DBS Offshore Wind

RWE Renewables UK Dogger Bank South (West) Limited

RWE Renewables UK Dogger Bank South (East) Limited

Dogger Bank South Offshore Wind Farms

Illustrative Underwater Noise Reduction Technical Note (Revision 4)

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01	April 2025	Submission for Deadline 4	RHDHV / ERM	RWE	RWE
02	May 2025	Submission for Deadline 5	RHDHV / ERM	RWE	RWE
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04	July 2025	Submission for Deadline 8	RHDHV	RWE	RWE

Revision Change Log			
Rev No.	**Page**	**Section**	**Description**
01	N/A	N/A	Submission for Deadline 4 in response to
02	22-23	4.1.1.2	Amended errors in presented impact ranges.
02	34	Appendix A	Added the modelled impact ranges in response to a request from Natural England during a meeting 7th May 2025.
03	25-30	4.1.1.4	Added assessment for the Wash and North Norfolk Caost SAC
03	35-47	Appendix A	Added the modelled impact ranges for the 135db as requested by Natural England in the Deadline 6 submission [REP6-074]
04	30	4.1.1.4	Error corrected in Figure 4-5 title.

Contents

Tables

Figures

Glossary

Term	Definition
Array Areas	The DBS East and DBS West offshore Array Areas, where the wind turbines, offshore platforms and array cables would be located. The Array Areas do not include the Offshore Export Cable Corridor or that part of the Inter-Platform Cable Corridor within which no wind turbines are proposed. Each area is referred to separately as an Array Area.
Dogger Bank South (DBS) Offshore Wind Farms	The collective name for the two Projects, DBS East and DBS West.
In Isolation Scenario	A potential construction scenario for one Project which includes either the DBS East or DBS West array, associated offshore and onshore cabling and only the eastern Onshore Converter Station within the Onshore Substation Zone and only the northern route of the onward cable route to the proposed Birkhill Wood National Grid Substation.
Impact	Used to describe a change resulting from an activity via the Projects, i.e. increased suspended sediments / increased noise.
Marine Mammal Observers (MMObs)	Trained members of the team who will observe the Monitoring Area.
Monitoring Area (MA)	The area around each pile location to be monitored in the pre-piling watch, and where possible during any breaks in piling or soft-start by either Marine Mammal Observers (MMObs) or Passive Acoustic Monitoring Operator (PAM-Op).
Mitigation Zone (MZ)	The area around each pile location in which it is predicted physical or permanent auditory injury is possible.
Passive Acoustic Monitoring (PAM)	Use of acoustic sensors to monitor the presence of marine mammals in the Monitoring Area.
The Projects	DBS East and DBS West (collectively referred to as the Dogger Bank South Offshore Wind Farms).

Acronyms

Term	Definition
ADD	Acoustic Deterrent Device
AEoI	Adverse effect on the site integrity
BBC	Big Bubble Curtains
BNNC	Berwickshire Northumberland and North Coast
dB	Decibel
DCO	Development Consent Order
DBBC	Double Big Bubble Curtains
DBS	Dogger Bank South
Defra	Department for Environment Food and Rural Affairs
ES	Environmental Statement
HiLo	High Frequency Low Impact
HRA	Habitats Regulation Assessment
HSD	Hydro Sound Dampers
MA	Monitoring Area
MMMP	Marine Mammal Mitigation Protocol
MMObs	Marine Mammal Observer
MMO	Marine Management Organisation
MZ	Mitigation Zone
NAS	Noise Abatement Systems
OWF	Offshore Wind Farm
PAM	Passive Acoustic Monitoring
PTS	Permanent Threshold Shift

Term	Definition
RIAA	Report to Inform Appropriate Assessment
SAC	Special Area of Conservation
SEL	Sound Exposure Level
SEL_{cum}	Cumulative Sound Exposure Level
SPL_{peak}	Peak Sound Pressure Level
TTS	Temporary Threshold Shift

1 Introduction

1. The Department for Environment Food and Rural Affairs (Defra) Policy Paper on Reducing Marine Noise was published on 21st January 2025 as part of Defra's Marine Noise Package. In line with this policy the Projects will utilise best endeavours to deliver noise reductions, where applicable, through the use of primary and / or secondary noise reduction based on the final project design.

2. For this reason, and as requested by the Marine Management Organisation (MMO) and Natural England, additional underwater noise modelling has been undertaken to illustrate the benefits achievable through a noise reduction of 10 decibel (dB). Such a reduction could be achieved by reducing hammer energies below those presented as worst case in the Rochdale envelope and / or through utilising other primary and / or secondary methods. Further information on potential noise reduction methods is available in section 2.

3. For clarity, the Applicants will not be committing to any specific secondary noise reduction methods until the final design parameters, including all relevant primary measures, are finalised post consent. Hence, this technical note is provided for illustrative purposes only. The final Marine Mammal Mitigation Protocol (MMMP) incorporating the final design information and all primary and any secondary measures will be agreed through consultation with the relevant Statutory Nature Conservation Body and signed off by the MMO.

1.1 Purpose of this Document

4. The purpose of this Underwater Noise Reduction Technical Note is to provide a purely illustrative demonstration of the potential reduction in impact ranges if primary and /or secondary measures implemented at Dogger Bank South (DBS) Offshore Wind Farms ('the Projects') are utilised which resulted in a 10dB reduction in sound levels. Any secondary measures implemented would be incorporated through the final MMMP to be submitted for approval as required under the Draft Development Consent Order (DCO) for the proposed Projects.

5. The Defra marine noise policy (2025) defines that: 'Primary methods aim to reduce noise emissions at the source through modifications of the piling process (for example, alternative hammer types, alternative foundation types). Secondary methods aim to reduce the noise propagated through the water column during pile driving by employing systems such as casings, resonators and bubble curtains'.

6. The JNCC *et al*. (2025) position paper classifies mitigation measures into one of three key types:

    1. Primary mitigation: these are measures which form an inherent part of the project design.

2. Secondary mitigation: typically for construction-related impacts, these measures require further activity to achieve the anticipated outcome.
3. Tertiary mitigation: these measures are required regardless of any EIA assessment, as they are imposed, for example, because of legislative requirements and/or standard sectoral practices.

7. This technical note presents the predicted impact ranges from the underwater noise modelling using a 10dB sound reduction for fish and shellfish (section 1) and marine mammals (section 4) for piling at the Projects' Array Areas if constructed in isolation or together.

1.2 Underwater Noise Modelling

8. Underwater noise modelling was undertaken by Subacoustech Environmental Ltd to estimate the noise levels likely to arise during noisy activities, in particular during impact pile driving (**Appendix 11-3 Underwater Noise Modelling Report (Revision 2)** [AS-137]) to determine the potential effects on marine mammals and fish.

9. Underwater noise modelling was undertaken against the currently recommended marine mammal injury thresholds presented in Southall *et al*. (2019). In relation to fish, the publication of Popper *et al*. (2014) was used to determine the thresholds for fish exposure to sound. Consideration has also been given to behavioural thresholds presented in Hawkins *et al.* (2014) on request from the MMO. It should be noted that that, in line with the views of the authors of the paper in question, the Applicants do not consider this threshold to be appropriate for impact assessment as stated within **The Applicants Response to Deadline 2 – Appendix B** [REP3-028].

10. As stated in section 11.6.1.1.1 of **Chapter 11 Marine Mammals (Revision 2)** [document reference 7.11] and section 10.6.1.3.5. of **Chapter 10 – Fish and Shellfish Ecology (Revision 2)** [document reference 7.10] the worst case locations for piling representing the maximum spatial extent were used for the impact assessment, these are;

- DBS East – south location; and
- DBS West – west location.

11. Further context relating to worst case scenarios used for Fish and Shellfish Ecology is presented within section 1.

12. Additional underwater noise modelling was undertaken to investigate the effects of impact piling noise at the Projects in conjunction with noise reduction. The exact mitigation to be used has not been confirmed, but a flat broadband 10dB noise reduction has been applied at source (based on generic data for a bubble curtain from Verfuss *et al.* 2019) for the monopile scenario at the two modelling locations used in the environmental statement. All other parameters used to generate the modelling outputs presented in this report remain identical to those discussed in section 5.2 of **Appendix 11-3 Underwater Noise Modelling Report (Revision 2)** [AS-137].

2 Noise Reduction Methods

13. An area of concern during the consenting of fixed foundation based offshore wind farms (OWF) is the emission of anthropogenic noise emitted through impact pile driving, which is used to install both turbine and offshore substation foundations. Metrics which could affect noise generation for impact pile driving activities include pile characteristics (pile type and diameter), hammer energy, environmental variables (bathymetry and sediment type), as well as spatial and temporal attributes such as the animal's distance from the pile and time since the first pile strike, respectively. A precautionary design envelope without mitigation has been presented in the Environmental Statement (ES) using the maximum hammer energy, duration of impact piling, pile diameter and number of turbines to form the worst case scenario for the Projects.

14. Noise reduction methods are used in the European sector of the North Sea as a standard requirement during offshore construction. Through the Defra underwater noise policy (Defra, 2025), it is expected that all offshore wind pile driving activity across all English waters will be required to demonstrate best endeavours to deliver noise reductions through the use of primary and / or secondary noise reduction methods in the first instance. Noise reduction measures rely on the use of primary and / or secondary noise mitigation (Bellmann *et al.* 2018).

15. These measures are aimed at:

- Ensuring that no marine mammal is present within the potential impact zone around the piling position (by conducting marine mammal monitoring and / or using acoustic deterrent devices (ADD)); or
- Protecting marine mammals during sensitive times and / or in sensitive habitats; or
- Reducing impacts to fish species sensitive to underwater noise, specifically within potential spawning grounds during the spawning period (JNCC *et al.* 2025); or
- Restricting the amount of noise energy emitted into the sea and reducing disturbance, for example, noise reduction measures have been required to meet specific noise thresholds (e.g., in Germany and are proposed for the UK by 2028).

2.1 Primary Noise Reduction

16. Primary noise reduction methods aim to decrease noise emissions at source. This can be achieved through modifications to the project design (e.g. pile design and type) and / or the impact piling process through adjusting the piling energy by reducing the maximum hammer energy and / or adjusting the strike rate (including soft start and ramp up procedure), or by the use of alternative installation technologies (e.g. vibro piling, blue piling, High frequency low-impact (HiLo) piling and drilling).

17. Hammer energy is only one of several factors that influence the sound levels generated from pile driving. Higher strike energy generally contributes to increased sound levels and cumulative sound exposure. Findings by Martin and Barcelay (2019) and Robinson *et al*. (2007) indicate that change in the strike energy increased the predicted sound levels, for instance a ramp up of pile driving energy from 80 to 800 kJ over 800 strikes increased the Sound Exposure Level (SEL) by 8dB.

18. For the Morecambe OWF project, it was also demonstrated that strike rates affect the sound levels. In the Morecambe OWF ES two different piling scenarios were presented, assessing both a lower and a higher strike rate. Both scenarios used the same pile diameter dimensions (Monopile = 12m; Pinpile = 3m) and the maximum blow energies (Monopile = 6,600kJ; Pinpile = 2,500kJ). Since a piling hammer is capable of more rapid strikes at lower blow energies, the 'high strike rate' scenario included a slower soft-start (i.e. 30 minutes at 550kJ with 0.5 to 100 blows per minute), and a greater total number of pile strikes over a shorter duration, resulting in faster strike rates. For example, in the 'higher strike rate' scenario, where the hammer energy ranged between 21% and 62% of its maximum, the strike rates ranged between 86 and 58 blows per minute (see Tables 4-45 and 4-46 in Section 4.4 of the UWN modelling report for the Morecambe Offshore Windfarm, 2025). In contrast, the 'lower strike rate' scenario assumed a consistent rate of 15 blows per minute between 32% and 80% of the maximum hammer energy (see Tables 3-2 and 3-3 in Section 3.2 in the UWN modelling report for the Morecambe Offshore Windfarm, 2025).

19. At their worst-case modelling location, the impact ranges between these two strike rates showed significant differences in the maximum PTS effect ranges (for weighted SEL_{cum} for a monopile). Specifically, the effect ranges increased from 2.5km with the 'lower strike rate' to 13km with the 'higher strike rate' for minke whale and from 1.5km with the 'lower strike rate' to 8.1km with the 'higher strike rate' for harbour porpoise.

20. Whilst modifications to the soft start and ramp up can reduce impact range for marine mammals, it is important to note that this noise reduction measure would not reduce the impacts to fish because they are not assessed as having a fleeing response.

2.2 Secondary Noise Reduction

21. Secondary noise reduction methods aim to reduce sound propagation during pile driving. This can be achieved by the use of Noise Abatement Systems (NAS) such as casings, resonators or bubble curtains (big and small bubble curtains). The area of noise exposure to fish and marine mammals can be significantly decreased by using secondary noise reduction measures (Koschinski and Lüdemann, 2020). Several parameters influence the resulting noise levels such as pile diameter, water depth, soil structure and blow energy (Verfuss *et al*. 2019).

22. **Table 2-1** presents examples of NAS along with the noise reduction in SEL (dB) that they could achieve. This shows that the majority of NAS would be expected to achieve a 10dB reduction or greater.

Table 2-1 Minimum and maximum noise reduction efficacy from NAS methods

NAS	Noise reduction (SEL)	Source
Bubble curtains		
Big Bubble Curtains (BBC)	7 – 15dB	Verfuss *et al*. 2019; Bellmann *et al.* 2020
	15dB	Bellman *et al*. 2018
Double BBC (DBBC)	8 – 18 dB	Bellmann *et al*. 2020
Hydro sound Dampers (HSD)		
HSD	10 – 12 dB	Bellmann *et al.* 2020
	10-30 dB	Elmer 2018
	20 dB	Bruns *et al*. 2014
Off Noise-Solutions GmbH provides HSD	11 – 14 dB at 750 m	Bellmann *et al*. 2020
Pile casing systems		
IHC IQIP NMS	13 – 16dB	Bellmann *et al*. 2020
The IHC-NMS8000	15 – 17 dB	Bellmann *et al*. 2020

3 Fish and Shellfish

3.1 Underwater Noise Impacts of Fish

23. Impacts on Fish and Shellfish receptors are assessed based on receptor groups as defined within Popper *et al*. (2014) and comprise:

- Fish with a swim bladder used in hearing;
- Fish with a swim bladder not used in hearing;
- Fish without a swim bladder; and
- Fish eggs and larvae.

24. The above receptor groups are listed in order of decreasing sensitivity to underwater noise. Species with a swim bladder that is used in hearing represent those species most sensitive to underwater noise impacts, and include clupeids such as Atlantic herring and shad, and gadids (e.g. Atlantic cod). This receptor group is used to determine the worst case scenario assessment for underwater noise impacts. As herring spawning grounds are known to exist within and close to the Dogger Bank, and herring fall within this receptor group, impacts to this species have been used to determine the worst case for impacts on Fish and Shellfish Ecology as a result of underwater noise throughout this application.

3.2 Worst Case Scenario

25. Within the original assessment, separate scenarios were presented for the Projects in isolation and together as described within section 10.6.1.3.5. of **Chapter 10 Fish and Shellfish Ecology (Revision 2)** [document reference 7.10]. These scenarios aimed to maximise spatial extent of underwater noise impacts to ensure the assessment of a worst case scenario applicable to all receptor groups.

26. The together scenario was represented by three simultaneous pin piles at DBS East, DBS West, and at the Offshore Export Cable Corridor Electrical Switching Platform (ESP). This scenario maximised both spatial extent, and temporal extent due to the increased piling time required for the installation of pin piles.

27. For the In Isolation Scenario two simultaneous monopile installations were considered within the Array Areas, with no simultaneous piling to occur at the ESP. In this scenario a precautionary approach to modelling was used to simplify assessment clarity whilst ensuring a worst case assessment was undertaken. Separation between the two piling locations within the Array Areas (the north most location at DBS West, and the south most location at DBS East) was used, rather than using two piling locations within a single Array Area as would be realistic in the In Isolation Scenario. This precautionary approach over-estimated the spatial extent of underwater noise in the In Isolation Scenario, but improved the clarity of the assessment.

28. Following revisions to project design presented within **Project Change Request 1 – Offshore and Intertidal Works** [AS-141] and **Appendix A: Fish and Shellfish Environmental Assessment Update** [AS-142] the potential for piling at the ESP was removed from assessment. In terms of temporal impacts, simultaneous pin piling at two locations remains the worst case scenario for the together assessment (maximising temporal extent). However, in terms of spatial impact, which remains the key consideration when determining potential impacts on Atlantic herring in this Technical Note, simultaneous monopiling at the same two locations that were used in the original assessment remained the worst case scenario for the In Isolation Scenario (maximising spatial extent). For the purposes of this Technical Note, therefore, the In Isolation Scenario is the same as the worst case together scenario.

3.3 Projects in Isolation and Together

29. Impacts associated with monopiling at the DBS West north location, and the DBS East south location both with and without a f 10dB reduction are presented within **Figure 3-1**. The same information cropped to the Array Areas is presented within **Figure 3-2**. These figures present the noise impacts in relation to potential herring spawning habitat. As indicated within these figures, a reduction of 10dB results in a large decrease in total area associated with each of the underwater noise impact ranges (dotted lines indicating unmitigated noise contours, solid lines indicating mitigated noise contours) and therefore decreases in overlap of underwater noise impacts with potential herring spawning habitat.

30. Note that the Kyle-Henney *et al.* (2024) methodology does not prescribe set cut off points for the classification of potential habitat suitability. Rather, habitat is assigned a value between 0 and 1, with smaller values indicating greater spawning habitat potential. For clarity, changes in the overlap of underwater noise impacts with potential herring spawning habitat are presented within **Table 3-1**, with nominal grouping included for legibility. Values <0.1 may be considered as moderate and higher, values from 0.1-1 may be considered moderate to lower.

31. Examination of the modelling indicates that with a 10dB reduction, underwater noise impacts within each of the impact ranges defined in Popper *et al.* (2014) for fish with a swim bladder used in hearing (186dB SEL_{cum} for temporary threshold shift; 203 dB SEL_{cum} for recoverable injury; and 207 dB SEL_{cum} for mortality or potential mortal injury) are limited to regions either unsuitable for herring spawning, or regions with a spawning potential >0.25.

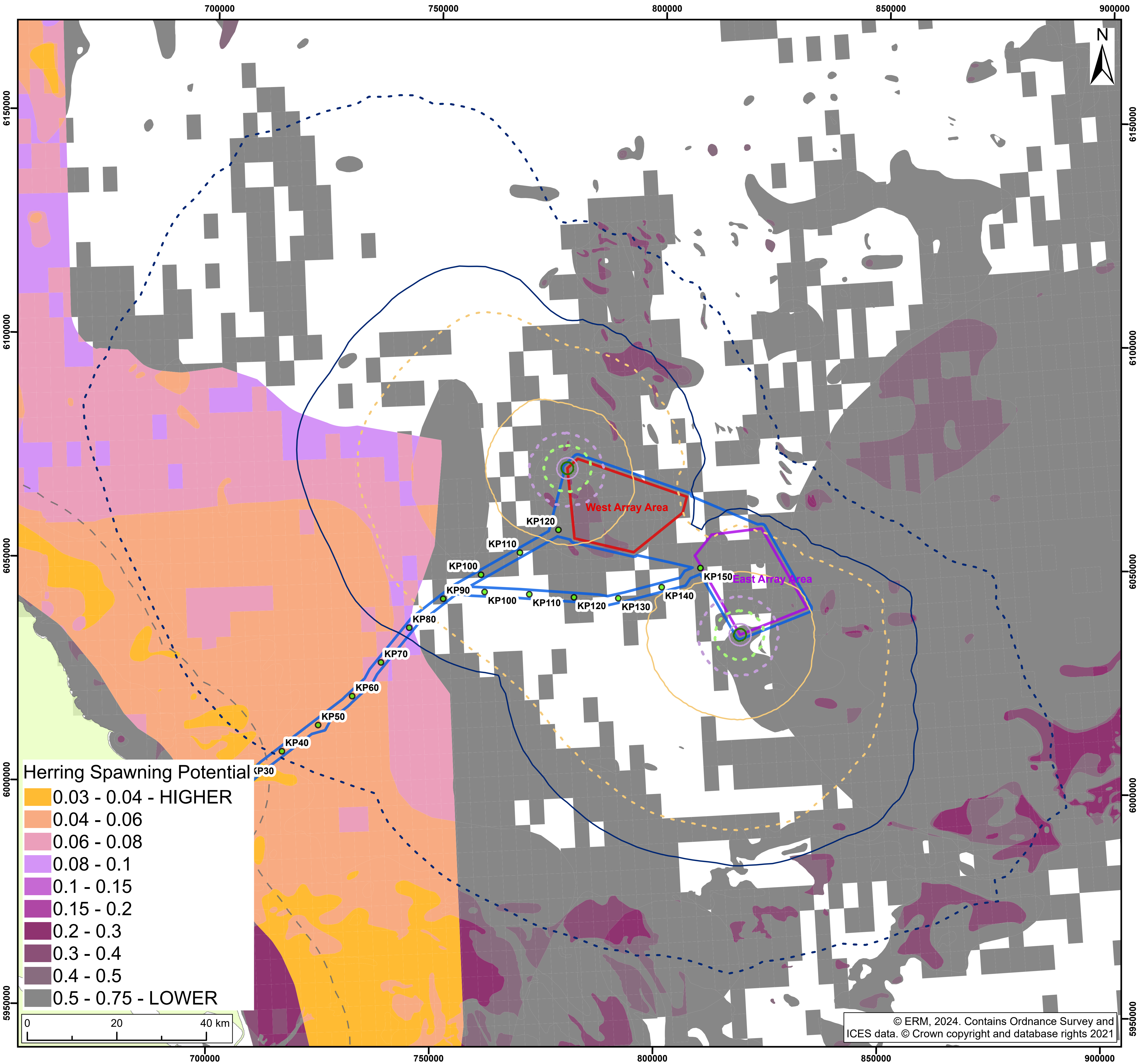
32. Within the 135 dB SEL_{ss} contours, areas of herring spawning potential of a value <0.05-<0.1, and 0.05 (moderate to higher potential) are reduced by 80.91% and 100% respectively. Whilst it is maintained that the 135dB SEL_{ss} threshold is not considered appropriate for the determination of population level impacts, it is noted that the impact range of this contour is greatly reduced via the introduction of noise reduction methods.

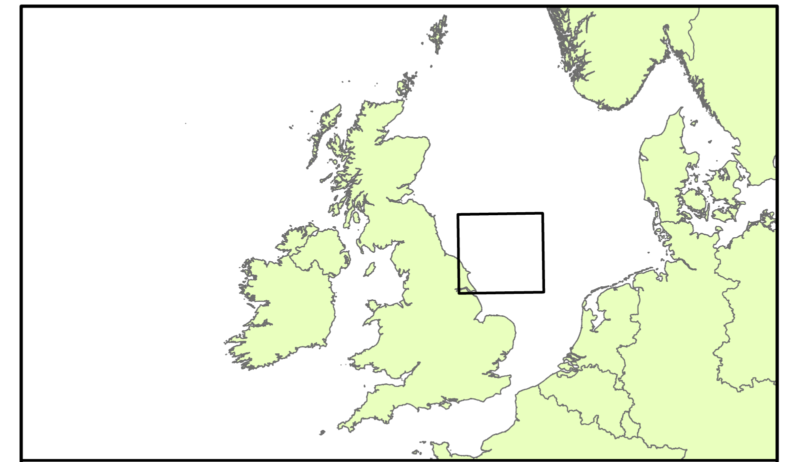
3.4 Summary

33. The modelling presented within the ES is based on a precautionary design envelope and without mitigation as a worst case. It is likely that the DBS Projects would be developed with a less impactful envelope than that presented in the ES and that noise mitigation would be provided that would deliver substantial reductions of impact ranges, benefitting fish species.

34. The information presented in **Figure 3-1** and **Figure 3-2** clearly shows the reductions in impact ranges that could be achieved if a 10db reduction of noise impacts was realised through such means. The Projects will utilise best endeavours to deliver noise reductions, where applicable, through the use of primary and/or secondary methods based on the final project design. By utilising underwater noise reduction methods that lead to a 10dB reduction in piling noise, impacts relating to underwater noise would cover a reduced area of potential herring spawning grounds. Indeed, under such a scenario, if a 10dB reduction could be achieved the temporary threshold shift boundary would move entirely outside of regions of potential herring spawning with a value of <0.25 as shown in **Figure 3-1**.

35. The final noise impacts will be remodelled post-consent as part of the development of the MMMP. This remodelling will demonstrate the final reductions of noise impact ranges achieved through any changes to project design and through the application of primary and/or secondary noise mitigation. The Applicants consider that, on the basis of the information presented in section 2, a 10dB reduction could be achieved through the adoption of a number of different potential options and that the benefits of such a reduction would remove the risk of noise impacts to herring utilising the main Banks herring population spawning ground during their spawning season (August to October).





Legend:

- UK 12 nm limit

Array Area

- KP Points
- DBS East Array Area
- DBS West Array Area
- Offshore Development Area

Mitigated Thresholds (10 dB Reduction)

Disturbance Threshold (Based on Hawkins et al. 2014)

- 135 dB re 1 μPa^{2}SELss -10dB (Behaviour Threshold)

Key UWN Thresholds (Popper et al. 2014)

- 186 dB re 1 μPa^{2}s SEL$_{cum}$ -10dB (TTS)
- 203 dB re 1 μPa^{2}s SEL$_{cum}$ -10dB (Recoverable Injury)
- 207 dB re 1 μPa^{2}s SEL$_{cum}$ -10dB (Mortality/Potential Mortal Injury)

Unmitigated Thresholds

Disturbance Threshold (based on Hawkins et al., 2014)

- 135 dB re 1 μPa^{2}s SEL$_{ss}$ (Behaviour Threshold)

Key UWN Thresholds (Popper et al., 2014)

- 186 dB re 1 μPa^{2}s SEL$_{cum}$ (TTS)
- 203 dB re 1 μPa^{2}s SEL$_{cum}$ (Recoverable Injury)
- 207 dB re 1 μPa^{2}s SEL$_{cum}$ (Mortality/Potential Mortal Injury)

SUI	REV	DATE	DESCRIPTION	DRW	CHK	APR
S1	P01	4/15/2025	J0754512-MAP-111-NoiseAbatement-01	MW	OW	

Title: Potential spawning habitat heat map for Atlantic herring in the vicinity of the Dogger Bank South Offshore Winds Farms. Produced using the approaches from Kyle-Henney et al. (2024). Unmitigated and mitigated (-10dB) underwater noise contours overlaid.

Figure: 3-1 | Drawing No: J0754512-MAP-111-NoiseAbatement-01

Co-ordinate system: WGS 1984 UTM Zone 30N | Page Size: A3 | Scale: 1:850,000

Project: Dogger Bank South Offshore Wind Farms

Report: The Applicants' Responses to Deadline 2 Documents - MMO

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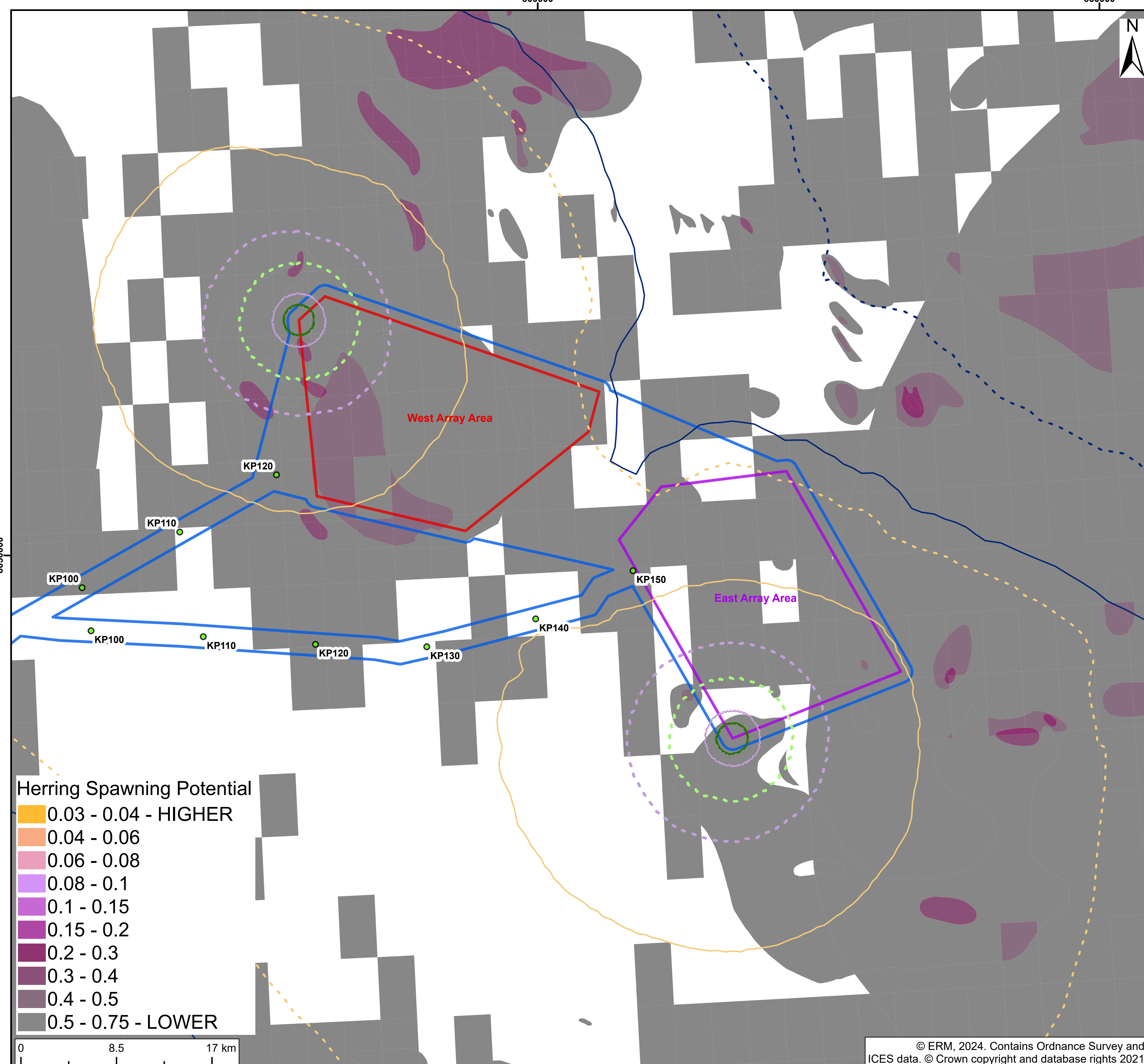
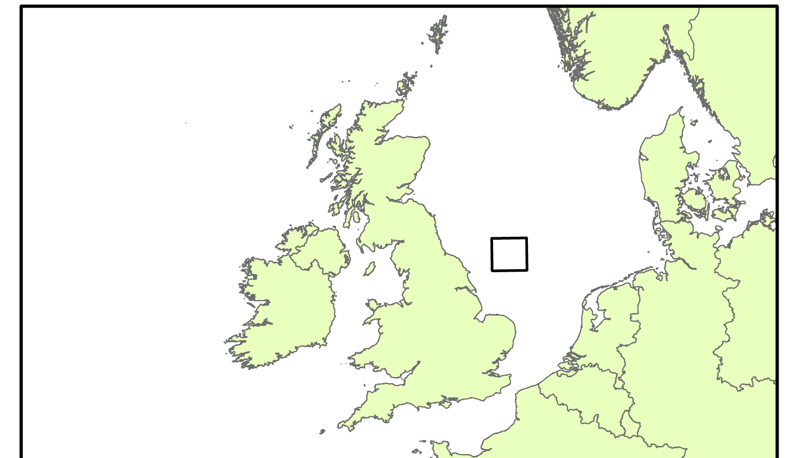
DBS Offshore Wind





Legend:

UK 12 nm limit

Array Area

- KP Points
- DBS East Array Area
- DBS West Array Area
- Offshore Development Area

Mitigated Thresholds (10 dB Reduction)

Disturbance Threshold (Based on Hawkins et al. 2014)

- 135 dB re 1 μPa²SELss -10dB (Behaviour Threshold)

Key UWN Thresholds (Popper et al. 2014)

- 186 dB re 1 μPa²s SEL_{cum} -10dB (TTS)
- 203 dB re 1 μPa²s SEL_{cum} -10dB (Recoverable Injury)
- 207 dB re 1 μPa²s SEL_{cum} -10dB (Mortality/Potential Mortal Injury)

Unmitigated Thresholds

Disturbance Threshold (based on Hawkins et al., 2014)

- 135 dB re 1 μPa²s SEL_{ss} (Behaviour Threshold)

Key UWN Thresholds (Popper et al., 2014)

- 186 dB re 1 μPa²s SEL_{cum} (TTS)
- 203 dB re 1 μPa²s SEL_{cum} (Recoverable Injury)
- 207 dB re 1 μPa²s SEL_{cum} (Mortality/Potential Mortal Injury)

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Figure: 3-2 | Drawing No: J0754512-MAP-111-NoiseAbatement-01

Co-ordinate system: WGS 1984 UTM Zone 30N | Page Size: A3 | Scale: 1:350,000

Project: Dogger Bank South Offshore Wind Farms

Report: The Applicants' Responses to Deadline 2 Documents - MMO

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DBS Offshore Wind

Table 3-1 Changes in total area of underwater noise contours between unmitigated and with a 10dB noise reduction simultaneous monopiling at the DBS West north location and the DBS East south location.

Noise Contour (dB re 1µPa²s)	Herring Spawning Potential	Total Area Unmitigated (km²)	Total Area with -10 dB noise reduction (km²)	% Reduction from Unmitigated to 10 dB noise reduction
135 **SEL_{SS}**	<0.05	466.36	0.00	100.00
	0.05-<0.1	4366.37	833.37	80.91
	0.1-<0.25	315.44	238.10	24.52
	>0.25	8487.29	4972.74	41.41
186 **SEL_{cum}**	<0.05	0.00	0.00	-
	0.05-<0.1	392.90	0.00	100.00
	0.1-<0.25	113.80	0.00	100.00
	>0.25	4217.71	1226.63	70.92
203 **SEL_{cum}**	<0.05	0.00	0.00	-
	0.05-<0.1	0.00	0.00	-
	0.1-<0.25	0.00	0.00	-
	>0.25	239.79	22.44	90.64
207 **SEL_{cum}**	<0.05	0.00	0.00	-
	0.05-<0.1	0.00	0.00	-
	0.1-<0.25	0.00	0.00	-
	>0.25	143.05	11.58	91.90

4 Marine Mammals

4.1 Projects in Isolation

36. Permanent Threshold Shift (PTS) can occur instantaneously from acute exposure to high noise levels, such as single strike Sound Pressure Level (SPL_{peak}) of the maximum hammer energy applied during piling. PTS can also occur as a result of prolonged exposure to increased noise levels, such as for the duration of pile installation (cumulative Sound Exposure Level (SEL_{cum})).

37. For the Projects constructed in isolation, the assessment for potential PTS was presented in section 11.6.1.1.2.1 of **Chapter 11 Marine Mammals (Revision 2)** [document reference 7.11] without mitigation to represent the worst case scenario for piling. This technical note presents the predicted impact ranges based on a 10dB reduction in noise levels in comparison with the predicted impact ranges presented in **Chapter 11 Marine Mammals (Revision 2)** [document reference 7.11].

4.1.1 PTS Impact Ranges

38. The impact ranges presented in Table 11-21 of **Chapter 11 Marine Mammals (Revision 2)** [document reference 7.11] are the Projects' absolute worst case. However, with the new Defra noise policy in place and with the Applicants committing to utilise best endeavours to deliver primary and / or secondary noise reduction methods, this technical note presents predicted impact ranges that could be achieved using noise reduction methods. Maximum marine mammal PTS impact ranges with and without a 10dB noise reduction are presented in **Table 4-1** and **Table 4-2.**

4.1.1.1 PTS from Peak Sound Pressure Levels

39. Peak Sound Pressure Level (SPL_{peak}) are often used to characterise sound transients from impulsive sources, such as percussive impact piling. A peak SPL is calculated using the maximum variation of the pressure, from positive to zero, within the wave. This represents the maximum change in positive pressure (differential pressure from positive to zero) as the transient pressure wave propagates.

40. **Table 4-1** presents the predicted impact ranges using SPL_{peak} for a single strike at the maximum hammer energy in the current design envelope of 6,000 kJ for a monopile installation. The predicted impact range for harbour porpoise would decrease from 740m in Table 11-21 of **Chapter 11 Marine Mammals (Revision 2)** [document reference 7.11] without any mitigation to 150m using a 10dB noise reduction.

41. Based on the reduction to a 150m predicted impact range for a single strike at maximum energy for harbour porpoise, the monitoring area (MA) would be reduced to 500m in line with the JNCC (2010) guidance where marine mammal observers (MMObs) and Passive acoustic monitoring (PAM) will be effective at monitoring the full MA.

Table 4-1 Predicted Impact Ranges for PTS SPL_{peak} in all Marine Mammal Species, at the Worst Case Modelling Location (DBS East (south location)), from a single strike of the Maximum Hammer Energies of Monopiles for the Projects in isolation (Table 11-21 of Chapter 11 Marine Mammals (Revision 2) [document reference 7.11])

Marine mammal species	Location	Potential impact ranges for PTS from a single strike at maximum hammer energy	
		Unmitigated presented in the ES	**With -10 dB noise reduction**
Harbour porpoise	DBS East	740m	150m
Dolphin species	DBS East	50m	<50m
Minke whale	DBS East	130m	<50m
Seal species	DBS East	60m	<50m

4.1.1.2 PTS from Cumulative Exposure

42. Cumulative Sound Exposure Level (SEL_{cum}) is the cumulative sound exposure level throughout the duration of piling, including soft-start, ramp-up and time required to complete the installation of the foundation. To determine SEL_{cum} ranges for marine mammals, a fleeing animal model has been used. This assumes that the animal exposed to high noise levels would swim away from the noise source. For this, a constant swimming speed of 3.25m/s has been assumed for minke whale (Blix and Folkow, 1995), and as a precautionary approach for all other species, a constant swimming speed of 1.5m/s has been used, based on the average swimming speed for harbour porpoise mother and calf pairs (Otani *et al.*, 2000). This is considered a worst case scenario, as marine mammals are expected to be able to swim faster.

43. The maximum predicted impact range for PTS from cumulative exposure (SEL_{cum}) during a monopile installation with maximum hammer energy was up to 11km for harbour porpoise and 18km for minke whale as presented in Table 11-23 of **Chapter 11 Marine Mammals (Revision 2)** [document reference 7.11] for two sequential monopiles installed with a maximum hammer energy of 6,000kJ. The impact ranges are decreased from 18km to 1.6km for minke whale (**Table 4-2**) and from 11km to 980m for harbour porpoise with a 10dB reduction at source (**Table 4-2**).

Table 4-2 The Predicted Impact Ranges for PTS in all Marine Mammal Species, at the Worst Case Modelling Location, for the Cumulative Exposure of Monopiles with and without a 10dB noise reduction at the Projects in isolation (Table 11-23 of Chapter 11 Marine Mammals (Revision 2) [document reference 7.11])

Marine mammal species	Location	Potential impact ranges (and areas) for PTS due to cumulative exposure	
Cumulative exposure from two sequential monopiles in the Array Areas			
		Unmitigated presented in the ES	**With -10 dB noise reduction**
Harbour porpoise	DBS East	10km (240km²)	0.98km (2.4km²)
	DBS West	9.0km (200km²)	0.83km (1.8km²)
Dolphin species	DBS East or DBS West	0.1km (0.0km²)	<0. 1km (0.1km²)
Minke whale	DBS East	18km (560km²)	1.6km (4.6km²)
	DBS West	16km (460km²)	1.1km (2.5km²)
Seal species	DBS East	1.6km (6.2km²)	<0. 1km (0.1km²)
	DBS West	1.3km (4.3km²)	<0. 1km (0.1km²)

4.1.1.3 Acoustic Deterrent Device activation times

44. **Table 4-3** provides a summary of the ADD activation durations required to allow animals to flee from the modelled piling PTS SEL_{cum} impact ranges.

45. The predicted PTS SEL_{cum} impact ranges in **Table 4-3** are for a single monopile installation at DBS East as the impact ranges are slightly larger compared to the predicted impact ranges at DBS West and therefore represent the worst case. This can be due to differences that occur with the temperature, salinity, and depth of the water, as well as the sediment type at the modelling locations.

46. The maximum activation time recommended through consultation with regulators and assessed in the ES, is 80 minutes (as presented in Table 11-50 in section 11.6.1.2.2.5 of **Chapter 11 Marine Mammals (Revision 2)** [document reference 7.11]), as ADDs are deemed effective range up to a of 7km, which is approximately 80 minutes of usage based on the harbour porpoise swim speed of 1.5 m/s. **Table 4-3** presents the impact ranges and potential ADD usage based on the PTS SEL_{cum} from a single monopile at DBS East.

47. During unmitigated piling, a minimum 112 minute ADD activation would be required to deter harbour porpoise from the mitigation zone (MZ) prior to monopile installation (**Table 4-3**). This activation time would also be sufficient to cover the impact ranges for minke whale, dolphins and seals.

48. With the decrease in impact ranges due to the 10dB noise reduction (**Table 4-2**), the ADD activation time is greatly reduced (**Table 4-3**). For a single monopile installation at DBS East, the ADD would need to be activated for a minimum of 25 minutes for minke whale to move outside of the MZ, which is also sufficient to cover the deterrent ranges required for harbour porpoise, dolphins and seals which would only need 12 minutes of ADD use.

Table 4-3 ADD Duration, Marine Mammal Swim Speed and Calculated Range for the Cumulative Exposure of a Single Monopile with and without -10dB noise reduction at the DBS East in isolation

Species	Swim speed (m/s)	ADD duration required		Range of deterrence		Area of deterrence	
		Unmitigated	With -10dB noise reduction	Unmitigated	With -10dB noise reduction	Unmitigated	With -10dB noise reduction
Harbour porpoise, dolphins and seals	1.5	112 minutes	12 minutes	10km	1.08km	319km^2	3.7km^2
Minke whale	3.25	93 minutes	25 minutes	18km	4.9km	1,033km^2	75.4km^2

49. **Table 4-1** and **Table 4-2** show large decreases in predicted impact ranges with a 10dB noise reduction. With noise reductions the potential impact ranges become more manageable to mitigate the risk of PTS for marine mammals when combined with standard mitigation measures (MMObs, PAM, and ADDs). As stated in section 4.1.1.1 MMObs and PAM can be effective at monitoring the full MA with a 10dB noise reduction.

50. In addition to MMObs and PAM monitoring the ADD can be activated for a decreased duration to deter marine mammals, with 25 minutes of ADD activation required to deter minke whale, compared to 93 minutes, without noise reduction (**Table 4-3**). With a decrease in required ADD durations, the overall noise in the marine environment and therefore any additional disturbance to marine mammals is reduced.

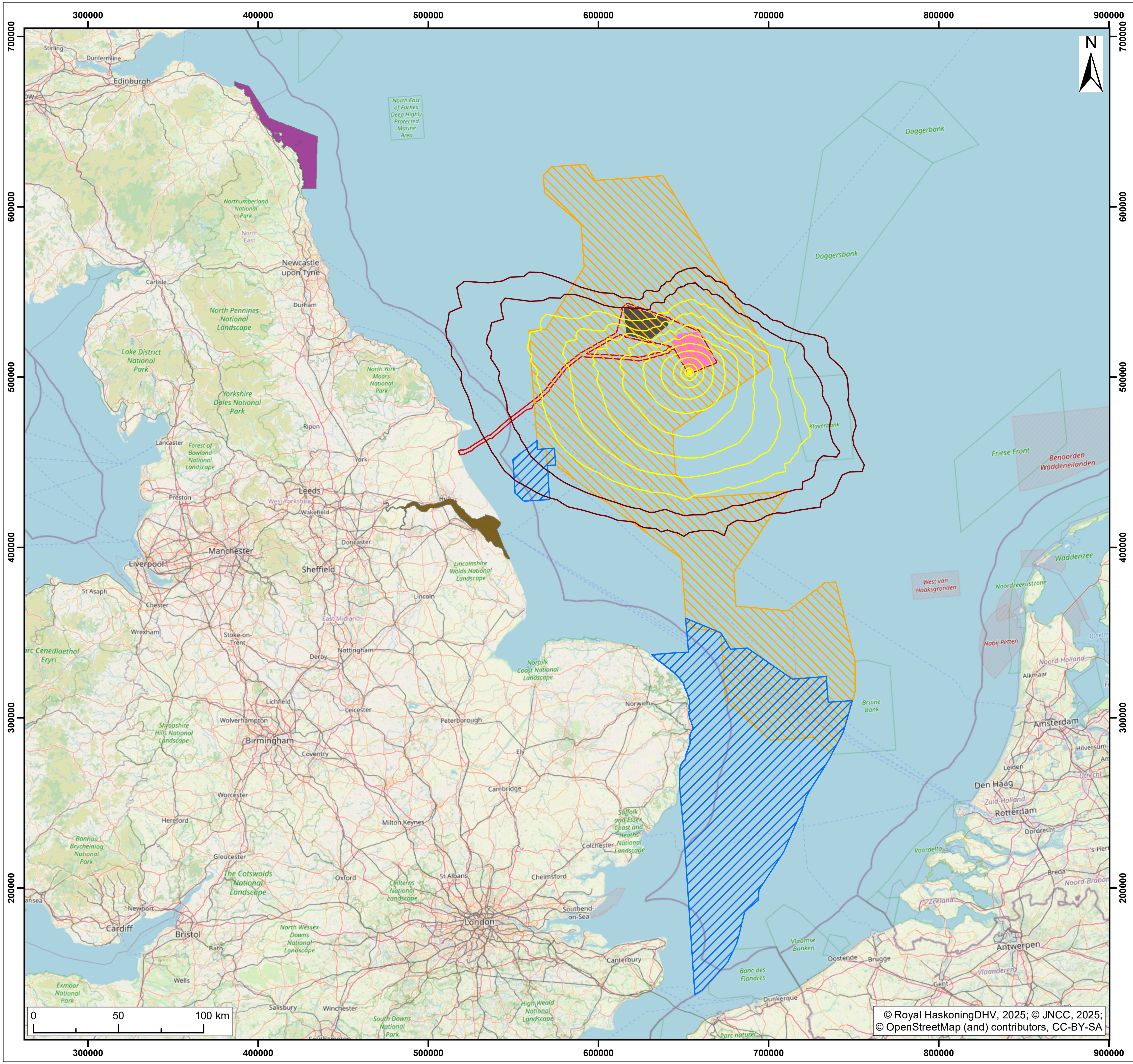
4.1.1.4 Results of noise reduction on Seal Special Areas of Conservation

51. **Figure 4-1** and **Figure 4-2** presents the mitigated (in yellow) and unmitigated (in red) sound contours for piling noise for a single monopile installation at the worst case locations at the DBS East Array Area and DBS West Array Area. The sound contours are unweighted PTS SEL_{cum} impact ranges with 5dB increments.

52. **Figure 4-3** presents the unweighted PTS SEL_{cum} sound contours with and without a 10db noise reduction at DBS West Array Area in relation to the grey seal foraging population at sea of the Berwickshire Northumberland and North Coast Special Area of Conservation (SAC). This figure shows that the sound propagation is reduced and further away from the Berwickshire Northumberland and North Coast SAC with a 10dB reduction. Without mitigation the last noise contour at 120dB level is almost 72km from the SAC and with the 10dB noise reduction the sound is approximately 152km away from the Berwickshire Northumberland and North Coast SAC. **Figure 4-3** shows a maximum grey seal mean percentage of at-sea population estimate of 0.04 to 0.07 per km^2 within the unweighted SEL_{cum} that could be impacted from piling noise with a 10dB noise reduction. This shows that a very small proportion of the Berwickshire Northumberland and North Coast SAC grey seal population could be impacted from piling noise.

53. **Figure 4-4** presents the unweighted PTS SEL_{cum} sound contours with and without a 10dB noise reduction at DBS East Array Area in relation to the grey seal at sea foraging population of the Humber Estuary SAC. The unmitigated sound contours fall in range of the higher grey seal densities at the Humber Estuary SAC, however, by adding a 10dB reduction, the unweighted SEL_{cum} sound contours do not propagate into that area. **Figure 4-4** shows a maximum grey seal mean percentage of at-sea population estimate of 0.2 to 0.3 per km^2 within the potential impact range from unmitigated piling noise; while a mean percentage of at-sea population estimate of 0.02 to 0.04 per km^2 of the Humber Estuary SAC population that could be impacted by piling noise with a 10dB noise reduction.

54. **Figure 4-5** presents the unweighted PTS SEL_{cum} sound contours with and without a 10dB noise reduction at DBS East Array Area in relation to the harbour seal at sea foraging population of the Wash and North Norfolk Coast SAC. The unmitigated sound contours fall in range of the higher harbour seal density from the Wash and North Norfolk Coast SAC, however, by adding a 10dB reduction, the unweighted SEL_{cum} sound contours do not propagate into that area. **Figure 4-5** shows a maximum harbour seal mean percentage of at-sea population estimate of 0.04 to 0.07 per km^2 within the potential impact range from unmitigated piling noise; while a mean percentage of at-sea population estimate of 0.004 to 0.016 per km^2 of the Wash and North Norfolk Coast SAC population that could be impacted by piling noise with a 10dB noise reduction.



Legend:

- Offshore Development Area
- DBS East Array Area
- DBS West Array Area
- Berwickshire and North Northumberland Coast Special Area of Conservation (SAC)
- Humber Estuary Special Area of Conservation (SAC)
- Southern North Sea Summer Area
- Southern North Sea Winter Area
- DBS East Mitigated (-10dB) Unwtd SELss 5dB increments
- DBS East Unmitigated Unwtd SELss 5dB increments

SUI	REV	DATE	DESCRIPTION	DRW	CHK	APR
S2	P01	04/04/2025	Suitable for information	SM	SB	RF

Title:

Mitigated and Unmitigated Sound Contour files at 5dB increments at DBS East Array Area

Figure: 4-1 Drawing No: PC2340-RHD-OF-ZZ-DR-Z-1035

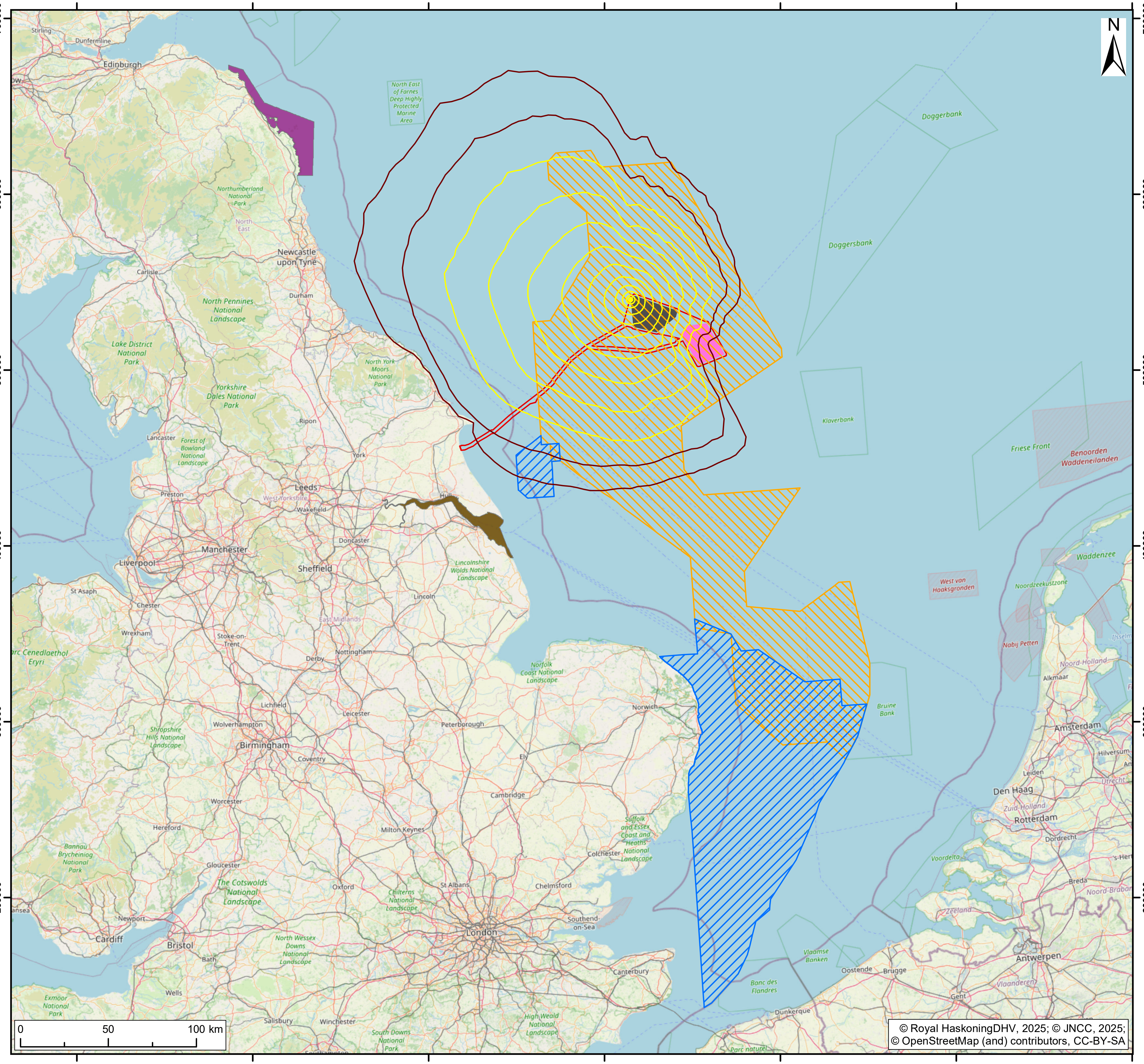
Co-ordinate system: British National Grid
Page Size: A3
Scale: 1:2,200,000

Project: Dogger Bank South Offshore Wind Farms

Report: Marine Mammal Sound Contours

Royal HaskoningDHV Enhancing Society Together

DBS Offshore Wind



Legend:
- Offshore Development Area
- DBS East Array Area
- DBS West Array Area
- Berwickshire and North Northumberland Coast Special Area of Conservation (SAC)
- Humber Estuary Special Area of Conservation (SAC)
- Southern North Sea Summer Area
- Southern North Sea Winter Area
- DBS West Mitigated (-10dB) Unwtd SELss 5dB increments
- DBS West Unmitigated Unwtd SELss 5dB increments

SUI	REV	DATE	DESCRIPTION	DRW	CHK	APR
S2	P01	04/04/2025	Suitable for information	SM	SB	RF

Title:

Mitigated and Unmitigated Sound Contour files at 5dB increments at DBS West Array Area

Figure: 4-2 Drawing No: PC2340-RHD-OF-ZZ-DR-Z-1036

Co-ordinate system: British National Grid | Page Size: A3 | Scale: 1:2,200,000

Project: Dogger Bank South Offshore Wind Farms

Report: Marine Mammal Sound Contours

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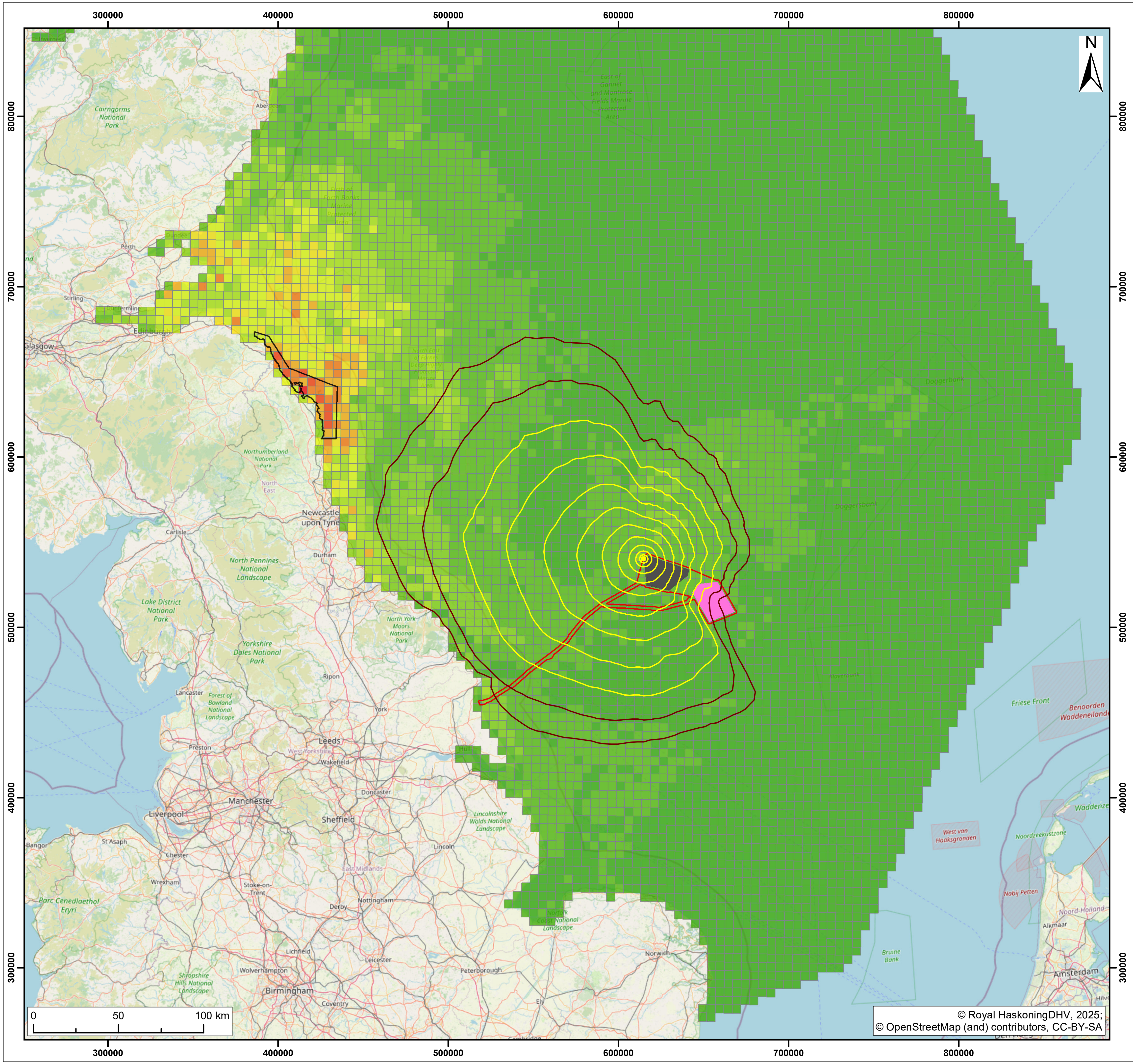

Legend:

- Offshore Development Area
- DBS East Array Area
- DBS West Array Area
- Berwickshire and North Northumberland Coast SAC
- DBS West Mitigated (-10dB) Unwtd SELss 5dB increments
- DBS West Unmitigated Unwtd SELss 5dB increments

Berwickshire and North Northumberland Coast SAC Proportion of the population per 25km² (as a %)

- 0.000000 - 0.004647
- 0.004648 - 0.016101
- 0.016102 - 0.039155
- 0.039156 - 0.074405
- 0.074406 - 0.118941
- 0.118942 - 0.183456
- 0.183457 - 0.288694
- 0.288695 - 0.523660
- 0.523661 - 1.012806
- 1.012807 - 1.803618

Maps show mean percentage of at-sea population estimated to be present in each 5 km x 5 km grid cell square at any one time, and the cellsquare-wise (Carter et al., 2022)

S2	P01	08/04/2025	Suitable for information	SM	SB	RF
SUI	REV	DATE	DESCRIPTION	DRW	CHK	APR

Title: Mitigated and Unmitigated Sound Contour files at 5dB increments at DBS West Area, with the at sea foraging density of grey seal at the Berwickshire Northumberland and North Coast SAC (Carter et al. 2022)

Figure: 4-3 | Drawing No: PC2340-RHD-OF-ZZ-DR-Z-1037

Co-ordinate system: British National Grid | Page Size: A3 | Scale: 1:2,200,000

Project: Dogger Bank South Offshore Wind Farms

Report: Marine Mammal Sound Contours

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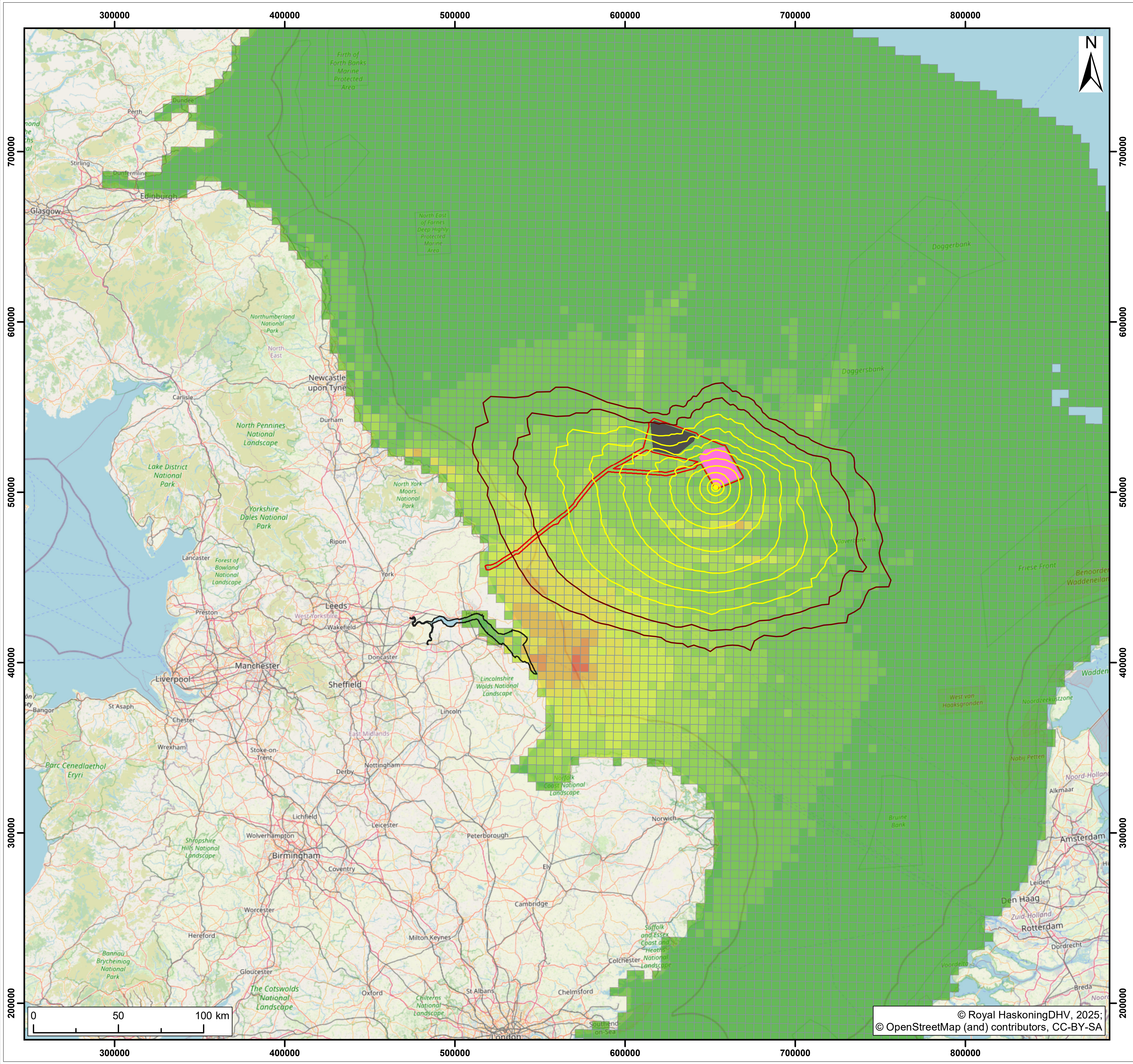
DBS Offshore Wind



Legend:

- Offshore Development Area
- DBS East Array Area
- DBS West Array Area
- Humber SAC
- DBS East Mitigated (-10dB) Unwtd SELss 5dB increments
- DBS East Unmitigated Unwtd SELss 5dB increments

Humber SAC
Proportion of the population per 25km² (as a %)

0.000000 - 0.004647	0.118942 - 0.183456
0.004648 - 0.016101	0.183457 - 0.288694
0.016102 - 0.039155	0.288695 - 0.523660
0.039156 - 0.074405	0.523661 - 1.012806
0.074406 - 0.118941	1.012807 - 1.803618

Maps show mean percentage of at-sea population estimated to be present in each 5 km x 5 km grid cell square at any one time, and the cellsquare-wise (Carter et al., 2022)

SUI	REV	DATE	DESCRIPTION	DRW	CHK	APR
S2	P01	08/04/2025	Suitable for information	SM	SB	RF

Title: Mitigated and Unmitigated Sound Contour files at 5dB increments at DBS East Array Area, with the at sea foraging density of grey seal at the Humber Estuary SAC (Carter et al. 2022)

Figure: 4-4 Drawing No: PC2340-RHD-OF-ZZ-DR-Z-1038

Co-ordinate system: British National Grid | Page Size: A3 | Scale: 1:2,200,000

Project: Dogger Bank South Offshore Wind Farms

Report: Marine Mammal Sound Contours

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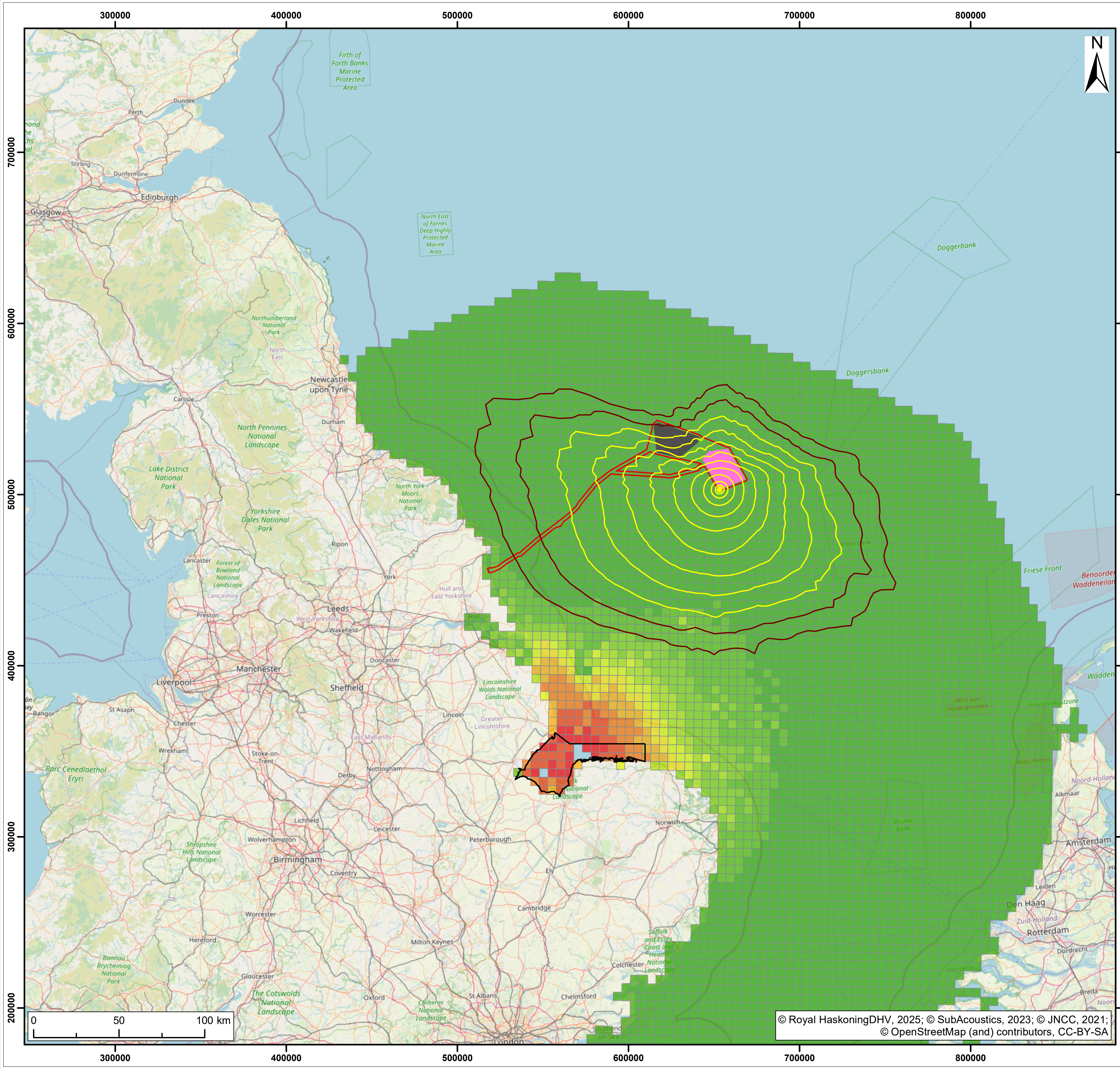
DBS Offshore Wind



Legend:

- Offshore Development Area
- DBS East Array Area
- DBS West Array Area
- The Wash and North Norfolk Coast SAC
- DBS East Mitigated (-10dB) Unwtd SELss 5dB increments
- DBS East Unmitigated Unwtd SELss 5dB increments

The Wash and North Norfolk Coast SAC
Proportion of the population per 25km² (as a %)

- 0.000000 - 0.004647
- 0.004648 - 0.016101
- 0.016102 - 0.039155
- 0.039156 - 0.074405
- 0.074406 - 0.118941
- 0.118942 - 0.183456
- 0.183457 - 0.288694
- 0.288695 - 0.523660
- 0.523661 - 1.012806
- 1.012807 - 1.803618

Maps show mean percentage of at-sea population estimated to be present in each 5 km x 5 km grid cell square at any one time, and the cellsquare-wise (Carter et al., 2022)

SUI	REV	DATE	DESCRIPTION	DRW	CHK	APR
S3	P02	30/06/2025	Suitable for review & comment	SM	AS	RF
S2	P01	20/06/2025	Suitable for information	SM	AS	RF

Title: Mitigated and Unmitigated Sound Contour files at 5dB increments at DBS East Array Area, with the at sea foraging density of harbour seal at The Wash and North Norfolk Coast SAC (Carter et al. 2022)

Figure: 4-5 Drawing No: PC2340-RHD-OF-ZZ-DR-Z-1097

Co-ordinate system: British National Grid | Page Size: A3 | Scale: 1:2,200,000

Project: Dogger Bank South Offshore Wind Farms

Report: Marine Mammal Sound Contours

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4.2 Projects Together

4.2.1 PTS Impact Areas

55. **Table 4-4** presents the potential impact areas from the concurrent piling monopile scenarios at DBS East and DBS West Array Areas with and without the 10dB noise reduction.

56. The potential impact areas are decreased from 2,400km² as presented in Table 11-26 of **Chapter 11 Marine Mammals (Revision 2)** [APP-095] to 290km² for minke whale (**Table 4-4**) and from 1,400km² (Table 11-26 of **Chapter 11 Marine Mammal**s **(Revision 2)** [document reference 7.11]) to 180km² for harbour porpoise when considering a 10dB reduction at source (**Table 4-4**).

Table 4-4 Summary of the Potential Impact Areas for the Concurrent Installation of Monopile Foundations at multiple locations at the Projects, for Marine Mammals using the Impulsive Southall *et al.* (2019) criteria assuming a fleeing animal. [Table 11-26 of Chapter 11 Marine Mammals (Revision 2) [document reference 7.11]

Marine mammal species	Potential impact areas for PTS due to cumulative exposure	
Cumulative exposure from two sequential monopiles in both the Array Areas		
	Unmitigated presented in the ES	**With -10 dB noise reduction**
Harbour porpoise	1,400km²	180km²
Dolphin species	0.2km²	<0.1km²
Minke whale	2,400km²	290km²
Seal species	230km²	<0.01km²

4.3 Summary

57. The modelling presented within the ES is based on a precautionary design envelope and without mitigation. It is likely that the DBS Projects would be developed with a less impactful envelope than that presented in the ES and that noise reduction would be provided that would deliver substantial reductions of impact ranges, benefitting marine mammals. The 10dB reduction has been shown to be achievable in practice and is a fair illustration of what might be achievable through altering the worst case scenario presented in the ES and the adoption of noise reduction measures. The illustrative results from the underwater noise modelling with noise reduction measures to present a 10dB reduction in sound levels show a decrease in the predicted impact ranges for marine mammals.

58. **The Outline MMMP (Revision 4)** [REP4-054] has been updated, and submitted at Deadline 2, in reference to the Defra Policy Paper on Reducing Marine Noise that was published on 21st January 2025 as part of Defra's Marine Noise Package.

59. In line with this policy the Projects will utilise best endeavours to deliver noise reductions, where applicable, through the use of primary and / or secondary noise reduction based on the final project design. By utilising measures of primary and / or secondary noise reduction it would ensure that the final project design and mitigation measures applied would result in no residual PTS. With a 10dB reduction the MA would be reduced, so that MMObs, PAM and the ADD could ensure the PTS range is fully cleared before the start of impact piling.

60. The decrease in impact ranges with a 10dB reduction would also minimise disturbance of all marine mammal species in the wider area and a lower effective deterrence range could be applied to the calculations for the Projects in the Southern North Sea SAC Site Integrity Plan, reducing their contribution to seasonal and daily thresholds for underwater noise.

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Appendix A – Underwater Noise Modelling

Mitigated noise levels

1. The Dogger Bank South (DBS) Offshore Windfarm Projects are located in the North Sea more than 100km off the northeast coast of England and consist of two adjacent sites, DBS East and DBS West. As part of the Environmental Impact Assessment (EIA), Subacoustech Environmental Ltd. have undertaken detailed modelling and analysis in relation to the effect of underwater noise on marine mammals and fish at the sites (**Appendix 11-3 Underwater Noise Modelling Report (Revision 2)** [AS-137]).

2. In addition, there is a possibility that impact piling will occur with mitigation measures in place. The exact mitigation to be used has not been confirmed, but a flat, broadband, 10 dB reduction in source level has been used to reflect a generic noise attenuation. A 10 dB reduction gives a conservative estimate for most types of mitigation that could be considered, as derived from data presented in Verfuss *et al.* (2019). In this paper, as an example, data for the Big Bubble Curtain (BBC), a commonly deployed noise mitigation method, show that it provides a minimum of 10dB attenuation in the frequency bands where marine mammals are most sensitive (i.e., 250 Hz and above). In a comprehensive review of pile driving with and without noise mitigation, Bellman *et al.* (2020) found that, where it was deployed in depths of 30 m or shallower, an attenuation of 10 dB was commonly achieved by a single BBC. There are many ways that noise levels can be reduced including through development of the foundation design, and the methodology to provide attenuation of this order, compared to the values in **Table A 1** , will be determined once the piling methodology is finalised.

Table A 1 Summary of the unweighted apparent source levels used for modelling

Source levels	Location	Monopile foundation 15 m / 6,000 kJ	Multi-leg foundation 4 m / 3,000 kJ
Unwtd SPL_{peak}	DBS East: S location	243.0 dB re 1 μPa @ 1m	241.7 dB re 1 μPa@ 1m
	DBS East: NW location	243.0 dB re 1 μPa@ 1m	241.5 dB re 1 μPa@ 1m
	DBS West: NE location	243.0 dB re 1 μPa@ 1m	241.6 dB re 1 μPa@ 1m
	DBS West: W location	243.0 dB re 1 μPa@ 1m	241.7 dB re 1 μPa@ 1m
Unwtd SEL_{ss}	DBS East: S location	224.2 dB re 1 μPa²s@ 1m	222.5 dB re 1 μPa²s@ 1m
	DBS East: NW location	224.2 dB re 1 μPa²s@ 1m	222.2 dB re 1 μPa²s@ 1m
	DBS West: NE location	224.2 dB re 1 μPa²s@ 1m	222.3 dB re 1 μPa²s@ 1m

Source levels	Location	Monopile foundation 15 m / 6,000 kJ	Multi-leg foundation 4 m / 3,000 kJ
	DBS West: W location	224.2 dB re 1 µPa²s@ 1m	222.5 dB re 1 µPa²s@ 1m

Mitigated impact piling

3. **Table A 2** to **Table A 19** present the modelling results for the monopile foundation scenarios at two separate locations using a 10 dB reduction in source level to represent generic mitigation measures, as discussed above. Separate results have been considered for a single pile installation and multiple piles installed sequentially at the same location, four in the case of multi-leg foundations.

4. The addition of the mitigation measures brings the maximum Southall *et al.* (2019) impact ranges for marine mammals down from 18km at the DBS West: W location for LF cetaceans, to 1.6km. For fish, recoverably injury (203 dB SEL_{cum} threshold) impact ranges are reduced from 8.6km to 2.3km for a stationary receptor and 680m to less than 100m for a fleeing receptor.

DBS East: S location

Table A 2 Summary of the mitigated (-10 dB) unweighted SPL_{peak} impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria for the monopile foundation modelling at the DBS East: S location for the first pile strike

Southall *et al.* (2019) Unweighted SPL_{peak}		Monopile foundation, first strike (mitigated)			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	< 0.01km²	< 50m	< 50m	< 50m
	HF (230 dB)	< 0.01km²	< 50m	< 50m	< 50m
	VHF (202 dB)	0.01km²	70m	70m	70m
	PCW (218 dB)	< 0.01km²	< 50m	< 50m	< 50m
TTS (Impulsive)	LF (213 dB)	< 0.01km²	< 50m	< 50m	< 50m
	HF (224 dB)	< 0.01km²	< 50m	< 50m	< 50m
	VHF (196 dB)	0.09km²	180m	170m	170m
	PCW (212 dB)	< 0.01km²	< 50m	< 50m	< 50m

Table A 3 Summary of the mitigated (-10 dB) unweighted SPL_{peak} impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria for the monopile foundation modelling at the DBS East: S location for the maximum hammer energy

Southall *et al.* (2019) Unweighted SPL_{peak}		Monopile foundation, maximum energy (mitigated)			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	< 0.01km²	< 50m	< 50m	< 50m
	HF (230 dB)	< 0.01km²	< 50m	< 50m	< 50m
	VHF (202 dB)	0.07km²	150m	150m	150m
	PCW (218 dB)	< 0.01km²	< 50m	< 50m	< 50m
TTS (Impulsive)	LF (213 dB)	< 0.01km²	< 50m	< 50m	< 50m
	HF (224 dB)	< 0.01km²	< 50m	< 50m	< 50m
	VHF (196 dB)	0.48km²	390m	390m	390m
	PCW (212 dB)	< 0.01km²	< 50m	< 50m	< 50m

Table A 4 Summary of the mitigated (-10 dB) weighted SEL_{cum} impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria for the monopile foundation (single pile installation) modelling at the DBS East: S location assuming a fleeing animal

Southall *et al.* (2019) Weighted SEL_{cum}		Monopile foundation, single pile (mitigated)			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	4.6km²	1.6km	830m	1.2km
	HF (185 dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (155 dB)	2.4km²	980m	780m	870m
	PCW (185 dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Impulsive)	LF (168 dB)	1,600km²	32km	12km	22km
	HF (170 dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (140 dB)	750km²	20km	11km	15km
	PCW (170 dB)	96km²	6.3km	4.8km	5.5km

Table A 5 Summary of the mitigated (-10 dB) weighted SEL_{cum} impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria for the monopile foundation (2 piles installed per 24 hours) modelling at the DBS East: S location assuming a fleeing animal

Southall *et al.* (2019) Weighted SEL_{cum}		Monopile foundation, 2 sequential piles (mitigated)			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	4.6km²	1.6km	830m	1.2km
	HF (185 dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (155 dB)	2.4km²	980m	780m	880m
	PCW (185 dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Impulsive)	LF (168 dB)	1,600km²	32km	12km	22km
	HF (170 dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (140 dB)	780km²	20km	11km	16km
	PCW (170 dB)	100km²	6.6km	4.8km	5.7km

Table A 6 Summary of the mitigated (-10 dB) unweighted SPL_{peak} impact ranges for fish using the Popper *et al.* (2014) pile driving criteria for the monopile foundation modelling at the DBS East: S location for the first pile strike

Popper *et al.* (2014) Unweighted SPL_{peak}	Monopile foundation, first strike (mitigated)			
	Area	Maximum range	Minimum range	Mean range
213 dB	< 0.01km²	< 50m	< 50m	< 50m
207 dB	< 0.01km²	< 50m	< 50m	< 50m

Table A 7 Summary of the mitigated (-10 dB) unweighted SPL_{peak} impact ranges for fish using the Popper *et al.* (2014) pile driving criteria for the monopile foundation modelling at the DBS East: S location for the maximum hammer energy

Popper *et al.* (2014) Unweighted SPL_{peak}	Monopile foundation, maximum hammer energy (mitigated)			
	Area	Maximum range	Minimum range	Mean range
213 dB	< 0.01km²	< 50m	< 50m	< 50m
207 dB	0.01km²	70m	70m	70m

Table A 8 Summary of the mitigated (-10 dB) unweighted SEL_{cum} impact ranges for fish using the Popper *et al.* (2014) pile driving criteria for the monopile foundation (single pile installation) modelling at the DBS East: S location assuming both a fleeing and stationary animal

Popper *et al.* (2014) Unweighted SEL_{cum}		Monopile foundation, single pile (mitigated)			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 ms^{-1})	219 dB	< 0.1km²	< 100m	< 100m	< 100m
	216 dB	< 0.1km²	< 100m	< 100m	< 100m
	210 dB	< 0.1km²	< 100m	< 100m	< 100m
	207 dB	< 0.1km²	< 100m	< 100m	< 100m
	203 dB	< 0.1km²	< 100m	< 100m	< 100m
	186 dB	120km²	7.1km	5.2km	6.1km
Stationary	219 dB	< 0.1km²	150m	130m	140m
	216 dB	0.1km²	230m	200m	210m
	210 dB	0.9km²	550m	530m	540m
	207 dB	2.2km²	850m	830m	840m
	203 dB	7.3km²	1.6km	1.5km	1.5km
	186 dB	560km²	15km	12km	13km

Table A 9 Summary of the mitigated (-10 dB) unweighted SEL_{cum} impact ranges for fish using the Popper *et al.* (2014) pile driving criteria for the monopile foundation (2 piles installed per 24 hours) modelling at the DBS East: S location assuming both a fleeing and stationary animal

Popper *et al.* (2014) Unweighted SEL_{cum}		Monopile foundation, 2 sequential piles (mitigated)			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 ms^{-1})	219 dB	< 0.1km²	< 100m	< 100m	< 100m
	216 dB	< 0.1km²	< 100m	< 100m	< 100m
	210 dB	< 0.1km²	< 100m	< 100m	< 100m
	207 dB	< 0.1km²	< 100m	< 100m	< 100m
	203 dB	< 0.1km²	< 100m	< 100m	< 100m
	186 dB	120km²	7.4km	5.2km	6.2km
Stationary (0 m/s)	219 dB	0.1km²	230m	200m	210m
	216 dB	0.4km²	350m	330m	340m
	210 dB	2.2km²	850m	830m	840m
	207 dB	5.4km²	1.4km	1.3km	1.3km

Popper *et al.* (2014) Unweighted SEL_{cum}		Monopile foundation, 2 sequential piles (mitigated)			
		Area	Maximum range	Minimum range	Mean range
	203 dB	18km²	2.4km	2.4km	2.4km
	186 dB	950km²	20km	14km	17km

Table A 10 Summary of the mitigated (-10 dB) and unmitigated unweighted SEL_{ss} impact ranges for fish using the Hawkins *et al.* (2014) 135dB criteria for the monopile foundation modelling at the DBS East: S location for the first pile strike assuming a stationary animal

Hawkins *et al.* (2014) Unweighted SEL_{ss}	Monopile foundation, first strike			
	Area	Maximum range	Minimum range	Mean range
135 dB mitigated (-10dB)	3,100km²	41,000m	20,000m	31,000m
135dB unmitigated	9,200	75,000m	30,000m	52,000m

Table A 11 Summary of the mitigated (-10 dB) and unmitigated unweighted SEL_{ss} impact ranges for fish using the Hawkins *et al.* (2014) 135dB criteria for the monopile foundation modelling at the DBS East: S location for the maximum hammer energy assuming a stationary animal

Hawkins *et al.* (2014) Unweighted SEL_{ss}	Monopile foundation, maximum hammer energy			
	Area	Maximum range	Minimum range	Mean range
135 dB mitigated (-10dB)	6,000km²	59,000m	25,000m	42,000m
135dB unmitigated	15,000km²	61,000m	26,000m	43,000m

DBS West: W location

Table A 12 Summary of the mitigated (-10 dB) unweighted SPL_{peak} impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria for the monopile foundation modelling at the DBS West: W location for the first pile strike

Southall *et al.* (2019) Unweighted SPL_{peak}		Monopile foundation, first strike (mitigated)			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	< 0.01km²	< 50m	< 50m	< 50m
	HF (230 dB)	< 0.01km²	< 50m	< 50m	< 50m
	VHF (202 dB)	0.01km²	70m	70m	70m
	PCW (218 dB)	< 0.01km²	< 50m	< 50m	< 50m

Southall *et al.* (2019) Unweighted SPL_{peak}		Monopile foundation, first strike (mitigated)			
		Area	Maximum range	Minimum range	Mean range
TTS (Impulsive)	LF (213 dB)	< 0.01km²	< 50m	< 50m	< 50m
	HF (224 dB)	< 0.01km²	< 50m	< 50m	< 50m
	VHF (196 dB)	0.09km²	170m	170m	170m
	PCW (212 dB)	< 0.01km²	< 50m	< 50m	< 50m

Table A 13 Summary of the mitigated (-10 dB) unweighted SPL_{peak} impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria for the monopile foundation modelling at the DBS West: W location for the maximum hammer energy

Southall *et al.* (2019) Unweighted SPL_{peak}		Monopile foundation, maximum energy (mitigated)			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (219 dB)	< 0.01km²	< 50m	< 50m	< 50m
	HF (230 dB)	< 0.01km²	< 50m	< 50m	< 50m
	VHF (202 dB)	0.07km²	150m	150m	150m
	PCW (218 dB)	< 0.01km²	< 50m	< 50m	< 50m
TTS (Impulsive)	LF (213 dB)	< 0.01km²	< 50m	< 50m	< 50m
	HF (224 dB)	< 0.01km²	< 50m	< 50m	< 50m
	VHF (196 dB)	0.45km²	380m	380m	380m
	PCW (212 dB)	< 0.01km²	< 50m	< 50m	< 50m

Table A 14 Summary of the mitigated weighted SEL_{cum} impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria for the monopile foundation (single pile installation) modelling at the DBS West: W location assuming a fleeing animal

Southall *et al.* (2019) Weighted SEL_{cum}		Monopile foundation, single pile (mitigated)			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	2.5km²	1.1km	550m	870m
	HF (185 dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (155 dB)	1.8km²	830m	680m	750m

Southall *et al.* (2019) Weighted SEL_{cum}		Monopile foundation, single pile (mitigated)			
		Area	Maximum range	Minimum range	Mean range
	PCW (185 dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Impulsive)	LF (168 dB)	1,500km²	31km	14km	21km
	HF (170 dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (140 dB)	640km²	17km	11km	14km
	PCW (170 dB)	73km²	5.3km	4.1km	4.8km

Table A 15 Summary of the mitigated weighted SEL_{cum} impact ranges for marine mammals using the Southall *et al.* (2019) impulsive criteria for the monopile foundation (2 piles installed per 24 hours) modelling at the DBS West: W location assuming a fleeing animal

Southall *et al.* (2019) Weighted SEL_{cum}		Monopile foundation, 2 sequential piles (mitigated)			
		Area	Maximum range	Minimum range	Mean range
PTS (Impulsive)	LF (183 dB)	2.5km²	1.1km	550m	880m
	HF (185 dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (155 dB)	1.8km²	830m	680m	760m
	PCW (185 dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Impulsive)	LF (168 dB)	1,600km²	31km	14km	22km
	HF (170 dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (140 dB)	680km²	18km	11km	15km
	PCW (170 dB)	77km²	5.6km	4.1km	4.9km

Table A 16 Summary of the mitigated unweighted SPL_{peak} impact ranges for fish using the Popper *et al.* (2014) pile driving criteria for the monopile foundation modelling at the DBS West: W location for the first pile strike

Popper *et al.* (2014) Unweighted SPL_{peak}	Monopile foundation, first strike (mitigated)			
	Area	Maximum range	Minimum range	Mean range
213 dB	< 0.01km²	< 50m	< 50m	< 50m
207 dB	< 0.01km²	< 50m	< 50m	< 50m

Table A 17 Summary of the mitigated unweighted SPL_{peak} impact ranges for fish using the Popper *et al.* (2014) pile driving criteria for the monopile foundation modelling at the DBS West: W location for the maximum hammer energy

Popper *et al.* (2014) Unweighted SPL_{peak}	Monopile foundation, maximum hammer energy (mitigated)			
	Area	Maximum range	Minimum range	Mean range
213 dB	< 0.01km²	< 50m	< 50m	< 50m
207 dB	0.01km²	70m	70m	70m

Table A 18 Summary of the mitigated unweighted SEL_{cum} impact ranges for fish using the Popper *et al.* (2014) pile driving criteria for the monopile foundation (single pile installation) modelling at the DBS West: W location assuming both a fleeing and stationary animal

Popper *et al.* (2014) Unweighted SEL_{cum}		Monopile foundation, single pile (mitigated)			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 ms^{-1})	219 dB	< 0.1km²	< 100m	< 100m	< 100m
	216 dB	< 0.1km²	< 100m	< 100m	< 100m
	210 dB	< 0.1km²	< 100m	< 100m	< 100m
	207 dB	< 0.1km²	< 100m	< 100m	< 100m
	203 dB	< 0.1km²	< 100m	< 100m	< 100m
	186 dB	91km²	6.1km	4.4km	5.4km
Stationary	219 dB	< 0.1km²	150m	130m	140m
	216 dB	0.1km²	230m	200m	210m
	210 dB	0.8km²	530m	500m	510m
	207 dB	2.1km²	830m	800m	810m
	203 dB	6.8km²	1.5km	1.5km	1.5km
	186 dB	470km²	13km	11km	12km

Table A 19 Summary of the mitigated unweighted SEL_{cum} impact ranges for fish using the Popper *et al.* (2014) pile driving criteria for the monopile foundation (2 piles installed per 24 hours) modelling at the DBS West: W location assuming both a fleeing and stationary animal

Popper *et al.* (2014) Unweighted SEL_{cum}		Monopile foundation, 2 sequential piles (mitigated)			
		Area	Maximum range	Minimum range	Mean range
Fleeing (1.5 ms^{-1})	219 dB	< 0.1km²	< 100m	< 100m	< 100m
	216 dB	< 0.1km²	< 100m	< 100m	< 100m
	210 dB	< 0.1km²	< 100m	< 100m	< 100m

Popper *et al.* (2014) Unweighted SEL_{cum}		Monopile foundation, 2 sequential piles (mitigated)			
		Area	Maximum range	Minimum range	Mean range
	207 dB	< 0.1km²	< 100m	< 100m	< 100m
	203 dB	< 0.1km²	< 100m	< 100m	< 100m
	186 dB	96km²	9.6km	4.5km	5.5km
Stationary (0 m/s)	219 dB	0.1km²	230m	200m	210m
	216 dB	0.4km²	350m	330m	340m
	210 dB	2.1km²	830m	800m	810m
	207 dB	5.1km²	1.3km	1.3km	1.3km
	203 dB	16km²	2.3km	2.2km	2.3km
	186 dB	810km²	18km	14km	16km

Table A 20 Summary of the mitigated (-10 dB) and mitigated unweighted SEL_{ss} impact ranges for fish using the Hawkins *et al.* (2014) 135dB criteria for the monopile foundation modelling at the DBS West:W location for the first pile strike assuming a stationary animal

Hawkins *et al.* (2014) Unweighted SEL_{ss}	Monopile foundation, first strike (mitigated)			
	Area	Maximum range	Minimum range	Mean range
135 dB mitigated (-10dB)	3,000km²	39,000m	23,000m	30,000m
135dB unmitigated	11,000km²	81,000m	34,000m	56,000m

Table A 21 Summary of the mitigated (-10 dB) and mitigated unweighted SEL_{ss} impact ranges for fish using the Hawkins *et al.* (2014) 135dB criteria for the monopile foundation modelling at the DBS West:W location for the maximum hammer energy assuming a stationary animal

Hawkins *et al.* (2014) Unweighted SEL_{ss}	Monopile foundation, maximum hammer energy			
	Area	Maximum range	Minimum range	Mean range
135 dB mitigated (-10dB)	6,300km²	61,000m	28,000m	44,000m
135dB unmitigated	19,000km²	109,000m	40,000m	74,000m

Non-impulsive criteria

5. Following from the Southall *et al*. (2019) modelled impact ranges presented in Mitigated impact piling section, the modelling results for the non-impulsive criteria from impact piling noise at DBS, as discussed in section 2.2.1 of **Appendix 11-3 Underwater Noise Modelling Report (Revision 2)** [AS-137], are presented below. The predicted ranges here fall well below the impulsive criteria previously presented.

6. **Table A 22** to **Table A 25** expand on the results presented above for the mitigated impact piling scenarios, covering the non-impulsive criteria from Southall *et al*. (2019) for marine mammals.

Table A 22 Summary of the mitigated weighted SEL_{cum} impact ranges for marine mammals using the Southall *et al.* (2019) non-impulsive criteria for the monopile foundation (single pile installation) modelling at the DBS East: S location assuming a fleeing animal

Southall *et al.* (2019) Weighted SEL_{cum}		Monopile foundation, single pile (mitigated)			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1km²	< 100m	< 100m	< 100m
	HF (198 dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (173 dB)	< 0.1km²	< 100m	< 100m	< 100m
	PCW (201 dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Non-impulsive)	LF (179 dB)	77km²	6.2km	3.6km	4.9km
	HF (178 dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (153 dB)	10km²	2.0km	1.7km	1.8km
	PCW (181 dB)	< 0.1km²	< 100m	< 100m	< 100m

Table A 23 Summary of the mitigated weighted SEL_{cum} impact ranges for marine mammals using the Southall *et al.* (2019) non-impulsive criteria for the monopile foundation (2 piles installed per 24 hours) modelling at the DBS East: S location assuming a fleeing animal

Southall *et al.* (2019) Weighted SEL_{cum}		Monopile foundation, 2 sequential piles (mitigated)			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1km²	< 100m	< 100m	< 100m
	HF (198 dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (173 dB)	< 0.1km²	< 100m	< 100m	< 100m
	PCW (201 dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Non-impulsive)	LF (179 dB)	78km²	6.2km	3.6km	4.9km
	HF (178 dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (153 dB)	10km²	2.0km	1.7km	1.8km
	PCW (181 dB)	< 0.1km²	< 100m	< 100m	< 100m

Table A 24 Summary of the mitigated weighted SEL_{cum} impact ranges for marine mammals using the Southall *et al.* (2019) non-impulsive criteria for the monopile foundation (single pile installation) modelling at the DBS West: W location assuming a fleeing animal

Southall *et al.* (2019) Weighted SEL_{cum}		Monopile foundation, single pile (mitigated)			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1km²	< 100m	< 100m	< 100m
	HF (198 dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (173 dB)	< 0.1km²	< 100m	< 100m	< 100m
	PCW (201 dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Non-impulsive)	LF (179 dB)	55km²	5.0km	3.1km	4.1km
	HF (178 dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (153 dB)	8.2km²	1.7km	1.5km	1.6km
	PCW (181 dB)	< 0.1km²	< 100m	< 100m	< 100m

Table A 25 Summary of the mitigated weighted SEL_{cum} impact ranges for marine mammals using the Southall *et al.* (2019) non-impulsive criteria for the monopile foundation (2 piles installed per 24 hours) modelling at the DBS West: W location assuming a fleeing animal

Southall *et al.* (2019) Weighted SEL_{cum}		Monopile foundation, 2 sequential piles (mitigated)			
		Area	Maximum range	Minimum range	Mean range
PTS (Non-impulsive)	LF (199 dB)	< 0.1km²	< 100m	< 100m	< 100m
	HF (198 dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (173 dB)	< 0.1km²	< 100m	< 100m	< 100m
	PCW (201 dB)	< 0.1km²	< 100m	< 100m	< 100m
TTS (Non-impulsive)	LF (179 dB)	55km²	5.0km	3.1km	4.1km
	HF (178 dB)	< 0.1km²	< 100m	< 100m	< 100m
	VHF (153 dB)	8.4km²	1.8km	1.5km	1.6km
	PCW (181 dB)	< 0.1km²	< 100m	< 100m	< 100m

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RWE Renewables UK Dogger Bank
South (West) Limited

RWE Renewables UK Dogger Bank
South (East) Limited

Windmill Business Park
Whitehill Way
Swindon
Wiltshire, SN5 6PB