Options 2 and 3 of the Band (2012) collision risk model.

Avoidance rate (%)	Collision risk estimates
Option 2	
99.4	27
99.5	22
99.6	18
Option 3	
98.7	19
98.9	16
99.1	13

Great black-backed gull

1.4.1.4 The preliminary annual collision risk estimates (Options 2-3) calculated for great black-backed gull using Band (2012) are shown in Table 1.9.

Table 1.9: Preliminary annual collision risk estimates for great black-backed gull calculated using the Band (2012) and updated Masden (2015) collision risk models using Options 2 and 3.

Avoidance rate (%)	Collision risk estimates
Option 2	
99.4	71
99.5	59
99.6	47
Option 3	
98.7	58
98.9	49
99.1	40

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Appendix A Additional collision risk modelling outputs

A.1.1 Gannet

Table A.1: Monthly collision risk estimates for gannet calculated using Option 2 of Band (2012).

Avoidance rate (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
98.7	0.51	0.00	0.00	5.63	0.00	3.33	6.37	1.05	3.14	2.37	1.79	14.59
98.9	0.43	0.00	0.00	4.77	0.00	2.82	5.39	0.89	2.66	2.00	1.52	12.34
99.1	0.35	0.00	0.00	3.90	0.00	2.31	4.41	0.73	2.17	1.64	1.24	10.10

Table A.2: Monthly collision risk estimates for gannet calculated using Option 3 of Band (2012).

Avoidance rate (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
98	0.19	0.00	0.00	2.05	0.00	1.21	2.32	0.38	1.14	0.86	0.65	5.32

A.1.2 Kittiwake

Table A.3: Monthly collision risk estimates for kittiwake calculated using Option 2 of Band (2012).

Avoidance rate (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
98.7	14.88	5.40	0.00	96.77	55.28	11.65	98.87	9.25	31.34	3.41	15.55	60.65
98.9	12.59	4.57	0.00	81.88	46.78	9.86	83.66	7.83	26.52	2.88	13.16	51.32
99.1	10.30	3.74	0.00	66.99	38.27	8.07	68.45	6.41	21.70	2.36	10.77	41.99
99.2	12.59	4.57	0.00	81.88	46.78	9.86	83.66	7.83	26.52	2.88	13.16	51.32
99.5	9.16	3.33	0.00	59.55	34.02	7.17	60.84	5.69	19.29	2.10	9.57	37.32

Table A.4: Monthly collision risk estimates for kittiwake calculated using Option 3 of Band (2012).

Avoidance rate (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
98	4.57	1.66	0.00	29.75	17.00	3.58	30.40	2.84	9.63	1.05	4.78	18.65

A.1.3 Lesser black-backed gull

Table A.5: Monthly collision risk estimates for lesser black-backed gull calculated using Option 2 of Band (2012).

Avoidance rate (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
99.4	0.00	0.00	0.00	1.06	0.00	19.05	6.85	0.00	0.00	0.00	0.00	0.00
99.5	0.00	0.00	0.00	0.88	0.00	15.87	5.71	0.00	0.00	0.00	0.00	0.00
99.6	0.00	0.00	0.00	0.70	0.00	12.70	4.57	0.00	0.00	0.00	0.00	0.00

Table A.6: Monthly collision risk estimates for lesser black-backed gull calculated using Option 3 of Band (2012).

Avoidance rate (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
98.7	0.00	0.00	0.00	0.73	0.00	13.09	4.71	0.00	0.00	0.00	0.00	0.00
98.9	0.00	0.00	0.00	0.61	0.00	11.08	3.99	0.00	0.00	0.00	0.00	0.00
99.1	0.00	0.00	0.00	0.50	0.00	9.06	3.26	0.00	0.00	0.00	0.00	0.00

A.1.4 Great black-backed gull

Table A.7: Monthly collision risk estimates for great black-backed gull calculated using Option 2 of Band (2012).

Avoidance rate (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
99.4	8.68	2.53	0.00	1.50	0.00	3.17	6.47	0.00	2.91	2.16	13.12	30.18
99.5	7.23	2.11	0.00	1.25	0.00	2.64	5.39	0.00	2.42	1.80	10.94	25.15
99.6	5.79	1.69	0.00	1.00	0.00	2.11	4.31	0.00	1.94	1.44	8.75	20.12

Table A.8: Monthly collision risk estimates for great black-backed gull calculated using Option 3 of Band (2012).

Avoidance rate (%)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
98.7	7.08	2.07	0.00	1.22	0.00	2.59	5.27	0.00	2.37	1.76	10.70	24.61
98.9	5.99	1.75	0.00	1.03	0.00	2.19	4.46	0.00	2.01	1.49	9.06	20.83
99.1	4.90	1.43	0.00	0.84	0.00	1.79	3.65	0.00	1.64	1.22	7.41	17.04

Appendix B Migratory seabirds

B.1 Introduction

B.1.1.1 This Annex presents the results of collision risk modelling undertaken for migratory seabirds in relation to Hornsea Three which will be used to inform assessments conducted in Volume 2, Chapter 5: Offshore Ornithology. The results will also be used to inform HRA Screening for migratory seabirds however, additional steps are required in order to conduct this process with these to be included as part of the RIAA for Hornsea Three.

B.1.1.2 This Annex is structured to include the following sections:

- Migratory seabird species considered with reference to their known migratory behaviour and the Biologically Defined Minimum Population Scale (BDMPS) populations applied;
- Collision risk analysis methodology including the calculation of potentially interacting populations and modelling parameters; and
- Collision risk modelling results; assessment for the Project alone and cumulatively with other plans and projects.

B.2 Species for consideration

B.2.1.1 A number of information sources, including migratory routes, migratory behaviour and regional SPA populations have been used in order to identify migratory seabird species to be included in this modelling process. Based on this information five species have been identified the migratory routes from which may interact with Hornsea Three:

- Arctic skua;
- Great skua;
- Little gull;
- Common tern; and
- Arctic tern.

B.2.1.2 This suite of species is also consistent with those species incorporated into migratory collision risk modelling at the Hornsea Project Two and Hornsea Project One offshore wind farms (SMart Wind, 2013; SMartWind, 2015a; SMartWind, 2015b).) and it is not considered necessary to include any additional species. The following sections outline the migratory behaviour and Biologically Defined Minimum Population Scales (BDMPS) used for each of the five species which was used in the identification of species for inclusion in the modelling presented in this Annex with additional information provided in Annex 5.1: Baseline Characterisation Report.

B.2.2 Arctic skua

B.2.2.1 Arctic skuas breed in small numbers in northern Scotland and more widely in the Arctic and sub-Arctic. The species is a transequatorial migrant moving to wintering areas off Australia, South Africa and southern South America (Wernham *et al*., 2002). Arctic skuas generally migrate through coastal waters, often associating with aggregations of terns and small gulls in areas such as estuaries from which they are able to obtain food by kleptoparasitism (Taylor, 1979). Birds that migrate through UK waters are UK breeding birds, mainly from Shetland and Orkney, and birds that breed in northern Europe (Furness, 1987).

B.2.2.2 Autumn migration of Arctic skua starts in August (Wernham *et al*., 2002; Forrester *et al*., 2007; Pennington *et al*., 2004). Peak autumn migration through UK waters occurs in August-September (Wernham *et al*., 2002) with peak migration in English waters occurring in September (Brown and Grice, 2005). In spring, birds begin to reach UK waters from early April with peak in migratory movements in April to May (Wernham *et al*., 2002).

B.2.2.3 Furness (2015) presents UK North Sea and Channel BDMPS populations for Arctic skua in both the post-breeding and pre-breeding seasons. In the post-breeding season the BDMPS is 6,427 birds composed mainly of birds from Scottish colonies with a smaller proportion from Arctic and northern European populations. In the pre-breeding season the BDMPS is 1,227 birds again composed mainly of birds from Scottish colonies and much smaller proportions from Arctic and northern European colonies.

B.2.3 Great skua

B.2.3.1 The majority of the global population of great skua breeds in Scotland with the remainder breeding in Iceland. Great skua is principally a passage migrant through English waters moving between breeding colonies in Scotland and wintering grounds in southern Europe (Wernham *et al*., 2002).

B.2.3.2 Autumn migration of great skua starts in August with peak autumn migration through UK waters occurring between August and October (Wernham *et al*., 2002; Brown and Grice, 2005). In spring, migration begins in March and peaks from late March into April (Wernham *et al*., 2002; Pennington *et al*., 2004; Forrester *et al*., 2007). During spring migration, a much smaller proportion of great skuas migrate through the North Sea.

B.2.3.3 Furness (2015) presents UK North Sea and Channel BDMPS populations for great skua in both the post-breeding and pre-breeding seasons. In the post-breeding season the North Sea and Channel waters BDMPS population is 19,556 birds composed mainly of birds from Scottish colonies with a smaller proportion from northern European populations. In the pre-breeding season the North Sea and Channel waters population is 8,485 birds again composed mainly of birds from Scottish colonies and smaller proportions from northern European colonies.

B.2.4 Little gull

B.2.4.1 Little gull is primarily a passage migrant to the UK occurring during both autumn and spring migration. Birds from breeding colonies in north-western Russia migrate through the Baltic into the North Sea with birds then moving on to wintering areas in the western Mediterranean (Wernham *et al*., 2002).

B.2.4.2 Birds begin to arrive in the North Sea in late July and early August off the coast of eastern Scotland. These birds precede a second wave of birds which reaches England and Wales (Wernham *et al*., 2002). Movements of birds out of the North Sea occur in October with the majority of the flyway population of little gull (40-100%) leaving the North Sea through the English Channel (Wernham *et al*., 2002; Stienen *et al*., 2007).

B.2.4.3 Spring migratory movements of little gull back to breeding areas occurs from April into early May with birds moving up the west coast of the UK and through the English Channel into the southern North Sea (Wernham *et al*., 2002).

B.2.4.4 The population of birds that migrate via the North Sea in autumn and spring has not been quantified (e.g. in Furness, 2015) and therefore for the purposes of this analysis the flyway population of little gull (75,000 individuals) is applied to the analysis as defined for the English Channel by Stienen *et al*. (2007).

B.2.5 Common tern

B.2.5.1 Common tern is a migrant breeder and passage visitor to the UK and throughout Europe that winters on the western and southern African coast, with a small proportion wintering as far north as Portugal (Wernham *et al*., 2002).

B.2.5.2 Post-fledging dispersal of common tern starts as early as July and continues into October (Wernham *et al*., 2002). Peak autumn migratory movements of common tern through UK waters occurs in August-September (Wernham *et al*., 2002) with peak movements through northern England occurring in August with the movement of many birds likely to occur overland (Ward, 2000). Many common terns return to breeding areas by April with peak pre-breeding movements occurring in English waters during this month (Brown and Grice, 2005). The frequency of inland sightings during spring suggests that a large proportion of spring movements also occur overland.

B.2.5.3 Furness (2015) presents UK North Sea and Channel BDMPS populations for common tern for migratory seasons with the same number of birds considered to migrate through this area during both autumn and spring. This population is estimated to consist of 144,911 birds originating mainly from UK North Sea colonies but also from northern European colonies and a smaller proportion from colonies on the west coast of the UK.

B.2.6 Arctic tern

B.2.6.1 Arctic tern is a migrant breeder and passage visitor to the UK which undertakes extensive migratory movements to waters off the west and south African coast, continuing on as far south as Australia. The species has a circumpolar breeding distribution with the populations in the UK and Ireland on the southern limit of this distribution (Wernham *et al*., 2002).

B.2.6.2 Autumn migratory movements of Arctic tern through UK waters start in early July, with the majority of movements completed by October (Pennington *et al*., 2004; Forrester *et al*., 2007). The majority of these movements are thought to occur offshore (Wernham *et al*., 2002). Peak autumn migratory movements through Shetland and Scotland occurs in July (Pennington *et al*., 2004; Forrester *et al*., 2007), with peak movements in southern England occurring in September (Brown and Grice, 2005). The first spring migrants arrive in UK waters in March (Wernham *et al*., 2002) with peak spring migratory movements occurring through UK waters in May (Brown and Grice, 2005; Pennington *et al*., 2004; Forrester *et al*., 2007).

B.2.6.3 Furness (2015) presents UK North Sea and Channel BDMPS populations for Arctic tern for migration seasons. The same number of birds is considered to migrate through the UK North Sea and Channel during both the post-breeding and pre-breeding seasons. This population is estimated to consist of 163,930 birds originating mainly from UK North Sea colonies but also from northern European colonies.

B.3 Methodology

B.3.1 Overview

B.3.1.1 Unlike the modelling approach used for collision risk modelling for regularly occurring seabird species at Hornsea Three, density data collected during site-specific surveys is deemed to be unsuitable to estimate the impact of collision for migratory seabird species. This is due to the snapshot nature of site-specific surveys and consequential limitations in recording sporadic movements of migratory species. Therefore the collision risk modelling approach used for migratory seabirds incorporates species-specific information relating to population estimates and migratory behaviour. A generic 'migratory front' is then defined which is then used to calculate the number of birds that have the potential to interact with Hornsea Three during spring and autumn migration.

B.3.1.2 In order to identify the interacting population for use in collision risk modelling the following stages are applied:

1. Define relevant seasonal BDMPS populations for each species considered;
2. Define a migratory front that incorporates the longest width of Hornsea Three across which migration will occur;
3. Calculate the proportion of the migratory front represented by Hornsea Three; and
4. Calculate interacting populations for each species in each migratory season.

B.3.1.3 The interacting populations are then incorporated into collision risk modelling to provide a collision risk estimate for each species.

B.3.1.4 Collision risk modelling has been undertaken using the Band (2012) CRM which, allows for consideration of birds on migration. As the modelling approach used for migratory seabird species uses population estimates, the update to the Band (2012) CRM presented by Masden (2015) cannot be used as this requires density information.

B.3.2 Calculation of interacting populations

B.3.2.1 In order to calculate the number of birds that may interact with Hornsea Three, a BDMPS must first be defined for each species which represents the population from which birds may exhibit connectivity with Hornsea Three. In most cases this population represents those birds that migrate through the North Sea and English Channel between breeding and wintering areas.

B.3.2.2 The proportion of this population that may interact with Hornsea Three is calculated based on the proportion of the migratory front represented by Hornsea Three. The migratory front represents a hypothetical line across which the whole BDMPS population will cross, incorporating the greatest width of Hornsea Three. It is assumed that birds are equally distributed across this front, however it should be noted that the migratory movements of some species may be biased towards inshore or offshore waters (Stienen *et al*., 2007).

B.3.2.3 The migratory front to be used to estimate the population of migratory seabirds passing through the Hornsea Three is assumed to extend from the UK coast to the edge of UK waters (Figure B.1). The populations of migratory seabird species considered to have potential to interact with Hornsea Three are calculated using the following formula:

*Interacting population = Width of development area / width of migration route * species population*

B.3.2.4 The length of this migratory front is 202.1 km with Hornsea Three representing 32.4 km. Hornsea Three therefore represents 16.0% of the total migratory front with this proportion applied to the BDMPS populations in Table B.1

Table B.1: Migratory seabird BDMPS populations and the proportion of these populations predicted to have potential to interact with Hornsea Three.

Species	Season	BDMPS population (Furness, 2015)	Migrant estimate of BDMPS population
Arctic skua	Autumn	6,427	1,031
	Spring	1,227	197
Great skua	Autumn	19,556	3,136
	Spring	8,485	1,361
Little gull	Autumn/Spring	75,000	12,026
Common tern	Autumn/Spring	144,911	23,236
Arctic tern	Autumn/Spring	163,930	26,286

B.3.3 Peak migratory movements

B.3.3.1 To populate a collision risk model, single months are selected to represent autumn movements and spring movements respectively. In the Band (2012) CRM these months are populated with the populations in Table B.1, while the months selected are presented in Table B.2 (as informed by the information detailed in Section B.2).

Table B.2: Months populated with potentially interacting populations for collision risk modelling.

Species	Post-breeding peak migratory month	Pre-breeding peak migratory month
Arctic skua	September	April
Great skua	September	April
Little gull	September	April
Common tern	August	April
Arctic tern	August	May

B.3.4 Collision risk modelling

B.3.4.1 To quantify collision risk, collision risk modelling has been undertaken using the Band (2012) CRM. Band (2012) uses information derived from population estimation, bird behaviour, biological parameters and project specific turbine information to calculate monthly collision risk values (see Section 1.2).

B.3.4.2 The wind farm and turbine parameters used for migratory seabird collision risk modelling are consistent with those used for regularly occurring seabirds (see Table 1.4).

B.3.4.3 The species-specific parameters used in the Band (2012) collision risk model for migratory seabirds are presented in Table B.3.

Table B.3: Species input parameters used in collision risk modelling.

Parameter	Source	Arctic skua	Great skua	Little gull	Common tern	Arctic tern
Bird length (m)	Robinson (2017)	0.44	0.56	0.26	0.33	0.34
Wingspan (m)	Robinson (2017)	1.18	1.36	0.78	0.88	0.8
Flight speed (m/s)	Pennycuick (1987) or Alerstam (2007)	13.8	14.9	11.5	10.9[5]	10.9
Nocturnal activity[6]	King *et al.*, (2009)	1	1	2	1	1
Flight type (flapping/gliding)	N/A	Flapping	Flapping	Flapping	Flapping	Flapping

B.3.4.4 Due to the snapshot nature of surveys there is limited Hornsea Three specific data to inform the calculation of the proportion of migratory seabirds at collision height. Therefore generic flight height data from Johnston *et al*. (2014) has been used to inform Options 2 and 3 of the Band (2012) CRM.

B.3.5 Avoidance rates

B.3.5.1 No species-specific avoidance rates are available for the migratory seabird species considered (e.g. in Cook *et al*., 2014) and therefore results are presented at a variety of rates. However, Cook *et al.* (2014) does calculate a rate for small gulls, a category which includes data relating to little gull. Therefore this avoidance rate is considered the most applicable to little gull for Option 2 only.

B.3.5.2 Cook *et al*. (2014) derived avoidance rates for small gull spp. and gull spp., two groups which included data relating to the avoidance behaviour of little gull. Avoidance rates of 99.2% and 98.9% were derived for the small gull spp. and gull spp. respectively. As such, avoidance rates of 98%, 98.9%, 99.2% and 99.5% will be used in the collision risk modelling for little gull, with a 99.2% avoidance rate considered to be the most relevant for assessment purposes.

[5] No flight speed is available for common tern and therefore the flight speed for Arctic tern is used as a surrogate
[6] A 1-5 scale is used for nocturnal activity with 1 representing limited nocturnal activity and 5 large amounts of nocturnal activity

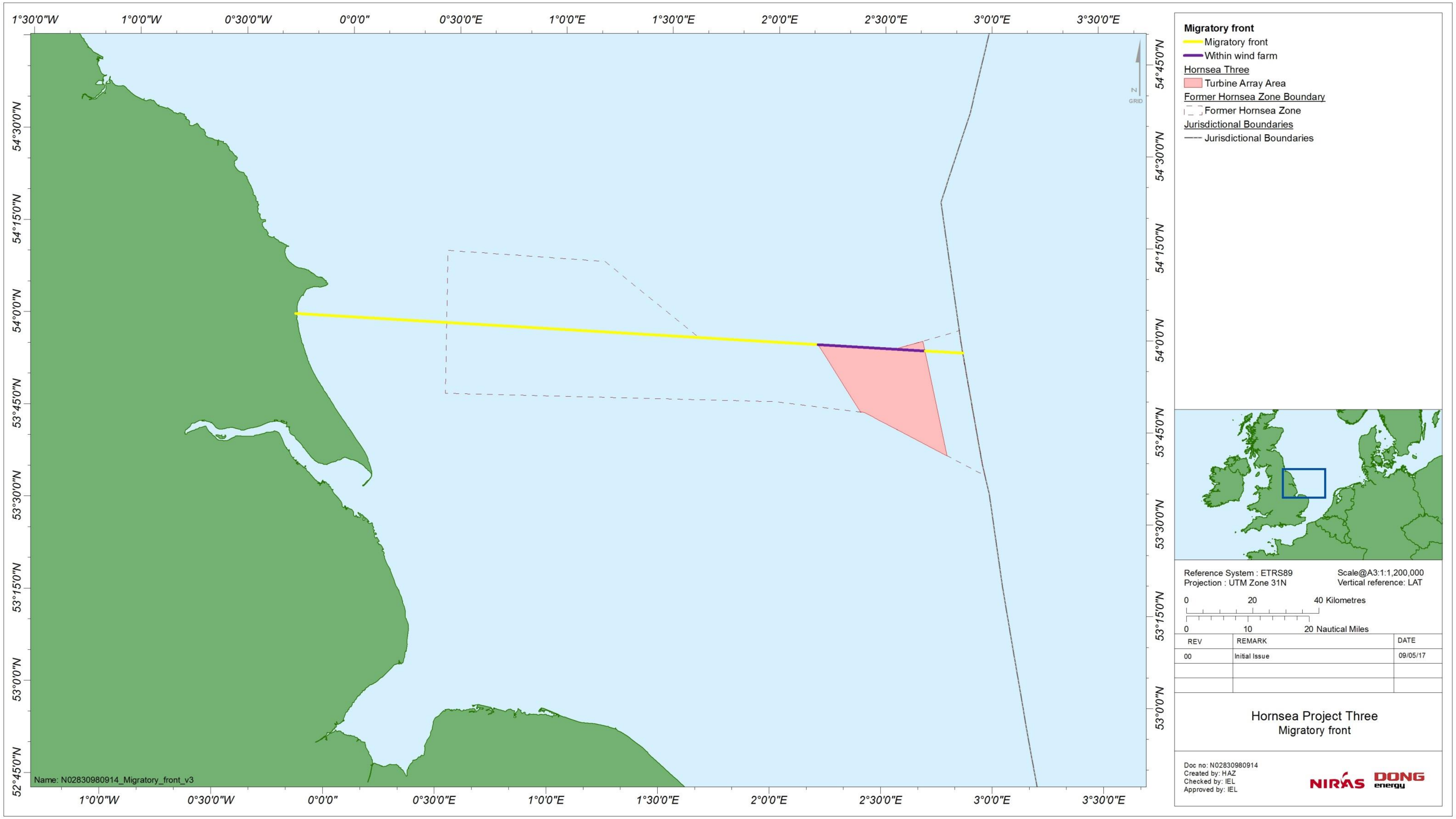

Figure B.1: Migratory front used to calculate populations of migratory seabirds interacting with Hornsea Three.

B.4 Results

B.4.1.1 Collision risk estimates calculated using Options 2 and 3 of the Band (2012) CRM are presented in Table B.4 and Table B.5 respectively.

Table B.4: Band (2012) Option 2 migratory seabird collision risk (collisions/annum).[7]

Species	Avoidance rate (%)				
	95	98	99	99.2	99.5
Arctic skua	0.01	**0.00**	0.00		0.00
Great skua	0.18	**0.07**	0.04		0.02
Little gull	3.15	1.26	0.63	**0.50**	0.31
Common tern	2.01	**0.80**	0.40		0.20
Arctic tern	0.78	**0.31**	0.16		0.08

Table B.5: Band (2012) Option 3 migratory seabird collision risk (collisions/annum).

Species	Avoidance rate (%)				
	95	98	99	99.2	99.5
Arctic skua	0.00	**0.00**	0.00		0.00
Great skua	0.04	**0.01**	0.01		0.00
Little gull	0.80	**0.32**	0.16	0.13	0.08
Common tern	0.44	**0.18**	0.09		0.04
Arctic tern	0.14	**0.06**	0.03		0.01

[7] Grey cells indicate not relevant to the species.

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Appendix C Migratory waterbirds

C.1 Introduction

C.1.1.1 Migratory birds move across offshore areas in large numbers predominantly over short temporal periods. These movements are poorly recorded by traditional boat-based or aerial surveys used to define the baseline environment for Environmental Impact Assessments of offshore wind farms. As such, this report uses a migratory collision risk modelling approach, as described by Wright *et al.* (2012), that is used to inform the assessment of collision risk at Hornsea Three for migratory waterbirds.

C.2 Species for consideration

C.2.1.1 For the purposes of collision risk modelling, a list of 12 species were selected based on a relatively high proportion of birds occurring at locations (e.g. SPAs) close to Hornsea Three. This list is consistent with the suite of species incorporated into similar modelling undertaken for other offshore wind farms in the vicinity of Hornsea Three (i.e. Hornsea Project One and Hornsea Project Two). The following species were therefore incorporated into modelling:

- Bewick's swan (*Cygnus columbianus bewickii);*
- Taiga bean goose (*Anser fabalis fabalis*);
- Dark-bellied brent goose (*Branta bernicla bernicla*);
- Shelduck (*Tadorna tadorna*);
- Wigeon (*Anas penelope*);
- Golden plover *(Pluvialis apricaria*);
- Grey plover (*Pluvialis squatarola*);
- Lapwing (*Vanellus vanellus*);
- Knot (*Calidris canutus*);
- Dunlin (*Calidris alpina*);
- Black-tailed godwit (*Limosa limosa*); and
- Bar-tailed godwit (*Limosa lapponica*).

C.2.1.2 The species parameters used to populate the collision risk models for each species are shown in Table C.1 Bird length and wingspan have been sourced from Robinson (2017) with flight speed sourced from Alerstam *et al.* (2007) or Pennycuick *et al.* (2013). The flight type was set at 'flapping' for all species with the nocturnal activity factor, sourced from King *et al.* (2009), was set at 5 for all species.

C.2.1.3 As stated in Band (2012), the proportion of birds on migration at rotor height is likely to be different from the proportion of birds at potential collision height (PCH) when not on migration for a number of species. Wright *et al*. (2012) makes recommendations for the values to use for the proportion of birds at rotor height. For swans, geese, ducks and waders Wright *et al*. (2012) recommends PCH values of 50%, 30%, 25 % and 15 %, respectively.

C.2.1.4 Parameters for the wind farm, including turbine parameters are consistent with those presented in Table 1.4.

Table C.1: Species parameters used for collision risk modelling.

Species	Bird length (m)	Wingspan (m)	Flight speed (m/s)	Nocturnal activity[8]	Flight type	PCH (%)
Bewick's swan	1.21	1.96	18.5	5	flapping	50
Taiga bean goose	0.75	1.58	17.3	5	flapping	30
Dark-bellied brent goose	0.58	1.15	17.7	5	flapping	30
Shelduck	0.62	1.12	15.4	5	flapping	15
Wigeon	0.48	0.8	20.6	5	flapping	15
Golden plover	0.28	0.72	17.9	5	flapping	25
Grey plover	0.28	0.77	17.9	5	flapping	25
Lapwing	0.3	0.84	12.8	5	flapping	25
Knot	0.24	0.59	20.1	5	flapping	25
Dunlin	0.18	0.4	15.3	5	flapping	25
Black-tailed godwit	0.42	0.76	14.4	5	flapping	25
Bar-tailed godwit	0.38	0.75	14.4	5	flapping	25

[8] A 1-5 scale is used for nocturnal activity with 1 representing limited nocturnal activity and 5 large amounts of nocturnal activity

C.3 Methodology

C.3.1 Overview

C.3.1.1 This modelling process uses guidance from the British Trust for Ornithology (BTO) (Wright and Austin, 2012), relating to the SOSS Migration Assessment Tool (MAT), which details a method in which the migration passages of migratory species can be calculated. This guidance (Wright and Austin, 2012) states that, as a general rule, the use of the MAT is not relevant for pelagic seabirds, such as gannet, or land-based seabirds that follow the coastline during migration. However, this approach was used, where appropriate, in the CRM process for other species.

C.3.2 Migration passages

C.3.2.1 The MAT utilizes 251,599 lines of connectivity which were constructed as line of sight sea crossings for migrants travelling across UK waters. These lines were then assigned on a species-specific basis based on the migration routes presented in Wright *et al.* (2012).

C.3.2.2 Provided with the guidance is a GIS shapefile which is used to determine those lines of connectivity which interact with a wind farm site. A dataset which details those lines which interact with the wind farm site can then be extracted from GIS and imported into the MAT. For Hornsea Three this dataset contained 15,217 lines of connectivity.

C.3.2.3 The next stage in the process is to decide which sea crossings are pertinent to the wind farm being assessed. The following sea crossings were selected for Hornsea Three based on the descriptions given in Wright and Austin (2012):

- Central Europe North Sea coast to England North Sea coast;
- Central Europe North Sea coast to Norway;
- Central Europe North Sea coast to Orkney;
- Central Europe North Sea coast to Scottish mainland North Sea coast;
- Central Europe North Sea coast to Shetland;
- Denmark to England North Sea coast;
- England North Sea coast to Orkney;
- England North Sea coast to Scottish mainland North Sea coast;
- England North Sea coast to Shetland; and
- Norway to England North Sea coast.

C.3.2.4 The final stage of the MAT requires two parameters relating to the population estimated to interact with Hornsea Three. The first parameter is the population size of the considered species that occurs in UK waters. These values were obtained from Wright *et al.* (2012). The second parameter is a population correction factor which estimates the percentage of the GB population that interacts with the Hornsea Three array area. The population of each species predicted to interact with the footprint of the wind farm was estimated using the maps presented in Wright *et al.* (2012). All of these data are presented in Table C.2. Two months during each generic migration period (spring and autumn) were populated (April and September) with the number of movements across the Hornsea Three footprint.

Table C.2: The population size, population corrections factors and movements across the Hornsea Three footprint for species included for collision risk modelling.

Species	Population size	Population correction factor	Number crossing Hornsea Three footprint
Bewick's swan	7,000	100	2,709
Taiga bean goose	730	50	79
Dark-bellied brent goose	91,000	80	30,852
Shelduck	61,000	40	4,442
Wigeon	440,000	40	31,186
Golden plover	400,000	40	38,072
Grey plover	43,000	40	3,098
Lapwing	620,000	40	44,662
Knot	32,000	40	2,283
Dunlin	350,000	50	45,370
Black-tailed godwit	43,000	40	4,167
Bar-tailed godwit	38,000	40	2,916

C.3.3 Collision risk modelling

C.3.3.1 The width of the migration corridor, required for the migratory stage of the CRM, was calculated using ArcGIS. The migration corridor was taken as the longest width of Hornsea Three across which a species migratory route would cross. For birds migrating north to south, a migration corridor of 32.4 km was used with a migration corridor of 36 km used for birds migrating east to west (Figure C.1). The proportion of flights upwind for migratory species was assumed to be 50% for all species.

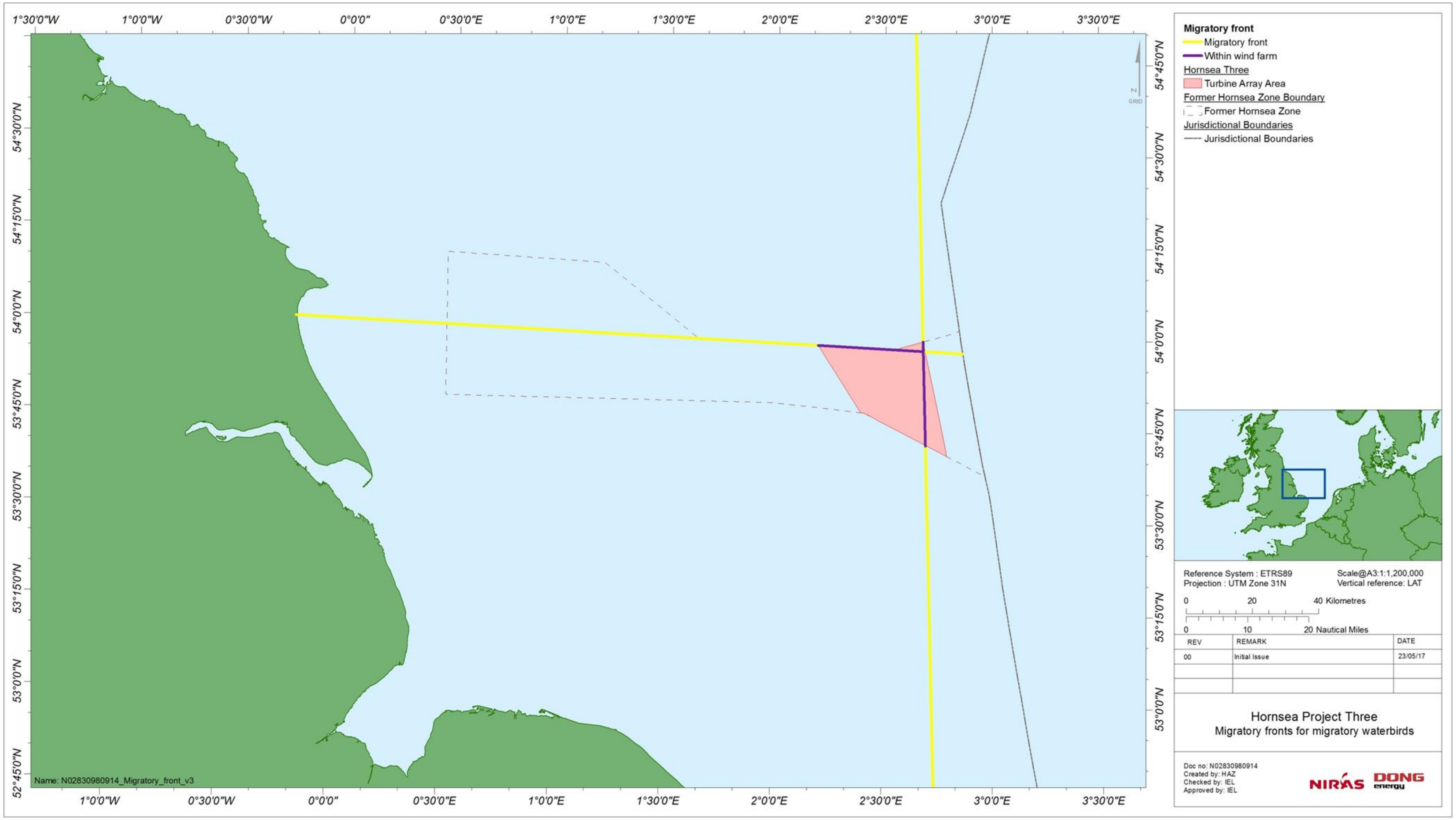

Figure C.1: Migratory fronts used for migratory waterbirds interacting with Hornsea Three.

C.3.3.2 The Band (2012) CRM includes two models (basic and extended) which both incorporate two 'Options'. Generic flight height distributions, used for Options 2 and 3 of Band (2012) are unavailable for the species considered in this Appendix and therefore it is not possible to use these model options. Therefore Option 1 is used incorporating the PCH values from Wright *et al.* (2012). Collision risk estimates are calculated using a default avoidance rate of 98%, as recommended by SNH guidance (SNH, 2010), applied for all species.

C.4 Results

C.4.1.1 Table C.3 presents collision risk estimates for all waterfowl species included in the modelling process.

Table C.3: Seasonal and annual collision risk estimates for migratory waterbirds at a 98% avoidance rate.

Species	Spring	Autumn	Total
Bewick's swan	2.12	2.13	4
Taiga bean goose	0.03	0.03	0
Dark-bellied brent goose	11.16	11.20	22
Shelduck	0.85	0.86	2
Wigeon	5.09	5.11	10
Golden plover	10.78	10.82	22
Grey plover	0.80	0.80	2
Lapwing	12.67	12.72	25
Knot	0.62	0.62	1
Dunlin	10.90	10.94	22
Black-tailed godwit	1.34	1.34	3
Bar-tailed godwit	0.82	0.83	2

C.5 References

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